Development and Application of Wood Adhesives in China

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Abstract
Rapid economic development and growth in China has resulted in a substantial increase in the demand for utilization of bio-based composites. This provides a unique opportunity for developing wood adhesives. This study reviews research development and major accomplishments in wood adhesives and technology in China over the last 50 years. It also discusses the characteristics of China’s wood adhesive supply and utilization. The results show that urea-formaldehyde adhesive is still the dominant wood adhesive with about 70% of total adhesive use. However, public health and environmental concerns require development of new, safe, and green adhesive systems. It is expected that future research and development of wood adhesives in China will not only focus on performance improvement and cost reduction but will also address public interest concerns such as efficient resource utilization, product sustainability, pollution control, green construction, and global climate change.

Introduction
Since 1978, China has been following an “Open Door” policy for its economic reforms resulting in very rapid growth in the past few years. The supply of wood, as a raw material, has also changed dramatically from large-diameter logs from forests to small-diameter logs from plantations and thinnings. These small-diameter trees, along with agricultural residuals, have become the dominant woody-fiber supply for bio-based composites. Although the fiber supply is increasing, these resources are still unable to meet the demand and usage of bio-based composites due to extraordinary economic development and growth. China is now one of the top five major wood-producing countries in the world, having invested in a number of large processing facilities over the past decade to supplement outdated and inefficient small mills [Gu 2006]. Significant quantities of all wood products are manufactured with the main ones being plywood, particleboard, laminated flooring, and medium density fiberboard (MDF). Of these, MDF is the most important and production quality has been continuously improved. Wood-based panel production in China in 2007 reached $8.4 \times 10^8$ m$^3$ [Table 1] and wood flooring production was about $3.42 \times 10^9$ m$^2$ [Fig. 1]. The total production value of Chinese furniture and of forest products reached ¥$5.4 \times 10^9$ Chinese Yuan ($¥7.9 \times 10^9$ USD) and ¥$1.17 \times 10^9$ Chinese Yuan ($¥17 \times 10^9$ USD), respectively [Gu 2008]. Since most furniture and wood panel products are made with wood elements that are bonded together with various adhesives, they are usually considered to be the major wood adhesive utilization. This paper presents an overview of the development and characteristics of the wood adhesive industry in China.

Major Wood Adhesives and Their Utilization
Most wood panel manufacturers in China rely on their in-house adhesive manufacturing facilities to produce the adhesive for their products. Adhesive production is considered to be part of panel production and the volume of adhesive utilization is usually not directly released by the manufacturer. It is therefore impossible to determine usage from the published data. However, it can be estimated from the panel production and its estimated adhesive content. Table 2 shows that the total estimated adhesive utilization in 2007 in China was about 4.9 Tg [Gu 2008]. It is interesting to observe that among particleboard, MDF, plywood, and other composite panels, MDF products used nearly 50% of total adhesive usage.

In addition, the development of impregnated laminated paper for furniture products and bamboo composites greatly increased the use of other adhesives. In 2007, the production of laminated papers for decorative surface products was about $2.57 \times 10^9$ m$^2$ [Gu 2008]. If resin impregnation were 120 g/m$^2$, the adhesive utilization for laminated papers in China would be 31 tons. Taking all possible wood composites into consideration, it can be reasonably...
estimated that the total adhesive solids utilization in 2007 was over 5 Tg. This is much higher than 0.9 Tg, which was the projected adhesive usage for 2010 by Hse (1999).

Most wood-based composites produced in China are used primarily in furniture and interior decorative products, although there have been a few plants producing exterior grade plywood in recent years. Urea formaldehyde (UF) adhesive still dominates the adhesive market in China due to its low cost and trouble-free process. It is estimated that approximately 70% of wood-based composites were bonded with UF adhesive (Gu 2008).

Recently, the use of other adhesive systems, such as melamine-formaldehyde, melamine-urea-formaldehyde (MUF), phenol-formaldehyde (PF), and aqueous polymer isocyanate (API), increased because of increasing market demand for moisture- and water-resistant panels. PF adhesive has been widely used in producing high-performance panel products, reconstituted bamboo composite panels, and value-added plywood that could be used as container flooring and concrete formwork/mold panels.

**Development of Wood Adhesives in China**

Rapid economic development and growth has resulted in substantial increases in demand and utilization of bio-based composites in China. This provides a unique opportunity for developing new types of wood adhesives. Adhesive research and development started in 1958 when Shidou Lu introduced the first generation of synthetic urea-formaldehyde adhesive and modified it by adjusting the mole ratio. He developed a UF adhesive called “Zhongling 64 UF adhesive” with a molar ratio of formaldehyde/urea (F/U) = 1.6 in 1964, which was successfully used to produce plywood (Gu 1993).

In the 1960s, China was working on developing adhesive systems suitable for the particleboard manufacturing process. The “Zhongling 64 UF adhesive” was modified to a higher molar ratio F/U = 1.73 in order to improve its thermal curing performance for producing particleboard. To reduce the content of free formaldehyde and the formaldehyde emission of the final particleboard products, the molar ratio of the UF adhesive, however, needed to be reduced. “L-142 UF adhesive” with a molar ratio F/U between 1.25 and 1.35 was developed by Norwegian Dyno Chemicals and was used in Chinese particleboard mills (Gu 1998).

In the 1970s, the demand for particleboard panels with high mechanical strength (especially high screw-withdrawal strength) triggered the development of high performance UF adhesives in China. A type called “NQ-80”, developed at the Chinese Forestry Academy, and the type “DN-1”, developed at the Northeast Forestry University, started to be used in the early 1970s (Gu 1998).

In the late 1970s and early 1980s, Chinese economic development and construction increased dramatically due to its Open Door policy. The economic growth resulted in substantial increases in demand for wood-based composites and improvements in product efficiency. This provided overseas adhesive companies a good opportunity for exporting their high quality adhesives to China. Norwegian Dyno and German Karl Fisher Chemical Companies were among the pioneer adhesive suppliers. In addition to its adaptation in the panel manufacturing process, the adhesives could also be used to produce wood panels classified upon their formaldehyde emission as Class E2 without the addition of melamine (Gu et al. 1996).

Imported adhesives soon replaced the domestic adhesive market share in China, which stimulated the development of new domestic UF adhesives. The primary adhesive development research then focused on melamine-based UF adhesive systems. Initially, a low-melamine content was used due to cost concerns. “DN-6 UF” adhesive with its low molar ratio F/U = 1.05...
and its low melamine content (1% of urea mass in the liquid adhesive) was developed at the Northeast Forestry University and was used to produce particleboard panels that met Class E1 certification based upon the formaldehyde emission. Later, a series of melamine-fortified UF adhesive systems with a range in the molar ratio F/U from 1.05 to 1.20 and melamine contents from 1 to 5% based on urea mass in the liquid adhesive were developed to meet different formaldehyde emission and strength requirements. Because of its high moisture resistance and low formaldehyde emission, the MUF adhesive now is mainly used to produce high performance panels for kitchen and laminated flooring applications (Gu 2008).

Another thriving wood-product market in China is laminated wood flooring. Papers impregnated with melamine formaldehyde (MF) adhesives are widely used in decorative surface finishing of engineered wood-based panels for indoor and outdoor applications. The need for high surface abrasion and water resistance fostered the development of rapid curing and cost effective MF adhesives.

### Characteristics of Wood Adhesive Development and Production in China

In terms of quantity, China is one of the largest producers and consumers of wood panel products in the world. However, many wood panel manufacturers in China are small or medium size companies with annual production capacities of less than 30,000 m³. Most wood-panel manufacturers rely on their in-house adhesive manufacturing facilities to produce the adhesives needed for their products. The typical characteristics of wood adhesive manufacturing in China can be summarized as follows:

1. Most companies do not have adequate resin formulation and quality control capability. Some small and medium size companies only have resin production facilities which simply allow them to mechanically mix the adhesive. Adhesive formulation and its quality closely rely on the operators’ skill, knowledge, and experience.

2. Product specifications and standards vary considerably among the manufacturers. The manufacturers follow both voluntary and mandatory standards with their own interpretations and capabilities.

3. Most small and medium size companies over-emphasize cost reduction and use low-quality raw materials. Most in-house adhesives exceed the usual requirements concerning the content of free formaldehyde, which causes environmental concerns.

4. Adhesive manufacturers usually focus on their adhesive development and often fail to work with panel manufacturers to provide optimal adhesive curing and bonding parameters to improve their production efficiency.

5. Most adhesive and panel manufacturers neglect the effect of bonding material on adhesive bonding performance. After being developed for a certain species in the lab or plant, the adhesive is usually considered as fitting for all materials regardless of different species, surface quality, wettablity, and pH-values. No technical support is provided after the adhesive is sold.

### Wood Adhesive Development and Manufacturing in the Future

Urea-formaldehyde adhesives are expected to dominate the Chinese adhesive market with a 70% share for the next five years. The utilization of MUF, PF, and API will increase due to the higher market demand for moisture- and water-resistant panels. Future adhesive research and development in China will still emphasize improvement of UF adhesive systems in order to lower formaldehyde emissions, reduce costs, and improve moisture resistance. Development of successful scavengers for free formaldehyde during the hot-pressing process will be the key for UF adhesive products to meet the increasingly strict formaldehyde emissions requirement. New formulations for melamine-modified UF adhesives will be another key research area for developing cost-effective wood adhesives. PF adhesives will gain an increasing market share due to their excellent mechanical and exterior performance. Recent interest in using soybean-derived or other protein-based adhesives has increased dramatically due to environmental concerns and the high cost of petroleum-based adhesives. However, the insufficient supply of protein limits the commercialization of protein-based adhesive systems in China.

To meet the demand of high quality wood-based composite panels, large-scale production factories and equipment for wood adhesives will replace small factories using old and inefficient equipment. Recently, the opening ceremony occurred for the construction of the Phase II project of the Qingdao Winlong International
Chemical Company (Qingdao branch of the Internet Wood Glue Co. Ltd.). The project covers 8.9 ha of land in the suburban area of the city of Laixi in the Shandong province. The Phase II project, mainly producing adhesives for woodworking, is expected to become the largest wood-adhesive producer in China, with an annual production of 115,000 Mg by the end of 2010 (Wood-Based Panels International 2009).

Conclusion

China is one of the largest countries in the world in producing and utilizing wood-based composite panels with its annual panel production of over $88 \times 10^6$ m$^3$ and a wood adhesive utilization of over 5 million Mg [solids base] in 2007. Most wood panel manufacturers are small- and medium-size companies that rely on their in-house adhesive manufacturing facilities to produce the adhesive for their products. Urea formaldehyde adhesives dominate the Chinese adhesive market with a share of about 70%. MUF, PF, and API utilization is going to increase due to the higher market demand for moisture- and water-resistant panels.

Future adhesive research and development in China still emphasizes UF adhesive systems improvement in order to lower formaldehyde emissions, reduce cost, and improve moisture resistance. Interest in using soybean-derived or other protein-based adhesives has increased dramatically due to environmental concerns and the high cost of petroleum-based adhesives. However, the insufficient supply of protein limits the commercialization of protein-based adhesive systems in China.

Requirements stated in Chinese panel product standards for consistent performance stipulate the need for high quality adhesive systems. Large-scale adhesive production factories and equipment will replace small factories with old equipment to meet the demand for high quality wood-based composite panels. This will provide an opportunity for adhesive companies to establish a wood-adhesive supply chain in China.

Literature Cited
