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CHARACTERISTICS OF REPROCESSED WOOD PLASTIC COMPOSITES

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ABSTRACT

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Wood Plastic Composites (WPCs) are green materials having several applications in different industrial sectors such as building and construction, automotive industry, and consumer products. This thesis is an experimental study on reprocessing wood plastic composites (WPC) and its effect on various properties of the composites.

The feasibility of using pre-mixed composites to produce WPCs is evaluated in this study. WPCs containing 10, 20 and 30 % of wood fiber were prepared by reprocessing a WPC pre-mix containing 50 wt% of wood fiber. The tensile strength of reprocessed WPCs slightly increased at fiber loading of 20 wt%. Elongation and impact strength of reprocessed WPCs decreased by increasing fiber content. Whereas, tensile modulus of composites increased by increasing fiber content. The mechanical test results indicated that additives are required to achieve better strength of reprocessed WPC. It was interesting to note that the water uptake in WPCs containing 50 % wood fiber was almost like those reported for commercially available WPC decking. The burning test indicated the feasibility of using studied wood plastic composites as interior parts in the vehicles.

Key words
Burning property, Mechanical properties, Reprocessing, Water Absorption, Wood Plastic Composites

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I would like to thank my beloved friends and teachers who supported me during my entire study life. Finally, I thank my parents for their love, caring and for educating and preparing me for my bright future.

CONCEPT DEFINITIONS

ABS	Acrylonitrile Butadiene Styrene
CNC	Computer Numerical Control
DSC	Differential scanning calorimetry
FRP	Fiber Reinforced Polymer
HDPE	Haigh Density Polyethylene
LDPE	Low Density Polyethene
MAPP	Maleic Anhydride Polypropylene
PA	Polyamide
PC	Polycarbonate
PE	Polyethylene
PLA	Polylactic acid
PMC	Polymer Matrix Composites
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl Chloride
TGA	Thermogravimetric Analysis
UV	Ultra Violet
WPC	Wood Plastic Composite

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1 INTRODUCTION

Wood plastic composites are produced mainly by melt mixing polymer with wood flour in presence of additives. The production and feeding of wood flour/fiber during extrusion generate dust and increase the risk of fire and explosions and loss of raw material. To avoid the complications with feeding hygroscopic wood flour/fiber, utilization of pelletized wood flour or densified wood fibers in forms of dice is a viable solution to this issue. This results in dust free and reduced pre-production steps in the WPC production. There are few commercially available woods fillers in form of dice and pellets in the market. The aim of this thesis is to study the effect of diluting pre-mixed WPCs with 50 wt% wood fiber content on the various properties of polypropylene based wood plastic composites. The schematic representation of aim of the study and the methodology is shown in Figure 1. The influence of reprocessing the pre-mix or concentrate on tensile and impact resistance of the composites will be studied. The water absorption, thermal decomposition and the flammability of the WPCs also will be evaluated. This study is expected to provide necessary information on reprocessing the wood plastic pre-mix or concentrates to produce wood plastic composites.

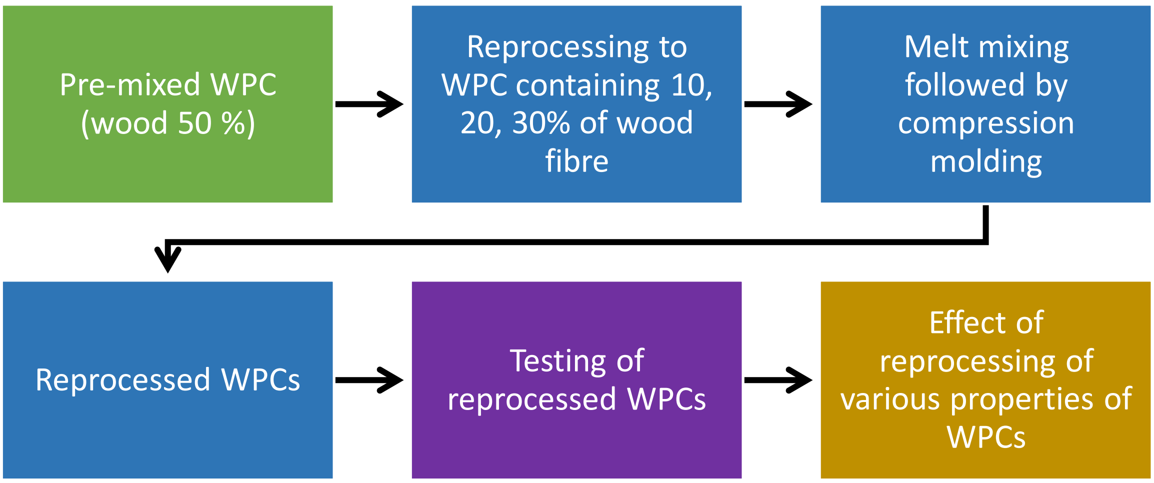


FIGURE 1. Schematic diagram of research methods of the study

Composites are materials which are made of two or more than two materials. Based on the matrix used composites can be classified into three parts; ceramic composites, metal composites and polymer composites (FIGURE 2). Composite materials are becoming essential part of today's materials because of several advantages such as low weight, corrosion resistance, high fatigue strength, and faster assembly. Polymer matrix composites (PMC) are those materials which consist of polymer (resin) matrix combined with the fibrous reinforcing dispersed phase which is typically reinforcement such as glass, aramid, or carbon fibers. Polymer composites have lots of advantages such as lightweight, high modulus and glass transition temperatures, it has ability to tailor for a wide range of applications, good fatigue resistance, easy to mold, and low thermal expansion. Low thermal resistance and high ecoefficiency of thermal expansion are the main disadvantages of polymer composites. (Domininghaus 1993.)

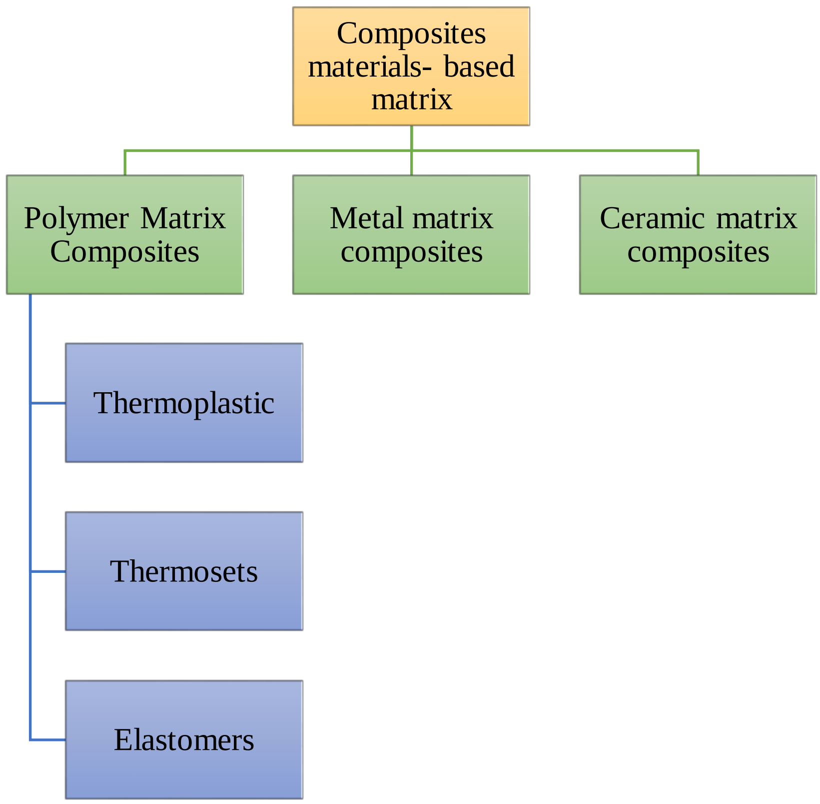


FIGURE 2. Classification of composites materials based on matrix (adapted from Ibrahim, Jamiru, Sadiku, Kupolati, Agwuncha, & Ekundayo 2015, 1348)

Polymer matrix composites which are reinforced with fibers are called fiber reinforced polymer (FRP). FRP composites are progressively being considered an upgrade or substitute for infrastructure components or frameworks that are built for the civil engineering materials such as concrete and steel. Because light weight, non-corrosive, and high strength can be easily constructed, these composites have been included in modern development. (Masuelli 2013.)

Behavior of the composite materials is explained based on the combined behavior of the reinforcing element, polymer matrix and the fiber-matrix interface. The Interfacial adhesion should be strong to get the maximum mechanical properties which affects the properties of PMCs. The other factors which affect the properties of PMCs is shape and orientation of dispersed phase inclusions such as particles, flakes, fibers, and laminates. Properties of different polymers will determine the application to which it can be appropriate. The types of polymer composites are thermoplastics polymers, thermosets polymers and elastomers. Fiber reinforcement composites include glass fiber, carbon fiber, aramid fiber and natural fiber. (Thomas, Joseph, Malhotra, Koichi & Sreekala 2012.)

2 POLYMER COMPOSITES

Polymer composites are those which are reinforced with polymer matrix. Polymer matrix and reinforcements are discussed in this section.

2.1 Matrix

Polymer composites matrix consists of thermoplastics, thermosets and elastomers which are briefly described in section below.

2.1.1 Thermoplastics

Thermoplastics are the types of polymer that can be heated and softened, cooled and hardened and then remolded while maintaining their characteristic properties from their first uses. These are used for many products which include shopping bags, soda bottles, jugs, and pipes. Heating up these polymer chains, disentangles and allows them to slide past to each other and it allows for reprocessing. Common types of the thermoplastics used in processing of polymer composites are High Density Polyethylene (HDPE), Polypropylene (PP), Polyvinyl Chloride (PVC), Poly carbonate (PC), Polyamide (PA), and polystyrene (PS). Due to the thermal degradation temperature of natural fibers only those polymers which can be processed below 200°C are suitable to manufacture natural fiber composite. These polymers are mostly used because they can be cut, screwed and nailed with tools. (Schwarzkopf & Burnard 2016.)

2.1.2 Thermosets

Thermosets are the types of polymers that cannot be re-melted or reprocessed for the same type of uses. It contains polymers that chemically cross link together. Once curing reaction is over the materials is not re-moldable. It has chemically strong covalent bonds between polymers which cannot be broken easily but polymers keep shape on heating. Common thermosets include unsaturated polyester, epoxy, polyamides, phenol formaldehyde, and urea formaldehyde. (Schwarzkopf & Burnard 2016.)

2.1.3 Elastomers

Elastomers are elastic polymers such as rubber. It is the polymer which has the properties of viscoelasticity meaning having both viscosity and elasticity properties, generally having low Young´s modulus compared with other materials. Young´s modulus is also called tensile modulus which is defined as resistance of materials to breaking under tension. Each of the monomers that links to form the polymer is usually made of carbon, hydrogen, oxygen, and silicon. Elastomers are amorphous polymers and they are soft and deformable. The application includes for seals, adhesives, and molded flexible parts. Examples of the elastomers are such as natural rubber, thermoplastic elastomers, polysulfide rubber, and Fluoroelastomers. (Thomas et al. 2012.)

2.2 Reinforcement

Polymer matrix composites reinforcements include glass fibers, carbon fibers, aramid fibers and natural fibers. Reinforcements are discussed in this section.

2.2.1 Glass Fiber

Glass Fiber reinforced polymers are types of plastic composites which specifically uses glass fiber materials to mechanically improve the strength and stiffness of plastics. It is in the form of filaments and textile that is used as reinforcement in polymer composites. Because of its properties such as incombustibility, corrosion resistance, high strength at low densities, good thermal, and sound insulation, it has many applications. Those applications include aircraft, automotive, marine, corrosion resistance products, consumer goods, electrical roads, tubes and components, land transportation, constructions, and pipe & pump supports. (Landesmann, Seruit, & Batista 2015.)

2.2.2 Carbon Fiber

Carbon fiber reinforced polymers are those composites materials which rely on the carbon fiber to provide the strength and toughness. It is the material consists of thin and strong crystalline filaments of carbon. It is gaining popularity in the field of luxury, sport segments for mass reduction as well as in aerospace industries because of light weight. (Xiao-SU Yi 2015.)

2.2.3 Aramid fiber

Aramid fiber is an aromatic polyamide containing the chains of benzene rings linked together with -CO- and -NH- end groups. It has many favorable physical and chemical properties at high temperatures. Such fiber reinforcement is highly used in bullet proof vests, rope for offshore oil rigs, aircrafts, marine, and automobile. These are five times stronger than steel and heat resistant. (Talikoti & Kandekar 2018.)

2.2.4 Natural fibers

Fibers which are not man made are natural fibers which come from the plants or animals. The increased concern on environmental protection led to implementation of strict environmental rules and regulations. By using natural fibers in polymer composites lion share of non-renewable source-based polymers is replaced by the fiber. In addition, the uses of natural fibers in composites can replaced man-made fibers like glass fibers and carbon fibers which are less environmentally friendly and made from high energy consuming process. Plant based natural fibers such as oil palm, sisal, kenaf, flax, and jute is well researched and are commercially available in market. Application of the natural fiber reinforced composites are growing rapidly in numerous engineering fields such as automotive applications (FIGURE 3), construction industry for example, window frame, decking, and bicycle frame. (Mohammed, Ansari, Grace, Jawaid & Islam 2015.)

FIGURE 3. Materials made from natural fiber composites

3 WOOD PLASTICS COMPOSITES (WPC)

Wood plastic composites (WPCs) are the combination of the wood, plastics and the additives. The main idea of them is to combine the best features of both wood and plastics. Coupling agents, lubricants, colorants, flame retardants, and inorganic fillers are some of examples of additives used in wood plastic composites. (Liukko, Salila, Platt & Kärki 2007.) It has many industrial and commercial values and nowadays researchers are still looking forward more applications fields for the WPCs. Utilization of the fibers from the natural resources can replace the synthetic fibers and 40-50 % of the synthetic polymers and is environmentally friendly approach. WPC were the products into which wastepaper and waste plastics could be recycled. The concept of the WPC is simple where fine wood powder or wood biomass from the forest or agriculture residues is combined with the polymers such as PP or PE with in to the extruder machine. The extruded materials can be pelletized for the later processing by compressing molding or injection molding or extrusion. (Klosov 2018.)

WPCs is gaining popularity because researchers are currently searching more information especially with its properties and advantages. Advantages such as high durability, low maintenance, acceptable relative strength and stiffness, fewer prices relative to other competing materials, and most fast that it is natural resource which attracts researchers. Other advantage is resistance in opposition to biological deterioration especially for outdoor applications where untreated timber products are not suitable, but combination of fine particles of wood materials and polymer guarantee sustainability and improved thermal and creep performance. It can be obtained in structural building applications such as decking, window trims, and sheathings. (El-Hagger & Kamel 2011.)

The demand of construction materials is growing which can be fulfilled by WPCs products by improved mechanical properties and other characteristics of WPCs. WPCs are capable to replace traditional materials such as wood or metal. Hence, WPCs production is increasing. In Europe, production of WPCs was 250,000 tons in 2015 with annual growth rate 11 %. (Turku, Kärki & Puurtinen 2018.) WPC sample plates made by compression press can be seen from Figure 4.

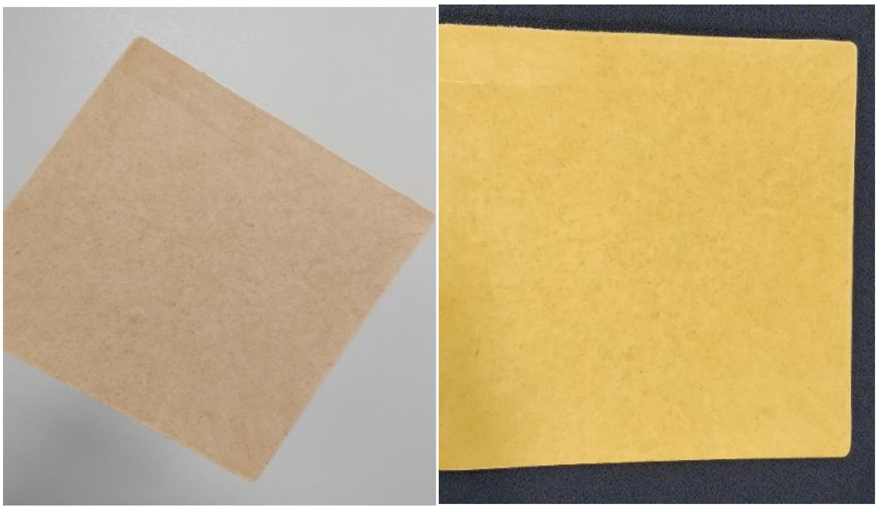


FIGURE 4. Wood plastic composites plates

3.1 Manufacturing of Wood Plastic Composites

The primary manufacturing technologies for the WPC are extrusion, compression molding (Hot press), and injection molding. New processes include additive manufacturing via fused layer modeling and laser sintering. Main important limitation for polymers utilized in WPCs is requiring process conditions such as melt temperature, and pressure that will not thermally degrade the word filler used. Thermal degradation of wood is approximately 220 °C. Hence, general purpose polymers such as Polypropylene (PP), polyethylene (PE) and PVC (Poly vinyl chloride) that can be formed below wood degradation temperature are typically used to manufacture of WPCs. Wood fiber are hydrophilic because of the hydroxyl groups contained in the cellulose and hemicellulose of the molecular chains. Hence, modification of the wood fiber through the chemical or physical treatment is very critical to improv WPCs. The main primary manufacturing methods are briefly described below. (Gardner, Han & Wang 2015.)

3.1.1 Raw Materials

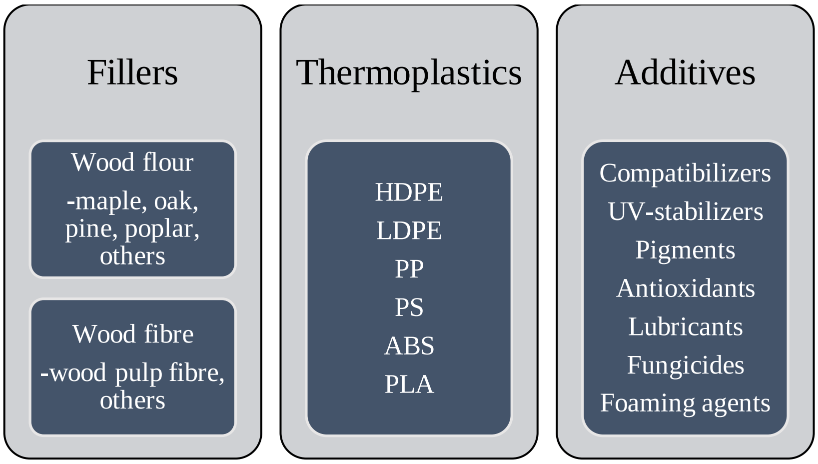
Thermoplastics

Thermoplastic polymers mainly used in WPC production are recycled or virgin - polyethylene (PE), polypropylene (PP), polyvinylchloride (PVC), Acrylonitrile butadiene styrene (ABS) and polystyrene (PS). Polyethylene grades of thermoplastics are used more in Northern America. While the European

WPC market is dominated by polypropylene based WPC's. Among the listed polymers in Table 1, the world market is dominated by polyethylene and polypropylene based WPCs.

Based on the grade, the virgin plastics are preferred than the recycled plastics by European WPC manufacturers. Polypropylene is a most preferred virgin grade of plastic, while polyethylene is in demand as recycled plastic in production. When the polyolefin-based WPC are used as decking, PVC based WPC are mainly focused on the windows and doors. PVC based WPC are widely used in building-construction applications because they offer acceptable mechanical properties, chemical and water resistance as well as a good UV resistance, and long life of the product. (Haider & Eder 2010.)

TABLE 1. Raw materials for production of Wood Plastic Composites (adapted from Gardner, Han & Wang 2015)



Fillers

The wood-flour is in particulate form or very short in length. Advantageous characteristics of wood flour over wood-fiber is the relatively high bulk density, free flowing nature, low cost and the availability of wood-flour for manufacturing of WPC. On another hand, the potential of improved mechanical properties offered by the fillers of higher length to diameter ratios, the wood-fiber is preferred over wood-flour by the manufacturers when aiming high material property.

FIGURE 5. Cellulose fiber in pellet and powder form

Some development has been achieved in overcoming this issue by pelletizing the wood-fiber. The pelletized wood-fiber provides the ease of handling and processing (Jacobson, Caulfield, Sears, Underwood, & Caufield 2001). Wood Force, produced by Sonae Industria, France, is a densified wood-fiber supplied in form of an easy to handle dice-like cubes. Their production plant in Le Creusot, France has a capacity of 130,000 tonnes/year (Eder 2013). Available forms of cellulose fiber are shown in Figure 5.

Additives for WPC manufacturing

The main additive used in WPC manufacturing is coupling agents. They effectively promote the adhesion between the hydrophilic wood fiber and hydrophobic thermoplastic polymers. There are other types of additives used during the manufacture of WPC to prevent the degradation of the material during the processing, UV-stabilizers to protect from UV-degradation, biocides to prevent the decay of the wood filler and lubricants to improve the flow and throughput. The major type of additives and its functions are listed in Table 2.

TABLE 1. Some commercially available additives used in polyethylene and polypropylene based WPC (Adapted from Sherman 2004)

Additive	Function	PE		PP	
		Name	Loading (%)	Name	Loading (%)
Coupling agent	Promote adhesion and dispersion	Polybond 3009 Polybond 3029 (maleated poly-olefins)	1 - 4	Polybond 3000 Poly-bond 3200 Eastman G-3015 (Maleated polyolefin)	1 - 4
Lubricants	Improve flow and throughput. Pre-vent edge distor-tions	White oils PE waxes (Fatty acid salts, amide, oil, waxes)	0.25-2	White oils PE waxes	0.25-2
Stabilizers	Prevent degrada-tion during pro-cessing and ser-vice	Naugard76 Naugard524 (hindered phenol and phosphate)	0.01-0.02 0.04-0.08	Naugard B25 (hindered phenol and phosphate)	0.1-0.25
UV-Stabi-lizer	Prevent light deg-radation	Chemasorb 944 Tinuvin 327 (Hindered amines)	0.1-0.25	Chemasorb 944 Tinuvin 327	0.1-0.25

Pre-mixed WPC

Several companies now produce wood composite pellets for processors who do not want to blend their own material. The pellets can be made with an exact fiber content required for a particular application. The advantage of purchasing compounded pellets is that the initial capital investment in equipment is lower, as only a single screw extruder would be required rather than a compounding extruder. On the other hand, if large volumes of compounded pellets are required it may be more economically feasible to compound in-house.

3.1.2 Extrusion

It is the widely used technology for the WPC production. The extruder is the core part of the WPC profile processing system. The main purpose of extruder is to melt the polymer then mix with wood and additives. This process is known as the compounding. In this process, the components of polymer composites are melt mixed depending upon selected compounding parameters. The industry has many kinds of the extruding technologies which are used to produce a variety of the different types of products. Mainly there are three different varieties of the extrusion systems used in WPCs manufacturing which include single screw, co-rotating twin screw and counter rotating twin screw. (Gardner, Han, & Wang 2015.)

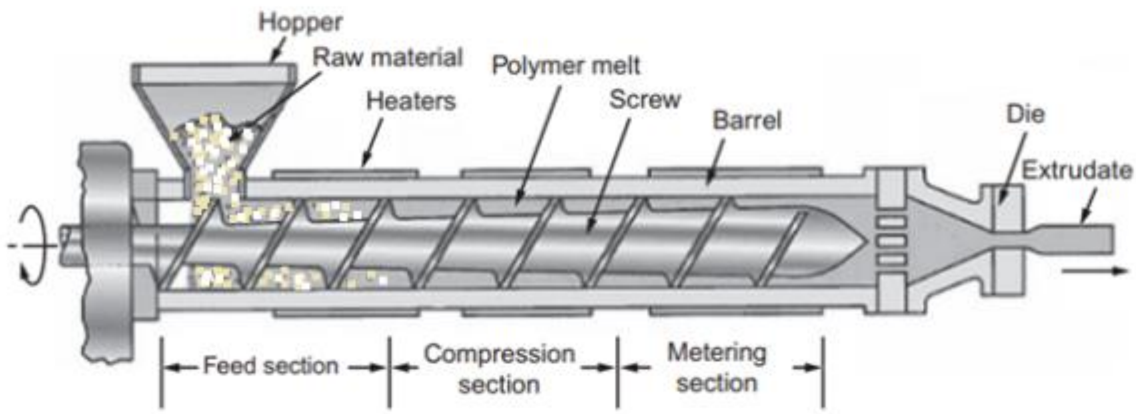


FIGURE 6. Schematic representation of extruder and its various parts (adapted from Tanzi, Fare & Candiani 2019)

Single screw Extruder

It is the simple extrusion system which is used to produce the WPC profiles which has a barrel length and diameter at the ratio of 34:1. The barrel will allow two stages, melting and metering, and a ventilation section which remove volatiles. The material form for single screw extruder will be pre-compounded fiber-filled polymer pellets. When the WPCs are extruded, it is compulsory to cool down extrudate pellets. To dry the pellets, a dryer may be needed. Basically, by running the product through water pellets are cooled (Taylor and Francis 2006). Feed materials pass through the gravity hopper. The mechanism of melting or mixing are barrel heat and screw shear. This extruder has advantage of lowest capital acquisition cost and it is proven technology. Raw material cost, lower output rates, requiring of drying system, high screw speed which led to risk of burning at screw tip, cannot keep melt temperature low with higher head pressures. The schematic representation of a typical single screw extruder is shown in Figure 6. (Gardner, Han & Wang 2015.)

Counter rotating twin screw Extrusion

Counter rotating twin screw extruders are used where low temperature extrusion for fibers and foams, non-compounded materials such as powder blends as well as materials that are difficult to feed, and materials which require degassing, and heat sensitive polymers such as rigid PVC are applied. Material feed is commonly use is crammer feeder. The melting or mixing mechanism is barrel heat and screw mixing. Screw mixing is proficient through the screw flight cut-outs and gear mixers. Moisture is removed by the vacuum venting. It has low screw speed as well as shear mixing, and it is also a proven technology which are advantages of the counter rotating twin screw extruders. It has disadvantages also which include that size reduction system for the fed materials may be necessary if the materials size is bigger, pre-blending system, and a drying system are necessary (Gardner, Han & Wang 2015). The counter rotating twin screw extruders which provides the maximum positive displacement is best choice for extrusion of wood plastic composites. (Shah & Gupta 2004.)

Co-rotating twin screw extrusion

Co-rotating twin screw extrusion is chosen for compounding, devolatilization and chemical reaction. In co-rotating twin screws the materials are pushed out of channel of one screw by fight of other screw. Wood fiber or flour, polymers are the materials. Moisture contents of wood fiber during the processing must be 5 to 8%. Materials are not required for the pre-blending components. Gravimetric feeders and twin-screw side feeders are used for the materials feed. Barrel heat, screw heat which is rpm and screw mixing are the melting/mixing mechanism. Using atmospheric and vacuum vents, moisture will remove. It has advantages of good fiber and polymer mixing as well as it has ability to process wood at ambient moisture content since the extruder is used to dry the wood fiber with the elimination of the drying and pre-blending. It needs peripheral feeding systems, high screw speed and it has no screw cooling which has risk of burning the materials, and it has not ability to keep melt temperature low with high head pressures. Schematic representation of counter rotating twin screw and co-rotating twin screw can be seen from Figure 7. Schematic representation of counter rotating, and co-rotating twin screws can be seen from Figure 7.

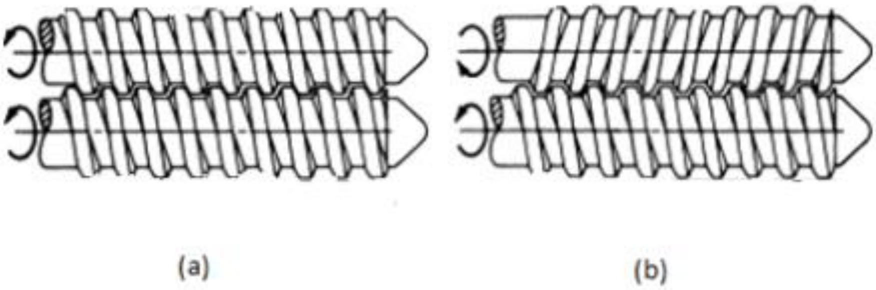


FIGURE 7. Inter meshing twin screw (a) co-rotating and (b) counter rotating (adapted from Martelli 1983)

3.1.3 Compression molding

Compression molding is one of the widely used process and it is also known as hot pressing where material usually in the form of molding powder, flakes, granules or pellets are heated and compressed into the specific shape at the same time (Tanzi, Fare & Candiani 2019). In the initial step, the material to be melted is loaded into the mold maintained at a selected temperature. The mold is pressed at a particular load and for selected time. Once the press is over the mold is transferred to a cold press to cool to room temperature or the mold is cooled rapidly to room temperature if the mold is equipped with cooling. After cooling the mold, the product is removed by ejector pin. (Kutz 2017.)

The device of compression molding is a vice-like press with heat, thus it is also known as heated press (hot press). The schematic view of the basic machine is shown as Figure 8. Apparatus is compact but heavy and often has its own support structure, but we also can be placed on a sturdy table or platform where it can fit. Lower platen is made up of heavy-duty metal which supports the machine, and it has four guide roads which enables the up and down motion of hydraulics. Lower platen is usually heated by electric cartridge, hot oil or with steam but it has other methods too. Electric heaters are easily controlled in the common molding range of °F (150-200 °C), but hot is preferred mode when higher temperatures are called for. In addition to provide a platform a platform for any mold, this paten directly heats lower half of mold, then set upper platen directly above the lower platen. Similarly, heated to transfer thermal energy to top surface of upper mold half. A part ejector system consisting of ejector (knockout) pins connected to an ejector plate may be integral to the platen system or part of the mold. (Kutz 2017.)

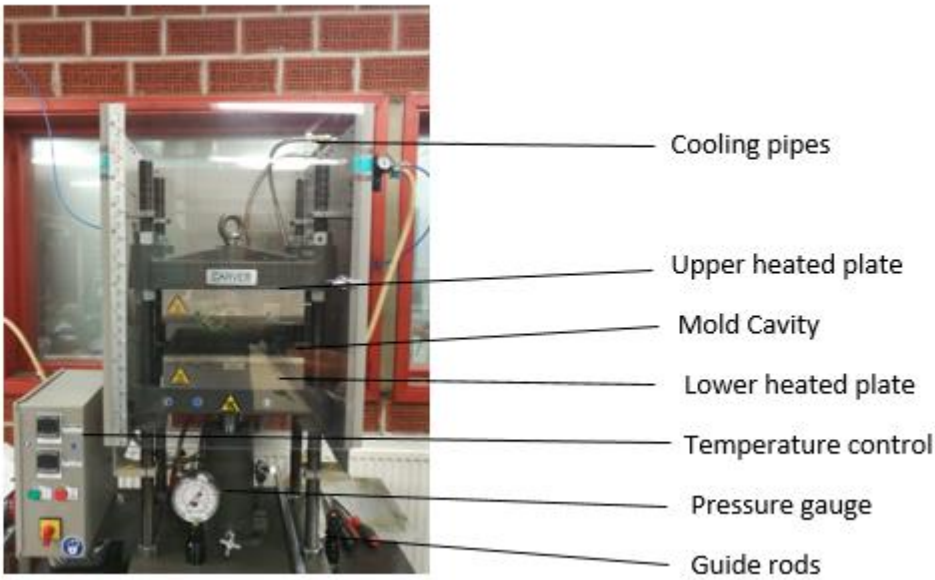


FIGURE 8. Schematic view of major components of compression press

The upper portion of the machine shown in Figure 8 houses the hydraulic unit, which consists of a hydraulic-powered piston or ram. Operation of the ram may be manual which means pumped by hand, semiautomatic (opening a valve that supplies pressure), or automatic (controlled by time). The hydraulic ram forces upper platen down on the upper half of any mold placed within the machine, and this type of compression press is termed a down stroke machine. If hydraulic force is upwards direction, then it is upstroke machine. Press force may also be mechanical, as in a toggle arrangement, or pneumatic that utilize a facility's compressed air for lower-forced moldings. The daylight opening is the distance between main plates represents available space for platens and limits the thickness of mold. At minimum, the daylight must accommodate a stroke of twice the parts depth. Molds may be bolted to platen or simply placed upon lower one. Some presses also have a tilting option for upper platen where it hydraulically tilts upwards up to 45 °. Hence, laying open the upper mold half for better access, cleaning, and maintenance. In the configuration shown in FIGURE 8, the platens transfer heat only through flat surfaces in direct contact with mold halves. To improve thermal transfer, and option is to recess the platens for mold insertion; this provides excellent mold body support as well as more uniform heating due to fact that the mold body is partly enveloped by heated surface area. Once the compression stage is completed, the part is ready to be removed by dripping water until sufficiently cool for safe handling or cooled by circulating water through upper and lower platens while still contacting the closed mold. Thermosets are nearly fully cured and can be taken out even while still somehow hot and need minimal cooling. For bigger or complex types of molds, cooling channels are machined into the mold itself and water is pumped through them. Thermoplastics parts must be completely cooled so they are not deformed when ejected from mold. (Kutz 2017.)

3.1.4 Injection molding

Injection molding is also a common type and important manufacturing method for WPCs. It is based on the ability of composites to be soften by heat and harden after cooled. This molding process looks simple, but injection molding process is complicated. The injection machine consists of mainly three parts, feed hopper, screw and heated barrel can be seen in Figure 9. (Tanzi, Fare & Candiani 2019.)

The WPCs in pellet form are fed through Hooper leading them into heated barrel. In the heating zone the WPCs are heated and softened rapidly. Barrel is heated at desired temperatures to allow the materials to melt and to move along the screw. When screw rotates, material move forward with the pressure and speed determined to fill the cavity efficiently. When the material exits the nozzle at the end of barrel it is injected into feed channels of mold tool. (Taylor and Francis 2004.)

Feed channels allow material to flow into open cavity of mold tool which later form the shape of finished product. Because of contact temperature of mold tool, it allows ease of material flow and to draw out the heat from product after injection and material sets off as solid form. After predetermined cooling time, mold tool is opened when moving platen carrying ejection half is retracted. The mold tool opens with product in ejection half tool. This ejection system moves forward to release product from mold tool. Finally, products gather in collection box after the cycle is complete. (Pentagon plastics ltd 2019.)

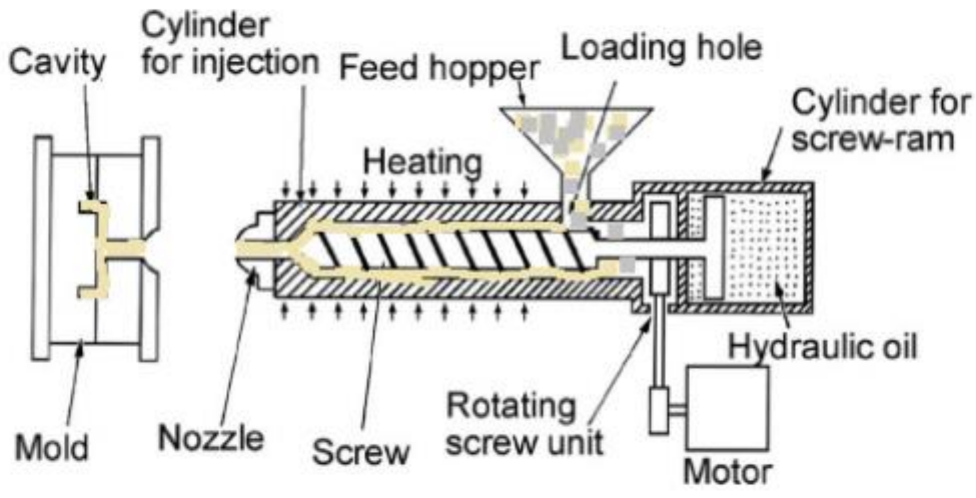


FIGURE 9. Schematic representation of Injection molding machine (adapted from Tanzi, Fare & Candiani 2019)

3.2 Properties of WPC

Wood plastic composites reveals the hybrid properties of the wood-based components and the polymer. In general, according to Wolcott & Englund, while adding wood to the thermoplastic matrix increases the mechanical properties if we compared to the solid thermoplastics. Conversely, thermoplastic component can present moisture barriers to the wood elements, decreasing the water adsorption and swelling characteristics as compared to wood and traditional wood-based composites. (Wolcott & Englund 1999.)

3.2.1 Tensile properties

Tensile properties of wood plastic composites play vital role to decide suitability of the products in various applications fields. Developing the mechanically strong, durable as well as attractive WPCs which is not only helping the economic growth for wood and plastic industries, but it also ensures exciting and interesting new options for the end user. Using universal tensile testing machine properties are studied.

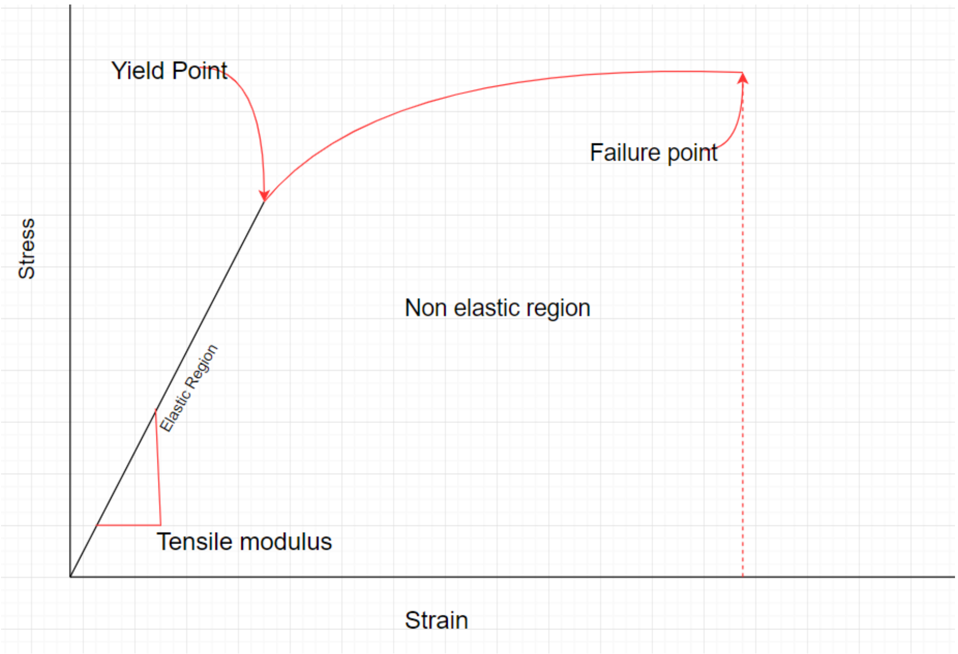


FIGURE 10. Stress-strain curve of polymeric materials (adapted from Villasenor-Ochoa 2017)

In tensile testing a stress-strain curve is plotted as shown in Figure 10 which shows materials reaction to the forces being applied. From stress-strain curve, we can find breaking point of the materials and other properties such as modulus of elasticity, yield strength, strain and ductility (Sain & Pervaiz 2008). When stretching the material in elastic region, material comes in its original position when the applied force is removed. This region is called elastic region where tensile modulus is calculated. If stretching is applied beyond yield point material do not come back on its original position and certain point is breaks that is called facture or failure point. That region is plastic region.

3.2.2 Flexural or three-point bending

Flexural strength and flexural modulus are tested by three-point bending test using standard materials testing system. According to Bhaskar et al. the PP based composites have flexural strength of 27 MPa to 50.6 MPa. They found that flexural strength and modulus increases with wood content as well as by addition of coupling agents. According to them, flexural strength of the composites made from 50% wood flour increased from 31.5 MPa to 48.3 MPa by addition of 3 wt% MAPP and 50.6 MPa by addition of 5% MAPP. (Bhaskar, Haq & Yadaw 2011.)

3.2.3 Impact resistance

Toughness is measure of energy that a WPC product will absorb before it is breaking. Lu and Oza studied the impact strength behavior for hemp reinforced PP composites and they reported that addition of the natural fiber increased area of stress concentration and hence, initiated crack growth. The crack growth created fracture in fiber or matrix which causes reduction of impact strength of the composites as the fiber loadings increased. (Lu & Oza 2013.)

3.2.4 Water absorption

Water absorption behavior for composites materials is important for durability of composites materials. Adhikary et al researched water absorption of wood plastic composites and concluded that water absorption increases with increasing wood content in the composites. On the other hand, higher plastic has less water absorption sites. They did 2 h and 24 h water immersion test for virgin HDPE and recycled HDPE. The water absorption of rHDPE or vHDPE is only 0.03-0.04 % after 2h and 0.05 % after 24h immersion in water. Water absorption of rHDPE based composites was with 30 wt% wood flour content was 0.39 % after 2 h and 0.98 % after 24 h, while 50 wt% wood flour content were 1.7 % and 4.1 % respectively. Thus, composites made up of rHDPE have lower water absorption than vHDPE at the same wood content. (Adhikary, Pang & Staiger 2008.)

3.2.5 Thermal Properties

Thermal properties of WPCs are usually analysis by differential scanning calorimetry (DSC) and Thermogravimetric analysis (TGA). It has become normal and popular practice for the characterization of polymer mixture composition due to its simplicity and fast performance as well as helping in identifying the polymeric contaminations in recycled materials. Kadi et al studied over PP/beech flour composites over thermal decomposition and melting temperature by TGA and DSC. Composites showed high thermal decomposition temperature at 377-degree C in a nitrogen atmosphere. Most of weight loss occurred between the temperature range of 377-537. (Kadi, Evlen & Özmert 2017.)

3.3 Factors Affecting Properties of WPCs

Wood as a filler or reinforcing materials have historically used minerals and synthetic materials such as calcium carbonate, talc, mica, glass fibers and carbon fibers as extenders and reinforcing materials. Wood has several advantages to traditional fillers such as lower cost, relatively high strength to the weight ratio, low density, relatively soft and easy to integrate into the production assembly as well as it is renewable resource. WPCs properties are significantly influenced by the wood species and the particle size characteristics of the wood particles used on it. (Schwarzkopf & Burnard 2016.)

3.3.1 Wood species

The uses of the wood species in WPC is mainly determined by the geographical location, availability and price of the species. Common types of the wood species used in WPC include pine, maple, and oak. Berger and Stark (1997) tested variety of the wood species in WPC after the injection molding process. After the research they found that hard wood species provide improved tensile properties of the WPC and heat deflection while comparing with soft woods. And pine wood flour provided the maximum blend of mechanical property enhancements.

3.3.2 Wood particle size

Wood particle size and geometry being used in WPCs have also important affect for the flow or handling characteristics and mechanical properties. Stark and Rowlands (2003), researched the effects of the wood particle size on the mechanical properties of WPC. According to them, they manufactured WPC test specimens using the wood particle sizes 35-235 mm and performed a variety of mechanical properties. They found the larger particles size contain more stress concentrations which affected the impact energy of the product (Schwarzkopf & Burnard 2016). If wood particle size is larger, toughness and elongation at break of resultant materials decreased (Bouafif, Kou-baa, Perre, & Cloutier 2008).

3.3.3 Modification of wood fiber

Different wood fibers show different properties over wood plastic composites. Bouafif et al. researched the effects of wood fibers (sapwood, softwood and bark). Wood plastic composites which are made from heartwood and bark from sapwood showed higher toughness and elongation at break compared to wood flour used as filler in WPC. This effect was more significant when concentration of particle increased (Bouafif et al. 2008).

According to Gwon et al, chemical treatments and alkali treatment have great effects on physical properties of wood plastic composites. The alkalization of wood fibers increased tensile strength of WPC as well as reduced moisture absorption comparing to the composites with the untreated wood fibers (Gwon, Lee, Chun, Doh, Kim 2010.)

3.3.4 Effect of coupling agent

Coupling agents also play vital role to affect the properties of wood plastic composites. Silane or maleated polypropylene (MAPP) are most commonly used coupling agents in wood plastic composites to improve the compatibility between filler fibers and polymer matrix. It improves the interfacial adhesion of the filler fibers and PP matrix by forming hydrogen bonds and covalent bonds between them. MAPP as a coupling agent showed better flexural strength, tensile strength, and Brinell hardness but composites containing 20% of recycled mineral wool, composite treated with 3% silane solution did not show much difference over those properties. (Väntsi & Kärki 2015.)

3.4 Applications of WPCs

Wood plastics composites are a hybrid material which has best qualities of wood and plastic. As being a sustainable bio-product, hence demands of WPC is to set grow steadily. WPC offers better mechanical properties than traditional products such as rigidity and strength comparing with other plastic materials and improved resistance as well as maintenance compared to traditional lumbar. (McCormick 2018.) WPCs manufacturing sector has grown rapidly in recent years because of its applications. North America and China are the largest producers of WPCs products, Europe being third largest producers (Keskisaari

& Kärki 2018). The major applications of WPCs are building and construction. Based on application fields WPCs is classified and described below.

3.4.1 Building and construction

Wood Plastics composite is widely used in decking, molding, sliding and fencing. Since, WPC consists of wood fibers, thermoplastic and additives, lubricants blowing as well as foaming agents in some small quality. They are found to be durable and last longer than raw woods and possess a long shell life since, they are mostly prepared using saw-mill products and re-cycled plastics as well as they are also considered to be environmentally friendly. Due to sustainable preference towards wood plastic composite the market has been growing since last decades. (McCormick 2018.)

Since, in the present world these materials are easy to maintain as well as clean which saves time. Their uses in building and construction has increased since decades. Continued research and development of WPCs expanding markets. In North America, construction and building applications increasing the market include siding, fencing, bridge decking, marine structure, residential furniture, railroads ties. These materials also found to be resistance towards ultra-violet lights and its color doesn't fade away easily. WPC is highly durable and not affected by rain, snow, or peak summer conditions due to which WPC has preferred highly in building and construction. (Matuana & Stark 2015.)

3.4.2 Automotive composites

The wood plastic composite has been widely used as an automotive component besides building and construction. The automotive industry in Europe has been leading by using WPCs . The application of wood plastic composite (WPC) in automotive is growing due to increasing awareness among costumers about the various use and benefits. Automakers are focusing on making automobile parts either recyclable or biodegradable. The incorporation of wood plastic composite based parts is recyclable or bio-degradable is expected to enhance the mechanical strength and acoustic performance, reduces materials weight, fuel consumption, improve passenger safety and shatter proof performance under extreme temperature changes. (Matuana & Stark 2015.)

The uses of composite in automobiles interior makes those parts biodegradable which found to be key points to enhance the demands of these materials during the forecast period. Being eco-friendly and available in many textures these composites are used nowadays. (McCormick 2018.)

3.4.3 Industrial and Consumer Products

Industrials and consumer goods manufacturing constitute another large segment that uses wood plastics composite, although found to be more expensive than unfilled PVC (polyvinylchloride). Wood filled PVC is preferred because of its balance of thermal stability, moisture resistance, stiffness and strength since patent activities is very high in these areas. Many industries across globe are offering product line but approaches with an unfilled PVC for durability while some companies extrude a PVC core with a wood filled PVC surface that can be painted. (McCormick 2018.)

4 EXPERIMENT

In this experimental section materials, methods and characterization of reprocessed WPCs and pre-mixed are discussed. Sample preparation methods using extrusion and compression molding machine as well as test specimens for testing the physical, mechanical, burning and thermal properties are well described.

4.1 Materials

Polypropylene used in this study is a high impact copolymer from Lyondell Basell named Moplen EP240H as seen from Figure 11 (a). The pre-mixed WPC used to dilute and prepare wood plastic composites with different fiber content was kindly provided by Centria Research & Development (FIGURE 11 (b). The concentrate contains 50 % (by weight) of softwood fiber with maximum size of 500 µm. The pre-mix contains 3 % (by weight) of additives which includes the MAPP.

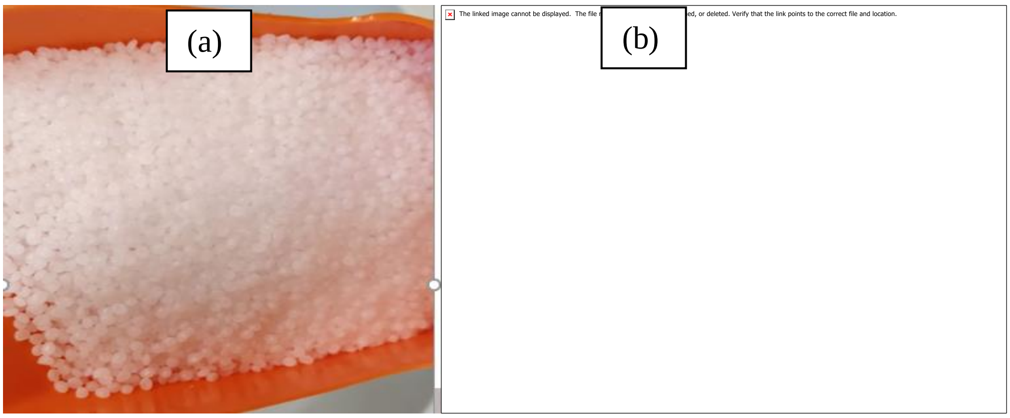


FIGURE 11. PP neat and Pre-mix wood plastics composites

4.2 Preparation Methods for Wood Plastic Composites samples

WPCs were produced in a corotating twin-screw extruder Coperion ZSK 18 Megalab. The temperature profile during the compounding was set between 190 ºC – 200 ºC. The PP/wood concentrate (50 wt% wood) was diluted by neat polypropylene (PP neat) to produce composites with fiber content of 10, 20 and 30 wt%. The composite designations and details can be found from Table 3. They were produced using three different screw speed 150 rpm, 300 rpm and 500 rpm. The PP neat was fed from the main feeder and the PP/wood concentrate was fed from side feeder. The total feed rate during compounding was selected as 5 kg/h. The extrudate was cooled and pelletized for further processing.

FIGURE 12. Manual hydraulic laboratory hot press used to produce composite plates

TABLE 3. Description of composites

Composites	**Polypropylene (%)**	**Wood (%)**	**Screw speed**	**Processing Method**
PP neat	100	0	--	Compression molding
PP W20-150	80	20	150	Compounding and compression molding
PP W20-300	80	20	300	Compounding and compression molding
PP W20-500	80	20	500	Compounding and compression molding
PP W30-150	70	30	150	Compounding and compression molding
PP W30-300	70	30	300	Compounding and compression molding
PP W30-500	70	30	500	Compounding and compression molding
PP W10	90	10	150	Compounding and compression molding
PP W20	80	20	150	compounding and compression molding
PP W30	70	30	150	Compounding and compression molding

PP W50	50	50		Compression molding

The composite plates for testing were prepared by compression molding. A 25-ton, manual hydraulic laboratory press from Carver (3856) with two heated platens equipped with water cooling option was used to prepare the composite plates (FIGURE 12). Initially the press along with the mold was heated up to 200 ^oC. Once the mold temperature reached processing temperature (200 ^oC), 137 g of WPC pellets were weighed and loaded in the center of the mold. The mold was later closed and placed back to hot press. A pre-heating time of 10 minute without any load was given to reach the processing temperature and to ensure that the remaining moisture in the pellets was removed. Pre-heating was necessary because in this study no pre-drying of pellets before processing was done. After the pre-heating time the applied load was increased to 14 ton and was pressed for 3 minutes. Once the press time reached, the platens were air-water cooled to room temperature. During the cooling the press force was maintained at 14 ton and cooling time was approx. 15 minutes. The composite plates produced had an average thickness of 3.6 mm.

4.3 Characterization of Reprocessed Wood Plastic Composites

This section deals with the experimental tests of the reprocessed and pre-mix wood plastic composites. The water absorption test, burning test, tensile testing, impact strength test and TGA analysis test procedure are discussed briefly.

4.3.1 Water Absorption Test

A gravimetric water absorption test was done according to ISO 62 with few changes to determine the water absorption properties of wood plastic composites specimens at room temperature. The edges of test specimens were not sealed. Water gain percentage of specimens was calculated by using following equation.

$$c = \frac{m2 - m1}{m1} * 100$$

Where,

m1 = mass of specimen after drying and before immersion in water

m2 = mass of specimen after immersion at specific time

c = weight gain percentage of specimen

Test specimen samples were cut into 60 mm*60 mm square shape and for each composites wood contains 20, 30 and 50 wt% three specimens were made. Test specimens were kept for drying 50 °C for 24 h before starting water absorption test. After drying, test was done by placing the specimens into distilled water filled container (7 L water) at room temperature. The first weighting test was done after 24 h, second was done after 3 days (72 h) and last one after 9 days (216 h). Each weighing was done within one minute after taking the sample from water and specimens were wiped using lint free fabric to remove surface water and specimens were kept back to water after weighing for next test.

4.3.2 Tensile testing

Tensile test was performed using according to ISO 527-2:2012 using a Tiratest 2705 tensile testing machine equipped with a 5 kN load cell. The test was carried out at room temperature with a speed of 5 mm/minute. Dumbbell shaped tensile test specimens were prepared by CNC (Computer Numerical Control) machining. The total length of the sample was 150 mm and the length of narrow portion was 80 mm. The average thickness of the tensile specimens were 3.6 mm. Tensile properties are calculated as the average of 6 specimens. Before testing the specimens were conditioned at 50% relative humidity and 23ºC for 24 hours before the testing. Universal tensile testing machine and tensile sample specimens are shown in Figure 13.

FIGURE 13. Universal tensile testing machine & Sample specimens for tensile test

4.3.3 Impact testing

Charpy impact test was performed on un-notched specimens according to ISO 179:2010. The direction of impact was flatwise. Test was carried out on mechanical impact tester (QC-639D, Cometech testing machines, Taichung Hsien, Taiwan). The specimen dimension was 80 mm x 10 mm x 3.6 mm and the impact strength was calculated as the average of 5 specimens.

4.3.4 Microscopy testing

Polishing of sample surface to be examined was carried out by grinder-polisher machine (Company-BueHler) with the speed of 200 rpm (FIGURE 14). First, SiC grinding paper (grit P 400) used for 2 minutes 50 seconds. Again, Grit P 1200 paper used for 30 seconds. Again, samples were grinded three times using grinding cloth 9 µm, 3 µm and 1 µm respectively for 4 minutes 10 seconds. Small amount of grinding liquid (monocrystalline diamond suspension) was used for cloth grinding. To prepare microscopy test sample, first samples were embedded in a methacrylic resin (FIGURE 15 (a)). Infiltration solution was prepared by 50 ml of basic resin and 1 packet (0.5 g) activator. Stirred until dissolved completely. Then 15 ml infiltration solution and 1 ml hardener mixed and used immediately for each sample. Six different samples were prepared by immersing and orienting the specimen into the small box. Samples were left for 24 h in room temperature for curing. After polishing, orientation of fibers and size were studied by using Olympus microscope which is shown in Figure 15 (b).

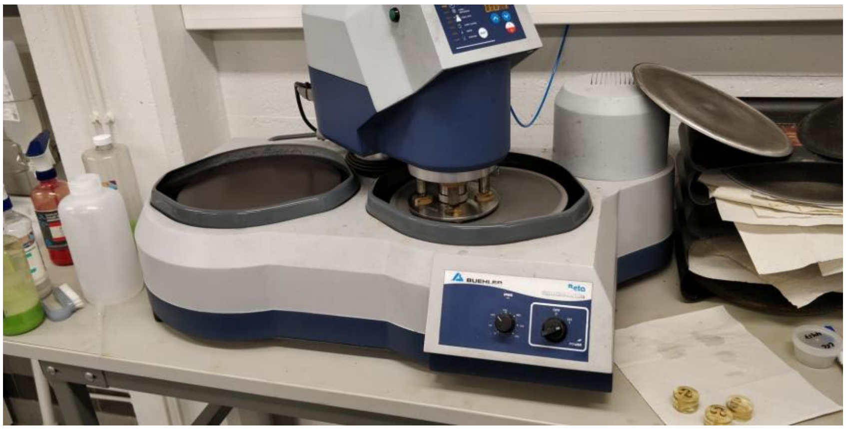


FIGURE 14. Instruments used for polishing the surface of microscopic test samples

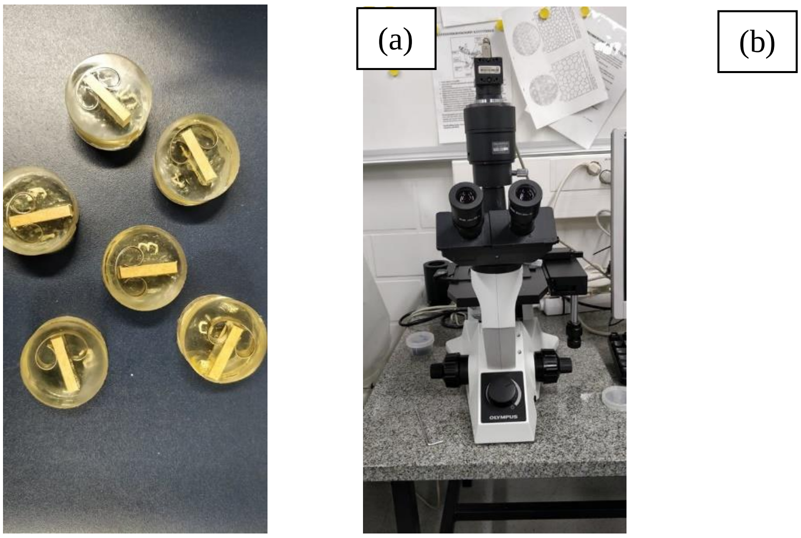


FIGURE 15. Microscopy test specimens (a) and Olympus microscope (b)

4.3.5 Burning testing

Burning test for all the composites was conducted according to the ISO 3795:1988. A sample is fixed horizontally in a U-shaped sample holder. The free end of the sample is exposed to a low-energy flame for 15 seconds. The test measures the time taken to self-extinguish or the time in which the flame passes a measured distance. The test specimen was 138 mm in length and 60 mm in width. The burning rate was calculated as the average of 3 specimens. The measurement starts at the moment when the foot of the flame passed first measuring point and ends when the flame reaches distance of 100 mm from the first measuring point. The horizontal flammability test and chamber can be seen in Figure 16.

FIGURE 16. Horizontal burning test of wood plastic composites

4.3.6 Thermogravimetric analysis (TGA)

Thermal degradation of the WPC's was studied using a thermogravimetric analyzer, Netszch DMA 242. The test was conducted in a nitrogen atmosphere by heating from 25ºC to 800ºC at 10ºC/minute. The sample mass for all the composites was 20 mg (±2). The protective gas flow and purging gas flow was 15 ml/min and 25 ml/min respectively. Firstly, pellets were pressed to flatten and then desired amount of sample was cut from it.

5 RESULTS AND DISCUSSION

This section deals with the all results from the experiments and discuss about the various changes over the properties of wood plastic composites.

5.1 Water Absorption Properties

Water gain percentages of WPCs are shown in Figure 17. Water absorption percentages of composites which depends upon fiber loading and coupling agent content. It can be seen from Figure 17 that water gain percentage is increasing with more fiber content. It is said that polymers slightly absorb moisture, indicating that water is absorbed by lignocellulosic fibers in the composite. When fiber content increases, there will be more water residence sites and hence more water will absorb. Furthermore, fiber contains large number of porous tubular structures which accelerates the penetration of water which is known as capillary action. Same result was found by Ashori et al and Ahikary et al. The water absorption test was done on samples without edge sealing. The results show that exposure of fiber ends increases the water absorption. Therefore, when WPCs are drilled for fastening purpose the free edges will be escaped for moisture absorption. Measures should be taken to prevent water uptake in this kind of situation.

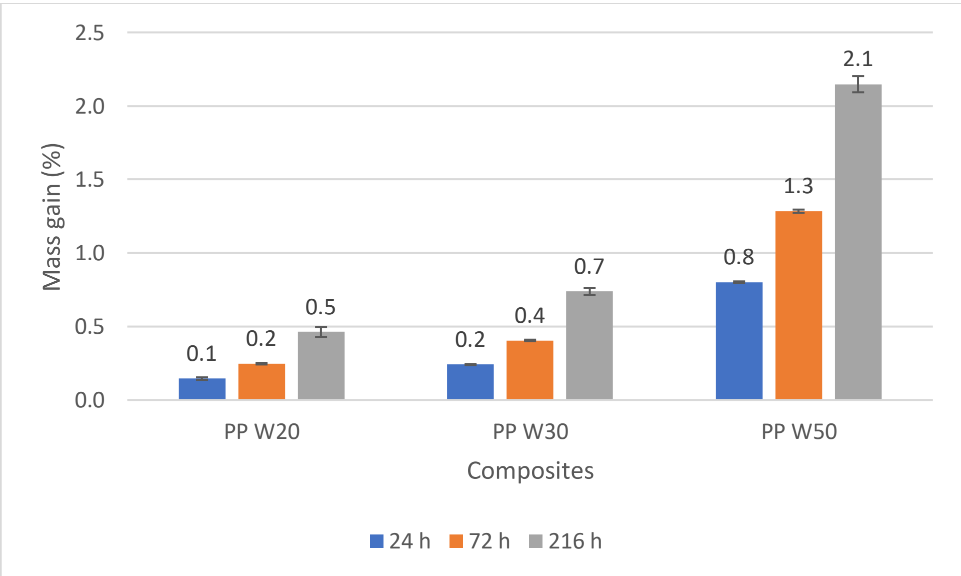


FIGURE 17. Mass gain during water absorption test of composites

5.2 Tensile Properties

The maximum and break strength of WPCs with increasing speed has significantly no change as can be seen from Figure 18. Fibers are well distributed with higher screw speed and fiber size are smaller because of high screw speed which is discussed in section microscopic test. With higher screw speed, the residence time is less and chances of well mixing between polymer and fiber might be less. Therefore, lower screw speed 150 rpm was chosen for further studies because of higher residence time. There were not significant differences between changing the screw speed of extruder in tensile properties of WPCs containing wood fibers 20 and 30 wt%.

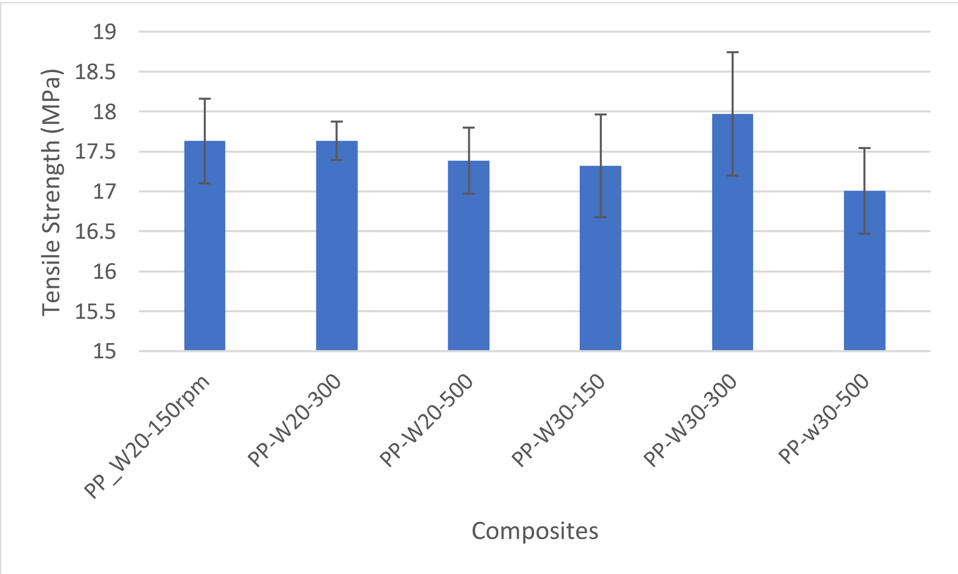


FIGURE 18. Variations in tensile strength over different screw speed

The maximum and breaking strength of WPCs with different fiber content are shown in Figure 19. The maximum tensile strength of PP neat is 18.8 MPa. However, increasing the wood fiber content seems to be decreasing the tensile strength. There was 10% and 6% decrease in strength for PP W10 and PP W20 respectively when compared to PP neat. As seen from Figure 15, the reinforcing effect of wood fiber in terms of maximum and breaking tensile strength is slightly lower for PP W10 compared to PP W20 and PP W30. The breaking strength of PP W10 is measured to be 15.4 MPa while, both PP W20 and PP

W30 shows 16.8 MPa. Similarly, as in the case of maximum tensile strength, breaking strength also shows an increase by addition of 20 – 30 wt% fiber.

Bouafif et al. (2009) explained the increase in tensile strength of WPCs based on the adhesion between fiber and polymer matrix in the composites. The results from this study shows that there is a small increase in tensile strength by increasing fiber content above 10 wt%. Bledzki, Faruk & Haque (2002) found that softwood fiber/PP composites without coupling agent gradually decreased with increasing fiber content. The pre-mix with 50 wt% fiber from which the WPC's are reprocessed contained 3% of additives including coupling agent. The small increase in tensile strength of reprocessed WPC with higher fiber content might be due to coupling agent present in additives. According to Karmarkar, Chauhan, Modak & Chanda 2017 (p. 131), the addition of additives improves interaction between fibers and polymer. Although, to achieve a significant increase in tensile strength of reprocessed WPCs more coupling agent is needed.

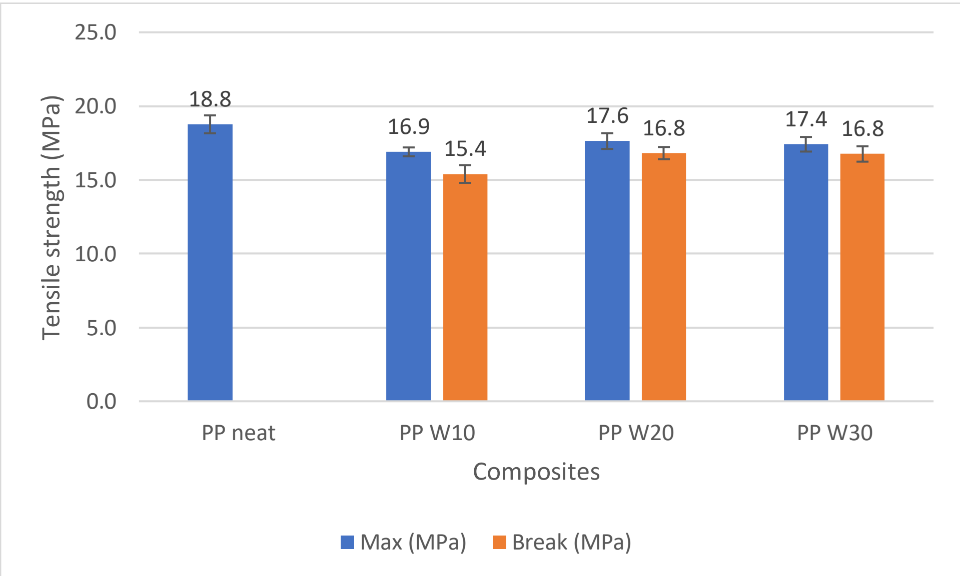


FIGURE 19. Effects of increasing fiber content on tensile strength of the composites

From Figure 20, it seems that elongation of composites is decreasing with increasing wood content. The elongation at max of PP neat is 7.8 %, composite which contain 10 % wood fiber shows an elongation of 7.1 % and the composite with 30 % fiber content shows an elongation of 6.0 %. This results clearly shows that by increasing the fiber content, the elongation of the WPC's decreased. Similar trend is observed when comparing elongation at break of WPC's. The difference between each composite is more prominent. There was a decrease of approx. 50 % in elongation at break of PP W30 when compared to PP W10.

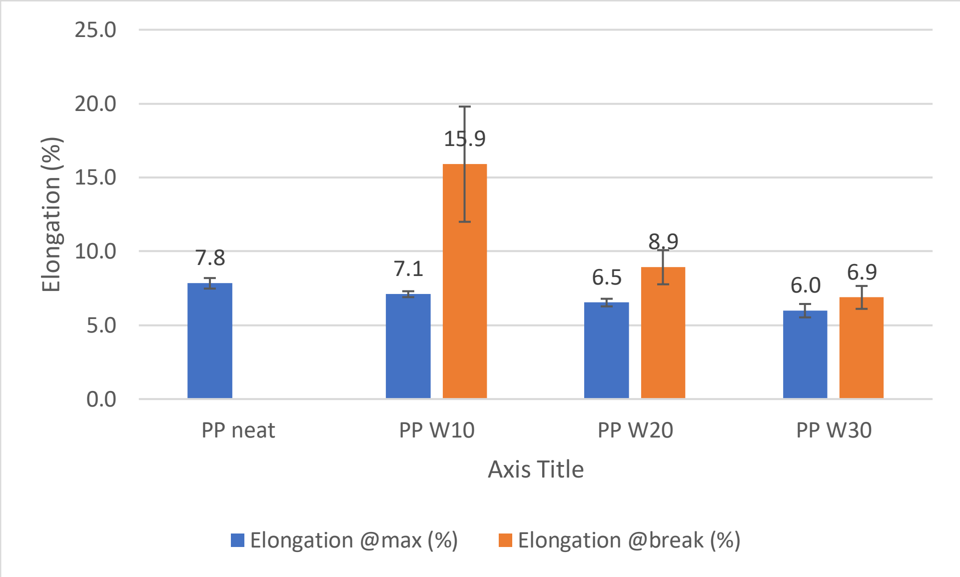


FIGURE 20. Effects of increasing fiber content on the elongation of the composites

According to previous studies by Bouafif et al. (2009) and Bladzki et al. (2002), the elongation at break of WPC's decreases with increasing wood fiber content. Elongation at break of the composites decreases with decrease in polymer content. Thus, it shows that increasing the fiber content in reprocessed WPC's decreases the plasticity of composites. In other way, the decrease in elongation at break is also influenced by lower elongation at break values of wood fiber.

The tensile modulus of WPCs can be seen from Figure 21. The tensile modulus of the WPCs was found to be increasing by increasing the wood fiber content in the composites. There was 30 % increase in tensile modulus of PP W30 when comparing to PP neat. When comparing WPCs, the composite containing 30 wt% showed 11 % increase in tensile modulus when compared to composite with 10 wt% of fiber content. Same result was found by Khoathane et al. that increasing fiber content increases the tensile modulus of composites. Tensile modulus is a measure of stiffness of the material. The increase in tensile modulus of WPCs indicate that the stiffness of the reprocessed WPCs is not affected by reprocessing conditions. This also shows that coupling agent is not a significant factor determining the modulus of the WPCs.

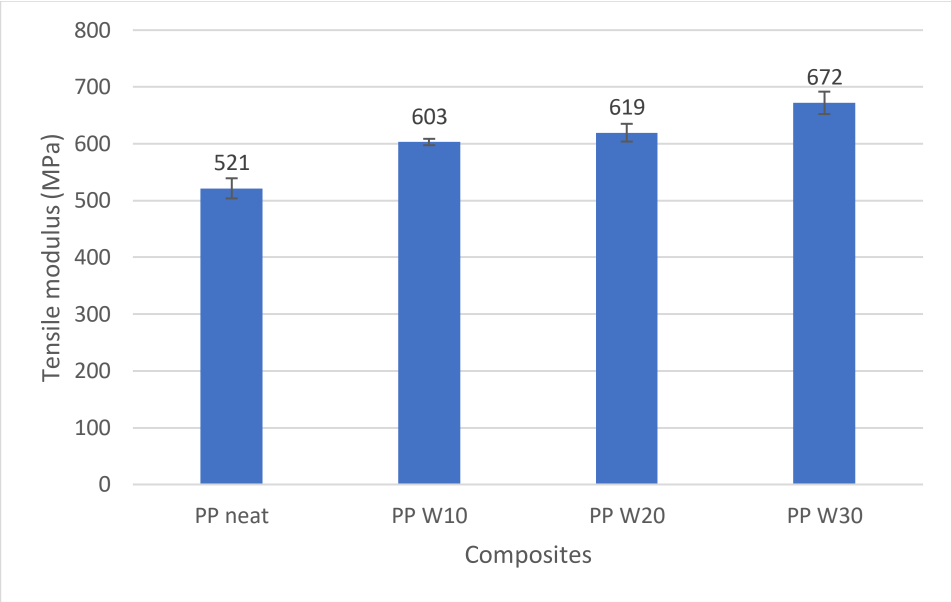


FIGURE 21. Effects of increasing fiber loading on the tensile modulus of the composites

5.3 Charpy Impact strength

The effect of fiber content is highly significant for Impact strength test as shown in Figure 22. Charpy impact strength of the resultant composites decreased steadily with increasing wood fiber content. WPC with 10 wt% wood content has 31 % higher Charpy impact strength than WPC with 20 wt% wood content. similarly, same trends followed by WPC with 30 wt% wood content which is decreased by 36 % comparing with WPC 20 wt% wood content.

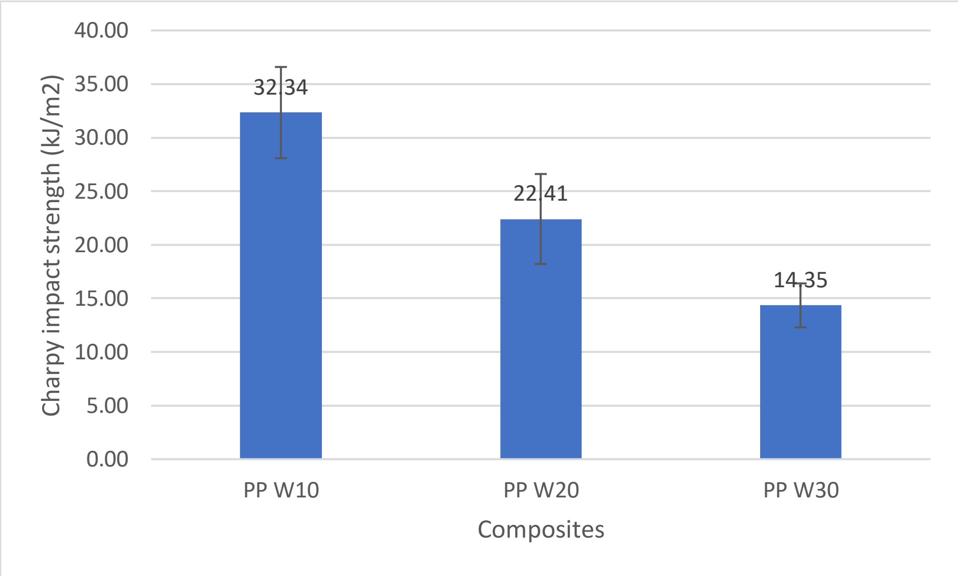
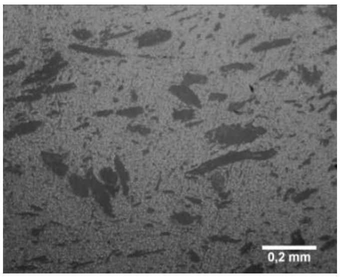


FIGURE 22. Effects of increasing fiber content on Charpy impact strength of composites

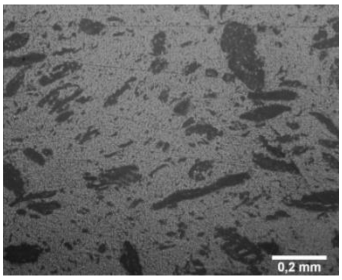
The impact strength of materials is directly related to toughness. Impact strength of composites is influenced by many factors such as matrix facture, fiber matrix debonding and fiber pull out. It is reported by Bledzki et al. that Charpy impact strength decreased with increase in wood content. Their studies showed that the impact strength decreased even in presence of coupling agent. (Bledzki et al. 2002.)

5.4 Microscopic test

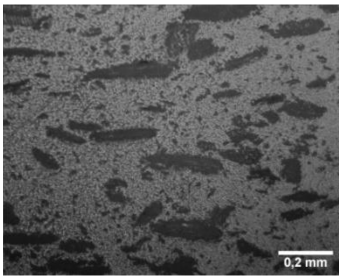
Microscopic pictures of WPCs containing 20-30 wt% wood fibers with different screw speed are shown in Figure 23. When comparison of composites having same fiber content but processed by different screw speed, fiber distribution found to be different. In PP W20 with 150 rpm screw speed shows less fiber content and fiber length also can be seen longer. When increasing screw speed to 300 and 500, fibers are well distributed when comparing to screw speed 150 rpm. Length of fibers can be seen shorter. Likewise, same things can be seen in PP W30. When increasing processing screw speed of extruder, the fibers will well distribute, and fiber length become shorter. Because of the maximum share forced and less residence time. When processed with 150 rpm, residence time is high, and polymer and fiber can be well mixed.



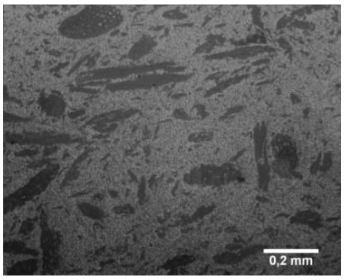
PP W20-150



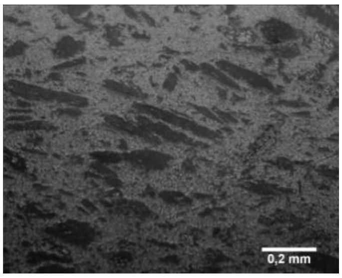
PP W20-300



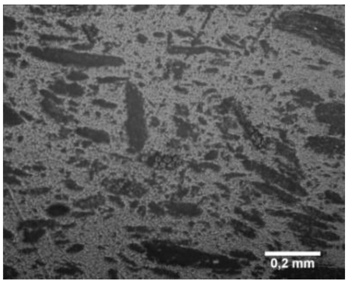
PP W20-500



PP W30-150



PP W30-300



PP W30-500

FIGURE 23. Microscopic pictures of composites

5.5 Burning Properties

The effect of wood content in composites varies significantly over burning rate can be seen from Figure 24. The burning rate of WPC with 20 wt% wood content has increased by 21% than PP neat. It shows that burning rate of WPC is higher than polymer composites. When comparing between WPCs with different wood content, 20 wt% and 30 wt% wood content have same burning rate, but 50 wt% wood content WPC has slightly increased by 1mm/min. Burning rate between wood plastic composites having 20 %, 30 % and 50 % wood content by weight have significantly not much difference while considering error. The results from this study show that reprocessed WPCs can be used to produce parts for interior of vehicles.

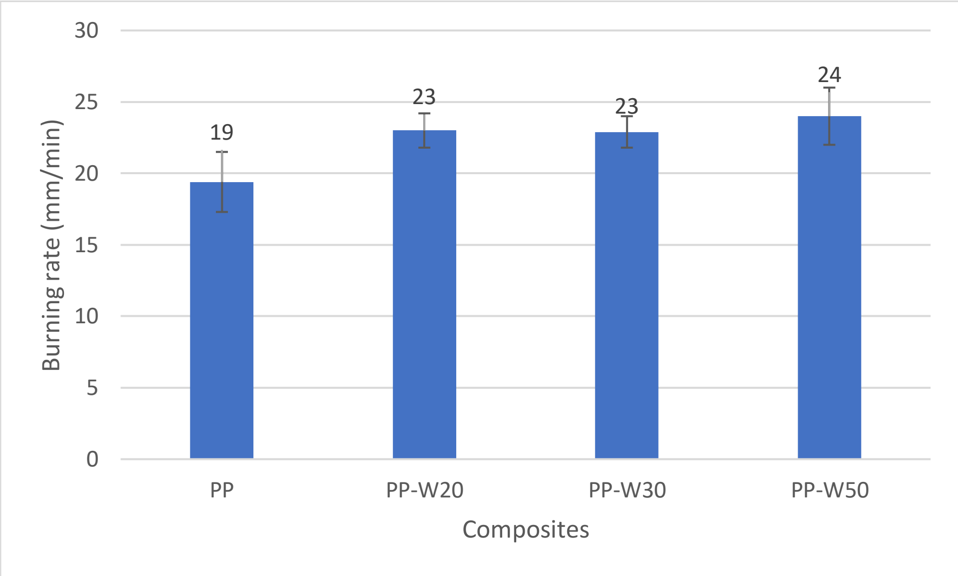


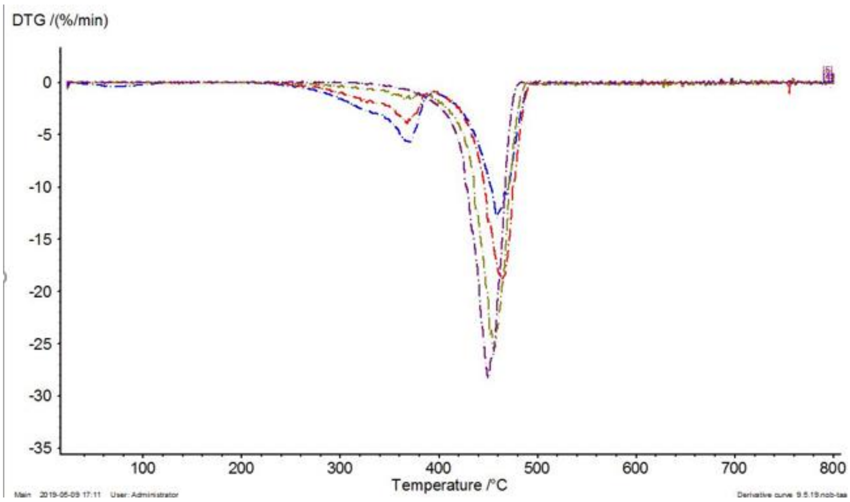
FIGURE 24. Effects of fiber content on burning characteristics of composites

5.6 Thermal properties

The results from thermogravimetric analysis of reprocessed and pre-mix wood plastic composites can be seen from Figure 25 and from Table 4. The mass loss during the thermal decomposition occurs in one stage for PP neat, in two stages for reprocessed WPCs (PP W10, PP W20 and PP W30). However, Pre-mix (PP W50) shows three stages decomposition. First stage in reprocessed WPCs can be related to thermal decomposition of wood fiber. Second stage includes thermal decomposition of polymer and remaining wood fiber. In the case of pre-mix, the first decomposition stage can be due to evaporation of moisture. Second decomposition is from wood fiber and final stage decomposition includes mainly polymer and remaining wood fiber. The thermal decomposition of hemicellulose, cellulose and lignin occur between 180 °C- 350 °C, 275 °C-350 °C and 250 °C- 500 °C respectively as reported by Kim et al (2006). Initial decomposition temperature is taken at 5 % mass loss. The initial decomposition of PP neat is 396 °C but it decreased to with addition of 10 wt% wood is 358 °C. The thermal decomposition of pre-mix started at 282 °C. This shows that the initial decomposition temperature decreases with increasing wood fiber content.

From Table 4, final decomposition temperature of reprocessed WPCs and pre-mix increased by 30 °C when compared to PP neat. Beg and Pickering (2008) reported that the char formation occurring due to thermal decomposition of lignin component helps to insulate against further thermal decomposition. As discussed above, the lignin decomposition takes place between 250-500 °C. The final decomposition of PP neat is 465 °C. Thus, char formation from lignin component might have delayed the thermal decomposition of reprocessed composites and pre-mix.

Furthermore, the residual mass of both reprocessed and pre-mix WPCs can be seen increasing with increasing wood content from Figure 25 and Table 4. WPC with 10 wt% wood fiber content has double residual mass than PP neat and exhibited further increased in residual mass when fiber content was increased. The increase in residual mass in reprocessed and pre-mix WPCs can be due to increasing content of lignin and impurities in WPCs. (Beg & Pickering 2008).



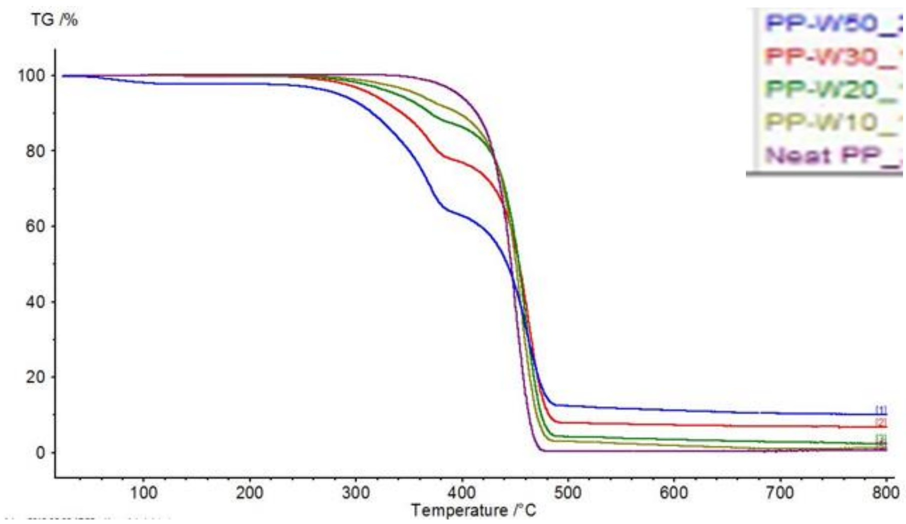


FIGURE 25. Thermogram and derivative curve for wood plastic composites

TABLE 4. Results from Thermogravimetric Analysis of reprocessed WPCs and pre-mix

Composites	**Temp at 5% mass loss (Cº)**	**Final Temp (Cº)**	**Resid-ual mass (%)**
PP neat	396	465	0.64
PP W10	358	490	1.28
PP W20	338	494	2.45
PP W30	315	495	6.77
PP W50	282	495	9.28

6 CONCLUSION

The effect of reprocessing Wood Plastic Composites (WPC) on physical, mechanical, thermal and burning properties were studied. It is found that increasing screw speed during compounding has no significant effect on tensile strength of reprocessed WPCs. The tensile strength of reprocessed WPCs found to be decreased with wood fiber content comparing to PP neat. It is found that by increasing fiber content to 20 wt%, the tensile strength of reprocessed WPCs increased slightly. The elongation at break of composites decreased with increasing wood fiber content. The tensile modulus of composites increased with increasing wood fiber content. The impact resistance of reprocessed WPCs decreased with increasing fiber content. The burning rate of composites increased with wood fiber content. Water gain percentage of WPCs increased with increasing wood content. Thermogravimetric Analysis shows that initial decomposition temperature decreased, and residual mass increased with increasing wood fiber content of WPCs.

It can be concluded that reprocessing WPCs from pre-mix containing 50-70 wt% of wood fiber is a viable method to avoid feeding issues with wood fiber during WPCs production. Although, in this study it was found that to achieve a reasonable fiber- matrix adhesion additional coupling agent are necessary. Further research is needed to identify the optimum amount of coupling agent for reprocessing of WPCs. The burning test results showed that both reprocessed WPCs and pre-mix are suitable for applications for interior parts of vehicles. The water absorption of pre-mix containing 50 wt% of wood fiber was found to be on par with the reported 24h water absorption of commercially available wood plastic composites decking.

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