CHAPTER II
LITERATURE REVIEW

2.1 Wood plastic composites (WPCs)

Wood plastic composites (WPCs) are the mixture under ratio around 20:80 to 55:45 of thermoplastic polymers and small waste wood particles. The WPCs are compounded above the melting temperature of the thermoplastic polymers but not more than 220℃ which is the wood degradation temperature.

WPCs can be manufactured in a variety of shapes (Soury, et, al. 2009), colors and sizes, and with alternative surface textures depending on the processing method. Applications of WPCs, include windows, door frames, interior panels in cars, railings, fences, landscaping timbers, cladding and siding, park benches, molding and furniture. (Falk, et, al. 2000)

WPCs offer a number of potential benefits. To mix wood in thermoplastic polymer resulting in stiffer and lower cost materials. The compression properties for most WPCs are superior to that of wood loaded perpendicular to the grain. The plastic in the product has low degree of water absorption, so the WPCs can have lower maintenance requirements than solid wood. (Fabiyi et, al. 2008)

The use of wood – a natural and renewable resource can reduce the “carbon footprint” of plastics, because less fossil energy and material are required to make the final product. Also, WPCs can recyclable, because the material can be melted and reformed.

WPCs offer great flexibility in the shapes and colors of the materials produced. Materials usage can also be reduced through the engineering of special shapes e.g. hollow-core decking boards.

WPCs have many advantages; however: color fade from sunlight is accelerated when wood is added to thermoplastics, causing a whitening or graying of the surface of the composite.

WPCs are usually quite heavy and not as stiff as solid wood. This limits the potential use of WPCs in many structural applications and creates the potential creep or sagging problems, especially in a warm environment.

2.2 Wood

Wood used in WPC manufacturing is in the form of dry particles with a powdery consistency, often called “wood flour.” In general, the wood waste is in the form of sawdust and/or planer shavings.

There are two steps to produce wood flours: size reduction and size classification (screening). In case of large pieces of wood, size may be reduced using equipment such as a hammer mill, hog or chipper. Wood from such processes is coarse and is usually ground further using an attrition mill (grinding between disks), rollers, hammer or knife mills.

Wood flour can also be obtained from wood products operations such as sawmills, mill work or window and door manufacturers that produce sawdust as a by-product. It contains various sizes of particles. These wood particles are classified using vibrating, rotating or oscillating screens. The size of wood particles is often described by the mesh of the wire cloth sieves used to make them.

The commonly used wood species for commercial WPC production are pine, maple and oak. As with many wood-based products, regional availability and cost are key factors in species selection. WPCs have been manufactured in the lab using a wide variety of species, including osage orange, walnut, yellow poplar, hickory, Utah juniper, salt cedar and emerald ash borer-infested ash.

Research indicates that species effects on the mechanical properties of WPCs are small; however, they can have a substantial influence on the processing attributes of the WPC. In practice, wood species has not been considered to be an important variable; any fiber source that is readily available and inexpensive is generally preferred.

Wood flour must be dried before it is used in WPC manufacturing. Because during the high-temperature compounding and forming process moisture can evaporate and increases gas pressure, created voids in the final product and strongly affect mechanical properties.

Moisture content levels of 2-8 percent are typical, but also vary based upon the manufacturing platform. Many drying methods can be applied to remove moisture content from wood, including steam tubes and rotary drums driers. Moisture is also removed during the composite processing step. Therefore, the control of moisture in wood flour and compounded material is very important in processing wood plastic composites.

2.3 Plastics

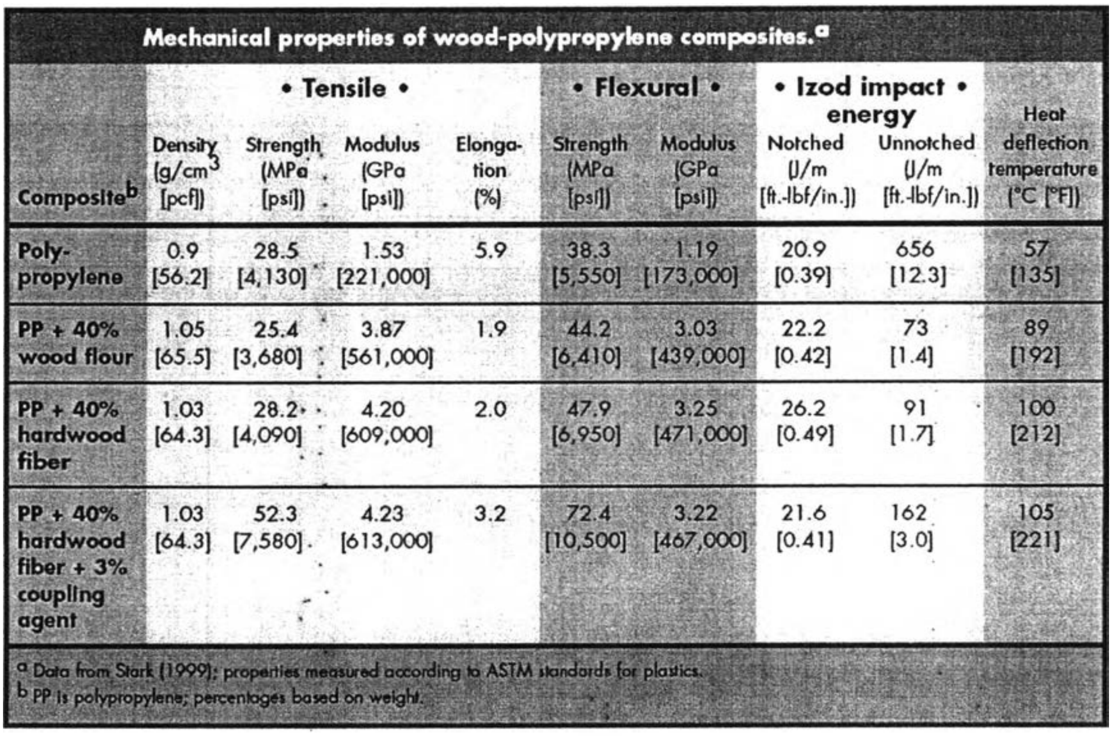
WPCs are made with thermoplastic polymers. The materials molten in high temperature and harden in cool temperature. To prevent the wood component damages, thermoplastics for WPCs should have processing temperatures under 220°C.

Common materials used include polypropylene, polystyrene, polyvinylchloride and polyethylene (low and high density). Recycled polymers are often used, but they must be relatively clean and homogeneous. Different polymer types cannot mix together well.

WPCs made with wood-polypropylene are typically used in automotive applications and consumer products, and these composites have recently been investigated for use in building profiles. Wood-PVC composites typically used in window manufacture are now being used in decking as well. Polystyrene and acrylonitrile-butadiene-styrene (ABS) are also being used.

The plastic is often selected based on its inherent properties, product need, availability, cost, and the manufacturer's familiarity with the material. Small amounts of thermoset resins such as phenolformaldehyde or diphenyl methane diisocyanate are also sometimes used in composites with a high wood content (Wolcott and Adcock 2000).

Table 2.1 Mechanical Properties of Wood-PP composites (Clemons, 2002)



Mechanical properties of wood-polypropylene composites.[a]

	• Tensile •				• Flexural •		• Izod impact • energy		
Composite[b]	Density (g/cm^3 [pcf])	Strength (MPa [psi])	Modulus (GPa [psi])	Elongation (%)	Strength (MPa [psi])	Modulus (GPa [psi])	Notched (J/m [ft.-lbf/in.])	Unnotched (J/m [ft.-lbf/in.])	Heat deflection temperature (°C [°F])
Polypropylene	0.9 [56.2]	28.5 [4,130]	1.53 [221,000]	5.9	38.3 [5,550]	1.19 [173,000]	20.9 [0.39]	656 [12.3]	57 [135]
PP + 40% wood flour	1.05 [65.5]	25.4 [3,680]	3.87 [561,000]	1.9	44.2 [6,410]	3.03 [439,000]	22.2 [0.42]	73 [1.4]	89 [192]
PP + 40% hardwood fiber	1.03 [64.3]	28.2 [4,090]	4.20 [609,000]	2.0	47.9 [6,950]	3.25 [471,000]	26.2 [0.49]	91 [1.7]	100 [212]
PP + 40% hardwood fiber + 3% coupling agent	1.03 [64.3]	52.3 [7,580]	4.23 [613,000]	3.2	72.4 [10,500]	3.22 [467,000]	21.6 [0.41]	162 [3.0]	105 [221]

[a] Data from Stark (1999); properties measured according to ASTM standards for plastics.
[b] PP is polypropylene; percentages based on weight.

2.4 Additives

While WPC consists of mainly thermoplastic polymer and wood flour, a variety of materials are added in relatively small quantities to improve the properties or lower the cost. These additives are included for a variety of reasons.

- Lubricants help the molten WPC mixture move through the processing equipment
- Coupling agents improve the wood and polymer interaction. Wood is naturally hydrophilic, while the thermoplastic polymers are hydrophobic. This basic chemical incompatibility makes it very difficult to bond polymers to wood. The use of coupling agents can help to overcome this incompatibility.

- Fillers, such as calcium carbonate, talc, are used to reduce the cost of materials and to improve stiffness and durability.
- Biocides can be added to protect the wood component of WPCs from fungal and insect attack.
- Zinc borate is the most commonly used wood preservative added to WPCs to incorporate fire retardancy property. Fire-retardant chemicals reduce the tendency of the WPCs to burn.
- Pigments are added to provide a desired color to the product. UV stabilizers can help to protect the color, but some fading and whitening will occur with most WPCs exposed to sunlight.

2.5 Manufacturing

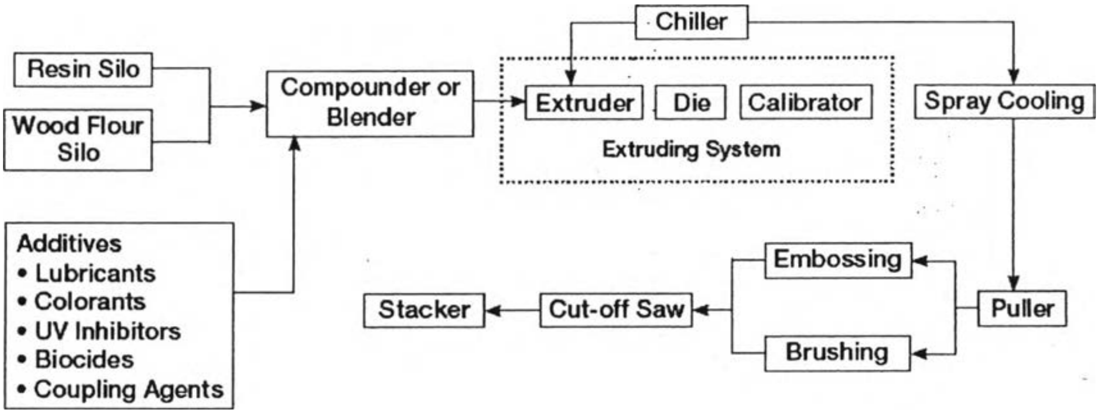


Figure 2.1 The WPCs manufacturing process, with extrusion forming.

Manufacturing of WPCs can be done using a variety of processes; however, the key to making any WPCs is through efficient dispersion of the wood component into the thermoplastic matrix. Generally, this can be accomplished in twin-screw extruders or other melt-blending processes. Once the materials are sufficiently mixed, the composite can then be formed into the final shape using forming technologies such as extrusion or injection molding.

Most WPCs are manufactured using profile extrusion, which creates long continuous elements, such as deck boards and window components. The wood-thermoplastic mixture is conveyed into a hopper that feeds the extruder. As the material enters the first zone of the extruder, the heated screws and barrel melt or soften the thermoplastic. The molten material is then forced through a die to make a continuous profile of the desired shape.

Molten WPCs material is highly viscous, so the equipment needs to be powerful enough to force the material though the machinery and out of the die. As the material exits the extruder, it is cooled in a water spray chamber or bath to rapidly harden the thermoplastic matrix, embossed with a desired pattern, and cut to a final length.

Extruders can have single screw or twin feed screws, which are counter- or co-rotating. These screws can be parallel, for mixing only, or conical, to increase pressure in the die to aid in consolidation. Tandem extruders have one component for the compounding step and one for the shaping process. While extrusion methods create lineal elements, injection molding produces three-dimensional parts and components.

The unique shapes and profiles that can be created with injection molding provide the potential for diversifying from the current WPCs markets. The injection molding process involves two steps. The first is to melt-blend or compound the wood-plastic mixture, and the second is to force the molten WPCs into a mold under high pressure. The molten material fills the cavity in the mold and solidifies as it is cooled. Injection molding is used to manufacture a variety of parts, from small components to large objects.

Injection molding is a common method of production and is especially useful for making irregularly shaped pieces.

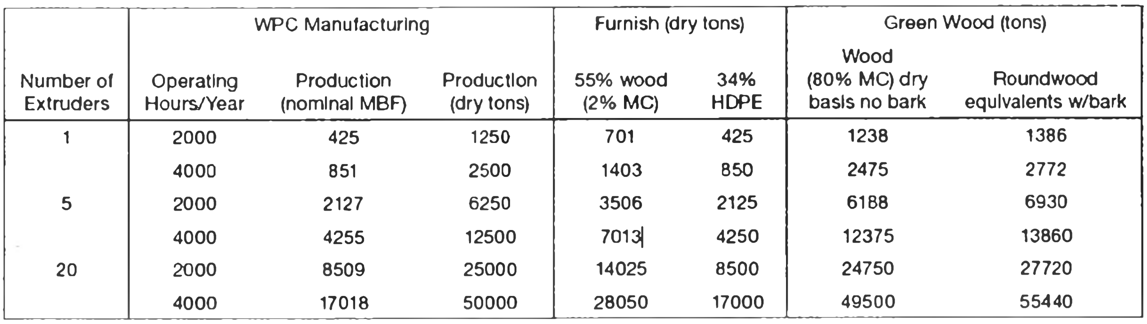
Other types of molding processes include compression, vacuum bag, resin transfer (RTM), reaction injection (RIM) and matched die molding. These manufacturing technologies each have the ability to keep the full length of the fiber and provide high strength composite, such as those used in automotive applications. The main disadvantages to these techniques are that they are batch processes, which require longer processing times and are more costly. All of these methods could have application to WPCs; however, only limited research has addressed their use.

2.6 Markets

The wood-plastic composites market share has been growing rapidly, especially for applications such as decking and railing. The main drivers for WPCs acceptance are the perceived improved performance and appearance attributes (e.g., no checking) over existing products such as treated wood decking. Stricter regulations on the use of chemicals in building materials, such as the phasing out of CCAtreated lumber for residential decking and the desire for 'green' building materials (WPCs can use waste wood and recycled plastics) have also contributed to greater acceptance of WPCs by builders and homeowners. Two-thirds of the WPCs produced are decking and railing products, accounting for almost $1 billion annually. (Smith and Wolcott, 2006)

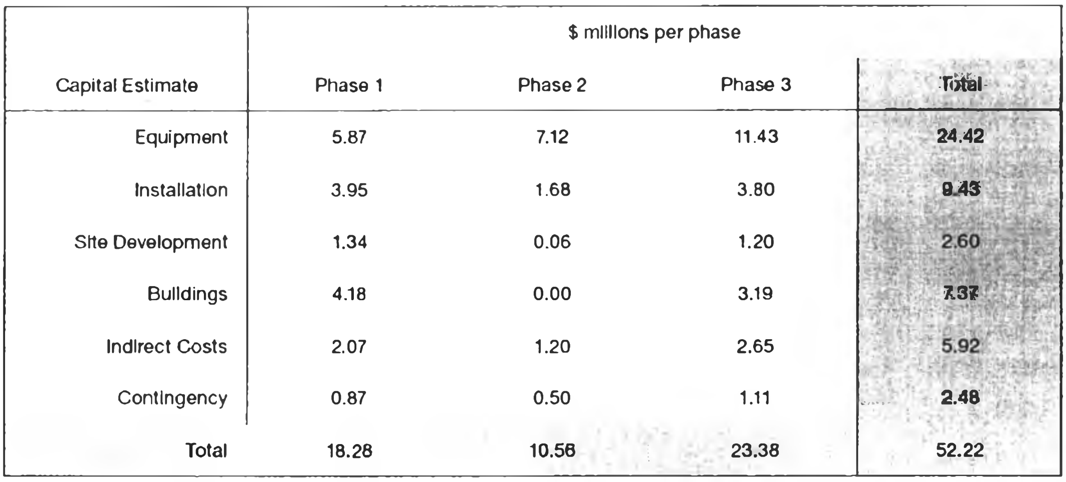
Other important products are window and door frames. Additional potential applications for WPCs include siding, roofing, residential fencing, picnic tables, benches landscape timber, patios, gazebos and walkways, and playground equipment.

Table 2.2 Raw material requirements for a typical WPCs plant (Brackley and Wolcott, 2008)



	WPC Manufacturing			Furnish (dry tons)		Green Wood (tons)	
Number of Extruders	Operating Hours/Year	Production (nominal MBF)	Production (dry tons)	55% wood (2% MC)	34% HDPE	Wood (80% MC) dry basis no bark	Roundwood equivalents w/bark
1	2000	425	1250	701	425	1238	1386
	4000	851	2500	1403	850	2475	2772
5	2000	2127	6250	3506	2125	6188	6930
	4000	4255	12500	7013	4250	12375	13860
20	2000	8509	25000	14025	8500	24750	27720
	4000	17018	50000	28050	17000	49500	55440

Table 2.3 Capital investment estimates for WPC plant – starting with 2 extruders in Phase 1, and expanding to 10 extruders in Phase 2 and 20 extruders in Phase 3 (Evergreen Engineering, 2005)



	$ millions per phase			
Capital Estimate	Phase 1	Phase 2	Phase 3	Total
Equipment	5.87	7.12	11.43	24.42
Installation	3.95	1.68	3.80	9.43
Site Development	1.34	0.06	1.20	2.60
Buildings	4.18	0.00	3.19	7.37
Indirect Costs	2.07	1.20	2.65	5.92
Contingency	0.87	0.50	1.11	2.48
Total	18.28	10.56	23.38	52.22

2.7 Mechanical Properties

Joa˜o *et al.* (2003) studied the tensile strength and ultimate elongation of wood plastic composite by using maleic anhydride grafted on polypropylene as a coupling agent at the mixture ratio between wood:PP as 20:80 by wight.

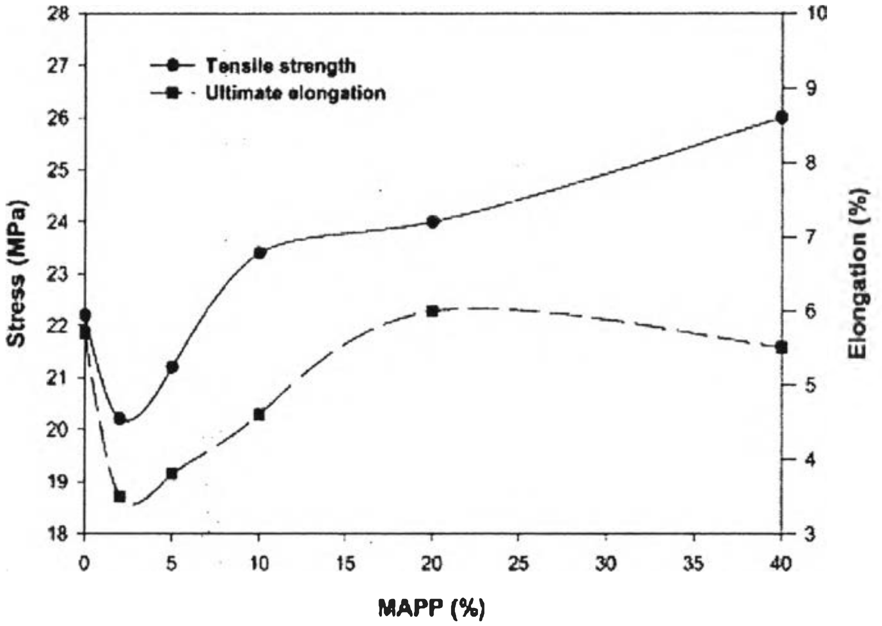


Figure 2.2 Tensile properties of WPC without and with MAPP.

The tensile property shown when amount of MAPP increase the tensile strength also increase. But at the ratio 2 and 5 %wt tensile strength was drop because amount of MAPP is not enough for coupling 2 phases. Coupling agent made composite is stiffer so too large of MAPP decrease ultimate elongation.

Danyadi *et al.* (2009) studied the effect of variour surface modification of wood flour on the properties of PP/Wood composite. The studied four different coupling agents which are MAPP, StAc, CP and chemical modification and the ratio of WPC is 20 and 50 %wt.

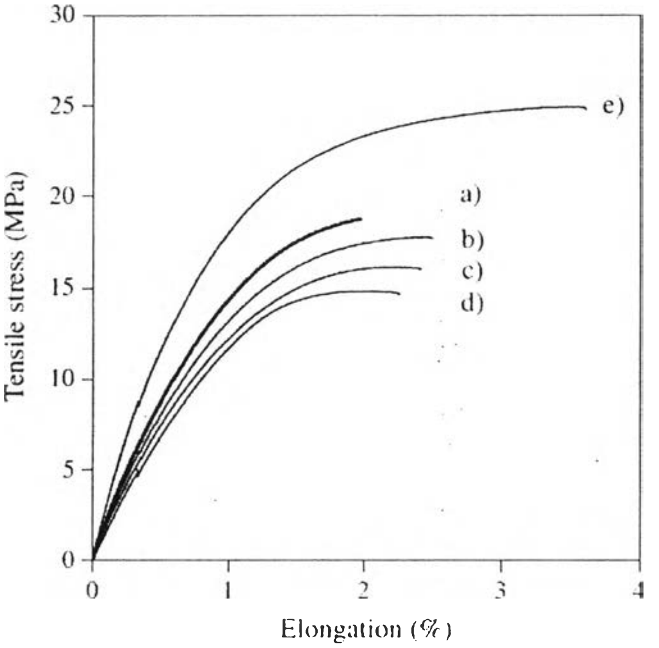


Figure 2.3 Effect of surface modification on the deformation behavior of PP/wood composites. Wood content: 20 wt.% (a) neat wood, (b) 1wt.% StAc, (c) 1wt.% CP, (d) benzylation, 120 min and (e) MAPP 0.1 MAPP/wood ratio.

Tensile stress shown MAPP gave the highest tensile stress while StAc, CP and benzylation increase slightly elongation but decrease tensile stress. Because these 3 coupling agents is too less for coupling 2 phases (PP and Wood flour) together.

Nachtigall *et al.* (2007) studied the differences mechanical properties between using vinyltriethoxysilane as a couping agent compared to MAPP.

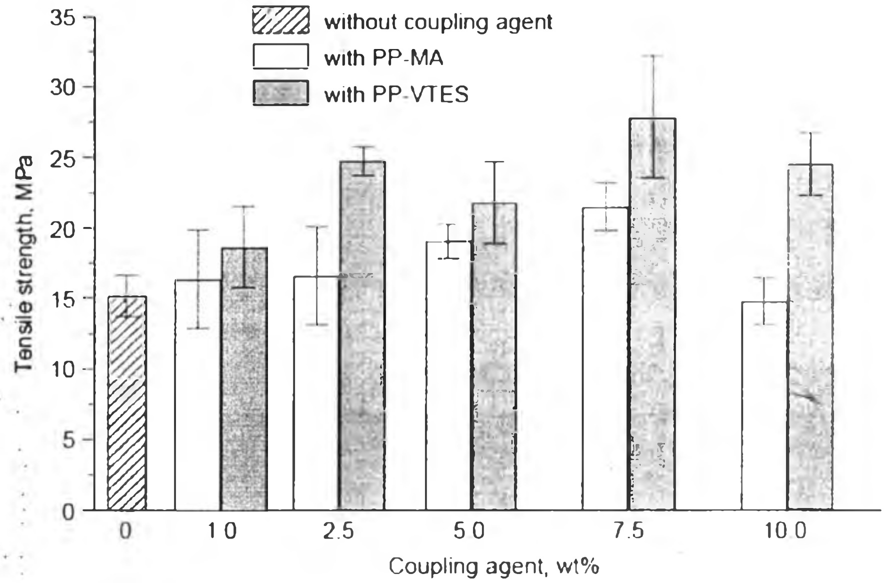


Figure 2.4 Tensile strength of PP composites containing 30wt% Wood Flour (WF) as a function of the coupling agent concentration.

From Figure 2.4 shown that PPVTES was more efficient than PPMA as coupling agent. The highest value of tensile strength for composites containing 30 wt% WF was obtained with 7.5wt% PPVTES.

The tensile strength value determined for this sample was more than 80% higher than that determined for the non-coupled composite. On the other hand, the behavior of the systems coupled with PPMA showed a tendency to get worse at high PPMA concentration.

Chiang *et al.* (1999) studied the effect of matrix graft modification Using Acrylic Acid (AAc) on the PP/$Mg(OH)_2$ Composites.

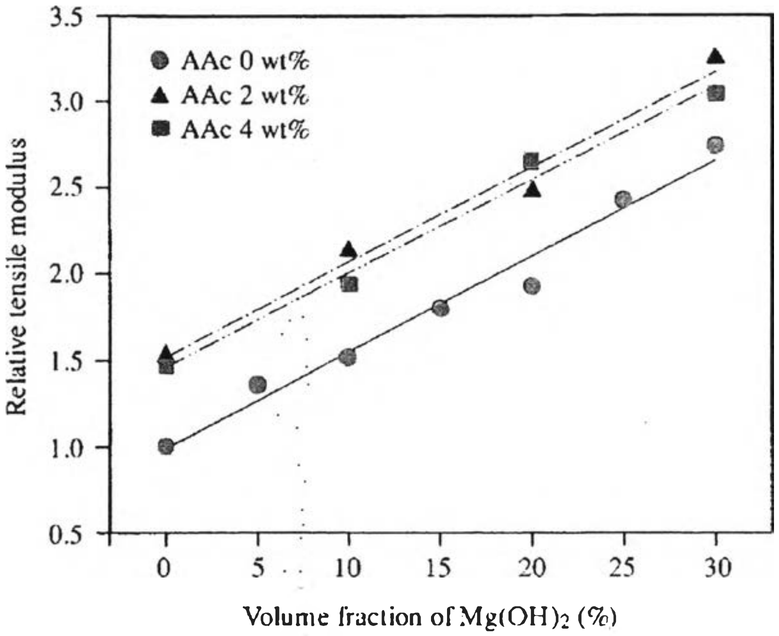


Figure 2.5 Tensile Young's modulus of PP/$Mg(OH)_2$ composites with various AAc grafting amount.

For this work, they are dealing with adding flame retardant, $Mg(OH)_2$, into PP and using AAc as a coupling agent.

The flame retardant additive $Mg(OH)_2$ is a rigid filler, so the tensile modulus of the polymer increased with the filling fraction. The modulus of PP/ $Mg(OH)_2$ is increase proportionally with the increase of filler volume fraction. The effect of AAc on the modulus seems to shift the linear tendency upward about 50%. The difference between the effect of 2%wt and that of 4%wt of AAc is not very obvious.

2.8 Degradation Temperature

Nachtigall *et al.* (2007) studied the heat distortion of using PPVTES and PPMA as a coupling agent.

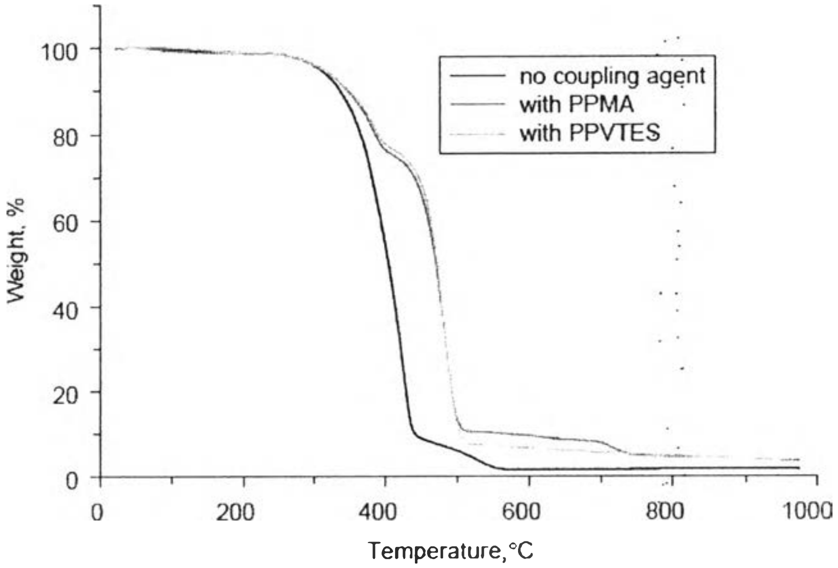


Figure 2.6 TGA curves of the composites (30wt% WF).

For virgin PP the degradation temperature is showed around 475°C. For the non-coupled PP/WF composite prepared at 30% fiber loading, it was verified that the maximum degradation rate was shifted to a lower temperature (around 423°C) showing that the presence of the wood flour lowered the thermal stability of the polymer.

The temperature of degradation of the polymer matrix increased about 60°C in comparison to the non-coupled composite, indicating that PPMA and PPVTES improved the thermal stability of the polymer. This indicates that the compatibility and the interfacial bonding increased by mixing both components in the presence of the coupling agents

2.9 Water Absorption

Danyadi *et al.* (2009) studied the effect of variour surface modification of wood flour on the properties of PP/Wood composite.

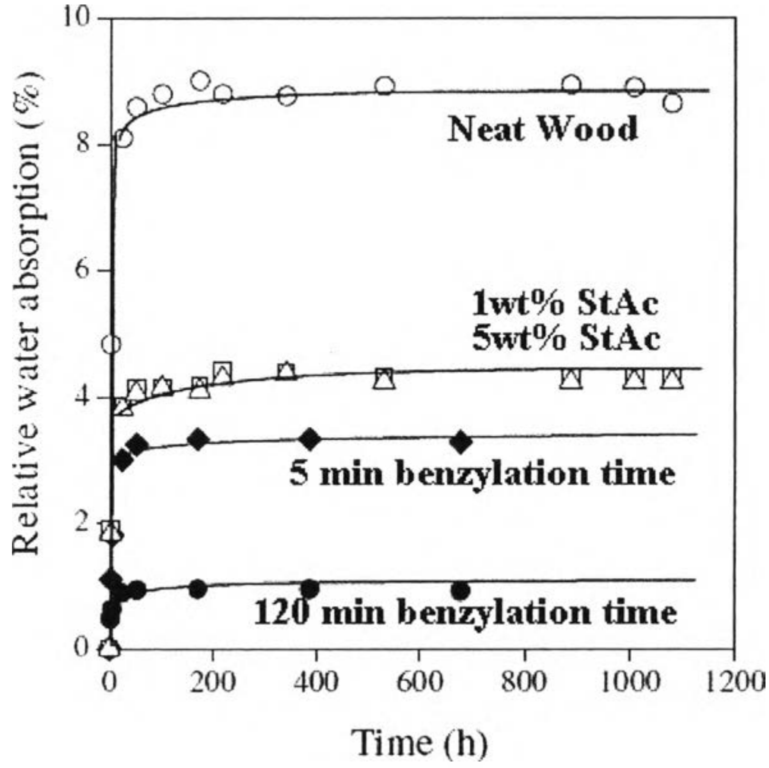


Figure 2.7 Water absorption kinetics of neat wood and wood modified with StAc as well as benzylation.

Cellulose palmitate and MAPP were added to the composite during homogenization thus their effect on the water absorption of neat wood could not be determined.

Neat wood particles absorb water very fast and reach the equilibrium level of about 9 wt.%. Small amounts of stearic acid do not have much effect on the final level of water uptake. Increase of surfactant level to 5 wt.% does not result in further decrease of water absorption.

On the other hand, benyzlation changes water sensitivity drastically, water absorption decreases below 1 wt.% at around the equilibrium level of substitution, i.e. above 120 min reaction time. Although both approaches decrease surface energy significantly, chemical modification seems to be considerably more efficient in decreasing water absorption than the simple coating with a surfactant.