Proceedings of the International Poplar Commission (IPC) Working Party on Harvesting and Utilization of Poplar/Willow Wood

Conference on Engineered Wood Products Based on Poplar/Willow Wood

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Proceedings of the Conference on Engineered Wood Products Based on Poplar/Willow Wood

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Conference on Engineered Wood Products Based on Poplar/Willow Wood
(October 21st-24th 2008)

Organized by College of Wood Science & Technology, Nanjing Forestry University, P.R. China.

Editors:

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PREFACE

Under the structure of The International Poplar Commission (IPC) the “Working party (WP) on harvesting and utilization of poplar & willow wood” initiated this conference on Engineered Wood Products Based on Poplar/Willow Wood (Nanjing Forestry University - China, October 21st-24th 2008). The conference was announced in the 2004-08 program and is a great opportunity to step forward in the technical and scientific issues of the working party, before the 23rd IPC meeting. The conference is organized in Nanjing China, with our Vice-Chair, Professor Hua Yukun and his team, as the distinguished host of this meeting. The high level laboratories and team are a significant place to understand the huge and effective Chinese poplar market integrated in a "poplar" country. The region covers more than 6 million ha of hybrids plantations and many industrial poplar products are produced. Their experience has an industrial background, where applied science took place to understand and answer to the wood market demands.

The conference is organized back to back with the IPC 23rd full session in Beijing scheduled October 26th-30th 2008. The IPC Working party on Harvesting and Utilization of Poplar and Willow Wood organizes this separate conference to initiate a renewed network on the topics of this group and intends to involve especially industry to stimulate future networking. All abstracts of this conference in Nanjing are included in the formal Book of Abstracts being prepared for the IPC 23rd Session in Beijing.

The **International Poplar Commission (IPC)**, an FAO technical statutory body on forestry, aims to promote the cultivation, conservation and utilization of members of the family Salicaceae, which includes poplars and willows.

Scientific and technical problems related to poplars and willows are investigated by six working parties of the International Poplar Commission (IPC) dealing with: genetics, conservation and improvement; production systems; environmental applications; insect pests; diseases; harvesting and utilization of wood.

The Working Party on Harvesting and Utilization of Poplar and Willow Wood is specifically dedicated to the poplar/willow forestry-wood industry chain and has taken the initiative to organize this conference in Nanjing organized back to back immediately prior to the 23rd IPC meeting in Beijing.

The organisers and editors would like to thank the speakers for their papers because without them there is no conference. I am sure that everyone involved in the conference from organiser to participant would like to thank the local organisers at the College of Wood Science & Technology of Nanjing Forestry University.

We hope that you enjoy the conference and find the papers useful in your future work.

Prof. Joris VAN ACKER
Chairman IPC WP Harvesting & Utilization
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Products and Manufacturing Processes of Poplar Plywood

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Keywords: plantation poplar, plywood, product research and development, poplar utilization mode

ABSTRACT

The poplar trees have improved the local ecological environment, the sandstorm has been short and the crops growth condition is good. With an annual log harvest volume of about 2 million m^3, Jiangsu ranks as the second most composites producing province in China. Because fast-growing poplar has been planted massively, China's wood-based panel industry as well as the Jiangsu Province wood processing industry obtained the rapid development in recent years. This paper gives a brief introduction of the development of poplar industry in Jiangsu while at the same time focusing on the research and development of poplar plywood products. Wood characteristics of the poplar tree and its effects on the production techniques of plywood are discussed. According to the end-use of veneer-based poplar products, they can be subdivided into several products, i.e., plywood for decoration, plywood for specific use, plywood for general use, plywood for concrete forms, plywood for furniture parts, laminated plywood and blockboard. A unique utilization mode of plantation poplar has been formed based on the location, scale, wood processing level, product type of the mill, and end-products market as well.

INTRODUCTION

With the rapid development of the economy and the improvement of living standards, the annual wood consumption of China is around 365 million m^3, and the gap between the demand and the supply of wood is around 100 to 150 million m^3 annually. To satisfy the industrial need for raw wood materials and to improve the ecological environment as well, the Chinese government has been encouraging and promoting the plantation of fast-growing wood species especially in plain areas including Jiangsu province and other middle and lower reaches of Yangtze River while simultaneously making a lot of efforts to utilize plantation forests effectively to manufacture wood products. To meet the growing demand and to utilize wood resources more efficiently, the wood-based composites industry in China has been

rapidly developing in the past several years. The annual wood-based composites production volumes in China as a whole in the past decades are listed in Table 1. By 2006, the total production volume reached 74.28 million m^3, making China one of the top wood-based composites producers in the world.

Among the fast-growing plantation forests, poplar, with its unique characteristics of being fast-growing and high yielding, is one of the most important wood species for afforestation in China and one of the main wood species for dealing with timber shortage and ecological environment improvement due to its high quality and its ability to be easily renewed.

This paper reviews the development of poplar industry in Jiangsu province, the wood properties of poplar related to plywood manufacturing techniques and the research & development (R&D) on veneer-based polar products while stressing the poplar veneer-based products and manufacturing processes of poplar plywood. The authors also present the unique mode of poplar utilization related to veneer-based products.

Table 1: Chinese production volume of wood-based composites (unit: 1.0×10^4 m^3)

Year	Total	Plywood	Particleboard	Fibreboard		Other products	
				total	MDF	Total	Blockboard
1951	1.69	1. 69	0	0			
1970	24.04	17.07	1.50	5.47			
1980	91.44	33.0	7.82	50.62			
1990	235.91	75.6	42.8	117.24	8.68		
1995	1684.6	759.26	435	216.4	59	273.85	-
2000	2001.66	992.54	286.77	514.42	-	208	-
2001	2110.82	404.06	344.53	570	527.11	292	-
2002	2930	1135	369	764.62	695	658	550
2003	4553.36	2102.35	547.41	1128.33	1070	775.27	617.24
2004	5446.49	2098.62	642.92	1560.46	-	1144.94	880.94
2005	6393	2515	576	2061	1854	1241	982
2006	7428.56	2728.78	843.26	2466.6	2222.04	1389.92	1155.3

THE PLYWOOD CLASSIFICATIONS IN CHINA

Fig. 1 illustrates the common plywood classification in China. According to the end-use of veneer-based poplar products, they can be subdivided into several products, i.e., plywood for decoration, plywood for specific use, plywood for general use, plywood for concrete forms, plywood for furniture parts, laminated plywood and blockboard.

The majority of plywood produced in China is three-layered panels for interior decoration and the furniture manufacturing industry. According to the board thickness, veneer-based poplar plywood can be divided into two types, thin and thick plywood. Normally, thin plywood is UF bonded, three-layered structure, with a size of 1220 x 2440 mm. The thickness of plywood for export is around 9 mm to 30 mm; the plywood for exporting and plywood for concrete formwork is mostly 12 mm to 18 mm, while the thickness of blockboard is within the range of

15 mm to 50 mm. The width and length of the variety of sizes described above are generally 1220 mm and 2440 mm respectively. The size of LVL is comparatively special; its common size is 2030 x 920 x 30mm or 2430 x 920 x 35mm.

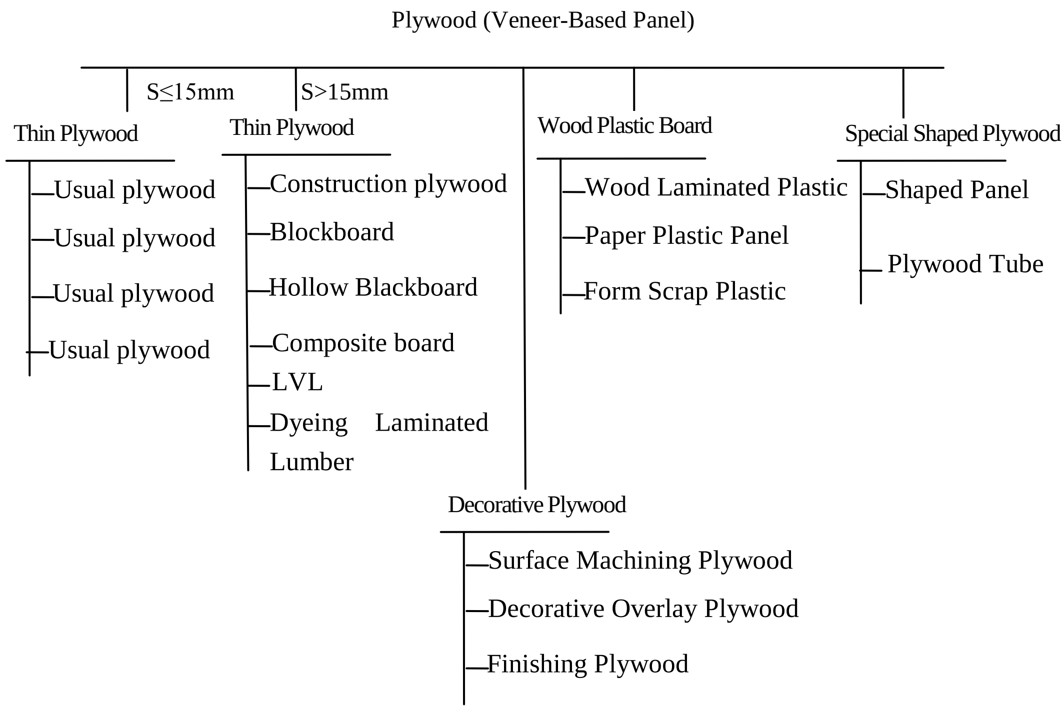

Figure 1: The common plywood classification in China

FAST-GROWING PLANTATION POPLAR INDUSYRY IN JIANGSU

Jiangsu province, which is located in the low reaches of Yangtze River, has historically been lacking of forest resources. Back to 1949 when the People's Republic of China was founded, the total forest area in the province was only 85 thousands hm^2 with a forest coverage rate of 1.4 %. For a long time during the planned economic time, wood consumed in Jiangsu was mainly imported, while some were allocated and transferred from the north east part of the country. The experts at Nanjing Forestry University successfully planted one fast-growing poplar species (*Populus deltoiides*) at the beginning of 1970 in Siyang County, Jiangsu Province. From then on, poplar trees have been widely planted in the northern area of Jiangsu, and there have been a dramatic increase in both the afforestation area and the wood stock volume. So far, there are more than 200 million individual poplar trees in Jiangsu and they make up a total poplar plantation area of more than 200 thousands hm^2, a total stock volume of 20 million m^3 and an annual log harvest volume of about 2 million m^3 (Table 2) (Hua and Jin 2006).

After having successfully planted fast-growing poplar in the northern part of Jiangsu, experts at Nanjing Forestry University initiated a series of plantation poplar-related R&D programs. The systematic series of R&D programs formed a beneficial cycle and has developed an industrial chain from poplar breeding to end products manufacturing, as well as having promoted the great development of the fast-growing poplar industry in Jiangsu. As a result, the annual wood processing volume is more than 10 million m^3 and the production value of the poplar industry in the counties of northern Jiangsu accounts for 15% to 30% of the total local agricultural value. Through poplar cultivation, the development of the Jiangsu forestry industry has greatly increased. The poplar industry has not only improved the ecological environment, but also helped to develop the rural economy, as well as making the rural residents wealthier and improving their living standards. Poplar, widely distributed and extensively cultivated, plays an important role in the Jiangsu provincial economic development.

Table 2: General information about the forestry in Jiangsu Province

Year	Forest land ($10^4 hm^2$)	Forest coverage rate (%)	Total Standing Stock Volume ($10^4 m^3$)	Commercial growing stock of Poplar ($10^4 m^3$)	Annual volume of wood provided (m^3)
1949	8. 5	1. 4 %	-	-	-
1986	-	-	-	-	Allocated 20000 m^3 from the north to make match sticks
Now	100	16.4	4074	2 000	> 2 million

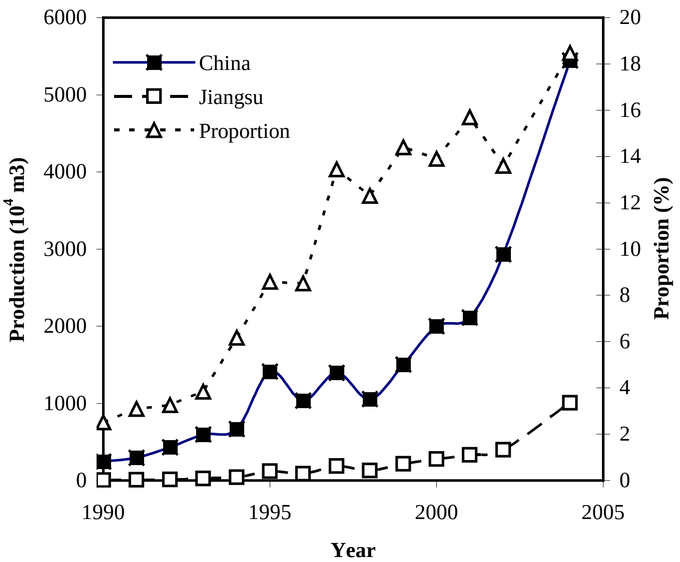

Figure 2: Wood based composites production volumes of Jiangsu Province and its proportion to the nation's total

Figure 2 shows the annual production volumes of wood based composites in Jiangsu Province in the last decades. Both the provincial production volume and its portion to the total national production volume are gradually increasing year by year. For instance, the total annual production of wood-based panels in 1990 accounts for only 2.46 % of the national total, while

the production in 2004 was up to 10.06 million m^3, which made Jiangsu rank as the second most composites producing province in China. The east China area was historically lacking of forests. However, its total production volume of wood based panels accounts for 51.09% of the national total (Table 3), which partly benefited from the development of fast-growing plantation poplar.

Table 3: Wood based composites production volumes of provinces in east China in the year 2004

Item		Production volume (1.0×10^4 m^3)	Portion to the Nation's total (%)
Nation total		5446.49	100
Provinces in East China Area	Shandong	1013	18.60
	Jiangsu	1006	18.47
	Zhejiang	508	9.32
	An Hui	238	4.70
	total		51.09

WOOD PROPERTIES AND PLYWOOD MANUFACTURING TECHNIQUES

Because of its fast growth and shorter rotation period, plantation poplar has different wood properties than natural forest poplar and it shows unique characteristics. Hence some specific measures are taken in manufacturing plywood.

General Description on Wood Properties

The wood density of plantation poplar ranges from 0.28 to 0.40 g/cm^3. The average fiber length of poplar wood is about 1.04 to 1.13mm and the ratio of fiber length to fiber width is around 41.0 to 49.6. Though not as good as that of softwood, poplar wood fiber is still similar to that of common hardwood trees. The timber from poplar sapwood is close to the timber from basswood which is a traditional Chinese wood species for plywood manufacturing (Hua and Zhou 1994).

Property Differences between Sapwood and Heartwood

Compared to other wood species, the differences between sapwood and heartwood of plantation poplar trees mainly exist in the following three aspects, i.e., unevenly distributed moisture, different color and acidity (Table 4). Moreover, the sapwood often has gelatinous fibers and a different annual ring width as well (Hua and Zhou 1994).

Moisture content

The green wood from fast-growing poplar has a high moisture content with an average value around 150%. The problem is not the high moisture content itself, but different moisture contents of heartwood and sapwood. The moisture content of heartwood is 140-250%, while that of sapwood is only 80-120%.

Table 4: Main differences between sapwood and heartwood

Item	Sapwood	Heartwood	Remarks
Moisture content (%)	80-120	140-250	average 150
Color	White color	Dark	
pH value	5.02-6.07	6.34-8.73	
Buffer capacity (mmol)	0.193	0.053	0.025N H_2SO_4

Color and Acidity

The chemical differences between heartwood and sapwood cause both differences in color and appearance, and in pH and buffer capacity.

- Sapwood veneers look light white and heartwood veneers look dark brown. When they are used as faces, products will look dark brown with the result of a bad quality in appearance even if decorated carefully.
- pH and buffer capacity

Another important species variable that requires attention is the acidity, as measured by pH and buffering capacity, which determines compatibility of wood species with the adhesive used in making wood-based composites. While pH of the wood measures the specific level of acid activity under given conditions, the buffering capacity evaluates the resistance of the wood to a change in pH level. A wood with high buffering capacity calls for the addition of a greater amount of acid catalyst to reduce the pH to the level required for optimum resin cure while bonding with UF resin.

More alkaline content in heartwood leads to a high pH value and alkali buffer capacity. As opposed to the heartwood, the acidity of sapwood is similar to those of normal timbers for plywood manufacturing (Table 5).

Table 5: pH values and buffer capacity of fast-growing Italian Poplar

Location	pH value	Acid buffer capacity		Alkaline buffer capacity	
		(ml)	(mmol)	(ml)	(mmol)
Heartwood	6.34-8.73	6.56	0.082	12.81	0.320
Sapwood	5.02-6.00	10.96	0.137	4.35	0.109
Remarks		0.025N H_2SO_4		0.025N NaOH	

Gelatinous fiber and different annual ring widths

More gelatinous fibers, whose cell walls are thicker than normal ones, are found near poplar heartwood. Annual rings with different width are also discovered. In the first four years, the poplar grows very fast with larger ring widths, but after that period, it grows slowly with narrow ring widths.

Features of Plantation Poplar Plywood Manufacturing Techniques

Because of the above mentioned unique characteristics of plantation poplar wood, special procedures must be taken in order to produce veneer-based products with sound property in a cost-effective way. The features of poplar plywood manufacturing are outlined as follows:

Peeling without conditioning
Because of its initial high moisture content, its soft quality and straight grain, peeling bolts need not to be conditioned before rotary cutting. If the log is air dried for a period of time, it is necessary to dip the log into water or take other moisture adjustment methods.

The average bevel angle of the peeling knife is around 18° to 20° while rotary-cutting plantation poplar wood. Because there are more gelatinous fibers with thicker cell walls near the heartwood, the woolly grains often appear on veneer surfaces. Thus thinner veneers of high quality are not easy to be peeled from poplar heartwood. Moreover, the annual ring width across the cross section is different and logs with deviated centre are often found, therefore the quality of peeled veneers deviates largely, which makes veneers easy to deform and have a stripy outside appearing.

Drying after clipping
Due to the large moisture content difference between sapwood and heartwood, veneers from sapwood and heartwood have different final moisture contents if they are dried with the same drying techniques. Drying defects such as warping and splitting are often found. Therefore deformation will easily occur on products assembled with these veneers. 'Drying after clipping' is a good technique in production. It is better to use roller drier or hot-plates drier to dried air pre-dried veneer to decrease production costs and increase product quality.

Bonding with a special UF resin
In China, most plywood is produced with UF resin, which cures under an acid condition and its curing speed is related to pH values. Due to the high pH and buffering capacity, when plywood is assembled with the heartwood veneers of poplar, the conventional UF resin can not cure properly and product defects such as low shear strength and delamination happen. It is very important to develop a UF with a specific recipe to ensure that they cure properly when bonding veneers from the heartwood of poplar.

CATEGORIES AND CHARACTERISTICS OF VENEER-BASED POPLAR PRODUCTS

In order to utilize the poplar resources properly and efficiently, experts at Nanjing Forestry University have developed and commercialized its technologies of producing plywood, blockboard and oriented strandboard, which brought great changes both to the wood supply and wood processing industry in Jiangsu Province and also in east China area. The main veneer-based poplar products researched and developed so far are presented in Figure 3.

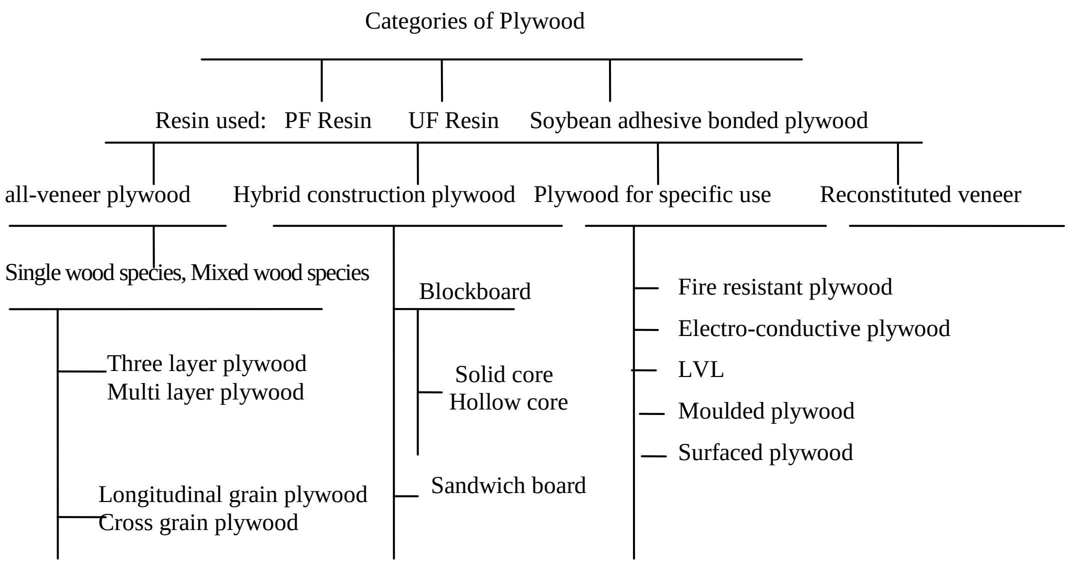

Figure 3: Categories of veneer based poplar products

As mentioned early, the majority of plywood produced in China is three-layered panels. When making three-layered plywood, the poplar veneer is normally used for the core while the face veneers are generally imported veneers, or veneers peeled from the imported wood species such as Lauan and Okoumé, or reconstituted wood veneers. Veneers from Birch and Chinese Ash are partly used to make the face of plywood. Occasionally, imported veneers act as the core material. The eastern areas of China have pioneered the use of fast-growing Poplar for core and imported logs for the face and back veneer. The thickness of face veneer is around 0.55 to 0.65 mm, while that of poplar core veneer is about 1.6 to 1.8mm. Generally, the volume of poplar wood accounts for 60% of the total three-layer plywood.

The physical and mechanical properties of three typical veneer-based poplar commercial products are listed in Table 7 to Table 9.

Table 7: Physical and mechanical properties of multi-layered poplar plywood

Property \ Mill	1	2	3	4	5	6
Panel thickness (mm)	18	18	18	18	18	15
Moisture content (%)	9.5	6.4	8.3	7.3	8.9	9.3
Bonding strength (MPa)	1.15	1.75	1.70	1.5	1.10	1.40
MOR(MPa)	49.0	47.0	38.0	44.0	47.0	39.0
MOE(10^3MPa)	5.5	4.8	4.9	5.2	6.2	4.5

Table 8: Properties of poplar blockboard bonded with UF resin

Property	Mill			Requirements of GB/T 8849-1999
	1	2	3	
Panel thickness (mm)	18	18	18	-
Moisture content (%)	10.6	12.2	12.9	6~14
MOR(MPa)	32.0	27.5	25.2	≥22
Bonding strength (MPa)	1.03	1.18	1.09	≥0.70

Table 9: Physical and mechanical properties of poplar LVL

Compression ratio	MOR (MPa)	MOE (MPa)	$S_{/\!/}$[a] (MPa)	$S_{\perp}$ (MPa)	Density (g/cm^3)	EMC (%)
21	103	9910	7.2	8.1	0.54	2.8
18	96.4	9160	6.9	7.8	0.52	3.2
24	128	11560	8.0	9.2	0.59	3.0
27	145	13200	11.5	13.8	0.66	3.8

[a]*shear strength*.

PLANTATION POPLAR UTILIZATION MODE

By carrying out researches as described above on different products at the attached factory of Nanjing Forestry University and successfully cooperating with mills, experts had began to commercialize the technology of making veneer and its products from poplar wood. Thus, Plantation poplar wood was gradually used to produce commercial veneer-based products, which eventually has promoted the extensive application of plantation poplar in the plywood industry.

From the rural poplar plantation sites to the veneer-based product manufacturing sites, a unique utilization mode of plantation poplar has been formed based on the location, scale, wood processing level, product type of the mill, and end-products market as well. This unique mode is illustrated as Fig. 4.

As for those veneer manufacturing on the poplar plantation bases in the rural areas, there is no need of making great investment of establishing a small-scale veneer manufacturing factory, and therefore it is practical for the local residents to go into the poplar processing industry. Core veneer for plywood can easily be made from small diameter poplar logs with small spindleless lathe, and the moisture content of the peeled veneer can be easily reduced through air drying. Thus, not only the transport cost is reduced but also dry energy consumed is conserved. The log core can be sawn and cut into the strips used for blockboard production, the roundings can be used as raw materials for papermaking or particleboard, and the large diameter log can be sold to large-scale plywood factories at high price. Hence, the comprehensive utilization ratio of poplar is increased to as high as 95%. The industrial chain, which consists of poplar planting, log felling, transporting, processing in situ and trading, has not only promoted the development of the local poplar processing industry, but has also developed the local services industry and information trade. It also provides new employment

opportunities for the local agricultural work force, promotes the construction of a harmonious countryside, and accelerates the development of the rural economy.

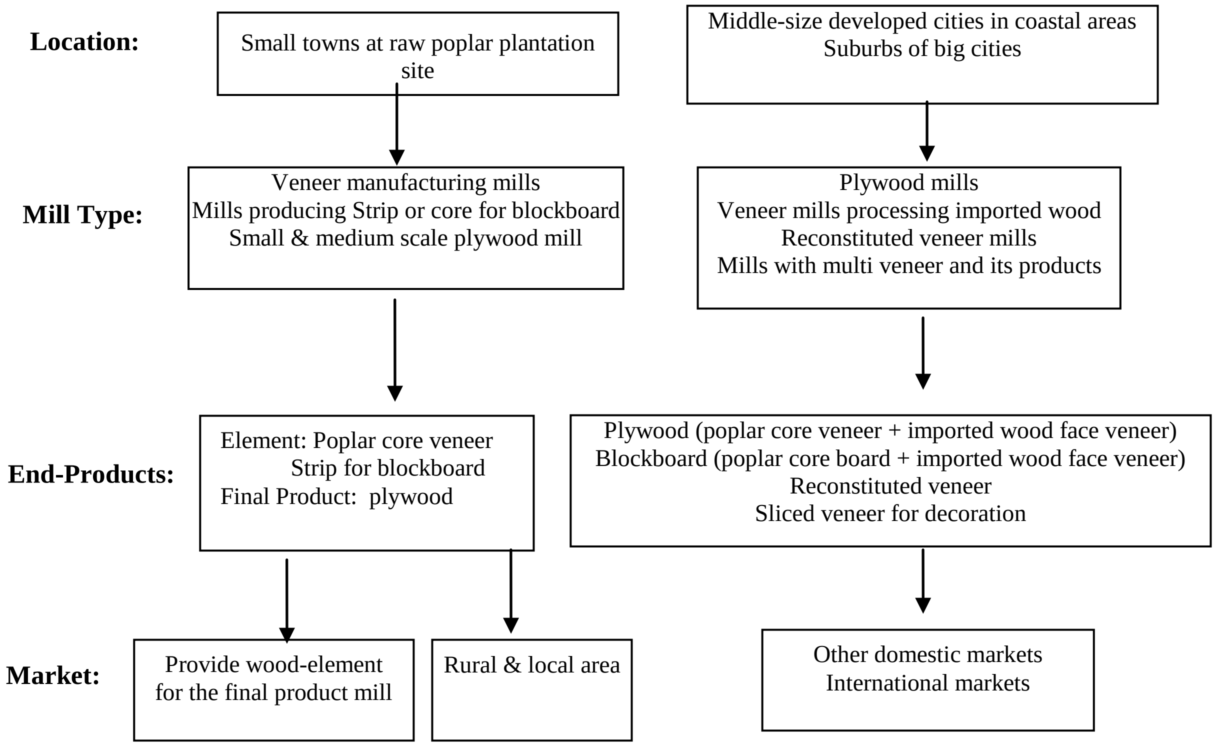

Figure 4: Poplar utilization mode in veneer-based products manufacturing

In the conjoining areas of rural countrysides and urban cities, main equipments including veneer clippers, glue spreaders, prepresses, hot presses and small-capacity boilers are enough to build several small-scale plywood factories, while the produced plywood or blockboard can be sold in the local or nearby towns for furniture processing and interior decoration. With the centralisation of high technology, production of high-quality veneer-based products in the medium to large-sized cities meets the domestic consumption and part of the export needs.

This mode is suitable for the popularization of the fast-growing trees industry in developing countries, especially in countries like China whose agricultural population accounts for over half of the national population, and it has been playing an important role to realize rural industrialization, computerization, urbanization, and also to solve the 'Three Rural' Issues of our country.

CONCLUSIONS

The plywood industry is in ways resource-dependant, and a lack of resources would mean that it would not be possible for the industry to develop. Plantation forests have contributed a lot to the wood processing industry, but plantation forests themselves are not enough. The development of the plantation poplar veneer-based product industry in Jiangsu province has stressed a fact that tree cultivation and proper commercial utilization based on effective

product R&D are two key methods in developing a sustainable wood composites industry. It is realized that an industrial chain and a suitable utilization mode are the foundations of successful plantation forest industry. To make a successful industry, it is necessary to join production, teaching and research to improve production, teaching and scientific research abilities as well as to serve people for the betterment of society.

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Resources and market balances in poplar plywood manufacturing, the outstanding European experience of Garnica Plywood

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Keywords: Poplar plywood, manufacturing, engineering, sorting, sustainability

ABSTRACT

This presentation discuses the data of the company Garnica which is currently increasing yearly 20% the production of their poplar plywood specialised lines. The existing factories are located in Spain and are being extended this year in South-Western France. The objective of this synthesis is to propose an overall evaluation of the technical and economical assessments of this poplar plywood industry. The different parts of this presentation show how plywood production gives: (1) technical efficiency to supply the market with high quality and flexible products, (2) flexibility to organise the production lines, (3) an effective use of the best characteristics of the raw material and, (4) a global and very favourable energy balance considering the sustainable resources used and the optimisation steps of poplar wood layers combining, gluing, drying and pressing.

FLEXIBILITY AND DURABILITY OF FINAL PRODUCTS

The manufacturers must meet the demands of diversified products within very short time which correspond to increasingly strict standards of quality. To those requirements in homogeneous quality, are added the needs for increasing quantities of products for increasingly larger markets. Wood manufacturing is not an exception to this rule, but as a natural material, it is biologically less homogeneous than transformed natural resources. The logs peeled in more or less thick veneer make it possible to overcome this variation of wood characteristic and keep up with the high standards of quality and also meet the fluctuating quantity requirements using the resources in a sustainable way. In relation to raw sawn wood, the association of selected veneer elements in as many layers as needed gives the guarantee to obtain a final board of all needed thickness and with high and homogeneous resistance

ENGINEERING PROCESS TO OPTIMISE HOMOGENEITY OF FINAL PRODUCTS

Plywood products composed of veneer of hybrid poplars can respect the quality and the quantity requirements of markets for silvicultural and process reasons that will be summarised. Higher homogeneity of wood structure can be obtained more easily with clonal plantations. Often, the effect of this easy vegetative reproduction, that reduces the effects of genetic variation on wood growth, enters in interaction with the land variation (topography, water table level and other soil elements) and is mainly expressed by changes in wood colour and by the presence of tension wood structures. The other growth-related defects can be avoided adapting the clone to the climatic situation of plantation and by respecting the silvicultural, pruning and harvesting rules. The length of logs will be presented. The thickness of veneer is also monitored during the peeling operation, changing from 0.9 mm to more than 2.5 mm.

RAW MATERIAL PROPERTIES AS A SORTING OUT KEY

The production model of Garnica Plywood optimises the use of wood by the operating specialised equipment designed for poplar transformation. Each group of logs is transformed separately according to its characteristics. The veneers are classified on the base of the moisture content, and visual criteria as coloration and size & quantity of knots. By this mean the time of process and the requested quality can be reached.

SUSTAINABILITY AND GLOBAL ENERGY BALANCE OF POPLAR PLYWOOD MANUFACTURING

Plywood gives the highest aggregate value to poplar considering economic, technical and environmental perspectives. The veneer has an economic value 10 times superior to triturating wood and 5 times superior to logs that have only sawing value. To add to this highly efficient wood use, the integrated model of Garnica is also optimised in the energy consumption and in the environmental friendly processes.

Potential of new selected Belgian poplar clones for the production of plywood and Laminated Veneer Lumber based on *P. deltoides* x (*trichocarpa* x *maximowiczii*) and *P. deltoides* x *maximowiczii*

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Keywords: Poplar wood, plywood, LVL, physical and mechanical properties, *P. deltoides* , *P. trichocarpa* and *P. maximowiczii*.

ABSTRACT

In the Northern part of Belgium (Flemish region) poplar stands account for almost 25% of the afforested land area (35000 ha). Yearly around 350 000 m³ round wood of divers quality is harvested from these stands. The poplar cultivation in Flanders is aiming at producing large dimension trees using wide planting distances (10 by 10 meter). To acquire high quality logs an intensified management is required (especially pruning). Last century these stems were peeled for the production of matches. However this production has disappeared and the high quality trees are now mainly used for poplar veneer based products as plywood.
From the beginning of the nineties up till now, the use of monoclonal large scaled plantations is under discussion from an environmental point of view. This pressure was mainly due to the occurence of severe poplar rust disease, spreading easily once adapted to the new planted clones. A number of measures are intended to counteract this trend. Several new poplar clones (continuing selection) are planted in mixed stands for better sanitation. In addition, poplar wood is searched for to be applied in higher value added products. Local products with a prolonged lifetime (LCA) have a significant better environmental balance.
This paper discusses the use of poplar wood from new selected Belgian poplar clones for veneer based construction materials, i.e. plywood and Laminated Veneer Lumber (LVL). A sampling of clones was made within mixed stands of DM clones (*deltoides* x *maximowiczii*) and DTM clones (*deltoides* x (*trichocarpa* x *maximowiczii)*) on two different sites. Per clone-site combination the sampling consisted of 3 to 5 trees.
By planting different clones - having similar growth characteristics and disease resistance – in mixed stands, a higher degree of variability in physical and mechanical wood properties can be introduced when these stands are finally used as raw material. Determination of allowable distribution characteristics of the input material is needed in relation to the production of an end-product with standard features (limited variation).

Both plywood and LVL are evaluated in relation to the European standards for CE marked load bearing constructive products.

INTRODUCTION

In the Northern part of Belgium (Flemish region) poplar stands account for almost 25% of the afforested land area (35000 ha). Yearly around 350 000 m³ round wood of divers quality is harvested from these stands. The poplar cultivation in Flanders is aiming at producing large dimension trees using wide planting distances (10 by 10 meter). To acquire high quality logs an intensified management is required (especially pruning). Last century these stems were peeled for the production of matches. However this production has disappeared and the high quality trees are now mainly used for poplar veneer based products as plywood.
From the beginning of the nineties up till now, the use of monoclonal large scaled plantations is under discussion from an environmental point of view. This pressure was mainly due to the occurrence of severe poplar rust disease, spreading easily once adapted to the new planted clones. A number of measures are intended to counteract this trend (De Boever *et al.* 2007).
Several new poplar clones (continuing selection) are planted in mixed stands for better sanitation. By planting different clones - having similar growth characteristics and disease resistance – in mixed stands, a higher degree of variability in physical and mechanical wood properties can be introduced when these stands are finally used as raw material. Determination of allowable distribution characteristics of the input material is needed in relation to the production of an end-product with standard features (limited variation).
In addition, poplar wood is searched for to be applied in higher value added products. Local products with a prolonged lifetime (LCA) have a significant better environmental balance.

Laminated veneer lumber (LVL) and plywood belong to the family of the engineered products, both based on reconstituting veneer sheets. Demand for engineered products is driven by many factors including diminishing old forests, new transformation technology and performance based building codes (Schuler and Adair 2000).
Plywood and LVL products can be divided into two major groups.

- Structural products include all end-uses dealing with load-bearing applications (beams, I-joists, trusses, structural sheeting, rafters). These products are competing with large dimension timber, steel or concrete). Their main competitive factors are strength, weight, dimensional stability and price.
- Non-structural products include all end-uses without specific load-bearing function (window joinery, door frames, furniture parts). Main competition lies in products as MDF, particleboard and plastics. Competitive factors here are appearance, machinability, dimensional stability and also price.

According to the European Federation of the Plywood Industry (FEIC), the European plywood production remained stable in 2006 and increased by 2% in 2007 to reach 3.5

million m³ (excluding the Russian production). In Russia the plywood production increased by 6.4% to amount to 2.8 million m³ (Anonymous 2008).
For several years, European plywood producers witnessed impacting competition with extra-European imports and other substituting wood-based panels. The number of plywood imports is more rapidly increasing than the local productions. Especially imports from China and Russia were increasing during 2007, gaining 31% and 35% respectively. The growing import from China can almost be exclusively attributed to imports of broadleaved plywood as poplar. On the other hand, extra-European exports decreased significantly. As such can be concluded that the demand for plywood in the European Union is improved (Anonymous 2008).

The main production of LVL is situated in North America and is based on softwood. This is due to the fact that major LVL production plants are connected to a plywood production unit. As such, LVL is merely a by-product of the plywood production in an attempt to optimize the use of higher quality veneer sheets. The inverse situation can be seen in Europe were LVL production is limited. However, the European market is using extensive imported quantities of LVL.
There exists a clear difference between the amounts of LVL used for structural or non-structural applications in the three main areas. Figure 1 demonstrates the use of LVL products for North-America, Europe and Asia in function of load bearing demands.

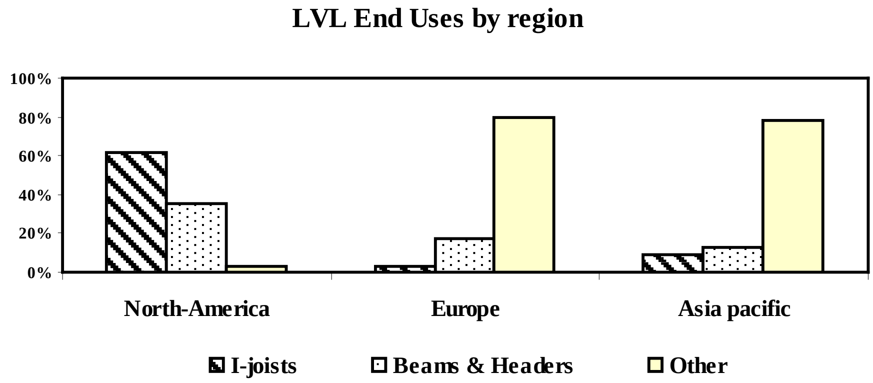


Figure 1: LVL end-use for North-America, Europe and Pacific Asia for structural (I-joists and Beams & Headers) as well as non-structural (Other) applications.

This study evaluates the potential of poplar wood from new selected Belgian poplar clones of DM clones (*deltoides* x *maximowiczii*) and DTM clones (*deltoides* x (*trichocarpa* x *maximowiczii)*) for the production of veneer based construction materials, i.e. plywood and Laminated Veneer Lumber (LVL).

EXPERIMENTAL METHODS

A sampling of clones was made within mixed multiclonal stands of DM clones (*deltoides* x *maximowiczii*) and DTM clones (*deltoides* x (*trichocarpa* x *maximowiczii)*) on two different

sites. Trees were felled in “Holsbeek” and in “Bassilly”. Per clone-site combination 3 to 8 trees were felled and subsampled.

Holsbeek has a sandy (to loamy sand) soil with good drainage (Classification code Zdp within the Belgian soil classification) while Bassilly has a (sandy to) loamy sand soil with good drainage (Classification code Sdp within the Belgian soil classification). The planting distance was 9 by 9 meter and an intimate mixture of trees was used in establishing the multiclonal stand. Trees were selected in respect of their diameter at breast height. Trees that were suspected to suffer from border effects, e.g. standing near the border of the site or near a dead tree, were excluded. All trees were 21 years old and their circumference at breast height ranged from 139 to 210 cm. Table 1 gives an overview of the genetic background and the stand characteristics of the selected poplar clones.

Clone 70 078/2 was present at the “Bassilly” site but was not sampled due to the limited number of trees without influencing border effects.

Table 1: Characteristics of the selected trees, number of trees per clone-site combination and growth characteristics.

				Growth characteristics			
		Number of trees selected		**Mean circumference Stand level [cm]**		**Mean radial increment of selected trees [cm]**	
Clone	**Crossing**	**Holsbeek**	**Bassilly**	**Holsbeek**	**Bassilly**	**Holsbeek**	**Bassilly**
70 078 /2	DTM*	6	-	172.8	210.5	1.27	-
70 078 /6	DTM*	-	4	-	204.2	-	1.49
70 078 /11	DTM*	8	3	139.8	201.1	1.05	1.54
71 106 /1	DM**	4	-	146.0	-	1.13	-
71 106 /5	DM**	5	3	147.7	172.8	1.15	1.40

* DTM 70 078 S.333-44,Michigan x S.725-37 (S.3-5(V.26,Washington x V.23,Idaho) x *P. maximowiczii*)
** DM 71 106 S.333-44 Michigan x S.122-3,Hokkaido

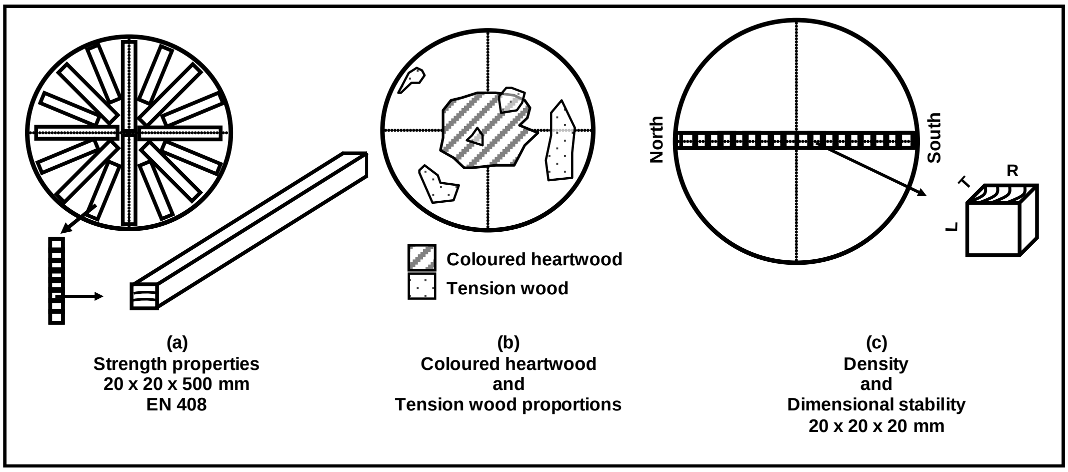
Each stem was divided into stem discs and small logs, depending on the different tests to be performed. Stem discs were taken at breast height (1.3 meter) and at 6.8 and 12.1 meter for the determination of density and dimensional stability (Fig. 2c). Additional discs were taken at the same heights for evaluating the tension wood and heartwood proportions (Fig. 2b). The lower stem part (1.3 meter) is subdivided into samples for the determination of the mechanical properties according to the European standard EN408 (Fig. 2c). Two larger logs of 5.2 meter (from 1.4 to 6.8 and from 6.9 to 12.1 meter) were used for a rotary peeling experiment. These logs were subdivided into two stem pieces of 2.6 meter before peeling. As such, per tree 4 stem pieces were processed.

Figure 2: Partitioning of the stem discs in relation to the different specimens required for testing: (a) samples according to EN408 for determining strength properties at breast height; (b) stem discs for the determination of heartwood and tension wood proportions at breast height, 6.8 and at 12.1 m; (c) stem discs for the determination of density and dimensional stability at breast height, 6.8 and at 12.1 m

In order to quantify wood density and the dimensional stability of timber, cubic specimens with 20 mm ribs, were cut out of the stem discs from north to south. The specimens were first measured in fresh condition and then subjected to consecutive changes in relative air humidity (RH) in a climate room at 90% RH over 60% RH to 30% RH, all at 20°C, and finally to oven-dry state. Dimensions were measured using a precision calliper (0.01 mm). For each direction a red marking point was used in order to measure each time at the same location. Mass was determined using a precision balance (0.001 g). In the climate room 10 reference samples were monitored till constant mass was reached for three consecutive days, before executing measurements at each specified climate condition. Volume changes were calculated using the three measured dimensions.

To identify the tension wood zones, the surfaces of the cross sections were stained with a zinc-chloride-iodine solution. The cumulative area of the tension wood zones was then digitally measured and expressed as a percentage of the cross-sectional area. Due to the limited colour variation, the tension wood areas were manually marked on digital photographs. A similar procedure was used for determining the readily visible dark coloured heartwood proportion.

For the mechanical tests, stem parts of 50 cm in length were taken at breast height. The material was subsampled into test specimens of 50 cm axial length and a cross section of 2 by 2 cm in accordance with EN 408. The specimens were sawn and subsequently planed parallel to the grain, keeping the annual rings aligned with one side of the cross section. The sawn pattern was designed to provide a maximal number of flawless test specimens. The static edgewise modulus of elasticity (MOE) and the modulus of rupture (MOR) were determined by means of a four-point bending test. The knot-free specimens were loaded at the centre at a rate of 8 mm per minute in order to allow a maximal duration of the test of 300 ± 120 seconds.



Of each stem, four logs of 2.6 meter were peeled using industrial equipment to evaluate veneer quality and, subsequently, plywood and LVL properties. The thickness of the veneer was 3 mm. The logs were exactly measured using laser scanning technology, allowing to determine the centre points for optimal yield. The total amount of veneers produced allowed a first yield figure.

After drying, the veneer sheets were individually sorted in five quality classes. These quality classes were described by the commercial grading system of the peeling company. Table 2 gives a short description of the discerned quality classes for the veneer sheets.

Table 2: Discerned quality classes for rotary veneers sheets, abbreviation and description

Abbreviation	Description
A	Closed veneers, absence of defects, even coloured
B1	Closed veneers, sound knots allowed up till 15 mm
B3	Cracks up till 40 cm (not wide open) but maximum 3 Sound knots allowed up till 30 mm Defects can be technically repaired
C	No limit for sound knots Loose knots allowed up till 30 mm No limit on cracks (but cracks are not wide open) Interior plies only
D	Not classified in the above. Can not be used as such (re-cut) Interior plies only
NC	Not classified (to wet, to small dimensions)

A parallel can be made to the five quality classes used by EN 635-2. The A-quality is referring to closed veneers (absence of defects, which is comparable with the combined classes E and I of EN 635-2), whereas B-quality allows small defects (small checks or holes) to the extent that they can be technically repaired (comparable with the combined classes II and III of EN 635-2). C/D-quality veneers contain larger defects and are used for the interior plies of the board only. The latter class is comparable to the quality class IV of the EN 635-2 standard.

Only out of the top quality veneers (A and B classes), seven-layer plywood panels and LVL boards were produced using an urea-formaldehyde glue. Two types of boards were made, one for every clonal group. As such, for the DTM clones as well as for the DM clones ten panels were produced. These boards were tested for density, MOE and MOR according to EN 310, EN 313 and EN 789. For plywood, boards of 122 by 244 mm were produced. For LVL boards were made of 122 by 122 mm.

In the result section the significance of a statistical analysis, is indicated by a number of asterisks (* p=0.05; ** p=0.01; *** p=0.001).

RESULTS AND DISCUSSION

At the time this paper was submitted, not all data were retrieved. For the physical mechanical properties of the solid wood, only preliminary results can be evaluated. LVL properties still have to be evaluated.

Growth and basic physical mechanical properties

Table 3 gives the mean values of the basic physical and mechanical features for the different clones.

Table 3: Mean values for basic physical and mechanical properties of the investigated clones

	Heartwood	Tension wood	Density	MOE	MOR

Clone	Site	proportion [%]	proportion [%]	[Kg/m^3]	[N/mm^2]	[N/mm^2]
70 078 /2	Holsbeek	28	24	380	7700	48
	-					
70 078 /6	Bassilly	48	21	360	7400	47
	-					
70 078 /11	Holsbeek	38	29	385	8100	51
	Bassilly	41	32	365	7600	48
71 106 /1	Holsbeek	54	42	365	7300	44
	-					
71 106 /5	Holsbeek	60	38	345	6900	42
	Bassilly	65	35	355	6700	44

As can be deducted from Table 1, growth vigour was significantly higher in “Bassilly” compared to the trees grown in “Holsbeek”. This can be mostly contributed to the richer soil at the “Bassilly” site. However, no significant correlation could be found between growth features and physical mechanical properties.

Hernández (1998) and Pilura (2005) found a significant but weak negative correlation between radial increment and density. Several features have an influence on this correlation. Firstly, the data set used here represents only a narrow range, both in growth rate and mainly density, which is insufficient to detect significant trends. Diffuse porous species, such as poplar, generally display only a weak response in density to changing growth rates. Finally, the presence of tension wood tends to increase the local density, irrespectively of growth rate.

The main characteristics describing veneer quality are colour, amount of knots and wooliness, the latter parameter being an indication of the presence of tension wood zones. For the top veneers of plywood but also for printable packaging material the whiteness of the veneers is often important. Therefore clones with low amounts of dark coloured heartwood are preferred. In that respect clones “70078/2” and “70078/11” are preferable compared to the other clones. Both clones have significant lower amounts of heartwood (approximately 30-40%) and both clones show lower occurrence of tension wood. In general can be stated that the DTM clones are more suitable for veneer production than the DM clones when evaluating only heartwood and tension wood proportions. However, the clone “70078/11” shows a highly irregular stem form, especially in the “Holsbeek” site. This irregular shape reduces the yield in rotary veneer significantly. On the other hand, the clone “70078/2” was heavily branched. These branches lead to lower yield in high quality veneer sheets and will lead to higher amounts of tension wood. Pruning could lead to significant increasing yield for this particular clone.

Waviness is often introduced by high local differences in the amount of tension wood or the moisture content. Both leading in the drying process to differential stresses. Waviness could lead in the pressing process to the formation of overlap which causes a 20% reduction of bending strength (Vassiliou 1996). Bao and Liu (2001) determined several models to relate basic anatomical and physical properties to veneer and plywood characteristics of Chinese plantation poplars. They determined that the ratio of lathe check is related to the tangential hardness, the modulus of elasticity, the oven dry density and the total volumetric shrinkage.

Rotary veneer process and Veneer quality

Tables 4a and 4b give an overview of the efficiency of the veneer processing as well as the different yield parameters for both trials (Holsbeek and Bassilly site were processed separately).

As yield is concerned, both veneer trials result in similar numbers concerning veneer yield and percentages of losses due to rest core and clipping. Clone “70 078/11” delivers the highest amounts of veneer sheets. This seems to be in contradiction with the earlier stated irregular stem form which should results in lower overall yield numbers. This loss due to stem form is compensated by a lower loss due to rest core as well as to clipping. Probably, the higher density and lower amount of tension wood prevent crack formation during peeling. Clipping losses were higher in the clone “70 078/6” due to the extensive presence of larger knots.

Veneer sheets of grade A were very limited. This is due to the fact that the samples stands were never pruned. As such, the real potential is underestimated.

Concerning the DTM clones, clone 70 078/11 has the largest potential. Despite the fact that the stem form is irregular, the clone shows the highest peeling yield (amount of wet veneers produced). In addition, this clone produced the highest amount of quality veneers that can be used for exterior plies (grade A and B1).

The potential of the clone 70 078/6 was underestimated due to the fact that most veneers were downgraded due to sound, but very large knots. The veneers had few cracks and the overall yield was high. Pruning will be necessary for this clone if used for veneer production. Clone 70 078/2 did also show large knots but suffered more severely from excessive crack formation. This clone shows the lowest potential for rotary veneer.

Concerning the DM clones, it can be stated that the overall quality is lower than that of the DTM clones. However the clone 71 106/5 showed high yield at the Bassilly site with almost 20% of high quality veneers.

Table 4: Basic yield numbers for the rotary veneer trials for Holsbeek (a) and Bassilly (b)with attention to total peeled volume under bark (m^3), produced wet veneers (% of total volume), loss due to rest core volume (%) and losses due to clipping (%).

(a) Holsbeek

Clone	Volume peeled [m³]	Produced veneer [%]	Rest Core volume [%]	Loss due to clipping [%]
70 078 /2	2.5	58	10	10
70 078 /11	4.0	64	8	8
71 106 /1	2.0	58	10	10
71 106 /5	2.8	62	10	8

(b) Bassilly

Clone	Volume peeled [m³]	Produced veneer [%]	Rest Core volume [%]	Loss due to clipping [%]
70 078 /6	8.2	63	7	10
70 078 /11	6.0	67	6	8
71 106 /5	4.1	65	8	10

Table 5: Graded amounts of veneer sheets for both peeling trials, per clone the yield (%) is given for five veneer quality classes (table 2).

		Veneer quality grade				
		A	**B1**	**B3**	**C**	**D and NC**
70 078 /2	Holsbeek	-	-	35 %	62 %	3 %
70 078 /6	Bassilly	3 %	10 %	34 %	49 %	4 %
70 078 /11	Holsbeek	-	7 %	37 %	47 %	10 %
	Bassilly	2 %	18 %	30 %	44 %	6 %
71 106 /1	Holsbeek	-	5 %	33 %	62 %	3 %
71 106 /5	Holsbeek	-	2 %	33 %	61 %	3 %
	Bassilly	2 %	17 %	47 %	31 %	3 %

Plywood properties

Only the A and B-quality veneers were used to produce plywood resulting in 10 panels (1250 x 2500 mm) per clonal family. Table 4 gives an overview of the density, modulus of elasticity and modulus of rupture for each clonal group. Both mechanical properties were tested perpendicularly and parallel to the grain as described in EN 789 (Baldassino *et al.* 1998). The average strength values of boards made of DM clones are significantly lower than those of the panels based on DTM clones.

The densification, i.e. the density of the raw material versus the density of the pressed board, is higher for DTM clones (30%) in comparison with DM clones (17%). However, the densification factor is higher than for inter-American (*P. trichocarpa x deltoides*) reported by De Boever *et al.* (2007).
Strength values of the boards do follow the ranking of the density. DTM clones produce significant stiffer boards than the boards made out of DM plies. The Bending strength of the boards does not differ significantly.

In regards of the densification and the reported strength values of the plywood, it can be expected that also the LVL strength properties will be sufficient.

The board features reported in Table 6 are well within range to produce technical plywood. Differences in plywood properties are expected to be lower when a mixture of veneers (different clonal groups and/or qualities) is used in the production process.

Table 6: Density [kg/m³], modulus of elasticity and modulus of rupture [N/mm²] for a 7-layer plywood for the DM and DTM clones and the multiple range statistics by Duncan.

	DTM	DM	Duncan ranking
Density of the board	485 ± 12	415 ± 21	ab
Modulus of elasticity ⊥	2830 ± 280	2315 ± 64	ab
//	4435 ± 255	3820 ± 246	ab
Modulus of rupture ⊥	28.1 ± 1.8	26.8 ± 2.3	aa
//	44.3 ± 1.4	42.4 ± 2.5	aa

CONCLUSIONS

This paper discussed the use of poplar wood from mixed stands as one source of raw material for veneer based construction materials, i.e. plywood and Laminated Veneer Lumber. The potential was evaluated for new Belgian poplar clones out of the crossings DTM and DM.
The clones 70 078/6 (DTM), 70078/11 (DTM) and 71106/5 (DM) clearly had the potential to produce high quality veneers at a sufficient yield. Clone 70078/11 (DTM) showed the highest potential, even in mixed stands where no management (pruning) was applied. The potential of clone 70 078/6 (DTM) can be significantly increased, but pruning will be necessary.
Both clonal groups could be used in the production of a technical plywood that showed sufficient strength properties according to European standards.
It is expected that also the evaluation of the LVL properties will be positive.

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Study on Laminated Strand Lumber from Poplar

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Keywords: Laminated Strand Lumber, strand geometry, stacking consequence, steam-injection.

ABSTRACT

This paper mainly focuses on the influence of strand geometry and stacking on the properties of laminated strand lumber from poplar. Furthermore, the influence of steam-injection on the temperature and gas pressure in the core layer of the LSL mat is discussed.
The impact of strand length, width and thickness on the mechanical properties of LSL were investigated. Strand geometry has major impact on the properties of LSL from poplar. Effect of strand alignment in different layers of LSL mat was also evaluated.
Steam-injection is an effective way to rise core temperature of the LSL mat. Meanwhile, the compaction ratio of the mat can highly influence temperature and gas pressure. The results showed an optimal compaction ratio of approximately 0.43. A longer injection time contributes to fast heat transfer to the core, but elevates the gas pressure significantly. By extending the vacuum time the gas pressure in the core of the LSL mat can be reduced.

INTRODUCTION

Laminated strand lumber (LSL) is a composite structural material consisting of oriented strands and compressed to form panels using steam-injection. LSL is an attractive alternative for solid wood. It can be produced from fast-growing, low-quality trees. Its final properties can be adjusted by controlling the species, geometry and orientation of strands and the density of the panel. Steam-injection press is an effective way to reduce press time, especially for thick boards. It is much more complicated than conventional pressing. Except for common variables, it has close connection with following variables, such as steam pressure, mat compaction ratio, steam injection time, degree of vacuum as well as vacuuming time. The process of hot-pressing is usually a complicated process with heat, mass and momentum transfer as well as a chemical reaction. Mat temperature and gas pressure have close connection with curing of adhesives, plastification of strands and board properties. Temperature and gas pressure in the mat were often measured using a thermal couple and gas sensor.

Thus, objectives of this study were to determine the effect of strand geometry, orientation and sequence on properties of LSL and the effect of steam-injection variables on core temperature and gas pressure of the LSL mat.

MATERIALS AND METHODS

Strands of poplar and PF with 45% solid content and 22s viscosity (23°C) were used in this study. The initial moisture content of strands was 4%. Strands were oriented by self-made equipment. The target density was 650kg/m³, and average final panel thickness was 18mm. Press method was conventional hot-pressing. For strands used to investigate the strand geometry effect, the three levels of strand length were 100mm, 150mm and 200mm respectively. As for strand thickness, it was 0.8mm, 1.1mm and 1.8mm respectively; as for strand width, it was 10mm, 20mm and 30mm. To investigate the effect of strand orientation, the mat was divided into three layers: two surface layers and one core layer. The strand orientation included 6 types. Type1 was fully oriented. Type 2 and 3 had a core layer who was oriented and random respectively, while surface layers were ±15°. Type 4, 5 and 6 were that surface layers were ±30°, ±45° and ±0° respectively, while core layer was random. Strand dimensions were 200mm long, 20mm wide and 0.8mm thick.
PressMAN (Albert Research Council instrument) was used to investigate the influence of compaction ratio, stream-injection time and vacuuming time on core temperature and gas pressure of LSL. Four compaction ratios (target mat density/raw material density) were 0.28, 0.43, 0.62 and 0.86 respectively, while steam-injection time was fixed at 20s. Three steam-injection time levels were 10s, 20s and 30s respectively, while the compaction ratio was fixed at 0.60. Three vacuuming time levels, being 30, 60s and 90s, were applied to determine the influence of vacuuming time, while compaction ratio and steam injection were fixed at 0.60 and 20s respectively. Strands were not resinated and average final panel thickness was 28mm.

RESULTS AND DISCUSSIONS

Effect of strand geometry on properties of LSL
Influence of strand length on properties of LSL is presented in Fig. 1. As shown in the Figure, MOR and MOE of LSL increase along with an increase of strand length which contributes to overlap in the longitudinal direction and exert wood mechanical properties in the panel. Also, it was reported that an increase of strand length makes for strand orientation. IB of LSL decreases slightly with an increase of strand length.

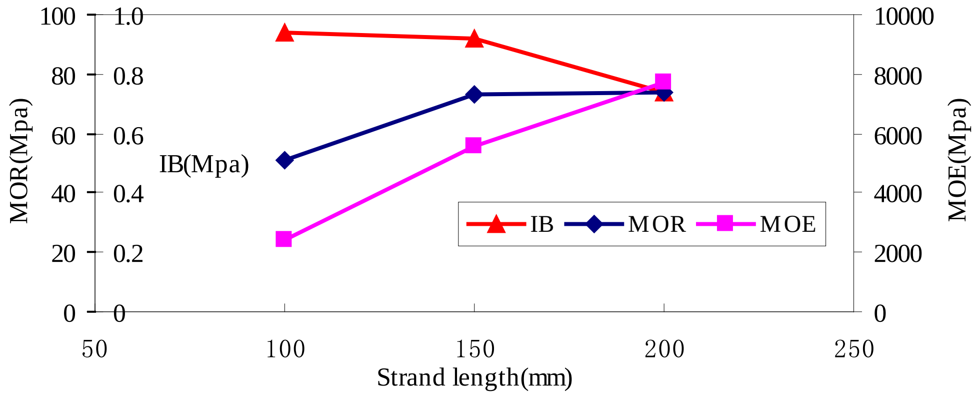

Figure 1: Properties of LSL with different strand length

Influence of strand width on properties of LSL is presented in Fig. 2. As shown in the figure, strand width had a very slight influence on MOR and MOE of LSL. As for IB, it increases slightly as strand widths increase. This could be attributed to the strand contact area. Increase of strand width increased strand contact area and adhesive joints.

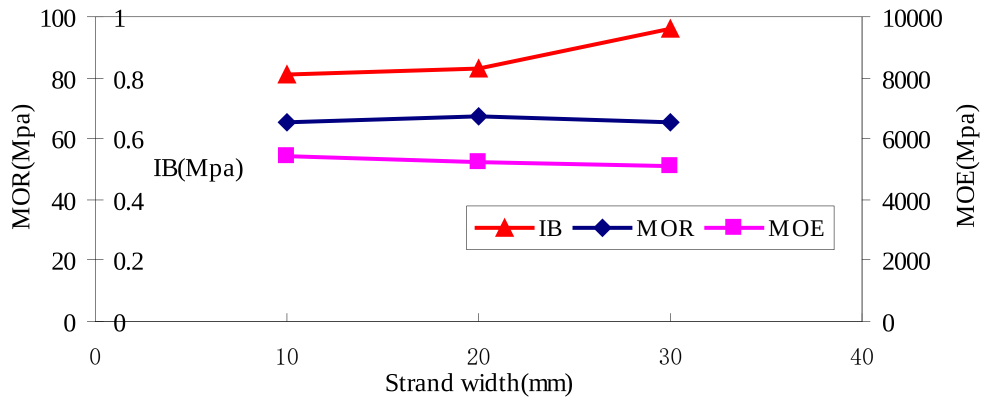

Figure 2: Properties of LSL with different strand width

Influence of strand width on properties of LSL is presented in Fig. 3. As shown in the figure, properties of LSL decrease as the strand thickness increases. This could be attributed to the aggrandizement of void among strands as well as increase of horizontal density difference.

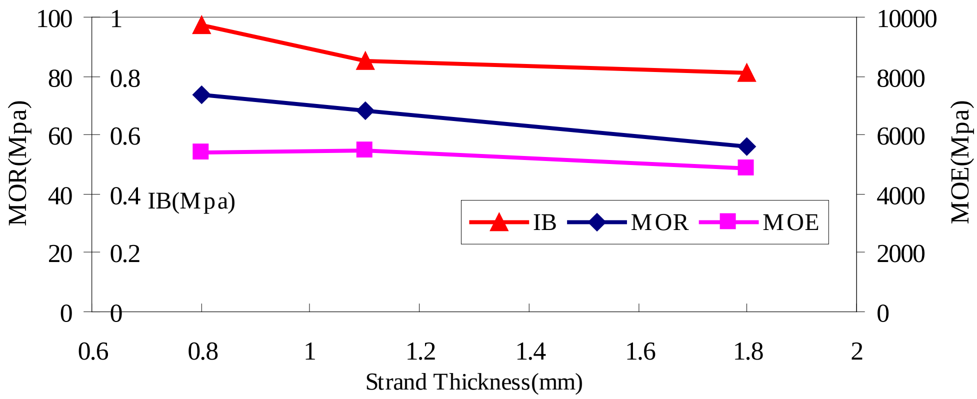

Figure3: Properties of LSL with different strand width

Effect of stacking consequence on properties of LSL

The influence of stacking consequence and strand orientation on properties of LSL is presented in Fig. 3. As shown in the figure, MOR and MOE of LSL decrease as the surface orientation angle increases. Strand orientation determines the type of force on strand. When the orientation angle is 0°, the strand is pulled longitudinally; when the orientation angle is 90°, the strand is pulled tangentially. Wood is an orthotropic material with a longitudinal tensile strength much higher than its tangential tensile strength. The core layer orientation angle has a slight influence on MOR and MOE of LSL. While the core layer is randomly aligned, its internal bond is slightly higher than that of an oriented layer. This indicates that to accommodate different application requirements, adjusting the orientation angle, especially surface layer angle, can acquire corresponding properties of LSL.

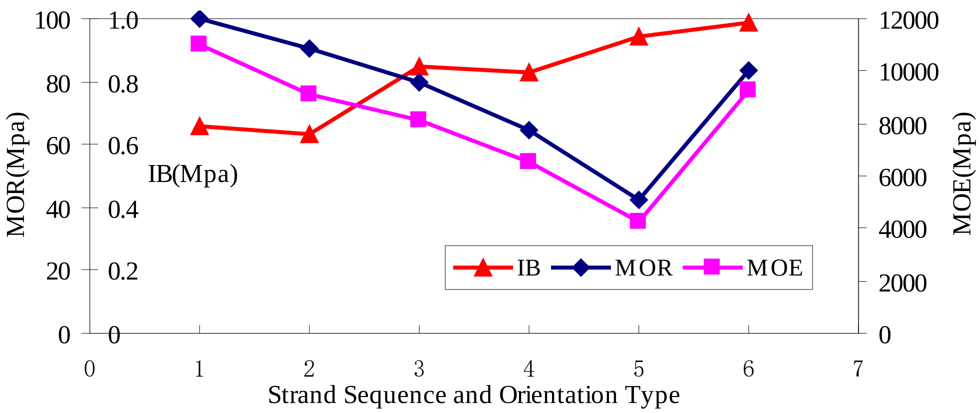

Figure 4: Properties of LSL with different strand sequence and orientation

Influence of compaction ratio on core temperature and gas pressure of LSL.

Temperature and gas pressure with different compaction ratios were presented in Fig.5. From the figure, the rise of core temperature in LSL mat was very sudden during the steam-injection, which shortens around 300s to raise the core temperature of LSL mat above 100°C compared with conventional hot-pressing. After the steam injection was finished and the board was pressed to its final thickness, temperature and gas pressure dropped slightly for which the extent of drop has a close connection with the compaction ratio. While the

compaction ratio was 0.28, extent of temperature drop is a maximum compared with another one. At a later stage of hot-press, the core temperature and gas pressure varied with different compaction ratios. When the compaction ratio was 0.43, temperature and gas pressure were the highest. Generally, effect of steam-injection has a close connection with porosity and permeability of the mat. From this test, when the compaction ratio is around 0.43, it can obtain the best steam-injection effect.

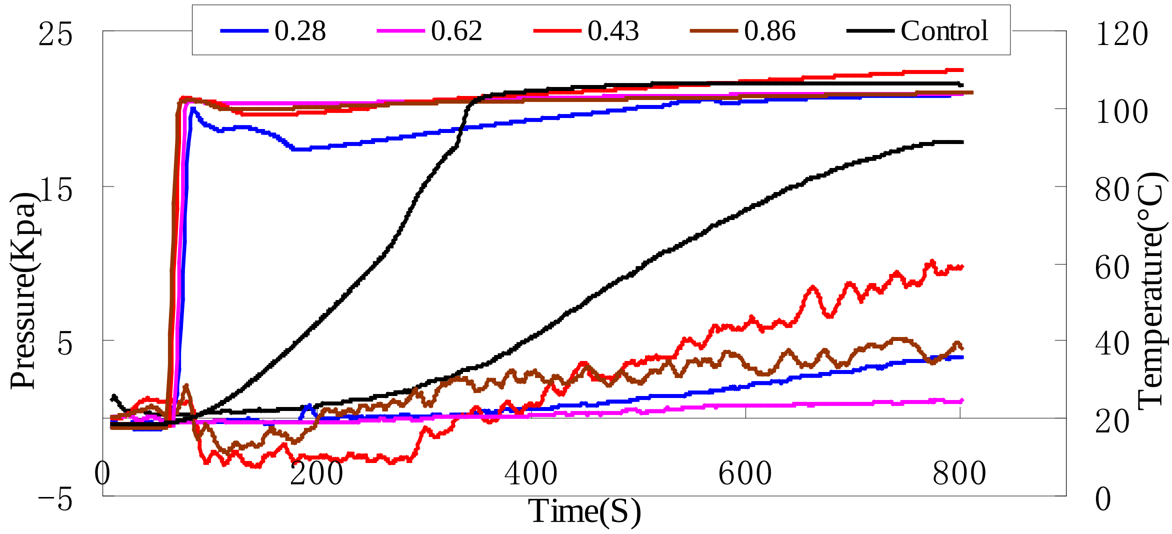

Figure 5: Core temperature and gas pressure curve of LSL with different compaction ratios

Influence of steam-injection time on core temperature and gas pressure of LSL

Temperature and gas pressure with different steam-injection times were presented in Fig.6. As shown in the figure, prolonging of steam injection time contributed to increase the final temperature. The maximum temperature was 115°C when steam injection time was 30s. As for 10s and 20s, it was 102.7°C and 103.5°C respectively. Gas pressure increased as steam injection time prolonged.

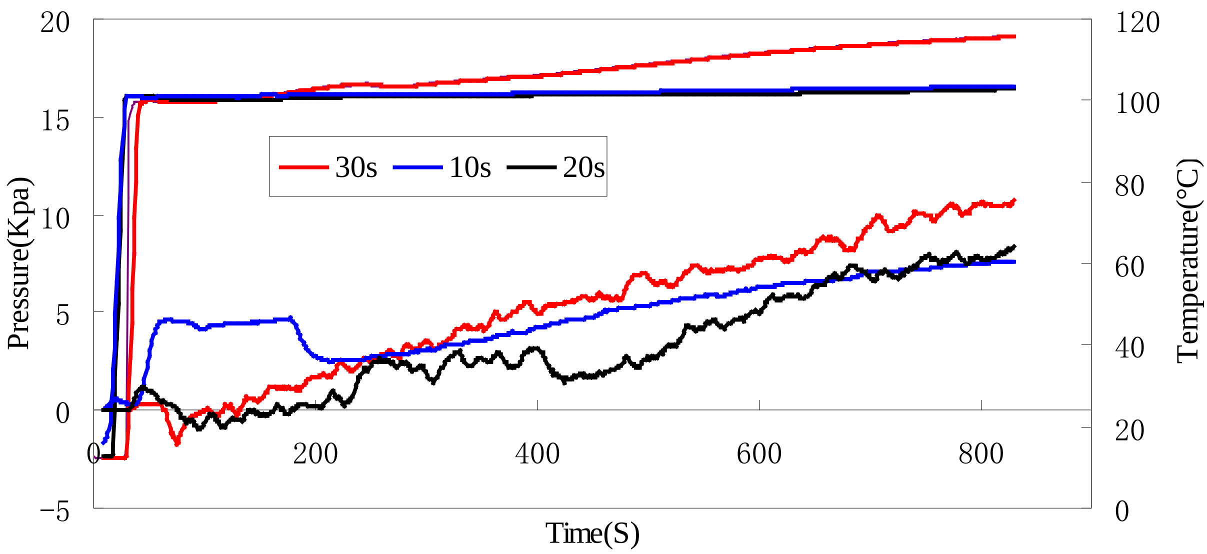

Figure 6: Core temperature and gas pressure curve of LSL with different steam-injection time

Influence of vacuuming time on core temperature and gas pressure of LSL

Temperature and gas pressure with different vacuuming times were presented in Fig.7. As shown in the figure, extension of vacuuming time has no influence on the core temperature of the mat. When vacuuming time increased from 30s to 60s, gas pressure in the mat dropped obviously. However, when it increased from 60s to 90s, gas pressure in the mat did not change.

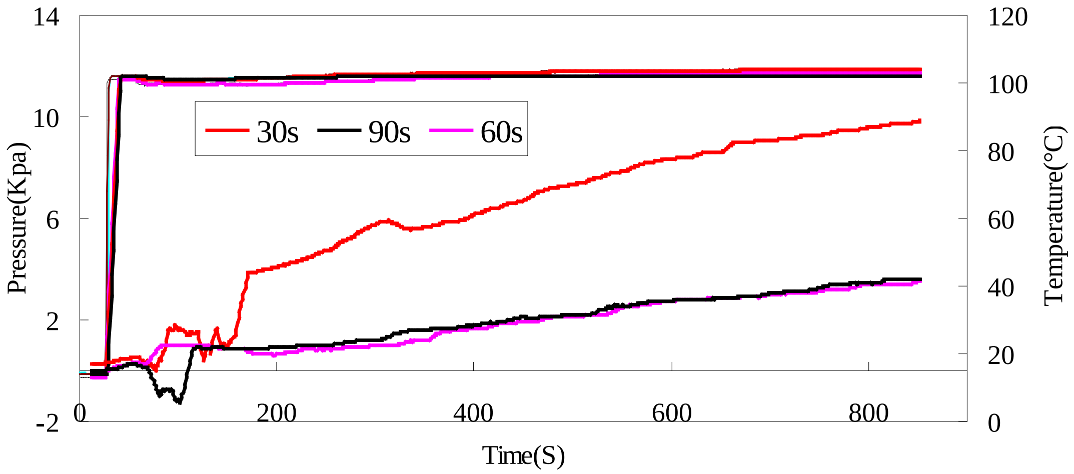

Figure 7: Core temperature and gas pressure curve of LSL with different vacuuming time

CONCLUSIONS

To provide fundamental knowledge to better understand and manufacture laminated strand lumber, effect of strands with different length, width and thickness on properties of LSL and effect of compaction ratio, steam-injection time and vacuuming time during steam-injection press on core temperature and gas pressure of LSL mat were investigated. The following conclusions were reached:

1. Strand geometry has great influence on the properties of LSL. The increase of strand length leads to enhancement of MOR and MOE and the reduction of IB; the change of strand width has little influence on the properties of LSL; the increase of strand thickness leads to the decrease of LSL properties.
2. MOR and MOE of LSL decrease as the surface orientation angle increases. Core layer orientation angle has a slight influence on MOR and MOE of LSL. While the core layer is randomly aligned, its internal bond is slightly higher than that of the oriented one.
3. Steam-injection is effective to raise the temperature of core layer in LSL mat. In this study, when the compaction ratio is around 0.43, it can obtain the best steam-injection effect. Prolonging of injection time contributes to the rise of the core layer temperature, meanwhile enhancing gas pressure. The extension of vacuuming time helps to reduce the gas pressure in the core of LSL mat.

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Effect of Plywood Technology on Poplar Veneer Linear Expansion Coefficient

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Keywords: Plywood technology, linear expansion coefficient, poplar veneer

1 ABSTRACT

In an environment of constant temperature and increasing humidity, the hygroscopic deformations of poplar veneers, which were treated by different glue spreading and hot pressing technologies, were tested in the longitudinal, transversal and thickness directions.
The results showed that in the range of moisture content from 0 to 25%, the veneer hygroscopic expansion coefficient can be regarded as constant. Besides, the technology factors including glue spreading, pressure and adhesive type affected veneer transversal and thickness hygroscopic expansion coefficients significantly. The lower molecular weight of Phenol-formaldehyde (PF) affected veneer hygroscopic expansion property more than that of Urea-formaldehyde (UF). The compressed veneer showed higher hygroscopic expansion in the thickness direction, but a lower hygroscopic expansion in the longitudinal and transversal directions.

INTRODUCTION

Plywood is a flat panel built up of sheets of veneer, united under pressure by a bonding agent to create a panel with an adhesive bond between plies. The hygroscopic expansion properties of each ply have great effects on the whole plywood. There are many factors affecting wood hygroscopic expansion properties, and technology factors such as gluing and compression ratio had great effects on the modulus of elasticity and other mechanical properties of veneer (Lu 2002, 2003, 2006). The primary goal of this study was to investigate the effect of primary technology such as glue spreading and pressure on the hygroscopic expansion properties of Poplar veneer.

EXPERIMENTAL METHODS

Test Material

Poplar veneer: nominal thickness 1.6 mm, moisture content (MC) 12%;
Urea-formaldehyde (UF) resins: solid content 58%, viscosity 16s ($4^{\#}$, 25);
low molecular weight Phenol-formaldehyde (PF) resins: solid content 41%.

Linear Expansion Coefficients

There are some relations of linear expansion coefficients definition between wood science and mechanics of complex materials (Wang 2007). In order to use the theory of mechanics of complex materials to calculate panel deformation, this study uses the definition of linear expansion coefficients in mechanics of complex materials.

Poplar veneer, as all other wood veneer, can be defined as orthotropic panels and have strain in longitudinal, transversal and thickness directions after absorbing moisture. However, the shearing strain is zero, $\gamma_{LT}^{H} = 0$. As a result, in the range of Poplar veneer with MC from ovendry to fiber saturation point(FSP), the linear expansion coefficients in longitudinal, transversal and thickness directions can be defined as Eq. 1.

$$\beta_{\mathrm{L}} = \frac{\varepsilon_L^H}{W}, \quad \beta_T = \frac{\varepsilon_T^H}{W} \quad \beta_R = \frac{\varepsilon_R^H}{W} \qquad [1]$$

Where $\beta_L, \beta_T, \beta_R$ is the linear expansion coefficients in longitudinal, transversal and thickness direction, $\varepsilon_L^H, \varepsilon_T^H, \varepsilon_R^H$ is the hygroscopic strain in longitudinal, transversal and thickness direction, W is the veneer moisture content (%).

Experiment Design

In this study, we mainly investigated the effect of technology factors on veneer hygroscopic expansion properties. The factors include veneer glue spreading, pressure, flour amount and adhesive type. For each kind of technology, five 80 x 80 mm specimens were cut. The specimens were dried to ovendry weight and length, width and thickness were measured after treatments in different technologies. Then the specimens were placed in an environment of constant temperature (30°C) and different relative humidity: 40%, 60%, 70%, 80%, 90%, 95% and 99%. In every environment, the specimens were treated until their quality became invariable and length, width and thickness were measured. Finally the relation between veneer MC and hygroscopic strain was received and the linear expansion coefficients in three directions can be received using data fitting. The experiment design is shown in Table 1.

Table 1: Single factor experiment design

Glue Spreading [g • m^{-2}]	Level	Pressure [MPa]	Level
A_1	0	B_1	0
A_2	150	B_2	2
A_3	350	B_3	3
A_4	550	B_4	4
		B_5	5
Adhesive Type	**Level**	**Flour Amount [%]**	**Level**
C_1		D_1	0
C_2	UF	D_2	10
C_3	PF	D_3	30

RESULTS AND DISCUSSION

Fitted Value of Linear Expansion Coefficients

The linear expansion coefficients were fitted through strain-MC figure, the fitted value is showed in Table 2.

Table 2: Linear expansion coefficients of test specimen

Specimen	β_L [%]	β_T [%]	β_R [%]
A_1	0.00721	0.296456	0.20199
A_2	0.00702	0.26507	0.11913
A_3	0.00477	0.31434	0.181542
A_4	0.00484	0.35510	0.17811
B_1	0.00721	0.296456	0.20199
B_2	0.00504	0.23908	0.38379
B_3	0.00486	0.2325	0.60184
B_4	0.006	0.241278	0.92312
B_5	0.00580	0.242428	1.5751
C_1	0.00721	0.296456	0.20199
C_2	0.00702	0.26507	0.11913
C_3	0.00456	0.239424	0.116622
D_1	0.004200	0.269000	0.316700
D_2	0.002200	0.275900	0.371600
D_3	0.004910	0.301500	0.368700

According to the data fitting figures, the relation between moisture strain and MC in three directions was nearly rectilinear. So the linear expansion coefficients could be seen as constant in the moisture content range from 0% to 25%.

Direct Analyzing

Comparing linear expansion coefficients of reference specimen with those of treated specimens, the tendency is shown in Fig. 1.

In Fig. 1 (g)—(i), the linear expansion coefficients in three directions were the biggest in the reference specimens, then the UF specimens and the smallest in the PF specimens. It could be observed that both PF and UF could improve veneer dimension stability. PF specimens had better dimension stability because PF had better water-repellent properties than UF. Seen from Fig. 1 (j)—(l), it was shown that the linear expansion coefficients in three directions of specimen became bigger along with an increasing flour amount. This is because flour additives will raise veneer hygroscopic expansion. As for Fig. 1 (a)—(c), where veneer glue spreading was little, the dimensional stability of adhesive effect more than the hygroscopic expansion of flour. The flour amount increased along with veneer glue spreading, the hygroscopic expansion of flour effect more than the dimensional stability of adhesive. Finally in Fig. 1 (d)—(f), it was shown that the linear expansion coefficients of compressed veneer in longitudinal and transversal direction were both less than that of uncompressed veneer, however, the linear expansion coefficients in the thickness direction was reversed. When compressed veneers are placed in an environment with high humidity, cell walls will absorb moisture and expansion, the internal stress in veneer will release. As a result, veneer thickness expansion happened (Zhou 2000). As for expansion in longitudinal and transversal direction, veneer was consolidating after been compressed and veneer density was also increased, so it was more difficult to absorb moisture and the expansion properties became better.

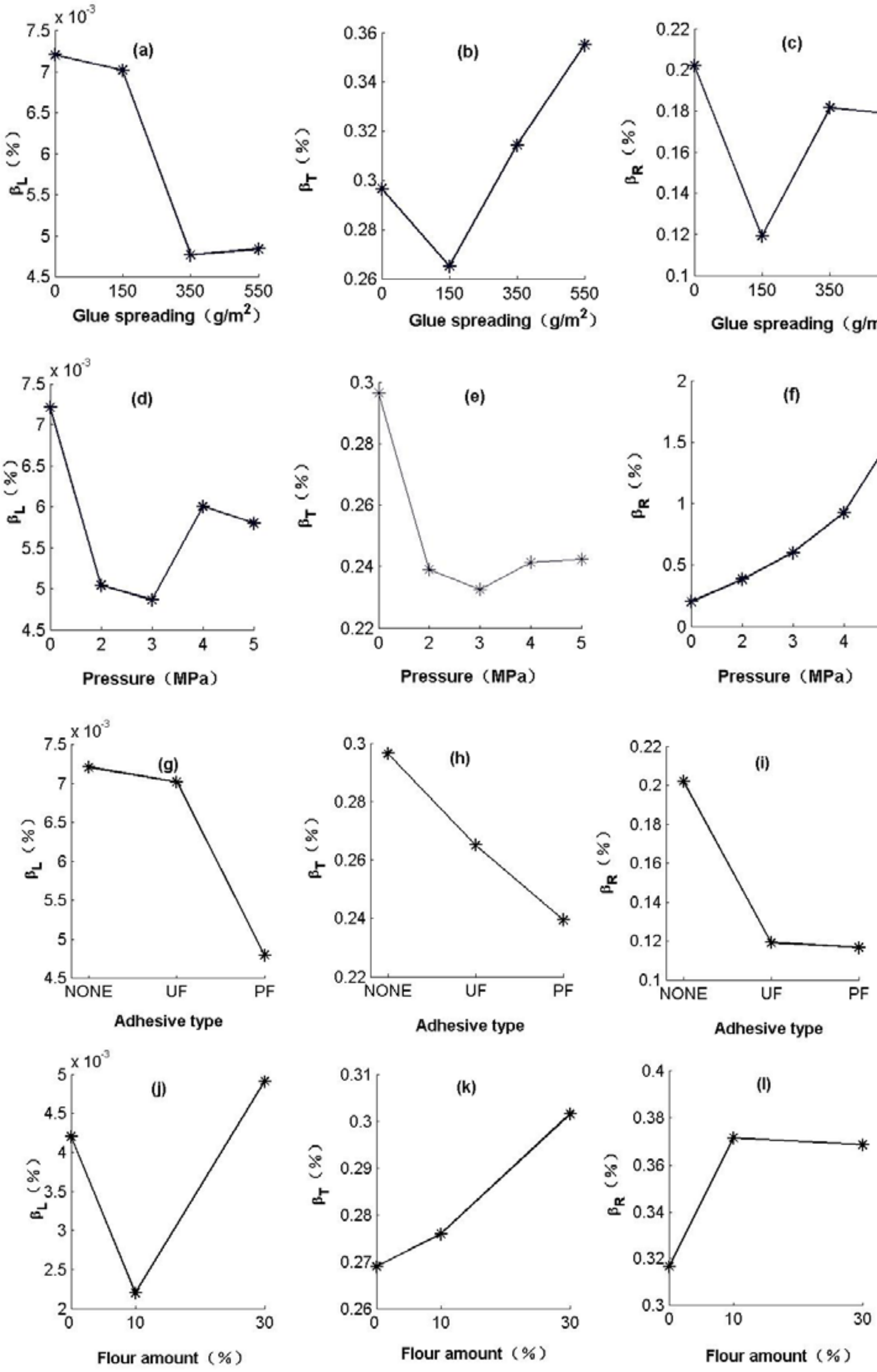

Figure 1: Direct analyzing of linear expansion coefficients

Single Factor Variance Analyzing

The results of single factor variance analyzing are shown in Table 3.

Table 3: Single factor variance analyzing

Factors	Linear Expansion Coefficients	*F*	F_α
Glue Spreading	β_L	1.29	$F_{0.05}$（3,16）＝3.24 $F_{0.01}$（3,16）＝5.29
	β_T	8.67^{**}	
	β_R	8.28^{**}	
Pressure	β_L	0.59	$F_{0.05}$（4,20）＝2.87 $F_{0.01}$（4,20）＝4.43
	β_T	12.79^{**}	
	β_R	161.04^{**}	
Adhesive Type	β_L	1.63	$F_{0.05}$（2,12）＝3.89 $F_{0.01}$（2,12）＝6.93
	β_T	10.36^{**}	
	β_R	34.89^{**}	

From Table 3, it was concluded that the three factors affected the linear expansion coefficients in transversal and thickness direction remarkably. On the other hand, because of the tiny expansion in longitudinal direction, there was much trial error in longitudinal expansion.

CONCLUSIONS

In the range of the MC from 0% to 25%, the linear expansion coefficients of untreated or treated veneer could be seen as constant. The plywood technology such as glue spreading, pressure and adhesive type affected the veneer expansion properties in transversal and thickness directions remarkably. The mechanical properties of plywood are related with that of each ply, which may be treated with different technologies. As for plywood hygroscopic expansion properties, it is related with each ply which has different hygroscopic expansion properties under different technologies.

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Research on Concrete Form from Poplar Plywood

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Keywords: Poplar, plywood concrete form, hot pressing technology

ABSTRACT

With the development of the economy and architecture scale in China, the demand of concrete formwork in the building industry is also increasing. Plywood, as an important concrete formwork in architecture industry, is facing shortage of natural tree resources, and fast growing poplar is an ideal substitute. In the paper, PF-bonded poplar plywood was made using three processing factors, i.e., resin content, hot pressing time, and compressibility. Every factor has three levels.

Results showed that the mechanical properties of plywood formwork increased with the resin content at a low level, then decreased afterwards, related to the inner stress by the cured resin body. Accordingly, the best level of resin content is $275g/m^2$. Similarly, the best hot pressing time is 1mm/min, and the optimized compression ratio is 31.5%.

INTRODUCTION

So far, based on the material, the concrete form can be classified into several kinds. The first one is steel form, and it is mainly combined steel form. There are already 600 steel form factories around the country until 1993. Steel form so far is the main body of form project in our country. The second kind is wood form. It is used earliest. The development of wood form is restricted because of the shortage of forest resources in our country. The third is bamboo form, including bamboo plywood form, bamboo intertexture form and surface decorated bamboo concrete form, bamboo particle form and plastic bamboo composite high intensity plywood and so on. The fourth is composite concrete form including steel bamboo composite form, steel frame-plywood composite form, steel frame and non-wood based panel composite form. The fifth is other forms including glass steel column form, plastic concrete form, cast-aluminium alloy form, surface decorated hardboard form, MDF form and so on. They are all developed and applied and gained a certain effect.

Plywood form is a kind of wood form used and developed from the 1960s. The characteristics of plywood form are as follows:

Plywood form is easy to install and easy to make from hull. The surface of plywood form is big so it can reduce the joint number of forms, and it will prevent leaking slurry. It ensures the project quality of concrete. Plywood form has good performance on heat preservation, and it can diminish the effect from outside temperature to concrete. Surface decorated form is usually used 20 times upwards. Plywood form has good waterproof and anti-aging quality because it uses I type waterproof resin.

There are two usable surfaces on plywood form. So when pour concrete structure, the surface is smooth and glazed. Plywood form is easy to clean, and its surface is hard to mangle. The plywood form is used extensively in some developed countries such as USA, Germany and Canada, because plywood form has good properties and many advantages. So the plywood form has become the mainstream of form projects. Because wood resource is ample in these countries, the material of plywood is not a problem. But in our country, the development or plywood form can only stay on a certain level because of the shortage of wood resources, especially the big diameter logs used for manufacturing plywood.

The manufacturing of plywood used for concrete form began in the early 1960s. At that time, some plywood factories in Shanghai start making plywood forms with imported Apitong. The manufactures of plywood forms reached a certain scale in the middle time of the 1970s in the south of China and Beijing. 90% of plywood forms are used for export, mainly in Hanghong and Macao. The scale of architecture is rapidly increasing with the development of the Chinese economy and the increase of external trade. Plywood form surfaces, being big and light, are thus suited for making large-scale forms. It can increase efficiency and quality of construction and accelerate the development of plywood forms. Wood resources used for plywood changed a lot in the 1990s. The demand of a good quality mature forest is more and more stand out. The situation of wood resources for making plywood changed a lot in 1990s, when many factories were making thin board before began to make thick board. So plywood for concrete form became the main part of plywood products.

Nowadays among architecture projects in China, the concrete constructed capacity is every year more than 900 million m^3, and needful concrete output is more than 90 million. When making concrete form plywood of 15mm thick, there are about 1 million 350 thousand m^3 forms every year. And because form is a kind of wasting material, some must be discarded as useless every year. The wasting forms are about 10% among all forms by estimate, almost 8 million m^3, that needs to be replaced/supplied every year. In addition, the ratio of forms falling into disuse will increase with the development of architecture technology and constructing quality. Plywood has preeminent properties as form material among all kinds of form. With the development of the Chinese economy, plywood form has a great market developing space and a bright future.

Italian poplar is a kind of species that is easy to distort and warp. Its density is 0.28 to 0.40 g/cm^3, and the compress ratio is big. Knars are rare in Italian poplar panel, and this poplar panel is soft, so it is easy to repair. Compared to *Pinus massoniana*, there are less knars and less turpentine in poplar panels. Also, the poplar appearance quality grade is better than *Pinus massoniana*. As a cement form, Italian poplar panels can reduce the dependence on *Pinus massoniana* so it is good for protecting *Pinus massoniana* log resources. They also have a good economical benefit. The price of a general *Pinus massoniana* panel is 1400 to 1600 yuan/m^3, but the average price of an Italian poplar panel is 50% of it. The price difference between making a cement form of the same size with *Pinus massoniana* and Italian poplar is about 15 yuan. Under the same price, a cement form company using Italian poplar middle board produces more than 500m^3 every month so that earnings are 3 million every year. So it has a great economical benefit.

MATERIALS AND METHODS

Raw materials for this research are poplar panel, measuring 1270 x 85 x 1.8mm/2.7 mm. This research uses PF resin with a content of solid matter of 43%. Viscosity is 220s. This research uses the method of the orthogonal test. Factor A is a different resin level, which is 250 g/m³, 275 g/m³ and 300 g/m³. Factor B is a different hot pressing time, which is 0.9 mm/min, 1 mm/min and 1.1 mm/min. Factor C is a different compression ratio which is 20%, 25.5% and 31.5%.

Compression ratio, resin level and hot pressing time are three main factors effecting plywood mechanical properties. Poplar is soft timber, so it is important to control the compression ratio. This research tried to find the best and most economical process to supply a certain theoretical basis for manufacturing poplar plywood.

RESULTS AND DISCUSSION

Longitudinal MOE analysis

We can describe the relationship of factor and level using level as X-axis and using corresponding effect as Y-axis.

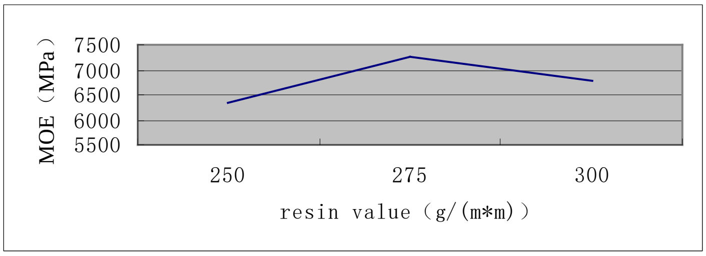

Figure 1: The relationship between level and average value under factor A

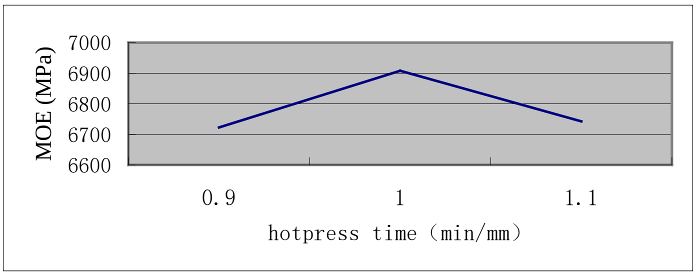

Figure 2: The relationship between level and average value under factor B

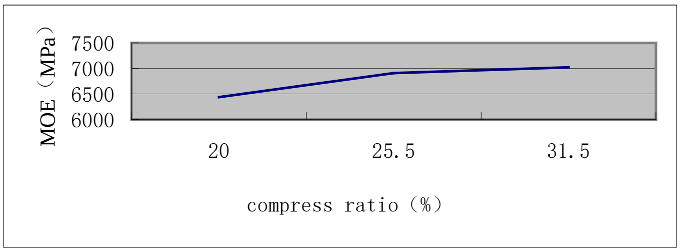

Figure 3: The relationship between level and average value under factor B

Level analysis under all factors

1. When the resin level increased from 250 g/m² to 275 g/m², the average MOE increased from 6324 MPa to 7265 MPa. When the resin level increased from 275 g/m² to 300 g/m², the average MOE decreased from 7265 MPa to 6783 MPa, which means that 275 g/m² is the best resin level.
2. When the hot pressing time increased from 0.9 min/mm to 1 min/mm, the average MOE increased from 6722 MPa to 6907 MPa. When the hot pressing time increased from 1 min/mm to 1.1 min/mm, the average MOE decreased from 6907 MPa to 6742 MPa, which means that 1 min/mm is the best hot pressing time.
3. When the compression ratio increased from 20% to 25.5%, the average MOE increased from 6441 MPa to 6907 MPa. When the compression ratio increased from 25.5% to 31.5%the average MOE increased from 6907 MPa to 7023 MPa, which means that the best compression ratio is between 25.5% and 31.5%. Once below 25.5% MOE will decrease.

Primary and secondary analysis of factors

According to the value of R from all data, it can be estimated that the primary and secondary effect of factors to target. When R1 = 941.4, R2 = 185.7 and R3 = 582, the primary factor is resin level, the secondary factor is compression ratio and the third factor is hot pressing time.

Better manufacture choice

The better manufacture is A2C3B2. So the better resin level is 275 g/m², the better compression ratio is 31.5%, and the better hot pressing time is 1min/mm.

Other mechanics property analysis

Tangential MOE data analysis

According to Fig. 4, the best level of three factors is the second level. The best manufacture condition is A2C2B2. The resin level is 275 g/m², the compression ratio is 25.5% and the hot pressing time is 1 min/mm.

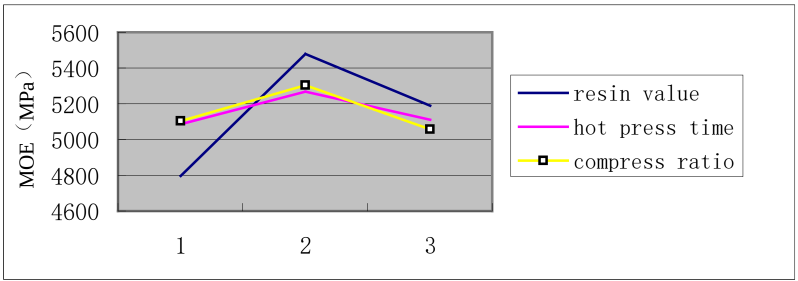

Figure 4: The relation figure of factor and average MOE

Longitudinal MOR data analysis

According to Fig. 5, the best level of resin level is the second level, the best level of hot pressing time also is the second level and the best level of compression ratio is the third level. The best manufacture process is B2A2C3 according to all factors. It means the best hot pressing time is 1 mm/min, the resin value is 275g/m³ and compression ratio is 31.5%.

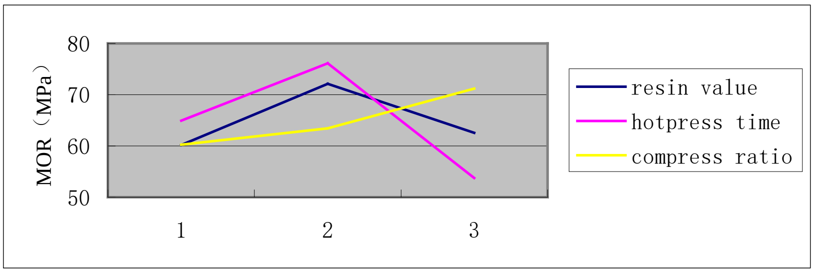

Figure 5: Relationship between factors and average MOR

Tangential MOR data analysis

According to Fig. 6, the best hot pressing time is1 mm/min, the resin value is 275g/m³ and compression ratio is 31.5%.

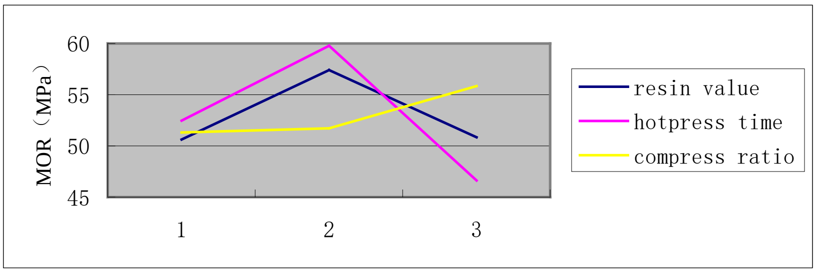

Figure 6: Relationship between factors and average MOR

Bonding strength analysis

According to the Table 1 and Fig.7, the best manufacture process is A2B1C2. The best hot pressing time is 1 mm/min, the resin value is 275g/m³ hot press time is 0.9mm/min and compression ratio is 25.5%.

Table.1: Bonding strength analysis

K11	3.54	K12	3.74	K13	3.34
K21	3.9	K22	3.42	K23	3.44
K31	2.76	K32	3.04	K33	3.42
W11	0.046667	W12	0.113334	W13	-0.02
W21	0.166667	W22	0.006667	W23	0.013334
W31	-0.21333	W32	-0.12	W33	0.006667
R1	0.38	R2	0.233333	R3	0.03334

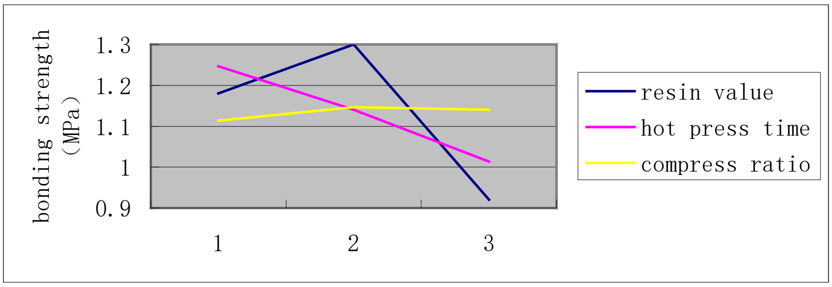

Figure 7: Relationship between factor and average bonding strength

CONCLUSIONS

According to this research, we can conclude the manufacture choice as follows: resin content is 275 g/m³ hot press time is 1 mm/min and compression ratio is 31.5%. The most economical manufacture is as follows: resin content is 250 g/m³, hot press time is 0.9 mm/min and compression ratio is 20%.

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Heat Transfer Characteristics of Compound Wall from OSB, Low Density Strawboard and Gypsumboard

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Keywords: OSB, low density strawboard, heat transfer characteristics

ABSTRACT

The thermal transport properties of low density strawboard and the compound wall from Oriented Strandboard(OSB), Low Density Strawboard(LDSB) and Gypsumboard were tested. The unsteady heat transfer characteristic of the compound wall was analyzed with the method of Response Coefficient. The indoor environment of the build from the compound wall was investigated and compared with the house from common construction materials, so that the heat transfer characteristics and the energy-efficient performance of the compound wall can be evaluated. The results show that Low density strawboard is one kind of ideal heat insulation material for buildings. The compound wall has better performance to prevent the periodic thermal wave from propagating across the wall than the brick and the aerated concrete.

INTRODUCTION

China is an agricultural country. Abundant agricultural straws are produced every year. As it is reported, about 0.6 to 0.7 billion ton straws are yielded every year in China. In the past, after being processed roughly, the agricultural straws were used as fuel, fertilizers, forage, raw material for producing paper and building farmhouses (Zhou *et al.* 2000). With the improvement of science and technology, the above applications of agricultural straws are eliminated gradually. In the harvesting season, agricultural residues are usually set on fire, which results in air pollution and traffic accidents. How to use the agricultural straws is an actual problem that either numerous farmers or scientists must face and solve.

Considering its low density, heat insulation and sound absorption, straws are good enough to substitute for rock wool and glass wool used as building insulation materials. Up to now, three kinds of straw-based wallboard have been developed in China which are presented as follows: (1) Platen-pressed Straw-based Wallboard with low density was invented by Nanjing Forestry University. Straws are pressed into low density heat insulation panels. Secondly, the panel is covered with cement board, gypsum board or wood-based panels on both sides to form a multiple wallboard. (2) Extruded Straw-based Wallboard was imported from Great Britain and developed in the Shanghai Wood-based Panel Machinery Factory; made from wheat or rice straw without being cut and spread with resin which is extruded under high temperature and pressure in the forming machine directly to be densified and then covered with paper on both surfaces of the board. (3) Mould-pressed Straw–based Wallboard was invented by Sicuan Xinghe Construction Material Co. Ltd. and is named “FGC Wufang

Partition" which is made from wheat straw, rice straw and inorganic materials by mould pressing (Zhou *et al*. 2005).
The objective of this paper is to study the thermal transport properties of low density strawboard and the compound wall from Oriented Strandboard(OSB), Low Density Strawboard(LDSB) and Gypsumboard, analyzing the unsteady heat transfer characteristics of the compound wall and investigating the indoor environment of the build from the compound wall thus comparing it with a house from common construction materials, so that the heat transfer characteristics and the energy-efficient performance of the compound wall can be evaluated.

MATERIALS AND METHODS

1.1.1 Manufacturing the low density strawboard (LDSB) and the compound wall

Wheat straws are gathered from the countryside (moisture content must be kept around 15~20%) and trimmed to remove fines, leaves, sand and stones. Then they are cut into pieces with a length of 50~60mm by a straw-cutter. It is not necessary to dry these pieces since they are blended with MDI which can react with water. After blending, the mat is formed and pressed with a pressure less than 0.5MPa. In order to keep the cavities of straws and the good heat insulation of the low density strawboard, lower pressure is chosen. The density of this panel is about 0.3~0.4kg/m^3 and thickness is around 80~100mm, so that steam-injection pressing is commended. The thickness of the panel is determined by the wallboard according to the code of construction. After being cut into the right size, the panel is covered by gypsum boards on both sides to make the compound wall. The joints between the covers and the low-density strawboard can be an adhesive or metal joints. Table 1 shows the main manufacture variables of LDSB.

Table 1: Main manufacture variables of LDSB

Item	Value
Pressing temperature	160~170 °C
Pressing time	0.2~0.4 min/mm
Pressure	0.2~0.5MPa
Moisture content	15~20%
Resin content	2~4%

Testing the thermal transport properties of LDSB

The basic thermal properties of LDSB were measured by the Transient Plane Source (TPS) technique. The Transient Plane Source (TPS) technique is used to perform simultaneous measurement of thermal conductivity and thermal diffusivity. TPS technique is based on the theory of transient heat flow through a plane. The test apparatus uses an electric plane heater and two temperature sensors on the side of the sample with the size of 200x200mm. During the experiment, voltage variations of sensors, the output power of the plane heater, heating and cooling times are recorded. Thermal conductivity, thermal diffusivity and specific thermal capacity can then be calculated (Log *et al.* 1995) .

Analyzing the heat transport characteristics of the compound wall

JW-I apparatus was designed for measuring the heat resistance of the compound wall according to the standard GB 13475-1922. There are three boxes of this apparatus: heating box, sample box and cooling box. Samples with size of 1000x1000mm was put into the sample box and sealed at the age by heat insulation materials. The heating and cooling boxes are used for simulating the outdoor and indoor air condition. If the temperature is different between the two surfaces of the sample, the heat will transfer from the high temperature side to the lower one. Finally, the temperature difference will remain stable. Then record the rate of heat flow and the difference between the temperatures of opposite faces of the sample. The thermal resistance (R-value) can be easily computed as the following equation:

$$R = \Delta T / Q$$

Where R is the thermal resistance [in $m^2 \cdot k/w$] ΔT is the difference between the temperatures of opposite faces of the sample [in K] and Q is the rate of heat flow [in w/m^2].

The effect of the compound wall structure on the R-value and the difference of the heat transport characteristics between the compound wall and the traditional construction materials were analyzed.

Evaluating the unsteady heat transfer characteristic and the energy-efficient performance of the compound wall.

The method of Response Coefficient in terms of triangular wave decomposition was applied to evaluate the unsteady heat transfer characteristics and the energy-efficient performance of the compound wall. Meanwhile, it was compared with the common building materials(Zhou *et al.* 2007).

Investigating the indoor environment of the building from the compound wall

A two-story demonstration house with an area of $120m^2$ made from OSB-Strawboard-Gypsumboard Compound Wall was built on the campus of Nanjing Forestry University. One room on the first floor of this building was chosen for field-testing. Another concrete frame room with the same area was chosen for comparison. The air temperature and the temperature of the wall on both sides were monitored.

RESULTS AND DISCUSSION

The thermal transport properties of Low Density Straw-based Board(LDSB)

Table 2 shows the thermal transport properties of different materials. It is indicated that the thermal conductivity of LDSB is quite close to that of the foamed plastic, which could be named as heat insulation materials since the thermal conductivity is less than 0.25W/(m•K) (Lu 1986). Air and other gases are generally good insulators, in the absence of convection. Therefore, many insulating materials function simply by having a large number of gas-filled pockets which prevent large-scale convection. LDSB was pressed under lower pressure in order to keep the voids of the straws which can form lots of gas-filled pockets. Therefore, it has good heat insulation.

Table 2: Thermal transport properties of some materials

Materials	Density kg/m^3	Thermal Conductivity W/(m•K)	Thermal Capacity J/(kg•K)	Thermal Diffusivity $\times 10^{-4} m^2/h$
Low Density Strawboard	350	0.063	2430	5.7
Polyurethane foamed plastic*	50	0.037	1386	9.7
Mineral wool/Cement Board*	500	0.16	1050	10.9
Aerated concrete*	700	0.22	1050	26.8
Hollow clay brick*	200	0.33	1050	17.6

*Note: * The data came from the code of Residential Building Design in Thermal Characteristics GB 50176-93*

Substances with high thermal diffusivity rapidly adjust their temperature to that of their surroundings, because they conduct heat quickly in comparison to their thermal 'bulk'. In other words, the little the thermal diffusivity of materials is, the slower speed heat transferring in the wall is (Wang 1988). It is also important when evaluating the properties of heat insulation of building materials. LDSB has a relatively small thermal diffusivity.

The thermal capacity is the ratio of heat absorbed by a material in reaction to a change in temperature. Materials with high heat capacities require greater amounts of heat to increase their temperatures than do substances with low heat capacities. It is the characteristic of materials themselves which depends on the mineral component and the content of organic compounds. The thermal capacity of LDSB is higher than that of the inorganic materials (Wang 1988) .

The heat transport characteristics of the compound wall

A material's R-value is the measure of its ability to prevent heat from flowing through it. It is important to know the R-value because many states or regions require that the building materials for both commercial and industrial buildings have a minimum amount of thermal resistance. The way it works is simple: the higher the R-value, the more the building insulation's effectiveness. The R-value of the compound wall from OSB, Low Density Strawboard and Gypsumboard and some common building materials are shown in the following table.

It is indicated that the R-value of he compound wall from OSB, Low Density Strawboard and Gypsumboard vary from slightly less than 1.00 to approximately 2.00 (See Table 3, No.1 to No.5). It met the requirement of the minimum amount of thermal resistance of building materials in China. Comparing compound wall No.1 with common wall materials, it is clear that the R-value of the compound wall No.1 is about 4 times that of the brick and concrete wall. It is close to that of the aerated concrete, while its thickness is only one-third of the aerated concrete. It proves that the compound wall from OSB, Low Density Strawboard and Gypsumboard has significant heat insulation.

In addition, the thermal resistance of the compound wall is increased with the air space being added (Table 3, No. 1 to No. 3). However, when increasing the thickness of the air layer, the thermal resistance of the compound wall is decreased dramatically due to convection and radiation developing in the big air space (Table 3, No. 4 and No. 5). Meanwhile, putting the

air layer on the side with low temperature will decrease radiation, so that the R-value will be improved slightly (Table. 3 No.2 and No. 3) (Jiang *et al.* 2002).

Table 3: Thermal resistance of some building materials

No.	Wall System	Thickness mm	Thermal conductivity W/(m·K)	Thermal resistance $m^2 \cdot k/w$
1	Gypsumboard	6	0.52	1.51
	LDSB	80	0.063	
	OSB	8	0.146	
2	Gypsumboard	6	0.52	1.75
	Air Layer	40	—	
	LDSB	80	0.063	
	OSB	8	0.146	
3	Gypsumboard	6	0.52	1.76
	LDSB	80	0.063	
	Air Layer	40	—	
	OSB	8	0.146	
4	Gypsumboard	6	0.52	1.10
	LDSB	40	0.063	
	Air Layer	80	—	
	OSB	8	0.146	
5	Gypsumboard	6	0.52	0.81
	LDSB	20	0.063	
	Air Layer	100	—	
	OSB	8	0.146	
6	Cement mortar	20	0.87	1.45
	Aerated concrete	240	0.19	
	Cement mortar	20	0.93	
7	Cement mortar	20	0.87	0.49
	Brick	240	0.81	
	Cement mortar	20	0.87	
8	Cement mortar	20	0.87	0.33
	Concrete	240	1.74	
	Cement mortar	20	0.93	

The unsteady heat transfer characteristic and the energy-efficient performance of the compound wall

Fig.1 shows the maximal thermal reaction factor of the compound wall, brick and aerated concrete with different thickness. The thermal reaction factor is the hour to hour heat transfer quantity per unit. The maximal thermal reaction factor of the compound wall is only one-fourth of that of brick and aerated concrete which means the hour to hour heat transfer quantity across the compound wall is much lower. Furthermore, when the thickness of the compound wall is reduced to one-third of the aerated concrete, its maximal thermal reaction factor is still approximate to that of the aerated concrete. It is shown in Fig. 2 that the heat transfer quantity of the compound wall with a thickness of 250mm during one day is only one-third of that of the brick and one half of that of the aerated concrete. Even if its thickness is one-third of them, its heat transfer quantity is still much lower than that of the brick and close to that of the aerated concrete. In other words, it can keep good heat insulation even if

the thickness is reduced, so that the effective area of the building from this compound wall can be increased and the cost of the building base can be decreased as well.

In addition, the smaller the heat transfer quantity of wall is, the lower energy consumption is. Comparing with the brick wall, the aerated concrete can save energy of 47%, the compound wall (T=250mm) 29% and the compound wall (T=80mm) 49% under the same environment.

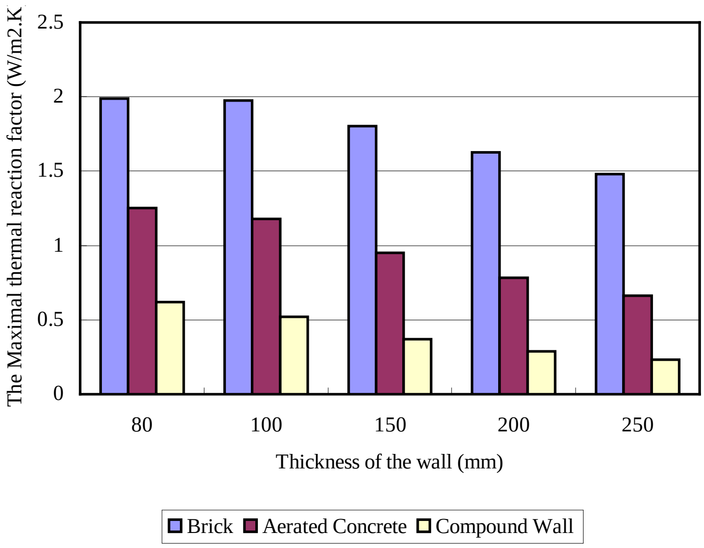

Figure 1: Maximal thermal reaction factor of different walls

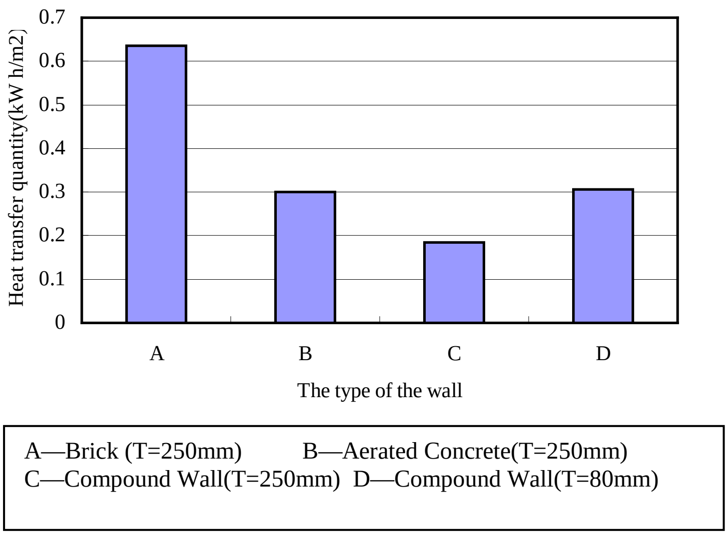

Figure 2: Heat transfer quantity of the different walls in one day

The indoor environment of the building from the compound wall

The variation and swing of the external environmental temperatures result in a heat propagation process by a periodic thermal wave from the outside to the inside of a wall with the flux always taking place from the hotter to the colder surface of the cross section arrangement of the wall. The thermal wave, which propagates from the external (entry) to the internal (exit) surface of the wall, is diminished and shows a time delay (phase difference) which is due to the thermal mass of the materials. Thus, it can be defined: "as attenuation multiple ν_0" the decreasing amplitude of the thermal wave during its propagation process from outside to inside, which is the ratio of the external environmental temperature difference to the internal surface temperature difference of the wall in the whole day, and "as time lag ξ_0" the time it takes for a heat wave, with period *P* (24-h), to propagate from the outer surface (minimum or maximum external temperature peaks) to the inner surface (minimum or maximum internal temperature peaks) of the wall formation. The above parameters are defined respectively by the following equations (Asan *et al*. 1998).

$$\nu_0 = \frac{2A_e}{2A_{if}} = \frac{\theta_{e.\max} - \theta_{e.\min}}{\theta_{if.\max} - \theta_{if.\min}}$$

$$\xi_0 = \tau_{if.\max} - \tau_{e.naxn} = \tau_{if.\min} - \tau_{e.\min}$$

Table 4 and 5 show the results from field testing of the attenuation multiple and the time lag of the compound wall(T-80mm) and brick (T=250mm) in winter. It is obvious that the multiple attenuation of the compound wall is higher and the time lag is longer than that of the brick wall, while its thickness is only one-third of the brick. Namely, the compound wall has better performance to prevent the periodic thermal wave from propagating across the wall.

Table 4: Multiple attenuation of buildings

Buildings	$\theta_{e.max}$(℃)	$\theta_{e.min}$(℃)	$\theta_{if.max}$(℃)	$\theta_{if.min}$(℃)	ν_0
Compound Wall	14.8	5.5	13.0	11.5	6.2
Brick	14.5	5.9	13.6	11.8	4.8

Table 5: Time lag of buildings

Buildings	$\tau_{e.max}$	$\tau_{if.max}$	$\tau_{e.min}$	$\tau_{if.min}$	ξ_0***(h)***
Compound Wall	14：00	18：30	5：00	9：30	4.5
Brick	14：00	17：30	5：00	8：30	3.5

CONCLUSIONS

Low density strawboard is an ideal kind of heat insulation material for buildings. Its conductivity is much smaller than that of the common building materials, its thermal diffusivity is lower and the thermal capacity is higher relatively speaking.

Comparing with common building materials, the thermal resistance (R-value) of the compound wall made from OSB, Low density strawboard and Gypsumboard is higher than that of the brick and concrete wall and close to that of the aerated concrete, while its thickness is only one-third of the aerated concrete. It proves that the compound wall has significant heat insulation.

According to the theoretical analysis, the heat transfer quantity of the compound wall is much lower than that of the brick and the aerated concrete, even if its thickness is one-third of them. So, the effective area of the building from this compound wall can be increased and the cost of the building base can be decreased as well.

The results of the field testing prove that the compound wall has better properties to prevent the periodic thermal wave from propagating across the wall.

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Nano-mechanical properties of the pre-compressed poplar cell wall based on nanoindentation

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Keywords: Poplar, compressing process, cell wall, elastic modulus, hardness, nanoindentation.

ABSTRACT

Heating and pressing play a very important role in the utilizing and processing of wood and wood-based composites, especially in manufacturing compressed wood. The objective of this study was to measure the longitudinal elastic modulus and hardness values of the samples pre-compressed in transverse direction based on nanoindentation. Focus was on the influence of various compression ratios, the platen temperature and the pressing time on the nanomechanical properties of the cell wall. It was shown that the nanomechanical properties were significantly affected by the compressing parameters. The elastic modulus and hardness values were linearly increased with either the compression ratio or the pressing time. A cubic polynomial trend for the relationship between the platen temperature and elastic modulus or hardness was found. This means that the impact of the platen temperature was more complex than both other parameters, the compression ratio and the pressing time. More attention should go to the platen temperature when studying and manufacturing compressed poplar.

INTRODUCTION

Natural forest resources of most countries are declining, which contradicts the rising cost of wood and wood-based materials in recent years. More and more researchers have paid considerable attention to the effective use of fast-growing wood, such as poplar, the most representative one of the fast-growing tree species for wood production in China. However, the fast-growing poplar wood exhibits many drawbacks, such as low density due to fast growing, low durability caused by bio-deterioration, and relatively low mechanical properties compared with other natural tree species (Zhang 2004).

In the last decades, more attention was paid to physical and chemical modification of poplar, which was anticipated to maximize wood hardness and dimensional stability (Wei 2004, Hu 2005, Ouyang 1997, Wang *et al.* 2001, Zhang 2004). Compared to the chemical modification method, compressed wood is a simple promising and good physical modification technique when utilizing fast-growing wood. Wood properties, such as surface, mechanical and processing properties, are improved by compressing. Hence, it can be used for flooring, glue-laminated, concrete-moulding board furniture, doors, windows and carriage boards (Zhang

2004).

As the indispensable process, heating and pressing treatments play a very important role in utilizing and processing wood and wood-based composites, especially in manufacturing the compressed wood. (Wei 2004, Hu 2005, Inoue and Rowell 1993, Inoue *et al.* 1993b, Wang and Zhao 1999, Fukuta *et al.* 2007).

As far as we know, however, few researches were presented to discuss the influence of a compressing process on mechanical properties at nanoscale. Concerning the nanomechanical properties of compressed poplar cell walls, no published works were reported up till now.

The nanoindentation technique has become a popular tool for direct measurement of mechanical properties of the materials at nanoscale, which involves penetrating a sample material using an indenter by means of nanoindentation. Wimmer *et al.* (1997) introduced nanoindentation to wood science by estimating the mechanical properties of the secondary wall and the cell corner middle lamella of spruce tracheids. The subsequent investigations conducted by Gindl *et al.* (2002, 2004) focused on microfibril angle (MFA) and lignification related to longitudinal hardness and elastic modulus of the secondary cell wall of the spruce tracheids, as well as the difference in elastic modulus and hardness between the cell walls of earlywood and latewood tracheids reported by Jiang *et al.* (2004).

As the first part of a series of investigations on the mechanism of dimensional stability of compressed poplar at nanoscale, this paper focused on the effect of a compressing process of the poplar samples on nanomechanical properties of compressed poplar cell walls by means of nanoindentation and atomic force microscope (AFM). Also, the influences of compression ratio (CR), platen temperature (PT) and time of holding (TH) on the nanomechanical properties were investigated respectively in this paper.

Table 1: Experimental treatment conditions

Exp. Item	No.	CR, %	PT, °C	TH, minute
Various compression ratio (CRs)	1	20	160	40
	2	40	160	40
	3	60	160	40
	4	80	160	40
Various platen temperature (PTs)	1	50	120	40
	2	50	140	40
	3	50	160	40
	4	50	180	40
	5	50	200	40
Various time of holding (THs)	1	50	160	20
	2	50	160	30
	3	50	160	40
	4	50	160	50
	5	50	160	60

Note: The compressing rate was 5 mm/s.

EXPERIMENTAL METHODS

Raw material

Fast-growing poplar (*Populus adenopoda* Maxim.), 16-year-old, taken from Jiangsu Province, China, was selected as the test samples for this study. A long log of 150 centimetres in length, with a diameter of 30 centimetres or so, was taken from the green wood trunk at 1.3 meter height. All the samples taken were free from knots and visible defects. A long strip with three growth rings was cut from the poplar log in the longitudinal-tangential (LT) direction, and the strip was then crosscut into several parts equally for all specimens. Ultimately, all specimens were classed, numbered and cured in an oven at 103°C for 3 hours before the next treatment was performed.

Treatments with different experimental conditions

In this study, fifteen samples with the same three growth rings were selected and were soaked in boiling water for 3 hours. Fourteen samples of them for the further compressing process, and another specimen untreated for a comparative experiment. They were cured in an oven at 103°C for 3 hours. The compressing process was performed in radial direction with the restriction of transverse deformation by a hot-press machine equipped with various gauges, which were used to control the CR of the samples.

All the compressing processes used in this paper, were similar. The platens were heated to the determined temperature (PT), and then the water-saturated sample was placed between the platens to compress to the designed CR at a continuous loading speed of 5 mm/s. The TH was recorded starting from the time the designed CR was attained. At the end of the TH, the compressed sample was taken out to cool down in open air. The experimental treatment conditions were listed in Table 1.

Specimen preparation for indentation and image scanning

To reduce variability, all the cells investigated by nanoindentation were taken from the latewood of the second growth ring among samples, and only the cell walls in the longitudinal direction were examined. Therefore, similar cellulose microfibril angles and components can be assumed for all specimens.

All the specimens cooled down and were cut into very small blocks at cross section using sharpened blades after which the specimens were embedded in epoxy resin (Spurr 1969), which was commonly used as an embedding medium for electron microscopy of biological samples. The embedded specimens were placed in a desiccator under vacuum for 24 hours and were then cured in an oven at 70°C for 8 h. The cured specimens were glued to an acrylic block using a five-minute epoxy, and the top surface was trimmed with new razor blades to form a small trapezoidal base. The acrylic block was then mounted onto an ultra-microtome, and the top face was cross-sectioned with a glass knife. Finally, the top surface was smoothed with a diamond knife. The final specimens were conditioned at 21°C and 65% relative humidity for at least 24 h in the test room before the nanoindentation test (Xing *et al.* 2008).

Instrumentation

In this paper, the theory used for nanoindentation of compressed poplar was based on the O & P method (Oliver and Pharr 1992). The elastic modulus (Es) and hardness (H) of the

specimens can be obtained from the following equations:

$$H = \frac{P_{\max}}{A} \quad [1]$$

$$E_s = (1-\nu_s^2)\left(\frac{1}{E_r} - \frac{1-\nu_i^2}{E_i}\right) \quad [2]$$

where P_{max} is the indentation load, *A* is the contact area, which is a function of the contact depth, ν_s is Poisson's ratio of the specimen, E_i and ν_i are the corresponding values of the indenter, respectively.

A Nano Indenter II (MTS Systems Corp., Oak Ridge, TN, USA) with a diamond Berkovich tip (a three-sided pyramidal tip) mounted on a stainless steel cantilever was utilized in this study. The nanoindentation procedure of compressed wood cells was described by Xing *et al.* (2008). 100 indents (an array of 10 by 10 in 5 μm intervals) were made on the cell wall of each compressed poplar specimens.

To confirm the indents to be made on the mid-width of the secondary cell wall, an atomic force microscopy (AFM XE-100, PSIA Corp., Korea) was conducted to characterize the topographies of the samples. For AFM scanning, the specimens were glued to the steel discs and mounted on the magnetic sample holder of the AFM.

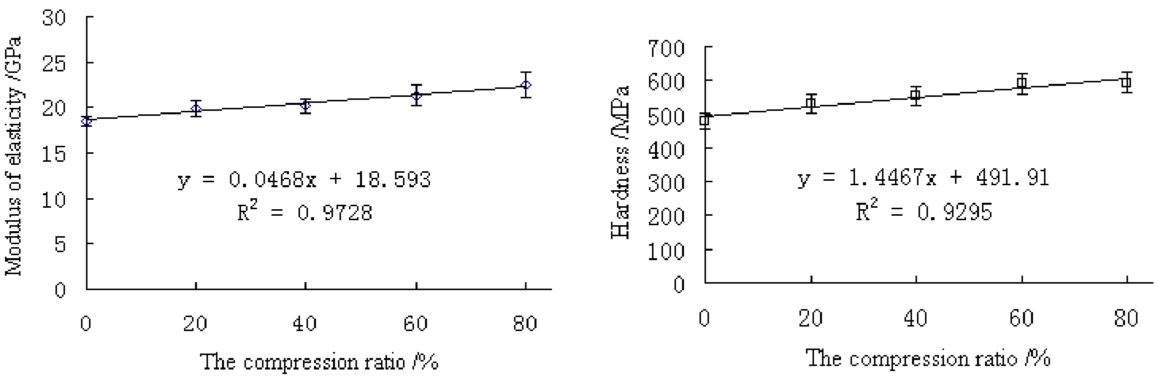
Table 2: Elastic modulus and hardness value of the cell wall under the different treatment conditions

Influence factors	**Variable value**	**Elastic modulus**			**Hardness**		
		Mean, GPa	**Sta. D**	**CV**	**Mean, MPa**	**Sta. D**	**CV**
Compression ratio (CR)	0%	18.52	1.439	7.769	478.59	0.039	8.086
	20%	19.87	2.225	11.199	530.81	0.051	9.597
	40%	20.15	2.093	10.383	555.86	0.052	9.363
	60%	21.31	2.706	12.698	589.95	0.053	8.947
	80%	22.47	3.563	15.855	593.69	0.053	8.955
Platen temperature (TP)	120°C	19.53	2.429	12.437	464.53	0.058	12.414
	140°C	19.56	2.344	11.984	537.53	0.059	10.99
	160°C	18.68	1.565	8.377	534.7	0.038	7.179
	180°C	18.12	1.615	8.914	537.72	0.065	12.056
	200°C	19.42	2.432	12.521	542.96	0.067	12.289
Time of holding (TH)	20 min	17.25	1.001	5.802	506.6	0.043	8.544
	30 min	18.15	1.864	10.273	507.74	0.049	9.719
	40 min	19.19	2.582	13.454	516.76	6.573	8.837
	50 min	19.97	2.564	12.839	533.33	0.068	12.776
	60 min	19.98	1.067	9.241	557.86	1.201	10.331

Note: Sta.D - standard deviation; CV- coefficient of variation

RESULTS AND DISCUSSION

The mean values and standard deviation of elastic modulus and hardness of the compressed poplar cell walls with different treatment conditions were presented in Table 2. In comparison with the compressed wood, an untreated specimen was measured as 0% of CR.



(a) (b)

Figure 1: Variation of elastic modulus and hardness of the compressed poplar cell walls with the different compression ratios

The effect of the compression ratio

Fig. 1 illustrates the changes in elastic modulus and hardness at varying compression ratio under the same treatment conditions.

Seen from Fig. 3(a) and (b), a slightly increasing tendency in either elastic modulus or hardness of the compressed poplar cell walls was observed with the compression ratio of the cell wall rising, which is a high positive linear relationship (R^2 = 0.9728 and 0.9295).

There are two possible explanations for the tendency mentioned above (Bergander and Salmén 2002, Yang and Evans 2003). At first, the microfibril angles related to the axes of the cell changed because the longitudinal elastic modulus of the cell wall was affected by the properties of cellulose. This is assumed as the main reason. Secondly, the densification of samples due to the extra-pressure applied also increased the elastic modulus and hardness of cell wall.

It was well known that the thickest S_2 layer of the cell secondary wall is composed of the spiral winding cellulose microfibrils embedded in the matrix substance consisting of hemicelluloses and lignin (F.P.L. 1999).

After reviewing the reported studies on the glass transition of wood and its components under various wet conditions, Okuda *et al.* (2006) deduced that the glass transition temperatures (Tgs) of lignin and hemicellulose are about 60°C and below room temperature, respectively.

Under radial loading, wood was flat pressed to the designed CR quickly. Heat via platens was conducted from the sample surface into the sample core. The water in the sample and parts of moisture content (MC) in the cell wall were removed. The rest of MC in the cell wall reduced with the temperature of the sample core increasing.

When the temperature attained to the above of the glass transition temperatures (Tg), the matrix substance began to soften under the combination of the temperature and MC, but the cellulose was still stiff because of its higher Tg (Bergander and Salmén 2002). Thus, the cellulose microfibrils realigned because of the reduction of the residual stress produced by the extra-pressure. The CR of wood is in accordance with the extra-pressure applied. The higher the CR, the more evident the microfibrillar realignment was. When the time of holding was over, the sample was cooled down in air. The cellulose microfibrils recombined due to the matrix substance fixed quickly.

Because it was compressed in transverse direction, the cellulose microfibrils were recombined along the axes of the cell, namely the longitudinal direction. Thus, conclusions can be drawn that the microfibril angle (MFA) of the cell wall decreased during compression in the transverse direction, and the relationship between elastic modulus and MFA was negative.

Therefore, the elastic modulus increased with the CR increasing. This was well in accordance with the previous studies (Cave 1969, Page *et al.* 1977, Wimmer *et al.* 1997, Gindl 2002, Jiang *et al.* 2004, Tze 2007), namely, the longitudinal elastic modulus of cell wall is highly dependent of MFA.

The CR of wood was in accordance with its density, which was the main contributor to the hardness (Bodig 1965, Bergander and Salmén 2002). The higher the CR, the more the densification of wood cell wall and the bigger the hardness of wood cell wall. Therefore, the increasing tendency of the hardness was also observed with the CR increasing.

The effect of the time of holding

The analogous tendency occurs in the experiments of the various times of holding, which discussed the influence of the times of holding on the elastic modulus and hardness of compressed poplar cell wall, as shown in Fig. 2 (a) and (b). With the time scales maintaining, either the elastic modulus values or the hardness values increased. This means that the time of holding was a high positive linear relationship with the elastic modulus (R^2 = 0.9951) or hardness (R^2 = 0.9213).

However, the elastic modulus value at the time scale of less 30 minutes, 17.25 GPa and 18.15GPa, is less than the elastic modulus of 18.52GPa of untreated wood cell wall, as listed in Table 2, whereas all the hardness value (506.60MPa) is more than the one of untreated wood cell wall (478.59 MPa). This indicated that the treating time of less than 30 minutes under 160°C reduced the elastic modulus, but increased the hardness.

At 160°C of the platens, the core of the samples was below 160°C in 30 minutes, and the matrix substance was in the transition state and was not so softened that cellulose microfibrils did not re-align sufficiently. Thus, the matrix structure of the cell wall was destroyed due to the residual stress produced by the extra-pressure applied, which contributed to fix the cellulose microfibrils alignment.

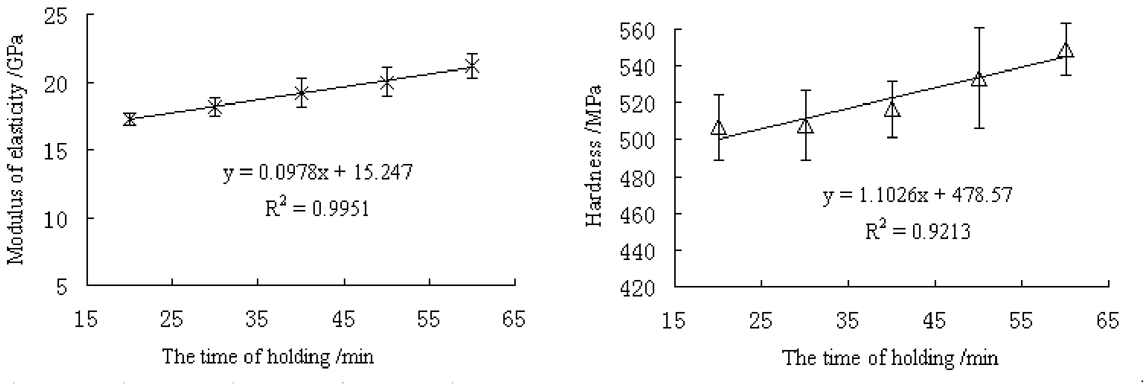
In addition, part of the lignin and hemicellulose began to experience decomposition and degradation during the hot-pressing process. The higher the temperature was, the more evident the decomposition and degradation was.

The decrease in hemicellulose and lignin contents weakened the rigidity of matrix components (i.e., hemicellulose and lignin). The fixation of the matrix substance on the cellulose microfibrils became weaker. After the time scale of 30 minutes was finished, the matrix substance was densitified, but the cellulose microfibrils were changed less. This exhibited that the elastic modulus was less than one of the untreated sample.

With the time of holding lasting, the temperature of the samples core increased. The longer the time of holding was, the higher the temperature of the sample core was, and the easier and more evident the microfibrillar realignment was. Consequently, the elastic modulus increased.

Unlike the elastic modulus affected by MFA, the hardness was determined by the matrix substance, which is in accordance with its density (Bergander and Salmén 2002). Regardless of whether the structure was destroyed or not, the matrix substance was still densitified more than the untreated sample. This contributed to the hardness increasing.

The elastic modulus varied tendency (from 17.25GPa to 20.12GPa) in the TH experiments is not as significant as one in the CR experiments shown in Fig. 1(a) (which varied ranged from 19.52GPa to 22.47GPa). This indicates that the TH has a less effect on the micromechanical properties than the CR does.

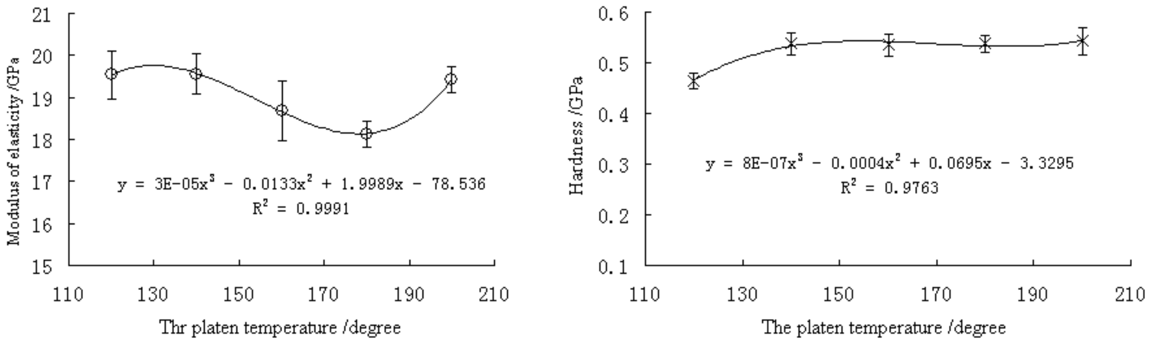


(a) (b)

Figure 2: Variation of elastic modulus and hardness of the compressed poplar cell wall with the different times of holding

The effect of the platen temperature

Table 2 also shows the limited experiments data for both elastic modulus and hardness obtained as the platen temperature increased. It was difficult to discuss the relationship between the platen temperature and elastic modulus or hardness measured in this part of the experiment. However, the cubic polynomial was found to be a reasonable function to fit the limited data shown as Fig. 3. As seen in Fig.3 (a), the elastic modulus increased with the temperature rising, which attained a peak at the temperature of 130°C or so. Subsequently, the tendency of the elastic modulus value decreased with the temperature rising, and an inflexion occurred at the temperature of 180°C. After that, the elastic modulus value increased again.
So did the hardness, shown as Fig. 3(b). However, the tendency is not as significant as one shown in Fig.3 (a).



(a) (b)

Figure 3: Variation of elastic modulus and hardness of the compressed poplar cell wall with the different temperatures

It was assumed that the combination of the MC and MFA varying resulted in the tendency. Furthermore, part of the components of wood cell wall, esp. lignin and hemicelluloses, began to experience decomposition and degradation during the PT varying, which may help to understand the obtained results.
At the same treatment conditions, the higher the platen temperature, the more quickly the core temperature increased (F.P.L. 1999).

At first (about 130°C for 40 minutes), the core temperature increased slowly and the thermal softening of lignin and hemicelluloses was suggested to play an important role because the temperature was round about the Tg of them. The cellulose microfibrils can re-align easily. Therefore, the elastic modulus increased with the temperature increased.
With the temperature of the specimen increasing, namely the platen temperature was in 130-180°C, the temperature was over the Tgs of lignin and hemicellulose. And part of the lignin and hemicellulose began to experience decomposition and degradation under the combination of the MC and temperature. The higher the temperature was, the more evident the decomposition and degradation was (F.P.L. 1999). The decrease in lignin and hemicellulose contents weakened the rigidity of matrix components. The fixation of the matrix substance on the cellulose microfibrils became weaker. The cellulose microfibrils experience the least changes, which contributed to the elastic modulus decreasing.
When the platen temperature attained 180°C, the core temperature increased quickly, which contributed that the MC decreased and Tg increased. The softening of the matrix substances played a role, again. Thus, after 180°C, the elastic modulus and hardness increased.
Seen from Fig. 3, the effect of the PT on the elastic modulus or hardness is more complex than the CR and TH, which need to be paid more attention to when manufacturing the compressed wood.

CONCLUSIONS

The nanomechanical properties were obviously affected by the compressing process conditions. The elastic modulus and hardness values were linearly increased with either the compression ratio increasing or the time of holding maintaining. However, there was a cubic polynomial trend found for the relationship between the platen temperature and elastic modulus or hardness. This meant that the platen temperature was more complex than the other two factors, namely the compression ratio and the time of holding, and more attention needed to be paid to the platen temperature when we studied and manufactured the compressed poplar.

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Study on the properties of compressed poplar veneer

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Keywords: Pressing parameters, veneer compression ratio, recovery ratio, veneer properties, shear strength.

ABSTRACT

This paper describes the ratio of veneer compression and recovery by different experimental factors as well as the properties of veneer with different compression set. Test results revealed that the major factor that works on compression set is the pressing pressure. The higher the pressure, the greater veneer's compression set will be. When the pressure was 4MPa and 2MPa, the compression set reached 50% and 29%, respectively.

Pressing temperature is a secondary influencing factor. The compression set of veneer was 49% when the temperature was 180°C. Pressing time shows the lowest impact.

The pressing temperature and pressure also affected the recovery set of veneer. When the temperature and pressure were 180°C and 4MPa, the recovery set and actual compression ratio measured were 8.26% and 22.74%, respectively, and compared to those veneers had not been dealt with, the compressed veneer's properties such as modulus of elasticity (MOE), modulus of rupture (MOR) were 4762.32MPa and 47.85MPa, both improved by 120% and 60%. The untreated veneers and compressed ones were made into plywood, and the results confirmed that the adhesive shear strength of the latter plywood was 0.72MPa, increased by 112%.

INTRODUCTION

Fast-growing tree is a kind of soft material, which will be a main supply for the wood industry. It has the characteristic of low density, hardness, mechanical properties, and easy to corrupt. Due to all these defects, the traditional wood process and utilizing methods cannot meet the demands for improving its value, it also brought about a negative impact to the effective use of poplar resources. So, how to expand the use area of low-quality poplar is a problem to solve. The project will use an environmentally friendly method of physical to enhance the properties of fast-growing tree veneer. The research work carried out has the following practical significances: 1) Using a compression method with high temperature and high pressure condition to strengthen the properties of veneer. The manufacturing process is harmless to both human and the earth because no chemical stuff is used and no harmful substances are set free. It is a physical environmental approach; 2) Improve fast-growing tree values to meet the needs of plywood.

EXPERIMENTAL METHODS

Test materials

The Poplar veneers were obtained from a plywood manufacture (Jiangsu Province, P.R.China). The veneers size was 150 x 150 x 2.5 mm and 400 x 400 x 2.5mm. Urea formaldehyde resin adhesive (UF) was obtained from the Dajiang wood industry.

Test methods

The poplar veneers were pressed at a moisture content of 10%, 20% and 30%.with a pressure of 2 MPa, 4 MPa and 6 MPa and a pressing temperature of 160°C, 180°C and 200°C. The pressing time was 2min, 4min and 6min. The pressure conditions of veneer were shown in Table 1. Their initial compression ratio (ń), recovery set (Ï) and actual compression ratios ($\acute{L}$) were calculated using the following formulas:

$\acute{N} = [(H_1-H_2) / H_1] \times 100\%$ (1)

$\ddot{I} = [(H_3-H_2) / H_1] \times 100\%$ (2)

$\acute{L} = [(H_1-H_3) / H_1] \times 100\%$ (3)

Where H_1 is the veneer thickness before compression, H_2 is the veneer thickness after compression, and H_3 is the veneer thickness after the recovery test.

The recovery test has three treatment conditions. First, put the compressed veneer at room temperature during a week and determine the thickness of veneer. Second, immerse the compressed veneer in water of 20± 2°C for 24 hours. Third, cook the compressed veneer in boiling water for two hours.

According to the test results of first phase, processing parameters were chosen. The test method is listed on Table 2. After compression, the veneer was cooked in boiling water for two hours, and its recovery ratio as well as the actual compression ratio was calculated. The mechanical property of veneer such as modulus of elasticity (MOE) and modulus of rupture (MOR) were measured. The shear strength of plywood was measured according to the China Country Standard of plywood GB/T 17657-1999.

Table 1: Different parameters

NO.	Moisture content (%)	Pressure (MPa)	Pressing temperature (°C)	Pressing time (min)
1	10	2	160	2
2	10	4	180	4
3	10	6	200	6
4	20	2	180	6
5	20	4	200	4
6	20	6	160	2
7	35	2	200	4
8	35	4	160	6
9	35	6	180	2

Table 2: Parameters of hot-press processing

Test numbers	Pressing Temperature (°C))	Pressing Pressure (MPa)
1	180	2
2	180	4
3	200	2
4	200	4

RESULTS AND DISCUSSION

The effect of different parameters on compression ratio

According to the balance analysis of the orthogonal test, the parameters that have effects on compression ratio can be clearly recognized as shown in table 3 and figure 1. The applied pressure has the most effect on the compression ratio. When pressure was 2 to 4MPa, the higher the pressure was, the greater the compression ratio was, and the highest compression ratio was 50% under 4MPa. When the pressure was reaching to 6MPa, the compression ratio decreased to 40%. The following factors are the pressing time and pressing temperature. The preferable pressing time was 4 min or 6 min, from which the compression ratio can reach to about 45%. The preferable pressing temperature was 180°C. When the temperature was over it, the compression ratio would decline from 48% to 45%. The last is the moisture content. It didn't have remarkable effect on compression ratio which of this test was nearly 40%.

Table 3: Balance analysis of orthogonal test

Level	A (Moisture content)	B (Pressing pressure)	C (Pressing temperature)	D (Pressing time)
k1	0.44	0.3	0.33	0.47
k2	0.38	0.5	0.46	0.32
k3	0.41	0.43	0.44	0.44
R	0.06	0.2	0.13	0.15
Prominence: B-D-C-A				

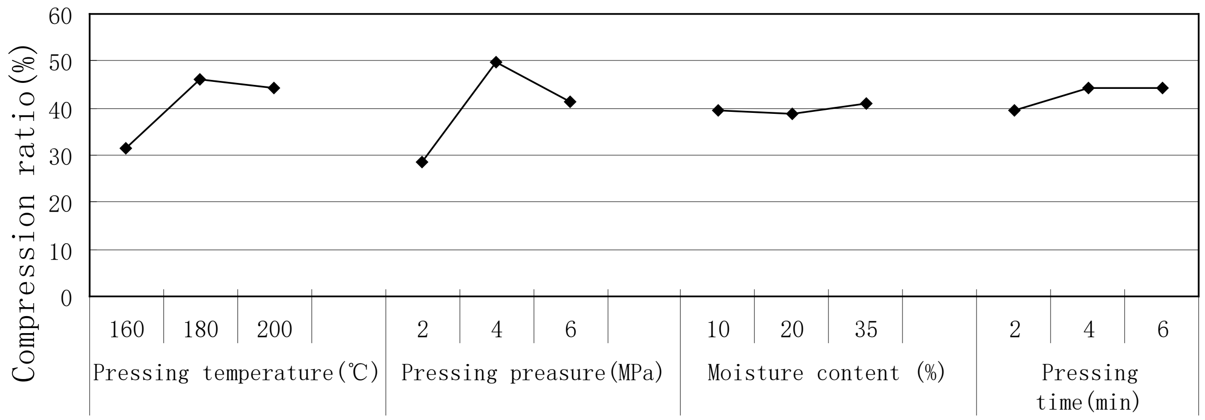


Figure 1: Compression ratio of different pressing parameters

The recovery ratio and actual compression ratio of veneer

Three recovery tests were carried out. The test results were represented on Fig. 2, 3 and 4. When the compressed veneer was placed in room temperature, they can absorb water from the atmosphere. The test results of compressed veneer placed in room temperature for a week show the greatest recovery ratio was nearly 32% under a pressure of 2MPa and a temperature of 160°C , while the smallest one was only 3% and the actual compression ratio was 48% with the help of preferable parameters of pressure 4MPa, pressing time 4 min and temperature 180°C. According to this test result, the recovery ratio was the smallest when the compression ratio was the biggest.

When the compressed veneer was immersed in the water of 20 °C ± 2 °C for 24 h, the biggest recovery ratio reached nearly 42%, and the smallest one was about 8%. The actual compression ratio was nearly 50% under the temperature of 180°C, pressure of 6MPa and time of 2min. Because the treatment was more violent than the former test, the recovery ratios were commonly bigger than those of the former one.

The test results represented the compressed veneer recovery ratio as the most marked when the compressed veneer was cooked in boiling water for 2 hours. The highest recovery ratio reached to nearly 50%, the actual compression ratio was only 4%. As the treatments are different, the recovery ratios of compressed veneer are different. In the three tests, the recovery ratio of compressed veneer cooked in boiling water was the highest, because the treatment was the harshest.

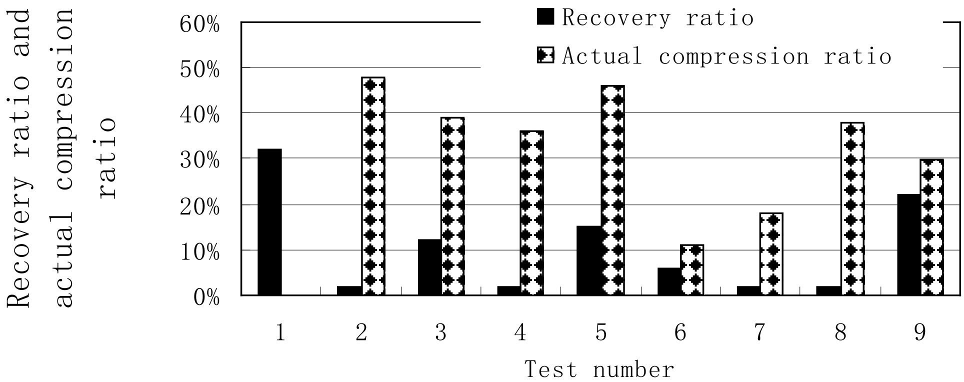


Figure 2: Recovery ratio and Actual compression ratio of veneers after placed in room temperature for a week

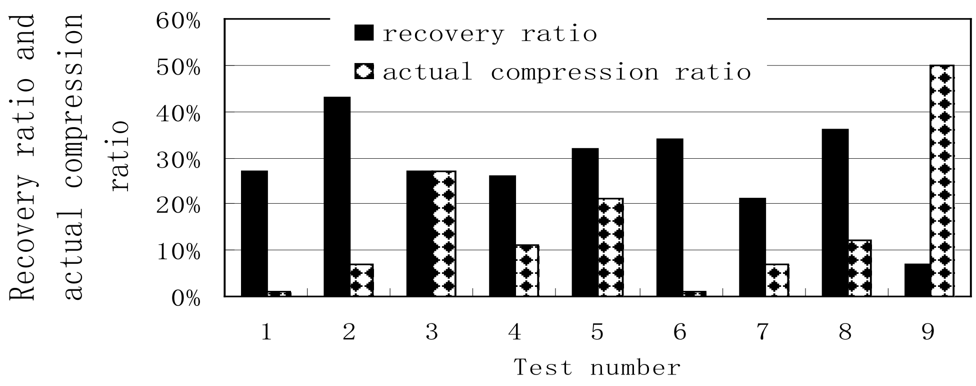


Figure 3: Recovery ratio and actual compression ratio of veneers after immersion in water of 20°C ± 2 °C for 24h

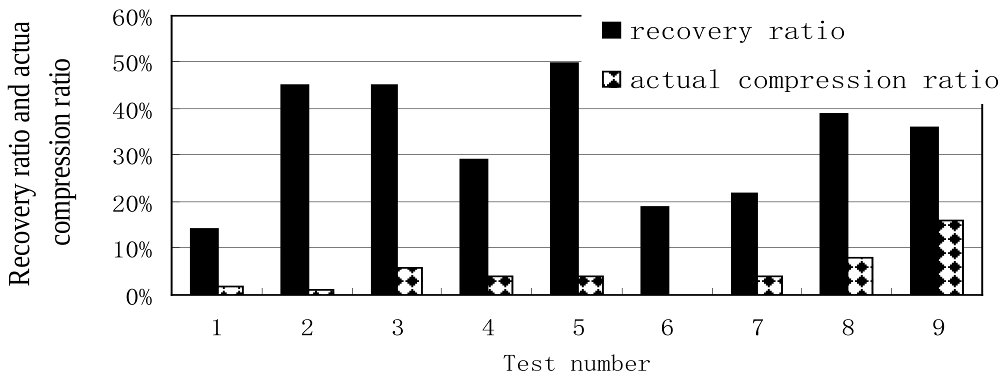


Figure 4: Recovery ratio and actual compression ratio of veneers after cooking in boiling water for two hours

The compression ratio, MOR and MOE of veneers

In accordance with the principle of "smallest recovery ratio and appropriate actual compression ratio" and the analysis of test results above, processing parameters were chosen. The poplar veneers were pressed at a pressure of 2MPa and 4MPa; a pressing temperature of 180°C and 200°C; a moisture content of 10% and a pressing time of 32 min.

Fig. 5 represents the veneer compression ratio after compression under different parameters shown on Table 2. The test results showed the highest compression ratio was about 31% under the applied pressure of 4MPa and a temperature of 180°C.

After compression, the veneer was cooked in boiling water for two hours, and its recovery ratio as well as the actual compression ratio was calculated on Fig. 6. The recovery ratio was 8% and the lower actual compression ratio was 23% under the pressing pressure of 4MPa, temperature of 180°C.

The mechanical property of veneer such as modulus of elasticity (MOE) and modulus of rupture (MOR) were measured. According to Fig. 7, MOE and MOR were 4762.32MPa and 47.85MPa respectively with an applied pressure of 4MPa and pressing temperature of 180°C, each improved by 120.5% and 60.3% compared to the untreated veneers.

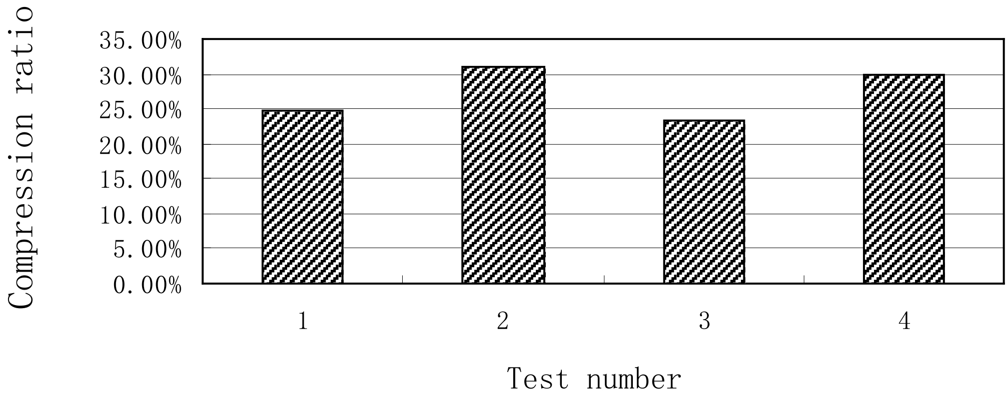


Figure 5: Compression ratio of veneer

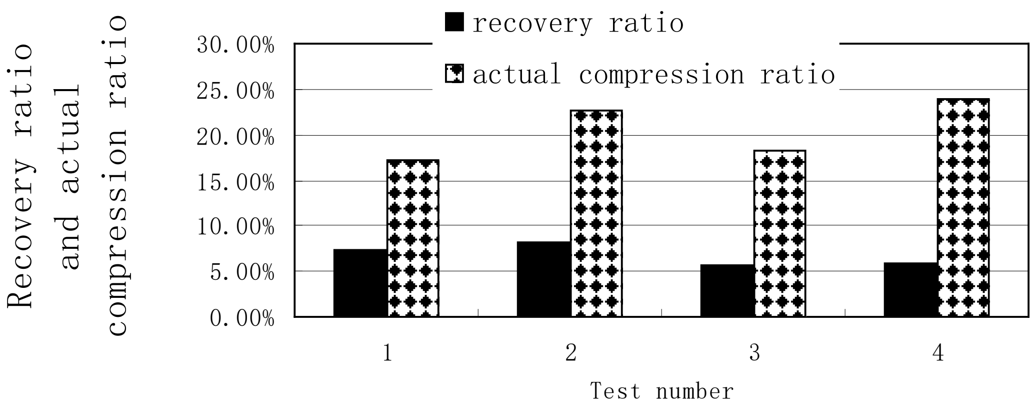
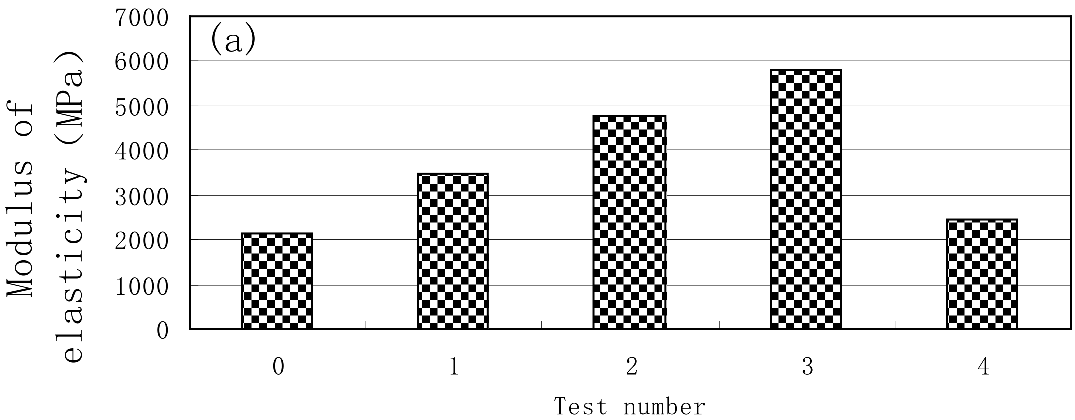


Figure 6: Recovery ratio and actual compression ratio of veneer after cooking in boiling water for two hours



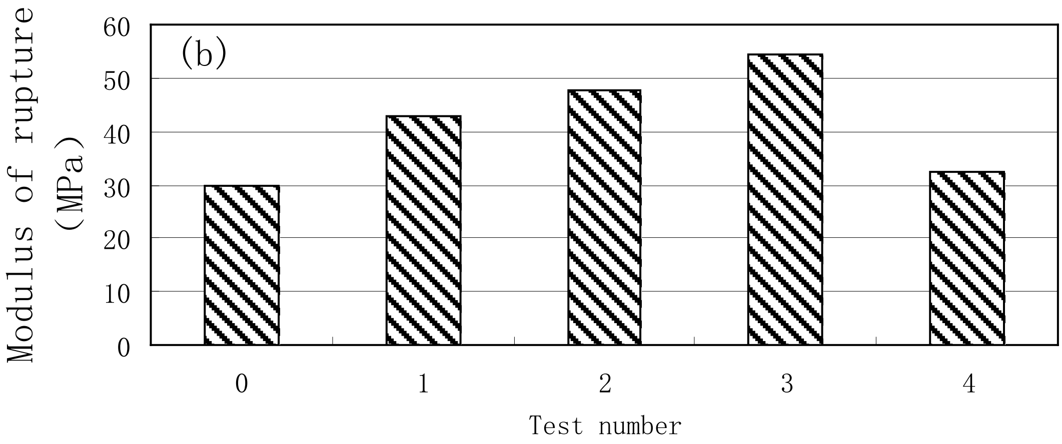


Figure 7: Modulus of elasticity and modulus of rupture of veneer
0: veneer of the untreated technology; 1~4: veneer of the technology shown in Table 2

The Shear Strength of Plywood

The untreated veneers as well as the compressed ones were made into plywood, and the results of Fig. 8 confirmed that the shear strength of the plywood reached to 0.72MPa under the pressing pressure of 4MPa, temperature of 180°C , while that of the plywood made by untreated veneers was 0.34MPa, which was increased by 111.8%.

According to the test results, conclusion was derived that the compressed veneer recovery ratio was controlled and the mechanical property of veneer such as MOE and MOR were enhanced. The shear strength was improved compared to the untreated ones under the pressing pressure of 4MPa, temperature of 180°C.

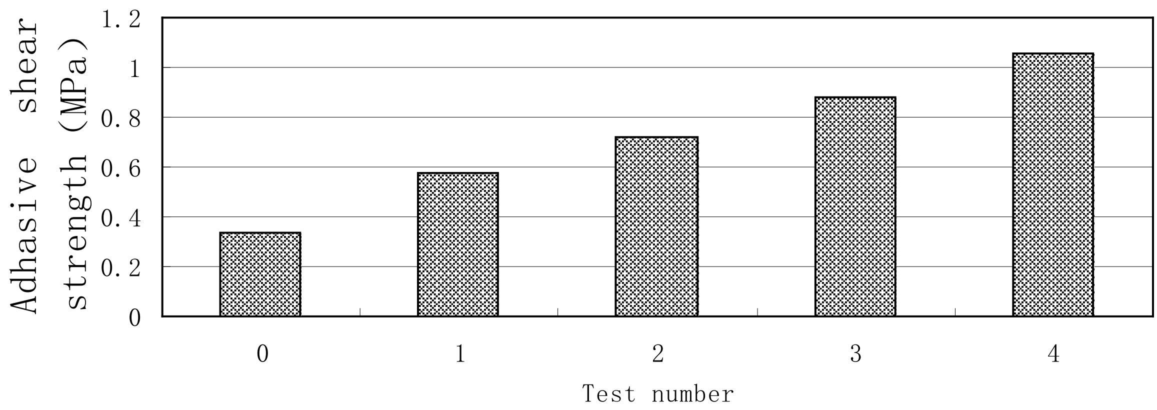


Figure 8: Adhesive shear strength

CONCLUSIONS

According to the test results, the pressing pressure has the most effect on compression ratio. The following factors are the pressing time and pressing temperature. The moisture content doesn't have a remarkable effect on compression ratio.

The veneer's actual compression ratio can be advanced. Meanwhile, the veneer's properties such as MOE and MOR can be improved, and the shear strength of Plywood will also be significantly enhanced when the poplar veneers were pressed at a pressure of 4MPa; pressing temperature of 180°C; moisture content of 10% and a pressing time of 32 min.

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Present Status of Development of Plywood Industry Cluster in China

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Key words: Industry cluster, plywood, development, present status suggestion

ABSTRACT

With the rapid development of the plywood industry in China, there have appeared four plywood clusters, which are located respectively in Zhejiang, Jiangsu, Shandong, and Hebei provinces, producing nearly 70% of total amount of plywood in China. This paper analyzed the product sales, company distributions, economical power and advantage in each cluster area, as well as positive and negative effects of plywood industry cluster on economics and plywood manufacturing based on investigation in Jiashan, Pizhou, Linyi and Zuogezhuang districts. The results indicated that there are two unstable product ends, the key problems of plywood industry in China, in plywood industry line in the clusters. The authors suggest that governments, technical departments and associations pay more attention to those, and take effective measurements for keeping the plywood industry cluster developing towards further stability.

INTRODUCTION

Since China's reform and opening-up to the year 2000, four large plywood industrial clusters have been formed: Hebei industrial cluster with Xintai with Langfang as center, Huabei industrial cluster with Linyi as center, Zhejiang industrial cluster with Jiangshan as center and Subei industrial cluster with Xuzhou s center. The plywood yield of the four provinces accounted for 68%~70% of that of China. The formation of the plywood industrial cluster reflects a region development of the chinese plywood industry with its own characteristics: appearance of ownership, transfer of industrial center and industrial cluster. Before 1985, the main producing area of Chinese plywood focused on Dongbei, Shanghai, Jiangxi and Fujian; by 1990s in 20 centuries with the sudden rise of Guangdong as representative as well as the growth of Hebei and Shandong. After 1995, Zhejiang and Jiangsu caught up fast, and gradually formed the present four large industrial clusters. In this paper, by on-the-spot investigation, the plywood industrial situation, manufacturing technology and development were discussed on the universal attribute and characteristic of several plywood industrial clusters.

Industrial cluster changed the enterprise investment scale and industrial situation

Specialization division of plywood manufacturing technology is a basic condition to form lots of small and medium state-owned enterprises.

The past production mode of Chinese plywood was enterprise integration, that was, the main technological processes such as log rotary cutting, veneer and plywood were included in the production scope of one plywood enterprise. Even lots of wood products were included such as plywood, particleboard, fiberboard, furniture and lumber in some enterprises which were called "integrated timber processing plants" in the past. In theory, such mode could use the raw materials effectively and reasonably. But the problem are large investment enterprises with a 50,000 m^3 production line and a fixed-asset investment over 10 million yuans. Seen from current and previous situations in China, the development of plywood production is more difficult in rural areas, especially the backward areas of economic development, as well as the limit of raw materials, organization and supply in enterprises in non-forest areas.

The birth of Veneer Company broke the integration situation of plywood production, so that the original one production line was further divided into specialized sections. That was, from one enterprise to lots of small and medium state-owned enterprises with a certain specialization degree forming an industrial chain with other corresponding enterprises. Although we couldn't prove that the Veneer Company was one necessary condition to form the cluster, it was found in our investigation that there was a cluster of small veneer companies no matter which area. Because of simple core board processing equipment of decorative plywood and the fall of the access to industry, veneer companies would be involved with 100,000 to 200,000 yuan of investment which made thousands of families into veneer processing plants, while small plywood factories are built which could be involved accompanied by a general 400,000 to 1 million yuan investment. Thus to establish the basis of industrial clusters from the manufacturing technology from the production process by laying a foundation for the formation of industrial clusters.

Lots of small and medium state-owned enterprises could come into being a hybrid of supply and demand relationships. The veneer amounts were divided into that of local plywood enterprises supplied by a local area and that of supplied by out-of-town, coupled with that of a local area supplying to out-of-town (if one enterprise has one production line integrated by veneer and plywood production, it was also divided into two parts of veneer and plywood) could be expressed by the following mode:

- $A(1,B)+A(2,B)+...+A(i,B)...+A(n,B)=C(1,B)$

A(i,B) is veneer amount that the i veneer enterprise supplied to local area:

C(1,B) is veneer amount that local plywood enterprises produced:

total of n local veneer enterprises

- $A(1,W)+A(2,W)+...+A(i,W)...+A(n,W)=C(1,W)$

A(i,W) is veneer amount that i veneer enterprise supplied to out-of-town:

C(1,W) is veneer amount that out-of-town plywood enterprises produced

- $W(1,B)+W(2)+...+W(j)+...+W(h)=C(2,B)$

W(j,B) is veneer amount that out-of-town j place supplied to local area:

C(2,B) is veneer amount that out-of-town supplied to local plywood enterprises:

total of h out-of-town veneer-supplying places

- $C(1,B)+C(2,B)=C(B)$

C(B) is plywood amount produced in local area:

- $C(1,B)+C(2,B)+C(1,W)=C(0)$

C0 is total veneer amount of local area:

Supposed m local plywood enterprises:

- $P(1)+P(2)+...P(v)+...P(m)=C(B)$

P(v) is veneer amount that v plywood enterprises demanded

Total yield of plywood enterprise also exist with integration of local production and out-of-town such as the substrate to produce decorative plywood.

It was obvious that it is not simply an addition and subtraction of n veneer enterprises, m plywood enterprises, h out-of-town veneer suppliers and k plywood suppliers, but a farraginous combination in the market economy, reflecting the plywood production of the region, to be the most effective combination with operational research （Ju, 1995). According to the cluster theory, it was to improve benefit and reduce costs by means of scale economy (exterior scale of enterprise) and diversification economy thus to enhance the competitive power of both enterprise and region which was one of the economic impetuses of the cluster. Such combination was based on the regional competition and had dynamic characteristics; once the two sides of supply and demand were confirmed, the local production balance came into existence.

The formation of industrial clusters changed the industrial situation of regional economy

Since the plywood industry chain was open in which the chain from raw materials to end products could be extended to domestic and international market from cluster region, the production balance we talked about was only relative which was not stable in market economy. It could easily be stimulated by environment so as to produce change; which also promotes the development of the plywood industry in non-forest regions. For example, in Jiangshan town north to Zhejiang, there are over 200 wood enterprises, with an annual plywood yield of 335 million m^3 which accounted for $1/3^{rd}$ of the Chinese total yield (Hua and Jia, 2000). Jiangshan lies in the Yangzi river delta region and has unique region advantages and humanistic conditions, situated near the biggest wood port Zhangjianggang and not far away from Yangzhou port. The main characteristic of its products is that it was developed by using north Jiangsu veneers as core boards and importing wood as core board and grown by means of the biggest plywood terminal centre of china Nanxun and the construction of Shanghai Pudong development zone.

The plywood cluster of Huabei industrial region with Linyi, Shandong as center had great radiation on Jiangshan. The radiation also led to the birth of new clusters such as north of

Jiangsu industrial region with Xuzhou as center as well as the development of its vast regions. In the case of Jiangsu province, originally a forest-lacking province, poplar was developed vigorously and the fast-grown poplar was used to manufacture plywood, with its output accounting for about 20% of China total output (Horn, 1997).

Such development brought a new production situation of Chinese plywood: The plywood industry is booming in the coastal areas and the past sunset industry has glowed with vigor, which more or less declined the productivity of east-north plywood enterprises. The main reason of the situation change should be attributed to factors such as business, market, economy, resource and policy that the modern production has had.

The manufacturing technological process was more specialized in the cluster

According to the industry cluster theory of MARSHALL, the plywood enterprises got economical benefit in the cluster: First is to enlarge the production scale and increase the cluster degree of production elements to reduce the unit product costs; second is to choose close connection with other enterprises to get the exterior benefit; third is to coordinate together in the same department. Because of the severe competition of plywood enterprises in the cluster, the plywood production lines began to split into more and more element cluster.

The common dry-hot plywood manufacturing technology is:

1 Log→2 tri mming→3 barking→4 block heating→5 centering→6 rotary cutting→7 clipping→8 drying→9 clipping→10 repairing→11 grading→12 gluing→13 lay-uping→14 pre-pressing→15 hot-pressing→16 cutting→17 sanding→18 repairing→19 testing→20 grading→21 packing→22 storing

The biggest change in the course of industrial cluster was production process division of plywood which showed that incessant bankrupt of large and medium state-owned plywood enterprises and emergency of small and medium state-owned enterprises became the mainstream of the Chinese plywood production.

The first process was divided into 11(i.e., 1 to11) veneer enterprises and 11(i.e., 12 to 22) plywood enterprises.

The second phase process was divided into：1，2-11, and 12-22；

The third phase process was divided into：1， 2， 3-11，and 12-22；

Several phase process divisions made a giant leap in the development and management of plywood production. The first phase solved the investment induction; the second phase was to use wood reasonably which had great effectiveness of log management and purchase. For example, each wood port had its supplying characteristic, most of which supplied directing at wood products. The third phase made a major step in the management of veneer utilization rate and comprehensive utilization, the veneer production enterprises could stipulate the size and grade of log according to their own product requirement so that they could make precise management, and the suppliers could also turn the residues to other wood industry effectively.

With the requirement of reducing cost and specialization, the specialized division in the cluster was tapering. For example, rotary cutting was developed to that of single tree species and the veneer enterprises using *Anisoptera* sp., *Shorea* sp. and *Aucoumea klaineana* as raw materials appeared; the adhesives manufacturing was getting more and more specialized and more adhesives companies appeared. In addition, the assistant section went towards

independence which could provide a share of specialized service. For example, professional equipment repair and maintenance, equipment reinforcement and manufacturing, specialized tool-whetting factories, etc. In Linyi, the tool-whetting factory could provide the tool with reasonable angle and long durable time which had low price, one 8′tool was only cost 20 yuan and provided service to home. In Zuogezhuang, the maximum of equipment maintenance response time was one hour. We call all of these cluster advantages.

It was found in our investigation that serial change of enterprises in the cluster obtained the lowest cost of each procedure and the best quality in the achieved condition; for example, secondary gluing technology was used to reduce core stacking and gaping of plywood. From the angle of industrial chain, in the industrial cluster existed the vertical (forward/backward) and horizontal connection between the various entities which could reduce cost, improve efficiency and enhance the region competitiveness through the obtainment of scale economy linked with specialization and scope economy linked with diversification economy. In essence it was a space economy, an intensive economy linked with production elements and industrial intensiveness.

The cluster promoted change of product structure

One of the competitive advantages the industrial cluster obtained was the enterprise efficiency which could be improved by competition, the enterprises were close to each other and the enterprises were obliged to make the technique and organization innovation for the severe competitive pressure and self-esteem. The last competitive result was that high-efficiency enterprises survived and low-efficiency exited the competition or bankrupted (Wang and Zhao, 2001). So, the survived enterprises were all high-efficiency enterprises. For a long time, we thought that the Chinese plywood industry is an industry with a single product and low quality, and can be subjected to great loss in the severe international competition (Cheng and Cao, 1997). In fact, since joining the WTO, Chinese plywood found a market position whose export amount increased dramatically. Participation in the international arena inspired the enterprise organization for further innovation of cluster.

In the cluster, the product structure developed from an original simple product manufactured from veneer to a high value-added and multiple product structure in a pyramid-like form. The high value-added products lay in the upper part of the pyramid due to more investment and equipment conditions. Taking the successful leading enterprise in the cluster as an example, the developing process of its product was shown as follows (Fig. 1).

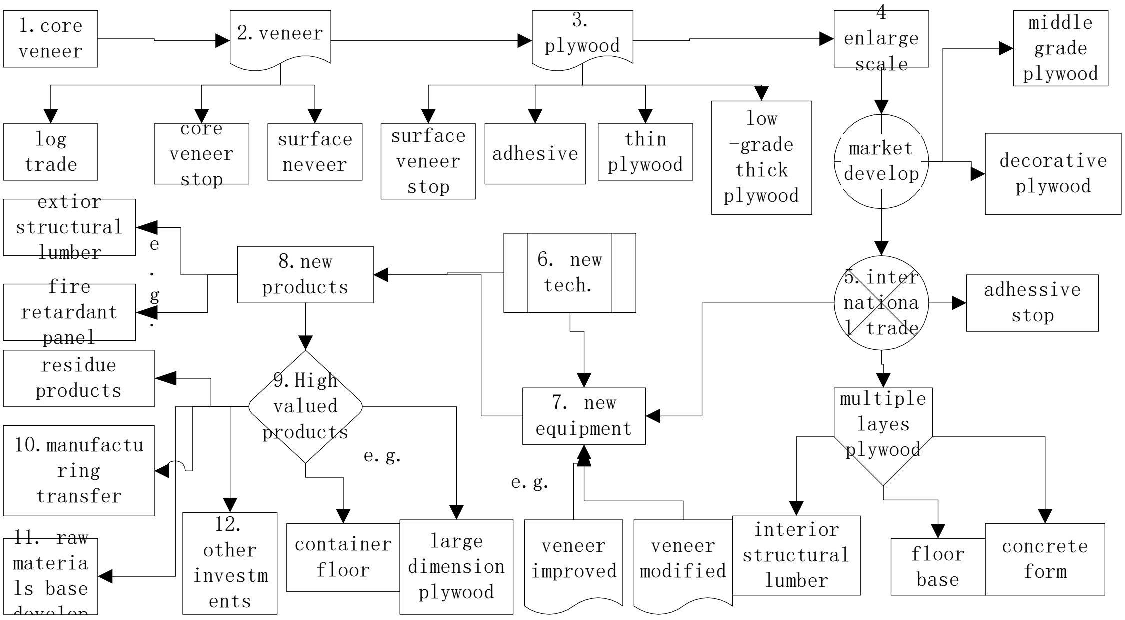

Figure 1: Developing process of plywood in the cluster

Generally, the forming mode of a plywood industrial cluster determines the product structure. The industrial cluster generally has three forming methods: spontaneous formation, artificial promotion and spontaneous and artificial promotion together (Wang and Teng, 2005). The basic direction of spontaneous industrial cluster was spontaneous or market, cluster from below, and difficult to attain the orderly development of industry; due to lack of industrial economy basis and ingenious society cultural basis, its product structure was only low-level duplicable development and had low ingenious force. The Feng town in Jiangsu province for instance, has a product structure with only the phase 1-3 of Fig. 1 and with its region advantages could achieve the fourth or fifth; the industrial clusters by the artificial promotion and spontaneous and artificial promotion together had more developing force: the cluster can make quality change happen with the guidance of the government, intervention of scientific departments and coordination of trade associations. It was analyzed from our investigation results: taken the Xuzhou and Pizhou cluster (according to the output value) as an example, 15% of the enterprises lay in the upper part of the product pyramid, which in this 15%, 25% were developed to phase 12, 30% were developed to phase 9-11, the others were developed to phase 6-8, 60% remained phase 4-5. Although there were few top-pyramid products in China, it was necessary that enterprises had greater fund accumulation. Found from the investigation, this was the direction of product variety and quality development of Chinese plywood. On the surface, it was part of a reunification of technological process. In fact the enterprises were booted in the soil of the cluster, correlating enterprises and institutions formed a huge network system in a certain region. It could be forecasted, along with the accumulation of enterprise funds and development of region economy, the technological process division in the cluster

would happen again under the high-quality and high-level conditions, which could be explained by phase 10-12.

Change of plywood enterprises in the cluster had great influence on the plywood quality

Large number of preliminary processing enterprises in the cluster easily produced low-end instability

The early veneer enterprises in the cluster existed with a form of primitive fund accumulation, with a large number, the number of veneer enterprises was 10-20 times that of the plywood enterprises (except Jiashan). These enterprises were of low-level either in equipment or in technique whose products gained the competitive advantage with low cost and price such as Zuogezhuang in Hebei and Linyi in Shandong. Such competitive advantage was based on the high utilization rate of raw materials and belittlement of labor unit value, mainly manufacturing core board, its product increasing speed and fund accumulation increasing speed was low but steady relative to the input, usually in the form of family shops, usually 3-6 years with an average of 4.8 years. When the production output reached a certain level and the fund accumulation reached more than 200,000-250,000 yuans, the existing equipment and production capacity was hard to meet the need of expanding output. At this time about 20% of enterprises were shifted to log purchase and rotary cutting of surface board to seek higher benefit. The enterprises entering into surface board production found that there was great risk in the log purchase and storage. Due to the great change of species to manufacture plywood and the material being difficult to control, some enterprises chose single species to manufacture plywood, trying to keep the maximum utilization rate of veneer. When the rapid accumulation of fund reached a stable level, many enterprises turned to manufacture deep product-plywood whose funds had reached more than 300,000—400,000 yuans. Such an evolution in situation of enterprises was called low-end instability. In one cluster, an average 3% to 5% of the enterprises (including directly transferred from the core board production) were turned to manufacture the plywood which lays in phase 3 shown in Fig. 1. These enterprises turning to the plywood industry found out that it was hard for them to manufacture high-quality products because of their bad equipment, funds and technology.

High-end instability in the development of plywood industrial cluster

We also found the high-end instability in the cluster from our investigation. When the output of a plywood enterprise reached 20000 m^3 in one year and staff developed to more than 400 people, a situation came into existence where the scale was hard to expand and the benefit could not increase. The first problem was the broken balance among equipment, output, staff and management, because such enterprises are basically labor-extensive enterprises which could not stand outside stimulation such as increase of labor cost, increase of raw materials price, market fluctuation and policy change, etc, and its management mode was basically family-run management. The second problem was: basic products are hard to get high benefits. So such enterprises had to seek outlet and appeared unstable which was called production high-end instability. High-end instability would make some enterprises transfer, of which one direction was to transfer out of the region which usually was undeveloped and had favorable policy; the other direction was to transfer to other fields and seek new development such as Jiashan in which about 20 enterprises had transferred into other industries in the recent 2 years.

Two-end instability existed in all clusters which greatly influenced the product quality and could not influence the product quantity in short time. On the surface, disorder of the clusters would tend to orderly under the market mechanism, but with time expansion, the cluster would become a low-benefit development area and a shoddy product area. The production level and ability of the low-end unstable enterprises could not reach the requirement of qualified plywood because of lack of funds, but there are still certain market demands for them for their low cost and price. Their entering had stroke the high-end production of enterprises inside and outside the cluster and led to competition disorder. In recent years, product stopping and bankrupt of many large and medium-sized plywood enterprises in Shenzhen, Guangzhong and Shanghai outside the cluster also confirmed the result of such vicious competition. High-end instability was partly caused by the upgrading of low-end enterprises, but largely lack of technology and organization innovation ability of enterprises. If we let it grow, the Chinese plywood industry would be placed at a disadvantage in the international market.

Resolving such unstable situation needed "human attribute", that was, the government, scientific departments and financial business participle; the government intervened with the upgrading of low-end enterprises, lay down the local fair competitive policy and regulations, and made full use of the role of association and quality inspection departments. We make the following comparison between the Chinese plywood industry and international plywood industry: one advantage was the low labor cost with rural workers as main sector; the solar energy resource was used fully; high utilization (although there were unreasonable compositions); largely one way for farmers to get rich, and force to greatly develop afforestation; but the main problem was low quality, and most products were low value-added. In this aspect, the industry-access system should use quality as standard and not only in terms of output limits. The government should support and guide the high-end plywood enterprises including setting up training schools, promoting the intervention of scientific departments and financial support, building innovation and a quality guarantee system to ensure that the industrial clusters develop orderly and keep growing. On the other hand, the government should maintain a regional advantage and sustainable development of industrial clusters which are not only concerned with the development of one particular industry but also pay attention to the industry transition and extension of industrial chain. In spite of the government establishing and implementing the system, scientific and economical workers should discuss the cause of product low-quality of the cluster together: how to build specialized production refinement points or splitting points of new quality-guaranteed system and develop the optimal economical utilization of residues from standpoint of market economy. These are unresolved and most critical problems for current industrial clusters.

To sum up the above arguments: the Chinese plywood output was mainly concentrated in the plywood industry cluster which represented the mainstream of plywood production. Studying the internal structure and mechanism of industrial cluster was helpful to know the present situation and development of Chinese plywood. In other words, the scientific departments should study the causing mechanism and developing information of the plywood cluster, especially the 4 large plywood industrial clusters. The plywood industrial association and scientific management departments should afford correct guidance and a plan to industrial specialization of the cluster in order to optimize the structure and guide the enterprise production and industrial development. The two-end instability of the plywood cluster should be paid enough attention by the government, scientific departments and industrial association.

The government should play a functional role, lay down fair competitive regulation, grasp plywood entry thresholds which use quality as premise, not only output as yardstick. At the same time, the government should discuss the industry innovation together with plywood associations and plywood enterprises of the cluster so as to take the road of plywood industry development with Chinese characteristics, thus having an ability to withstand the strike and effect of some factors including resources change, increase of labor costs and market demand, etc on Chinese plywood enterprises and promote the stable and orderly development of plywood industrial clusters.

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Development of decay in preservative treated poplar plywood

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ABSTRACT

Poplar is a fast growing species and may become more important in future for both the conversion of agricultural crops and the self supplying policy of the EU. In Flanders, the northern region of Belgium, poplar has become a widely spread species. It provides approximately one third of the wood volume produced while covering merely 10 % of the forest area. Poplar has also very interesting wood properties. Besides a range of specific end products as a light hardwood it is most suitable for the production of plywood.

Yet poplar is very vulnerable to the attack of wood destroying organisms, such as wood rotting Basidiomycetes. Therefore poplar plywood should be preserved in all cases where a sufficient service life is at risk. The research described here focuses in particular on the preservative treatment of assembled poplar plywood.

Despite poplar plywood being easily treatable, standard retentions for different preservatives do not always result in good protection. To achieve full biological protection of poplar plywood a high loading of preservative is required. The glue-line in poplar plywood does not cause significant problems but it certainly needs consideration.

When translating toxic thresholds derived from toxicity testing to practical retention requirements it should be realised that no unique ‘multiplication’ factors can be established. For special wood products like preservative treated plywood it is important to evaluate the biological durability of the commodity and it should be recommended to introduce a commercially viable quality mark, too.

Poplar plywood is considered the most suitable hardwood plywood to be upgraded by means of a preservative treatment. It is easy treatable and its susceptibility to degrade by the white rot fungus *Coriolus versicolor* is lower than for plywood made of low density tropical wood species.

INTRODUCTION

Poplar plywood is more common in interior use, however it is also the duty of scientists to enlarge the range of end-uses and maximise service life of home grown wood species to become competitive with imported wood materials in the near future. This will lead to the

reservation of durable wood species for more upgraded applications and thus protect them from overconsumption.

Poplar is one of the tree species that has been upgraded genetically most intensively and is widely used in man made plantation type forests. It is the ultimate interacting crop between different types of land use, which is both loved and feared by foresters, environmentalists and farmer organisations. Besides the controversy towards this wood species it remains the fastest growing hardwood in the temperate forest region and therefore also the most eminent possibility for industrialised countries to help solving the CO_2 balance.

The utilisation of poplar for the production of wood panel products has been investigated quite intensively at the beginning of the nineties, e.g. for particleboard (Roffael and Dix 1988), for cementboard (Roffael and Dix 1991) for MDF (Roffael *et al.* 1992) and for OSB (Zhou 1990). Plywood based on poplar and oak bonded with phenolic glue performed very well during 10 years of exterior exposure (Jokerst 1985). The development of this product was linked to the common presence of these hardwoods east of the Mississippi river close to a large number of potential consumers. This is actually also true for poplar in Europe. Poplar laminated veneer lumber (LVL), a similar product to plywood, is no longer just a research topic but its production already reveals concern for quality control (Zhang *et al.* 1994).

The experiment described below focuses in particular on the preservative treatment of assembled poplar plywood. Both other preservation techniques for plywood, namely treating veneers and the use of glue-line additives still have a lot of disadvantages, e.g. cost effectiveness, production interferences and sometimes doubtful efficacy.
The treatment of manufactured plywood neither is without difficulties. So can the glue-line become an obstruction for the preservative, and the effect of the treating solution on the stability of plywood may even be a bigger problem. Swelling and shrinkage of plywood by waterborne preservatives may lead to deformation and also glue bonds may become weaker due to the preservative treatment.
Such considerations were the subject of a separate study on the treatment of poplar plywood. The resistance to fungal attack by Basidiomycetes of poplar plywood treated with 8 different preservatives by means of a range of treating cycles is presented hereafter.

MATERIALS AND METHODS

Three different types of poplar plywood were studied (Table 1) which differed in glue (UMF, UF), total thickness (12 and 15 mm) and thickness of the outer veneer (0.9 and 2.7/3.0 mm). The preservatives used ranged from traditional types to new generation products (Table 2). Out of a range of treatment processes a selection was made (Table 3). The research aimed at reaching the maximum penetration achievable combined with a reasonable level of preservative uptake. Therefore full-cell processes were favoured for waterborne preservatives. Because of high retention figures for poplar plywood, common full-cell treating cycles somewhat similar to a double vacuum process were chosen. The pressure or atmospheric immersion period needed to be long enough to reach sufficient penetration. To avoid overconsumption of oilborne preservatives the first vacuum was eliminated from the double

vacuum process. Since poplar plywood is rather easy to treat, soaking/steeping and dipping schedules were also applied with respectively water- and oilborne preservatives (Table 4).

Table 1: Poplar plywood tested

Denomination	Origin	Glue classification	Total thickness (mm)	Veneer thickness (mm)
Poplar 1	Belgium	UF (MR)	12	0.9/3.9/2.4
Poplar 2	France	UMF (A100)	12	2.7/1.8/3.0
Poplar 3	Belgium	UMF (AW100)	15	3.0/3.0/3.0

Table 2: Preservatives used for treatment of poplar plywood

Preservative	Type	Fungicidal active ingredients	%	Concentration in solution (% w/w)
CCA	waterborne	copperoxide	11	3.3
		chromiumtrioxide	30	
		arsenic acid	26	
CCB		coppersulphate	34	3.3
		potassiumdichromate	39	
		chromiutrioxide	1	
		boric acid	26	
CCF		ammoniumdichromate	63	3.0
		copperhexafluorsilicate	36	
AAC1		diC_{10-14}dimethylammoniumchloride	38	2.0
		C_{12-14}dimethylbenzylammoniumchloride	38	
AAC2		diC_{10-14}dimethylammoniumchloride	50	3.0
Aza/Li		azaconazole	3.3	10.0
XAl/Li	oilborne	Xylasan Al		5.0
AAC/Pe		diC_{10-14}dimethylammoniumchloride		4.8
		C_{12-14}dimethylbenzylammoniumchloride		4.8

Table 3: Vacuum pressure treating cycles for the treatment of poplar plywood

Process code*	Period 1 Initial vacuum		Period 2 Pressure period		Period 3 Final vacuum	
	(min)	(kPa)	(min)	(MPa)	(min)	(kPa)
W1	60	- 35	90	0.0	60	- 95
W2	60	- 77	90	0.0	60	- 95
W4	60	- 95	90	0.1	60	- 95
W6	60	- 95	90	0.8	15	- 35
O1	-	-	1	0.0	15	- 60
O2	-	-	5	0.0	15	- 60

** W for waterborne preservatives; O for oilborne preservatives*

Table 4: Soaking / dipping treating cycles for treating poplar plywood

Process code*	Soaking / dipping submersion time
W10	1 day
W11	4 days
W12	8 days

O10	30 seconds
O11	2 minutes
O12	8 minutes

** W for waterbone preservatives; O for oilborne preservatives*

Plywood boards were cut in specimens of 20 by 48 cm. These samples were edge-sealed and systematically selected to become sets equivalent to the boards from which they originated from. All material was tested on fungal resistance according to the vermiculite method described by Kerner-Gang and Grinda (1984) very similar to the afterwards defined European test standard ENV 12038. For fungal testing of wood preservatives on hardwood plywood 4 types of fungi were used: *Coriolus versicolor* (Linnaeus) Quelet (strain CTB863A), *Poria placenta* (Fries) Cooke sensu J. Eriksson (strain FPRL280), *Lentinus cyathiformis* (Schaeffer ex Fries) (strain CTB67-02B), and *Stereum sp.* (strain BAM544).

Laboratory decay testing of CCA treated poplar plywood allows the determination of toxic threshold values. The standard toxic threshold values are based on concentration levels in evenly impregnated wood blocks and tested according to EN 113. The standard ENV 12038 provides a similar approach for wood based panels like plywood. The practical interpretation of these threshold values is based on retention figures corresponding to the higher concentration inducing total prevention of decay and the concentration still allowing decay. A new procedure for analysing data from soil- or agar-block decay test was reported by Gezer *et al.* (1999) to estimate the toxic threshold retention comparing their system with methods reported earlier by Nancy and Amburgey (1976), Link and DeGroot (1987) and Liu and Goodell (1991). The use of a two-slope model or a three-slope model each time defining consecutive areas with linear correlation between retention of the preservative and the mass loss percentage recorded from testing are proposed as an alternative to logarithmic transformation systems. When focussing on treated plywood a more practical toxic threshold level can be derived from the mass loss data. Such retention values correspond with a preservative treatment and could qualify this treatment.

RESULTS AND DISCUSSION

High decay of untreated plywood is observed for all three poplar plywoods (Table 5). Mass losses after 16 weeks of fungal exposure range from 25 to 46% for the first three fungi. The higher decay caused by *Poria placenta* than by *Coriolus versicolor* is exceptional, this is in contrast to other hardwood plywood types. *Stereum sp.* shows a significantly lower mass loss of approximately 10%.

Table 5: Median mass loss of untreated poplar plywood

Plywood	**Mass loss (%)**			
	Coriolus	***Poria***	***Lentinus***	***Stereum***
Poplar 1	30.0	46.2	28.9	9.6
Poplar 2	29.9	24.5	33.3	14.1
Poplar 3	26.5	39.1	25.1	10.2

In accordance with the criteria used in EN 113 and EN 599 for basidiomycetes testing a tested board can be designated as fully resistant to attack by wood-destroying basidiomycetes if:

- the mean loss of the test specimens is less than 3% (m/m); and

- not more than one test specimen has suffered a loss in mass greater than 3% (m/m) but less than 5% (m/m).

The different treating cycles appear to produce a wide range of CCA uptake data (Table 6). A CCA salt retention of 5 kg/m³ does not provide a sufficient resistance against fungal attack. Even 10 kg/m³ is ineffective to prevent *Poria placenta* from decaying poplar plywood. This latter retention figure appears to be a good estimation of the toxic limit. It is also interesting to notice that the poplar plywood 2 is more refractory to impregnation than both other types. Some of the other preservative treatments using CCB, CCF, AAC and azaconazole reveal mass losses diverging substantially from the CCA data. So there proves to be no alkyd ammonium compound (AAC) treated poplar plywood sufficiently protected at the treating levels used. CCB shows toxic limits below 5 kg/m³, while CCF behaved more or less similar to CCA. Only high uptake levels of azaconazole of about 1 kg/m³ can prevent fungal attack.
Both oilborne preservatives are unable to protect the various types of poplar plywood from decay by *Coriolus versicolor* as their mass losses were nearly equal to these of untreated plywood (Table 7). The AAC oilborne preservative was equally ineffective as the waterborne homologues with regard to *Poria placenta.* Despite being made of the same wood species there is clearly a difference in treatability of the three poplar plywoods. The AAC and the oilborne preservatives exhibit lower retention figures owing to the more difficult penetration of poplar plywood 1. This plywood sample also required a stronger initial vacuum (process W2 instead of W1) to reach a comparable level of CCA retention to poplar 2 and 3 (Table 6).

Steeping or soaking of poplar plywood in an aqueous CCA solution is not able to prevent fungal decay (Table 8). This could be mainly attributed to the fact that a fast fixating preservative as CCA is not fit for such treatment but it also underlines that even 12 to 15 mm poplar plywood can be refractory when inappropriate treating schedules are used. The results with the oilborne Xylasan Al preservative are more promising as retentions of 15 to 25 kg/m³ are controlling decay except for *Coriolus*. Process O11 could be a good alternative for the autoclave treatments O1 and O2; only requiring some 2 minutes dipping time in the oilborne preservative and yet achieving a liquid uptake of 37 kg/m³ corresponding to a loading of 1.9 kg a.i./m³.

Table 6: Mass loss of poplar plywood autoclave treated with waterborne preservatives

Plywood	Preservative	Process	Retention (kg/m³) treating solution	Retention (kg/m³) a.i.	Median mass loss (%) *Coriolus*	*Poria*	*Lentinus*	*Stereum*
Poplar 1	CCA	W2	207	6.9	9.8	14.1	-0.1	0.2
		W4	421	14.0	1.3	3.0	-0.1	0.4
		W6	670	22.3	0.1	3.4	-0.2	-0.1
	AAC1	W2	84	1.3	26.7	33.8	17.1	2.7
	AAC2	W2	144	2.2	27.9	13.4	10.5	3.4
	Aza	W4	194	0.65	17.9	15.1	13.5	2.8
Poplar 2	CCA	W1	165	5.5	1.3	1.3	0.4	0.8
		W2	314	10.5	0.6	6.0	-0.3	0.1
		W6	667	22.3	0.2	2.4	-0.1	0.0
	CCB	W1	160	5.3	1.8	0.9	1.3	1.4
	CCF	W1	160	4.8	1.9	11.4	0.7	1.2
	AAC1	W1	183	2.8	21.6	4.0	0.8	3.3
	Aza	W2	289	0.96	1.9	1.1	2.2	2.2
Poplar 3	CCA	W1	159	5.3	5.7	11.0	1.6	1.5
		W2	351	11.7	0.5	5.9	0.3	0.2
		W6	698	23.3	0.4	1.9	0.4	0.2
	CCB	W1	150	5.0	2.0	0.6	2.1	1.8
		W2	321	10.7	0.8	0.2	0.8	0.8
	CCF	W1	153	4.6	8.9	8.9	0.7	0.6
		W2	316	9.5	2.4	5.1	0.4	0.8
	AAC1	W1	176	2.7	21.8	9.2	1.7	3.1
	AAC2	W1	175	2.7	28.4	8.4	1.6	1.4

Table 7: Mass loss of poplar plywood autoclave treated with oilborne preservatives

Plywood	Preservative	Process	Retention (kg/m³) treating solution	Retention (kg/m³) a.i.	Median mass loss (%) *Coriolus*	*Poria*	*Lentinus*	*Stereum*
Poplar 1	XAl	O2	24.6	1.2	28.1	1.5	0.6	0.6
	AAC	O2	19.5	1.9	26.9	26.7	0.8	2.6
Poplar 2	XAl	O1	50.0	2.5	23.8	-0.7	0.9	1.3
		O2	52.4	2.6	24.0	0.2	1.5	2.1
	AAC	O1	30.9	3.0	24.5	21.9	1.2	2.9
Poplar 3	XAl	O1	41.2	2.1	24.6	0.3	1.5	1.5
		O2	46.0	2.3	22.7	0.6	0.7	1.2

Table 8: Mass loss of poplar plywood treated with dipping (O) / soaking (W) treatments

Plywood	**Preservative**	**Process**	**Retention (kg/m³)** treating solution	a.i.	**Median mass loss by fungus (%)** *Coriolus*	***Poria***	***Lentinus***	***Stereum***
Poplar 3	CCA	W10	104	3.5	24.7	16.4	3.3	24.1
		W11	148	4.9	24.1	31.1	20.2	3.2
		W12	191	6.4	32.6	29.8	17.1	2.7
	XAl	O10	29	1.5	22.1	4.8	0.6	-0.5
		O11	37	1.9	19.1	-0.4	-0.2	-0.3
		O12	51	2.5	18.6	-1.1	-0.3	-0.3

These technical more simple treatments result in higher fungal attack than expected. Their penetration profiles presumably are affected by the presence of glue-lines causing toxic gradients in the surface layers only, which may explain partly the severe degradation of the core veneers (Table 9). As expected the concentration of active elements in the inner veneers is lower than the mean value for the total board. The somewhat refractory character of poplar plywood 1 is demonstrated by the fact that both chromium and arsenic are accumulated in the outer veneer. This thin top veneer (0.9 mm) is creating a superficial barrier that is highly loaded with preservative by the fast fixation mechanism of CCA and as such inhibiting further distribution and penetration of chemicals. The same phenomenon is present when soaking poplar plywood 3 in CCA for 8 days (process W12). Such long treatment only resulted in a retention of 6.4 kg CCA salt/m³ with almost no presence of active ingredients beyond the first glue-line. A complete imbalance of the components deposited in the outer veneer indicating the preferential uptake of some components is an important factor related to treatment of wood with waterborne salt preservatives.

Based on the penetration figures for Cu and the mass loss data reported in Table 6, a copper content of over 1 kg/m³ for the second veneer might be a good prerequisite for biological effectiveness against fungal attack (including *Poria placenta*) which could be used for quality control.

To get more insight into the onset and development of decay individual test block data were plotted against the mean CCA retention data of all treated specimens of poplar plywood type 3. The main purpose of this exercise is to determine ‘practical’ toxic limits derived from basidiomycete testing of small test blocks extracted from large-sized treated boards. This is different from the toxic threshold values that are determined for wood preservatives in EN 113 where an even distribution of chemical in individual small test blocks is achieved by means of a laboratory treatment. Curve fitting is used to get a good estimate of the actual CCA retention that prevents decay. For this curve fitting some logical assumptions were made, summarized hereafter. The untreated material results in the highest mass loss. The mass loss starts decreasing from a certain level on and finally gets to zero at high retention level. Transition equations seemed to be the best apt and several equations were examined.

Table 9: Concentration of active component in the different veneer layers of CCA treated poplar plywood

Plywood	Process	CCA salt retention (kg/m^3)	Active ingredients	Concentration of active ingredients in veneer layers (kg/m^3) surface	cross	inner
Poplar 1	W2	6.9	Cu	1.2	0.6	0.6
			Cr	3.3	0.8	0.6
			As	4.0	0.9	0.9
Poplar 3	W1	5.3	Cu	0.7	0.3	0.6
			Cr	1.0	0.6	1.0
			As	0.6	0.3	0.7
	W2	11.7	Cu	1.2	1.1	1.0
			Cr	1.9	0.8	0.9
			As	1.2	1.3	1.2
	W12	6.4	Cu	1.8	0.0	0.0
			Cr	7.2	0.2	0.1
			As	10.9	0.2	0.4

The functions giving the best fit when considering all 4 fungi were asymmetric transition functions:

(1) the Weibull cumulative function

$$Y = a\ [1 - \exp(-((X + c\ (\ln 2)^{1/d} - b) / c)^{d})]$$

(2) the asymmetric sigmoid function

$$Y = a / [1 + \exp(-(X - c \ln (2^{1/d} - 1) - b) / c)]^{d}$$

(3) the logistic dose response (LDR) function.

$$Y = a / (1 + (X/b)^{c})$$

(4) Based on biological consideration a growth relationship according to the model of Richards (Hunt, 1982) was evaluated additionally:

$$Y = a\ .\ (1 - (1 + b\ .\ \exp(-c.\ X)^{-1/d})$$

all with
Y = mass loss (%)
X = preservative retention (kg/m^3)

The data are plotted together with the best fit curves in Fig. 1 to 4 for *Coriolus versicolor, Poria placenta*, *Lentinus cyathiformis* and *Stereum sp.*, respectively. The Weibull cumulative curve may well be best ranked in most cases though some features in the curve do not entirely comply with expectations. Especially the very abrupt changes for *Coriolus* and *Lentinus* are surprising and unreal, but the mass loss of the untreated controls is well respected. The curve does not reach 0 % for *Coriolus* which may illustrate lower accuracy. The asymmetric

sigmoid seems to become less accurate when a limited amount of intermediate values are available for *Lentinus* and additionally the horizontal platform close to the zero retention is

lost once this becomes less obvious. The logistic dose response was less accurate as it was ranked 4th except for *Poria*. All assumptions on how decay develops in relation to higher concentration of fungicides are covered by this curve. The fact that the curve is decreasing slower for *Lentinus* after having reached 5% mass loss could make estimation of toxic limits based on lower mass loss less predictable. Surprisingly the model of Richards, which is not standard provided as a curve fit transition equation, performed very well in fitting with most fungi showing even higher R square values (0.66 up to 0.78) than for more common equations. In Fig. 1 the control mass loss was even better respected than with the LDR curve and the asymptotic zero mass loss agreed better. On the other hand for *Poria* the stricter trend towards a zero value could be contradicting the observation that even at very high CCA loadings some mass losses were recorded for treated poplar plywood. Using the 5 % mass loss criterion some 'practical' toxic limits can be derived based on either the logistic dose response curve or according to the model of Richards (Table 10).

Table 10: 'Practical' toxic threshold values for CCA treated poplar plywood based on curve fitting

Fungus	**Toxic threshold values at 5% mass loss (kg/m^3) treating solution – salt / concentrate**
Coriolus versicolor	240 – 8
Poria placenta	400 – 13
Lentinus cyathiformis	220 – 7
Stereum sp.	90 – 3

Strict estimation based on individual concentration sets according to the criteria of EN 113 and EN 599 would bring these values up to 12 for *Coriolus*, 8 for *Lentinus*, 6 for *Stereum* and undefined for *Poria.*

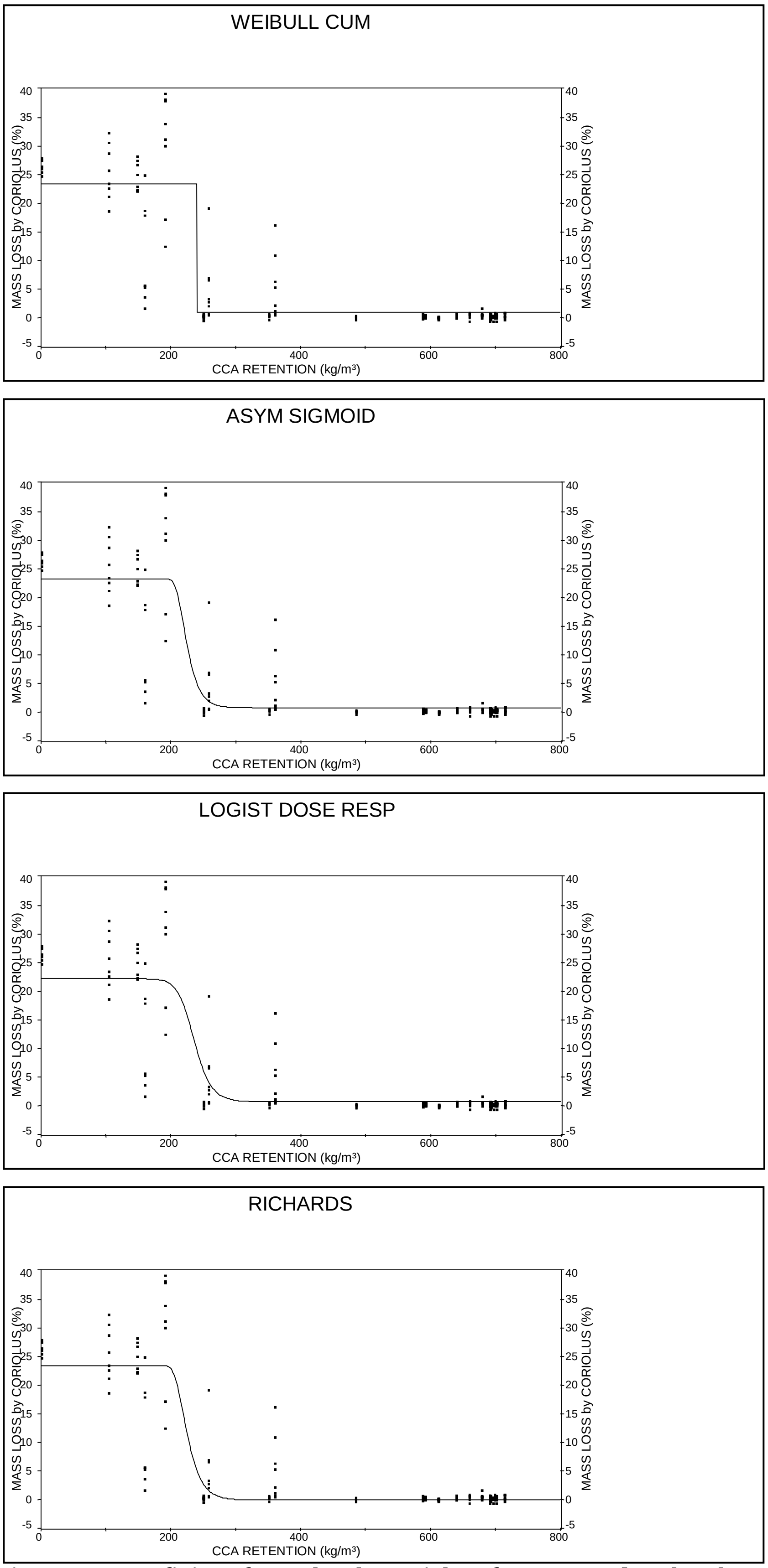


Figure 1: Curve fitting of mass loss by Coriolus of CCA treated poplar plywood

F ***oplar plywood***

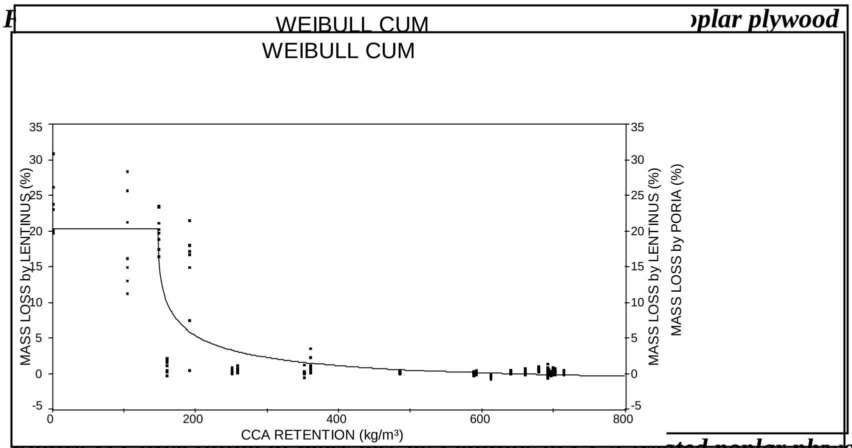
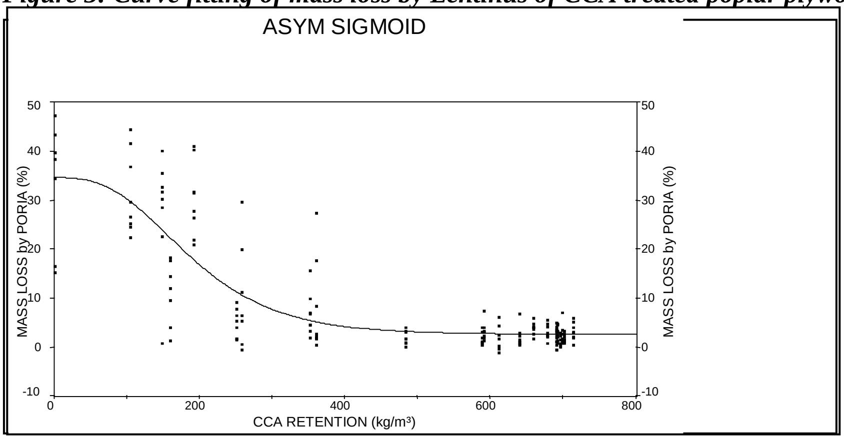
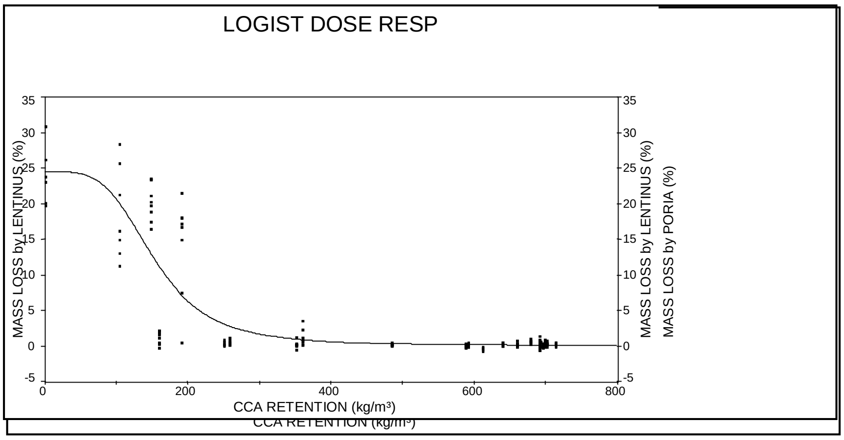
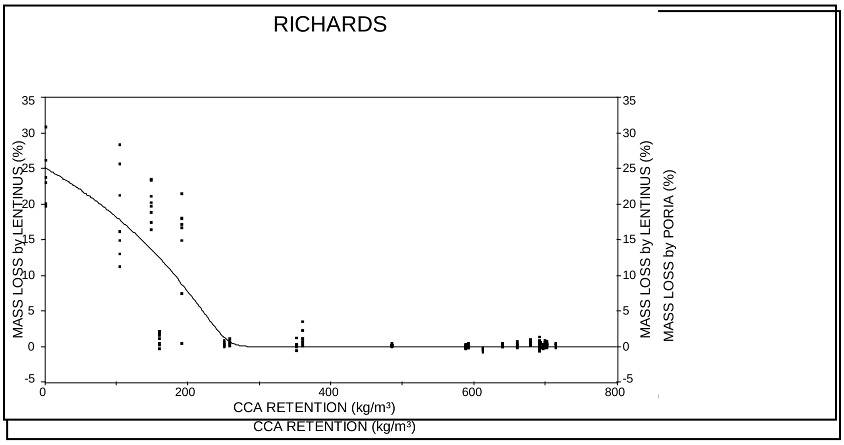
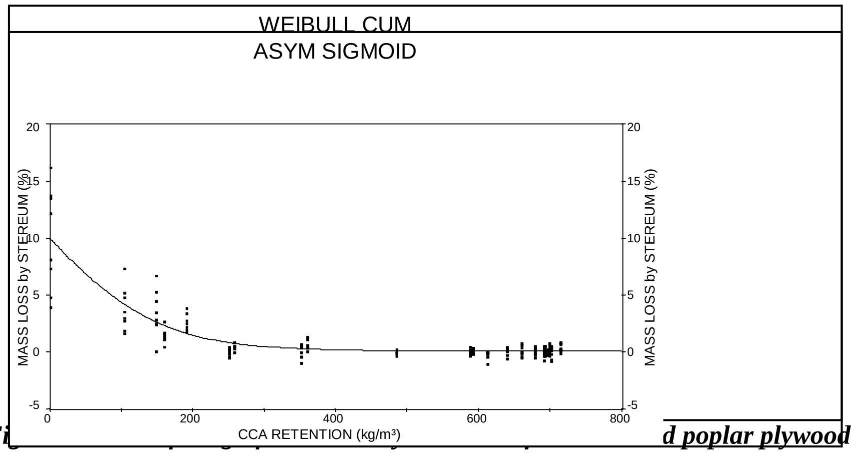


Figure 5: Curve fitting of mass loss by Lentinus of CCA treated poplar plywood

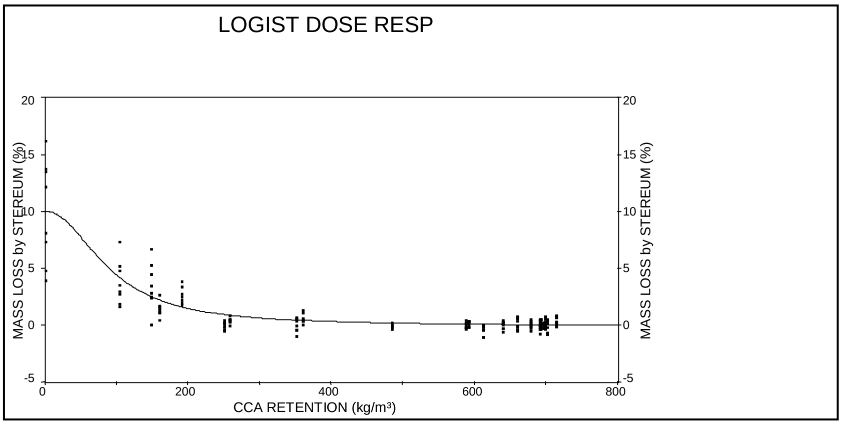


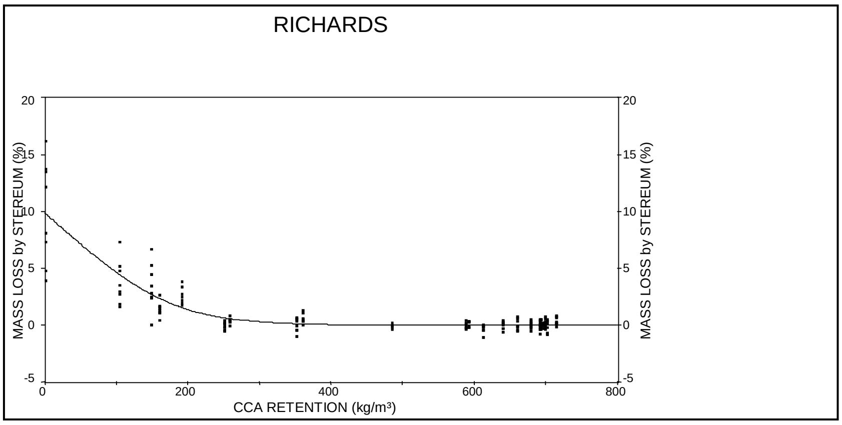






Fi ***d poplar plywood***





CONCLUSIONS

As poplar is a most vulnerable wood species protection is desirable in many applications. Despite poplar plywood being easily treatable standard retentions for different preservatives do not always impart good protection. To achieve full biological protection of poplar plywood a high loading of preservative is required. The glue-line in poplar plywood does not cause significant problems but it certainly needs consideration. It was shown that test methods using samples from material treated at larger scale, as is done in industrial plants, gives a better picture of the protection potential that is attainable. This way it is possible to establish practical toxic limits.

When translating EN 113 toxic thresholds to practical retention requirements it should be realised that no unique ‘multiplication’ factors can be established. For special wood products like preservative treated plywood it is important to evaluate the biological durability of the commodity and it should be recommended to introduce a commercially viable quality mark, too.

Poplar plywood is considered the most suitable hardwood plywood to be upgraded by means of a preservative treatment. It is easy treatable and its susceptibility to degrade by the white rot fungus *Coriolus versicolor* is lower than reported for plywood made of low density tropical wood species. Hence poplar proves to possess better starting properties to produce treated plywood than other low density species currently often used for plywood manufacture.

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Study on Creep Performance of Fast-growing Poplar modified with ACQ-D

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Keywords: Fast-growing poplar, ACQ, wood preservation, mechanical performance, creep deformation

ABSTRACT

People have paid more attention to continuous developing environmental quality since the new century. Now, designers attach importance to wood materials that could be used in construction. However, wood is liable to be attacked by fungi and insects. It is necessary to enable wood materials with strong anti-decay ability when the material is to be used in exterior applications. The major wood materials which could gain easily are based on wood from fast-grown trees. Therefore, fast-grown poplar was chosen for this experiment. Fast-grown poplar samples were modified with ACQ-D.
Furthermore the static mechanical and creep performance of this modified wood should be emphasized and measured when used as structural materials. The results showed that the mechanical strength of modified samples is almost equal to that of the unmodified. However, the anti-creep performance of modified samples was lower than that of the unmodified under the same bearing scales. Wood samples were much more affected by relative humidity after treatment with ACQ-D.

INTRODUCTION

Wood material was used widely for its friendliness. Wood material was maybe degraded when its quality was affected, as it was liable to be attacked by organisms. According to a great deal of statistical results about materials, the life cycle of preservative wood could be extended 5 to 6 times than that of untreated items (Li 2001). Therefore, preservative treatment for wood was necessary and important because its use cycle could be extended and its function could be enlarged. Fast-growing Poplar materials were planted and used at Jiangsu and neighboring provinces. However, Poplar materials were generally attacked by termite and decay fungi, especially at the hot and damp area, because of its loose nature and big vessel. Poplar was characteristic of low decay and durable resistant ability. (Luo 1999, Yue 2008).

ACQ-D was generally used as a water-soluble wood preservative, for its low toxin and high efficiency. When the modified wood was used as garden materials, its anti-decay ability was concerned. However, the creep performance was not negligible while it was used as structural

material. The creep performance of Poplar material was studied in this paper, as well as the modified samples with ACQ-D.

EXPERIMENTAL METHODS

Fast-growing Poplar, I-72, *Populus sp.* was dried when its moisture content reached to 10%. ACQ-D was bought from Tian Bao Wood Protection Sci-Tech CO., Ltd in Guangdong province. The 2% concentration of ACQ-D was prepared. Poplar was impregnated with the diluted ACQ-D by means of vacuum method. The modified samples were dried gradually. It was dried one day at 40°C after been laid one week at room temperature, and then put into an 80°C oven until its weight was constant. The preservative retention was calculated.

The modified and untreated samples were kept where relative humidity was 55% and temperature was 20°C until their weight was constant. The two kinds of samples were cut into 35:1 length/thickness.

The mechanical properties were tested, and then their ultimate stress was clear. The following step was the creep test by means of bending load. The detailed technology was that both sides were supported and the centralized loads were 30% and 50% ultimate stress.

RESULTS AND DISCUSSION

After being calculated, the preservative retention was from 12.01 to 12.56 kg/m^3.

The curves of creep deformation and time were shown as the following.

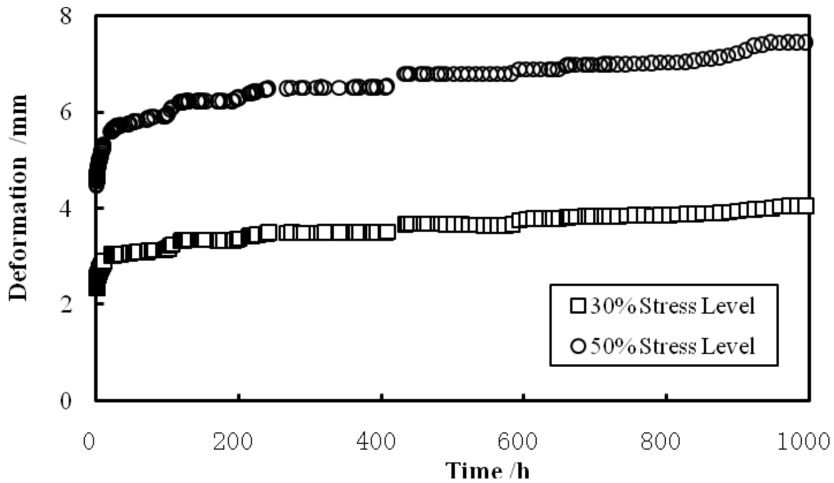

Figure 1: The curve of creep deformation of untreated samples at different stress levels

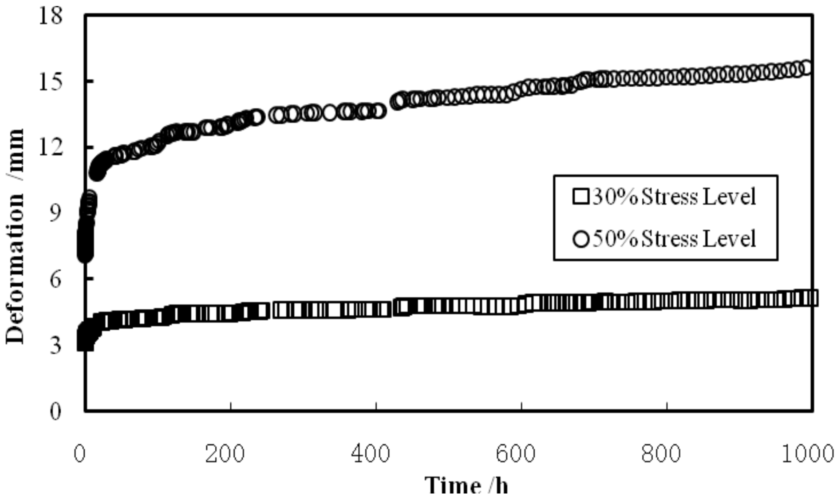

Figure 2: The curve of creep deformation of treated samples with ACQ-D at different stress levels

Some trends of the creep deformation curve from the Fig. 1 and 2, are very obvious. The creep deformation increased along with testing time. The creep performance of two kinds of samples was analogical. The creep curve of modified samples was alike as that of untreated at low stress level, however, the deformation of modified samples was much more notable than that of untreated at high stress level.

Surrounding conditions

It is well known that temperature and water could be looked on as plasticity. When temperature increased, the ingredients of wood could distort, because kinetic units were exploded and had the ability to get rid of bondage around it. Wood moisture content changed along with the relative humidity around it. The creep deformation could be more evident under load for the change of distance and bondage among fibres. For example, Bach (1965) deduced that creep flexible modulus was directly proportional to moisture content of wood by means of tension tests. Mukudai (1986, 1987) indicated that creep velocity increased according to exponent function as temperature and humidity increased.

Surrounding conditions were noted as Fig. 3 during the course of creep. Surrounding relative humidity changed from 36% to 67%, and temperature changed from 16°C to 23°C . The range exceeded 80%. Therefore, the fluctuation of temperature could be considered as negligible tractors.

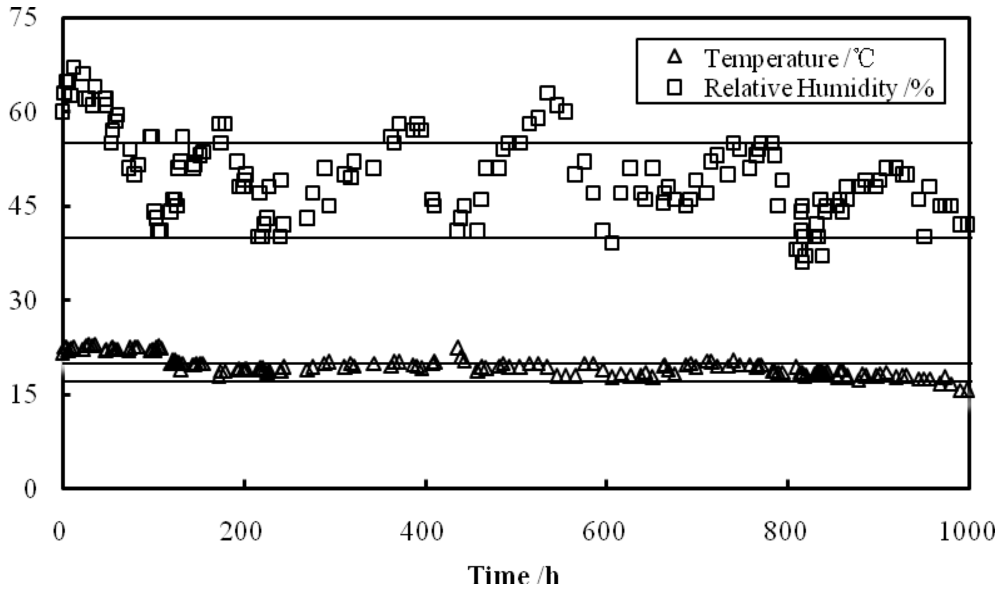

Figure 3: The recorded conditions during the procedure for creep evaluation

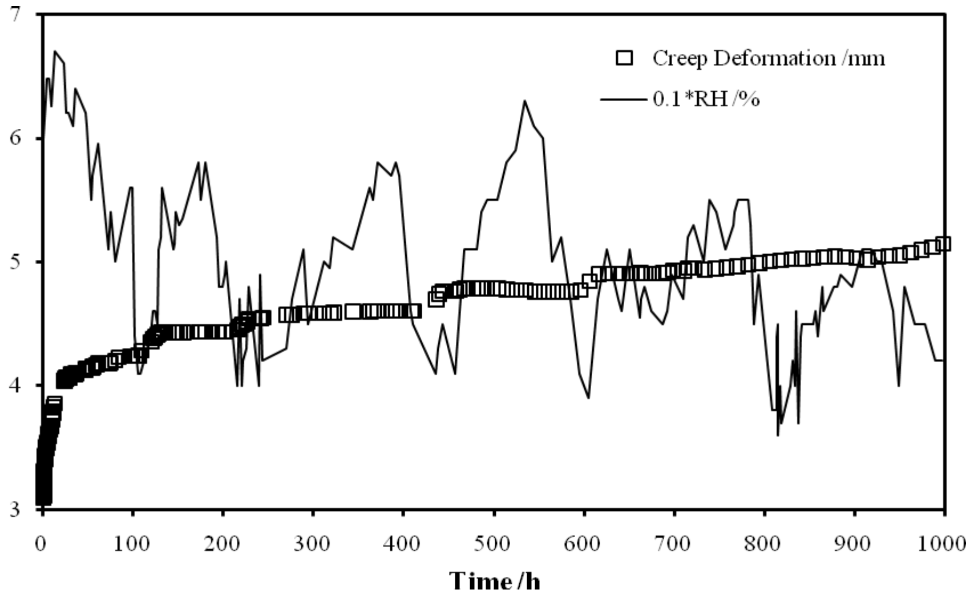

Figure 4: Relative humidity and creep deformation of modified samples with ACQ-D at 30% stress level

Being changed humidity data and creep deformation of modified samples with ACQ-D at 30% stress level put together, the relationship between humidity and deformation was clear in Fig. 4. In Fig. 4, humidity data was multiplied by 0.1 and its unit was percent.

The effect of humidity on creep deformation was obvious, and recorded humidity data changed periodically. In every period, there was a distinct jump of creep deformation when humidity increased suddenly, but the effect of humidity was decreasing as time went.

Stress level

The result from the comparison between Fig. 1 and Fig. 2 was that the effect of stress level on creep deformation was magnified after samples were modified with ACQ-D. The deformation of modified samples exceeded those of the untreated at the same stress level, especially at high stress level.

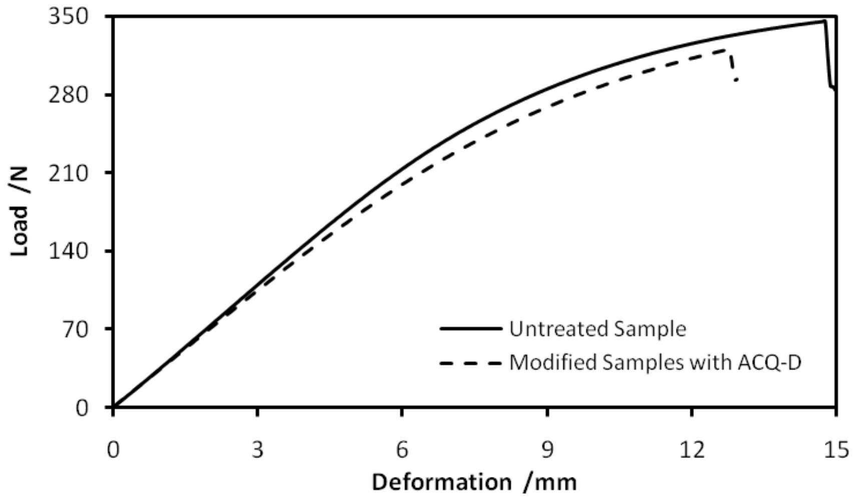

Figure 5: The curve of deformation and bending load of samples

Fig. 5 represented the comparison of modified and untreated samples between strain and stress. There was little difference and distance between the two kinds of samples when strain was not very high, the curve displayed direct proportion function discipline, and the overlapped extent of the curves was wide. The stain of samples went quicker than the velocity of stress under high load, and the materials were characteristic of viscidity. The deformation difference of the two kinds of samples was little, and the distance of modulus of elasticity between them was not obvious. So, it may be deduced that the creep performance of the two kinds of samples was the same.

The molecule weight of ACQ-D was low, so it could be easy to get into the interspaces among fibres of wood by means of vacuum impregnation, so the space between fibres advanced. When specimen bore load, relative movement between fibres was liable to occur.

ACQ-D was water-soluble. The connection between preservative and wood ingredients was the key to creep performance after preservative deposited in the wood. Some studies showed that the connection was weak, and the leach resistant of ACQ-D was not satisfying, especially in a damp surroundings. The preservative was characteristic of moisture absorption, and this was another reason for the higher deformation of modified samples with ACQ-D.

CONCLUSIONS

The effect of humidity on moisture content of modified samples with ACQ-D was obvious. The creep performance of modified samples was similar to that of the untreated at low stress level. The creep deformation of modified samples was much notable at high stress level. When being used as structural materials outside, the modified wood with ACQ-D should be improved further at the creep performance.

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Manufacture of PF Poplar Flakeboard with a Steam-injection-vacuum Press

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ABSTRACT

Besides reducing the pressing time, allowing to cure thick resin-bonded panels, steam-injection-vacuum pressing technique presents opportunities for increased panel dimensional stability, control of the density gradient, possibility for gas injection of fire retardant, preservatives, and catalysts. This study focused on the steam-injection-vacuum pressing technique of aqueous PF adhesive bonded poplar flake-board with an experimental lab press. The results showed that PF bonded poplar flake-boards could be produced with steam-injection-vacuum pressing technique, and vacuuming time, steam pressure, steam time and steam timing all had major impact on the properties of the boards. In the paper, the optimizing steam-injection-vacuum pressing factors within the range of the experiments are presented.

INTRODUCTION

Today the particleboard with a 0.3~0.5g/cm^3 density and a 60~100mm thickness is becoming more and more important in structural composites. But its hot-pressing cycle is very long when the conventional hot-pressing method is used. SIVP technique presents opportunities not only for a short hot-pressing cycle, but also for increased panel dimensional stability, control of the density gradient, possibility to decrease the rudimental steam and other harmful gases within the mats.

The prerequisite for a successful SIVP is to establish appropriate variables in view of both panel quality and productivity. This paper focused on SIVP technique for aqueous PF adhesive bonded Poplar flake-board with an experimental press in the lab.

EXPERIMENTAL METHODS

Variables for steam-injection-vacuum pressing

There are many factors that affect the properties of steam-injection-vacuum pressed poplar flake-boards, besides the conventional factors such as the geometry and moisture of flakes, the adhesive and its application, board normal density, board thickness, hot temperature, hot time and hot pressure. Those variables which are related to SIVP are more important. Based

on previous experiments[1], this paper chose saturated pressure, steam time, hold time and vacuuming time as four SIVP factors.

Materials and methods

Poplar flakes and aqueous PF adhesive used in the experiment came from Xuzhou Oriented Strand Board Factory, Jiangsu Province. The bulk density of flakes was 0.253g/cm^3 and its sifting value was shown in Table 1. The pH, viscosity and solid content of the adhesive were 10.9, 258 MPa, and 50.2% respectively.

The flake mats were hand-formed. The application of PF resin and melting wax were 7% and 1%, respectively. The panel size was 500×500×19mm, and the normal density and thickness were 19mm and 0.6g/cm^3, respectively.

Table 1: Sifting Value of Flakes

Geometry	Screen[mesh]	Percent[%]
1	M≤6	35.65
2	6<M≤9	30.74
3	9<M≤14	23.07
4	14<M≤42	9.70
5	M<42	0.84

In order to arrange the four variables in an efficient way, reduce the total experiment numbers, and analyze the data statistically, the Quadratic mathematical model and Dn-Optional Design method were used (shown in Tables 2 and 3). The flake-boards were produced with BY602×4 press in the lab. Copper meshwork was used to assure injecting steam into mat surfaces evenly and prevent mat conglutination. Temperature was 180°C, and maximum pressure of the press was about 3.2 MPa.

When the bulk density of the mat achieved 0.3 g/cm^3, steam injecting began. At the same time, the press's closing was interrupted. After 15s, the press was continued to close until attaching to the stop. After attaching the stop, the steam kept on injecting, and then vacuuming began. Total steam time and vacuuming time were shown in Table 3. The time for taking out the mat after vacuum processing was about 15s.

Table 2: Coding of factorial levels

Variables	Coding	-1.685	-1.494	-1	-1.907	0	0.644	1	1.685	1.784
Saturated pressure[MPa]	x_1	0.4		0.48		0.6		0.72	0.8	
Steam time[s]	x_2	10		20		35		50	60	
Hold time[s]	x_3	140		172		220		267	300	
Vacuuming time[s]	x_4		40		56	80	97			128

Table 3: Experiment plan

Panel No.	Saturated pressure [MPa]	Steam time[s]	Hold time[s]	Vacuuming time[s]
1	0.6	35	220	128
2	0.6	35	220	40
3	0.48	20	172	97
4	0.72	20	172	97
5	0.48	50	172	97
6	0.72	50	172	97
7	0.48	20	267	97
8	0.72	20	267	97
9	0.48	50	267	97
10	0.72	50	267	97
11	0.8	35	220	56
12	0.4	35	220	56
13	0.6	60	220	56
14	0.6	10	220	56
15	0.6	35	300	56
16	0.6	35	140	56
17	0.6	35	220	80
18	0.6	35	220	80

RESULTS AND DISCUSSION

Data and results

After removal from the press, the panel moisture content was tested immediately. Then the panels were conditioned indoors for 72hrs by exposure to a temperature of 20°C and a relative humidity of 65%, and then tested in accord with GB4896-4905-85 and prEn300-94. All data were shown in Table 3.

Table 3: Collections of test results

Panel No.	$MOR_{//}$ [MPa]	$MOR_{\perp}$ [MPa]	$MOE_{//}$ [MPa]	$MOE_{\perp}$ [MPa]	IB (Mpa)	TS [%]	MC_1 [%]	MC_2 [%]	ρ g/cm^3	D mm	F
1	31.9	25.3	5703	5373	0.370	5.09	6.40	10.2	0.613	18.9	7.7
2	34.5	28.0	3989	3604	0.363	6.94	7.10	9.4	0.650	18.3	9.9
3	32.5	31.0	5017	4589	0.347	9.90	6.86	9.3	0.618	19.1	
4	26.6	23.5	3588	3227	0.355	7.92	6.97	10.2	0.600	18.1	
5	31.1	27.8	4982	4631	0.428	6.88	7.00	9.8	0.597	18.6	
6	27.8	24.5	3572	3352	0.456	6.07	7.10	9.4	0.588	17.7	
7	25.4	20.5	4269	3847	0.361	6.46	6.72	10.8	0.596	19.4	
8	20.7	16.9	3387	3009	0.427	6.15	6.80	10.1	0.574	18.1	
9	25.0	20.8	3491	3083	0.378	5.71	6.80	9.6	0.579	18.4	
10	19.3	17.0	3326	2978	0.469	5.84	6.88	9.3	0.579	17.9	
11	22.1	20.1	3757	3377	0.448	5.68	6.98	11.2	0.611	17.6	
12	29.3	25.3	4483	4040	0.346	7.33	6.80	11.4	0.681	19.3	
13	21.0	19.9	3614	3108	0.395	6.14	7.00	8.7	0.610	17.8	
14	31.0	27.5	4577	3997	0.345	9.62	6.80	8.6	0.689	19.4	
15	23.7	19.8	3701	3288	0.409	6.65	6.70	10.2	0.608	18.5	
16	25.9	21.4	3894	3451	0.354	7.04	6.50	9.1	0.617	18.7	
17	31.4	26.6	3843	3500	0.381	6.35	6.83	9.7	0.631	19.1	8.6
18	25.8	23.8	4390	3853	0.419	5.64	6.83	9.5	0.633	18.9	8.7

1) MC_1 is moisture content of hot panels; MC_2 is moisture content of balanced panels.
2) Mat moisture content before and after resin application were 4% and 6.9%, respectively.
3) F means free formaldehyde content in mm tested using 100g flake-board samples.
4) D means average thickness of samples cut from the boards just removed from the press.

Data Processing and Regression

F values of testing indexes, test of regression coefficient, and test regression equations were shown in Tables 4 and 5, respectively.

Table 4: F values of testing indexes

Items	α=0.25	α=0.10	α=0.05	α=0.01
Equation distortion (F_1)	1.49	2.61	3.52	5.93
Equation significance (F_2)	1.37	1.84	2.20	3.02
Regression coefficient significance (F_3)	1.40	2.96	4.32	8.02

Table 5: Test of regression equations

Items	F value	Significance (α)	Results
$MOR_{//}$	F_1=0.19	0.25	simulation
	F_2=3.25	0.01	significance
MOR⊥	F_1=1.47	0.25	simulation
	F_2=3.65	0.01	significance
$MOE_{//}$	F_1=0.61	0.25	simulation
	F_2=4.50	0.01	significance
MOE⊥	F_1=0.21	0.25	simulation
	F_2=16.90	0.01	significance
IB	F_1=0.35	0.25	simulation
	F_2=28.96	0.01	significance
TS	F_1=1.07	0.25	simulation
	F_2=9.32	0.01	significance

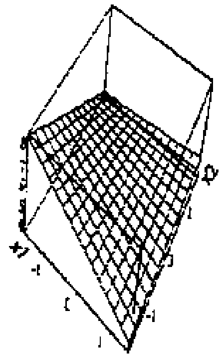
All F_1 values of equations were less than 1.49 (α = 0.25), so one conclusion was made that there were no other factors effecting the properties significantly in the experiment schedule, and Dn-Optional Design method could be used for arranging an experiment plan.
From Tables 4 and 5, another conclusion could be drawn that when the four variables were within the range of test schedule, all equations could provide excellent relationships between variables and panel properties, so all equations could be used to forecast panel properties. Table 6 showed regression equations of experimental indexes.

Table 6: Regression equations of experimental indexes

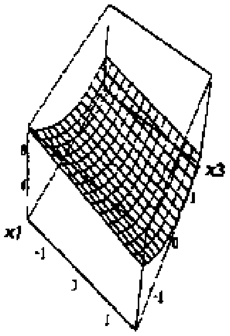
Regression equations	Distortion	Significance
$MOR_{//}=27.8-2.3x_1-1.4x_2-2.3x_3+1.8 x_2x_4-1.8 x_3x_4-1.4 x_3^2+2.2 x_4^2$	0.25	0.01
$MOR_{\perp}=24.2-2x_1-1.1x_2-2.5x_3+1.3 x_2x_4-2.2 x_3x_4-1.4 x_3^2+x_4^2$	0.25	0.01
$MOE_{//}=4045-374x_1-184x_2-220x_3+204x_4+224x_1x_3-174x_1x_4-180x_3x_4-193 x_3^2+398 x_4^2$	0.25	0.01
$MOE_{\perp}=3619-334x_1-155x_2-231x_3+250x_4+212x_1x_3-201x_3x_4-181x_3^2+411 x_4^2$	0.25	0.01
$IB=0.433+0.027x_1+0.024x_2+0.01x_3+0.008x_4+0.015x_1x_3-0.015x_2x_3+0.009x_2x_4-0.009 x_1^2-0.014x_4^2$	0.25	0.01
$TS=6.71-0.5x_1-0.9x_2-0.6x_3-0.3x_4+0.5x_1x_3+0.6x_2x_3-0.54x_3x_4+0.56 x_2^2-0.31x_4^2$	0.25	0.01

DISCUSSION

Effects of variables on panel properties were shown in Fig.1~Fig.6.



(1)Influence of steam pressure and steam time



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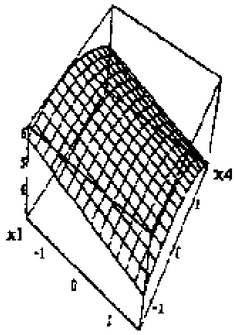

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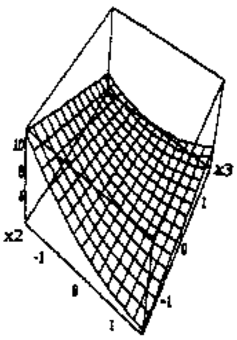

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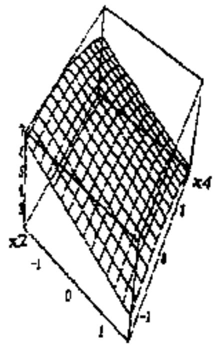

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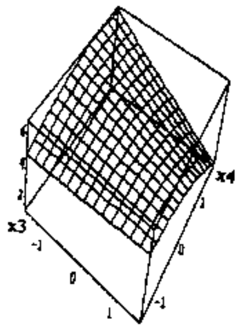
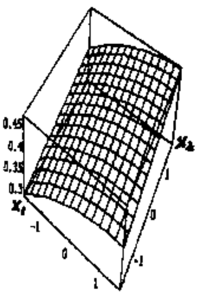


(6) Influence of hold time and vacuuming time

Figure 1: Influence of factors on TS



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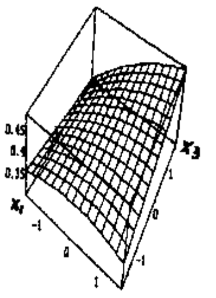

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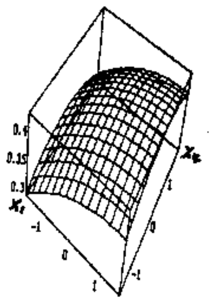
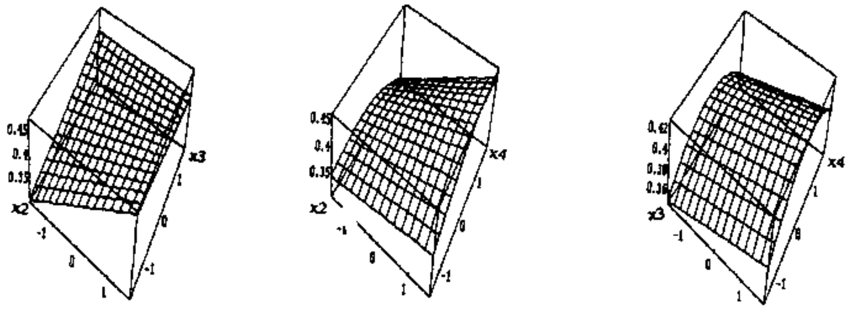


(3) Influence of steam pressure and vacuuming time

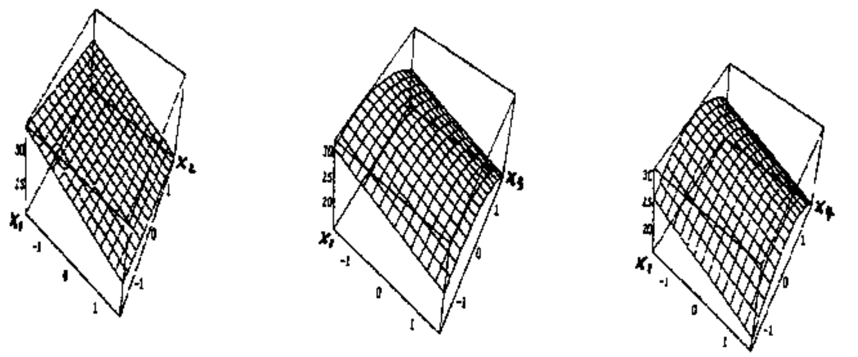


(4)Influence of steam time and hold time

(5)Influence of steam time and vacuuming time

(6) Influence of hold time and vacuuming time

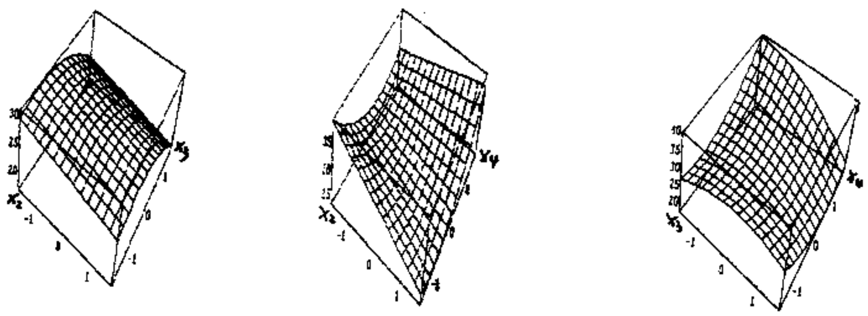
Figure 2: Influence of factors on IB



(1)Influence of steam pressure and steam time

(2)Influence of steam pressure and hold time

(3) Influence of steam pressure and vacuuming time

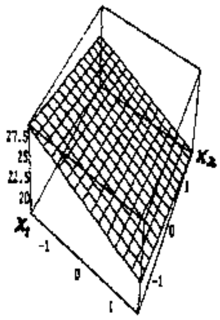


(4)Influence of steam time and hold time

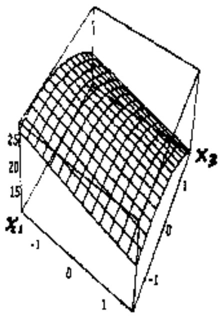
(5)Influence of steam time and vacuuming time

(6) Influence of hold time and vacuuming time

Figure 3: Influence of factors on $MOR_{//}$



(1)Influence of steam pressure and steam time



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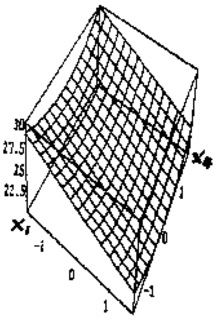
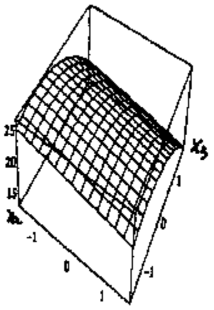


(3) Influence of steam pressure and vacuuming time



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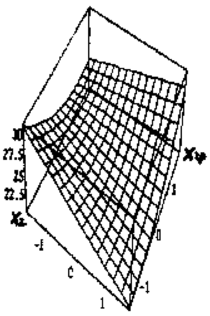
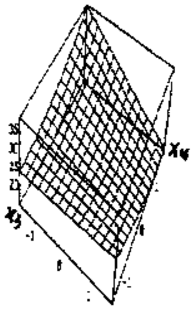
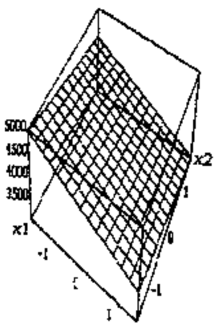


(5)Influence of steam time and vacuuming time

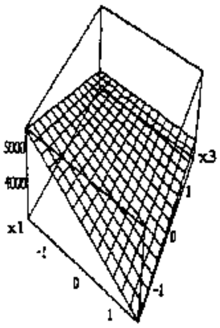


(6) Influence of hold time and vacuuming time

Fig. 4: Influence of factors on MOR⊥



(1)Influence of steam pressure and steam time



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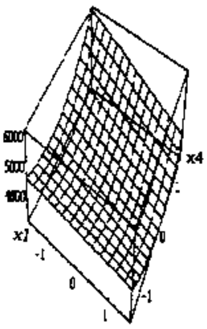
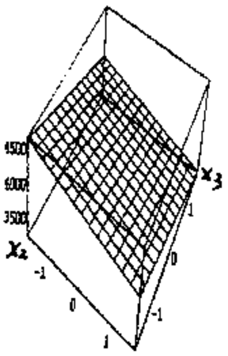
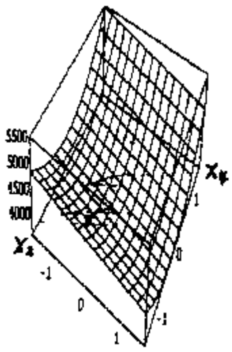
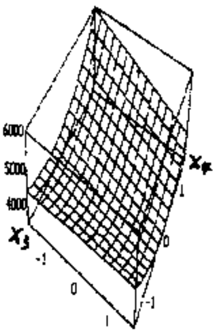


(3) Influence of steam pressure and vacuuming time





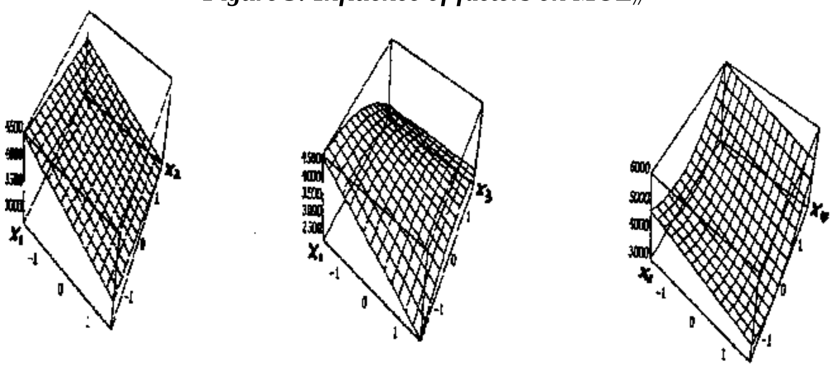


(4)Influence of steam time and hold time

(5)Influence of steam time and vacuuming time

(6) Influence of hold time and vacuuming time

Figure 5: Influence of factors on MOE$_{//}$



(1)Influence of steam pressure and steam time

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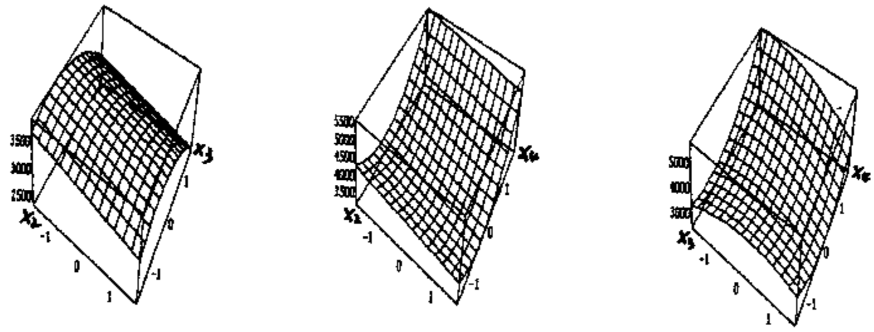

(4)Influence of steam time and hold time

(5)Influence of steam time and vacuuming time

(6) Influence of hold time and vacuuming time

Figure 6: Influence of factors on MOE$_{\perp}$

Effects of saturated pressure

<u>Effects of saturated pressure on TS</u>

Saturated pressure affects thickness swelling (TS) of flake-boards significantly. When saturated pressure changed from 0.4 MPa to 0.8MPa, TS decreased greatly. Under the high temperature and humidity of SIVP, Poplar flakes plasticize quickly and evenly, that is, hemicelluloses hydrolyze rapidly, lignin soft and degrade partly. The crystal zone and non-crystal zone of cellulose also hydrolyze partly and rearrange in its structure, resulting in the release of stress and strain existing in the micro-fibril, which improves the dimensional stability of panels effectively.

<u>Effects of saturated pressure on IB</u>

Influence of saturated pressure on internal bond strength (IB) of flake-boards was very significant, too, and within the range of the test, when saturated pressure increased, IB increased evidently. Under the environment of SIVP, a higher temperature level could be reached within the whole mat, which resulted in a more thorough adhesive curing, a more quick and even flake plasticization before the mat was pressed to the final thickness which could avoid the squishing of flakes, a more even density distribution, and a higher core

density than that of boards manufactured in the conventional hot pressing (CHP). It was well known that IB of boards has a linear relationship to the core density of the flake-boards[2,3]. The higher the saturated pressure, the more intense those actions are, and the better the IB of panels is.

But in the test, the IB of flake-boards was not much better, which might be explained as follows:

With the steam confection and contact transfer of press boards, flakes' pre-curing was not avoided. Although the condensation heat was helpful for the mat to reach a high temperature level, the condensation water is very harmful for aqueous PF adhesive's curing, because this type of water could destroy the balance of aqueous PF adhesive's curing reaction. Acetic acid that is the main hydrolysate of the self- hydroxylation of flakes is very harmful for alkalescent PF adhesive's curing reaction.

Effects of saturated pressure on panel bending properties

Impacts of saturated pressure on MOE and MOR of flake-boards were very significant, and within the range of the test, when saturated pressure increased, MOE and MOR of panels decreased. As recounted above, a more even density distribution along the panel thickness can be gained under the high temperature of SIVP, which results in a lower MOE and MOR than that of the CHP. The higher the saturated pressure is, the more drastic and quick the flakes' plasticization, and the lower the MOE and MOR of boards is.

Effects of saturated pressure on final thickness and density of boards

Within the range of the test, with the increase of saturated pressure, both the final thickness and density of boards decreased. The latter might be resulted from flakes' self- hydrolyzation under high temperature of SIVP.

Effects of steam time

In SIVP, steam time greatly affects not only the product quality, but also the productivity of flake-boards. Results of this test showed that with the increase of steam time, all IB, TS, MOE and MOR of improved panels decreased, and within the range of 10~35s, the longer the steam time was, the greater the decrease rates of TS, MOE and MOR were, and there was an ascending trend for IB. It was also found that when steam time was from 30s to 50s, the improvement of IB was not apparent. The prior test researched PF adhesive's flow and penetration into Poplar flakes under various SIVP conditions with reflected-fluorescence microscopy and image analysis technique[1], and it showed that the longer the saturated steam spraying time, the stronger the bathing of PF adhesive. This resulted in not only the excessive penetration into flakes, but also the lack of glue, which resulted in a bad IB of boards. From the study of the temperature behaviour in mats during steam-injection-vacuum-pressing[1], a conclusion had been made that within the range of test, 10s of steam time could make the 19mm mat core reach a temperature above 124°C, but here it was found that 10s of steam time was not enough to improve the dimension stability of boards effectively.

In addition, there was an evident interaction between steam time and saturated pressure in SIVP. Generally speaking, it was helpful for dimension stability and internal bond of boards to increase the steam time appropriately under a higher saturated pressure, but it was very bad

for the bending strength of boards. So a balance must be found for the steam time in a comprehensive view of productivity, IB, TS, MOE and MOR of boards.

Effects of hold time

Here, hold time means the time from beginning of closing the steam valve to opening of the vacuum valve. Within the range of this test, the longer the hold time, the bigger the IB, the smaller the TS and the lower the MOE and MOR were. After closing the steam valve, a longer hold time can make a higher mat core temperature and a more thorough curing of glue, which results in a better IB of boards. But on the other hand, a longer hold time means a more thorough plasticization of flakes and a bigger degree of self- hydrolyzation of flakes, which results in a smaller TS and a smaller bending strength of boards. So a conclusion can be made that an appropriate hold time in SIVP is very important for the improvement of TS and IB, but a too long hold time will be harmful for the bending strength of boards, and will prolong the pressing cycle.

Effects of vacuuming time

After hold time, vacuuming time began, that was, exposure of both mat surfaces into vacuum by collecting pipelines to the vacuum valve. With the help of the pressure gradient, rudimental steam and other harmful gases within the mats moved to the outside. Within the range of this study, vacuuming improved the dimension stability of flake-boards effectively, and with the increase of vacuuming time, TS decreased greatly, IB increased slightly, free formaldehyde content decreased, and moisture content of all hot boards decreased. More vacuuming time was no longer significant for the above improvement, and could prolong the pressing cycle.

Optimization

For the sake of getting the appropriate SIVP variables for aqueous PF adhesive Poplar flake-boards, Complex Method was used. The optimizing result was: saturated pressure--0.6MPa; steam time--35s; hold time-- 220s; vacuuming time--107s.
The properties of flake-boards were shown in Table 7.

Table 7: Comparison among test values and predicted values

Index	1 grade	Experiment	Prediction	Deviation
$MOR_{//}$[MPa]	17.2	28.8	30.0	4.0%
MOR⊥[MPa]	17.2	24.5	25.9	5.4%
$MOE_{//}$[MPa]	3400	3833	4492	14.7%
MOE⊥[MPa]	3400	3612	4185	13.7%
IB[MPa]	0.345	0.425	0.467	9.2%
TS[%]	<10	6.98	6.40	9.1%

It showed that the properties of flake-boards produced with the above optimizing variables were excellent. So a conclusion can be made that the properties of flake-boards can be predicted with the equations in Table 6.

CONCLUSIONS

With the optimizing SIVP factors-- saturated pressure, steam time, hold time, and vacuuming time, PF bonded Poplar flake-boards were produced with the SIVP technique successfully, and the properties of panels were excellent. The regression equations of experimental indexes were obtained and could be used to predict the properties of flake-boards produced with SIVP technique.

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The effect of temperature and relative humidity to the colour and moisture content of poplar clones' wood

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ABSTRACT

Plantations deliver the raw material in relatively short time for the wood working industry, including timber for construction, panel products, furniture, and pulpwood for paper. Furthermore, plantations can supply fuelwood and fodder, provide soil and water conservation, wind protection, and biological diversity conservation, combat desertification, rehabilitate degraded land, etc.

In Hungary the role of plantations is gaining more and more on importance, because there are free areas for the plantations, as agricultural land was exempted from cultivation. Up-to-date managed plantations deliver proper raw material for the wood working industry, as important properties of wood show lower variability compared to trees grown in natural forests. Through improvement specific wood properties can be enhanced (strength, growth rate, etc).

Because of their importance in Hungary the presented research work is focussing on two different hybrids *P. x euramericana* 'I-214' and *P. x euramericana* 'Pannonia'.

Simulated drying experiments at different temperatures were carried out in climate chambers to assess the effect of drying temperature on the colour of the investigated wood species, as this property is influencing the value of the end product considerably. Other important aim was to develop mathematical models to predict the colour change as a function of moisture content and temperature.

Relationships of bending properties of poplar clones with knots

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ABSTRACT

In Hungary the importance of forestry and wood industry of poplars is considered to be quite significant, its area ratio is over 10 % and gross yield ratios is 16 %. According to this fact it is one of the most important fields of wood industry research in Hungary. The value of wood materials of different poplars and hybrid poplars is lower than for pines, depending on several reasons such as the structure of tissue, low density etc. Certain hybrid poplars clones have higher density ρ>0,400 g/cm^3, and because of their certain properties they can be used in utilizations which are similar to utilizations of pines such as structural wood materials.

The utilization of wood materials is limited significantly by wood defects. The most important of these is the presence of knots that has a strong influence on the mechanical properties of the material. In terms of structural wood, knots are considered the most critical type of defect. Increasing knot area ratios and knot diameter ratios result in decreasing bending strength (MOR) and modulus of elasticity (MOE) values. This decrease may amount to as much as 40-50%. The aim of the research is to reveal the effects of knots on bending qualities of certain poplar clones such as bending strength and modulus of elasticity similarly to the characteristics of Scots pine.

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Visual and mechanical grading of poplar wood for glued laminated beams

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Keywords: Visual grading, mechanical grading, poplar wood, laminated beams, EN14081

ABSTRACT

Woody biomass from poplar plantations remains one of the most important resources for the wood processing industry market in several countries. As a fast-growing species, poplar enhances the possibility to cover increasing wood demands. Changing industrial requirements and the introduction of new poplar clones necessitates a continuous monitoring of wood quality in respect of possible end-uses. Wood is formed by a living tree with an annual growth-cycle, resulting in an annually fluctuating growth in width and height, which is dependent on site conditions and influenced by age. Consequently, wood properties can show a large variation between and even within the individuals of the same clone. This may affect the overall wood quality and its final utilisation.

The produced poplar wood is light, usually with a density between 360 and 540 kg/m³, and quite strong resulting in a high strength-density ratio. This provides poplar sawn wood with some specific technical advantages in light construction applications.

In this study the potential of two poplar clones 'Ogy' and 'Gaver' (both *P. deltoides x nigra* crossings) was evaluated envisaging the production of glued laminated beams. All lamellae were graded, both visually and mechanically in at least 3 grades. Laminated beams were produced using three different types of glue in three different lay-out types for the five lamellae counting laminated beams.

'Ogy' and 'Gaver' have a very similar average wood density. The visual grades are mainly based on the presence of knots. For both clones, no significant correlation could be detected between the visual grade and the Modulus Of Elasticity (MOE) determined in four-point bending test. Even when density was added to the correlation matrix, no trends were discerned. This limits the use of visual grades for poplar wood, especially when aiming at higher strength grades, which can only be retrieved by mechanical testing. The mean MOE is higher for 'Ogy' but the standard deviation is lower for 'Gaver'.

Beams glued with a two component isocyanate adhesive showed significant lower bending strength in comparison to the one component poly-urethane and phenol-resorcinol-formaldehyde bonded beams. The strength evaluation of the beams resulted in higher values than could be predicted, based on the individual properties of the lamellae.
The absence of a useful correlation between density, MOE and the bending strength will also limit the possibilities of an optimal mechanical grading. Secondary effects as local slope of grain or fibre length variation (e.g. linked to juvenile or tension wood) will need to be included in the grading of poplars when an efficient use of these fast growing species in load bearing applications is envisaged.

INTRODUCTION

Woody biomass from poplar plantations remains one of the most important resources for the wood processing industry market in several countries. As a fast-growing species, poplar enhances the possibility to cover increasing wood demands. Changing industrial requirements and the introduction of new poplar clones necessitates a continuous monitoring of wood quality in respect of possible end-uses. Wood is formed by a living tree with an annual growth-cycle, resulting in an annually fluctuating growth in width and height, which is dependent on site conditions and influenced by age. Consequently, wood properties can show a large variation between and even within the individuals of the same clone. This may affect the overall wood quality and its final utilisation.
The produced poplar wood is light, usually with a density between 360 and 540 kg/m^3, and quite strong resulting in a high strength-density ratio. This provides poplar sawn wood with some specific technical advantages in light construction applications.
Overall, timber is advantageous in constructions because it can be applied in a sustainable way, it provides a pleasant indoor environment and it is considered an efficient building material. However, timber is not associated as a high performance building material. Due to the fact that wood is a grown material, its properties can not be designed by recipe. In consequence, wood is a complex building material requiring specific expertise in its application. The estimation of the performance of a timber structure is associated with large uncertainties (loads, resistances, degradation processes, service life,…). Modern design codes are Load and Resistance Factor Design (LRFD) formats and are referred to as semi-probabilistic models. Partial safety factors are established and calibrated to provide similar failure probability over the different design equations. This calibration is very sensitive to representation of the load and the resistance (material dependent). However, modelling the timber material properties must overcome several difficulties. Timber is a graded material and grading is performed considering reference material properties. These properties themselves are depending on size, time (in respect to loads and moisture content) and type. As such, the whole modelling approach needs to carefully assess the different sources of uncertainties (natural variability, model uncertainties or statistical uncertainties).
Timber grading is used to point out and control a number of the uncertainties. The objective of timber grading is to divide a population of non graded timber in sub-populations that will fulfil certain requirements in respect to material properties. The attached strength class system specifies these requirements in regard to the bending strength, stiffness and density of the material at hand. It is very important to keep in mind that all other properties are estimated based on the set properties of the grade!

The complex process of timber grading can be presented as simply as regression between an Indicating Property (IP) and the Property Of Interest (POI).

In this study the potential of two poplar clones 'Ogy' and 'Gaver' (both *P. deltoides x nigra* crossings) was evaluated envisaging the production of glued laminated beams. All lamellae were graded, both visually and mechanically. Laminated beams were produced using three different types of glue in three different lay-out types for the five lamellae counting laminated beams.

EXPERIMENTAL METHODS

A total of 8 trees from two clones, both *P. deltoides x nigra* (DxN) hybrids, were felled in a multi clonal poplar plantation in Grimminge (Belgium): four 'Gaver' and four 'Ogy'. The site had a sandy to loamy sand soil with good drainage (Classification code Sdp within the Belgian soil classification). The planting distance was 8 by 8 meter. Trees were selected in respect of their diameter at breast height. Within the multi clonal stand all trees were measured and the diameter distribution per clone was drawn-up. For each clone, one tree out of the 25-percentile, two out of the 50% percentile and one tree out of the 75% percentile were selected. Trees that were suspected to suffer from border effects, e.g. standing near the border of the site or near a dead tree, were excluded. The trees were 21 years old and their mean circumference at breast height was 175 cm for 'Gaver' and 182 cm for 'Ogy'.
These clones were selected because 'Ogy' and 'Gaver' have very similar average wood density. As density is a good indicator of most physical and mechanical properties of poplar wood (De Boever *et al.* 2007) it is expected that both clones can be graded similarly.

Sawing and drying

From each stem, three to four stem pieces of two meter were sawn in an optimal pattern to obtain as much batons as possible (high yield). Freshly sawn beams had dimension of 2000x95x52 mm. Only full dimension batons were used (excluding wane). The beams were dried to an end-moisture content of 10%. Results of the drying experiment were reported earlier (De Boever *et al.* 2005).
The beams were further divided into four lamellae for the production of laminated beams. These lamellae had final dimension of 1400x30x18 mm. Out of the large batons also four specimens were sawn for the determination of Modulus of elasticity and Modulus of rupture in a four-pint bending test according to the European standard EN 408. These specimens can be used to establish a link between MOE and MOR in bending for the lamellae that can not be individually be loaded to maximum load. During the first processing the dimensions were about 10% more than indicated above. Final planning was only done within 12 hours prior to the gluing of the lamellae, to minimize interference of uprising fibres or large tension wood areas.

Grading

The main goal was to grade the relatively small lamellae visually as well as mechanically. As the lamellae were small and had limited number of defects, it was expected that correlations between defects (and density) and mechanical properties (Modulus of elasticity) can be established. A complementing measurement of the respective MOE values by a four-pint bending test (EN 408) is necessary in establishing this link. Furthermore, the smaller test specimens were used to link the MOE values to a maximal load described by the modulus of rupture.

For the visual grading, no classes were set in advance. All lamellae were evaluated individually and two main characteristic values were measured. The most important factor to account for the loss of strength is the presence of knots. All knots were measured in regard to their size as well as their exact position within the lamella. Based on this information the Knot Area Ratio (KAR), which expresses the total knot area as a percentage of the respective area of the lamella, could be calculated. Next to the KAR also a surface percentage was estimated of the tension wood occurrence. This was indirectly done by measuring the amount of woolliness surface. This was executed between sawing and planning to final dimensions, as the woolliness surface otherwise would influence the gluing performance. When a link can be established between the visual defects and the respective mechanical behaviour, visual grades can be discerned.

Based on the distribution of the MOE values of the individual lamella, three grades were separated. The lamellae into the lower 20% percentile were ranked as C-grade, while the upper 20% percentile was ranked as A-grade. The other lamellae were assigned to the B-grade. This ranking was done per individual clone. The grades were used to have different built-up designs for the laminated beams.

Production of the laminated beams

The laminated beams were produced using an experimental press. Pressure is regulated with pistons every 20 cm to ensure a uniform pressure. Fig. 1 gives a view of the press used in the experiment.

Figure 1: Experimental press used for the production of laminated beams with regulating pistons every 20 centimetres.

Three commercial glue types for constructive assembly were evaluated for the production of poplar laminated beams.

1. One component Poly-urethane (PUR) "Prefere 6000 – Dynea"
2. Two component Isocyanate (ISO) "Prefere 6151 – Dynea"
3. Phenol-resorcinol-formaldehyde (PR) "Dynosol S205 – Dynea"

The glues were used according to the specifications of the manufacturer to establish a connection for constructive performance. The glue was applied manually and the amount of glue was controlled using precision balances (0.01 gram). Pressure, pressure time and amount of glue were adopted in function of the mean density of the wood and the moisture content.
In function of the discerned grades of the lamella, three types of built-up for the laminated beams were made for every glue type. Several authors have demonstrated that the central part of the laminated beams is subjected to much lower stresses (tension, compression or shear) compared to the outer lamellae. Therefore, lower grades can be used in the body of the beams without significant loss in strength. The set-up as specified in Table 1 could help to sustain these findings.

Table 1: More specific built-up for the three five-lamellae glued laminated beams.

	Type III	**Type II**	**Type I**	**Type I***
Lamella 5	Grade B	Grade B	Grade A	Grade A
Lamella 4	Grade B	Grade C	Grade B	Grade A
Lamella 3	Grade B	Grade C	Grade B	Grade A
Lamella 2	Grade B	Grade C	Grade B	Grade A
Lamella 1	Grade B	Grade B	Grade A	Grade A

As such (three beam lay-outs, three glue types, six repetitions) 54 glued laminated beams were produced per clone. The remaining A-grade lamellae were used to produce a limited number of type I* laminated beams.

After curing and conditioning at 60% relative air humidity, the beams were tested according to European Standard EN 408 using a four-point bending test. Modulus of elasticity, modulus of rupture and failure type were registered.

Statistics

For the statistical analysis, ANOVA was used. Significant difference between mean values was pointed out by a post hoc Duncan test. Significant differences are always pointed out at the p=0.05 level, unless otherwise specified.

RESULTS AND DISCUSSION

Grading

For the visual and mechanical selected features as density, KAR, MOE, MOR, tension wood and moisture content are used. Table 2 provides an overview of these selected parameters for the two investigated clones ‘Gaver’ and ‘Ogy’ with respect tot their mean values as well as the recorded variability.

Table 2: Mean values and standard deviations of density (kg/m³), KAR (%), MOE (N/mm²), MOR (N/mm²), tension wood occurrence(%) and wood moisture content(%) for the population of lamellae for both investigated poplar clones ‘Gaver’ and ‘Ogy’ and statistics by Anova/Duncan.

	Ogy	**Gaver**	**Statistics Anova/Duncan**
Density [kg/m³]	425 ± 35	422 ± 33	aa
KAR [%]	0.6 ± 1.1	0.6 ± 0.9	aa
Moisture content [%]	8.2 ± 0.2	8.3 ± 0.3	aa
Tension wood [%]	10.5 ± 0.8	5.5 ± 0.5	ab
MOE [N/mm²]	8200 ± 221	7560 ± 126	ab
MOR [N/mm²]	68.2 ± 7.4	71.8 ± 6.7	aa

The moisture content of all lamellae is very uniform and for both clones equal to a mean value of 8%. Moisture content can have an influence on the glue performance or in differences between glue types. However, in this case the uniformity of the moisture content will equalise this effect over all lamellae.

The mean density for both clones does not differ significantly. Both clones have a relatively high density with their mean around 420 kg/m³ (De Boever *et al.* 2007, Hernandez *et al.* 1998, Pilura *et al.* 2005). It can be expected that differences in grading are due to differences in defects present in the lamella (knots, tension wood).

The mean values for KAR recorded do not point out differences between these clones. The presence of knots can be reduced to a management effect. In this case, it concerns a non managed multi clonal stand. As such, differences could be seen as an evaluation of the natural pruning ability. Despite the mean values do not differ, differences were noticed between 'Gaver' and 'Ogy' and pointed out by a box plot (Fig. 2) of the individual KAR values (Defect free lamellae were excluded from the graph).

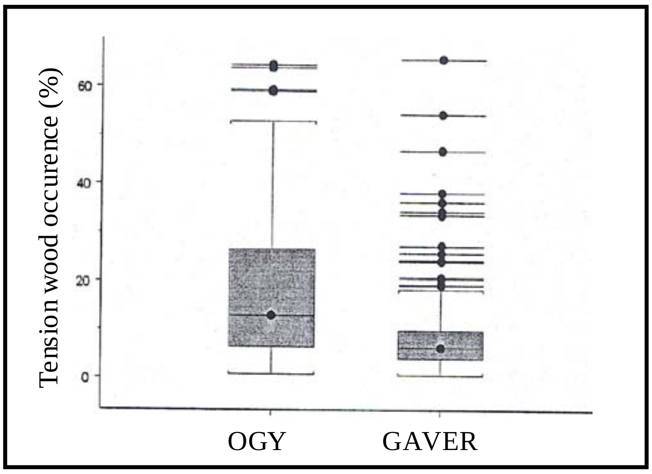

Figure 2: Box plot of the KAR values for 'Gaver' and 'Ogy' excluding the defect free lamellae

'Ogy' has more defect free lamellae. As the lamella with knots is concerned, 'Gaver' has clearly less knots present, but the individual knot size is bigger. The more evenly distributed knots in 'Ogy' can partly explain the higher observed MOE values (Table 2) at the same density.

Tension wood occurrence was indirectly estimated on the basis of the presence of a woolliness surface. This was done between the sawing of the lamellae and the planning towards final dimensions (within 24 hours before gluing). 'Ogy' shows a significant higher amount of tension wood (10%), having double the amount of the clone 'Gaver' (5%) (Fig. 3). However, these differences are significant, the influence is very limited as practical use (industrial implementation) is concerned. A presence of 10% of tension wood is low to very low for poplar wood (Badia *et al.* 2006, De Boever *et al.* 2007, Hernandez *et al.* 1998). No link can be established between tension wood occurrence and strength values. Contrary, 'Ogy' having the higher tension wood proportion, shows also higher values of MOE. This is somewhat contradictory as stiffness is associated with the crystalline cellulose fibrils.

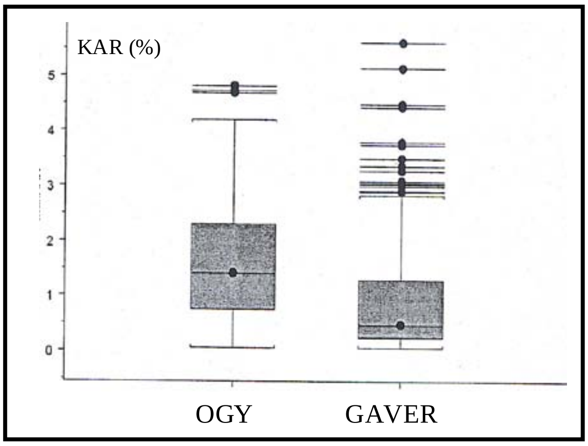

Figure 3: Box plot of the tension wood occurrence for 'Gaver' and 'Ogy' excluding the defect free lamellae

As rigidity (expressed by MOE) is concerned 'Ogy' shows significant higher values compared to 'Gaver'. These distributions were used to separate three grades of lamella, individual per clone. However, to be able to establish visual grades (based on defect as tension wood and knot occurrence) a significant correlation is required between the defect occurrence and the specified mechanical properties.

Fig. 4 gives the relationship between KAR and specific MOE (MOE divided by density) for the clone 'Ogy'. No relation could be established. Even when only the defect free lamellae are considered (KAR=0), a large variation is displayed (Fig. 4). This clearly points out that in poplar wood (and more general in hardwoods) secondary effects are in play. Explaining factors can be fibre length, micro fibril angle as well as local slope of grain. Further research should clarify this phenomenon. The same statements can be made for the clone 'Gaver'. Recently, Enderle (2007) also reported this bottleneck of visual grading for poplar wood in Germany.

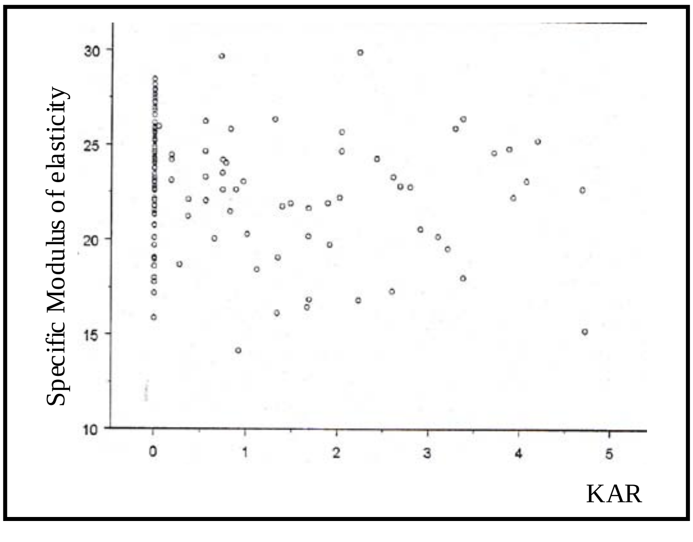

Figure 4: Scatter plot of KAR versus specific MOE (MOE/density) for the clone 'Ogy'

Moreover, no correlation exists between MOE and MOR values. Although 'Ogy' has significant higher MOE values compared to 'Gaver', their MOR values do not differ (Table 2). When compared to the grading requirements set in EN 338, it is clear that the MOR values are the limiting factor and not density or MOE.

It can be stated that visual grading of poplar wood does not sufficiently point out and control a number of the uncertainties used in modern design codes.
Mechanical grading can be conducted based on MOE. However, it should be kept in mind that MOE has low prediction value as the strength (MOR) is concerned. More sophisticated grading systems should be developed taking into account local slope of grain of micro-fibril angle. At this moment, no accredited systems according to EN 14081 are available for such purpose.

Laminated beams
The laminated beams were evaluated according to the European standard EN 408. As described above the test results were adjusted according to the standards EN 384 and EN 14080 for the comparison with the reported grades in European standard EN 338.

Only the first preliminary results are presented here. The beams can be classified according to the features of the individual lamellae (as tested for the grading) or based on the performance of the glued laminated beam itself (destructive testing). Table 3 and 4 give the classification for both systems for 'Ogy' and 'Gaver' respectively. In the table the type of beam (built-up) and the used glue is indicated. Based on the built-up structure it is expected to find that type II ≤ type III < type I as strength is concerned (per glue type).

Table 3: Classification of the laminated beams, based on beam properties and based on the properties of the individual lamellae (EN 338) with indication of beam type and used glue for the clone 'Ogy'

Type	Glue	Classification based on Beam properties	Classification based on lamella properties
II	PUR	Not classified	Not classified
II	ISO	GL 24	Not classified
III	PUR		
	ISO		
II	PR	GL 28	GL 24
III	PR		
I	ISO	GL 32	GL 24
	PR		
	PUR		

Table 4: Classification of the laminated beams, based on beam properties and based on the properties of the individual lamellae (EN 338) with indication of beam type and used glue for the clone 'Gaver'

Type	Glue	Classification based on Beam properties	Classification based on lamella properties
III	ISO	Not classified	Not classified
II	ISO	GL 24	Not classified
	PUR		
	PR		
III	PR		
III	PUR	GL 28	GL 24

I	ISO		
	PUR		
I	PR	GL 32	GL 24

As expected type I beams are clearly stronger than the other built-up lay-outs, irrespective of the glue type and the clone. This poplar wood clearly shows the potential to produce structural beams up to the GL 32 class in EN 338.

The two component isocyanate glue is linked to the lower strength classes compared to the other two glue types applied. The predicted strength based on the properties of the individual lamella lead to an underestimation of the potential.

CONCLUSIONS

This paper discussed the potential to use the wood of two Belgian poplar clones for the production of glued laminated beams.

The visual grades are mainly based on the presence of knots. For both clones no significant correlation could be detected between the visual grade and the Modulus of elasticity (MOE) determined in four-point bending test. Even when density was added to the correlation matrix, no trends were discerned. This limits the use of visual grades for poplar wood, especially when aiming at higher strength grades, which can only be retrieved by mechanical testing. The mean MOE is higher for ‘Ogy’ but the standard deviation is lower for ‘Gaver’.

The absence of a useful correlation between density, MOE and the bending strength will also limit the possibilities of an optimal mechanical grading. Secondary effects as local slope of grain or fibre length variation (e.g. linked to juvenile or tension wood) will need to be included in the grading of poplars when an efficient use of these fast growing species in load bearing applications is envisaged.

It can be stated that visual grading of poplar wood does not sufficiently point out and control a number of the uncertainties used in modern design codes.

Mechanical grading can be conducted based on MOE. However, it should be kept in mind that MOE has low prediction value as the strength (MOR) is concerned. More sophisticated grading systems should be developed taking into account local slope of grain of micro-fibril angle. At the moment no accredited systems according to EN 14081 are available for such purpose.

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The two component isocyanate glue is linked to the lower strength classes compared to the other two glue types applied. Predicted strength based on the properties of the individual lamella lead to an underestimation of the potential.

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Optimizing design for glulam beams made of modified wood of fast-growing poplar

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Keywords: Fast-growing poplar, glulam beam, calculating model, optimizing model mathematic model, optimizing design

ABSTRACT

This research focused on modified wood of fast-growing poplar for structural applications. A mathematic model was established in accordance with material mechanics and composite mechanics. The model was proved to be able not only to calculate the stiffness and strength of glulam beam, whose configuration of materials by layer was given in advance, but also to optimize the configuration of materials by layer of the beam on the premise of exceeding certain rigidity and strength. It helps to avoid redundancy of rigidity and strength and save the production cost of glulam beam.

EXPERIMENTAL METHODS

Experimental Materials
- Fast-growing poplar and its modified wood (including ACQ modified wood, PF modified wood and ACQ+PF modified wood)
- ACQ modified wood (M-ACQ): treated by preservative (ACQ)
- PF modified wood (M-PF): treated by initial polymerized phenol-formaldehyde resin of lower viscosity and molecular weight
- ACQ+PF modified wood (M-ACQ+PF): treated by ACQ and PF

Testing Methods
Make glulam beams (rectangular form) with different configurations and layers of different height, using the 4 kinds of materials mentioned above.
The beams were 1950mm x 45mm, while the heights varied according to the height of the layers.
One-component poly-urethane resin was used to glue beams with a glue spreading amount of 200g/m^2.
Pressing method is cold pressing for 24h.

The bending strength (MOR) and elastic modulus (MOE) of beams were tested by method of trisected bending (Fig.1).

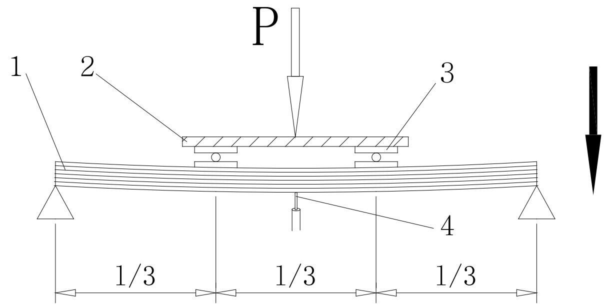


Figure 1: Method of testing glulam beam
1: Glulam beam; 2,3: Distributing device; 4: Sensor

RESULTS AND DISCUSSION

Calculating Model

As long as the properties of elements and joint form are given, the properties of composite can be calculated according to theories in mechanics of composite materials.

The anisotropic glulam beam and its Modulus Of Elasticity is different under axially loading or under bending. The modulus of elasticity in axially loading can be calculated by the law of distribution:

$$E_L = E_{L1}V_1 + E_{L2}V_2 + \cdots + E_{Lk}V_k + \cdots + E_{Ln}V_n \quad (1)$$

Where E_{Ln} is axial elastic modulus of *n*th lamina, and V_{Ln} is its voluminal ratio.

The law of distribution used in equation (1) is on the assumption that each layer is given the same strain when the beam is being loading axially. However, the strain of each layer is different when the beam is bended by getting load perpendicular to the span. The modulus of elasticity in bending should be

$$E_L = \frac{\overline{EI}}{I_y} \quad (2)$$

Where I_y is moment of inertia of the cross section about the neutral axis, and $\overline{EI}$ is bending rigidity.

$$\overline{EI} = \int_A E_x^{(k)} z^2 dA = \sum_{k=1}^{n} E_x^{(k)} I_y^{(k)}$$

Where $E_x^{(k)}$ is axial elastic modulus of the *k*th lamina, and $I_y^{(k)}$ is its moment of inertia about the neutral axis (y-axis).

There are two main factors which lead to the damage of the glulam beam (Christensen 1980):

1) Axial stress

$$\sigma_x = \frac{M E_x^{(k)} z}{\overline{EI}} \quad (3)$$

2) Shear stress between layers

$$\tau_k = \frac{Q\sum_{k=1}^{n} E_x^{(i)} S_i}{\overline{EI}b} \qquad (4)$$

When the axial stress of a certain layer is greater than its tensile or compressive strength parallel to the grain of wood, the beam will be damaged. This also occurs when the shear stress of the glue line between two certain layers is greater than the shear strength between them. Thus axial stress and shear stress between layers should be in accordance with

$$|\sigma_x| \le [\sigma_i] \qquad (5)$$

$$\tau_k \le q_i \qquad (6)$$

In Eq.(5), $[\sigma_i]$ is rating stress of layer, and in Eq.(6), q_i is shearing strength between layers.

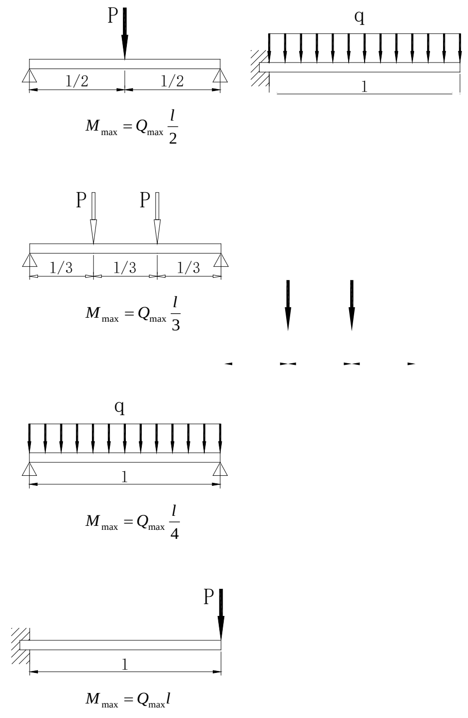
The bending strength of a rectangular formed beam is

$$\sigma_b = \frac{M}{W} = \frac{6M}{bh^2} \qquad (7)$$

There is no definite relationship between moment (M) which gives the axial stress, and area moment (Q) which gives the shear stress of the glue line between layers.

But if the form of the load to the beam is determined, there will be a definite relationship between M and Q. Therefore we can find out which factor leads to the destruction of the beam and the maximum moment the beam can support by comparing Eq.(3) and Eq.(4) and combining Eqs.(5) , (6) and (7).

$$\sigma_b = \begin{cases} M \min\left(\frac{6\overline{E}[\sigma_i]}{bh^2 E_x^{(k)} z}, \frac{3l\overline{E}Iq}{bh^2\sum_{k=1}^{n} E_x^{(i)} S_i}\right) \\ M \min\left(\frac{6\overline{E}[\sigma_i]}{bh^2 E_x^{(k)} z}, \frac{2l\overline{E}Iq}{bh^2\sum_{k=1}^{n} E_x^{(i)} S_i}\right) \\ M \min\left(\frac{6\overline{E}[\sigma_i]}{bh^2 E_x^{(k)} z}, \frac{3l\overline{E}Iq}{2bh^2\sum_{k=1}^{n} E_x^{(i)} S_i}\right) \\ M \min\left(\frac{6\overline{E}[\sigma_i]}{bh^2 E_x^{(k)} z}, \frac{6l\overline{E}Iq}{bh^2\sum_{k=1}^{n} E_x^{(i)} S_i}\right) \end{cases}$$



Model Validation

The following are the mechanical properties results from actual tests and nominal calculations. MOE is Modulus of Elasticity and MOR is Modulus of Rupture or bending strength (Tab.1).

Table 1: Results of actual and nominal MOE, MOR

NO.	MOE[MPa]			MOR[MPa]				
					Not modified		Modified**	
	Actual	Nominal	RE[%]	Actual	Nominal	RE[%]	Nominal	RE[%]
0	5245.15	5493.35	4.73	43.53•	55.34•	27.14	44.27•	1.71
1	8917.82	9132.82	2.41	74.50•	88.86•	19.27	79.98•	7.35
2*	7961.48	7028.23	-11.72	62.74•	82.82▲	32.01	79.91▲	27.37
3	8449.03	8138.32	-3.68	65.48•	84.20•	28.58	67.36•	2.87
4	9121.24	9081.37	-0.44	68.56▲	81.01▲	18.16	73.32▲	6.94
5	9428.73	9078.67	-3.71	55.20▲	61.39▲	11.21	55.25▲	0.09
6	8907.64	9110.18	2.27	56.73▲	64.16▲	13.09	57.75▲	1.79
7	8371.42	9076.28	8.42	55.35▲	56.81▲	2.64	51.12▲	-7.64
8	9524.8	9136.15	-4.08	57.78▲	67.78▲	17.30	61▲	5.57

** When beam #2 was testing, PF resin in layer materials M-PF and M-ACQ+PF was not cured completely. So in calculating MOE of the time is used, which are 7973.83MPa and 6793.02MPa respectively.*
*** Modify the model by means of multiplying axial strength and shear strength respectively by coefficient k_1 and k_2.*
• Ruptured by axial stress, ▲Ruptured by shear stress between layers.   RE: relative error

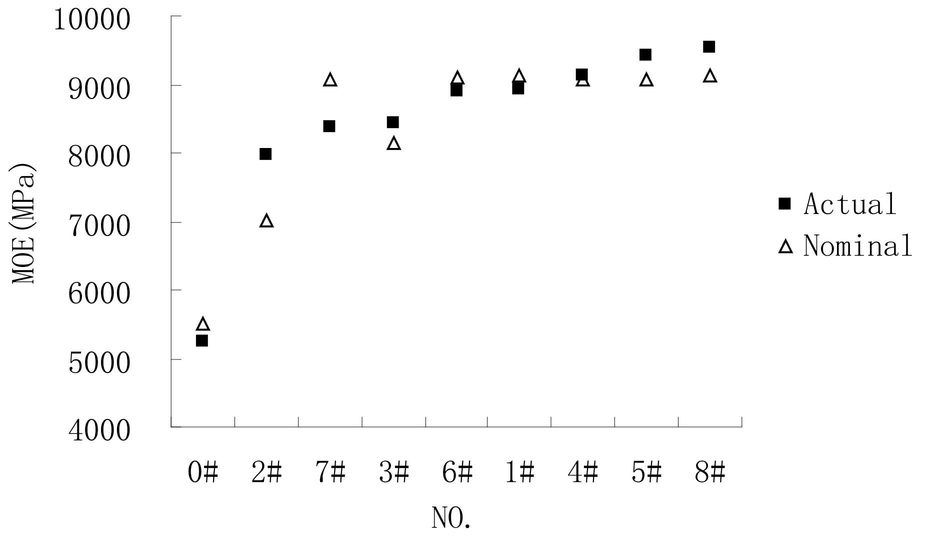


Figure 2: MOE comparison of actual testing and model calculating

Fig.2 shows that MOE of model calculating tally very well with the actual data, and there are only little tolerances under 12%. The rigidity calculating part of the model thus proves veracious and useful.
However, there are obvious discrepancies between actual and nominal value on MOR. The nominal MOR is much larger than actual. That is because during calculation, we did not think enough about negative influence, whether the axial stress strength of lamina is as much as what's tested in advance and if one lamina could be glued to another ideally.
Generally there will be derogations of varying degrees to materials strength when sizes increase. Big sized materials have more disadvantages such as partial disfigurements and discontinuity of glue line.

Keeping this in mind, we multiply axial strength by coefficient k1 and shear strength by coefficient k2 to compensate for strength derogations respectively caused by partial disfigurements and discontinuity of glue line. Then the tolerance can be reduced to allowed band (Tab.1 and Fig.3)

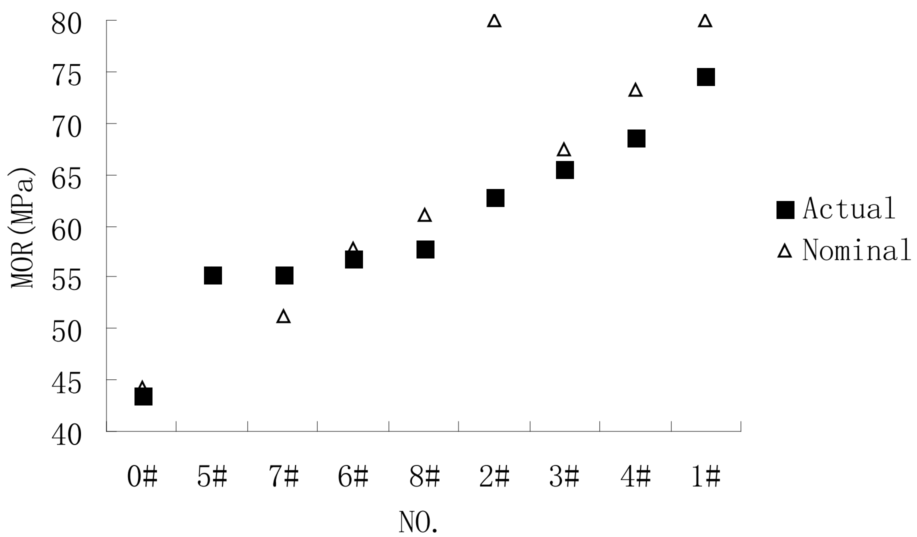


Figure 3: MOE comparison of actual testing and model calculating

Optimizing Model

The optimizing model is founded by VB program in the base of the calculating model which is proof to be correct up front.
This model can optimize the configuration of materials by layer of the beam on the premise of exceeding certain rigidity and strength. It helps to avoid the redundancy of rigidity and strength and save the production cost of glulam beam.

The model works as follows:
(1) Find out the largest number of layers in accordance with the largest height of the beam allowed in the wood structure and the thickness of layer.
(2) List all of the projects of configuration by combining the largest of layers and the kinds of materials.

(3) Calculate the rigidity, strength and cost of the beam by project using the calculating model in VB program.
(4) Find out the configuration of lowest cost and of rigidity and strength meeting the command by comparison.
An optimization example is in Fig.4

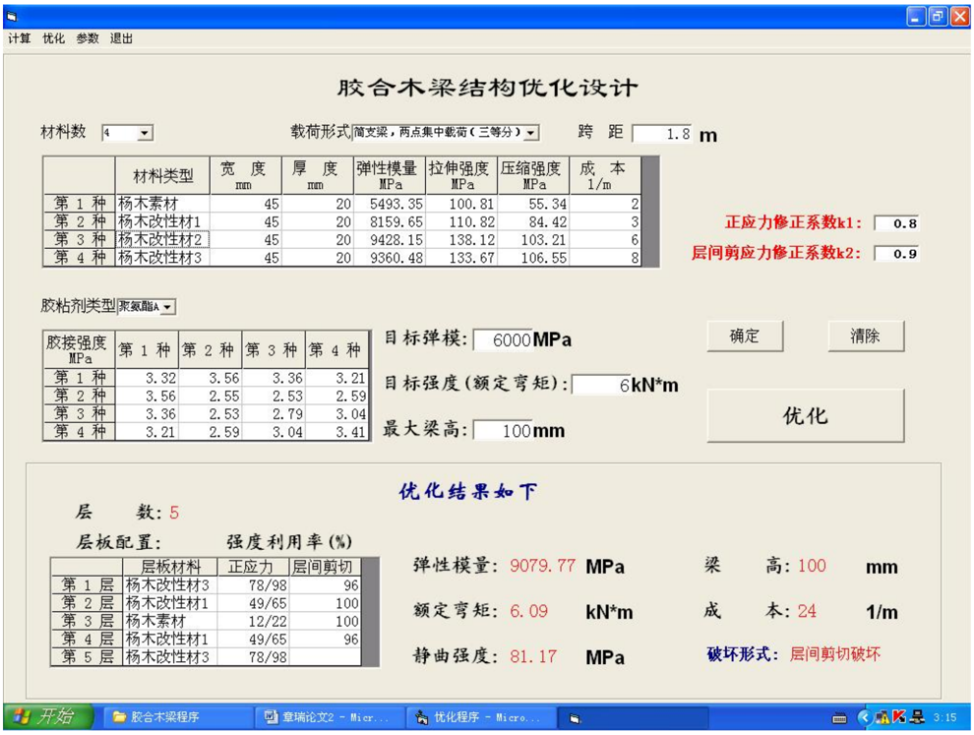


Figure 4: Optimization example and program surface

CONCLUSIONS

Model for calculating rigidity and strength of glulam beam made of modified poplar is proven to be useful. It can almost judge which factor leads to the damage of the beam: axial stress or shear stress. The tolerance can be reduced to allowed band after modifying the model by means of multiplying the axial strength and shear strength respectively by coefficient k_1 and k_2.

Optimizing model can theoretically reduce the configuration of lowest cost and of rigidity and strength meeting the command by comparison. The useful strength ratio (axial or shear stress divided by corresponding strength) on different position of cross section is listed so designers can optimize autonomously.

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Indian willows-based cricket bats of international significance of trade and income

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Keywords: Mechanical properties, export potential, demand and supply

ABSTRACT

Salix popularly known as willow is a diffuse porous hardwood species which occurs in natural stands and grows in the Indian subcontinent from 900 up to 3500 meter above sea level. On account of its excellent wood properties like shock resistance, strength and light weight is it aptly considered fit for the manufacture of sporting cricket bats. It deserves a mention here that the game of cricket is played with great fervor among the commonwealth countries, particularly in India, Pakistan, Bangladesh and Sri Lanka. To develop the choice based on the quality, willows have great reputation in the market for its wood. During 1930s, willows of exotic species were introduced in Indian Himalayas, particularly in Kashmir Himalayas, where its production touches in million per annum (1.2 million in 2003-04). Kashmir manufactured bats on account of its least accessibility to the outside market have not touched popularity and export potential as otherwise it should have been. With this in view a survey was conducted by the author to explore the willow based industrial and market potentials. The mechanical properties taken into consideration by the local manufacturers and also the production status and market trends were studied in Kashmir valley. The present annual turnover of the products from *Salix* in Kashmir is 600 million in Indian rupees. The production is targeted to the demand of the Indian market presently.

The present paper deals comprehensively on need and priorities for the incentives and promotion of the sector and the communities involved in the production and marketing, besides the gaps in the integrated approach to fill the demand and supply.

INTRODUCTION

Salix species (willow / veer) in Kashmir is one of the most famous multipurpose tree species whose almost every part is of some use to the mankind. This wonderful species belongs to the family poplar, that is, Salicaceae under Amentiferae (i.e catkin bearers) of Salicales or Salicinae order. The willows are deciduous trees widely spread throughout Europe, North America, North Africa and Asia. In Northern hemisphere there are about 300 species and

hybrids and only a few in Southern hemisphere. These are plants of temperate regions growing along the water courses, shores, swamps and at higher elevations, where moist conditions prevail. Willow is a diffuse porous hardwood species which occurs in natural stands and grows in the Indian subcontinent from 900 up to 3500 meter above sea level. On account of its excellent wood properties like shock resistance, strength and light weight is it aptly considered fit for the manufacture of sporting cricket bats. It deserves a mention here that the game of cricket is played with great fervour among the commonwealth countries, particularly in India, Pakistan, Bangladesh and Sri Lanka.

To develop the choice based on the quality, willows have great reputation in the market for its wood. During 1930s, willows of exotic species were introduced in Indian Himalayas, particularly in Kashmir Himalayas, where its production touches in million per annum (1.2 million in 2003-04). Kashmir-manufactured bats on account of its least accessibility to the outside market have not touched popularity and export potential as otherwise it should have been. With this in view a survey was conducted by the author to explore the willow based industrial and market potentials. The mechanical properties were taken into consideration by the local manufacturers and also the production status and market trends were studied in Kashmir valley. The present annual turnover of the products from Salix in Kashmir is 600 million in Indian rupees. The production is targeted to the demand of the Indian market presently. The willow of Kashmir is the primary raw material for the sports industry (for cricket bats mostly) and wicker works like baskets, flower pots, fruit pots weaving etc. Salix alba c.v. calve (Syn. Salix caerulea Smith) is commonly referred as cricket bat willow.

In the state of Jammu & Kashmir in India, most of the willows grow naturally from the seed on wet grounds along the stream banks (as in Ladakh) or these may be cultivated with ease from cutting and pollards of 3m or more length or straight branch cuttings.

General requirements for manufacturing of cricket bats in India are as follows:

Moisture content of the clefts should be between 8-12% only.

Density of the timber at 12% moisture content should not be less than 400 kg/m3 and not more than 550 kg/m3.

Straightness of grains of the clefts should be smooth and of straight grain. The maximum inclination of the grain, spiral or diagonal, shall not exceed 1 in 20.

Size of the cleft should be about 70 cm. However, smaller size may be accepted for small size bats. The cleft shall have a triangular cross section with base about 12.5 cm and the other sides about 10 cm each.

Defects: Clefts should be free from sapwood, gum, veins, spongy heart or other forms of rot, shakes and splits, loose grain, gelatinous fibres, compression wood and pitch pockets. There should not be knots on the face and the edges of the cleft. Knots up to 15 mm are permissible on the back of the cleft provided they are not very near the edge.

Ring width: The width of the rings on the cross section should be between 3 and 8 mm.

MECHANICAL STRENGTH REQUIREMENTS

S. N.	Characteristic features	*Strength Value*
i.	*Fibre stress (FS) at limit of proportionality*	*23 N /mm ^{2}*
ii.	*Equivalent fibre stress at maximum load (modulus of rupture)*	*49 N / mm ^{2}*
iii.	*Modulus of elasticity (MOE)*	*44 X 10^2 N/ mm^2*
iv.	*Work up to limit of o proportionality*	*0.6 X 10^{-2}N/ mm^2*
v.	*Hardness radii or tangential (Indentation Test)*	*2500 N*
vi.	*Toughness or brittleness (Izod test)*	*150mm/N*

TRADE

The cricket bat industry in Kashmir consists of a number of small scale units spread mostly near a small town named Sangam lying along the border of districts Anantnag and Pulwama. Almost every unit was visited for the present study. The results show that production from all the units exceeds 20 Lakh (2 million) bats per year in addition to small size bats made for playing rubber ball at smaller levels. The turnover per year exceeds millions. The marketing of the products was found to be all over India with Delhi, Kolkata, Meerut and Mumbai as the main centres of sale. It was studied that so far no unit was exporting its product. Although there is some progress on its export potential and prospect.

NEED AND PRIORITIES

I. Need for the characterisation of sites for introduction of the species in larger area.

II. Studies on the plantation technique, machining work and post-harvesting and preservation methods.

III. Involvement of communities and development of their traits and skills.

IV. Market trend cost/supply/benefit/profit to the people in the field engaged for the management of plantation, transportation and in the manufacture.

V. International market practicality in cricket playing (Commonwealth) and potential countries (Holland, Canada).

VI. Improvement and development of tools and machinery for pre- and post-harvesting saw materials for cricket bats.

The multifunctional composite material made of Poplar Veneer and Expanded Polystyrene

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Keywords: Poplar veneer, expanded polystyrene, composite board

ABSTRACT

In this paper the poplar veneers used as surface layers and the expanded polystyrene were bonded by UF, MDI, PVAc and modified PVAc to manufacture a new multifunctional composite board. At the same time, the optimum production process was gained by experiments. The bond strength and heat conduction coefficients and sound absorption coefficients of the board were measured; the results showed that it was very suitable for internal wall board in thermal insulation and sound insulation and decoration.

The rapid increase of energy consumption has been a bottleneck that restricts the steady rise of the economy; the energy conservation has attracted more and more attention in worldwide range. At the same time as the nature wood resources reducing, exploring and utilizing of planted forest resources is required in current circumstances. In this paper a composite board was researched, which was made by combining poplar veneers with expanded polystyrene.

SELECTION OF TEST MATERIALS

The foam material

After referring to information and analyzing (Table 1), expanded polystyrene (EPS) was considered to be suitable for the middle layer of heat insulation materials, because the heat conduction coefficient is small and the thermal insulation performance is 21 times that of the normal brick (Li 2001). While it also possesses leveling off and strength and is easy to be slicked, the price is lower. 2.6mm, 1.5mm and 0.5mm are 3 kinds of thickness which were tested and used as core layer of composite board.

Poplar veneer

The poplar was planted in a growing forest in the north of Jiangsu province, and the veneers made of this poplar were used as the surface layers of our composite board. As to the wood characters of poplar are some flexible and less strength, the veneers of poplar were arranged in 2 or 3 layers with a thickness of 1.4mm, the size was 40×40mm.and it was dried to around 8% moisture content.

Table 1: Heat transmission coefficient of structure materials

Material	Heat transmission coefficient [W/m·K]	Thickness in the same heat insulation effect [mm]
Normal brick	0.698	860
Concrete	0.349	380
Expanded diatomite	0.052	50
Mineral cotton	0.034 – 0.037	45
Expanded polystyrene (EPS)	0.032 – 0.037	40
Polyurethane foam	0.017 – 0.025	25

The adhesive

Due to the EPS and veneer belong to different polarity; the adhesive must be able to glue the nonpolar EPS and the polar wood. At first, the adhesives of urea-formaldehyde resin (UF), Isocyanate (MDI), polyvinyl acetate resin (PVAc) and modified PVAc were tested to glue the two boards. Those adhesives were suitable for cold pressing and hot pressing. The EPS is only able to bear a temperature of less than 70°C, a higher temperature may lead to melting or distortion. So the composite tests were executed in the form of cold pressing or hot pressing with a temperature of 60°C to 65°C. After bond pressing, the bond effect of the different adhesives of composite board was inspected by dipping it in hot water at the temperature of 63°C for 3 hours. The results show (Table 2) that only the MDI erode the EPS slightly, the UF and modified PVAc had a better bond performance and their cost is lower.

Table 2: Effect of different adhesives on bonding of composite board

adhesives	Effect on the EPS	Dipping in water
UP	Without effect	not deguming
MDI	Eroding slightly	not deguming
PVAc	Without effect	delamination
Modified PVAc Ⅰ	Without effect	not deguming
Modified PVAc Ⅱ	Without effect	not deguming

THE EXPERIMENT OF MANUFACTURE COMPOSITE BOARD

The main equipment in this experiment of composite board manufacture, was a press. The adhesives were UF, PVAc and modified PVAc. In order to speed up the adhesive curing velocity, the hot pressing was adopted and the temperature of the platen was set at about 60°C which the EPS can withstand.
The glue was brushed by hand with a single side glue-spreading quantity of 100 to 150g/m^2 .

Method 1: The composite board was bonded together by the adhesive once pressing. The assembly was EPS as the core layer and 2 layers of veneer assembled with the grain direction at a right angle to the adjacent layer.

Method 2: First, 2 layers of veneer with the grain direction at a right angle to the adjacent layer, were bonded into plywood by hot pressing. Then, the plywood as surface layers and the core layer EPS were bonded into a composite board.

The EPS can only bear a pressure less than 0.3Mpa. In order to prevent the EPS from being squashed by a higher pressure thus leading to lower thermal insulation performance, the thickness gauges were used to control the thickness of the composite board. The cold and hot pressing parameters of experiments can be found in Table 3.

Table 3: Bond pressing processing parameters of experiments

No.	Thickness of EPS [mm]	Adhesive	Glue-spreading [g/m^2]	Pressing Temp. [°C]	Pressing time [h]	Remarks
1	26	PVAc	260	65	1.5	Method 1
2	26	PVAc	300	Normal Temp.	12	Method 1
3	26	UF	280	70	1	Method 1
4	26	PVAc	260	Normal Temp.	72	Method 1
5	26	UF	280	65	1	Method 1
6	26	UF PVAc	280 300	65	1	Method 2
7	15	UF	280	60	1	Method 1
8	5	UF	280	60	1.5	Method 1
9	5	UF PVAc	280 300	60	1	Method 2

Note: Difference of hot pressing temperature due to fluctuation of press temperature.

In Table 3, the UF was suitable to manufacture fiberboard, the UF was suitable for manufacture plywood. The temperature was low, so to speed up the curing velocity; a firming agent (ammonium chloride solution) content was added, about 1.5%.

PERFORMANCE TESTS OF THE COMPOSITE BOARD

The bonding performance, mechanical strength, heat conduction coefficient and sound absorbing coefficient of the composite boards were measured.

Bonding performance

These composite boards were different from other wood-based panels, for they can't bear high temperatures, so we couldn't do an internal bond strength test. Instead, the boards were sawn into 5×5cm small samples and dipped in water for 3 days and then the bond effect of the boards was observed, as given in Table 4.

In Table 4, No.1 and No.4 had a better bonding effect between the veneers and the EPS than between veneers. The reason was that veneers are not waterproof when bonded by PVAc and PVAc. Only when using UF, the bonding effect between the veneers was better than between the veneer and the EPS. The adhesive of No.6 and No.9 was the best, unifying the merits of the above two adhesives, and both the veneers and EPS with veneer were bonded first-class. First two veneers were bonded into plywood by the UF and the temperature at 110°C, then the plywood as surface layer was bonded together with the EPS by PVAc at a temperature of about 60°C. This method can obtain a solid bond quality. Cold pressing for 12 hours after hot pressing would be better to make the adhesive solidifying entirely.

Table 4: Bonding effect of boards after dipping in water

No.	Thickness of boards/mm	Bond effect
1	26.01	Delamination between veneers
2	26.74	Delamination between veneers
3	25.93	Delamination between veneers and EPS
4	25.75	Delamination between veneers
5	20.47	Delamination between veneers and EPS
6	26.01	Bond well
7	14.27	Delamination between veneers and EPS
8	7.44	Delamination between veneer and EPS
9	8.94	Bonding well

Mechanical strength

The mechanical strengths were tested by a multipurpose wood testing machine, according to the standard “Test methods of evaluating the properties of wood-based panels and surface decorated wood-base panels” GB/T17657-1999. The results can be seen in Table 5.

Table 5: Mechanical strength of the samples

No.	Thickness [mm]	Compression ratio [%]	MOE [MPa]	MOR [MPa]	Max. load [kN]
1	26.01	18.75	287.87	2.76	0.21
2	26.74	16.43	233.36	2.79	0.22
3	25.93	19.19	311.80	2.97	0.22
4	25.75	19.56	171.94	1.93	0.15
5	20.47	36.03	477.29	2.80	0.13
6	26.01	18.72	313.62	3.00	0.22
7	14.27	19.7	506.72	4.27	0.10
8	7.44	29.81	276.51	6.34	0.11
9	8.94	15.66	536.13	8.85	0.13

In Table 5, the more compression ratio, the bigger the modulus of elasticity. The modulus of elasticity and the bending strength of No.2 and No.4 were least, especially No.4 by cold pressing. In addition, the mechanical strength of samples, hot-pressed twice, was higher than those with the one time pressing technique. The thickness of EPS as core layer was an important factor: the less thickness of the EPS in the composite board, the higher the mechanical strength. For mechanical strength of wood is higher than that of EPS, the less thickness of the EPS, the more content of wood relative, the higher the mechanical strength.

Heat conduction coefficient

The heat conduction coefficient indicates the material performance of heat transmission. In construction, heat conduction coefficients less than 0.14W/m·K is defined as high quality thermal insulation material (Jian 2002). The heat conduction coefficients were measured by a HC-074 steady heat conduction coefficient testing instrument, the samples size were 20×20 mm and the results can be seen in Table 6.

Table 6: Heat conduction coefficient of samples

No.	Thickness [mm]	Thickness of EPS [mm]	Compression Radio [%]	Heat conduction coefficient [W/m·K]
1	26.01	26	18.75	0.0415
2	26.74	26	16.43	0.04027
3	25.93	26	19.19	0.04120
4	25.75	26	19.56	0.04004
5	20.47	26	36.03	0.04289
6	26.01	26	18.72	0.04035
7	14.27	15	19.7	0.04551
8	7.44	5	29.81	0.06025
9	8.94	5	15.66	0.05138

In Table 6, the heat conduction coefficients of all these composite boards were much lower than 0.14W/m·K, so they could not satisfy the thermal insulation request completely. The less the compression ratio of the EPS of the core layer of the composite board, the less the heat conduction coefficient. The thickness of the EPS has a great influence on the heat conduction coefficient. When the thickness of the EPS as the core layer of the composite board was 5mm, the heat conduction coefficient was biggest, 15mm thickness took second place, 26mm was the least. Thus it can be seen, for improving thermal insulation performance, it is essential to increase the thickness of the EPS. In addition, from the experiments data, the heat conduction coefficients of the composite board with twice hot pressing were less than those with once pressing, especially thick EPS core layer.

Sound-absorption coefficient

The sound absorption is the phenomenon where energy of a sound wave is lost after the impinging against the material surface. The sound absorption can reduce the acoustic pressure level in the room. The index of sound absorption is the sound-absorption coefficient (α), which represents a ratio of absorb sound energy and ripping into sound energy. Theoretically, if a material reflects sound completely: α=0. If a material absorbs ripping into sound energy completely: α=1. In fact, the α of all materials are between 0 and 1, i.e. ripping into sound is possible neither reflex nor absorbing completely. Any material can have the different sound-absorption coefficient in the different frequency. The sound absorption performance of materials in different frequency is described by the frequency response curve of the sound-absorption coefficient. The sound-absorption coefficients of composite boards which were made of 3 different thicknesses of EPS were measured by the testing instrument of JIZB sound-absorption coefficient. The results can be seen in Fig 1. This shows that there were very big sound-absorption coefficients under different frequency of all composite boards, which satisfy the sound insulation request completely.

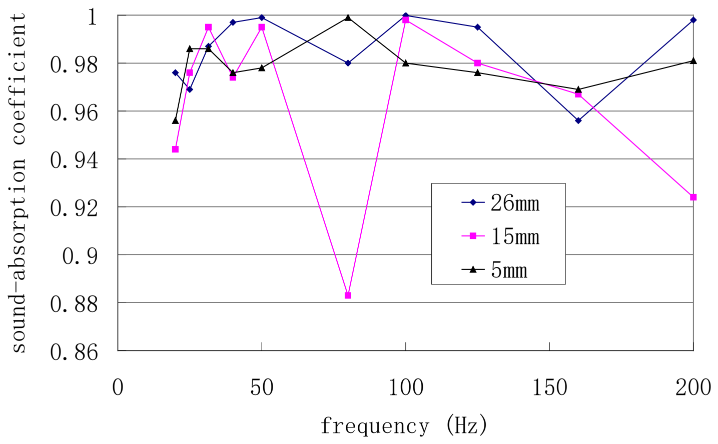

Figure 1: Sound-absorption coefficients of composite boards of 3 thicknesses EPS

CONCLUSION

The composite boards made of the poplar veneers, firstly bonded into plywood and afterwards bonded with the EPS by modified PVAc and hot-pressed twice at a temperature of 60 to 70°C, had a better bonding effect and mechanical strength.

The composite board made of the poplar veneers and the EPS had small heat conduction coefficients and big sound-absorption coefficients. It had a wood nature grain, which enables it to possess evident performances of thermal insulation, sound insulation and decoration.

The composite boards made of the poplar veneers and the EPS, with uniform performances and sound or thermal insulation are very suitable as interior partitions and decoration boards to be stuck on internal walls.

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Low-density magnesia wood-wool panel: Manufacturing technological parameters of steam-pressing technique

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Keywords: Steam-pressing, magnesia, wood-wool panel, technological parameters

ABSTRACT

In this paper, experiments with a technological steam-pressing process were carried out to manufacture low-density magnesia wood-wool panels. Special emphasis was on the reaction heat and airproof process to assure the process productivity and the panel quality. Using a team-pressing technique to manufacture low-density magnesia wood-wool panel improved the productivity significantly and the panel properties reached the product requirements.

INTRODUCTION

Cold-pressing technique is commonly used to manufacture low-density magnesia panels. By consulting concern information, $MgCl_2$ can generate Mg(OH)Cl precipitation in the high-temperature and steam condition. It is thus helpful to improve the brine phenomena of the product (Moslemi 1987, Pan 1984). In this paper, a technological process with steam-pressing technique is attempted to manufacture low-density magnesia wood-wool panel and use heat and airproof to improve the quality and productivity of product.

EXPERIMENT DESIGN AND MANUFACTURING

Wood-wools were mixed with magnesia to manufacture panels with certain heat and steam conditions.

Experiment design

The designing technological parameter variables were: steam-pressing time, wood-wool shape, ratio of ash and wood, density and thickness of wood-wool panel and additive category. The factors were analyzed on their effect on the panel properties. Parameter determination was based on analyzing material hydration heat and consulting concern information of inorganic bonding particleboard.

Fixed parameters: steam-pressing temperature is 140°C, internal maximum steam pressure is 0.27MPa, molar ratio of MgO and $MgC1_2$ is 6.43/1, panel dimension is 400×400mm.

The designing scopes of parameter variables were:

1. Slender ratio: 200; 300; 400 and the ratio of width and thickness was 3.
2. Steam-pressing time: 0.8; 1.25; 3.75 min/mm.
3. Ratio of ash and wood weight ratio: 1.25; 1.5; 1.65; 2.00.
4. Panel density: 0.25; 0.35; 0.45; 0.55g/cm^3.
5. Panel density: 16; 18; 20; 25mm.
6. Categories and proportion of additives according to magnesia weight ratio: 15% talcum powder; 15% talcum powder +3%oleic acid; 15% talcum powder +1.5% Al_2O_3 powder +1.5% $NH_4H_2PO_4$

The evaluating indexes of the panel: MOR, MOE, thermal conduction coefficient (k), sound-absorbing coefficient (a_0):2h TS.

Materials
Magnesia: from the Hongda building material factory in Laizhou, Shandong province which contained 80% MgO.
$MgC1_2$ solution: prepared to relative density 1.28 with density meter which contained 32.77 $MgC1_2$.
Poplar veneer: 0.5mm thickness, wood-wools of 1.5mm width and required length of 12% moisture content, prepared with cutting machine.

Manufacturing process and main equipment
The prepared $MgCl_2$ solution was put in a spraying barrel and sprayed evenly on the face layer of wood-wool, then magnesia (or magnesia added with additives) was sprayed evenly on the face layer of wood-wool to make them mix fully and evenly. The mixer was then put into a forming frame and pressed preliminarily; then the mat was put into steam-press. The finished panels were stacked and maintained for 21 days in a natural environment and samples were made to test the properties.

The steam-press (self-manufactured) is shown in the patent.

RESULTS AND DISCUSSION

The panel property is discussed from manufacturing technological parameters according to experiment design and results.

Steam-pressing time
In the conditions of ambient temperature, airproof and long time, the loss of moisture is low; the reaction between MgO and $MgCl_2$ is sufficient and stable crystals can be generated. Moreover, in the airproof steam-pressing condition, it is necessary to have a certain reaction time in spite of the accelerated reaction speed to generate high-strength crystals. So the strength property of the panel is determined by the steam-pressing time in this experiment scope. On the other hand, the panels can all reach the strength requirement in the selected

scope of steam-pressing time. According to the strength developing trend and requirement to improve the productivity, the steam-pressing time is determined to 0.8-1.25min/mm.

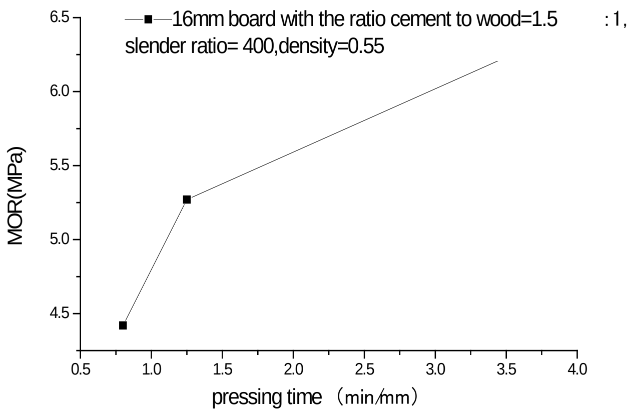

Figure 1: Effect of steam-pressing time on panel properties (MOR)

Ratio of ash and wood

The magnesia wood-wool panel is one density-density which uses wood-wool as enhancing material and magnesium oxychloride cement as adhesive, so the shape and proportion of wood-wool have great effect on the panel strength. One important problem is that the relationship between the panel strength and the ratio of ash and wood focuses on gluing or enhancing. Increasing the amount of wood will increase the substance with load-boring capacity of unit volume in impact pressed panel, which eventually led to the increase of MOR. The panel strength will have a decreasing trend when the ratio of ash and wood reduces certain degree for the reason that when the ash as the adhesive reducing certain degree, it is not bonded well with wood-wool and the bonding strength between wood-wool and cement, and the aligning direction is random. The relationship between increase of amount of wood-wool and increase of panel strength is not linear thus led to the decrease of whole panel strength when the increase of this strength can not exceed the reduction of that strength. Moslemi gave an explanation for this phenomenon: adding of aggregation material led to the stress concentration in the interface between the aggregation material and cement (Moslemi 1987). When wood particle increased, the stress concentration around the particle was dispersed thus led to increase of resistance of system to the environment. The amount of cement must be adequate to ensure an excellent bonding among particles. He thought that the ratio of ash and wood 2:1 was a critical value to ensure integrated interface of the whole panel (Tong 1995). This critical value was studied in many countries and its value changed from 1.5:1 to 3:1. The ratio changed with the particle morphology. For the wood-wool panel, the aggregation material used is wood-wool whose shape is different from the particle which led to the different ratio of ash and wood. In this paper, it was obtained from the experiment that the panel strength of magnesia wood-wool panel was high when the ratio of ash and wood was 1.5.

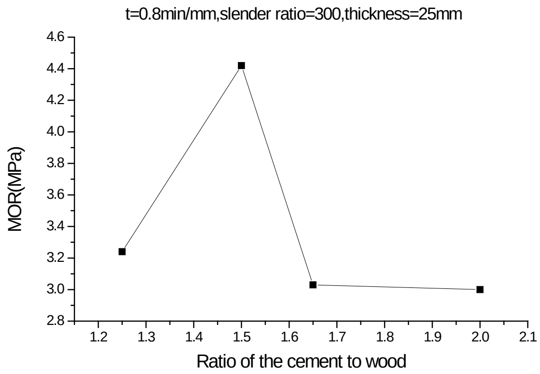

Figure 2: Effect of ratio of ash to wood on the panel strength

Slender ratio of wood-wool

When the tensile or bending strength is tested, it is always hoped that the wood-wool is pulled off in the panel rather than being pulled out. Such wood-wool panels can display the greatest wood fiber strength of particles. It is calculated according to the following theory:

$$\lambda = 2k\frac{\sigma_{fu}}{\tau}$$

λ——Slender ratio of wood-wool, dimensionless.

k——Structure coefficient of panel which relates to the aligning direction of wood-wool (0.5 1.0), 0.5

σ_{fu}——Tensile strength parallel to the grain of wood-wool (MPa) poplar is 60

τ——Bonding strength between particles (MPa); it is obtained from the experiment that the value is from 0.15 to 0.25 (related to density and ratio of ash and wood);

It was calculated that λ is 200-400.

It was shown from Fig. 3 that experiment results are basically in accordance with the theoretically calculated results; λ=300 was selected considering the technological forming feasibility.

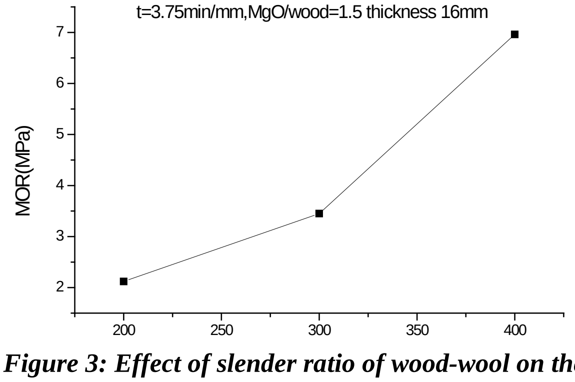

Figure 3: Effect of slender ratio of wood-wool on the panel strength

Density and thickness of panel

It was shown in Fig. 4 that MOR and MOE increased while 2h Ts reduces with the increase of the panel density.

It is stipulated in the national standard that material whose stacking density is less than 1000kg / m^3 and thermal conductivity coefficient is less than 0.175 W/(m•K) can be used as insulating material (Xu and Zhou 2001). By testing, the thermal conductivity coefficient of most panels are from 0.1~0.14 W/ (m•K), minimum 0.0914 W/(m•K), mainly due to the density, porosity and other relevant factors (see Fig. 4)

The effect of panel thickness variance on panel property focuses on MOR and MOE of the panel which is characteristic when hot-pressing panels. Despite the relatively high density in the face layer, that is, density scale increased with the increase of the panel thickness, this illustrates that MOE obtained a certain increase; but shear failure occured in the central panel for the low bonding strength of the panel which was verified by the experiment because the failures of thick panel all occurred in the core layer.

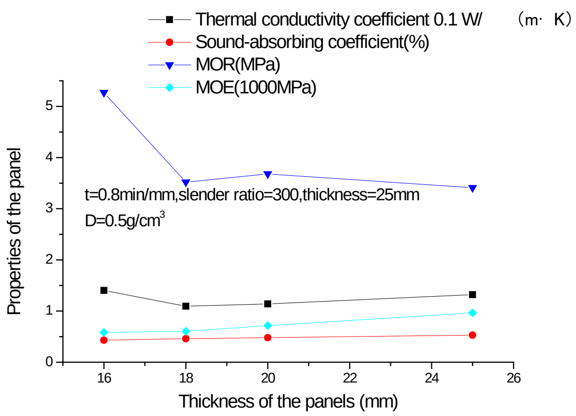

Figure 4: Effect of density on the panel property

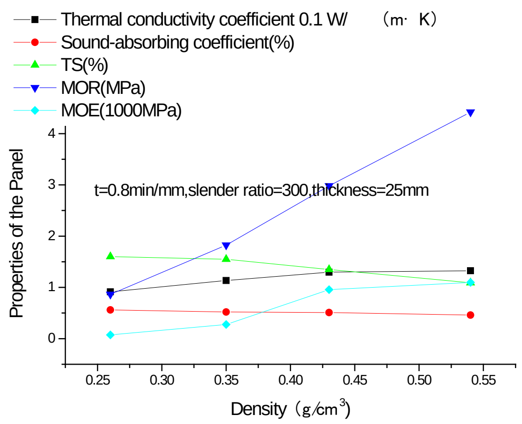

Figure 5: Effect of thickness on the panel property

The sound-absorbing property of panel

The sound-absorbing coefficient is main technical index for evaluating the sound-absorbing property of material which correlates to the sound frequency, the average sound-absorbing coefficient of six frequencies: 125, 250, 500, 1000, 2000, 4000 H_Z was commonly used in engineering to evaluate the sound-absorbing property of materials (Yang 1999). The sound-absorbing property of material is correlated with the structure, density, thickness and porosity of material; several factors which affect the sound-absorbing property of magnesium oxychloride cement were discussed. The sound-absorbing frequency scope of such material was 1000-3000Hz, the most effective is 2000Hz (seen in Fig. 6 and 7), the sound-absorbing coefficient was 0.92-0.98%, and average sound-absorbing coefficient was 0.42-0.56% in scope from 125 to 4000Hz. In experiment scope, the ratio of ash and wood has no significant

effect, but when the panel density changed to 0.55g/cm^3, the sound-absorbing frequency was gradually transformed into high frequency and when beyond 3000Hz the density had significant effect on the sound-absorbing coefficient.

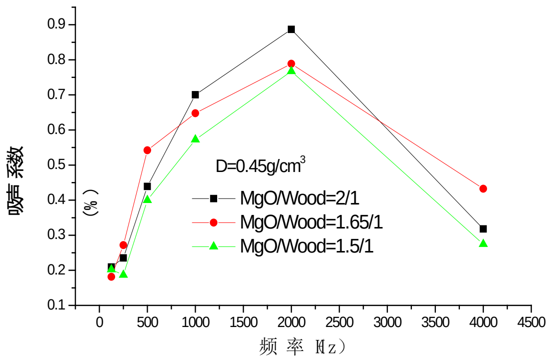

Figure 6: Relationship between the ratio of ash and wood and the sound-absorbing coefficient

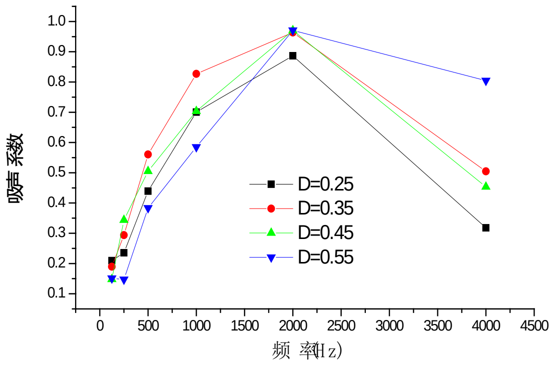

Figure 7: Effect of density on the sound-absorbing coefficient of panel

CONCLUSIONS

The productivity using steam-pressing technique to manufacture low-density magnesia wood-wool panels was greatly improved and the panel property can reach the product requirement. The basic technological parameters in this experiment were: steam-pressing time is 140°C, internal highest steam pressure is 0.27Mpa, molar ratio of MgO and $MgC1_2$ is 6.43:1. The slender ratio of wood-wool had great effect on the panel property which was determined about 300 as well as 1.5mm width and 0.5mm thickness based on theory and experiment. The extension of the steam-pressing time was helpful to improve the panel strength which was determined about 0.8-1.25min/mm considering quality and productivity and selected depending on the variance of the panel thickness. The weight ratio of magnesia and wood-wool (ratio of ash and wood) had effect on the appearance and property of panel; when the ratio of ash and wood went from 1.5 to 2.0, with the increase of the ash amount, the thermal conductivity coefficient of panel increased and the panel strength reduced; but when the ratio of ash and wood of panel was lower than 1.5, MOR reduced as well as a great reduction of MOE although the thermal conductivity coefficient of panel reduced; so the weight ratio of magnesia and wood-wool was 1.5. With the increase of panel density, the thermal conductivity coefficient increased, 2h TS reduced, MOR and MOE increased, and density could be selected from 0.35 to 0.45g/cm^3 depending on the requirement of thermal conductivity and strength of the product. The most effective sound-absorbing frequency of panels was 2000Hz, the sound-absorbing coefficient of panels could reach 0.92-0.98%, and the average sound-absorbing coefficient was 0.42-0.56% in the scope of 125-4000Hz. All materials could reach the requirement of insulating material according to the national standard.

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The Wettability Change of PF Resin on the Surface for Wood Strand under different drying conditions

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Keywords: Surface contact angle, wettability, absorbed liquid, phenol formaldehyde resin

ABSTRACT

In this paper the changes in surface wettability of wood strands by PF resin were tested by the Wilhelmy plate method after different drying conditions. Commercial strands of southern yellow pine, which were usually used as raw materials for OSB manufactures in the USA, were used in this study. The measurements included the surface contact angle (θ) and changes in the sample weight. Thirty industrial strands were randomly collected for each condition. The research results showed that the surface contact angle of oven dried and microwave dried strands was smaller than of the air dried ones. There was also a good relationship between the wettability of the wood strand and mass change.

INTRODUCTION

Strand drying is a necessary step to produce oriented strand board (OSB). It is a fact that there are different drying methods in which the temperature is usually different so that the result is also different. In recent years researchers have paid more and more attention to the microwave drying method. The microwave processing energy is supplied by an electromagnetic field directly to the material. These results in rapid heating throughout the material thickness with reduced thermal gradients and volumetric heating can also reduce processing times and save energy (Thostenson and Chou 1999). It will improve the productivity of a conventional hardwood veneer dryer (Chen *et al.* 1990). However it is also of great value to research the influence from the microwave drying method on the quality of strands, especially its surface wettability which has a big influence on the bonding strength of wood strand composites. In the past there have been many research papers concerned with it. Wetting is a term to describe what happens when a liquid comes into contact with a solid surface. The wood grain direction also affects the adhesive wetting process significantly (Shi and Gardner 2001). It is important to emphasize that the contact angle on a wood surface is a phenomenological parameter influenced not only by surface thermodynamics (i.e. wetting properties) but also by factors such as surface roughness, heterogeneity and porosity, as well as by contamination effects

caused by soluble extractives being taken up by the probe liquid (Nussbaum and Sterley 2002). Maldas and Kamdem (1999) revealed that water was absorbed rapidly into the transverse surface of untreated and water-treated wood, followed by radial, and then tangential surface. An obvious difference was found on the adhesive wetting behavior between the two wood grain directions (Shupe *et al.* 1998). Lu *et al.* 2002 improved that wood surface chemical composition and structure (e.g. polarity and roughness) influenced the wettability of yellow-poplar veneer.

As well known the surface contact angle and free energy can reflect the wet ability of wood strand. Therefore, the objective of this study was to investigate the surface contact angle and free energy of commercial wood strands after different dry condition by the Wilhelmy plate method. Commercial strands of southern yellow pine, which were usually used as raw materials for OSB manufactures in the USA, were used in this study. The strands were dried using different methods (see materials and method). The measurements included the surface contact angle, free energy and changes in the sample weights.

MATERIAL AND METHODS

Wood strands and specimen preparation

Strands of southern yellow pine, which included fresh and dried, came from an OSB mill. Thirty industrial strands were randomly collected for each condition. These thirty strands were divided into three groups based on their width (Wang and Winistorfer 1999). Each group consisted of ten southern yellow pine strands (see Fig.1). The strand width of the narrow group was 2-7mm, the middle group 7-15mm and the wide group 15-50mm. Most of the specimens were cut down to 25-26mm long, 7-8mm wide. If the strand width is smaller than 7mm it can keep its original size. In order to prevent the influence from moisture content of the strand to its wettability, after drying with different methods, all strand specimens were place in a desiccator to balance, in which there was a saturation water solution of potassium acetate to keep humidity 23%. In the test room the temperature was 21°C to 23°C so that the moisture content of the strand sample could be adjusted about 5%.

Drying condition

In this study there were four kinds of drying conditions, which are rotary drum dry, oven dry, microwave dry and air dry. Rotary drum dry was the common method in the OSB mill. The strand dried rotary drum came from an OSB mill. In its dry condition the highest temperature was 740° C and dry time was less than one minute. In oven dry the highest temperature was 190°C and dry time was ten minutes. In microwave dry the power was 687 W, the highest temperature was 70° C on the surface of the strand and dry time was four minutes. In air dry the temperature was 21°C to 23° C and dry time was more than two weeks.

Wilhelmy plate method and instrument

The test instrument was DCA 322 in this study. Contact angle and surface energy from liquid on strand could be measured with it. The weight of the liquid absorbed by the strand could be also tested during measurement. It would offer a better research condition to wettability.

In the Wilhelmy plate technique, the solid sample was hanged perpendicular to the liquid's surface (see Fig.2).When the solid was partially immersed in the liquid, the forces then acting

on the plate were three parts, i.e., the weight of the plate, the upthrust on the submerged part of the plate and the surface tension of the liquid on the plate. The equilibrated force could be expressed as Eq. 1.

$$F \times g = \gamma \times PR \times \cos\theta - \rho \times V \qquad (1)$$

Where F was the interaction force between solid and liquid, g was the gravitational constant, γ was the surface tension of the liquid, PR was the wetted perimeter of the solid, θ was the contact angle, ρ was the density of liquid, and V was the volume of solid immersed underneath the liquid.

Phenol formaldehyde (PF) resin is with 44.5% of solid content and 145 centipoises of viscosity. During the test, the dipping time of strands was 100 seconds and the dipping depth was 4 mm.

RESULTS AND DISCUSSIONS

The relationship between drying method and surface contact angle of strands

Fig. 1 showed the surface contact angle of Phenol formaldehyde (PF) resin on strands dried with different methods. From the figure it could be seen that the surface advancing contact angle from Phenol formaldehyde (PF) resin on strands dried with the oven dry technique was smallest in this study whose dry temperature was 190 ° C and dry time was ten minutes. The reason was that if the dry temperature of strands was too high, the cellulose and hemicelluloses were more easily hydrolysis so as to make strand surfaces age quickly just like longer time aging. The relationship between wood wettability and wood aging has been reported. The result proved that the contact angle increased with increasing aging time (Nguyen and Johns 1979, Gardner *et al.* 1995). Moreover, higher temperatures also made lignin plastic ate easily and the soluble material of hot water increased, so that the strand surface had more hydrophobic material which could make strand surface wetting decrease. Therefore, from the opinion on raising the strand wettability, too high dry temperatures were not suitable. But if the temperature decreased the productive yield would be influenced in the common dry method.

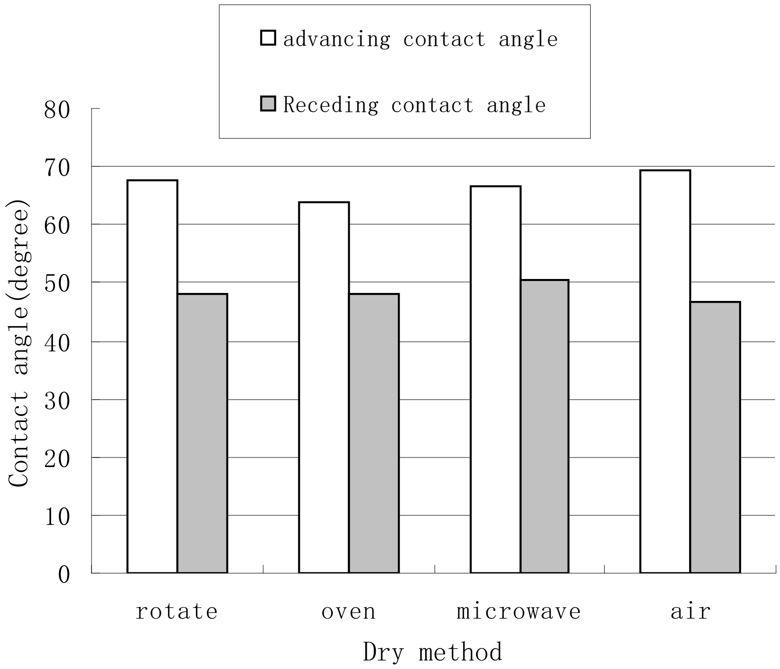

Figure 1: Relationship between dry method and surface contact angle of strand

The influence from absorbed liquid to the wettability of strand

As well known, when solid immersed liquid the interface between liquid and air was not changed, but the interface between solid and air was decreased and the interface between solid and liquid was increased. In this test the interface between strand and liquid was also increased when it was partially immersed in the liquid. The water absorbed during the DCA scans was changed (Gunnells *et al.* 1994). It could be assumed that there was some relationship between the absorbed liquid and wettability of wood. The amount of absorbed liquid would be changed in different strands dried by different methods (see Fig. 2). From the figure it was seen that the amount of absorbed liquid was also influenced by the type of liquid. Strands could get more liquid from distilled water than that from Phenol formaldehyde (PF) resin in the same test condition. In four dry methods the strand with oven dry could get the most liquid in the same test condition (see Fig. 2). This result matches figure 1, in which the surface receding contact angle of strand was smallest with oven dry. It could also be proved that there was a relationship between the absorbed liquid and wettability of strands. In Fig. 2, the surface area was used because during the test, the liquid only had direct contact with the surface area of strands under the level of liquid thus initiating the absorption. However, width and thickness of all samples are not the same, their surface area contacted with the liquid was different, so absorbed liquid per unit area was better to compare the different samples.

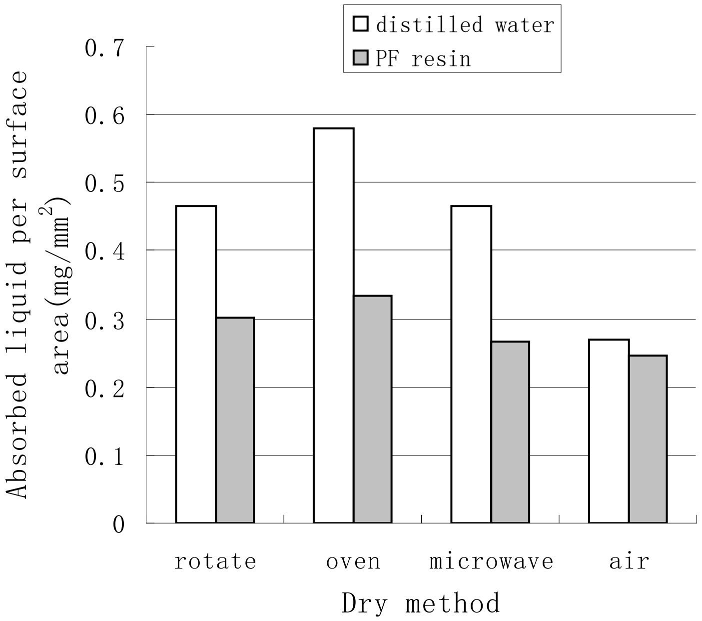

Figure 2: Relationship among dry method, test liquid and absorbed liquid

The change of surface polar section for strands dried with different methods

As stated earlier, the total surface energy γ_s of the wood was composed of the dispersive component γ_s^d and the poplar component γ_s^p , which could be test by different methods (Waelinder and Johanasson 2001, TZE and Gardner 2001). The surface energy characterizes the inherent ability of surface to interact with another surface. Its usefulness mostly lies in the advancing mode, i.e., the mode in which a surface first comes in contact with another. After the contact, the surface changes in character and it is no longer the same when characterized in the receding mode (Whang and Gupta 2000).

Figure 3 showed the surface polar energy of strands dried with different methods. It was found that the surface polar energy of strands dried by air was much smaller than that of strands dried by other methods and the surface polar energy of strands dried by oven or microwave was much bigger than those of strands dried by two other methods. It could also be proved that the wettability of strands was increased after oven or microwave dry.

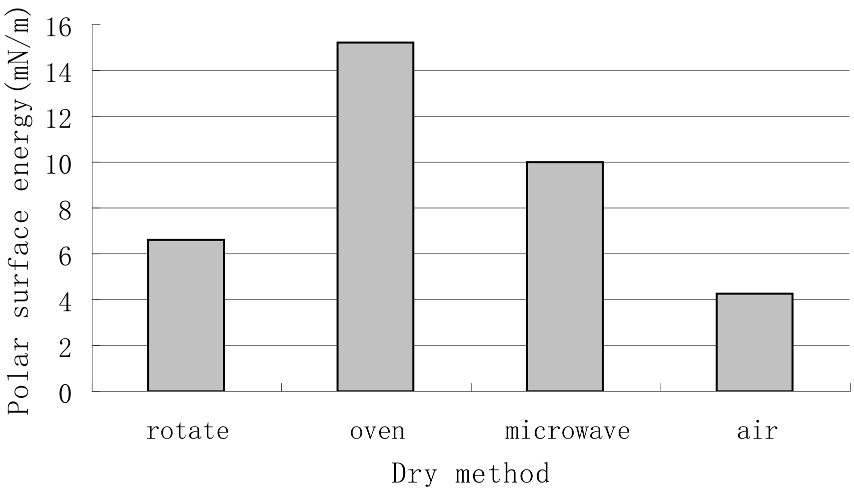

Figure 3: Change of surface polar section for strands dried with different methods

Compared with the surface contact angle between Southern Yellow Pine and Poplar

As well know there was a different wettability for diverse wood. Fig. 4 and Fig. 5 listed the surface contact angle with distilled water for Southern Yellow Pine and Poplar strand in four kinds of drying method. Fig. 4 indicates that the contact angle of air-dried pine strands including advancing and receding angle was the largest one while the surface contact angle of oven-dried strands was the smallest one among four drying methods. This could be due to more extractive was concentrated on strands surface during lower temperature air-drying. One the other hand, under higher temperature conditions, the extractive could be degraded and emitted into air and resulted in a lower contact angle. Fig. 4 also indicates that the long the time of strands exposed to higher temperature (190°C), the lower the contact angle obtained within 10 minutes. In contrast, under this drying condition within 10 minutes, the higher surface contact angle of poplar strands was obtained as shown in Fig. 5.

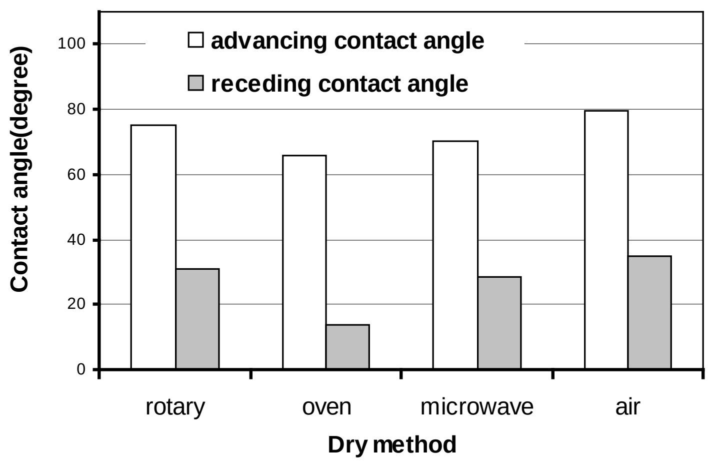

Figure 4 Surface contact angle of Southern Yellow Pine strand in distilled water as affected by drying method

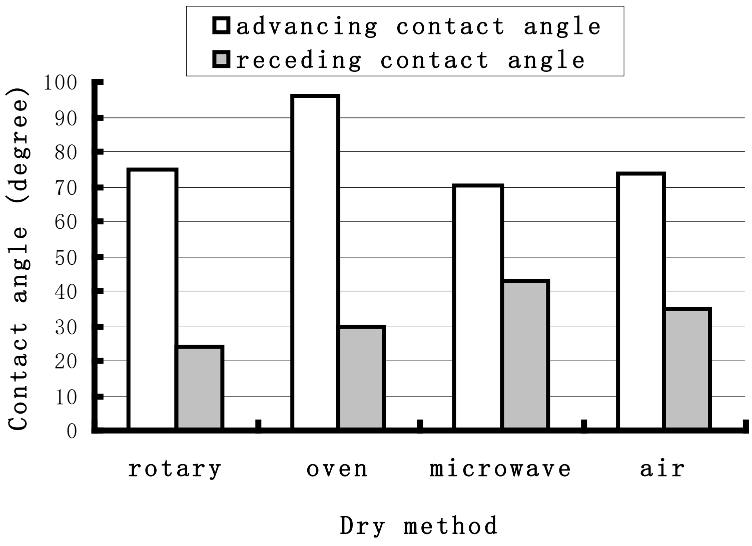

Figure 5 Surface contact angle of Poplar strand in distilled water as affected by drying method

CONCLUSIONS

This research has proved that the dry method could play an important role in the wettability of strands.
The surface advancing contact angle from Phenol formaldehyde (PF) resin on strands with oven dry was the smallest.
There was a relationship between the absorbed liquid and wettability of strands.
The surface polar energy of strands dried by oven or microwave was much bigger than those of strands dried by two other methods, which was one of the reasons why the wettability of strands was increased after oven or microwave dry.

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Manufacture, performance and application of Oriented Strandboard Cement Formwork

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Keywords: Oriented strandboard, cement formwork, poplar, masson pine.

ABSTRACT

A new cement formwork was developed by overlaying veneer and/or PF/UF resin impregnated paper on oriented strandboard (OSB). The impact of processing factors, i.e., veneer thickness (1.7mm vs. 0.8mm), veneer species (Masson pine vs. Poplar), and veneer overlaying direction (parallel vs. perpendicular), on properties of cement formwork were investigated. The cement formwork was industrially produced, and was utilized in high building application trials.

The products were tested according to specifications in GB/T17657-1999, and were assessed according to GB/T17656-1999 for plywood cement formwork. Generally, OSB cement formwork achieved satisfactory mechanical and physical performances comparable to traditional plywood, and showing higher bending strength, bending modulus, and lower thickness swelling than OSB panels. Masson pine veneer overlaid OSB showed better performance than poplar ones. The newly-developed formwork can be used repeatedly in cement engineering for 6 to 9 times.

INTRODUCTION

Cement formwork is widely applied in concrete construction accounting for approximately 20 to 30% of total engineering cost (Hou 2002). China consumes millions of cubic meters of cement formwork annually (Zhu 2001), classified into steel and woody panels, e.g., bamboo plywood formwork, bamboo curtain formwork, wood plywood formwork. Comparatively, woody formwork has following advantages towards steel ones: (1) is a biological material and is renewable; (2) is of low density while of high strength-to-weight ratios, and hence is suitable for high building engineering; (3) is liable to be cut into various dimensions, and hence is fit for complicated construction shapes, e.g., villas and residences; (4) is able to be surface reinforced, for instance, by glass fibers (Wang 1996), phenolic resin (Liu 2000) or resin impregnated papers (Ou 1999); and (5) is of low funding with comparable performance. Therefore, woody formwork is nowadays widely used in cast-in-place concrete engineering.

Oriented strand board (OSB) is made of small-diameter trees with water-proof phenolic formaldehyde (PF) resin. It shows high bending strength and modulus and is dimensionally

steady in humid environment. Hence, OSB has been widely used in building fields as substitute for structural plywood. However, in cement-forming area, OSB is demonstrated to be too rough on the surface. Correspondingly, discussed in this paper were OSB surfaces overlaid by veneers and/or resin-impregnated papers.

MATERIALS AND METHODS

Materials include: 1) OSB panel: Poplar OSB bonded with PF resin was made in Xuzhou Changqing OSB Co. Ltd., with thickness of 12, 15, and 18mm, and was sanded; 2) Veneers: masson pine (*Pinus massoniana* Lamb., 0.8mm in thickness) and poplar (*Populus euramenicana* cv., 0.8mm and 1.7mm in thickness); 3) Paper impregnated with PF/UF mixed resin at a PF to UF ratio of 3and with impregnation percentage of 120 and 4) Adhesive: brown PF resin at a solid content of 43%.
Experiment was conducted as follows (Fig. 1):

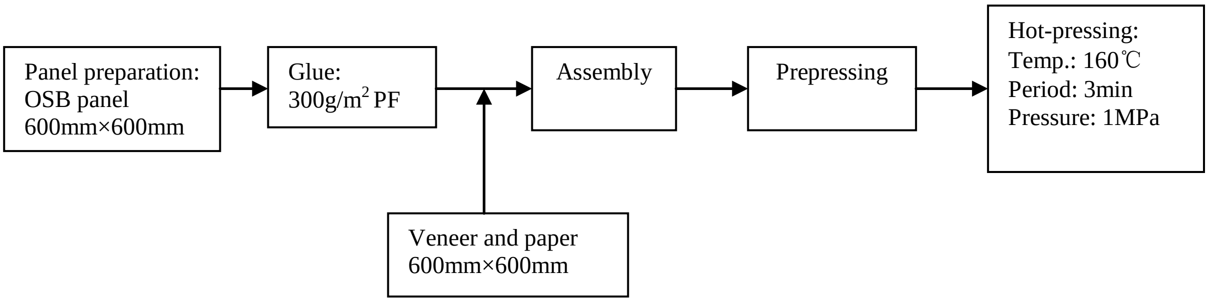

Figure 1: Flowchart of OSB cement formwork manufacturing

Formwork performances were tested according to the Chinese national standard for wood-based panels, i.e., GB/T17657-1999, including: density, 24-hour thickness swelling (24h TS), inner bonding strength (IB), parallel and perpendicular bending modulus ($MOE_{//}$ and $MOE_{\perp}$), bending strength ($MOR_{//}$ and $MOR_{\perp}$), and surface bonding strength (SB). The Chinese national standard for plywood cement formwork, i.e., GB/T 17656-1999 was referred to for analysis of experimental panel properties.

RESULTS AND ANALYSIS

Veneer Overlaying

Theoretically, materials under static bending load have linearly decreased inner stress from surface to core plane with maximum tensile stress at upmost surface and maximum compressive stress at lowermost surface (Shan 2004). To reinforce bending performance of OSB panels, its surface should be strengthened accordingly. It was shown that OSB was optimized by overlaying poplar or masson pine veneers both mechanically and physically. To demonstrate, 24h TS of OSB decreased from 14~20% to 8~14%, maximum MOE achieved 6286MPa (//) and 2498MPa (⊥), and MOR 42MPa (//) and 29 MPa (⊥), respectively. Bonding between veneers and OSB panel was proved to be prominent with SB up to 0.70MPa

or stronger. All above properties are comparable with specifications in the Chinese National Standard for plywood cement formwork, i.e., GB/T 17656-1999.

Influences of Veneer species

Masson pine and poplar are two widely planted and industrially used trees in China. Properties of veneer overlaid OSB formwork panels were listed in Table 1. Statistically, masson pine veneer strengthened OSB panels showed higher parallel bending modulus and strength ($MOE_{//}$: 35.21%, $MOR_{//}$: 11.53%), while no evident changes were found in perpendicular direction ($MOE_{\perp}$: 5.77%, $MOR_{\perp}$: -6.99%). Wood is anisotropic with strong longitudinal while weak transverse mechanical properties, which can account for the non-difference between $MOE_{\perp}$ and $MOR_{\perp}$ of OSB overlaid with two wood species. Studies by Luo (2002), Ji (2003), Li (2003), etc., gave the longitudinal bending strength of planted masson pine (107~122MPa) and poplar (50~70MPa), which explained the advantage of the former in reinforcement of OSB panel. Additional information on hygroscopic stability of masson pine veneer overlaid OSB cement formwork can also be found in Table 1, about 8.62% lower than those with poplar veneer. This can be due to the higher content of hydrophobic extractives in masson pine.

Table 1: Influences of veneer species on formwork properties (veneer thickness: 0.8mm)

Veneer species	Bending moduli[MPa]		Bending strength[MPa]		Thickness swelling [%]
	Parallel [$MOE_{//}$]	Perpendicular [$MOE_{\perp}$]	Parallel [$MOR_{//}$]	Perpendicular [$MOR_{\perp}$]	
Poplar (A)	3103.97	2778.72	25.58	23.99	12.22
Masson pine (B)	4196.88	2939.07	28.53	22.33	11.17
(B-A)/A(%)	35.21	5.77	11.53	-6.92	-8.62

Influences of Veneer thickness

Veneer thickness have bilateral influences on overlaid OSB panels. Relatively thin veneer may be helpful for OSB overlaying, but may result in lower bending strength or modulus, and if PF resin permeates through, may lead to board surface contamination. Comparatively, veneers with higher thickness may give stronger reinforcement, which can be demonstrated in Table 2, however, may lead to separation of veneers from OSB panel (Fig. 2) or even core delamination.

Table 2 presents the statistical data of OSB formwork with two poplar veneer thickness. Similar to influences of wood species, 1.7mm veneer overlaid formworks had stronger bending properties ($MOE_{//}$ 39.89%,$MOR_{//}$ 33.40%) and lower thickness swelling values (TS: -2.92%) than those with 0.8mm veneer, while no evident differences were found in perpendicular MOE or MOR values. Also found in Table 2 is the decrease by 47.54% of inner bonding strength from 0.57MPa to 0.33MPa.

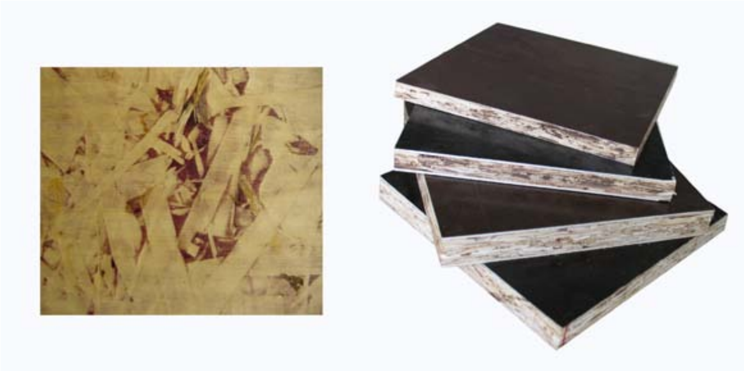

Figure 2: OSB cement formwork

(left: OSB surface after split of overlaid veneer; right: OSB with veneer and paper)

Table 2: Influences of veneer thickness on OSB formwork properties

Poplar veneer thickness [mm]	Bending moduli[Mpa]		Bending strength[Mpa]		Inner bonding strength [MPa]	Thickness swelling [%]
	Parallel [$MOE_{//}$]	Perpendicular [$MOE_{\perp}$]	Parallel [$MOR_{//}$]	Perpendicular [$MOR_{\perp}$]		
1.7 (A)	4698.96	2808.36	37.88	22.61	0.37	11.9
0.8 (B)	2824.48	2867.95	25.23	24.60	0.55	12.2
(A-B)/A(%)	39.89	-2.12	33.40	-8.81	-47.54	-2.92

Influences of Veneer Overlaying Directions

OSB is characterized with in-plane mechanical anisotropism similar to solid wood, i.e., strength or stiffness in longitudinal direction is different from that in perpendicular direction. However, sum of MOE or MOR values in two directions were proven to be constant, although strand distribution in plane may change (Zhou 1982). Composition of veneer and OSB may change the anisotropism of OSB. Following equations deduce ratios of MOE or MOR in two directions, marked as k_{MOE} and k_{MOR}, respectively:

$$k_{MOE} = \frac{MOE_{//}}{MOE_{\perp}} \text{ …………. (Eq.1)}$$

$$k_{MOR} = \frac{MOR_{//}}{MOR_{\perp}} \text{ …………. (Eq.2)}$$

K_{MOE} and k_{MOR} of OSB panels used in this research were tested to be 1.77 and 1.65, while 2.06 and 1.69 for veneer overlaid formworks in parallel direction, and 1.68 and 1.63 for OSB formworks with perpendicular overlaid veneers. Hence, veneer overlaying can effectively control the in-plane mechanical properties of OSB formwork.

Surface bonding properties

OSB matrix is constructed with large stands, i.e., 10 to 50 mm long, 5 to 15 mm wide, and 0.2 to 0.8 mm thick. Correspondingly, OSB is characterized by two rough surfaces with numerous openings, bringing difficulty for overlaying. Partial resin shortage may happen, therefore, and overlaid materials may break off OSB (see Fig. 2 left).

As a consequence, two technical measures were taken to avoid above problems: (1) OSB surface sanding to 120 mesh per inch to decrease the surface roughness; and (2) putting reasonably higher resin up to 300 grams PF resin per square meter. It's demonstrated that bonding between overlaid veneers and OSB panel reached 0.70~1.1MPa, and no evident veneer breakage was detected.

Influences of impregnated paper overlaying

Paper used in this research were impregnated with mixed PF and UF resins. Listed in Table 3 were the one-way ANOVA results about the influences of paper overlaying on formwork properties. It's shown that only transverse bending modulus ($MOE_{\perp}$) and strength ($MOR_{\perp}$) were significantly affected by paper overlaying while other properties, i.e., longitudinal bending modulus and strength, and 24-hour thickness swelling, showed no evident influences.

In cement engineering, impregnated paper basically makes it easier for formwork to break away from concrete. Simultaneously, if possible, the paper may stop water penetration and control formwork swelling. Interestingly found in Table 3, however, was the insignificance of TS variation between formworks with and without paper overlaying, which can be accounted for by the large holes on OSB edges. Water can easily enter the OSB matrix along lateral canals, although OSB surfaces were closed by impregnated papers and veneers. Anyhow, paper-overlaying optimized the concrete surface. Fig. 3 compares plywood and paper-overlaid OSB formworks engineering. Concrete surface formed by plywood was evidently rougher than paper-overlaid OSB.

Table 3: One-way ANOVA for paper overlaying (α =0.05)

	Without paper overlaying	**With paper overlaying**	**F**	**F crit**	**Significance**
$MOE_{//}$(MPa)	3738.64	4261.22	0.74	4.30	No
$MOE_{\perp}$(MPa)	2102.48	3581.62	8.03	4.30	Yes
$MOR_{//}$(MPa)	29.69	31.63	0.28	4.30	No
$MOE_{\perp}$(MPa)	17.70	28.24	7.68	4.30	Yes
IB(MPa)	0.39	0.41	0.06	4.35	No
TS(%)	11.77	11.74	0.001	4.30	No

Fig. 3: Concrete surface after formwork unloading: Paper-overlaid OSB vs. plywood

Applications of OSB formwork in Engineering

OSB formworks, overlaid by 1.5mm thick veneers and impregnated paper, were industrially manufactured in XuZhou Changqing OSB Co.Ltd., and tried in engineering by Jiangsu Hongsheng Construction Co.Ltd. Fig. 4 shows the product after 6 applications in floor engineering. Partial breakage of the panel during unloading may happen, while the board may be cut to smaller sizes and be used in other applications, e.g., stairs.

Figure 4: OSB partial breakage as formwork unloading

CONCLUSIONS

OSB manufactured with PF resin has good mechanical properties, and can be effectively reinforced by veneer and resin impregnated paper overlaying. The composite OSB panels were demonstrated to be fit for concrete forming with repetitions over 6 times. Veneer species, thickness and overlaying direction played significant influences on formwork properties, and resin-impregnated paper may optimize the concrete surface quality after formwork unloading.

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MOR and MOE of Plastic OSB with Poplar Strand

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Keywords: Fast-growing poplar, Plastic OSB, MOR, MOE, oriented angle

ABSTRACT

In this study, effects of strand density, resin content, hot pressing time and orientation angle on MOR and MOE of plastic OSB with thin and long strand from fast-growing poplar were investigated.
The strand length was fixed at 200mm. The results showed that a higher orientation angle could lead to lower MOE and MOR of plastic OSB. The board density has significant influence on the MOR (but the MOE was different), influenced by the hot press time. A plastic OSB with a density of 0.75g/cm^3 was produced using a hot press time of 1.4min/mm and a resin content of 350g/m^2, resulting in higher values of MOR (56.4-103 MPa) and MOE (7808-13455 MPa).

INTRODUCTION

Fast-growing poplar has been one of the main raw materials with its fast –growing ability, wide adaptability, light weight, easy processing, and it could be widely managed. The poplar plantation wood has become the main material for our panelboard industry(Kai *et al.*, 1994, Hua 2004). But it is difficult to be processed because this species has a low density, low strength, is easily harmed by bugs ,epiphyte and mildew. Also, it has small diameter logs, thinnings and plantations (Zhao *et al.* 2001) How to use this resource to produce high quality wood composites is being focused on.

Structural plywood, as a main product in the plywood family, was mainly used in container floorings, carriage board and concrete models. In comparison with normal plywood (Bai 2008), the structural plywood has more layers, is thicker (12mm), and it also has different physical properties and a different production process. OSB has superior performances and relatively lower production costs (Li *et al.* 2006) It maintains the natural properties of wood with high mechanical strength and it has a good dimensional stability when exposed to moisture. Highly workable (easy to saw, drill, nail etc.), OSB could be exempted from the phytosanitary restrictions. OSB was rapidly developed and is used in buildings, furniture and packaging materials. Today, as substitution of the structural plywood, the utilization of OSB is 70% and structural plywood is 30% (Jiang and Cao 2008) in the construction sector of residential and commercial buildings in North America. The domestic particleboard is produced with normal particles, the length of strands is 75 to 100 mm, it was not suitable for structural materials because of the shortages of point bonding from resin spraying, uneven forming and high amount of holes, and especially the creep would be serious in humid environmental conditions (He 1998). Wood is naturally an elastic-plasticity material and

under certain conditions, its mechanical strength properties could be improved and its structure retained when the density improved by a slight plastic-compresssion. The plastic OSB as a plastic-panel, is made of thin and long strands from fast growing wood, impregnated with PF resin, by static or mechanical oriented hot pressing.

He (1998) made plastic-OSB to avoid the shortage of the normal OSB by impregnate gluing, thus improving its properties. But this kind of gluing consumes high amounts of resin and it is costly. Another problem is how to optimize the resin distribution on the strand surface, where results are unknown. However, brush gluing could improve the efficiency of resin application. The purpose of this study was to evaluate the feasibility of manufacturing plastic OSB using fast-growing poplar with 200 mm long strands and to optimize appropriate technology parameters from both manufacturing technology and plastic OSB properties in laboratories.

MATERIALS AND METHODS

Strand preparation

The poplar panel comes from a Jianhu wood-based panel mill, Yancheng city, Jiangsu Province, with a density of 0.38g/cm^3. The parts of the panel with nature bug, colors, knurr and cracks on the surface were wiped off and cut with a knife into long and thin strands with a dimension of approximately 200mm (length), 10mm (width) and 1.5mm (thickness), The initial moisture content of these strands was 15.4%. and they were dried at 70°C in a dryer to a MC about 8.0%.

Resin blending

The Phenol-formaldehyde liquid resin (the solid content was 43%) was brushed on each face of each test strands.

Strand forming: The strands were enclosed in perforated Teflon pouches and carefully distributed by hand through the depth of the hand-formed mat at the predetermined location. The mat size was 400 x 250 mm. We manually controlled the homogeneous thickness with only one joint on each layer.

Hot-pressing

The nominal thickness of plastic OSB was 12 mm, and the hot pressing temperature was 150°C, the utmost pressure was 9MPa. The hot pressing time was determined according to the experimental design.

Property test

All boards were conditioned at 20+3°C and 65+1% relative humidity (RH) for one week, and then cut for routine performance assessments, i.e. bending modulus (MOE) and strength (MOR), according to the Chinese standard GB/T4897-2003.

The process chart was given in Fig.1

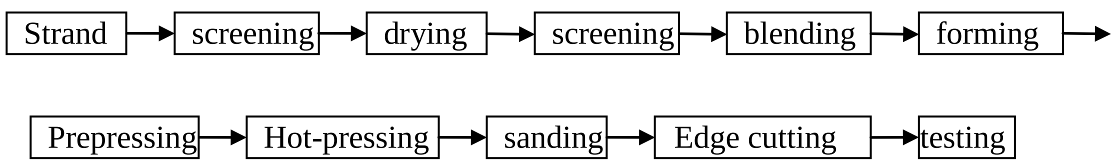


Figure 1: The process chart of OSB

Experimental Design

L9(34) mathematical orthogonal method was adopted to arrange the experimental design. Three factors were strand density, resin content and hot-press time. The level of testing factors was shown in Table 1.

Table1: Levels of experimental factors of orthogonal experiment

factors levels	Density A [g/cm^3]	Hot-press time B [min]	Resin level C [g/m^2]
1	0.65	12	300
2	0.70	14	350
3	0.75	17	400

Note: The resin contents were 16%,18% and 20% based on oven-dry weight of strands

Orientation angle specimen preparation

Sample boards of 500 x 500 x 12mm were manufactured at the end of the orthogonal experiment and cut from the sample boards according to Chinese standard GB/T4897—92 (shown in fig. 3.), with an orientation angle of 0, 10 or 20° respectively to the size of 290mm, 50mm and 12mm. and four density samples, with a size of 50 x 50 mm.

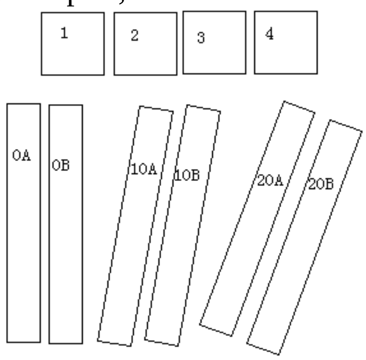


Figure 2: Orientation angle samples.

Note:
0A、 0B—— orientation angle was 0°；
10A、 10B——orientation angle was 10°；
20A、 20B——orientation angle was 20°；

RESULTS AND DISCUSSION

Optimal parameters of plastic OSB

Structural plywood commonly using as outside engineering, except need to favorable weatherability, long-term durability, earthquake resistance and impact resistance, but also request of Modulus of MOR and MOE. MOR is an important property of OSB as component, which indicates the utmost capability to resist rupture under outer force. MOE is an index of stiffness indicating the relationship between stress and strain. In wood technology, the modulus of rupture was representative to the degree of strength or elasticity of wood, it was the maximum surface stress in a bent beam at the instant of failure, and it was expressed the ability of withstand the distortion (Li 1994). The modulus of rupture is the ratio of the bending moment at the point of failure to the moment of resistance. And the modulus of

elasticity can be used to predict bending strength, as the bearing structural materials, the design stress or the loading of OSB should be limited in the range of critical elasticity or the ultimate creep, and avoid causing plastic deformation (Wang 1986) .

Table 2: Results of orthogonal experiment

NO.	**Design density A [g/cm^3]**	**Hot-press time B [min /mm]**	**Resin level C [g/m^2]**	**Test density [g/cm^3]**	**MOE [MPa]**	**MOR [MPa]**
1	0.65	12	300	0.69	7842	46.1
2	0.65	14	350	0.67	6726	46.8
3	0.65	17	400	0.67	10219	68.1
4	0.70	12	350	0.72	10264	61.6
5	0.70	14	400	0.73	8387	65.8
6	0.70	17	300	0.72	9170	56.8
7	0.75	12	400	0.78	10916	66.2
8	0.75	14	300	0.78	7894	69.5
9	0.75	17	350	0.78	13435	103.4

In the experiment, set pressing temperature at 150°C constantly, exam the OSB property influenced by different densities, pressing time and resin amount, to find the proper processing parameter for long strand OSB production, the effect of factors on MOR and MOE of longer strands Plastic OSB was studied to evaluate the feasibility of manufacturing structural products.

Table 3: Range analysis result of orthogonal experiment

	Levels	Density A	Hot-press time B	Resin level C
Fact density [g/cm^3]	k1	0.68	0.73	0.73
	k2	0.72	0.73	0.72
	k3	0.78	0.72	0.73
	R	0.10	0.01	0.01
MOE [MPa]	k1	8263	9667	8302
	k2	9274	7669	10142
	k3	10748	10941	9840
	R	2486	3272	1840
MOR [MPa]	k1	53.7	58	57.5
	k2	61.4	60.7	70.6
	k3	79.7	76.1	66.7
	R	26.0	18.2	13.1

The experiments and results were seen in Table 2, and the range analysis result was listed in Table 2 , Table 3 and Fig. 3-4.
From the table we could found the fact density was similar with the design density, the other factors had fewer influence on the density.

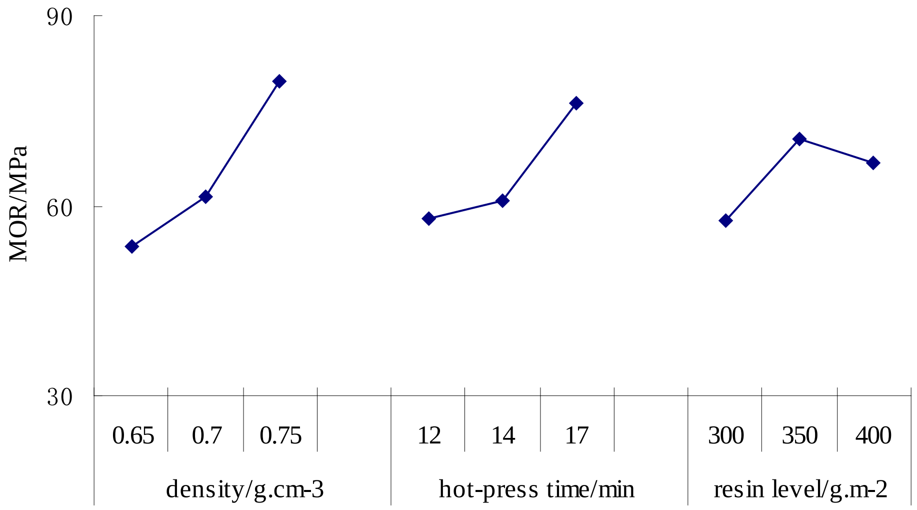


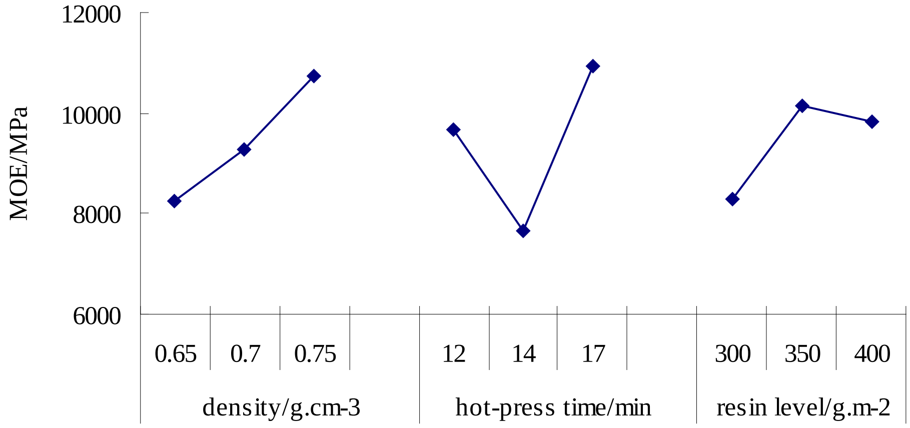
Figure.3: Relation between levels of testing factors and MOR

Discussion on the factors of each variable

The result of this experiment indicated that, among the three levels of three factors, board density had the most significant effect on various board properties and then the hot-press time. The MOR was highly correlated with the panel density. MOR was improved with the increase of the density, as shown in Fig.4, higher density means more wood strands in one unit and develops a closer contact among strands, thus a more effective resin bonding and a higher shear strength. Meanwhile, higher density also means more solid skeleton substantial

(cellulose) in unit, more effective area to bear force, thereby a higher MOR and MOE. When the density changed from 0.68g/cm^3 to 0.78g/cm^3, the MOR was improved by 48.4%.

The next factor was the hot-press time, longer time and suitable temperature made PF resin cure more completely. The effect of resin level was least, with the increased resin level, the bonded area in the board would be enlarged and the glue drops among strands would increase. Moreover, the contact of strands with glue would change from point to area to develop a better bonding, MOR was raised. But when the resin content from 350 g/m^2 to 400 g/m^2, the negative influence was found, because the excessive glue layer causes the difference of expansion to the interfacial inner stress and caloric stress would be greater, the number of air bubbles and the other disfigurement increased, the probability of early destroyed increased, then the MOR was lower (He 1998).



The results also demonstrated that the hot-press time plays an important role in the MOE, a more interesting phenomenon appeared in the experiment, that two different changes occurred with the raised time. MOE was first decreased and then increased, this may be explained by the principle of PF resin cure. A longer time and suitable temperature made the PF resin cure more completely, and at the same time the plastic of wood was increased, the mat easy to be pressed tightly, the strand closer contact, and better bonding developed in higher density board, MOE was increased. However, if the time became too long and the excessive cure of resin and possible damage to wood strand in face layer would have a negative effect on MOE, in this experiments limits, the negative influence of longer time wasn't found.

The influence of board density and resin level on MOE and MOR were the same.

According to the above optimal parameters, it was obvious that the 9th group was the best in 9 experiments. The final technological parameters were board density 0.75 g/cm^3, hot press temperature 150°C, hot-press time 17 min and the resin level 350 g/m^2. Its MOR (which was 103 MPa) and MOE (13455 MPa) reached or exceeded the nation's longitudinal specified value of Plywood for container flooring. Compared to the Industrial standard LY/T 1580-2000 of the People's Republic of China about OSB properties, it can be seen that the MOR is 2 times and the MOE is 1.6 times compared to the normal OSB. Therefore, the plastic-elastic of plastic OSB made of 200mm strand is better than that of normal OSB.

Table 4: Result of test for plastic OSB

Property	Standard of Plywood for container flooring				Common OSB	Test value
	China	Malaysia	Korea	Japan		
MOR [MPa] //	85 35	88.8 39.5	74 29.6	74 29.6	28	56.4－103
MOE [MPa] //	10000 3500	13800 4440	9870 2960	9870 2960	4800	7808－13455

Influence of orientation angle on MOR and MOE

Table 5: Sample orient angle with average MOE

Angle / Property	0°)	10°)	20°)
MOE	7808	7604	5722
MOR	56.4	48.5	42.2

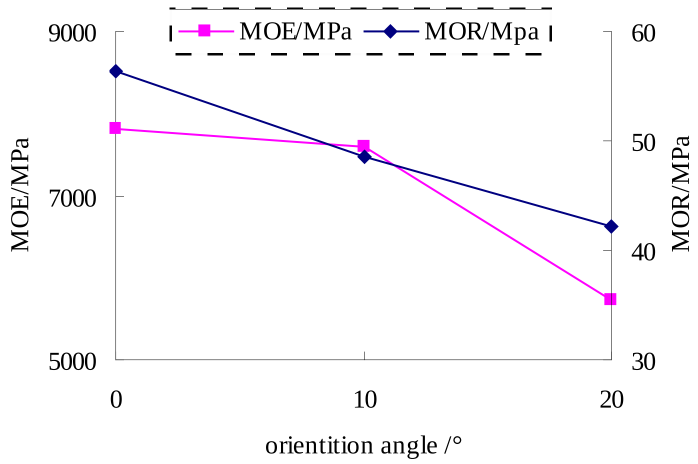


Figure 5: The relation between angle and MOE & MOR.

The reference to evaluate the performance of forming equipment is the orient result. It can be evaluated by measuring the orient angle of the strand. Oriental forming can change the strength ratio in the longitudinal and tangential direction of the board. To determine the proper angle, we need to cut it into different angles and perform strength test to find a good angle. The experiment, according to the orthogonal experiment result, is to make extend strand OSB sample size as 500 x 500 x 12mm, density was 0.75g/cm^3, PF amount was 400g/m^2, on both sides. Press temperature was 150°C and pressing time 17 min. We cut the sample with 0°,10°,20°, two of each, so that we can see the influence to the board by different angle. The results are indicated in Table 5 and Fig 5.

We could see that the bigger angle, the smaller the MOR. The MOR ratio for 0°, 10° and 20° is 1, 0.86 and 0.75, respectively. When the angle changed between 0° and 10°, there was no big change on MOE, but when the angle changed between 10° and 20°, the MOE decreased

observably. The MOE ratio for 0°,10° and 20° is 1, 0.97 and 0.73, respectively. Considering above aspects, the strand forming angle should be in the range of 0~10°.

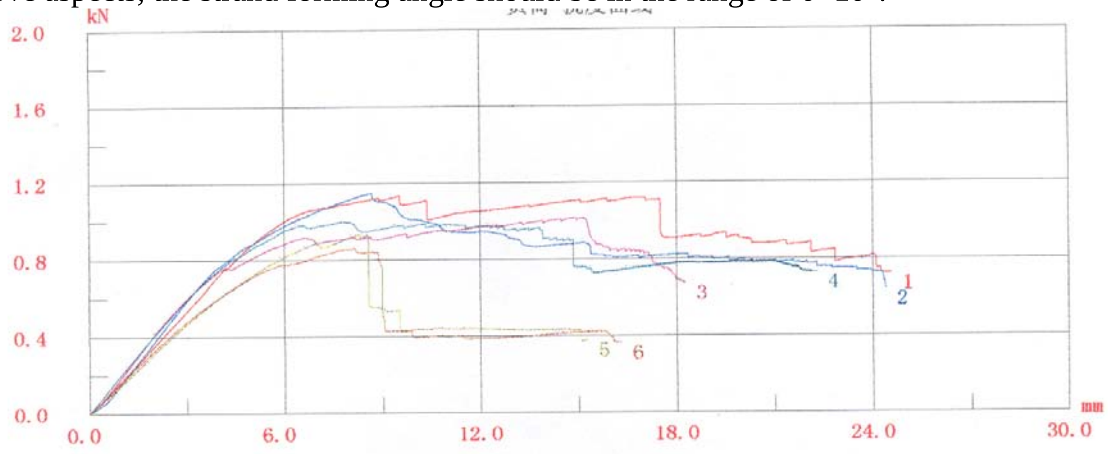


Figure 6: Load-deflection curve

In addition, from the Fig. 6 of load-deflection curve we could see that when the sample was broken, it still retained for some time. Still could bear rather high force. We could imagine that it is suitable to be a good structural board as it maintains high retentiveness after impact.

CONCLUSION

From the experiment results, the following conclusions were achieved:

Regarding the MOR, density is a main factor, then pressing time, and then the resin amount. As for MOE, pressing time is the main factor, then density, then resin amount. For 200mm strands from fast-growing poplar, to produce 12 mm OSB, the proper process condition is: density 0.75 g/cm^3, PF amount 350 g/m^2 on double sides, pressing temp 150°C, pressing time 17 min.

The smaller the angle, the better the elastic-plastic property, so the angle should be controlled between 0° and 10°.

It is suitable to be used as structural material, as it still maintains high retentiveness after impact.

The brush-gluing could make good use of the limit resin to form a continuous film on the strand surface. Its plastic mode for the extend strand increase the OSB MOR and MOE. But it is difficult to be carried out in industrial production. Therefore further research should adopt impregnate-gluing, control the resin amount and internal & external distribution, discuss the feasibility of extend OSB production with fast-growing poplar.

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Dynamic Wettability of Pre-compressed Poplar

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Keywords: Dynamic wettability, UF, PF, poplar, compressing process

ABSTRACT

Wettability is an important interface characteristic of wood-based materials to describe what happens on a wood surface when it comes into contact with an adhesive. A wetting model describing the dynamic contact angle (θ) process at the wood-based material surface was developed. The K-value was used to evaluate the kinetics of wetting during the adhesive wetting process. Applying the wetting model, urea formaldehyde resin (UF) and phenol formaldehyde resin (PF) wetting of pre-compressed poplar at different compressing process conditions were investigated. Moreover, the parameters of poplar pre-compressing such as compression ratio, the platen temperature and the pressing time, on the dynamic wettability were also compared. These results showed that the wetting model can accurately describe the dynamic adhesive wetting process on pre-compressed poplar surface. The contribution of compression ratios to the K value is the most significant of the studied parameters of pre-compressed poplar. This means that most attention should go to the compression ratio when processing poplar.

INTRODUCTION

Poplar is one of the most important and most representatives of the fast-growing tree species for wood production in China. However, due to fast growing, matured in 7-10 years, mostly poplar wood exhibits many drawbacks, such as low density, low durability, and relatively low mechanical properties compared with other natural tree species (Zhang 2004). Therefore, poplar is used as the main raw material for manufacturing wood-based composites, such as plywood, particleboard and fibreboard. The quality of poplar composite has been improved and its application field is also enlarged (Li 2002, Wei 2004).

An important characteristic in manufacturing wood-based composites is surface wetting, which has remarkable influence on the bonding strength of composites. Heating and pressing play a significant role in the utilizing and processing of wood and wood-based composites, especially in manufacturing the compressed wood. However, the time-dependent wetting process in compressed wood was not fully understood. Hence, it is necessary to study the characteristics of the dynamic wetting process for compressed wood surfaces.

In a previous study (Zhou *et al.* 2007), a dynamic wettability model to describe the time-dependent wetting process in wood and wood-based material surface was developed, in which a parameter (K) can be used to evaluate the wettability during the adhesive wetting process. By applying the wetting model, the characteristics of the dynamic wetting process for straw-based panel surfaces were investigated.

In this paper, the model in Zhou *et al.* (2007) was used for studying the wetting process in pre-compressed poplar surfaces. The contact angle of different adhesives droplets was measured and modelled. Based on the changing contact angle, the K value was achieved to illustrate kinetics of wetting, which could evaluate the dynamic wettability of pre-compressed poplar surfaces. Moreover, effects of the compressing process parameters, such as compression ratio, platen temperature and time of holding, on the dynamic wettability were also analysed.

EXPERIMENTAL METHODS

Materials and instruments

Fast-growing poplar (NL-6583), sixteen years old, obtained from a sawmill located Xuzhou, a northern city in Jiangsu Province, China.
Urea-formaldehyde resin (UF) and phenol-formaldehyde resin (PF). Major specifications of the two resins are shown in Table 1.

Table 1: Main parameters of two resins used for experiments

Adhesives	Appearance	Solid content, %	Viscosity (4#, s)	pH value
UF resin	Ivory-white	48	17.03	9.8
PF resin	Red-brown	51.72	21.06	7~7.5

The contact angles of the two resins on the surface of pre-compressed poplar were characterized by using a contact angle measurer (JC2000A, Shanghai Zhongcheng Technology Co., Ltd.).

Methods

Fifteen samples with the same three growth rings were selected. All the compressing processes were similar in this paper. The platens were heated to the determined temperature (PT), and then the water-saturated sample was placed between the platens to compress to the designed compression ratio (CR) at the same loading speed of 5 mm/s. The time of holding (TH) was recorded starting from the time the designed CR was attained. At the end of the TH, the compressed sample was taken out to cool down in air. The experimental treatment conditions were listed in Table 2.

Compressing process was performed in radial direction with the restriction of transverse deformation by a hot-press machine equipped with various gauges, which were used to control the CR of the samples.

All the contact angle measurements were conducted on the tangential section of the poplar samples. The samples were cut into a dimension of about 20 mm by 5 mm and were smoothed using a razor blade so that the fresh poplar surfaces were exposed to measure. To reduce any

surface aging effects, all specimens were kept in plastic bags in the absence of light during the time between the samples preparation and contact angle measurements.

Table 2: Experimental treatment conditions

Exp. Item	No.	CR, %	PT, ℃	TH, minutes
Various compression ratio (CRs)	1	20	160	30
	2	40	160	30
	3	60	160	30
	4	80	160	30
Various platen temperature (PTs)	1	50	120	30
	2	50	140	30
	3	50	160	30
	4	50	180	30
	5	50	200	30
Various time of holding (THs)	1	50	160	20
	2	50	160	30
	3	50	160	40
	4	50	160	50
	5	50	160	60

Note: The compressing rate was 5 mm/s.

In the adhesive wetting measurements, an adhesive droplet (about 5 μl) was placed on the sample surface. JC2000A contact angle measurer was used to snap the shape image during the droplet changing. The measurement was stopped after the droplet shape stabilized (equilibrium contact angle was obtained).

The wetting model (Zhou *et al.* 2007) used in this paper was as follows:

$$\theta = \theta_e + Ae^{-Kt} \qquad (1)$$

Where θ_e is the equilibrium contact angle, A is an integral constant, K is a constant referring to the intrinsic relative contact angle decrease rate.

Equation (1) expresses the contact angle of the liquid on the solid surface at t time. The physical meaning of the K-value represents how fast the liquid penetrates into the porous structure of wood. The higher the K-value, the faster the contact angle reaches equilibrium, and the faster the liquid penetrates and spreads.

RESULTS AND DISCUSSION

K-value analysis

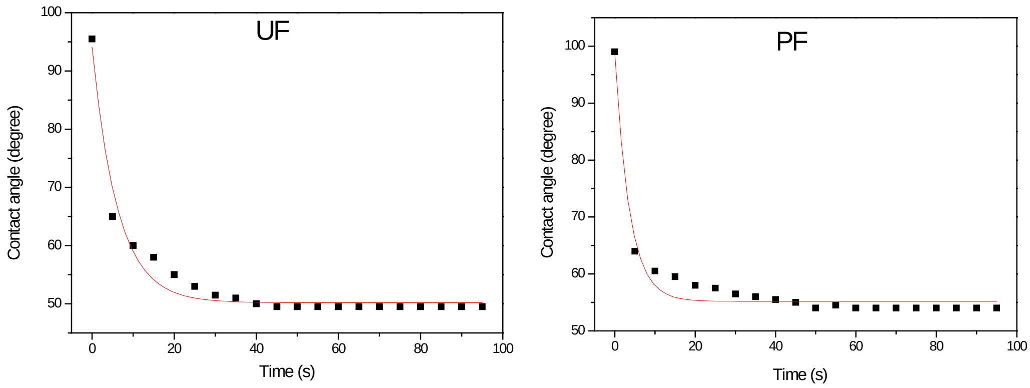

Figure 1: Curves of model fitting and experiment data of UF resin and PF resin (CR is 40%)

To obtain K-value for a particular liquid/solid system, a nonlinear curve-fitting method is used to fit the experimental datum. Fig. 1 is the curves of model fitting and experiment data of UF and PF on pre-compressed poplar with 40% compressed-radio. Other data with different compression ratios were similar. The K values of pre-compressed poplar treated with different compressing process parameters were listed in Table 3.

As seen from Table 3, the UF resin generally exhibited greater K-values than the PF resin for the pre-compressed poplar. These meant that the UF resin exhibited better wettability on the poplar surface than the PF resin did. In addition, the K value became large below 40% compression ratios for UF and PF, which suggested that the wettability was increasing. However, the K values decrease with the further increase of compressed ratio. It indicated that 40% compression-ratio was the optimal parameter. The K value tendencies of platen temperature and time of holding were same as compression ratio. 160°C and 30 min were the suitable compressing process parameter.

Effects of different compressing process parameters, such as compression ratio, platen temperature and time of holding, on the K value were compared. Fig. 2 was the K value comparison of two resins on the poplar surface under the same compressing process conditions. Seen from Fig. 2, the K value contributed from compression ratio is higher than platen temperature and time of holding of pre-compressed poplar. This meant that more attention needs to be paid on the compression ratio when utilizing and processing poplar.

Table 3: K value of different pre-compression poplar with UF and PF resin

Various parameters		**UF resin**		**PF resin**	
		K	**Error**	**K**	**Error**
Compression ratios (%)	0	0.1968	0.022	0.1788	0.02076
	20	0.2331	0.009	0.1984	0.02394
	40	0.2423	0.116	0.1981	0.02687
	60	0.1583	0.017	0.1817	0.01674
	80	0.1292	0.009	0.1167	0.01427
Time of holding (min)	20	0.2104	0.014	0.1488	0.01537
	30	0.2186	0.021	0.1961	0.01588
	40	0.2992	0.019	0.2143	0.04791
	50	0.2675	0.007	0.1379	0.1375
	60	0.2631	0.006	0.0843	0.0414
Platen temperature (°C)	120	0.1568	0.007	0.117	0.02125
	140	0.1714	0.006	0.1274	0.02154
	160	0.2096	0.009	0.1955	0.02311
	180	0.2047	0.011	0.1522	0.02505
	200	0.2069	0.013	0.1389	0.02281

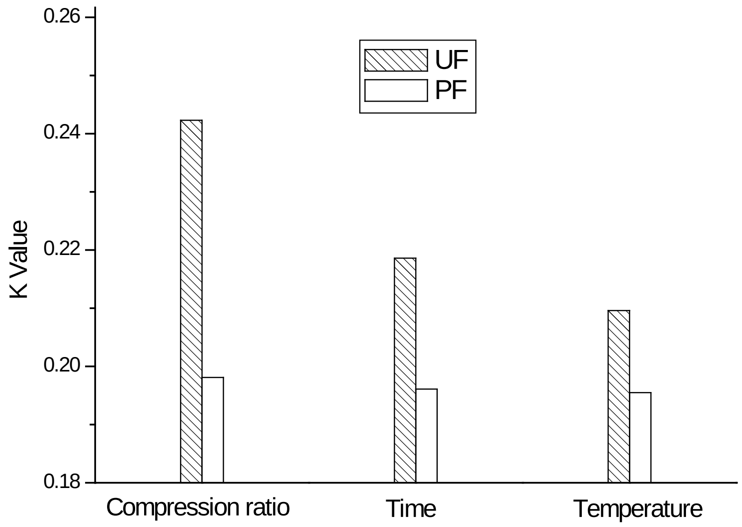

Figure 2: The K-value comparison of two resins on the poplar surface under the same compressing process conditions (CR is 40%, PT is 160°C and TH is 30 min)

CONCLUSIONS

The K value of the UF resin on pre-compressed poplar exhibited greater than the PF resin, which meant that the UF resin exhibited better wettability on the poplar surface than the PF resin. Moreover, the contribution of compression ratios to the K value was higher than the platen temperature and the time of holding of pre-compressed poplar. Our attention needs to be paid on the compression ratio when manufacturing compressed poplar.

ACKNOWLEDGEMENT

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Research on OSB panels from waste poplar veneer

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Keywords: waste poplar veneer, Strand geometry, UF, OSB

ABSTRACT

Waste poplar veneers were crushed into strands and were divided into big, medium and small strands. After drying and mixing with urea-formaldehyde (UF) resin, the strands were oriented into a mat and hot pressed “OSB panels”. The results showed that the big strands could be made into panels in appliance with the requirement of OSB/2 class in LY/T1580-2000, corresponding to the Chinese OSB national standard, and the medium and small strands could be made into panels satisfying the specifications of OSB/1. The waste poplar veneers after crushing are suitable to produce eligible UF resin OSB panels.

There are about 3 million m^3 waste veneer per year in China .The overall objective of the project was to investigate the technology of manufacturing waste veneer OSB . The waste veneer was crushed into strands and divided into big, medium and small flakes; they occupies about 86%. After drying, mixing with urea-formaldehyde (UF) resin, forming and hot pressing, the “OSB panel” was made. The mechanical properties of the panels were measured. The results showed: the big flakes could be made the panels according with the request of OSB2,dencity 0.60 g/cm^3 ,MOR 45 MPa , MOE 6632 MPa, IB 0.47 MPa, TS 12% . The medium and small flakes could be made the panels according with the request of OSB1. The waste veneer after crushing could be made eligible UF resin OSB: big strands UF resin 11%, hot temperature 160 ℃, hot pressing times 0.55 min / mm.

INTRODUCTION

With the quick increase of economy and peoples` living level in our country, more and more panels are needed. The annual yield was up to 74,285,600 m^3, thereto the plywood was 36.7% equal to 27,287,800 m^3. During the processing of veneer manufacture, about 10% was small pieces of veneer, namely every year it will produce 3,000,000 m^3 small pieces of veneer. The use of this veneer was for the raw material of particleboard or as fuel. This study is to explore whether this resource can be made into OSB or not.

EXPERIMENTAL METHODS

Material and method

The small pieces of Poplar veneer came from the plywood factory in *Subei*, with a totally weight of 105 kg, at first it was air-dried, then used in a small mill to make five different sized flakes. The size range and proportion of flakes were shown in Table 1. The moisture content was 8.9%. The resin was UF resin with a solid content of 48%. Table 2 was the test method using three factors and three levels orthonormal test. The factors: flake size, hot pressing time and resin content Three levels: flake size: big, medium and small; hot pressing time 0.40, 0.55, 0.70 min/mm; resin content 7, 9, 11%. The nominal thickness of panels was 10 mm, using the thickness gauge to control the thickness. The enacted density was 0.60 g/cm^3.

Table 1: Flake size and proportion (veneer thickness 2.1mm)

Specification (length mm)	Weight (kg)	Proportion of the total weight (%)
Big (about 170)	32.0	30.5
Medium (about 100)	28.6	27.2
Small (50 about)	26.0	24.8
Smaller <30	12.5	11.9
Powder	5.0	4.8
Non-recycle dash	0.9	0.8
Total	105	100

Figure 1: Small mill

Figure 2: Flake morphology after crushing

Table 2: Experiment plan

Serial number	Flake size	Hot pressing time min/mm	Using resin content %
1	Big	0.40	7
2	Big	0.55	9
3	Big	0.70	11
4	Medium	0.55	11
5	Medium	0.70	7
6	Medium	0.40	9
7	Small	0.70	9
8	Small	0.40	11
9	Small	0.55	7

The panel size pressed in lab was: S= 500 × 500 mm^2

The measurement of experiment data

According to the request of the corresponding standard, the following physical and mechanical properties were tested: density, 24 h TS, modulus of elasticity (MOE) and MOR, internal bind (IB). The results were listed in Table 3.

Table 3: Data collection

Serial number	Flake size	Using resin content	Hot pressing time min	Density g/cm^3	MOR MPa		MOE MPa		IB MPa	24h TS
					Parallel	Perpendicularity	Parallel	Perpendicularity		
1	Big	7%	4.0	0.66	43.82	33.41	6094.44	4510.24	0.33	13.62%
2	Big	9%	5.5	0.69	59.85	34.50	5934.63	3776.00	0.36	12.85%
3	Big	11%	7.0	0.67	51.28	37.00	9129.45	5555.18	0.33	10.94%
4	Medium	11%	5.5	0.58	25.52	20.71	4948.66	3517.56	0.51	13.99%
5	Medium	7%	7.0	0.64	19.33	14.53	2829.57	1485.07	0.55	14.47%
6	Medium	9%	4.0	0.62	18.59	11.03	2872.14	1051.20	0.47	11.47%
7	Small	9%	7.0	0.53	15.57	5.93	3539.33	620.97	0.54	15.22%
8	Small	11%	4.0	0.63	35.83	13.56	4226.88	2027.18	0.78	13.24%
9	Small	7%	5.5	0.64	21.36	15.96	2762.75	2086.65	0.60	13.10%
	OSB/1				20.0	10.0	2500	1200	0.30	≤25
	OSB/2				22.0	11.0	3500	1400	0.34	≤20

RESULTS AND DISCUSSION

IB (Internal Bond)

The influence of strand size on IB is shown in Table 4 and Fig. 4.

Table 4: Influence of strand size on IB

Strand size	IB MPa
Big	0.34
Medium	0.51
Small	0.64
Level difference	0.30

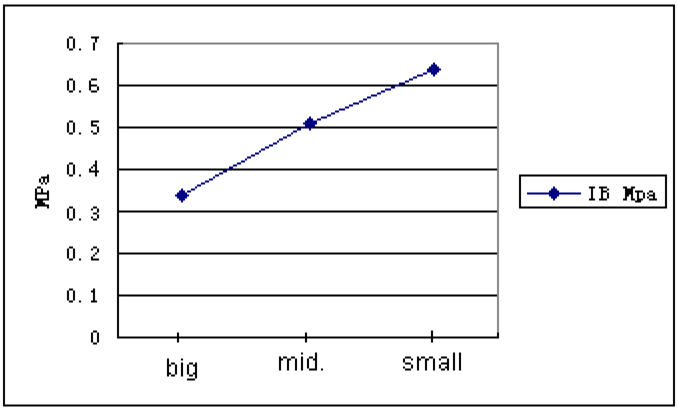

Fig. 4: Influence of strand size on IB

From Fig. 4 we can see clearly that there was a strong influence from strand sizes on IB. The bigger the strand size, the smaller the IB.

Influence of using resin content on IB

The influence of using resin content on IB can be seen in Table 5 and Fig. 5.

Table 5: Influence of using resin content on IB

Serial number	1	2	3	Level difference (MPa)
Using resin content	7%	9%	11%	
I B (Mpa)	0.493	0.637	0.537	0.14

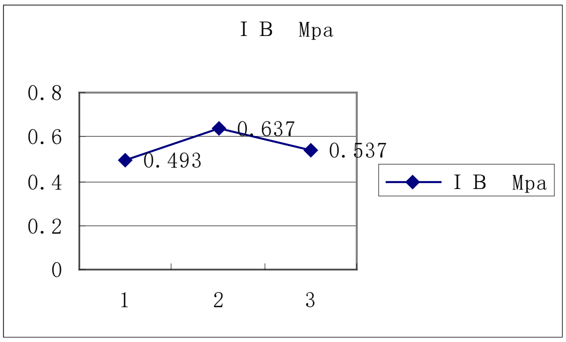

Figure 5: Influence of using resin content on IB

Fig. 5 showed that the maximum of IB appeared when the resin content was 9%.

Influence of hot pressing time on IB

Table 6 and Fig. 6 were the influence of hot pressing time on IB, respectively.

Table 6: Influence of hot pressing time on IB

Serial number	1	2	3	Level difference
Hot pressing time min	4	5.5	7	
I B Mpa	0.523	0.49	0.47	0.053

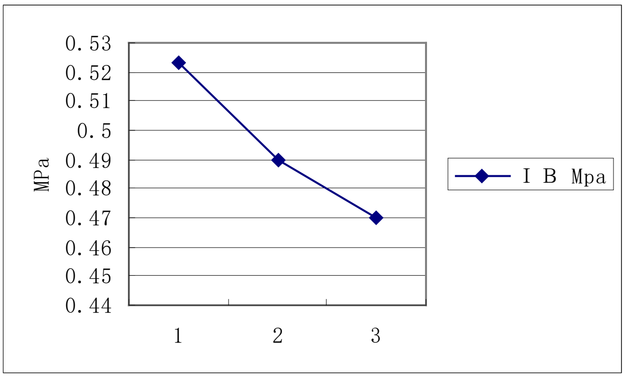

Figure 6: Influence of hot pressing time on IB

From the figure we can see that IB decreased when increasing the hot pressing time, but the change is not significant, the hot pressing time is not the main contributor.
Comparing with the three factors that influence IB, we can obtain Table 7 and Fig. 7.

Table 7: Level difference analysis

Factor	Strand size	Using resin content	Hot pressing time
Level difference Mpa	0.3	0.14	0.053

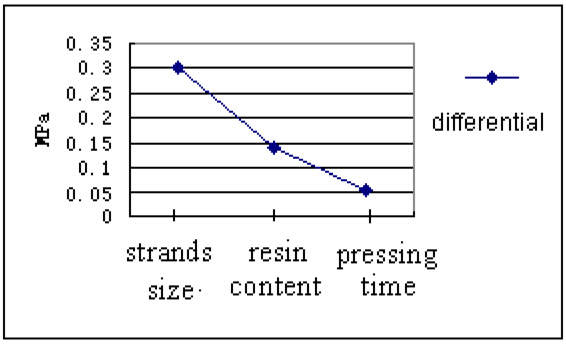

Figure 7: Main influence factor analysis of IB

Fig. 7 shows that the strand sizes are the main factor to influence IB, the smaller one is resin content and the smallest influence is hot pressing time.

According to the forestry industry standard of China LY/T 1580 – 2000 [1] about the part of OSB, the OSB can be divided into four classes, shown in table 8.

Table 8: OSB classification

Type	Using condition	Regulate value (MPa)	Experiment value (MPa)
OSB/1	General use board and fitment material (including furniture), fit for the room dry condition.	0.30	
OSB/2	Bear load board, fit for the room dry condition.	0.34	0.50

So the value of MOR in this study accorded with the request of OSB/2 completely, namely, it can be used as the bear load board under the room.

MOE and MOR

Effect of strand size on MOE and MOR

The effect of strand size on MOE and MOR can be seen in Table 9 and Fig. 8 and 9.

Table 9: Effect of strand size on MOE and MOR (MPa)

Size	MOE	MOE	MOR	MOR
Big	7052.84	4613.81	51.65	34.97

Medium	3550.12	2017.94	21.15	15.42
Small	3509.65	1578.27	24.25	11.82

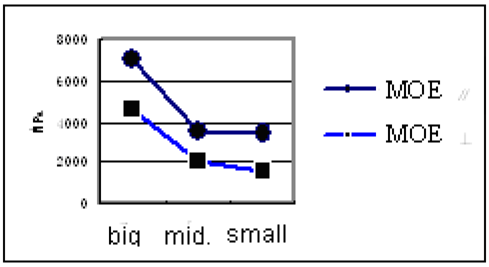

Figure 8: Effect of strand size on MOE

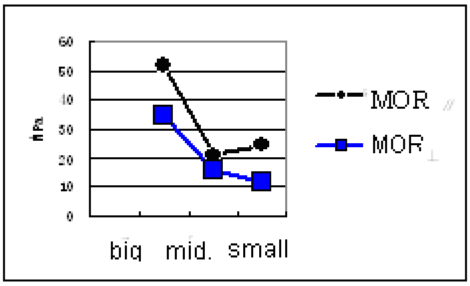

Figure 9: Effect of strand size on MOR

The Fig. 8 and 9 both show that there are significant influence of strand size on MOE and MOR, the bigger size has a better property, however, the medium and small size have no big difference.

Effect of resin content on MOE and MOR

The effect of resin content on MOE and MOR is shown in Table 10 and Fig. 10 and 11.

Table 10: Effect of resin content on MOE and MOR

Serial number	Resin content	MOR MPa		MOE MPa	
		Parallel	Perpendicularity	Parallel	Perpendicularity
1	7%	28.17	21.3	3895.59	2693.99
2	9%	31.34	17.2	4115.37	1816.06
3	11%	37.54	23.8	6101.66	3699.97

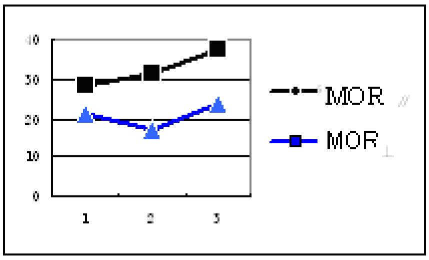

Figure 10: Effect of resin content on MOR

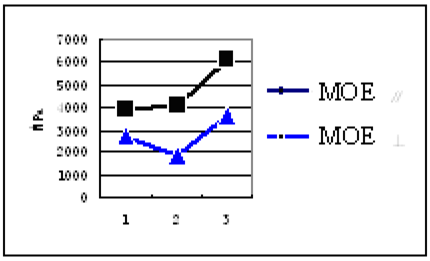

Figure 11: Effect of resin content on MOE

When the resin content was 11%, the MOE and MOR appeared the maximum values as shown in Fig. 10 and 11.

Effect of hot pressing time on MOE and MOR

The effect of hot pressing time on MOE and MOR is shown in Table 11 and Fig. 10 and 12.

Table 11: Effect of hot pressing time on MOE and MOR

Serial number	Hot pressing time	MOR (MPa)		MOE (MPa)	
	min	Parallel	Perpendicularity	Parallel	Perpendicularity

1	4	32.75	19.33	4398	2529.54
2	5.5	35.38	23.72	4549	3126.74
3	7	28.73	19.15	5166	2553.74

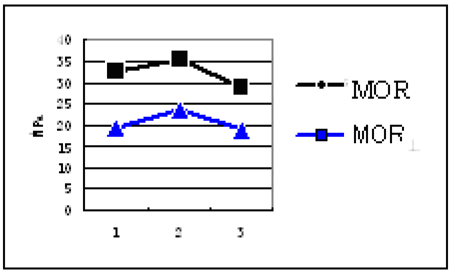

Figure 12: Effect of hot pressing time on MOR

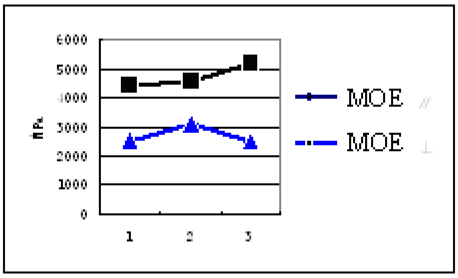

Figure 13: Effect of hot pressing time on MOE

From Fig. 12 and 13, we can see that there was no big difference of the hot pressing time on MOE and MOR.

Main influence factor analysis of MOE and MOR

Main influence factor analysis of MOE and MOR was shown in Table 12 and Fig. 14 and 15.

Table 12: Main influence factor analysis of MOE and MOR

Factor	MOR (MPa)		MOE (MPa)	
	Parallel	Perpendicularity	Parallel	Perpendicularity
Flake size	30.5	23.15	3543.19	3035.54
Resin content	9.37	6.61	2206.07	1005.98
Hot pressing time	6.65	4.57	768.3	597.2

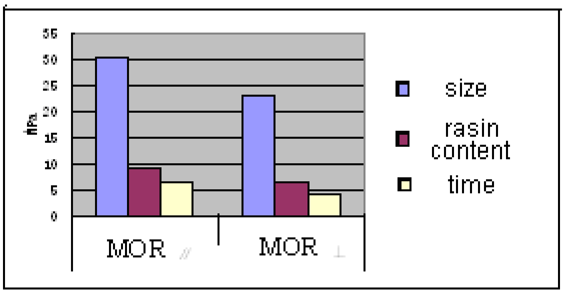

Figure 14: Comparison of the main influence factors of MOR

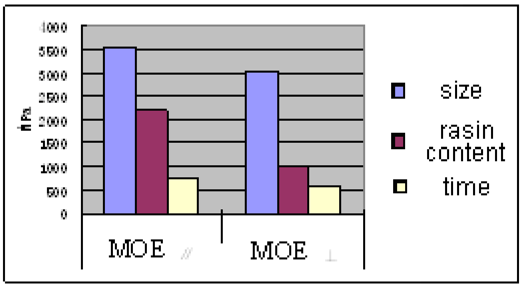

Figure 15: Comparison of the main influence factors of MOE

From Fig. 14 and 15, we obtained that the flake size was the main factor, secondly was resin content, the minimum was hot pressing time.

According to the forestry industry standard of the Peoples` Republic of China LY/T 1580 – 2000 about the regulation value of OSB/2 (general name depth is 10 mm) we compared the

MOE and MOR. The values obtained from big size flake pressed boards are all beyond the standard; and only the resin content was 11% where the medium size flake pressed boards could accord to the request of standard.

TS (Tensile Strength)

Influence of flake size on TS

The influence of flake size on TS was shown in Table 13 and Fig. 16.

Table 13: Influence of flake size on TS

Flake size	TS
Big	12.46%
Medium	13.31%
Small	13.85%

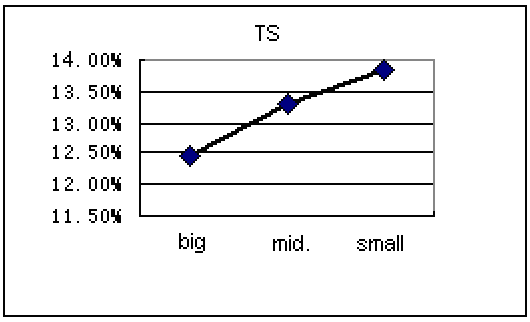

Figure 16: Influence of flake size on TS

The T increased with decreasing flake size as shown in Fig. 16.

Influence of resin content on TS

The influence of flake size on TS was shown in Table 14 and Fig. 17.

Table 14: Influence of resin content on TS

Serial number	Resin content	T S
1	11%	12.72%
2	9%	13.18%
3	7%	13.72%

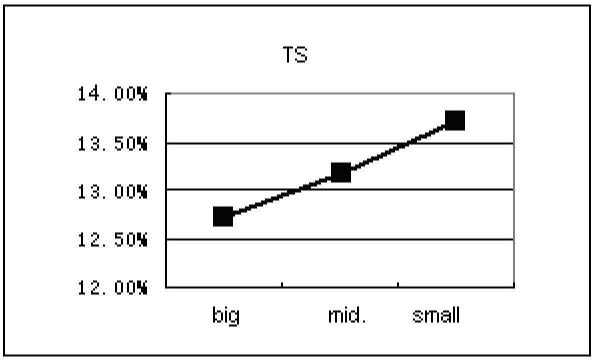

Figure 17: Influence of resin content on TS

Fig. 17 showed that TS increased when decreasing resin content.

Influence of hot pressing time on TS

The influence of hot pressing time on TS was shown in Table 15 and Fig.18.

Table 15: Influence of hot pressing time on TS

Serial number	Hot pressing time	T S
1	7.0	13.54%
2	5.5	13.31%
3	4.0	12.77%

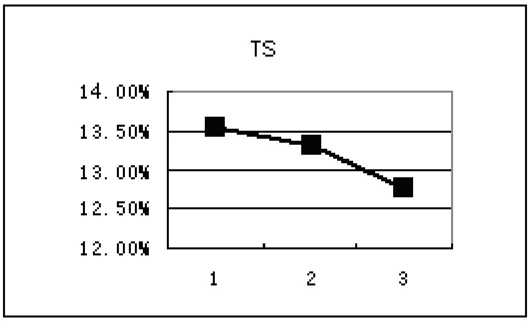

Figure 18: Influence of hot pressing time on TS

Fig.18 showed that TS increased when increasing hot pressing time.

Table 16 and Fig. 19 show the comparison of level difference of the three main influence factors.

Table 16: Comparison of main influence factor on TS

Factor	Level difference
Strand size	1.39%
Resin content	1%
Hot pressing time	0.77%

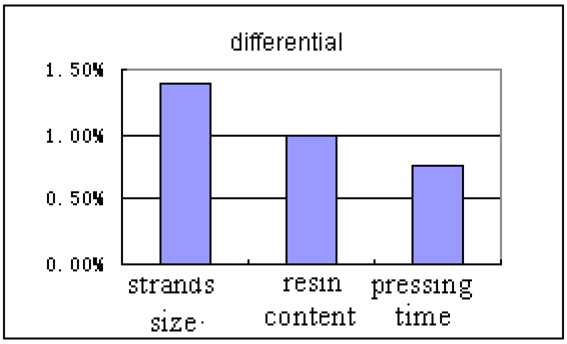

Figure 19: Comparison of main influence factor on TS

Fig. 19 showed that the flake size was the main factor, secondly was resin content, the minimum was hot pressing time.

According to the forestry industry standard of the Peoples` Republic of China LY/T 1580 – 2000 about the part of OSB, we compared the experiment value with the regulation value of this standard. Data analysis was shown in Table 17.

Table 17: Comparison of the experiment value and standard value

Serial number	1	2	3	4	5	6	7	8	9	Standard
TS	13.6%	12.8%	10.9%	14.0%	14.5%	11.5%	15.2%	13.2%	13.1%	20.0%

Table 17 shows that all experiment values are smaller than standard values, which accorded to the request.

Optimize test

According to the experiment result, the experiment plan was optimized (table 18) and the property was measured (Table 19).

Table 18: Optimize test plan

Strands size	Resin content (g)	Resin type	Hot pressing time min/mm
Big	11%	UF	0.55

Table 19: Main properties of optimized test

	MOE (MPa)		MOR (MPa)		IB	
Item	Parallel	Perpendicularity	Parallel	Perpendicularity	(MPa)	TS
Test value	6632.36	4477.99	45.26	28.7	0.47	12%
Standard value	3500	1400	20	10	0.34	20%

CONCLUSIONS

From the analysis of results, we obtained the optimized test plan. The waste veneer OSB had a better quality and superior property, which could achieve the use standard of OSB/2. Table 3 showed that the medium and small size flakes could also attain the standard of OSB/1.

The flakes that came from the crushed materials were tested, which accorded to the OSB standard (OSB/1 and OSB/2). The flake size was up to 80%. If we mass produce, the miller should be improved, which can enhance the efficiency of crushing the material and obtain a more uniformity flake size. We think that the pieces coming from the plywood remains can be made into OSB/1 and OSB/2. This can not only save the raw material but also decrease the dash giving off.

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The effects of Poplar clones age variations and production conditions on medium density fiberboard (MDF) properties

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Keywords: Poplar, fiberboard, fiber, resin, clone, steaming

ABSTRACT

In this study, MDF was produced from three clones of poplar (*P.e. vernirubensis*, *P.e. costanzo*, *P.e.*561.41). The age of the poplar clones was 4 and 12 years. In addition to age variation, the influences of three production variables (steaming time, press time and resin content) on MDF properties were investigated.
Variation of each variable was as follows:
Steaming time (5, 10, 15 minutes)
Press time (3, 4, 5 minutes)
Resin content (9%, 11%)
Fiber length and fiber diameter of 4 and 12 years old poplar clones (*P.e. vernirubensis*, *P.e. costanzo*, *P.e.*564.41) were measured 746, 25.23, 805, 25.76,751, 25.44 and 902, 31.62, 995, 29.23, 899, 26.83 micron respectively. MOR, MOE, IB, TS2, TS24 were determined according to European EN standards.
Increasing steaming time decreased the internal bond and bending properties of the boards. Also increasing press time increased the internal bond. The effect of press time on bending properties was not significant. As expected, the boards demonstrated better properties at higher resin consumption. Minimum board thickness swelling was obtained at 15 minutes steaming time because of fiber hydrophilic properties were decreased. There was no significant difference between the strength properties of boards made up of 4 and 12 year old poplar clones except for the thickness swelling. The effect of clones' age on thickness swelling after 2 and 24 hours was significant and thickness swelling of boards made by poplar clones of 4 year old was less than boards made by poplar clones of 12 year old.

Properties of Enhanced Laminated Veneer Lumber from Poplar

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Keywords: Poplar, laminated veneer lumber (LVL), mechanical properties, compaction ratio, fibreglass reinforcement, impregnated veneer, assembly structure

ABSTRACT

Fast-growing poplar plantation has greatly benefited the Chinese wood industry. And development of laminated veneer lumber (LVL) from poplar wood is an effective and efficient way of utilizing the poplar resource in China. To make common poplar LVL be more competitive as a construction material, enhancing the mechanical properties of common poplar LVL products is of very importance.

This paper investigated the effects of compaction ratio, assembly structure with veneers of different thickness, assembling with resin-impregnated veneers and fibreglass reinforcement on selected mechanical properties of enhanced poplar LVLs including modulus of rupture (MOR), modulus of elasticity (MOE), shear strength and bending creep behaviour. Among all the enhancement methods, increasing compaction ratio was the most effective way to enhance the properties. Higher compaction ratio resulted in higher MOR, MOE and shear strength and less deflection related to bending creep. LVL assembled using thinner veneers in the outer layers and thicker veneers in the core layers, as well as LVL made by resin impregnated veneers presented improved mechanical properties. Reinforcement with resin-impregnated fibreglass mat had less effective influence on the mechanical properties of LVL. The bending creep behaviour of LVLs was similar to that of wood. However, the instantaneous recovery of LVL specimens, measured after load was removed, was less than the instantaneous deflection. The enhancement methods investigated in this research could improve LVL products by increasing their MOR and MOE as well as modifying creep behaviour.

INTRODUCTION

China has 175 million hectares of forest, with a stock volume of 12.456 billion m^3 and forest coverage of 18.21%. The gap between wood demand and supply was 36 million m^3 in 2000, and that in 2004 was 109 million m^3. It is foreseen that the annual gap would be at least 100

million m^3 in the following years. To positively solve the domestic wood shortage problem, the Chinese government has been promoting the utilization of existing available wood resources efficiently, encouraging the plantation of fast-growing wood species, and focusing on developing high-performance structural-use wood-based composites from those low-grade small diameter fast-growing wood species. Poplar is the main fast-growing plantation wood species in Jiangsu province and the poplar industry has contributed a lot to the development of the wood processing industry and local economy in Jiangsu province. Current commercial poplar-based composites are mostly plywood for non-structural use and concrete forms, block board, and Medium Density Fibreboard. Using the small diameter logs efficiently and effectively is the key to plantation fast-growing wood species like poplar and to the development of a sustainable forestry. One way to achieve this is to manufacture highly value-added products from poplar wood such as various structural composite lumbers (SCL) and boards including Laminated Veneer Lumber, Oriented Strand Board, etc.

Laminated Veneer Lumber (LVL) is a veneer-based engineered structural composite lumber manufactured by layering dried and adhesive-coated wood veneers in the same direction followed by curing with a heated press. Being known as a structural composite lumber, LVL has unique characteristics such as uniform engineering property, flexible size and high strength. LVL can best be made from middle to small-diameter logs from fast-growing plantation forests, and it has been used as a construction component for beams and headers where high strength, dimension stability and reliability are required. Some mechanical properties are highly important for a structural material like LVL. MOE is a measure of resistance to deflection, and is one of the most important mechanical properties of wood composites since it impacts the serviceability and the structural performance for both exterior and interior applications (Chen *et al.* 2008). MOR is the measure of the force necessary to break a given substance across. Creep is defined as the time-dependent deformation exhibited by a material under constant load. Numerous examples can be cited in which the time-dependent stress-strain behaviour of wood composites is particularly important. Beams sometimes fail under sustained loads which are less than the ultimate static load (Bodig and Jayne 1993).

Some mechanical properties of fast-growing poplar, for instance MOR and shear strength of poplar LVL, are comparable to those of the natural poplar wood while others, like MOE, are inferior to those of nature poplar wood. Currently, around 40% to 60% of LVL produced is used as construction material, which has high requirements for the mechanical performance of LVL. Developing enhanced poplar LVL products with satisfactory mechanical properties is very crucial to properly and efficiently utilize the poplar wood and poplar LVL.

Several researches demonstrated that improvements in properties of LVL could make it more competitive for structural uses and mechanical properties when improved by increasing density, either by compaction during processing or by impregnating some or all of the veneers with subsequently polymerized material (Chui *et al.* 1994). Zhao *et al.* (2001) investigated the effect of veneer thickness on the strength of LVL made from *Populus ussuriensis*, and they found out that the thickness of veneer was the main factor that affects the strength of LVL. The thicker the veneer, the lower the shear strength was found (Zhao *et al.* 2001). Chui et al. made two types of LVL boards, one had all impregnated veneers and the other had only the outer veneers impregnated with a water-soluble, phenol-formaldehyde (PF) resin. Compared

with untreated LVL, both types of treated LVL had improved mechanical properties and dimensional stability (Chui *et al.* 1994).

Based on those previous works, several methods were tried to develop enhanced poplar LVLs with satisfied mechanical properties. The purposes of this research are:

- To investigate the effect of compaction ratio on mechanical properties;
- To examine the influence of assembly structure with poplar veneers of different thickness on mechanical properties of the LVL;
- To determine the effect of fibreglass reinforcement on the mechanical properties;
- To explore the effect of assembling structure with PF-resin impregnated veneers;
- To explore the creep behaviour of poplar LVL products.

MATERIALS AND EXPERIMENTAL METHODS

Materials

Phenol Formaldehyde (PF) resin

A commercial PF resin with a viscosity of 280mPa· s (20℃) and a solid content of 45±1% was used in the research. The free formaldehyde content of the resin was less than 0.5%.

Poplar Veneers

Poplar veneers were bought from a commercial production line. The thickness of thin poplar veneers was 1.5mm, while that of the thick ones was 3.0 mm. The moisture content before manufacturing was about 10%.

Fibreglass Mat

Type EW100-90 fibreglass mat with a thickness of 0.1mm was bought from a fibreglass research institute in Nanjing.

Experimental Methods

Experimental Design

In order to investigate the effects of compaction ratio, mat assembly structure, veneer resin-impregnation and PF-impregnated fibreglass reinforcement on the selected mechanical properties of enhanced poplar Laminated Veneer Lumber (LVL), seven different types of poplar LVL were made. Types A~D all consisted of PF resin-spreaded veneers with a thickness of 3mm; type E was assembled by combining veneers with two different thicknesses, i.e., 1.5 mm and 3.0 mm; type F was composed of PF resin-impregnated 3mm thick veneer, and type G was reinforced with PF-resin impregnated fibreglass mat. The details of the experimental design were listed in Table 1.

Table 1: Experimental Design

Type	Characteristic	CR [a] [%]	Mat structure
A	Control	21	Even, consisted of PF resin-spreaded 3mm veneers
B	Low CR	18	Even, consisted of PF resin-spreaded 3mm veneers
C	Middle CR	24	Even, consisted of PF resin-spreaded 3mm veneers
D	High CR	27	Even, consisted of PF resin-spreaded 3mm veneers
E	Mat assembled with combination of thin and thick veneer	18	Uneven, both the top and bottom 4 layers were PF resin-impregnated 1.5mm veneers, with the rest of the mat consisting of PF resin-spreaded 3mm veneers.
F	Mat consisted of PF resin impregnated veneer	21	Even, consisted of PF resin- impregnated 3mm veneers
G	Reinforced with PF-resin impregnated fibreglass mat	21	Uneven, the top and bottom 2nd and 4th layers were PF-resin impregnated fibreglass sheets, see Fig. 1.

[a]*compaction ratio*

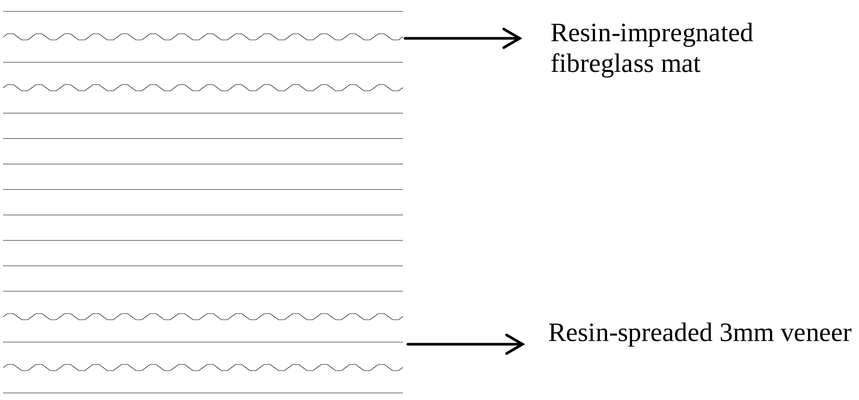

Figure 1: The location of PF-resin impregnated fibreglass mat in a LVL product

Manufacturing Parameters

The other parameters in producing the above-mentioned 7 types of LVL were listed as follows:

- Resin loading level for 3mm-thick poplar veneer (Resin spreaded): 220g/m^2 (double sides);
- Resin loading level for 3mm-thick poplar veneer (Resin impregnated): 25% (solid resin content based on the oven-dry wood basis);
- Resin loading level for 1.5mm-thick poplar veneer (Resin impregnated): 32% (solid resin content based on the oven-dry mass of wood);
- Resin loading level for fibreglass mat: 100% (solid resin content based on the oven-dry mass of fibreglass);
- Hot pressing temperature: 160 °C;
- Hot pressing time: 1 min/mm product thickness;
- Product dimensions: 1200mm×1200mm ×38mm

Evaluation of Properties

The tests for the evaluation of MOR, MOE, shear strength and density were conducted according to Japanese structural LVL standard- JAS 1494-1991.

Among the 7 types of LVL, five of them, i.e., types A, C, E, F, G, were selected for bending creep test. Types B and D, were not included in the creep test because of their similarities to types A and C. Prior to specimen preparation, all 5 types of LVL were conditioned in a standard conditioning climate of 20±2°C and 65±5% for a week. A load, corresponding to the one-third of ultimate short-term strength load, was applied on the length centre of specimen to create three-point bending. The distance between two loading heads was 24 times of LVL thickness. The bending creep tests were carried out in an uncontrolled indoor summer environment (28-36°C, 70% to 75% relative humidity). The load duration time was 504h, and midspan bending deflection was measured by a dial gauge with an accuracy of 0.01 mm. Also, the dial gauge was used to measure the deflection recovery 336h after the load was removed. The specimens were then used to determine the residual MOR.

RESULTS AND DISCUSSIONS

Results

The determined properties of 7 types of LVL were listed in Table 2 and plotted as shown in Fig. 2. The creep behaviours of 5 types of LVL were given in Table 3 and plotted in Fig. 3.

Table 2: Physical and mechanical properties of 7 types of LVL

NO.	MOR (Mpa)	MOE (Mpa)	$S_{/\!/}$ (Mpa)	$S_{\perp}$ (Mpa)	Density (g/cm^3)
A	103	9910	7. 2	8. 1	0. 54
B	96	9160	6. 9	7. 8	0. 52
C	128	11560	8. 0	9. 2	0. 59
D	145	13200	11. 5	13. 8	0. 66
E	121	11480	8. 6	10. 1	0. 53
F	109	11000	8. 8	11. 1	0. 61
G	106	9980	7. 6	9. 1	0. 67

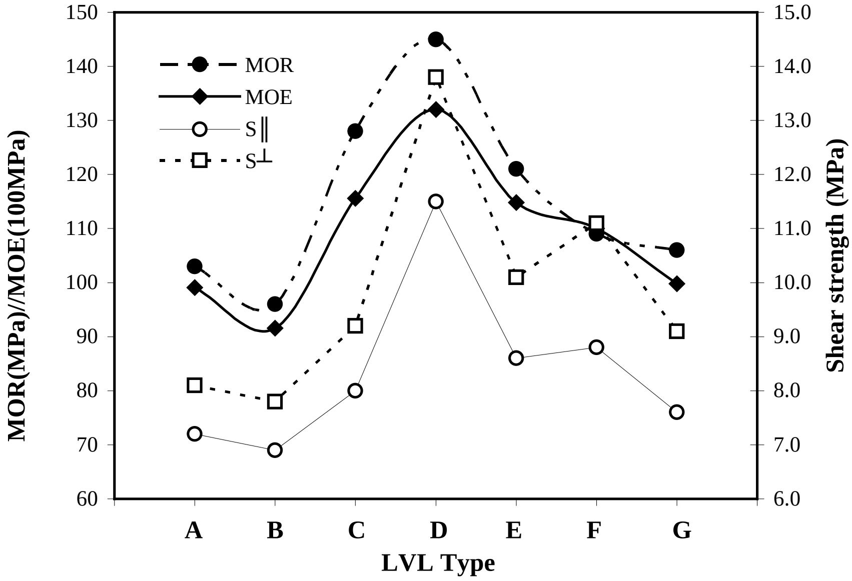

Figure 2: Mechanical properties of 7 types of poplar LVLs

Table 3: Results of bending creep test of 5 types of LVL

Type	A	C	E	F	G
Residual MOR (MPa)	87.9	123	117	100	96
Instantaneous deformation (mm)	4.05	2.42	3.50	3.72	3.85
Instantaneous recovery (mm)	3.80	2.15	2.94	3.15	3.26
Max. deflection (mm)	4.68	2.65	3.70	4.15	4.28
Permanent set (mm)	0.81	0.32	0.48	0.73	0.90

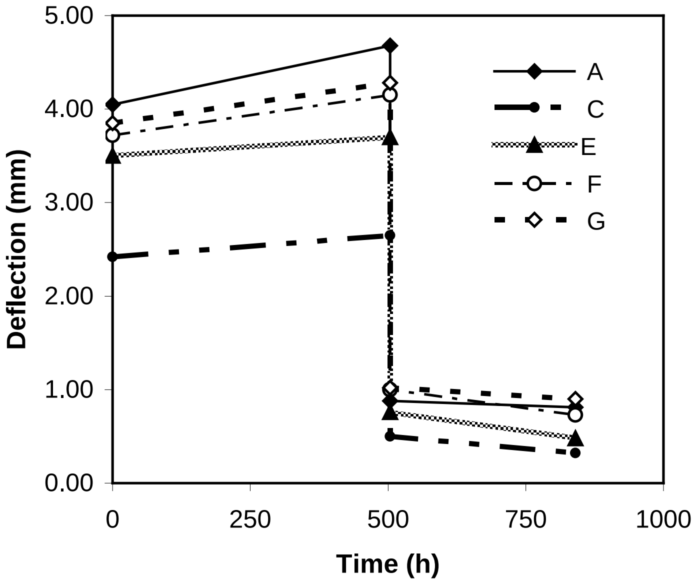

Figure 3: Creep curves of 5 selected types of poplar LVL

Discussions

It was clear from Table 2 and Fig. 2 that MOR and MOE of the LVL were increased with the increase of the compaction ratio among type A to type D, and type D had the highest values of MOR and MOE among the 7 types of LVL. The increase in compaction ratio directly increased the product density, which in turns enhanced the properties of the LVL products. For example, the density of type D was only 26% higher than that of type B, the resulted bending MOR and MOE of type D were 50% and 44% higher than those of type B respectively, while shear strengths in two directions were increased by 67% and 77% respectively. Obviously, enhancing the mechanical properties of poplar LVL by increasing the product density was highly effective.

Again, it was apparent from Table 2 and Fig. 2 that compared to type A, the bending properties of type F was increased only by 5.8% and 11.0%, while the increase in shear strength was much more significant, by 22 % in parallel direction and 37% in perpendicular direction. The shear strength of type F was even higher than that of type C which has a higher compaction ratio than type F. It seems that using resin-impregnated veneers did not increase bending properties that much, but it did enhance the shear strength. It was also clear that using resin-impregnated fibreglass mat did not enhance properties of poplar LVL compared to the properties of type A and type G products.

It was interesting to compare the product structure and property differences between type B and type E. Both these two types of LVL were hot-pressed under the same compaction ratio and the densities of them were close to each other, the only structure difference was that there were 4 layers of 1.5 mm-thick resin-impregnated veneers on both top and bottom of the type E products instead of 2 layers of 3.0 mm-thick resin-spreaded veneers in type B. This structure difference resulted in big differences in mechanical properties as we can see from the bending properties. MOR and MOE of type B were only 78% and 79% of those of type E, respectively, and the situation was similar for the shear strength of the two types. It was

obvious that the mechanical properties were enhanced by assembling the resin-impregnated thin veneer on the outer layers instead of using all even veneers of the same thickness to assemble a product.

As seen from Table 3 and Fig. 3, instantaneous deflections of all types of LVL were apparently observed. The creep curves were similar to that of solid wood (Fig. 4). Type A had the largest instantaneous deflection, maximum deflection and largest instantaneous recovery as well, followed in a decreasing order by type G, type F, type E and type C. This order was exactly the opposite to the order of bending properties (MOR and MOE), which meant that within the range of this study, LVL types with higher bending properties presented better creep behaviours and the methods enhancing the bending properties of LVL also benefited the product's creep behaviour.

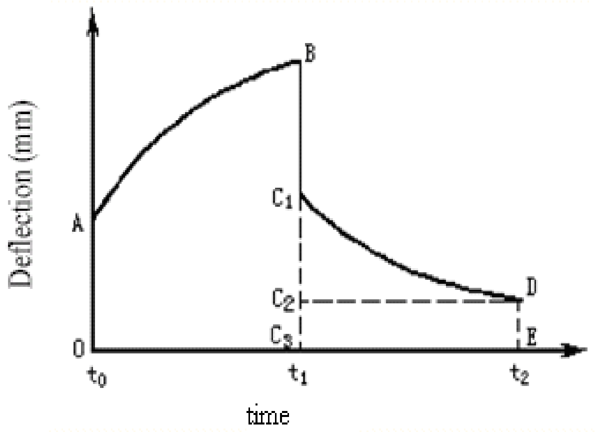

Figure 4: Creep curves of solid wood

When the load was removed, the instantaneous recovery of 5 investigated LVL types were all less than the instantaneous deflection value. This was different from the creep behaviour of solid wood. In the creep test of wood, the instantaneous recovery was found to be equal to instantaneous deflection as Fig. 4 shown (Fig. 4, AO=BC_1).

Among the 5 types of LVL, product C had the lowest value of deflections and highest value of residual MOR as shown in Table 3 and Fig. 3. Obviously, product C had much better creep resistance than the other 4 products, which indicated that compaction ratio had a strong influence on the creep performance and was the best way to enhance the creep performance within the research. The creep performance of type E was evaluated as the second following type C, which indicated that assembling with the resin-impregnated thin veneer on the outer layers also enhanced the creep behaviour of the products although type E was hot-pressed at the lowest compaction ratio.

Type A, type G and type F were three LVL types hot-pressed at the same compaction ratio, but there was difference found when comparing their creep behaviours. Type F had the best creep resistance property among them, which indicated that assembling with the resin-impregnated veneers could also benefit the creep behaviour of poplar LVL.

CONCLUSIONS

In order to improve and enhance the mechanical properties and creep resistance of common LVL from fast-growing poplar, several ways, including increasing the compaction ratio, assembling with resin-impregnated veneers and with veneers of different thickness, fibreglass mat reinforcement, were carried out and their effects on selected properties of poplar LVL were evaluated. Based on the research, the following conclusions could be drawn:

- Improving the density of resultant products and assembling the LVL product mat in a reasonable way (i.e., assembling with thin veneer in outer layers and thick veneers in inner layers) were the appropriate approaches to enhance the mechanical properties and creep resistance of poplar LVL;
- Assembling with resin-impregnated veneers may improve the mechanical properties and creep resistance of poplar LVL, while assembling with resin-impregnated fibreglass mat may not have significant effect on the properties of LVL;
- The creep behavior of poplar LVLs was found to be very similar to that of solid wood, with an instantaneous deflection higher than the instantaneous recovery;
- Improving the bending properties would benefit the creep resistance of poplar LVL.

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Manufacture of laminated veneer lumber with starch-based adhesives

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Keywords: Starch-based adhesive, laminated veneer lumber

ABSTRACT

A starch based adhesive was made with corn starch through hydrolyzation, oxidation, and co-reaction with propylene monomer. Solid content of the adhesive was controlled at 40 to 50 percent, and dry bonding strength of plywood with the adhesive achieved 0.8MPa. The starch based adhesive was further mixed with melamine formaldehyde resin (MF, 5~30%) or diphenylmethane diisocyanate (MDI, 5~10%) to produce laminated veneer lumber (LVL) in different trials. Hot-pressing technical data were: pressure 0.8~1.0MPa, temperature 120~130°C, and period 20~30min.

LVL products were tested following the Chinese national standard GB/T20241-2006. It was demonstrated that mechanical properties, e.g., peeling strength, are in line with the specifications in GB/T20241-2006, and that formaldehyde emission meets E1 grade.

INTRODUCTION

In the 21st century, environment-friendliness will become a major characteristic of new materials. Starch, as one kind of non-toxic, inexpensive, biodegradable and renewable resource, is extremely widespread in various applications and industries, such as chemical, papermaking, textile, printing, medicine, food, dressing, oil field mining, waste water treatment and packaging industries.

So far, starch adhesive is mainly applied in paper, woven cottons, envelopes, labels and corrugated paper panels, while in the wood gluing industry, the bond strength cannot achieve the requirement of synthetic resin bonded plywood.

This research began from traditional oxidation of corn starch, using different oxidant oxidation methods, initially improving the starch workability, and then grafted monomers further enhancing the bondability between starch and wood, hence increasing the bond strength.

On basis of production of starch adhesive, orthogonal design testing methods were used to prepare laminated veneer lumber (LVL) by mixing corn starch glue and melamine

formaldehyde (MF) resin, aiming at satisfying the national standard for LVL (GB/T20241-2006). The national standard of testing methods of wood composition boards (GB/T17657-1999) was followed in the tests.

EXPERIMENTAL METHODS

Fast grown poplar veneer was obtained from Jiangsu Siyang, with thickness of about 1.5mm, moisture content below 5%.

Starch-based adhesive was made in laboratory, with powder to water ratio as 2:3.

Using the orthogonal design testing method, experiments were conducted for three factors, i.e., the mass ratio of corn starch emulsion and MF resin, the hot-pressing temperature, the hot-pressing time.

Table 1: The testing factors and levels

Level	A: temperature (°C)	B: mass ratio	C: time(min)
1	120	7:3	30
2	130	8:2	35
3	140	9:1	40

RESULTS AND DISCUSSION

Test results of all laminated veneer lumbers following the above-introduced three factors were shown in Table 2.

Table 2: The testing result

Test No.	peeling strength	Modulus of Elasticity (MPa)	Modulus of Rupture (MPa)
1 A_1 B_1C_1	0.07	11251.22	104.02
2 A_1 B_2C_2	0.15	8525.37	83.76
3 A_1 B_3C_3	0.14	12060.41	103.78
4 A_2 B_1C_2	0.04	13090.63	130.56
5 A_2 B_2C_3	0.07	10343.59	97.84
6 A_2 B_3C_1	0.21	12210.07	110.12
7 A_3 B_1C_3	0.03	12157.64	120.39
8 A_3 B_2C_1	0.06	11270.88	100.66
9 A_3 B_3C_2	0.39	12767.60	114.18

Peeling strength

Table 3-1 and 3-2 analyzed the influence of mass ratio of corn starch and melamine formaldehyde on the stripping of LVL glue line. All three levels, i.e., 7:3, 8:2, and 9:1, meet the standard requirements, i.e., total glue line peeled length lower than 1/4 of total length of

LVL panel. The glue of 70% corn starch and 30% melamine is the best. Considering cost and LVL quality, mass ratio of corn starch to MF as 8:2 is suggested.

As for temperature at 120°C, 130°C, and 140°C, as well as pressing period of 30min, 35min, and 40min, all tested samples showed peeling strength satisfying the standard specification. 130°C and 30min is reasonable when regarding cost.

Table 3-1: Visual analysis of peeling strength

	A	**B**	**C**	
K -A_1	0.122	0.046	0.114	0.177
K- A_2	0.105	0.091	0.193	0.129
K- A_3	0.158	0.248	0.078	0.079
Range	0.053	0.202	0.115	0.098

Table 3-2: One way analysis of variance

Factor	**SS**	**Freedom**	**F**	**F critic**	**Significance**
A	0.004	2	0.286	19.000	
B	0.068	2	4.857	19.000	**
C	0.021	2	1.500	19.000	
Error	0.01	2			

Modulus of Elasticity

According to Table 4-1, the mass ratio of corn starch to melamine formaldehyde is the primary factor affecting the elasticity coefficient. Comparing three mass ratio levels, i.e., 7:3, 8:2 and 9:1, the latter is most superior. The reason is MF will become crisper, after solidifying. According to the data for MOE in different hot-compression temperatures 120°C, 130°C and 140°C, when the thermo-compression temperature increases, the elasticity coefficient increases accordingly. When thermo-compression temperature is 140℃, MOE is best.

Table 4-1: Visual analysis of modulus of elasticity

	A	**B**	**C**	
K- B_1	10612.34	12166.50	11577.39	11454.14
K- B_2	11881.43	10046.61	11461.20	10964.36
K- B_3	12065.38	12346.03	11520.55	12140.64
Range	1453.04	2299.42	116.18	1176.28

Table 4-2: One way analysis of variance

Factor	**SS**	**Freedom**	**F**	**F critic**	**Significance**
A	3755765.38	2	1.793	19.000	
B	9813463.20	2	4.685	19.000	**
C	20252.27	2	0.000	19.000	
Error	2094800.06	2			

Modulus of Rupture

According to Table 5-1, the corn starch and the melamine mass ratio is the primary factor affecting the static bending strength. Comparing corn starch and the melamine mass ratio 7:3, 8:2 and 9:1, when the corn starch and the melamine mass ratio is 7:3, it is best. According to the data of MOR in different hot-compression temperature 120°C, 130°C and 140°C, when the hot-compression temperature is 130°C, it is best. According to the data of MOR in

different hot-compression time 30min, 35min and 40min, when hot-compression time is 35min, it is best.

Table 5-1: Visual analysis of modulus of rupture

	A	**B**	**C**	
K- C_1	97.186	118.323	104.935	105.347
K- C_2	112.839	94.087	109.500	104.757
K- C_3	111.744	109.360	107.334	111.665
Range	15.653	24.236	4.565	6.908

Table 5-2: One way analysis of variance

Factor	**SS**	**Freedom**	**F**	**F critic**	**Significance**
A	458.157	2	5.207	19.000	
B	900.998	2	10.241	19.000	**
C	31.274	2	0.355	19.000	
Error	87.98	2			

Formaldehyde release

If melamine formaldehyde (MF) resin is added into starch glue, LVL bond strength will increase, and it is cheaper as for commercial purpose. However, the disadvantage is formaldehyde is introduced into the product. Formaldehyde release for LVL (18-20mm) produced with that process was 3.0-3.4mg/L. In the further experiment, 1% ammonia-based compound was added into starch base glue including MF, the formaldehyde release was 2.4-2.6mg/L. When the ammonia-based compound increased to 2-3%, formaldehyde release of LVL achieved E1 standard (lower than 1.5mg/L).

CONCLUSIONS

The best hot-pressing process for LVL preparation with starch-based adhesives: hot-pressing temperature is 130°C, hot-pressing time 30min, and the mass ratio of corn starch glue to melamine formaldehyde resin is 8:2. When the ammonia-based compound was added to the starch based adhesive, formaldehyde release of LVLs achieved E1 standard.

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Low-density magnesia wood-wool panel: Hydration reaction of materials

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Keywords: Magnesia, wood-wool panel, hydration reaction, additives

ABSTRACT

In this research on low-density magnesia wood-wood panels the hydration reaction of magnesia and brine was tested using heat as a parameter. The effect on the hydration reaction heat was analyzed in function of different wood species and additives. As such, a theoretical basis for manufacturing of functional magnesia wood particleboards in the future can be provided.

INTRODUCTION

With the improvement of living standards and the enhancement of environmental awareness, people increasingly focused on environmental protection, thermal insulation, sound-absorbing, decorative, and other multifunction integrated in the development of new building materials. Low-density magnesia wood-wool panel is such a building material. At present, it is produced and used widely abroad and commonly used for noise reduction and acoustic insulation materials in industrial and civil construction. In recent years, import low-density cement wood-wool panel is used widely as a decorative sound-absorbing material in some public buildings in China. Because of its excellent physical and mechanical properties and fashion decorative appearance, its recognition degree is getting much bigger and its application scope is getting more and more widely.

Magnesia (Armstrong 1976) is mainly composed of magnesium which is grinded after being sintered at high temperature from natural magnesite or dolomite and can form a gas rigid cementitious material by hydration reaction with $MgCI_2$. There are very rich magnesite resources in China, with a total reserve of about 80 million tons, ranking first in the world, of the world's total reserves of 1/4, mainly in Haicheng, Yingkou in Liaonning province and Laizhou in Shandong province and other places (Bai 1996).

The source of wood-wool can be from slipping of solid wood panel or also from cutting of veneers. The production of Chinese plywood ranks first in the world. In spite of being the first in production numbers, the products are middle and low-quality products, caused by the

excessive use of broken veneers. The development of reasonable and high value-added broken veneers is one of the directions to improve the benefits of Chinese plywood industry.

In this paper, rich resource of magnesia of China and plenty of deposed veneers made from fast-grown trees are used to manufacture low-density magnesia wood-wool panel. The paper will be published in succession divided into four parts: (1) the hydration reaction of material; (2) Manufacturing technological parameters of steam-pressing technique; (3) Comparison of manufacturing techniques; (4) Improvement of hygroscopicity.

The hydration reaction of material

The main products for making high strength magnesia are two double salt crystals: $5Mg(OH)_2 \cdot MgCI_2 \cdot 8H_2O$ and $3Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O$ (Bilinki and Matkovic 1984). The two double salt crystals link together and result in high strength magnesia, whose crystalline form directly affects the strength and property of magnesia. The main factor of effect is molar ratio of MgO, $MgCI_2$ and H_2O. Their chemical reaction equations are shown as follows:

$$5MgO+MgC1_2+13H_2O \rightarrow 5Mg(OH)_2 \cdot MgCI_2 \cdot 8H_2O$$

$$3MgO+MgCl_2+11H_2O \rightarrow 3Mg(OH)_2 \cdot MgC1_2 \cdot 8H_2O$$

Different molar ratio will generate different hydration products (Duan and Cheng, 2001);when the molar ration of MgO：$MgCl_2$ ：H_2O is 5：1：13, they are all 5 phase in magnesia; when the molar ratio is 8：1：14, they are 86.2% 5 phase, 12.2 % $Mg(OH)_2$ and 1.6 % MgO; when the molar ratio is 10：1：15, they are 50.9 % 5-phase and 49.1 % $Mg(OH)_2$; when the molar ratio is 3：1：11, they are 79 % 3-phase and 21 % 5-phase and the 21% 5-phase will turn into 3-phase within one month.

The crystal forms of 5-phase and 3-phase (Sorrell and Armstrong 1976) are fibrous, 5-phase is coarse like a bar and 3-phase is thin like a needle. The crystal morphology is a big massive crystal with a layered structure. From the crystal morphology (Urwongse and Sorrell 1980), the 5-phase crystal has excellent strength and stability. The hydration products of magnesia should be based mainly on the 5-phase crystals as well as adequate $Mg(OH)_2$ and MgO. So the molar ratio of MgO and $MgCl_2$ should be improved moderately to make magnesia strength best on the basis of the molar ratio of MgO, $MgC1_2$ and H_2O, satisfying the chemical equation 5：1：13 to generate the 5-phase crystals.

Magnesium oxychloride products can experience a phase transformation during the using period because of effect of the vapor and CO_2 in the air (Zhang et al 2002):

$$5Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O=5Mg(OH)_2+Mg^{2+}+2Cl^-+8H_2O$$

$$3Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O=3Mg(OH)_2+Mg^{2+}+2Cl^-+8H_2O$$

$$3Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O+2CO_2=Mg(OH)_2 \cdot 2MgCO_3 \cdot MgCl_2 \cdot 6H_2O+4H_2O$$

5.1.8-phase and 3.1.8-phase turn into $Mg(OH)_2$ phase after hydrolysis which turns into loose structure from previous impact structure and the porosity increases thus not only making strength lower but also appear brine and cream because of MgCl2, and a small amount of MgO will move to the products surface through nonporous due to the formation of free Mg^{2+} and Cl^-.

So there are several types of modifying methods, shown as follows: (1) add material which can react with $MgCl_2$; (2) add material which can block the capillary channel; (3) add surface treatment agent and form waterproof membrane. Thus different additives should be selected to improve the waterproof property.

The compatibility between wood and inorganic material is also very important during the inorganic bonding process. In the past, researchers focused on the research of bonding mechanism of portland cement and wood. The main contents in this paper are: by testing the hydration reaction heat of magnesia and brine, the effect of different species of wood and additive on the hydration reaction heat was analyzed in order to provide a theoretical basis for manufacturing the functional magnesia wood particleboard in the future.

MATERIALS AND METHODS

Materials

Poplar and southwest birch were selected to use in the experiment. The sapwood heartwood of two species are separated to test 1) poplar, sapwood pH=5.3 (heartwood pH=5.9) 2) southwest birch, sapwood pH=5.6, heartwood pH=5.8. Then they were made into wood flour and added with the ratio 100 : 15 of magnesia : wood flour.

The magnesia used accepted product accordance with the standard JC/T449-1991. Its components are shown in Table 1.

Table 1: Chemical components of magnesia

Variety	Specification	Ignition loss	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO
Magnesia	120	10	3	0.8	0.6	1.2	83％

Industrial $MgCl_2$ of 47% content was used as hardening agent and $MgCl_2$ solution of relative density was prepared by using a density meter. The brine which had relative density of 1.28 was used in the experiment. In this study, the molar ratio of MgO and $MgC1_2$ is 6.43:1 which was higher than the theoretical value of 6 : 1 for consideration of activity attenuation of MgO.

Talcum powder, oleic acid, ammonium and Al_2O_3 powder were selected as additives. Their adding proportion is shown in Table 2.

Table 2: Quality proportion of additives

Proportion	$MgC1_2$ solution	Al_2O_3 powder	Oleic acid	Ammonium	Talcum powder
Magnesia 100	110	3	3	3	3

Test method of hydration heat

The required materials were put into a plastic cup to mix uniformly, and then the plastic cup was put into a big mouth Vacuum Flask, around the cup filling insulation materials. The thermometer was inserted to observe and record temperature changes every 20-30 minutes until it reached the maximum temperature, and the highest attainable temperature and the required time were recorded.

Iw method was used to evaluate the hydration reaction between wood and magnesia.

$$Iw=100\times(\theta-\theta s)/\ \theta s$$

θ — required time to reach the highest hydration temperature after magnesia mixed with wood and water, h

θs— required time to reach the highest hydration temperature after magnesia mixed with water, h

The lower the Iw was, the lower the inhibition of material to magnesia hydration was, that is, the better the compatibility of material and magnesia was.

RESULTS AND DISCUSSION

Effect of species, sapwood and heartwood on the hydration reaction

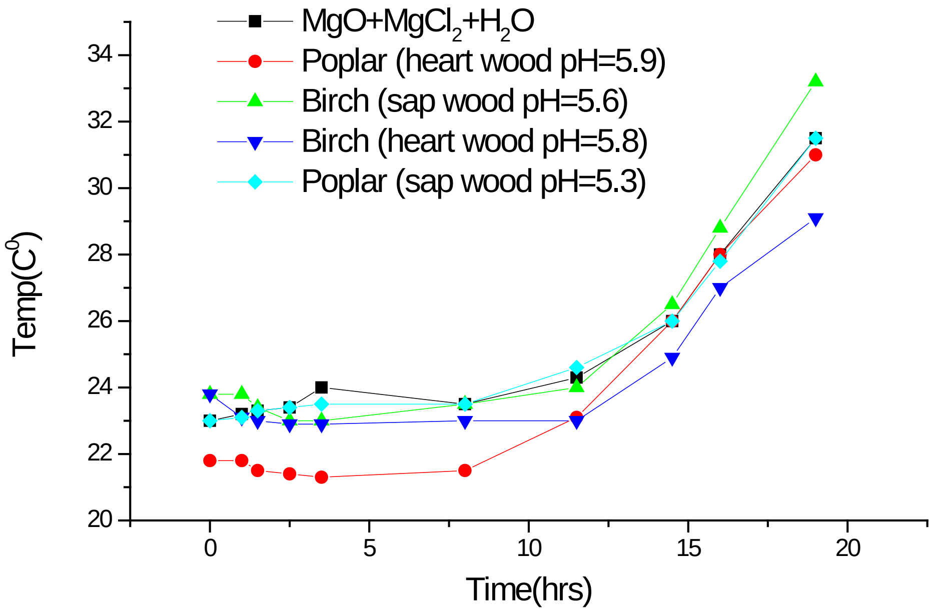

Figure 1: Effect of species, sapwood and heartwood on the magnesia hydration reaction

From Fig. 1, usually after 10 h hydration warming-up time, with the extension of time, hydration temperature changes at almost the same slope under different conditions. The selected species had no resistance condensate effect on magnesia hydration, that is, Iw≈0, the compatibility is very good. Although the PH value of sapwood was low as seen in Fig. 1, acidic conditions are beneficial to the reaction between magnesia and brine, but not significant in the variance analysis.

Effect of the additives on the hydration reaction

Seen from Fig. 2, the addition of oleic acid reduced the highest temperature of hydration heat reaction which illustrated that the addition of oleic acid would reduce the reaction degree of magnesia and brine; and the addition of Al_2O_3 powder did not effect the reaction and could promote the hydration moderately.

It was found that hydration reaction temperature reduced adding talcum powder as moistureproof additive which illustrates that the talcum powder was harmful to the reaction.

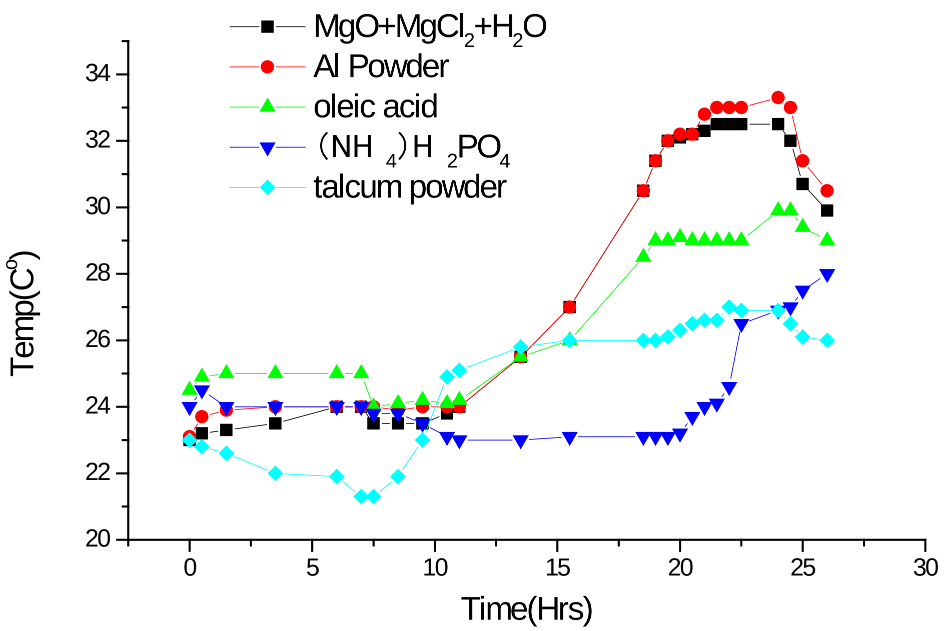

Figure 2: Effect of different additives on magnesia hydration reaction

Effect of mixed additives on hydration

Al_2O_3 powder could enhance activity, and other materials had excellent waterproof property but could reduce the hydration, so mixed addition was used to make up the insufficiency of moisture-reducing agent such as phosphate and talcum powder and achieve material versatility. Phosphate, Al_2O_3 powder and talcum powder were added in certain proportion to observe the characteristics. It was illustrated in Fig. 3 that the mixed additive made from Al_2O_3 powder improved the hydration temperature and was better than phosphate used alone.

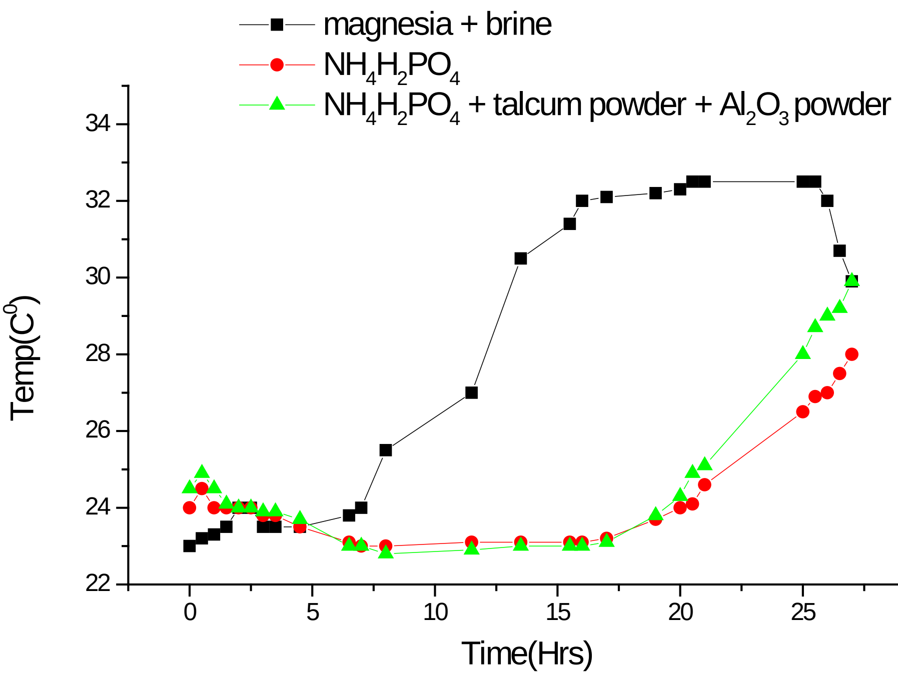

Figure 3: Effect of mixed additives on magnesia hydration reaction

CONCLUSIONS

Following conclusion could be drawn from above experiment results:

1) The hydration reaction of MgO and $MgCl_2$ had little to do with the species used in the experiment, and had much to do with the PH value of reaction liquid, but not very significantly. The lower the PH value of wood aqueous solution was, the higher the hydration temperature was, which illustrates that acid condition could promote the hydration reaction.

2) Respective addition into magnesia of talcum powder, oleic acid and Ammonium all extend hydration reaction time, especially the phosphate probably due to the broken molar ratio of MgO and $MgCl_2$. Adding Al_2O_3 powder will increase the hydration temperature thus to change the additive property. The mixed additives of phosphate, Al_2O_3 powder and talcum powder can be used to make up for the insufficiency of singer additive and achieve material versatility.

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Low-density magnesia wood-wool panel: Comparison of manufacturing techniques

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Keywords: steam-pressing, magnesia, wood-wool panel, manufacturing technique

ABSTRACT

In this paper, airproof hot-pressing is used to limit decomposition of inorganic material while manufacturing low-density wood-wool panels with magnesia. The production of low-density magnesia wood-wool panels using steam-pressing technique revealed high process productivity. Moreover, the boards have more stable properties compared with boards made with cold-pressing and hot-pressing techniques. As such, the panel properties can fully comply with the requirements for cement wood-wool panels both for the local Chinese market and for abroad.

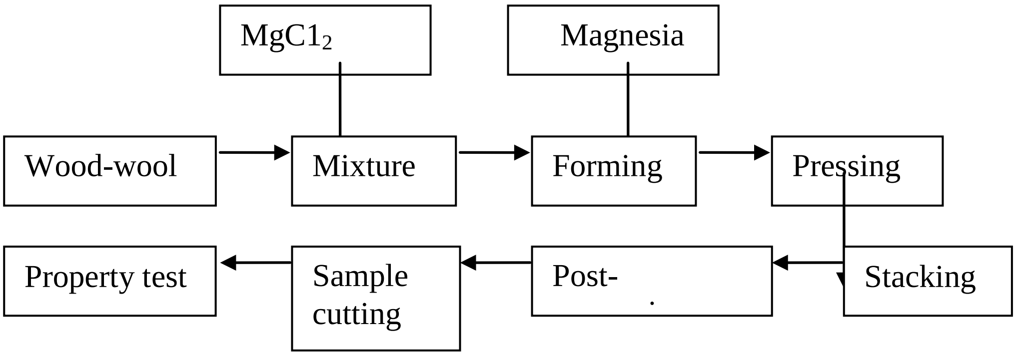
INTRODUCTION

As the manufacturing technique of inorganic bonding wood based panel is limited in cold-pressing, it has long production period, low output and low equipment utilization. LU Xiaoning et al. studied high-density cement particleboard with hot-pressing, the pressing time greatly diminished and the temperature is limited below 120°C. In this paper, airproof hot-pressing is used to diminish the decomposition of inorganic material and manufacture low-density wood-wool panel with magnesia.

EXPERIMENT DESIGN

Experiment project

Cold-pressing, hot-pressing and steam-pressing techniques are compared by using a property comparison in experiments and the panel density is designed in steam-pressing technique. The technique process is shown as follows:



Materials and technique mixture proportion

Wood-wool, south-west birch, 0.5mm thickness, 1 to 2mm width, average length: thickness is 300, 12%-15% moisture content. Panel design density: D=0.45g /cm3; the panel thickness: 16mm; MgO of magnesia is 80%, the molar ration of MgO and $MgC1_2$ solution is: MgO: $MgCl_2$: H_2O =6.43: 1: 13.2, the relative density of $MgC1_2$ solution is 1.26 g/cm3, ash: wood (weight ratio) is 1.5.

Steam-pressing technique: the time is 1.25min/mm, the temperature of hot-pressing board is 140°C, the pressure is 1.90Mpa;

Hot-pressing technique: using the flat sulfuration hot-press, the pressure is 1.90MPa, the temperature of the upper pressing board is 140°C, the hot-pressing time is 1.25min/mm[1].

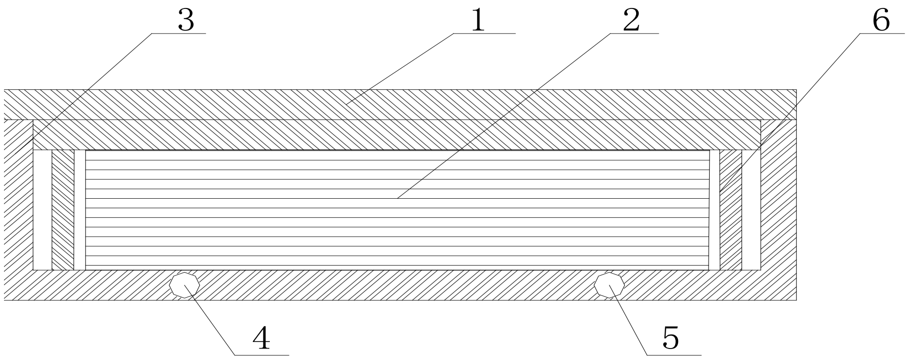
Cold-pressing technique: using a self-manufacturing steam-press, not heating, pressed for one hour with 1.90MPa pressure, airproof conservation for one day. The panel design density in the steam-pressing technique condition is: 0.25, 0.35, 0.45 and 0.55 g/cm³ with a thickness of 25mm.

Property test

Because now there is no unique standard of magnesia wood-wool panels, its property can only be compared with correlating cement wood-wool panel. The samples are tested after 21 days according to the standard GB/T17657-1999. The property indexes are: MOR and MOE, TS, sound-absorbing coefficient and thermal conduction coefficient.

Steam-press

The figure of steam-press is shown as follows:



1.Frame cover, 2. Steam-pressing product, 3.Frame, 4.Effluent /steam channel, 5.Influent channel , 6. Thickness regulation

RESULTS AND DISCUSSION

Comparison of pressing technique

As seen in Tables 1, different pressing techniques have significant effects on panel properties, MOR of the panels using cold-pressing and steam-pressing techniques is high. The reason: at the ambient temperature and airproof condition, the moisture loss is low, so the reaction between MgO and $MgCl_2$ is sufficient and can form stable crystal. Meanwhile the MOR of panels using hot-pressing technique is relatively very low partly due to the following reason: the high temperature made the reaction accelerate and because of the high reaction speed, MgO reacts not sufficiently with $MgCl_2$ and the internal stress increased. In addition to the escape of steam, molar ratio of H_2O and MgO decreased and formed few 5 phase crystals. Also because of the steam effect, the wood plasticity is improved and the MOE of the panel is improved significantly, greatly exceeding that when using the cold-pressing technique. This is because the high temperature of pressing board made a surface layer of mat fast cure and the density increased and the increase of surface layer is benefit to the improvement of MOE. Otherwise $MgCl_2$ could form deposit under high-temperature H_2O steam, block the capillary, solidify the panel and enhance MOE.

Table 1: Properties of magnesia wood-wool panel with different pressing techniques

Pressing technique	Thermal conduction coefficient W/m • K)	Sound-absorbing coefficient	2hTS (%)	MOR (MPa)	MOE (MPa)	Density (g/cm³)
Hot-pressing	0.1241	0.46	2.92	1.64	114.65	0.42
Cold-pressing	0.1065	0.50	4.17	5.39	199.39	0.45
Steam-pressing	0.1392	0.45	0.97	5.16	626.54	0.44

Note:Panel thickness is 16mm

Property comparison of similar products at home and abroad

The property indexes of similar wood-wool panel products are shown as follows by consulting concern information [2]:

Table 2: Physical and mechanical properties of wood-wool panels at home

Index	Unit	Permitting scope
Volume density	kg / m^3	350~500
Bending strength	Pa	≥5.9×105
Thermal conduction coefficient	W / (m • K)	≤0.23
Sound-absorbing coefficient	%	>20

Table 3-6: Physical and mechanical properties of wood-wool panels abroad

Thickness and face density	25mm，12~14 kg/m2 35mm，16~18 kg/m2 50mm，24~28 kg/m2
Nose reducing coefficient	NRC = 0.5~0.7
Thermal conduction coefficient	λ =0.09 W / (m • K)
MOR（MPa）	σ b =1.62 MPa

Compared with the similar product, the strength of panels using hot-pressing technique is equal to that of the foreign product and superior to that of the foreign product using steam-pressing technique. The panels using steam-pressing technique have excellent properties and are superior to the similar products at home. With the increase of density, the strength increases as the thermal conduction coefficient, meanwhile change of sound-absorbing coefficient is not proportional to that of the panel density.

Table 3: Results of panel with different density using steam-pressing technique（panel thickness = 25mm）

Actual density (g/cm3)	Thermal conduction coefficient W/m·K）	Sound-absorbing coefficient	2hTS (%)	MOR (MPa)	MOE (MPa)
0.26	0.0914	0.56	1.60	0.86	74.77
0.35	0.1135	0.52	1.55	1.82	277.28
0.43	0.1297	0.51	1.35	2.98	957.42
0.54	0.1325	0.46	1.09	4.42	1096.82

CONCLUSIONS

Manufacturing low-density magnesia wood-wool panels using steam-pressing technique have high productivity and stable-property products compared with cold-pressing and hot-pressing technique.

In the process of using steam-pressing technique to manufacture the low-density magnesia wood-wool panel, the moisture loss is low, MgO reacts more sufficient with $MgCl_2$, form more 5 phase crystals and accelerate when heating. The main steam-pressing technique conditions: The molar ratio of MgO and $MgC1_2$ is: MgO - $MgCl_2$ = 6.43 - 1, the steam-pressing time is 1.25min/mm, the temperature of hot-pressing board is 140°C.

The panel density has a significant effect on the physical and mechanical properties of the panel. The panel properties using steam-pressing technique can fully reach that of cement wood-wool panels at home and abroad.

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Low-density magnesia wood-wool panel: Improvement of hygroscopicity

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Keywords: Magnesia, wood-wool panel, hygroscopicity, steam-pressing, additives

ABSTRACT

This paper discusses the reduction of panel hygroscopicity by using a steam-pressing technique and different additives. The key element to improve the hygroscopicity of magnesia wood-wool panel is to increase the hydration reaction degree of MgO and $MgCl_2$ using a steam-pressing technique as well as prolonged pressing time.

The moisture-preventing property of the panel could be improved by implying additives which can react with $MgCl_2$ and block the capillary channels. In this paper, the compound additives talcum powder, oleic acid and phosphate could improve the brine phenomenon and hygroscopicity of panels effectively and also improve the panel strength compared with the other two additives. But the additives had an effect on the panel strength which could be analyzed from their respective hydration heat.

INTRODUCTION

Magnesium oxychloride cement is a gas rigid cementitious material formed by the reaction of light burning MgO, $MgCl_2$ and H_2O by certain proportion, but easy to appear brine in the using process basically due to the reason that there are excessive $MgCl_2$ in the products which lead to condensation of water drops on the surface of hardening substance because of its strong hygroscopicity. Excessive $MgCl_2$ come from two aspects: one is that $MgCl_2$ didn't react fully and the system remains after a curing period; the other is that $MgCl_2$ is generated because of the phase transformation. The brine phenomenon has great effect on the durability and surface decoration of products.

The specific reasons to lead to excessive $MgCl_2$ in the products are shown as follows: (i) During the calcined process of magnesium, for the excessive high temperature, excessively burned MgO are often generated which have a weak activity and slow reaction speed and can only begin to react after product curing. (ii) Because of excessively long storing times, some MgO can react with H_2O and CO_2 in the air and generate $Mg(OH)_2$ and $MgCO_3$ thus making the MgO activity reduce. By testing, MgO activity reduced 12% when stored for 25 days, reduced 32% when stored for 40 days, reduced 46% when stored for 60 days and reduced

51% when stored for 80 days[1]. (iii) If the molar ratio of MgO and $MgCl_2$ is lower than 4, excessive $MgCl_2$ exist besides the generated 5-phase; the insufficiency of reactive MgO and increase of $MgCl_2$ led to the brine phenomenon of products.

Magnesium Oxychloride products can experience a phase transformation during the using period because of the effect of vapor and CO_2 in the air:

$$5Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O = 5Mg(OH)_2 + Mg^{2+} + 2Cl^- + 8H_2O$$
$$3Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O = 3Mg(OH)_2 + Mg^{2+} + 2Cl^- + 8H_2O$$
$$3Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O + 2CO_2 = Mg(OH)_2 \cdot 2MgCO_3 \cdot MgCl_2 \cdot 6H_2O + 4H_2O$$

5.1.8-phase and 3.1.8-phase turn into $Mg(OH)_2$ phase after hydrolysis which turn into a loose structure from a previous impact structure and the porosity increases thus not only making the strength lower but also making brine appear and cream because $MgCl_2$ and a small amount of MgO will move to the products surface through nonporous because of the formation of free Mg^{2+} and Cl^-. This paper discusses the steam-pressing technique and additives was used to reduce panel hygroscopicity.

EXPERIMENT MATERIALS AND METHODS

Experiment materials

1) Magnesia: from the Hongda building material factory in Laizhou, Shandong province which contained 80% MgO.
2) $MgC1_2$ solution: prepared to a relative density of 1.28 with density meter which contained 32.77 $MgC1_2$.
3) Poplar veneer: 0.5mm thickness, about 12% moisture content.

Experiment project

1) Steam-pressing time—panel hygroscopicity relationship
2) Effect of different additives on the panel hygroscopicity

Experiment technological parameters

Steam-pressing temperature is 140°C, internal maximum steam pressure is 0.27Mpa, steam time is 0.8, 1.25 and 3.75min/mm, slender ratio of wood-wool is 300, the ratio of ash and wood is 1.5/1, panel density is 0.45, panel thickness is 16mm, the molar ratio of MgO and $MgC1_2$ is 6.43：1, panel dimension is 400×400mm.
Additives: a) 15% talcum powder, b) 15% talcum powder and 3% oleic acid, c) 15% talcum powder, 1.5% Al_2O_3 powder and 1.5% phosphate, d) without additive.

Experiment process

It is shown in “Low-density magnesia wood-wool panel: manufacturing technological parameters of steam-pressing technique”。

Hygroscopicity test

The panel was cut to samples of 150×50 mm and then the samples were put into a self-made airproof box which had water in the bottom and a wire netting frame on which we put the samples to test the hygroscopicity. The time-dependent moisture variance of the panel is tested.

RESULTS AND DISCUSSIONS

Steam-pressing time

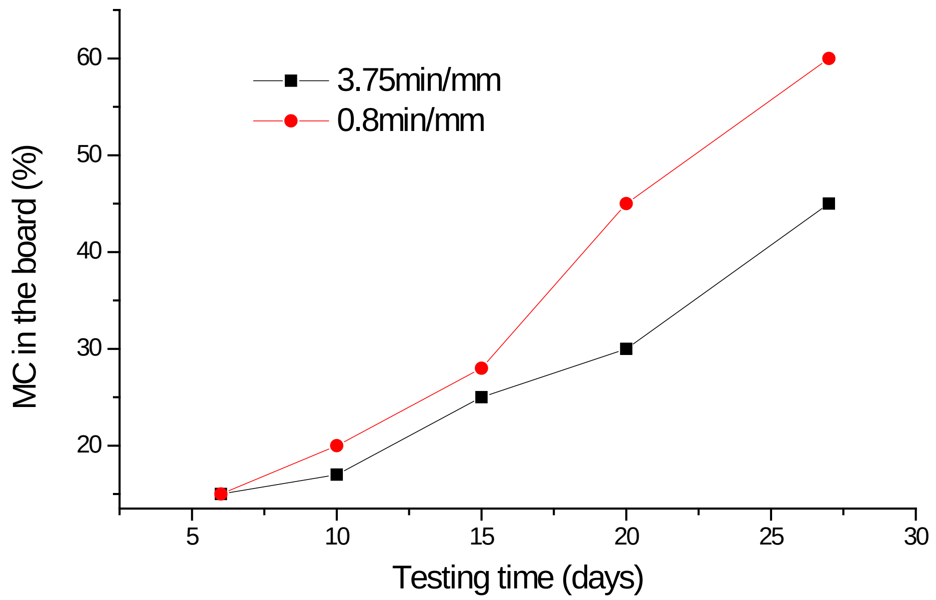

Figure 1: Effect of steam-pressing on panel hygroscopicity

The steam-pressing technique can make parts of $MgCl_2$ generate an Mg(OH)Cl deposit which improves the brine phenomenon of products. It is shown in Fig. 1 that with the extension of steam-pressing time, the brine phenomenon of products reduces, especially the material happened great changes in two weeks; on the whole, the brine increased with the increase of moisture content which could only illustrate that controlling the brine phenomenon in short time is effective.

Additives

It was shown in Fig. 2 that the additive c has a good moisture-reducing property. The phosphate could prevent the hydrolysis of magnesium oxychloride cement which did not change the material phase and changed its morphology. 5-phase was transformed into gelatinous or leaf shape from bar shape; after soaked by water, the gelatinous substances could partly transform into fiber or plate-like crystals with a high moisture-stability. The phosphate could generate a stable complex compound, reacted with Cl^- and generated insoluble salt $MgHPO_4$•$3H_2O$ and reacted with Mg^{2+} generated from hydrolysis to improve the moisture resistance. The adding of talcum powder could prevent capillary channel and reduce the moisture absorption by free $MgCl_2$ thus to improve the brine phenomenon of the panel in a certain degree.

Table 1: Effect of additive categories on the physical and mechanical properties of panel

Additive	Thermal conduction coefficient W/(m·K)	Sound-absorbing coefficient	2hTS (%)	MOR (Mpa)	MOE (MPa)	Density (g/cm³)
A	0.1412	0.48	1.61	3.28	355.79	0.41
B	0.1262	0.52	2.50	2.70	254.81	0.40
C	0.1300	0.53	0.60	3.47	317.44	0.37
D	0.1403	0.43	0.88	4.27	632.4	0.41

Note：Panel thickness is 16mm

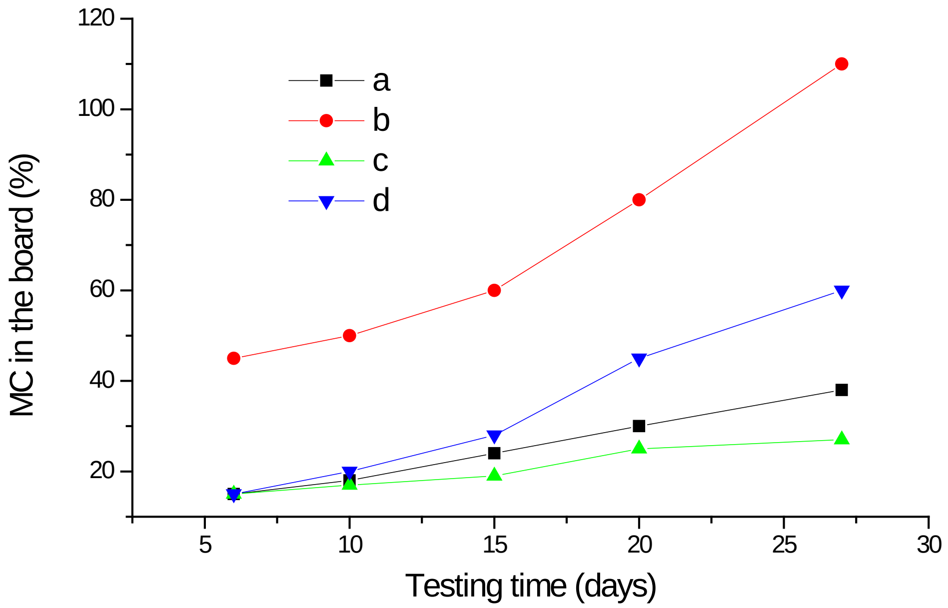

Figure 2: Effect of different additives on the panel hygroscopicity

Adding of oleic acid not only did not improve the brine phenomenon and hygroscopicity of panel but also reduced the panel strength because the enwrapping effect of oleic acid reduced the contacting chance between MgO and $MgCl_2$ thus making the reaction insufficient and instead generating more free $MgCl_2$; The oleic acid like oil-shape liquid weakened the bonding force of wood-wool and magnesium oxychloride cement. MOR of all panels reduced (seen in table 1) because of adding of oleic acid, the variance of reduce could be reflected from their respective hydration heat figures.

CONCLUSIONS

The essential method to improve the hygroscopicity of magnesia wood-wool panel was to increase the hydration reaction degree of MgO and $MgCl_2$ with steam-pressing technique as well as extension of the steam-pressing time; the moisture-preventing property of panel could be improved by adding an additive which could react with $MgCl_2$ and block the capillary channel. In this paper, the adopting compound additives (talcum powder, oleic acid and phosphate) could improve the brine phenomenon and hygroscopicity of panel effectively and also improve the panel strength compared with the other two additives. But the additives had effect on the panel strength which could be analyzed from their respective hydration heat.

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Research on Technology of Color uniformity for Inner Dying of Fast-Growing Poplar

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Keywords: Fast-growing poplar, solid wood dyeing, level dyeing, dye-uptake, chromatic aberration

ABSTRACT

Wood dyeing is one of modifying methods, which is often used to improve the added value of fast-grown wood. In this paper, effects of the temperature, time and concentration of dyeing solution on fast-growing poplar solid wood dyeing by vacuum pressure impregnation and heat were analyzed. After researched the level dyeing and dye-uptake of specimens based on operational principle of the colorimeter, the optimum dyeing process condition was available and a level dyeing effect was obtained.

INTRODUCTION

In the last few decades to expand the use and improve the added value of fast-growing wood, dyeing technique of wooden material has gained much attention. The research on dyeing technology is constantly advancing and veneer dyeing has realized industrialization. Now, lots of factories hope that the dyestuff could permeate into a certain depth timber, even into the whole logs so that it can withstand the later processing of planning, sanding, and so on. However, due to the characteristic of wood anisotropy and the different adsorption speed of various dyestuffs in the timber, some problems like uneven staining are easy to occur during the dyeing processing of solid wood. So research methods of solid wood dyeing need some breakthroughs.

Poplar, a main fast-growing tree species in the Middle-Lower Yangtze Area of China, has become one of the primary raw materials for wood-based panel industry. Usually it can't satisfy the decorative request on direct utilization of the log on account of the shallow white color materials. Therefore, the useable performance of the timber could be promoted greatly if the thicker fast-growing Poplar can be dyed into the colour of a valuable timber species and then made into ornamental structural timber.

In this connection, research on technology of level dyeing for fast growing poplar was discussed in this paper. Effects of temperature, time and concentration of dyeing solution on fast-growing poplar solid wood dyeing by vacuum pressure impregnation and heat were analyzed using the orthogonal test method.

EXPERIMENTAL METHODS

Specimen and dyestuff preparation

The dimensions of poplar samples are 200 x 30 x 30 mm. The samples were dried by air-drying, their moisture content was about 12-15%.
In order to make the test practically significant and to make sure the dyestuff can only penetrate along thickness direction, two ending and width surfaces of samples were sealed by glue.
The dyestuff consists of mixed acid red GR, acid black ATT, acid orange Ⅱ, acid flavine G, Direct Scarlet, direct blackG and assisting dyeing agent. The timber can be dyed near to teak colour by proper design of mixture dyestuff ratio.

Research methods

Dyeing technology

Vacuum and heat were utilized on poplar timber dyeing. The treatment processing for research was as follows: feeding, vacuum, adding dyeing solution, heat, stopping vacuum and heat, dip-dyed 10h at room temperature and pressure (dye-uptake on timber preferable), discharging, drying.

Test scheme

The dyeing technology was investigated with the orthogonal design tests of three factors and three levels (see Table 1): different concentration of dyeing (2‰,5‰,and8‰), different temperature level (60°C, 70°C and 80°C), different heat time in vacuum (6h, 8h, and 10h). After checking the dyeing effectiveness by chromatist, the effects of these factors on level dyeing of fast growing poplar were analyzed.

Table 1: Factors and levels charts of orthogonal test

Levels	Factors		
	A Concentration of dyeing (‰)	B Temperature (°C)	C Heat time in vacuum (h)
1	2	60°C	6
2	5	70°C	8
3	8	80°C	10

Chromatic aberration measurements

Chromatic aberration shows a kind of relation index between standard color's space and sample color's space. It can be expressed as follows:

$$\Delta E = \left[(L^*{}_i - L^*{}_0)^2 + (a^*{}_i - a^*{}_0)^2 + (b^*{}_i - b^*{}_0)^2 \right]^{1/2} \qquad \ldots\ldots(1)$$

In the previous relation, L^* is representing lightness index, a^*, b^* are representing chromatic indexes.
In this experimentation, measurements of chromatic aberration were carried out using a WSC-S automatic colorimeter based on CIE1976 $L^*a^*b^*$ system, which viewing condition is 10° and measuring range is 20mm.
Property of level dyeing was studied from two aspects: (1) dye-uptake; (2) level dyeing. During study on dye-uptake, original materials were used as measurement's standard samples,

then compared with dyeing timbers' color characteristic, carried out the numerical calculation (ΔE) respectively and the arithmetic mean values. If the value is big, it is indicated the sample had a preferable dye-take performance.

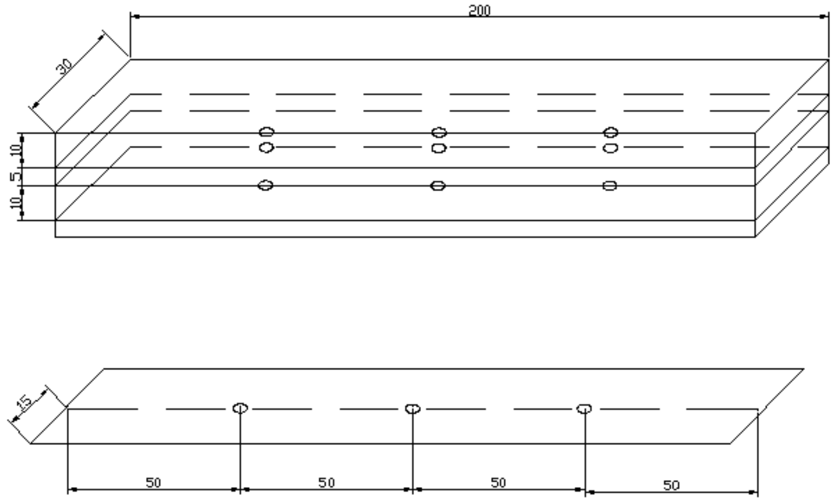

Figure 1: schematic diagram of measurements' samples

On Fig. 1 the schematic diagram on studying level dyeing of fasting-grow poplar is represented. Center spot was used as measurements' target samples, then compared with the other eight spots' the color characteristic, carried out the numerical calculation (ΔE) respectively and the arithmetic mean values. If the value is small, it is indicated the sample had a preferable level dyeing performance.

RESULTS AND DISCUSSION

Effect of different technology on dye-uptake of fast-growing Poplar

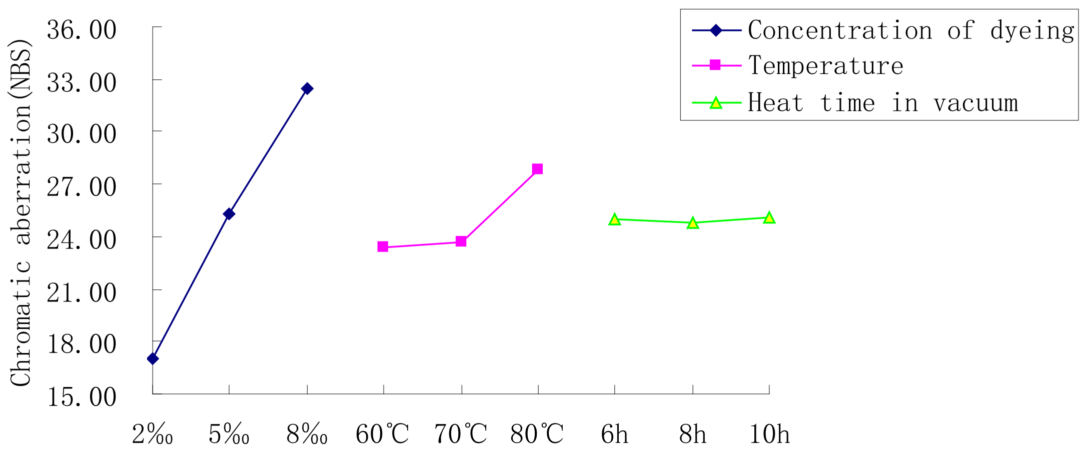

Figure 2: Relationship between dyeing technology and dye-uptake

The effect of different technologies on dye-uptake of fast-growing poplar is shown in Fig. 2. The results show that chromatic aberration increased evidently between the dyed and untreated material when concentration of dyeing increased, analysis of variance indicated

dye-uptake increases were significant at 0.10 level. So, increasing concentration of dyeing was an efficient way of adding dye-uptake. Figure 2 also indicates temperature was closely related to dye-uptake of dyestuffs. Improving temperature of dyeing solution was propitious to ameliorate dye-uptake because of increasing molecule free energy. The results of variance analysis showed that temperature is as well as the marked factor, which significance reached 0.10 level. When temperature reached 80°C in experiment, property of dye-uptake was the best. Heat time in vacuum had no obvious effect on dye-uptake because the timber had been dip-dyed sufficiently, kept on dyeing 10h again at room temperature and pressure after stopping vacuum and heat.

Effect of different technology on level dyeing of fast-growing Poplar

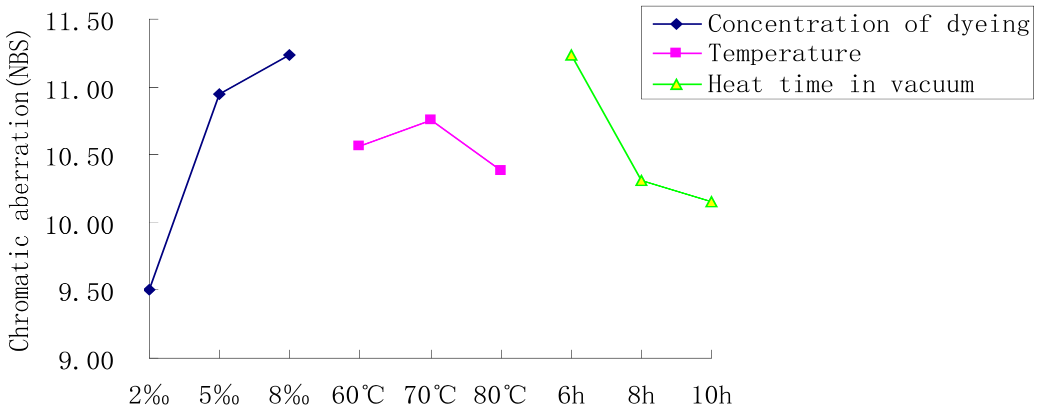

Figure 3: Relationship between dyeing technology and level dyeing

The effect of different technologies on level dyeing of fast-growing Poplar is shown in Fig. 3. Variance analysis showed that concentration of dyeing was considered one of the important factors that effected level dyeing. With increasing concentration of dyeing, the penetrated speed of dyestuff increased sharply. However, with the different adsorption speed of various dyestuffs in the timber, uneven staining occurred along thickness direction. In this experiment, we found that the minimum concentration of dyeing had the fastest penetrating speed. Figure 3 also indicates temperature has little effect on level dyeing. Chromatic aberration got maximal value when temperature was at 70°C, the percent change induced by temperature was very small, no more than 4%. Although we maintained a constant temperature by water bath heating, it is inevitable that temperature gradient would come into being temporary between dyeing solution and wood fiber. The length of time was related with the speed of dyeing solution flow across fibers, the fiber adsorbs less the dyestuff at places of low temperature. So, at different positions of the dyeing timber, uneven staining was very easily caused. On the other hand, with increasing temperature of dyeing solution, the speed of Brownian motion of dyestuff molecules enhanced and also promoted the dispersion. It resulted in level dyeing. Briefly, all of those indicate a trend that chromatic aberration will increase by degrees as temperature of dyeing solution enhanced but it has no large effect. The results indicated heat time in vacuum play an important role on level dyeing. Chromatic aberration of samples decreased gradually with increased time of dyeing. The performance of level dyeing was improved because the contact chance between wood fiber and dyestuff and dyestuffs' adsorption was added as the dyeing time increased. The increase amplitude of level

dyeing in the range of time from 6h to 8h was higher than the range of time from 8h to 10h. So, judging from an economic point of view, it is suitable to control heat time in vacuum at 8h.

CONCLUSIONS

In this experiment, the effects of different technologies on level dyeing and dye-uptake of fast growing Poplar were analyzed. Main conclusions are drawn as follows:

(1) While heat time in vacuum had a certain improving effect on level dyeing, it had no significant effect on dye-uptake. Considering economic benefit of practical production, dyeing technology can be used by short time.
(2) Temperature of dyeing solution had a marked improving effect on dye-uptake and had no significant effect on level dyeing.
(3) Concentration of dyeing is an important factor to level dyeing and dye-uptake, but their effect tendency is opposite to the beam. Considering the importance of economic value of dyeing timber, we can choose proper higher concentrations of dyeing.
(4) To sum up, the conclusion from above analysis points out that the optimal condition was dyeing temperature of 80°C, heat time of 8h and concentration of dyeing$\geqslant$0.5%. It can ensure a certain level dyeing and at the same time can get a preferable property of dye-uptake.

It is shown that the basic theories on solid wood dyeing are far from complete. The thicker the timber, the harder it is to dye. The theoretical research of solid wood dyeing of fast growing poplar on the greater thickness needs further consideration.

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Study on influence of different treating schemes on performance of bamboo-wood oriented strand board

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Keywords: OSB, surface wettability, physical and mechanical performance

ABSTRACT

Oriented strand board (OSB) was made and tested according to three lay-up schemes, by poplar, bamboo, and the blend of bamboo and poplar. The three lay-up schemes were combined with also three pre-treatments of the material, being treated with acid, alkali or untreated.

The surface wettability and the density of free radicals were analysed after treatment with acid and alkali. The physical and mechanical performance of the OSB was tested. The results showed that acid and alkali could improve the surface wettability of bamboo and wood materials. The physical and mechanical performance of OSB could be enhanced. The reasons for this improved performance are theoretically discussed.

INTRODUCTION

Bamboo-wood oriented strand board, manufactured with bamboo slices and poplar strands and PF resin, is a kind of structural board with high strength and sound comprehensive performances. Usage of bamboo and fast-growing trees can efficiently solve the wood shortage problem in China, since bamboo is botanically and chemically somewhat similar to wood. So far, research of bamboo and poplar composites mainly focused on the manufacturing technology, while in this paper, emphasis was academically put on reparation technology, which may guide manufacture of the composite OSB.

MATERIALS AND METHODS

Materials include:
1) Bamboo (*Phyllostachys*) slices: 5-year-old bamboo was used in this study, coming from the Botanical Garden of the Nanjing Forestry University, then it was cut to width 3.5-40 mm and thickness 2.5 mm;
2) Rotary-cut Poplar Veneer: 2.5mm in thickness;
3) Nitric acid and sodium hydroxide: using analytically pure acid as raw materials;
4) Adhesive: brown PF resin at a solid content of 43%.

Experiment was conducted as follows:
1) The concentration of nitric acid and sodium hydroxide was used to treat the surface of poplar and bamboo (Table 1).
2) The contact angles of phenol-formaldehyde adhesive on the surface of poplar veneers and bamboo strands treated with acid, alkali, or control, were tested, with a measuring time of 15 seconds.
3) The concentration of surface radicals on above poplar veneer and bamboo strands was tested after one day of treatment.
4) Bamboo-wood oriented strand board was hot-pressed with the ratio of 1:1 for bamboo and wood at 180℃ for 30s/mm, at 3.5 MPa for hot pressure and with 6% of resin. Mechanical properties of OSB including modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB) strength and thickness swelling (TS) were determined according to the national standard GB/T 17656-1999.

Table 1: Quantity of nitric acid or sodium hydroxide per 100 g materials（mol）

Treated mode	Poplar veneer	Phyllostachys slice
Strong acid	0.038	0.302
Weak acid	0.0094	0.076
Weak alkali	0.113	0.240
Strong alkali	0.450	0.960

RESULTS AND ANALYSIS

Contact Angle

Fig.1 suggested that acid and alkali treatment have a remarkable influence on the surface wetting of poplar veneer and bamboo strand with phenol-formaldehyde, and strong acid and alkali were much better.

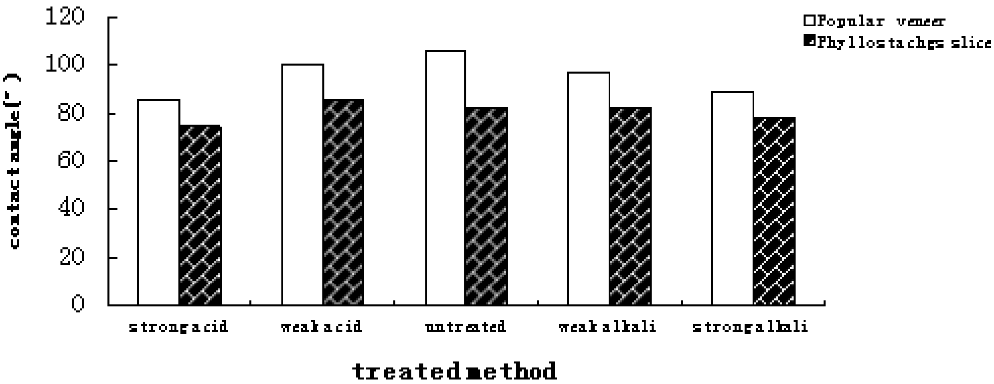

Figure 1: Contact angle on the surface of each material which was treated

According to harmonic mean method, the mathematic model which could characterize the surface free energy originated from both dispersion force and poplar force of poplar polymer was built.

$$\gamma_{lv}\left(1+\cos\theta\right)=\frac{4\gamma_l^d\gamma_s^d}{\gamma_l^d+\gamma_s^d}+\frac{4\gamma_l^p\gamma_s^p}{\gamma_l^p+\gamma_s^p} \quad (1)$$

On the right side of the formula, the first term is the unit of dispersion force; the second is the unit poplar force. After treating the surfaces of bamboo and wood with nitric acid and sodium hydroxide solutions, the interaction, dispersion force and polar force that contributed to the increase of total free energy between wood enhanced. When the surface tension of resin is equal to or lower than the free energy of wood, full wetting happens, and on the contrary, partial or no wetting occurs. The increase of bamboo and wood wetting should result from the enhancement of surface free radical after the acid and alkali treatment.

Free Radical Concentration

The testing results indicated that the popular veneer and bamboo slice after treatment with acid or alkali solution, or untreated, displayed ESR signal, and that spectral line didn't contain a very fine single splitting peak and the g value was between 2.0048 to 2.0052, which showed that there were free radicals on its surface.

Table 2: Free radical concentration of each material which was treated

Material Treating Method	Strong acid	Weak acid	Untreated	Weak alkali	Strong alkali
Popular veneer	$8.54*10^{16}$	$8.15*10^{16}$	$4.55*10^{16}$	$4.55*10^{16}$	$6.23*10^{16}$
Phyllostachgs slice	$3.44*10^{16}$	$3.22*10^{16}$	$1.62*10^{16}$	$2.64*10^{16}$	$2.87*10^{16}$

Table 2 showed that the free radical concentration of the popular veneer and *Phyllostachys* slice surface increased after treatment with either acid solution or alkali solution, and there is no difference between strong acid or weak acid, and between strong alkali and weak alkali.

Physical and Mechanical Performance

This result indicated that MOE, MOR and IB of this composite OSB increased obviously, and TS decreased when manifolding the content of alkali which was insufflated on the surface of the OSB.

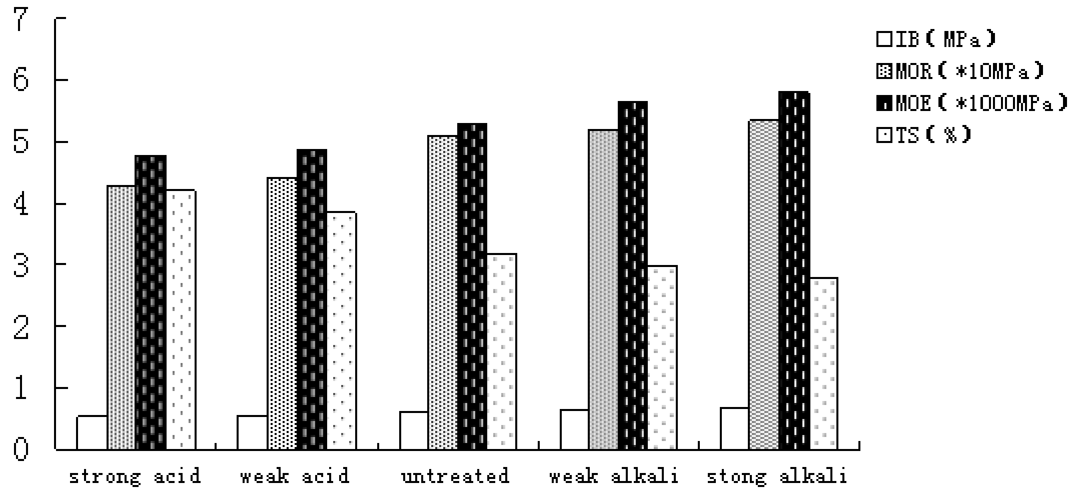

Figure 2: Physical and Mechanical Performance after treatment by different methods

Those performances of the OSB decreased by means of after treating with the acid solution. The major causes for this end are that the surface free radical and wettability of the raw material enhanced by after treating with the alkali solution and the PF was cured under alkali condition, so the properties and performances of the OSB are better by means of after treating with the alkali solution than when it received no after treatment. Although using acid treatment for the raw material of the OSB can improve its surface free radicals and wettability, there are some acid remainders on the surface of the material. PF resin was difficult to be cured in the acid condition, so this maybe is a important reason of resulting in decreasing the performance of the OSB.

CONCLUSIONS

The wettability and free radical concentration of the bamboo and wood material surface improved by means of either acid or alkali treatment.

The physical and mechanical performances of OSB could be enhanced after treatment of the raw materials with the alkali solution, while acid treating showed failure to enhance OSB performances.

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The Process and Property of the Bamboo-Wood Composite Plywood

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Keywords: Bamboo, composite plywood, poplar veneer, coating, water retardant

ABSTRACT

The process and properties of the bamboo-wood composite plywood were investigated. The optimum process parameters of the bamboo-wood composite plywood can be summarized as follows: the thickness of the weaved bamboo strip was 1mm, the thickness of the coated poplar veneer was 1.2mm, the moisture content of the weaved bamboo strip was lower than 12%, the UF resin addition was higher than 450g/m^2, and the UF resin was glued on the double surface layers of the sliver plybamboo. The hot-press temperature was 120°C, the hot-press pressure was higher than 35 N/mm^2, and pressing time was 1.5min/mm. Melamine addition was 6-8%.

INTRODUCTION

It is well known that China is abundant in bamboo. It has about 300 bamboo species, 1/3 of the total in the world. The utilization of bamboo is focused on the bamboo composites thanks to the substantive bamboo supply and forest resource (Hua *et al.* 1994, Fu *et al.* 1994). In the view of their potential as raw material for bamboo composites, many types of products have been designed and manufactured in the demand of structural plywood, such as bamboo weaving plywood, bamboo plywood, bamboo particleboards, and bamboo laminated board (Fu *et al.* 1994, 1995). In this study, the process and properties of the bamboo-wood composite plywood with a core ply of the sliver plybamboo and the surface layer of poplar veneer would be investigated.

MATERIAL AND METHOD

Material

Bamboo (*Phyllostachys pubescens*), supplied from Taihua town of Yixing, was used for weaving the sliver plybamboo. After weaving, the bamboo strip had a width of 17 mm, a height of 1.10±0.17 mm, and moisture content (MC) of 35-50%. Some mildew spots were

produced when the bamboo strip was folded in the month of May and June in Nanjing city. After weaving the two-side by turns, the size of the sliver plybamboo was 350×350 mm.

Poplar veneer has a thickness of 1.2mm, and MC of 8-12%.

Urea formaldehyde (UF) resin, from Meishan chemical plant, has a solid content of 60.7%, pH value of 8.4, curing time of 46''4, viscosity of 172cps, and free formaldehyde content of 1-2%. The ammonium chloride was used as curing agent, with the addition of 1 wt%, based on the overdried (OD) resin. The melamine was used to improve the water retardant of UF resin.

Experimental design

Experiment 1:

To investigate the effects of process parameters on the properties of bamboo-wood composite plywood, the glue spread amount, hot-press pressure and time were emphasized. The weaved bamboo strip was dried under pressure and glued on the single face. The sliver plybamboo was assembled with three layers, and coated the poplar veneer in the double surface layers.

Factor A (glue spread amount): 240, 280, and 320 g/m^2
Factor B (pressure): 12, 20, and 28 N/mm^2
Factor C (time): 0.8, 1.3, and 1.8 min/mm

Experiment 2:

To investigate the effects of hot-press pressure and glue spread amount on the water retardant of bamboo-wood composite plywood, the weaved bamboo strip was dried under pressure, and glued with 400g/m^2 of resin on the single face. The hot-press temperature was 120°C and pressure was 30 N/mm^2. The sliver plybamboo was assembled with three, four and five layers, and coated the poplar veneer in the two sides.

Experiment 3:

To investigate the effects of the addition of melamine on the water retardant of bamboo-wood composite plywood. 4, 6 and 8 wt% melamine (OD resin base) was mixed into the UF resin with an agitator. The weaved bamboo strip was dried under pressure, and glued with 450 g/m^2 of resin on the single face. The hot-press temperature was 120°C, time was 1.5 min/mm, and pressure was 35 N/mm^2. The sliver plybamboo was assembled with three layers, and coated the poplar veneer in the single surface layer or double surface layers. It was then kept for 20min before hot-press processing.

Experiment 4:

To investigate the effect of glue spread process on the water retardant of the bamboo-wood composite plywood, the weaved bamboo strip was dried under pressure, and glued with 450 g/m^2 of resin on the single and double surface. The hot-press temperature was 120°C, time was 1.5 min/mm, and pressure was 35 N/mm^2. The sliver plybamboo was assembled with three layers, and coated the poplar veneer in the double surface layers.

Process of bamboo-wood composite plywood

The wet weaved bamboo strip was dried with or without pressure in the hot press. After drying, the products had an MC of 10-12% and smooth surface.

The process of glue spreading was carried out manually. The weaved bamboo strip was glued on the single and double surface layers. The total amount of UF resin used was calculated with the resin consumption on the double surfaces.

The core layer of the sliver plybamboo was lay-up on the vertical direction with the surface of the sliver plybamboo or poplar veneer when the number of total layers of the sliver plybamboo was odd. On the contrary, the two core layers were kept parallel and lay-up on the vertical direction with the surface of the sliver plybamboo or poplar veneer when the total layers of the sliver plybamboo was even. The lay-up products were assembled for 20-30 min. Fig. 1 illustrates six different structures of the bamboo-wood composite plywood, and they were the sliver plybamboo assembled with three, four and five layers, and coated with the poplar veneer in the double surface layers. The poplar veneer was lay-up on the same direction with the surface of the sliver plybamboo.

The hot-press temperature was 120°C, time and pressure was changeable.

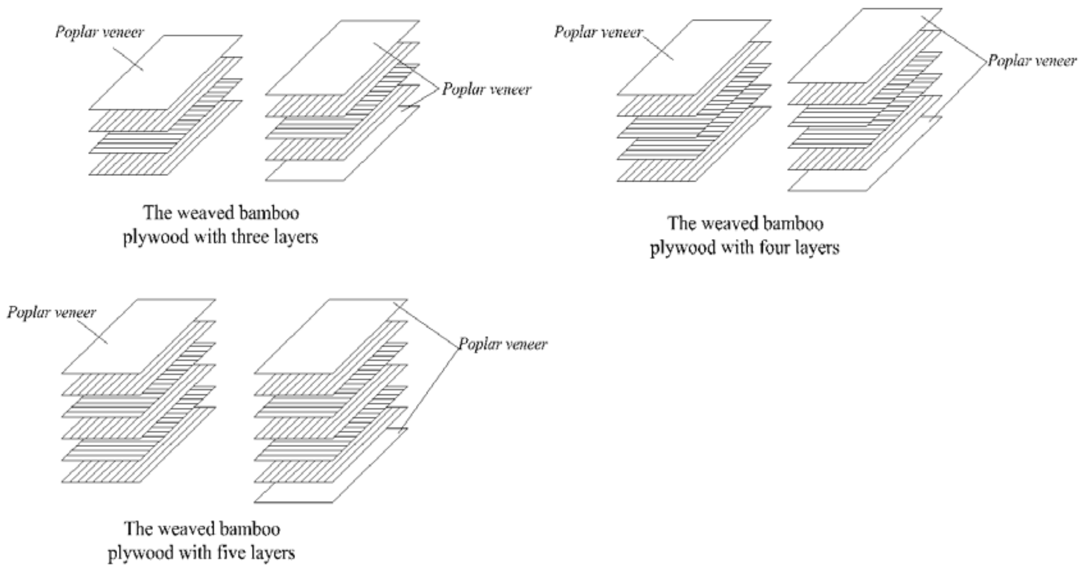

Figure 1: Structure of the bamboo-wood composite plywood

Physical and mechanical properties evaluation

All composite panels were kept at 22°C and 65% relative humidity conditions until the panels reached equilibrium moisture content. The mechanical and physical properties of the bamboo-wood composite plywood were evaluated according to the standard of the bamboo-wood composite plywood. These are density, MC, modulus of rupture (MOR) and water retardant.

RESULTS AND DISCUSSION

Effect of process parameters on properties

Table 1 illustrates the different process parameters on the mechanical and physical properties of the bamboo-wood composite plywood. The bending strength of this product was higher than 43.2MPa in the longitudinal direction, and 20.3MPa in the tangential direction. The water retardant of the bamboo-wood composite plywood was disqualified from the result of water soaking experiment. This was indicating lower hot-press pressure and insufficient glue spread amount could result in the lower water retardant of the bamboo-wood composite plywood. Furthermore, the resin couldn't penetrate into the inner of the sliver plybamboo when it was dried with pressure.

Table 1: Effect of process parameters on properties

Sample code	Thickness (mm)	Density (g/cm^3)	MC (%)	MOR(MPa) //	MOR(MPa) ⊥	Water-heating experiment
1				43.2	21.7	All samples were
2				58.3	30.0	delaminated after two
3				65.1	26.4	cycles of water-heating
4				57.2	29.4	experiment. This
5	7.2	0.68	5.4-8	58.4	25.8	phenomenon was
6				58.1	20.3	accelerated under the
7				52.8	23.3	condition of lower
8				61.8	29.3	pressure and insufficient
9				63.9	22.3	glue spread amount.

Effect of hotpress and resin addition on properties

Table 2 shows the water retardant of bamboo-wood composite plywood affected by hotpress pressure and UF resin addition. It was shown that higher hot-press pressure and sufficient resin addition could improve the water retardant of the bamboo-wood composite plywood. However, the value of water retardant of the bamboo-wood composite plywood still couldn't be in need of the usage demand.

Table 2: Effect of hotpress and resin addition on properties

Panel structure	Thickness (mm)	Density (g/cm^3)	MOR(MPa) //	MOR(MPa) ⊥	Water-heating experiment
Three layers	6.9	0.68	881	310	The water retardants of samples were still disqualified after two cycles of water-heating experiment.
Four layers	9.2	0.71	806	397	
Five layers	10.7	0.73	740	426	

Effect of melamine addition on water retardant properties

Table 3 shows the water retardant of bamboo-wood composite plywood affected by melamine addition. The water retardant of the bamboo-wood composite plywood can be significantly improved with the addition of melamine into the material from 4 wt% to 8 wt%.

Table 3 Effect of melamine addition on water retardant properties

The structure of sample	Water immersion Addition of melamine (wt%)			
	0	4	6	8
Three layers with single coating	A*	B	C	D
Three layers with double coating	A	B	C	D

*: A—disqualification
B—just qualification
C—qualification, but still some delamination
D—qualification, but just a little delamination

Effect of glue spread process on properties

Table 4 illustrates the water retardant of bamboo-wood composite plywood affected by glue spread process. It was shown that the sliver plybamboo, coated with the poplar veneer in the double surfaces had the better water retardant properties.

Table 4 Effect of glue spread on water retardant properties

The structure of sample	**Glue spread**	**Water immersion**
Three layers with double coating	Spreading resin in single surface	A*
	Spreading resin in double surfaces	B

*: A—disqualification
B—just qualification

CONCLUSIONS

The optimum process of the bamboo-wood composite plywood was as follows: the height of the weaved bamboo strip was 1mm, the height of the coated poplar veneer was 1.2mm, the MC of the weaved bamboo strip was lower than 12%, the resin addition was higher than 450g/m^2, and the resin was glued in the double layers of the sliver plybamboo. The hot-press temperature was 120°C, the hot-press pressure was higher than 35N/mm^2, and time was 1.5min/mm. And the addition of melamine was 6-8%.

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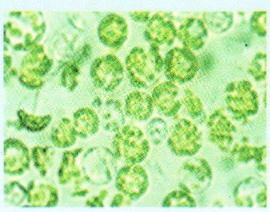


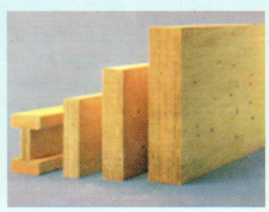
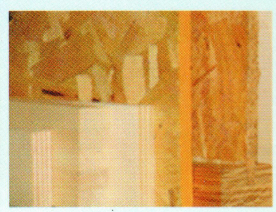

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