Extrusion of Wood Plastic Composites

Douglas J. Gardner
University of Maine
Advanced Engineered Wood Composites Center
Orono, Maine 04469

David Murdock
Fiber Composites
5775 Cells Mill Drive
Dublin, Ohio 43017

Abstract

The purpose of this paper is to provide an overview of wood plastic composite extrusion. Covered in this work is a brief introduction to wood plastic composites, the equipment and processing unit operations required to manufacture wood plastic composites, and the basic material properties of wood plastic composites. This paper is intended as a introductory pedagogical tool for discussing the basics of wood plastic composite extrusion.

Keywords: Extrusion, wood, thermoplastic, composite, extruder,

Introduction and Background

The manufacture of wood filled polymer materials has been an industrial process for about 80 years. Most of the early industrial applications of wood filled polymers occurred in thermosetting resin systems such as phenol-formaldehyde resins. Industrial applications of lignocellulosic filled thermoplastics were reported in the late 1960s (Rowell *et al*. 2002). A great deal of scientific literature began to appear on this topic during the 1980s into the 1990s (Lu *et al*. 2000). Also, in the 1990s, the industrial production of wood filled thermoplastic polymers became more wide spread. Also, during this time conferences in North America covering the topic of wood fiber plastic composites began to be held on annual basis. The last was held in Toronto, Canada in May 2002.

One of the largest segments of the wood filled thermoplastic industry centers on the production of wood plastic composite (wpc) decking material as a replacement for preservative treated wood and the more expensive durable wood species such as redwood and teak. Some of the positive attributes of wood filled plastic composite lumber compared to wood include it's durability, low maintenance, no painting, insect and decay resistance, and it will not warp, splinter, crack, is denser and thus holds screws better and can be manufactured to be resistant to ultraviolet light. This paper will address the manufacture of wood plastic decking by extrusion, and resulting properties of the wood plastic composite lumber. Topics to be covered include the materials used to manufacture wood plastic composites including thermoplastics, wood form and processing additives, the extrusion processes used to manufacture wpc lumber, and properties and products.

As an industry, the manufacture of wood plastic lumber decking is less than 15 years old. It has experienced an annual growth rate of 30% during the late 1990s (ASTM 1999**)**. Various extrusion processes are used to manufacture wood plastic lumber and some manufacturers, to reduce weight and material costs have adopted the manufacture of hollow cross-section profiles. The materials used to produce wood plastic composite lumber include thermoplastic resins, most notably, low and high density polyethylene, polypropylene and polyvinyl chloride. The polymers utilized typically need to have melting temperature that is below the thermal decomposition of wood (~225 degrees C). These thermoplastics can come from both virgin and recycled sources. The wood used to manufacture these composites is mostly in the form of wood flour (typically 40 mesh or lower) or recycled paper fiber. Wood contents typically range from 20 to 60% in these composites. Additives to the composites will include processing aids (lubricants, antioxidants, acid scavengers), and property enhancers (biocides, coupling agents, inorganic fillers, fire retardants, uv stabilzers, colorants, etc).

Processing Unit Operations

The unit operations for extruding wpc lumber include: wood processing and feeding equipment, polymer feeding, an extruder(s), die, cooling tank, cut-off saw and drop table (Figure 1).

Figure 1. WoodtruderÔ extrusion system showing material feeding systems, extruders and cooling tank.

Many manufacturers purchase processed wood flour that arrives in 25 Kg bags or 500 Kg super sacks. Wood flour or fiber moisture content will range from 5 to 8 percent. Some wpc lumber manufacturers will obtain saw dust and planer shavings from local secondary wood product manufacturers, and will hammer mill and screen their own wood flour. Wood species utilized will vary depending on the local source, but species differences do not appear to affect the properties of the final products. However, certain wood species may impact the extrusion process in terms of volatiles released during manufacture.

Wood Drying

The wood flour or fiber needs to be dry (< 1% moisture content) to facilitate adequate mixing with the polymer and provide maximum extruder output rate. Dried fiber cannot be stored for very long because it will tend to pick up moisture from the surrounding environment. Moisture removal from the wood flour can be accomplished by several means including the use of pre-heaters prior to feeding the extruder, the use of high intensity mixers for mixing the wood flour and polymer, and more commonly manufacturers will utilize a rotary furnace to dry the wood flour. The drying of the wood flour is the most potentially dangerous part of the extrusion operation.

Material Feeding

In certain instances, wpc lumber manufacturers will utilize pellets that contain the plastic, wood flour and additives that have been pre-compounded. Depending on the type of extruder and feeding system, the polymer can either be in the powder or pellet form. Powders will be used when the polymer, wood and additives are fed as a pre-blended mixture into the extruder. Pellets or powders can be used when the polymer is separately introduced into the extruder in the melt state to the wood. Volumetric feeding is used to either "cram" feed or "starve" feed the extruder. Gravimetric feeding can also be used to meter materials into the extruder. Gravimetric feeding is preferred because of adequate feeding regardless of material shape or bulk density, improved product quality control, and material savings can be realized.

Extruders

The extruder is the heart of the wpc lumber processing system, and the primary purpose of the extruder is to melt the polymer and mix the polymer, wood and additives in a process referred to as compounding. In addition, the extruder conveys the compounded wood-polymer mixture through the die. There are four primary types of extrusion systems used to process wpc lumber. These are the 1) single screw, 2) co-rotating twin screw, 3) counter-rotating twin screw, and 4) Woodtruder™. Cost for an extruder can vary from $150,000 for a simple single screw extruder to over $1 million for a complete wood plastic composite lumber extrusion system.

Single Screw Extruder

The single screw fiber composite extruder is the simplest extrusion system for producing wpc lumber. A typical single screw extruder will have a barrel length to diameter (L/D) ratio of 34:1. It will employ two stages, melting and metering, and a vent section to remove volatiles. The material form for the single screw extruder will be pre-compounded fiber filled polymer pellets. A dryer may also be required to dry the pellets. The material feed method is usually by gravity hopper. The melting/mixing mechanism is barrel heat and screw shear. Advantages of the single screw extruder are it's a proven technology and has the lowest capital acquisition cost. Disadvantages include: high raw material cost, lower output rates, drying system required, polymer is melted with the fiber with greater risk of fiber thermal decomposition, high screw rpm with greater risk of burning at the screw tip, and inability to keep melt temperature low with higher head pressures.

Counter-rotating twin-screw extrusion

Counter rotating twin-screw extruders excel in applications where heat sensitive polymers like rigid PVC are utilized, low temperature extrusion for fibers and foams, non-compounded materials like powder blends, materials that are difficult to feed, and those materials that require degassing. The counter rotating twin screw can either have parallel or conical screw configurations. The fiber/flour and polymer are in the same polymer size, usually 40 mesh. Material preparation includes fiber drying followed by high intensity blending with the polymer and additives. The material feed method usually utilizes a crammer feeder. The melting/mixing mechanism is barrel heat and screw mixing. Screw mixing is accomplished through screw flight cut-outs and gear mixers. Moisture removal is through vacuum venting.

Advantages of counter-rotating twin screw extrusion include its low screw rpm and low shear mixing and it is a proven technology. Disadvantages include that a drying system is required, a size reduction system for fed materials may be necessary, a pre-blending system is required, material transportation can impact the mix feed ratios. Because of the need for a dryer, additional plant floor space is required, higher operational costs including power maintenance, and labor. The polymer is melted with the fiber with a greater risk of burning the fiber.

Co-Rotating Twin Screw & Hot Melt Single Screw Wood Composite System

A co-rotating twin screw in combination with a hot melt single screw can be used to produce wood plastic composite lumber. In this case, a parallel 40:1 L/D co-rotating twin screw extruder is coupled with a "hot melt" 10:1 L/D, single screw extruder. The material for this system is wood flour or fiber at ambient moisture content (5 to 8%) and the polymer and additives can be in their natural states. No material preparation is required in terms of pre-blending components. The preferred material feed systems are gravimetric feeders and twin-screw side feeders. The melting/mixing mechanism includes barrel heat, screw rpm and screw mixing. Moisture removal is accomplished through the use of atmospheric and vacuum vents.

Advantages of this system include the ability to process wood at ambient moisture content since the extruder is used to dry the fiber with the elimination of drying and pre-blending operations, and good fiber/polymer mixing. Disadvantages include the need for peripheral feeding systems, high screw rpm and no screw cooling (greater risk of burning), inability to keep melt temperature low with higher head pressures, and polymer is still melted with the fiber (greater risk of burning, more difficult to vent.)

WoodtruderÔ

The Woodtruder™ includes a parallel 28:1 L/D counter-rotating twin- and a 75 mm single-screw extruder, a blending unit, a computerized blender-control system, a die tooling system, a spray cooling tank with driven rollers, a traveling cut-off saw, and a run-off table. As processing begins, ambient moisture content wood flour is placed into the unit's fiber feeder and dried within the twin screw. Meanwhile, separate from the fiber, the plastics are melted. The melting/mixing mechanism includes barrel heat and screw mixing. The separation of wood conveying and plastic melting ensures that fibers will not be burned during plastic melting and that the melted plastic will encapsulate the fibers completely. These materials are then mixed, and any remaining moisture or volatiles are removed by vacuum venting. Advantages of this system include that the flour and additives are in their natural states and no material preparation is required. Gravimetric feeders are preferred as material feed method.

Advantages of the Woodtruder™ include the ability to process fiber at ambient moisture content (5 to 8%), separate melting process of the polymer, good polymer/fiber mixing, screw cooling is included on the twin screw, the ability to maintain a low melt temperature with a high head pressure, superior venting, the elimination of drying, size reduction and separate pre-blending equipment, highly flexible integrated process control system for material feeding and extruder unit operations.

Miscellaneous Post-Extruder Unit Operations

Along with the extruder, the die is an important part of the wpc lumber extrusion system. The die dictates the dimensions and profile (shape) of the extruded part. The die is typically heated using band or cartridge heating elements, and may employ air-cooling to adequately process hollow profile parts. Dies can be quite simple or complex depending on the desired profile. The costs for dies can range from $15,000 for a simple die up to $50,000 or more for a foaming or co-extrusion die. After the die, comes the cooling tank, which is used to "freeze" the extruded profile in its linear shape. The cooling tank consists of a conveyer system with water spray heads that spray cool water on the profile extrudate. The cooling tank may be 20 to 40 feet long depending on the extruder material output and the cooling capacity required. The water spray is typically recycled and may go through a chiller or heat exchanger to keep the spray water cool. After the cooling tank the wpc profile goes through a cut-off saw that can cut the lumber to the desired lengths.

WPC Properties and Products

The properties of wpc lumber are dependent on the type of polymer and wood content used to manufacture the composite. While the material costs for the wood flour are relatively low, the costs for the polymer and additives are considerably high compared to thermosetting resins used in the manufacture of conventional wood composites. Strategies used by manufacturers to lower costs include maximizing the amount of wood used in the composite, the production of hollow profiles, and the use of recycled plastics, if readily available. Some basic material properties of interest to manufactures include measuring flexural strength (modulus of elasticity (MOE)) and strength (modulus of rupture (MOR)), tensile strength, shear strength, and slip resistance (coefficient of friction.

Poly vinyl chloride provides the greatest strength and stiffness for wpc composites followed by polypropylene and polyethylene. The greater the wood content, the better the stiffness properties of the composite. However, there is a direct trade-off between wood content and the moisture resistant properties of the wpc lumber. When the wood content of wpcs increases beyond 65 weight percent, the resulting water absorption will increase accordingly because the wood is less likely to be fully encapsulated by the matrix polymer. With high plastic percentages, wpcs are less likely to have much absorbed water from immersion tests.

Table 1. Summary of material properties for wood plastic composite lumber[a].

Matrix[b]	Flexural MOE (mm psi)	Flexural MOR (psi)	Tensile Strength (psi)	Shear Strength (psi)	Hardness (lbs)	Dry coefficient of friction
PE	0.1 – 0.26	1500 -3700	200 -2200	200 - 800	N/A	0.5
PP	0.6 – 0.8	4,000 - 5000	1700 - 1800	1300 -1400	3000	0.75
PVC	0.7 - 0.8	5000 - 6000	3000 - 4000	1500 - 1700	2500	0.75

a. Range of property values from various published and unpublished results.
b. Assuming a 50 or 60 % wood fiber composition

Wpc lumber also tends to be quite dense compared to regular wood, and means to reduce lumber weight have taken several approaches. One approach is to reduce section weight through the use of hollow profile cross sections (Figure 2).

Figure 2. Examples of wood plastic composite lumber profiles.

An added benefit of manufacturing using hollow profiles includes decreased product cost, and increased extrusion production rates. Section details such as mechanical fastening strategies become important with hollow profile wpcs. A second approach is to utilize polymer foaming technology through the use of either chemical or physical foaming agents.

References

ASTM. 1999. Standards Boost an Industry: Recycled plastic lumber gains ground. ASTM Standardization News July, pp 22-26.

Lu, J. Z., Q. Wu, and H. S. McNabb, Jr. 2000. Chemical coupling in wood fiber and polymer composites:A review of coupling agents and treatments. Wood and Fiber Science 32(1):88-104.

Rowell, R. M., S. E. Lange, and R. e. Jacobson. 2002. Effects of moisture on aspen-fiber/polypropylene composites. In Progress in Woodfibre-Plastic Composites Conference 2002, Toronto, Canada,