

Oriented Strand Board: Opportunities and Potential Products in China

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North America's first oriented strand board (OSB) mill was built in the early 1980's. Twenty years later, the industry was thriving, with over 50 mills producing the product. China's first OSB mill was built in 1990, and 25 years later, there are a few mills with a total capacity less than two large North America mills, most operating below capacity and struggling to identify domestic markets for the growing production. This paper briefly looks at the histories of OSB industries in North America and China, presents the current situation of China's wood-based panels industry and its downstream industries, and identifies OSB opportunities and potential products in China. Opportunity for sheathing-grade OSB is very limited in the current Chinese market, whereas industrial opportunities for specialty OSB products to replace plywood have great potential. Those specialty products include materials for furniture, wood doors, wood flooring, container flooring, concrete form, *etc.* OSB producers must designate the right OSB products for the Chinese market and cost-effectively manufacture those differentiated products to meet specifications for various end-applications.

Keywords: Oriented strand board; Chinese market; Industrial uses; Furniture; Wood doors; Wood flooring; Container flooring; Industrial packaging; Concrete form

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INTRODUCTION

Oriented strand board (OSB), a structural panel evolved from waferboard, originated and was first produced in the early 1980's in North America. The technological development for making structural-use OSB, shortage of peeler logs, and availability of abundant wood resources for OSB, building code approvals, and growing demand for structural panels have together made OSB gradually accepted in the construction sheathing market (Montrey and Utterback 1990). In 1984 there were only 12 OSB mills with a capacity of 812 million ft² (3/8-inch basis, 1000 ft² = 0.885 m³), and by 1994 the number of mills grew to 45 with a total capacity of 10.9 billion ft² (Hsu 2013). In 2000, OSB production slightly exceeded plywood production for the first time. In 2005, OSB production in North America had grown to 25.0 billion ft² (TECO 2015). Though the OSB industry was heavily hit by the US housing crisis starting from 2007, OSB prices and production have steadily recovered since 2012. At the end of March 2015, the total capacity of existing mills in North American was 26,954 million ft² (Anonymous 2015a). The OSB production volumes in 2013 and 2014 were 18,760 and 19,885 million ft², respectively, and the OSB consumption volumes in North America for those two years were 18,055 and 19,196 million ft², respectively (Anonymous 2014a and 2015a). The apparent consumption

of structural panel consumption in 2014 was 30,093 million ft² (Anonymous 2015a), which means that OSB had an approximately 64% market share for structural panels. The production and consumption of sheathing-grade OSB should continually recover and grow in North America if the US housing industry recovers to the level in early 2000. Europe has become the second major producer and consumer of OSB. Its OSB annual production capacity totaled approximately 6.068 million m³ at the end of 2013 (Anonymous 2014b) and 7.088 million m³ at the end of 2015 (Anonymous 2016).

While the OSB industry in North America and Europe has gone through a rapid growth, the development of the OSB industry in China is a totally different story. In the 1970's, researchers at Nanjing Forestry University started working on manufacturing technology and equipment for OSB production. The first OSB mill with a capacity of 10,000 m³, which was equipped with Maier strander and Siempelkamp former and press, was established in Nanjing Wood Products Factory in 1990 and started operation in 1991. The first OSB mill (10,000 m³ capacity) with 100% domestic equipment was built in Fujian Jianou Wood Processing Factory in 1995. By 2009, there were seven lines built and operated with a total capacity of 89,000 m³ (Xu 2010). The slow development of the OSB industry in China from 1991 to 2009 was in sharp contrast to the booming economy and to the rapid expansion of the wood-based panels (WBPs) industry in China.

Twenty years after the first OSB line was built in 1990, the first continuous press line with an annual capacity of 220,000 m³ was established and put into use in Hubei Baoyuan Wood Industry Co. LTD (Baoyuan) in 2010, but OSB production and consumption in China were still slow in the following couple of years. Things have started to change since 2014. In 2014, China started construction of four OSB lines. Establishment of three new Dieffenbacher continuous press lines, with a total annual capacity of 770,000 m³, were started in Hubei, Shandong, and Guizhou provinces (Anonymous 2014b). One line focusing on OSB for packaging and container flooring panel with a capacity of 200,000 m³ was reported to start construction at Jiangsu Happy Wood Group Co. Ltd (Happy Group) (Anonymous 2014c).

With those four new OSB lines and the existing one in Baoyuan, China's OSB production has expanded rapidly to a total capacity close to 1.2 million m³. Finding markets for this expanded production has proven to be challenging. North American sheathing-grade OSB has had little success in China. For OSB to succeed in China, a substitution strategy focusing on Chinese product requirements is needed. This paper reviews the current situation of China's WBPs industry and its downstream industries, identifies the opportunities in different industries, and gives examples of specialty OSB products for potential end-applications, including furniture, wood doors, wood flooring, container flooring, and concrete form (*i.e.*, forms for the pouring of concrete), *etc.* The purpose of this paper is to discuss the opportunities and potential end-applications of OSB and to elucidate how to develop OSB products accordingly in China, where WBPs are not traditionally used as construction materials but are consumed mostly for non-construction applications. Due to the lower volume and the longer time frame for the development of the European OSB sector relative to North America, this paper limits the comparison mainly to China and North America.

CURRENT SITUATION OF THE CHINESE WOOD-BASED PANEL INDUSTRY

China produced 20 million m³ of WBPs in 2000 (Wu 2001), and the production grew close to 274 million m³ in 2014 (Qian 2015a), which means an average annual growth of 18.14 million m³ in the past 14 years. Currently, there are more than 10,000 panel manufacturers employing over 3 million people. The percentage of China's production of the world total has grown quickly (Fig. 1). In 2013, the production of WBPs in China accounted for 58% of the global total (Qian 2015a). China is now the largest producer, consumer, and trader of WBPs in the world. The dominant wood-based panel in China is plywood. Of the total panel production in 2013, the percentages of plywood, fiberboard, particleboard, and other boards (including blockboard, *etc.*) were 53.7%, 25.0%, 7.4%, and 13.9%, respectively (Qian 2015b). Obviously, even running at full capacity, 1.2 million m³ of OSB from all the lines in China is still a very small part of the nation's WBPs production volume.

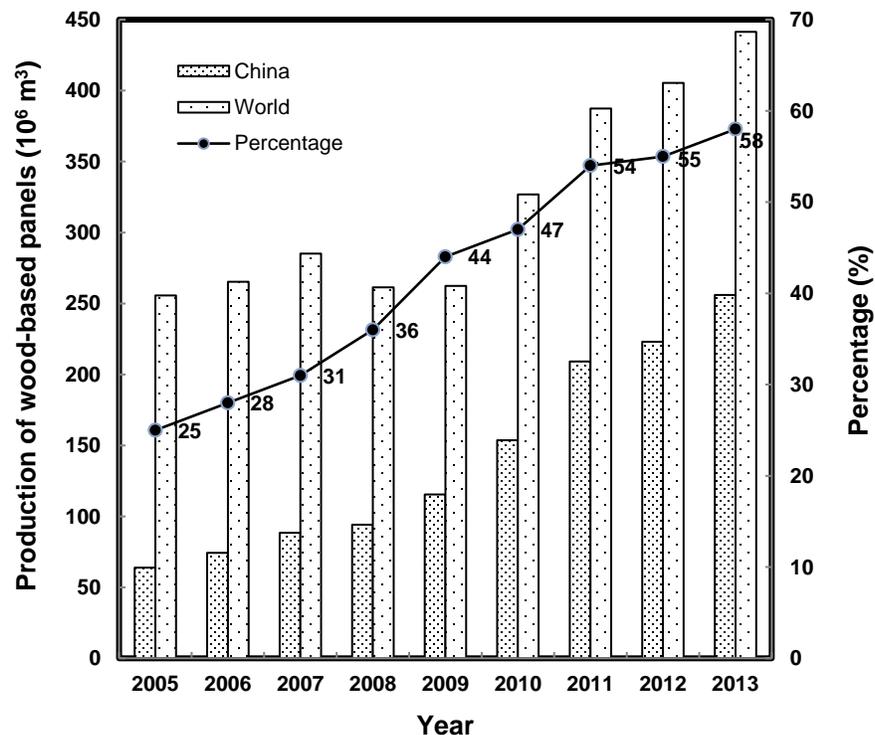


Fig. 1. Production of China's WBPs and its percentage in the world total (2005 to 2013) (redrawn from the data of Qian 2015b)

WBPs are used extensively in more than 10 downstream industries in China. The furniture and construction industries consume about 48% and 20% of the total production, respectively. Packaging, wood flooring, and wood door industries consume about 8%, 5%, and 4%, respectively (Fig. 2) (Qian 2015b). WBPs are widely accepted in those areas, and the panel industry gains experience and technology to manufacture products for those applications following well-established Chinese national and industry standards.

OPPORTUNITIES FOR OSB IN THE CHINA'S CONSTRUCTION INDUSTRY

Originally targeted for the construction industry, OSB was designed and is used extensively for construction structural uses, including wall, floor, and roof sheathing and in the web of wood I-joist in both commercial and residential buildings. In North America, about 65% of OSB is used for residential building and 6% for non-residential construction. Repairs and remodelling consume about 24% (Li *et al.* 2006). Roughly 95% of OSB produced in North America goes to the construction industry. In Europe, about 50% of OSB is consumed for residential buildings (Akrami 2014). For the first two decades of OSB production in China, the quality of commodity sheathing-grade OSB has not fit the overwhelming applications in China.

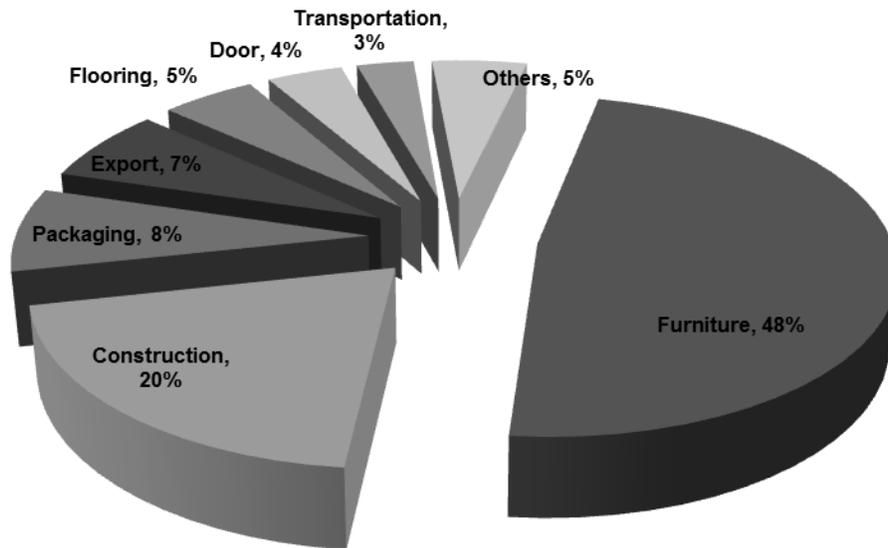


Fig. 2. End-applications of WBPs in China (redrawn from the data of Qian 2015b)

China's Housing Industry

Table 1. Construction Scale of Residential Buildings from 2007 to 2015

Year	Floor Space under Construction (10 ⁸ m ²)	Floor Space Started (10 ⁸ m ²)	Floor Space Completed (10 ⁸ m ²)
2007	18.7	7.88	5.82
2008	21.7	7.99	4.78
2009	25.1	9.24	5.77
2010	31.5	12.9	6.12
2011	38.8	14.6	7.17
2012	42.9	13.1	7.9
2013	48.6	14.6	7.87
2014	51.5	12.5	8.09
2015	51.2	10.7	7.38

Since the housing reform in 1998, which was aimed at market development and privatization of urban housing, the booming economy, population growth, and urbanization have caused the housing market in the urban areas of China to experience rapid growth and become a significant component of the Chinese economy. According to data for the construction industry released by the China National Bureau of Statistics (CNBS), the investment values in real estate development were 9,503.6 billion yuan (about US\$1,462.1 billion) (CNBS 2015a) and 9,597.9 billion yuan (about US \$1,476.6 billion) (CNBS 2016a) for 2014 and 2015, respectively. Table 1 lists the construction scale of residential buildings from 2007 to 2015 (Li 2014; CNBS 2015a and 2016a).

CNBS reported that the GDP growth rate of China ranged from 6.9% to 14.2% from 2001 to 2015 (CNBS 2006, 2011, 2015b, and 2016b), which shows a steadily growing economy for the past 15 years. China announced an economic growth target of 6.5% to 7.0% for 2016 and targeted at least 6.5% for the next five years (Xinhuanet 2016).

By the end of 2015, the total population in mainland China reached 1,374.62 million, and the urban population in 2015 amounted to 771.16 million (CNBS 2016b), which means that 56.1% of the population lived in urban areas and towns in 2015. China is promoting and undergoing a process of continuous urbanization, with a 60% rate targeted by 2020 (Xinhua News Agency 2014). The increased living spaces required in urban areas resulting from urbanization and the desire of middle class urban residents to improve their living conditions will have a profound effect on the housing market. Besides the residential construction in the urban areas, there were 603.46 million people or approximately 200 million households living in rural areas in 2015, of which approximately 20 million households built their new homes annually (Qian 2012). With government policies encouraging building new rural areas and the progress of the “building material going to countryside” project, housing construction in rural areas will continue to grow.

Starting from 2014, the growth of building construction has slowed down and has been going through an adjustment period. From a long-term development prospective, the steadily growing economy (with the GDP growth rate of 6.5%), along with massive urbanization and population growth, continue their profound effects on the construction industry, especially the housing sector. Housing construction volume in urban and rural areas should remain strong.

Opportunities for Sheathing-grade OSB in the Construction Industry

In contrast to the rapid growth of the housing industry in China in the past 30 years, light wood frame construction, which is the dominant residential construction in North America, has not developed well in China. In August 2013, the China Modern Wood Structure Construction Technology Industry (CMWSCTI) Alliance released a survey on utilization of modern wood construction technology. It was estimated that the total annual construction volume of wood construction in China was 3.0 million m², of which 2/3, *i.e.*, approximately 2.0 million m² was light wood frame construction (CMWSCTI Alliance 2013). Compared to the size of the residential building construction sector (Table 1), the market share of light wood frame construction is small. It is predicted that China’s market of wood construction will grow to approximately 3.5 million m² per year in the next three years (CMWSCTI Alliance 2013). If 2.5 million m² out of 3.5 million m² is light wood frame construction, and even all of them are built with Chinese produced OSB, this construction volume would still not consume a significant amount of OSB, *i.e.*, approximately less than a production capacity from one of the four continuous press lines. On August 31 2015, the Ministry of Industry and Information Technology of China (MIIT)

and the Ministry of Housing and Urban-Rural Development of China (MOHURD) jointly issued an action plan to promote production and application of green building materials. One purpose of the plan is to officially support and promote wood construction growth in China, such as low-rise government-invested schools, kindergarten, seniors housing, landscape structures, and flat-to-sloping roof conversion. Multi-story wood-steel and wood-concrete hybrid construction and rural wood residential in the developed areas of the country are also on the list (MIIT and MOHURD 2015). The plan will have positive impacts on the production and use of structural wood products including OSB, but how much and how soon the effects will be remains to be seen. In addition, performance standards, building codes, and third-party certification systems related to using OSB in the construction industry need to be developed or improved.

Opportunities for Non-sheathing-grade OSB in the Construction Industry

Most urban housing units in China are concrete-masonry and concrete buildings, and typically new units are unfinished rough shell apartments. Wood products are commonly used to finish housing units; therefore, the initial interior decoration or finishing (including flooring, doors, wall panels, cabinets and mouldings, *etc.*) and furniture to be filled in the units use a large amount of wood products. In addition, renovation or refurbishing of existing housing units, which typically happens 15 to 20 years later (Qian 2013), consumes a large volume of wood products. The upholstery industry consumes large amount of wood products, and together with the furniture industry, it has been a major contributor to the development of WBPs industry in China.

Another opportunity related to the construction industry is the consumption of WBPs for concrete form panels. It was estimated that more than 12 million m³ of wood is consumed annually as concrete form panels (Dang 2014). Currently, the dominant wood panels for concrete form are made from wood and bamboo plywood.

In short, OSB opportunities in the Chinese construction industry are different from those in North America. Given its high urban population density and limited land resources, the dominant urban residential buildings in China are currently mid-rise concrete and concrete-masonry buildings and high-rise concrete buildings. The light frame wood construction industry is still at a small scale and consumes a very small amount of OSB. The booming housing industry has resulted in huge consumption and demand for housing decoration wood materials, wood doors, wood flooring and furniture, and panels for concrete form. Therefore, the main opportunities for OSB in construction are not for structural construction sheathing-grade OSB, but for non-structural panels in house decoration and refurbishing, refurbishing applications, and concrete form.

INDUSTRIAL OPPORTUNITIES FOR OSB

OSB opportunities generally do not lie in the construction industry as structural panels because WBPs are not conventionally used that way in China. Percentages of each end-application of WBPs demonstrate that the main opportunities for WBPs in China are industrial uses, *i.e.*, furniture, concrete form for construction industry, wood doors, wood flooring, packaging, and transportation, among others (Fig. 2).

To be used in those industrial end-applications, OSB needs to compete mainly with plywood. Currently, plywood is the dominant wood-based panel produced in China, accounting for about 53.7% of the total WBPs production in 2013 (Qian 2015b). The

plywood industry is highly labor-intensive, with a lower degree of automation. The majority of the Chinese plywood mills are of small size with an annual capacity less than 10,000 m³ with little competitive advantage in terms of economical scale. Due to a big gap between domestic supply and demand, the price of logs for plywood production is rising. In central China, the price for poplar logs with a diameter of 240 mm was 1160 yuan per m³ in 2013 compared with 763 yuan per m³ in 2005. The price per m³ for eucalyptus logs with diameter between 80 mm to 120 mm in Guangxi province increased from 350 yuan in 2001 to 780 yuan in 2014. In addition, the labor cost is increasing. The average monthly salary for workers increased from about 1,500 yuan in 2006 to over 2,300 yuan in 2010. The salary for some plywood mills went up to 3,000 yuan in 2012, and reached 3,200 yuan in 2013 in the Yangtze River delta area (Mao and Wu 2015). The plywood industry in China, which depends on low labor cost, has been losing competitive advantages, and its margins are shrinking owing to increasing costs. Lumber-core blockboard, which is used widely in house interior decoration and furniture making, is facing the same problems as plywood does. In addition, blockboard faces complaints for having gaps in the core and lower strength in the direction perpendicular to the panel length. The Chinese plywood and blockboard industries are under a great deal of pressure to manage the rapid increase in labor and log costs. Furthermore, China bans commercial logging in state-owned natural forests in 2016 and will gradually ban commercial logging in collective-owned natural forests starting in 2017 (Shang 2015). Eventually, China will ban commercial logging in all natural forests as planned in the 13th Five-Year Plan (Anonymous 2015b). This logging ban in natural forests will reduce annual commercial wood harvesting by about 50 million m³. As a result, the log supply gap for domestic plywood production will be approximately 20 million m³, which needs to be filled with bigger logs from domestic plantation forests or imported logs (Qian 2016). This may cause higher reliance on imported logs and further raise log prices.

In contrast, OSB products are produced continually with highly automated and efficient large-scale production facilities, which enables producers to improve production efficiently, lower the production variable costs, and ensure product quality. Another major advantage of OSB over plywood and blockboard is that it can be made from small-diameter logs, which helps to lower the material cost, though in China OSB basically consumes the similar raw materials as the core layer of common plywood does. Besides the current limited wood construction market in China, the other main reason limiting the development of OSB in China in the past was the cost competition with plywood. Therefore, with the increasing costs for logs and labor, the main advantage of plywood over OSB in the past decades in China, *i.e.*, lower production costs, is diminishing. Producing and using specialty OSB products as substitutes for plywood and blockboard show improved economic viability.

In conclusion, the current major opportunities for OSB products in China exist not in the construction industry as in North America, but in industrial applications to replace plywood and blockboard and other end-uses calling for high-quality panel board. Those are areas where OSB products have the potential to gain market share if they can be produced properly at a reasonable cost with satisfactory specific technical attributes.

Core Stock for Doors and Furniture Opportunities

It has been reported that seven doors are needed for each 100 m² floor space (Qian 2013). Therefore, the rapid development of China's construction industry in the past decades had greatly promoted the development for wood door industry especially in the

first decade of the 21st century. The total annual gross output of wood doors increased from 17.0 billion yuan (about US\$ 2.62 billion) in 2004 to over 70.0 billion yuan (about US\$ 10.77 billion) in 2010 (Xu 2011), whereas the production volume grew from 27.75 million sets in 2003 to 180.27 million sets in 2014 (Fig. 3) (Qian 2015a). Besides solid wood and edge-jointed wood panels, plywood, fiberboard, tubular particleboard, blockboard, and all kinds of decorative WBPs are used widely for door-making (Qian 2012). Currently, about 4% of WBPs produced in China goes into the wood door industry (Fig. 2) that is surely another consumer of WBPs products.

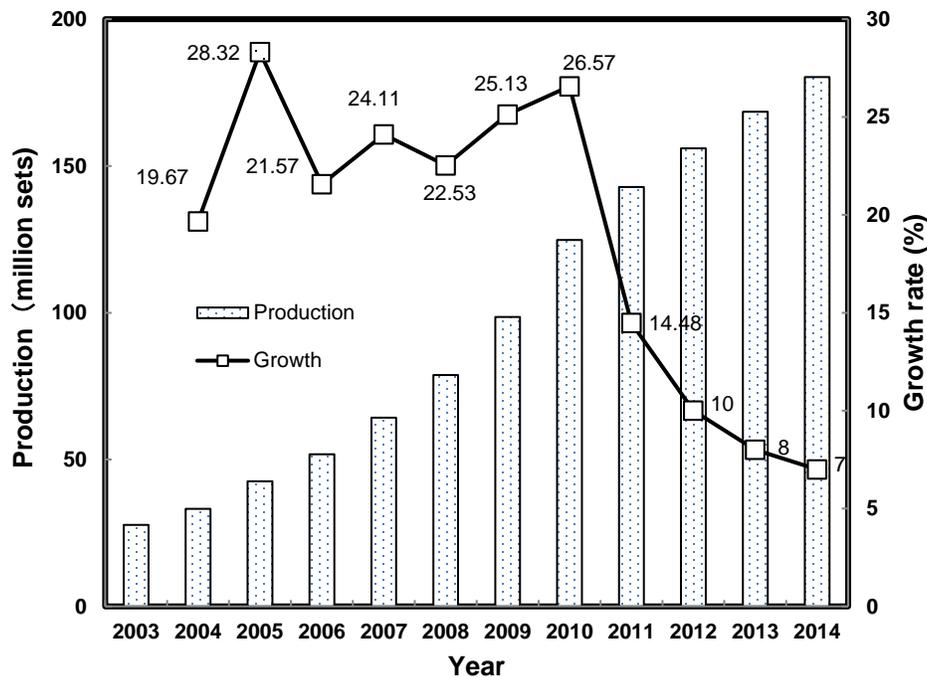


Fig. 3. Wood door production and growth rate from 2003 to 2014 (redrawn from the data of Qian 2015a)

The furniture industry in China has experienced steadily accelerated growth since the middle 1990's. The annual production value grew from 165 billion yuan (about US\$ 25.38 billion) in 2002 to 1,130 billion yuan (about US\$ 173.85 billion) in 2012 (Fig. 4), which accounted for $\frac{1}{4}$ of the world total. China has become the world largest furniture producer and exporter (Wu 2013). Currently, there are about 80,000 mills and 5 million employees. In 2014, China produced 260 million pieces of wooden furniture. Solid wood furniture and panel type furniture account for 24% and 36% of the total furniture produced in China in terms of production value, respectively. The production value of panel type furniture is about 60% of the total value of the wooden furniture, which determines that panel type furniture is the dominant type of furniture made in China (Qian 2015a). About 37% of the furniture material used in China is surface overlaid WBPs (Wu 2011). The 48% of WBPs produced in China are for furniture manufacturing (Fig. 2), making the furniture industry the dominant consumer and the major growth engine for WBPs industry in China.

Panel type furniture is made either from plywood, particleboard, medium density fiberboard (MDF), or blockboard. Its members are generally from panels overlaid with a layer of melamine formaldehyde (MF)-impregnated paper or wood veneer that covers the surface, and are mostly connected with metal fasteners. Therefore, surface quality for

overlay, screw holding, and machinability of a panel product are significantly important requirements in furniture production. Other important attributes required are no screen back surface (*i.e.*, smooth panel surface on both sides), smooth surface and tight thickness tolerance for minimum sanding for surface lamination, and dimensional stability. Originally, North American OSB was designed for use as construction sheathing. Much more attention has been paid to its bending strength than other properties such as surface properties and dimensional stability. A survey conducted among manufacturers of wood office furniture and doors indicated that major technical complaints with OSB for those applications include poor surface uniformity and smoothness, low moisture resistance causing strands to swell and destroy the paint finish, veneers and laminates that do not adhere properly to OSB, and low screw or staple holding ability on edge (Tabarsi *et al.* 2003). It is clear that commodity OSB is unsuitable for those core-stock applications. To expand OSB usage into the furniture and wood door core stock markets, there must be new OSB products or modified OSB with respect to surface quality characteristics and required workability.

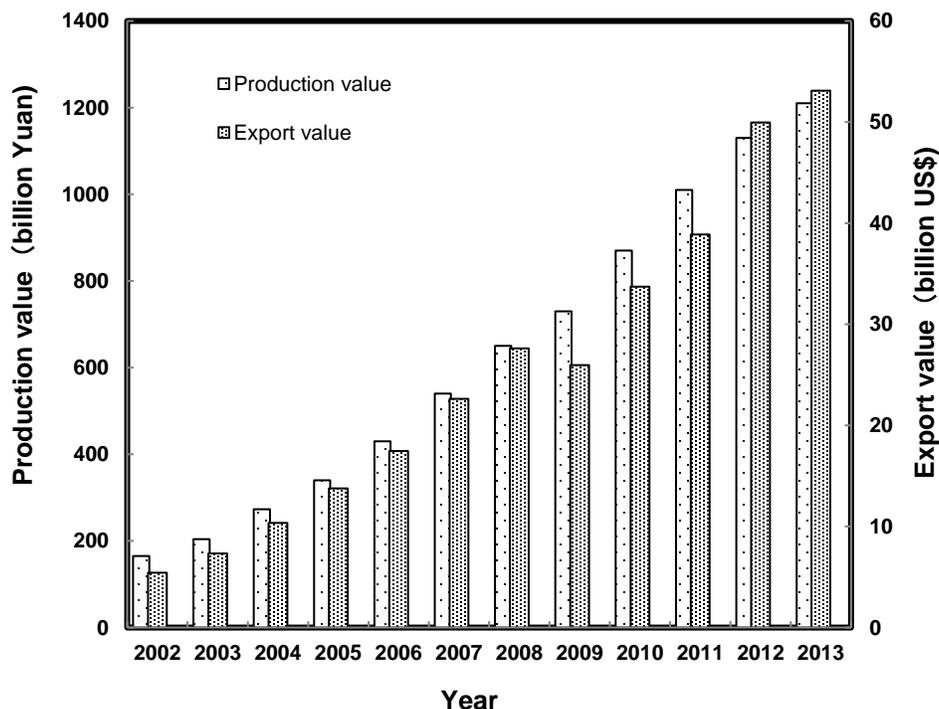


Fig. 4. Production and export value of China furniture from 2002 to 2013 (Data provided by Prof. Zhihui Wu at Nanjing Forestry University)

Alberta Innovates - Technology Futures (formerly Alberta Research Council, ARC) developed a proprietary technology to make a lighter, uniform, stable, optimized strand-based panel with the required dimensional stability and surface quality. The technology was later licensed to Ainsworth Engineered Canada LP (now Norbord Inc.) to produce specialty OSB panels for Dehua Tubao New Decoration Material Co. Ltd (Tubao) in China. Different from commodity OSB for construction sheathing, this OSB product is specialized for interior decoration and furniture making purposes, featuring 100% MDI bonded, lower thickness tolerance, better dimensional stability, and decent screwing holding capacity at edges (Xu *et al.* 2014). With this unique core stock, Tubao developed decorative OSB products overlaid with thin veneer or MF resin-impregnated paper, which are ideal

substitutes for high-end plywood and blockboard to be used widely in panel furniture making and interior decoration (Zhan *et al.* 2014). Currently, some Chinese door manufacturers are using North American softwood lumber for door core. Low-grade softwood lumber is cut to remove the defects and is then jointed into the core board for the doors. This requires a lot of labor, a bigger working area, and initial investment on equipment, resulting in higher production cost. The AITF technology of making low density OSB with flatter vertical density profile can also be used to make a thick strand-based panel for door core, which is well-suited to automation in door manufacturing. The size of the OSB panels could be optimized to reduce the amount of manpower required in furniture manufacturing and minimize the waste (Xu *et al.* 2014).



Fig. 5. Furniture and door made with OSB (Pictures provided by Baoyuan)

Chinese OSB producers and traders have worked hard on using OSB for furniture and interior decoration applications. As the first trader and promoter of European OSB in China, Beijing New Building Material (Group) Co. Ltd (BNBM Group) has invested considerable energy and efforts on expanding OSB applications. Zhang and Lv (2011), and Wang *et al.* (2011) from BNBM Group invented products based on OSB for interior decoration and furniture making. As the first big OSB producer, Baoyuan has allocated significant resources to expand their OSB products in Chinese domestic markets. Different OSB-based value-add products have been developed by overlaying with wood veneer, MF resin-impregnated paper, and MDF or painted with water-based varnish for furniture, doors, and interior decoration. Cai *et al.* (2013a, b) patented coating and overlay technology for Baoyuan's OSB products. Figure 5 gives examples of furniture and wood doors made

with OSB from Baoyuan's line. To fulfill the need for smooth surfaces and provide the feasibility of producing both OSB and particleboard, Shouguang Luli Wood Co. Ltd (Luli) has built a special production line that is equipped with one long log flaker, three ring flakers, and five forming heads. This line produces three different types of products including OSB, three-layer particleboard, and a particle and strand hybrid product (Liu 2014). Zhong and Guo (2016) from Luli were granted a Chinese patent on an OSB panel with fine wood elements on the surface, which can be overlaid directly without deep sanding.

Concrete Form Opportunities

Concrete form is important for concrete construction especially for cast-*in-situ* concrete structures. Concrete formwork accounts for 20% to 30% of total construction cost, 30% to 40% of total construction work, and 50% of construction duration for concrete structure (Hou 2002). With the booming construction sectors including residential, commercial buildings, and infrastructure construction, China consumes a great amount of WBPs, mainly plywood and bamboo plywood, as concrete form panels.

Hua and Qi (1996) initiated the first research in China to overlay OSB with veneer or with both veneer and MF-impregnated paper, and reported that the bending strength and stiffness of the resulted products exceeded the minimum requirements for plywood for concrete form. Later, a patent was granted for making concrete form from OSB to Xu *et al.* (2009) from Nanjing Forestry University. Li *et al.* (2013) invented an OSB-based concrete form panel with high wear resistance by overlaying resin-impregnated paper alone or with another paper impregnated with a resin containing aluminum.

Concrete form panel is a demanding application of OSB. Required attributes include exterior bond classification other than exposure 1 classification of sheathing OSB, fine surfaces for overlay, higher strength and stiffness in length and width, tight thickness tolerance, and excellent water and edge resistance for repeated concrete pours. The Guide on "Concrete Forming" from The Engineered Wood Association (APA) (2012) and the China national standard GB/T 17656 (2008) are good guidelines to engineer OSB products for this specific application.

Wood Flooring Opportunities

Wood flooring is widely used in housing decoration in China because Chinese people generally prefer wood flooring to ceramic tile or carpet. China ranks No. 1 in the world in terms of production, consumption, and export volume of wood flooring. In 2014, the production capacity was around 600 million m², and annual output value of the wood flooring industry was close to 100 billion yuan (US\$ 15.38 billion). There were about 2,800 wood flooring mills and 700,000 employees engaged in wood flooring production. Of the 688 million m² wood flooring produced in 2014, engineered wood flooring, laminated wood flooring, and solid wood flooring accounted for 37%, 25%, and 19%, respectively (Qian 2015a). The limited supply of high quality domestic logs, increasing raw material supply shortages, and high prices have resulted in a gradual decline in the production of solid wood flooring and the growth of both engineered flooring and laminated wood flooring industries. Currently, 5% of WBPs (Fig. 2) (*i.e.*, approximately 13.7 million m³ based on 2014 production) are used in the flooring industry.

OSB-based engineered flooring products have been developed in China. Lu and Wang (2007) from BNBM Group invented three-layer OSB-based engineered wood flooring. Baoyuan produced OSB engineered wood flooring (Fig. 6), and Cai *et al.* (2012a,

b, c, d) from Baoyuan were granted patents on OSB-based waterproof, heated flooring, *etc.* Zhejiang Layo Wood Industry Co. Ltd (2014) and Heilong Jiang Jiamu Panel Co. Ltd have developed OSB-based engineered wood flooring too (Yu 2012).



Fig. 6. OSB-based wood flooring (Pictures provided by Baoyuan)

Problems have been reported when making wood flooring with commodity OSB products. Due to its thickness variation and rough surface, OSB cannot be overlaid well directly with wood veneer (Zhejiang Layo Wood Industry Co. Ltd 2014), and a thorough sanding is a must, which is costly. Without solid wood banding, the edge of the flooring is rough, not aesthetic enough, and difficult to joint, has low water resistance, and presents lower connection strength. The surface workability, internal bonding strength, and edge properties need to be improved. Linear expansion and thickness swelling are two other critical properties of OSB for wood flooring. The basic requirements of fiberboard for flooring and plywood for engineered wood flooring are given in Chinese industry standards LY/T 1611 (2011) and LY/T 1738 (2008), respectively. Accordingly, the specification of laminated wood flooring and engineered wood flooring are given in Chinese National standards GB/T 18102 (2007) and GB/T 18103 (2013). In order to provide OSB-based flooring with acceptable performance at reasonable cost, tailored OSB products must be developed, and product standards need to be developed for both OSB substrate and flooring products.

Container Flooring Opportunities

The container industry in China started at the end of the 1970's. At the beginning, there were only four producers with a total capacity of less than 40,000 twenty-foot equivalent units (TEU). By the end of 2007, the number of producers increased to 58, and the capacity grew to 5.8 million TEUs, 144 times higher than the original capacity, which accounted for 96% of the global total. China ranks No.1 in the world in terms of manufacturing capacity, production volume, and sales volume of containers. It is estimated that 0.38 m³ of wood panel is consumed to build a new standard TEU (Zhang *et al.* 2011). Therefore, over 1.0 million m³ of flooring board is consumed annually in China for making new containers.

Typically, the container flooring is made from 28-mm thick, preservative-treated plywood consisting of 19 layers of veneer, which has been made from tropical hardwood species (Zhang *et al.* 2011). With the environmental issues and international pressures against harvesting of tropical forests, the supply from tropical hardwood resources has

become increasingly constrained, and the cost has greatly increased. Many attempts have been made to produce alternatives to plywood flooring from tropical hardwood.

For transporting goods or during loading or lifting, containers are subjected to high loads. Flooring panel is the main component and load-bearing member of the container, and it is the most demanding application for wood products with tight specifications on panel performances, including strength, long term adhesive durability, and longevity as specified in the Institute of International Container Lessors (IICL) performance standard TB 001 (2015). The attributes required in container flooring panels are high strength to sustain the heavy cyclic wheel loads of forklift trucks loading and unloading goods from a container and to sustain concentrated loading during transportation. Short spans and high rolling loads result in high shear stresses in the core and high bending stresses in the surfaces. The design of container flooring panels must account for the high stresses put on the floor.

Working with academic and industrial partners, AITF has developed an aspen OSB core for the container flooring. The flooring panel is then made with the OSB core and laminated with high density surface veneers on both faces. The OSB core provides sufficient shear strength, while the outer hardwood veneers provide the bending strength required. A product like this would displace the tropical hardwood-based plywood container flooring currently in use with species locally grown in China (*e.g.*, poplar) in a sustainable manner.

The OSB producers in China have been also working on developing container flooring from OSB. Patents related to OSB products for boxboard and container flooring were granted to Shao *et al.* (2014) and Wang *et al.* (2012 and 2013) from Happy Group, and Happy Group started to build a line with a capacity of 200,000 m³ in February 2014, to focus on OSB for packing and container flooring (Anonymous 2014c). He *et al.* (2014) invented a strand-based veneer combined container flooring and manufacturing method. A patent was granted to Li *et al.* (2015) from Kangxin New Material Science & Technology Stock Co. LTD (Kangxin) on OSB container flooring board. Moreover, Kangxin built a line with a capacity of 220,000 m³ to produce high density, high strength OSB for container flooring in 2014. The line produced its first OSB panel for container flooring in April 2015. The flooring board consists of a high-density OSB board made from local poplar wood and several cover layers of veneer. To facilitate production of denser and thicker OSB products, a steam pre-heating system is installed upstream of the press (Anonymous 2015c), which is not typically used in line for production of sheathing-grade OSB.

Industrial Packaging Opportunities

With the phenomenal growth of international and domestic trade in China, the industrial packaging industry has been rapidly developed, especially since China's entry to WTO in 2001. In 2013, there were 200 to 240 million pieces of pallets in China with an annual growth of 20 million pieces, where wood pallets accounted for 90% (Zhang and Yu 2014). Wood packaging has been used widely for international trade, but solid wood packaging materials call for either heat treatment or fumigation with methyl bromide, according to the guidelines of the International Plant Protection Convention (IPPC) (Jabara *et al.* 2008). Besides the stricter regulation, it is difficult and costly for China to provide high quality or large diameter logs for solid wood packaging. WBPs, which are mostly produced from small diameter fast growing trees, with its wood elements (*i.e.*, veneer, particle, strand, fibers, *etc.*) going through high temperature drying and hot pressing

processes, are exempted from insect treatment. Currently, only a small amount of OSB is consumed for packaging in China, and the majority of it is low-grade OSB in the form of small and middle size wood boxes and crates. With the increase in production cost for plywood and increasing demand for packaging material, it is expected that OSB will be used for a wide range of packaging applications in the long run, since a huge amount of wood products are needed for packing of mechanical and electrical, chemical, military, hardware, and some agricultural products (Zhang and Yu 2014). At present, the hurdle for OSB penetrating into this industry in China is the cost; there is no advantage for OSB to compete with the low-grade plywood for the general-purpose packing.

CONCLUSIONS

Chinese scholars started conducting research on OSB in the 1970's, and OSB production lines have been built since the early 1990's. However, the consumption of OSB has been limited, and the production has not been expanded until 2014, due to the low acceptance of commodity construction sheathing-grade OSB in the Chinese market and the advantages of plywood over OSB that was mainly based on the lower labor cost.

With the rapid growth of the economy and development in the forest product industry in the past three decades, China has become the world's largest producer and consumer of wood-based panels. The majority of those panels have been used for furniture, concrete form, wood flooring, wood doors, packaging, container flooring, *etc.* The huge demand for wood-based panels from these sectors, along with small and slow development in the wood construction industry, are leading to a gradual recognition that the opportunities for OSB in China are different from those in North America. It is clear that commodity construction sheathing-grade OSB is suitable for very few current existing markets in China, though wood construction in China may grow. To absorb the expanding production volume of Chinese OSB, the manufacture of specialty OSB products fitting the Chinese markets may be the key to develop the industry in China.

With the increasing labor costs and log prices, it is time to reconsider using OSB as a more economical alternative to conventional plywood and blockboard products. Chinese OSB producers need to manufacture differentiated products for different end-applications; examples include but are not limited to specialty OSB products to substitute for existing wood products for furniture, doors, concrete form, flooring, and container flooring, *etc.* Those industrial applications and requirements for OSB will be different, more varied, and demanding. The main challenge for OSB producers in China is how to cost-effectively manufacture specialty OSB products to meet varied specifications, *i.e.*, producing OSB products that compete with plywood in terms of cost and performance for various industrial uses. Chinese OSB producers must adapt or formulate their production processes to provide products with the required strength, dimensional stability, surface quality, or other desired specifications at reasonable costs. For the existing OSB production lines, technical strategies and modifications must be undertaken to produce specialty OSB products to meet the specific target market's requirements. For new OSB producers coming to market, it is critical to select the most suitable equipment to match their resources with the needs in Chinese domestic markets. It is highly recommended that both domestic and overseas OSB producers make specialty OSB products tailored to the needs of China's markets.

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