International Journal of Engineering Innovation & Research
Volume 4, Issue 6, ISSN: 2277 – 5668

Effects of Wood Filler Contents and Particle Sizes on the Mechanical and Thermal Properties of Polypropylene

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***Abstract* – Polypropylene composites of wood filler were prepared at filler contents of 0 to 60 wt%. The particle sizes of the wood filler investigated were 200, 400, and 800 µm. The polypropylene composites were prepared in an injection moulding machine and the resulting composites were extruded as sheets. Mechanical and thermal properties of the prepared composites were determined. The results showed a significant effect of both wood filler inclusion and particle sizes on tensile strength, impact strength, flexural strength, elongation at breakage and hardness, thermal conductivity, and melting temperate of polypropylene. The increase in wood filler weight % and particles sizes enhanced the tensile strength, impact strength and flexural strength of polypropylene composites. However, the elongation at breakage was observed to decrease with increases in the wood filler content and particle size. Interestingly, careful observation showed that all filler content had same endothermic melting peak at approximately 165 ^{o}C.**

***Keywords* – Polymer, Wood, Filler, Polypropylene, Particle Size.**

I. INTRODUCTION

The past decades have witnessed increasing interest in the use of fillers in polymer industry. Fillers greatly enhance the dimensional stability, impact resistance, tensile and compressive strength, abrasion resistance and thermal stability when incorporated into polymers. Fillers which merely increase the bulk volume, and hence, reduce price, are known as extender fillers while those that improve the mechanical properties particularly tensile strength are termed as reinforcing fillers [1-4].

Polypropylene is one of the most important polyolefin's that have wide range of applications. Presently, there has been an increase in the use of filled polypropylene in electrical and automotive engineering. This is mainly due to the unique property which polypropylene exhibits and which enables it to substitute conventional materials in demanding engineering applications [5].

The use of wood-based materials (wood flour and wood fibers) as reinforcing fillers for thermoplastics has received great attention from a number of researchers and manufactures in recent years [6]. The addition of the renewable natural filler in polymeric composites aims to produce unique characteristics of great versatility, light weight, biodegradability and recyclability with good specific properties. In comparison with other fillers such as traditional glass fiber and inorganic mineral fillers, wood is inexpensive, with low density and non-abrasive to processing machinery [7]. For over a decade, there have been a number of researches related to polyolefin composites reinforced with wood-based filler [8-10]. Bledzki et al. [8] studied polypropylene composite with modified cellulosic filler. They found that the tensile strength of modified composites increased to 45% in comparison to unmodified fiber composites.

Premalal et al. [9] reported that rice husk powder filled polypropylene composites provided lower Young's modulus and flexural modulus than talc composites. Adhikary et al. [10] reported that water absorption of the high-density wood flour-recycled polyethylene composites increased with weathering. Anomie et al. [11] reported that polypropylene/wood flour composite with maleate polypropylene (MAPP) treatment showed slight increase of tensile modulus and tensile strength. Mantia et al. [12] in their research argued that organic filler-polypropylene composites caused enhancement of rigidity and thermo-mechanical resistance, which was similar to the one observed for inorganic filler. Nachtigall et al. [13] showed that tensile strengths of polypropylene/wood flour composites with coupling agent were higher than one without coupling agent. Kim et al. [14] observed that MAPP-treated polypropylene composites showed improved mechanical and thermal stability. This enhancement is also observed in the system of polyethylene and wood flour with maleated polyethylene as compatibilizing agent [15]. Sombatsompop et al. [16] reported that increase of wood fiber into the polypropylene matrix could reduce the overall strength and toughness of the composites. Balasuriya et al. [17] postulated that wood flake wetting and filler distribution had a profound effect on mechanical properties. Guo et al. [18] revealed that the storage modulus of wood flour filled polypropylene composites was improved when MAPP was applied.

In this research, the mechanical and thermal properties of the polypropylene composite at various wood filler contents (0-60 wt%) and different particle sizes were investigated. The significance of this work lies on the pretext of understanding behaviors of the wood filler composites and filler sizes with the intent to accurately produce composite for specific applications which were absent in earlier researches.

II. EXPERIMENTAL WORK

A. Materials

Commercial grade poly propylene (pp) was supplied by Sabic-Saudi Arabia. The melt flow index and the density of this material were 11 g/10 min and 0.98 g\cm^3 respectively. Melting temperature was 168^{0}C. Commercial wood filler with particle size of 200, 400 and 800 µm were used to examine the effect of particle sizes on wood-poly propylene composites. Wood is selected as filler in this work due to its light weight, non-corrosive and less abrasive to processing equipment. In addition, it has high

specific strength modulus, low cost, and its abundant availability in most geographic regions.

B. Sample Preparation

The wood filler and polypropylene were dried blended and then compounded using 25 mm single screw extruder. The blending temperature profiles from hopper to die zones on the extruder were set at 170, 175, 180 and 185^{0}C, respectively. The die temperature controlled by a thermostat was adjusted together with barrel temperature leading to uniform output. A pressure of 20 kg\cm^2 was supplied for 5 minutes to allow the blend to melt and spread out between plates. Pressure was then increased to 200kg\cm^{2}for further 5minutes.Thepressure was removed and the mold sheet was quenched in water at room temperature. The extradite sheet were cooled in water then cut and put in the mold. A dimension of 3-4mm thick sheet of the composites were prepared by hot pressing the sheet between hydraulic press at170 ^{0}C and 0.65 MPa.

III. Characterization of Polypropylene–Wood Composite

A. Mechanical Properties

The evaluation of tensile strength properties was carried out on an Instron 5585H testing machine using the Instron Bluehill 2, version 2.14 software. Tests were performed in accordance with ASTM standard D638 using a crosshead speed of 5mm/min. Notched Izodimpact test was performed on a Tinius Olsen Izod impact tester (Model 892) in conformance with ASTM standard D256. The specimens were V-notched at 458 angle using a Tinius Olsen specimen notcher (model 899). Prior to testing, the samples were conditioned in a room at 23 ± 2 ^{0}C and 65± 4% relative humidity for at least 48 hrs and all tests were performed in this conditioning room. The conditioning was done to remove any impurity and keep the testing laboratory clean. For reliability on average means and standard deviations, 10 and 13 specimens were tested for the tensile properties and impact strength, respectively. Finally, the rock well hardness was determined through ASTM D 785.

B. Thermal Properties

Differential scanning calorimetry (DSC) was used to measure the thermal properties of the wood-polypropylene composites. The analysis was conducted under nitrogen gas flow with a heating rate of 20 ^{0}C/min using Q100 System (TA Instruments). The DSC instrument consists of a cell that contains a sample pan and a reference pan. The pans are usually made of aluminum. The pans are crimped and the heat flow difference between the two pans is usually monitored by increasing the temperature at a specific rate (usually 20 ^{0}C/min). During the run, the difference in heat flow between the sample and reference is recorded in a computer. The run lasts for about 1 hour depending on the DSC operating conditions. When phase changes are observed, an upward peak will show exothermic changes (crystallization, cross-linking, and oxidation) and a downward peak will show endothermic changes on the DSC graph.

IV. Results and Discussion

A. Mechanical properties

The mechanical properties of polypropylene composites prepared in this study have been determined and the results are shown in Figures (1-5). Figure (1) shows the effect of filler contents and particle sizes on the tensile strengths pure polypropylene and wood-polypropylene composites. The tensile strength of polypropylene composites was observed to increase with increases in wood filler content and particle size. It is clear that the smaller the particle sizes of wood filler, the higher the tensile strength of the polypropylene composite at any wood filler content. The better dispersion and filler-matrix interaction between the two compounds may be the main reasons or factors responsible for the observed trend. Similar observations have been reported by Balasuriya et al. [17], and Guo et al., [18] for other filler systems. In all three samples it can be clearly seen that the smaller sample size had the better tensile strength at higher filler compositions.

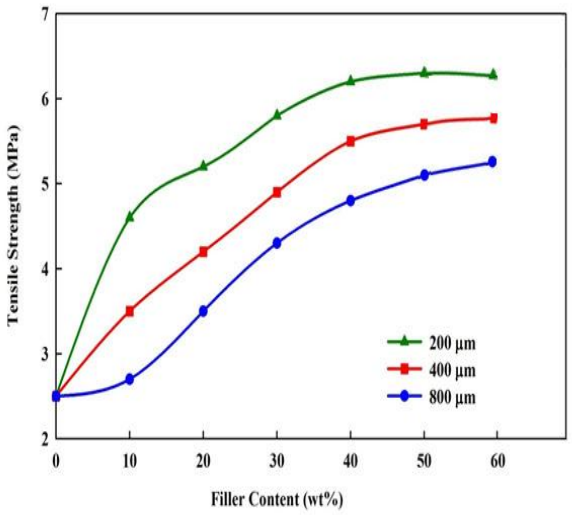

Fig.1. Relation between tensile strength and filler content of wood-polypropylene composites.

The impact strength of polypropylene composites was observed to increase with increases in wood filler content as shown in (Figure 2). The increase in impact strength of the prepared composites was very remarkable. This significant enhancement indicates that wood filler was more effective in distributing the applied stress over a large volume at the base of the notch, and which helped to prevent propagation of cracks by carrying large part of the load in the area under the crack. The increase in impact strength of the polymer composite with increase in filler content has been reported in the literature [17]. However, the impact strength of the prepared composites were observed to decrease with lower sample sizes. Hence it is concluded that increasing the particle size of wood filler would significantly decrease the level of stress concentration in the composites with a resultant increase in impact strength.

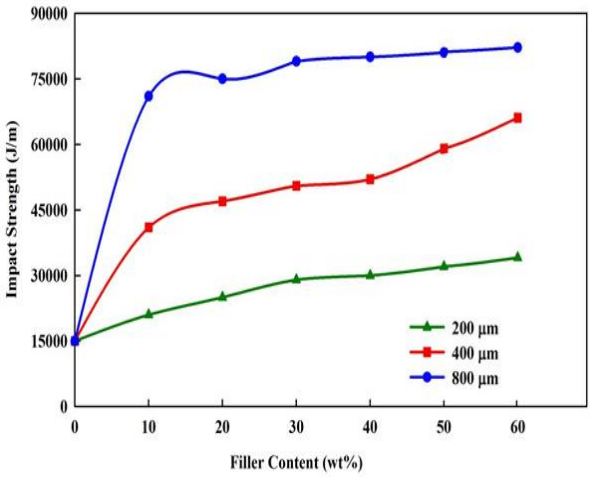

Fig.2. Relation between impact strength and wood-polypropylene composites.

Figure (3) shows that the flexural strength of polypropylene composites increases with the filler content increment but decreases with filler particle size increment. Embu et al, [19] studied effect of mica content on the mechanical properties of polypropylene composites. They reported increases in flexural strength of the composites with increases in mica content. The result from our study shows that wood filler can produce a flexural strength of 160 MPa at 50% filler loading which is higher compared to value obtained for mica filler at the same filler percentage.

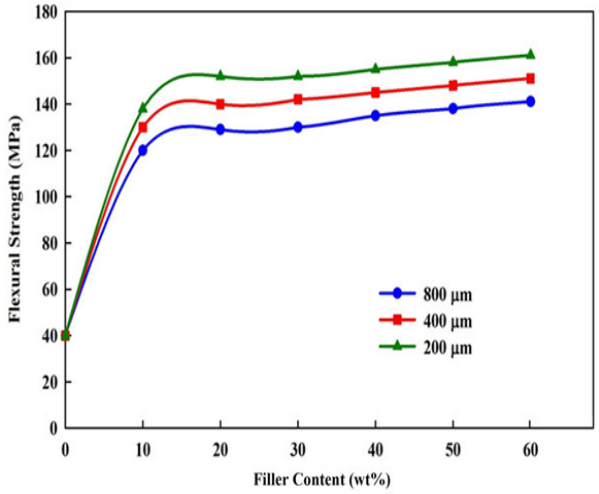

Fig.3. Relation between flexural strength and filler content on wood-polypropylene- composite.

In this study, elongation at breakage for polypropylene composites decrease with increase in filler content at any given filler particle size as shown in Figure 4. Fillers can be considered as structural elements embedded in polymer matrixes. The percentage of filler used in this work might not be high enough to significantly restrain the polypropylene molecules. Consequently, highly localized strains might have occurred at the concentrations investigated, leading to de-wetting between polypropylene and the filler, thus, leaving essentially a matrix that is not ductile. Such reduction in elongation at breakage of composite is observed as filler content increases irrespective of filler particle size. Careful observation shows that the elongation at breakage for all sample sizes follow closely in magnitude as filler content increases.

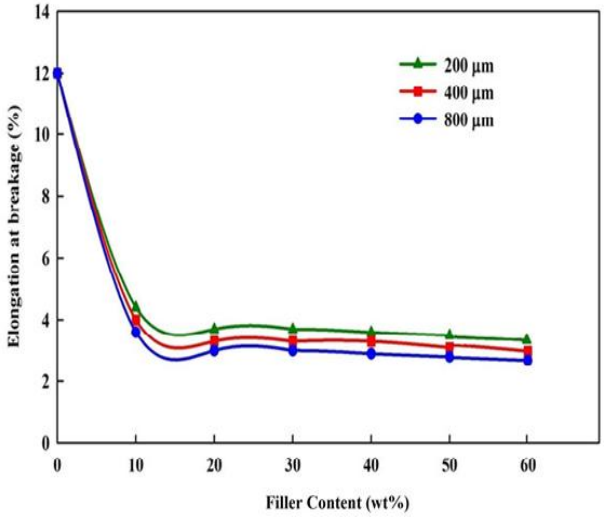

Fig.4. Relation between elongation at breakage and filler content of wood-polypropylene composites.

Shown in Figure 5 is the relation between hardness and wood filler content of composite for different particle sizes. Observation shows that the hardness of polypropylene composites increases with increase in the amount of filler incorporated into polypropylene. In addition, the result showed that smaller particle size have higher hardness in the composites, which might be attributed to large surface area due to small sample sizes. It is suggested that both particle size and filler content enhances the abrasion and impact strength of the composites. The decrease in the hardness as particle size increases is attributed to increase in resistance strength of polymer to plastic deformation. Decrease in the hardness of polypropylene composites with increase in filler particle size was reported by Bengtsson et al. [6] and Bledzki et al. [8].

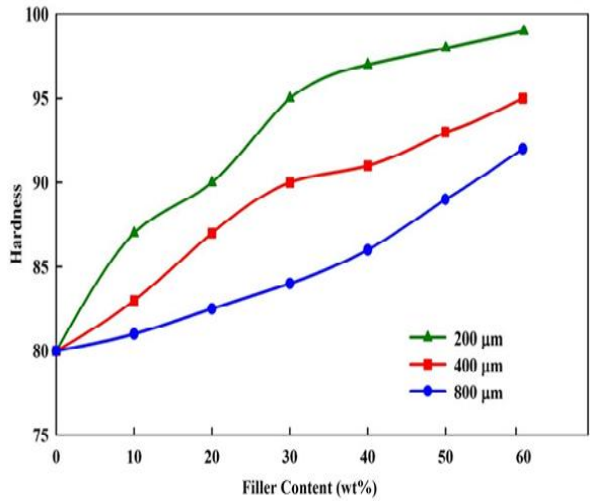

Fig.5. Relation between hardness and filler content of wood-polypropylene composites.

B. Thermal Properties

Figure 6 is DSC thermograms of pure polypropylene and composites at various filler contents and particle sizes. Careful observation shows that the thermograms for the various filler content have same endothermic melting peak at approximately 165^{o}C. The presence of filler in the composites seems to have no major influence on the melting temperature of the composites as evidently shown in the thermograms. It is possible that endothermic melting point for the different filler sizes do not show any significant change due to the percentage of filler used in the preparation of the composites. In addition, no significant effect on melting enthalpy, i.e. 43-46 J/g, was observed with filler inclusion in composite. The most important analysis in this result is that all samples had the same endothermic melting peak suggesting good sample preparation technique.

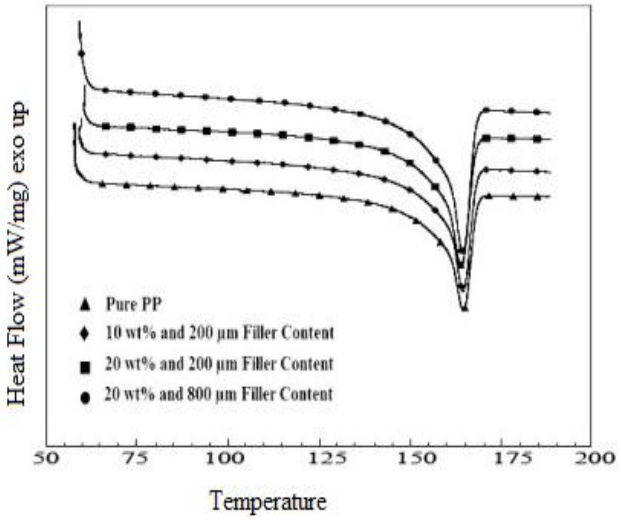

Fig.7. TGA thermograms of polypropylene, wood flour and composites.

V. CONCLUSION

In our work, wood flour was found to improve the hardness of composites. The hardness of composites was found to increase with increasing wt% of wood filler and decrease in particle size of wood filler. The impact strength, tensile strength was significantly increased with the addition of wood filler. However, the impact strength increased with increase in particle size whilst the tensile strength decreased with particle size increment. In addition, the thermal conductivity (k) decreased with increase of filler content and particle size of wood filler. The thermal degradation of unfilled pp was decreased with the wood–filler addition and increased in particle sizes. Also the DSC of unfilled pp is large, after addition of wood–filler (DSC) is decreased with increased filler content and particle size.

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was born on the 13th May 1973 at Baghdad, Iraq. In 1990, she finished her secondary education and then she enrolled in University of Technology to study in chemical engineering department where she received her bachelor's degree in 1994. She worked from 1997 until now as a lecturer in University of Technology. In September 2005, she joined University of Technology as a Master Student. She obtained her Master of Science in industrial polymers (2007) at Chemical Engineering Department, University of Technology, Iraq. In February 2014, she furthered her study as a Ph.D candidate at Department of Chemical and Environmental Engineering, Faculty of Engineering, Universiti Putra Malaysia. Her current research area focuses on graphene structure, kinetics reaction of graphene reactor, nanostructures and their applications.

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