Wood Plastic Composites Technology Trends

Douglas J. Gardner
AEWC Center, University of Maine
Orono, Maine, USA

Yousoo Han
AEWC Center, University of Maine
Orono, Maine, USA

Wayne Song
Futuresoft Technologies
Manalapan, New Jersey, USA

Abstract

Wood plastic composites are an important and growing segment of the forest products industry. This industry segment has grown in double digit percentages annually for the past decade. In North America, the WPC market has been dominated by rail and decking products while in Europe more emphasis has been placed on automotive applications. In China and other parts of Asia, the WPC market is beginning to experience considerable growth along with a wider variety of product offerings including pallets, doors, and architectural moldings. This presentation will cover some of the technology trends in WPCs including current applications around the world and current fundamental and applied research topics (durability, nanocomposites, processing and performance, foaming, and structural WPCs.)

Keywords: wood plastic composite, WPC world market, WPC applications, engineering plastics, blowing agents, cross-linking,

The Global Market for WPCs

Since the first WPC products were introduced in the 1980's, the market size has increased up to $1,565 million within 3 decades. That increase represents the potential of WPC as a construction material. The intial market breakthrough for WPCs began in the US in the decking and railing market in the middle of the past decade. These WPC home construction products were attractive to consumers because of their low maintenance even though WPC prices were higher than the alternative competitor – pressure treated lumber. In terms of market share, the rate of WPC increase compared to other deck board products, increased from 2% in 1997 to 8% in 2000, and exceeded over 20% in 2005 (Smith 2002 and Morton 2005). In 2006, the total market size of WPCs in North America reached $1,425 million, which mainly included decking/railing, window, transportation, and other markets (Yangling 2007). The array of WPC products has continuously expanded to roofing, molding or trim, doors, fencing, and landscaping materials.

In Europe, indoor applications including relatively cheap furniture moldings and trim products have been developed for consumers attracted to the flexibility and the variety of shapes and configurations possible with WPCs. The total market size of WPCs in Europe in 2005 was estimated to be $100 million, which is estimated to increase up to $380 million by 2010 (Green 2003 and Nash 2005). Even though the decking market in Europe is relatively small, the annual growth rate (AGR) has ranged around 12 to 14% during the last five years. It is estimated the growth rate will be over 10% for the next 5 years (Eder 2007). The high growth rate of decking indicates potential for an expanded market for WPCs which had a market share in Europe of only 6.1% in 2007.

In Asia, the major WPC markets have been in Japan, South Korea, and China since the 1990's. The Japanese WPC market which began in the 1990's increased to $300 million by 2005. (Green 2003). Today, about 30 manufacturers produce WPC for various applications from garden furniture, small garden structures, and balcony floors to indoor floors and outdoor decks. The Korean market which began in 2006 is increasing rapidly since the supply of tropical woods is not stable and customers' concerns for the environment is growing. China's WPC industry is making strides, growing 15 to 30 percent a year and, by some estimates in 2007, Chinese production soon could overtake European production. It was estimated by the Chinese WPC Council that the Chinese WPC market ranged from 75,000 to 150,000 metric tons (Toloken 2007). An early WPC product in China was pallets which now comprises 70% of the total WPC market (Song, 2005). It is expected that the WPC market in China will sharply increase due to environmental issues, dramatic increases in the construction materials market, and the decreasing availability of natural resources in China.

It should be noted that the major WPC quality desired by Asian customers is not durability of WPCs but the wood-like appearance even if it contains almost 50% synthetic petroleum polymers. So, the manufacturers of WPCs in Japan and South Korea have focused on the surface treatment combinations of embossing and mechanical processing for producing a realistic wood appearance. WPC products are expanding in market size and dispersionas new applications of WPCs are being developed and adopted according to the local market situations and local customers' cultural backgrounds.

Technology Trends

Current hot issues in WPC technology are weight reduction of the products and enhancement of mechanical properties for structural uses. Weight reduction can be achieved by using physical or chemical blowing agents that create cavities inside the polymer matrix. Unlike the general foaming process in unfilled thermoplastics, WPCs, highly-filled thermoplastic composites, place restrictions on foaming properties since wood fillers can negatively impact the foaming mechanism. Considerations and cautions of this issue have been well addressed by the University of Toronto, where appropriate amounts of blowing agent, minimization of gas diffusion to atmosphere, suppression of cell coalescence and cell collapse are controlled (Park 2004). High filler content causes foaming instability since the cells created exist in an open system, resulting in cell coalescence and collapse. Moreover, the cell sizes are various because of the variety of particle sizes. High filler content can lead to cell coalescence in the worst case and relatively weaker strength in several mechanical properties. Even though it is well known that there is a decrease in strength for foamed plastics, the strength decrease in WPCs is greater than with other thermoplastics.

Researchers have focused on development of physical blowing agents using a phase of super critical fluids that can be dissolved into polymer melts under high temperature and pressure (Rizvi 2003 and Matuana 1995). The solubility of physical blowing agents helps distribute the cells evenly and limits the cell size so that the significant mechanical deterioration can be avoided. Foamed styrene-wood composites have been produced at the Advanced Engineered Wood Composites Center using reactive extrusion (Han 2008). The blowing agents are created by the chemical reactions during the extrusion process and efficiently dissolved into the polymer melt where the dissolution occurs in the mixing zone of the barrel next to the venting zone so that there is a minimum loss of blowing agents through venting.

Another important issue is the increase of WPC applications for structural uses. To increase the stiffness of WPC-based polyolefin polymers, a cross-linking process has been examined using silane cross linking. The silane cross-linked high density polyethylene wood composites were stored at high humidity and high temperature to increase the degree of cross-linking (Bengtsson 2006). The toughness was significantly increased but the stiffness did not change. In another study of cross-linked WPCs, a silane compound was used as a coupling agent to improve the interfacial properties between wood fillers and HDPE and another silane compound was applied as the cross-linking agent of the polymer matrix (Han 2007). The combined silane compounds did not have any incompatibility issues since they are similar chemical structures. It was found that both mechanical properties of stiffness and strength were significantly improved. Wood flour acts as a solid structure networked with the cross-linked polymer matrix. Mechanical stresses can be internally transferred into the wood particle, a relatively stiff component of the composite, from the cross-linked polymer matrix. It is believed that a loading of wood filler treated with a coupling agent could interact with the polymer matrix in the cross-linking mechanism, resulting in an enhancement of the close contact and physical linkages between two different materials. The flexural modulus of cross-linked HDPE wood composite was around 470,000 psi which is two times higher than those of HDPE WPC's in the current market.

To upgrade the stiffness of WPCs, the selection of the polymer matrix is one of the major issues. Polyethylene terephthalate (PET), polyamide (PA, Nylon), and acrylonitrile butadiene styrene (ABS) are typical engineering plastics with superior mechanical and thermal properties. The melting or plasticizing temperatures, however, range from 230°C to 270°C which is enough to cause serious thermal degradation of the wood. Several strategies have been used to overcome this thermal degradation at the AEWC Center, Orono, USA. Two extruders were combined to minimize the retention time for wood exposure to the high processing temperatures. One extruder feeds melted polymer into a twin screw extruder designed for efficient and rapid mixing to compound the polymer melt and cold wood flour. The retention time of wood to be exposed to very hot polymer melt was controlled at less than 4 minutes residence time. In this process, the severe thermal degradation could be avoided and nylon-wood composites could be produced. Another method of using engineering plastics in WPCs is viscosity modification of the pure engineering plastics. At the AEWC Center, Orono, Maine, several viscosity modifiers, which have low viscosity or special functional groups, were tested to examine the viscosity decreasing effect. Moreover, various polymer blends were tested as well to observe the changes in rheological properties. This study is now in progress and the results will be published in the near future.

Nanocellulose which can be fabricated by chemical and mechanical processes, has recently become the focus of WPC manufacture. Due to the high aspect ratio and nano-scale sizes of nanocellulose, an expectation of remarkable increases in mechanical and physical properties of composites has received attention. In current processes, the nano-cellulose, however, can only exist unagglomerated in water suspensions since the nano scale particles can not be maintained after secondary processes, such as drying. During the drying process, the cellulose polymer chains are easily agglomerated due to hydrogen bonding between the polymer chains, resulting in increases of particle sizes. With this motivation, cellulose nano-whisker suspensions were plasticized using a plasticizer and pumped into an extruder to produce cellulose acetate butyrate composite reinforced with cellulose nano-whiskers (Bondeson 2007). It was found that the tensile modulus and strength indicated an improvement with 300% and 100%, respectively, compared to control samples. At the AEWC Center, various studies are being conducted in developing efficient drying methods, functionalization of nanocellulose, development of new processes directly using nanocellulose suspensions in thermoplastic matrices, etc.

Conclusions

The WPC industry is now maturing in the US. In the world markets, WPC's are evolving into various applications according to the specific local needs. The technology used in WPC's is now expanding the research areas from a new material selection to the nano-scale structures. This new movement in the WPC industry and academic organizations will not only expand the applications but also their market sizes.

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