https://doi.org/10.26525/jtfs2018.30.1.8994

THE INFLUENCE OF PUMICE DUST ON TENSILE, STIFFNESS PROPERTIES AND FLAME RETARDANT OF EPOXY/WOOD FLOUR COMPOSITES

Koyuncu M

Yuzuncu Yill University, Van Vacational Higher School, Department of Textile, +9065080, Van/Turkey

mendereskoyuncu@gmail.com

Submitted March 2017; accepted June 2017

This study evaluated the mechanical and flammability properties of wood plastic composite panels made from pumice powder formulations, using a conventional hand lay up method under laboratory conditions. Wood flour was stirred with pumice in order to improve the mechanical properties of the wood flour-epoxy composites. Five levels of pumice powder, 5, 10, 20, 30 and 50%, based on the composition by weight, were mixed with the wood flour. The tensile strength of the composites prepared with pumice stirred wood flour were found to increase substantially compared to those of unstirred ones. The tensile and stiffness strength of the composites improved with increasing pumice powder content, up to 50% weight. The effect of pumice on the flammability properties of wood plastic composites (WPCs) was also investigated. Flammability properties of composites decreased with addition of pumice.

Keywords: Epoxy-matrix composites, hand lay up, wood flour, tensile strength, stiffness strength

INTRODUCTION

Wood plastic composite (WPC) covers a wide range of area in the composite field (Selke and Wichmen 2004). The WPCs are ecofriendly, low cost consuming, biodegradable, renewable and have advantages of good dimensional stability during their lifetime, i.e. lower water uptake, and durability against fungi and insects compared with wood (Umemura et al. 2004, Ashori 2008). The consumption of plastic materials has increased enormously due to their various advantages. The disposal of post-consumer plastic materials in the form of carry bags, packaging films, boxes, etc. causes environmental pollution. The majority of waste plastic materials consist of a substantial amount of polyethylene, polypropylene and less amount of polyvinyl chloride, polystyrene and polyethylene terephthalate. Recycling and reusing is one of the processes to reduce the environmental pollution caused by post-consumer plastic materials. The use of recycled plastic materials is restricted due to their poor mechanical properties. The properties can be improved if the waste plastics are combined with cellulosic materials.

The WPCs are basically produced by mixing wood flour and plastics, a similar process to produce 100% plastic-based products. Some of the major advantages of wood plastic composites include their resistance against biological deterioration for outdoor applications where untreated timber products are not suitable. The sustainability of this techology becomes more attractive when the low-cost and high availability of fine particles of wood waste is considered. Although WPCs offer many advantages, it is necessary to improve their physical and mechanical properties, as well as apperance to have a strong market share in the wood composite panel industry. Products, which cost money for proper disposal, can be used instead as a beneficial resource for profitable and environmental recycling (Rashid et al. 2011). The WPCs represent a growing class of durable, low-maintenance construction materials, whose use can decrease dependence on petroleum (Minelli 2010).

The wood flour acts as a reinforcing agent to polymer, hence improves various properties. One of the major disadvantages of WPC is the poor interfacial adhesion between inorganic wood flour and organic polymer. This results in poor compatibility among the constituents, hence decreases the properties of composites. To improve the miscibility between organic and inorganic phase, certain compatibilisers are used. The compatibiliser enhances interaction between hydrophilic wood fibres and hydrophobic polymers, and at the same time improves interfacial adhesion among different thermoplastic materials. The addition of a small amount of maleated polypropylene to polypropylene/cellulose composite improves its mechanical properties (Qiu et al. 2005). The uses of glycidyl methacrylate and polyethylene-co-glycidyl methacrylate as compatibiliser for making wood polymer composite have been reported (Devi & Maji 2007, Deka & Maji 2010).

In the polymer composites, different types of fillers are used for improving the thermal, mechanical as well as other properties Among them, nanopowder is widely used as a filler. The surface characteristics of nanopowders play a key role in their fundamental properties from phase transformation to reactivity. Due to a large fraction of surface atoms and a higher surface area, a nanopowder would be expected to be more active. A dramatic increase in the interfacial area between fillers and polymer can significantly improve the properties of the polymer (Song 1996, Minelli et al. 2010). Several articles have been reported on composites based on natural fibre and their stucture development where different types of metal oxide nanoparticles such as SiO_2, TiO_2, ZnO, pumice and marble dust are widely used for this purpose (Shaker et al. 2016). The SiO_2 nanopowder is one of the widely used fillers that can enhance mechanical as well as thermal properties of composite. The SiO_2 nanoparticles increase tensile and impact strength of epoxy nanocomposite (Minelli et al. 2010, Zheng et al. 2003). To increase the hydrophobicity of the inorganic silica particles, the surface is modified by different silane compounds (Minelli et al. 2010, Hu et al. 2016). In recent years, many researches have reported similar results related to pumice dust combined with wood flour (Akkus et al. 2016). One major disadvantage of WPC is its high flammability. To modify the flammability of WPCs, fire retardants are added during the compounding process. Halogenated compounds based on chlorine and bromine are effective flame retardants. However, halogenated compounds produce toxic gases, thus they should be avoided. It has been reported that 25% of magnesium hydroxide can effectively reduce the burning rate of WPC to 50% without flame retardant, confirming a marginal reduction in the mechanical properties of the composites with addition of flame retardant (Sain et al. 2004, Rashid et al. 2011).

The main objective of the present study was to determine the effect of pumice particles on the mechanical and flammability properties of WPC.

MATERIALS AND METHOD

Materials

Epoxy/hardener was supplied by a chemical company. All chemicals used were of laboratory grade, and the size of pumice was 250 mesh. A recent study reported that pumice dust is the most widely used filler for green composites (Turkmenoglu et al. 2015). The chemical properties of pumice is shown in Table 1.

Table 1 The chemical properties of pumice dust

Components	%
SiO_2	74.5
Al_2O_3	15.5
Fe_2O_3	2.50
Na_2O	0.2
MgO	0.05
K_2O	5.35
CaO	1.32
TiO_2	0.58
Ignition loss	3.33

Preparation of wood flour polymer composites

Wood flour was dried in an oven at 100–105 °C for 180 min. Then, the mixing of the wood flour, epoxy/hardener and different amount of pumice dust (size 250 mesh) were carried out using a blender at room temperature, for 30 min. All specimens were prepared by hand lay up method. The specimens for tensile (3.0 mm thick, 197 mm long, 25 mm wide) were prepared based on ASTM D 3039.

Tensile testing of WPC

The tensile properties were detemined according to ASTM standards (ASTM D-3039). Three specimens were used for each type of test and the average values were reported. The tensile properties of wood flour composite were measured using a universal testing machine at a constant crosshead speed of 100 mm min^{-1}. The average value of tensile strength was calculated using at least five samples.

Shore A stiffness testing

The stiffness tests of the composites were carried out using shore A stiffness testing machine.

Flammability test

The flammability test, based on UL-94 flammability standard, is usually applied to evaluate and classify the fire performance of a material. The UL-94 test results are classified by burning ratings V-0, V-1 or V-2. The V-0 rating represents the best flame retardancy of polymeric materials. Vertical tests are more rigorous than horizontal burning tests since the vertical specimens are burnt by their lower ends (Umemura et al. 2004, Huang et al. 2010). Therefore, a vertical burning test was conducted to investigate the effect of pumice used as a fire retardant on flammability of WPCs. The sample was held vertical and a flame fuelled by natural gas was applied to light one end of the sample for 20 sec. The height and angle of a flame against vertical direction were 10 mm and 30 °C, respectively. A wire sheet was held 10 mm under the specimen to consider the effect of dripping, which is the falling of fire source. After that, the time of burning was measured. When the combustion of the specimens stopped and the flame went out, the sample was ignited again for 10 sec. The combustion time, dripping of sample and burning state at fixing were investigated to determine the class of sample. Prior to the test, the specimens were dried at 100 °C for 2 h. The tests were conducted in triplicates.

Thermogravimetric analysis (TGA)

All runs were carried out on a standard TG-DTA instrument. Sample weight was approximately 4–6 mg and the runs were carried out with high purity Ar, flowing at 100 ml min^{-1}. The heating rate was 10 °C min^{-1} over a range of 50–1000 °C.

RESULTS AND DISCUSSION

Tensile testing

As shown in Figure 1, the average of tensile strength of untreated and treated composites is 7.981 MPa, 8.764 MPa, 10.428 MPa, 12.133 MPa, 13.016 MPa and 14.738 MPa respectively. Tensile strength increases with percentage of pumice, showing compatibility and strong interfacial adhesion between matrix and filler, manifesting as increased mechanical properties since stress is transferred from matrix to wood flour (Kazayawoko et al. 1999). Wood flour with lower polarity is more compatible with thermoplastics, resulting in better dispersion in polymer matrix and improved fibre wettability (Hosseinaei et al. 2012, Arwinfar et al. 2016).

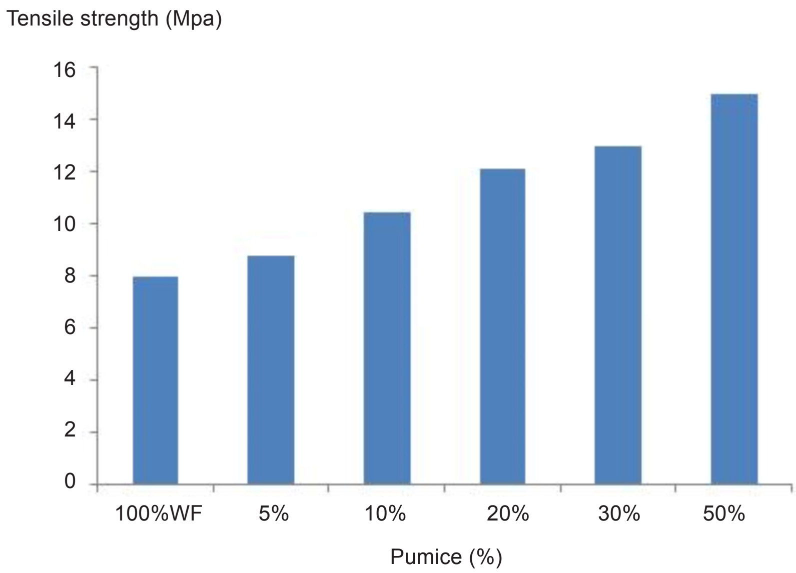

Figure 1 Tensile strength with different percentage of pumice dust; WF = wood flour

Shore A stiffness testing

Stiffness of composite material refers to its resistance to shape damage when a force is applied. For wood flour composites, it depends on the distribution of wood flour into the matrix. Figure 2 shows the stiffness values (shore A) of WPC at various percentage of pumice powder. As the percentage of pumice powder increased, the stiffness (shore A) also increased, in the the case of unfilled composite. Increasing the amount of pumice had a positive influence, both on the tensile strength and stiffness value of WPC. Pumice treatment improved the dispersion of wood flour in matrix. The 50% weight filled pumice dust composite had better stiffness, compared to unfilled. This could be attributed, to both better dispersion of the wood flour into the matrix with minimisation of voids and stronger interfacial adhesion between matrix and wood flour (Liu et al. 2004, Sultana et al. 2013).

Flammability testing

Table 2 shows the burning speed and flame classifications of untreated and treated composites. The addition of pumice dust significantly decrased the burning speed of composites. All samples of treated composites showed self extinguish properties, while untreated composites showed continuous burning. Therefore, treated composites is classified as V-0, which is the highest class, with no dripping (Umemura et al. 2004). This indicates that flamability properties of pumice dust filled composites has a marginal increase, compared to composites without pumice dust.

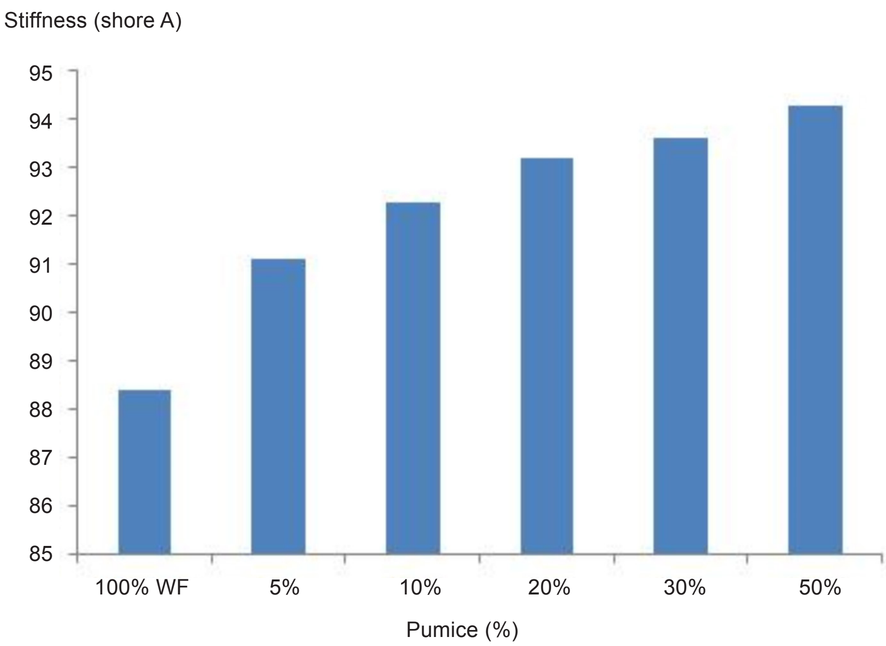

Figure 2 Shore A stiffness values as a function of pumice for wood flour composites; WF = wood flour

Table 2 Burning speed and flame classifications of unfilled and filled composites

Composite	Average burning speed (sec)	After removal flame source	Class based on UL94
100% WF	7–8	Flame contiuned	V-1
5% Pumice, 95% WF	15	Self-extinguished	V-0
10% pumice, 90% WF	17	Self-extinguished	V-0
20% pumice, 80% WF	20	Self-extinguished	V-0
30% pumice, 70% WF	23	Self-extinguished	V-0
50% pumice, 50% WF	35	Self-extinguished	V-0

WF = wood flour, UL94 = standard for safety of flammability for plastic materials

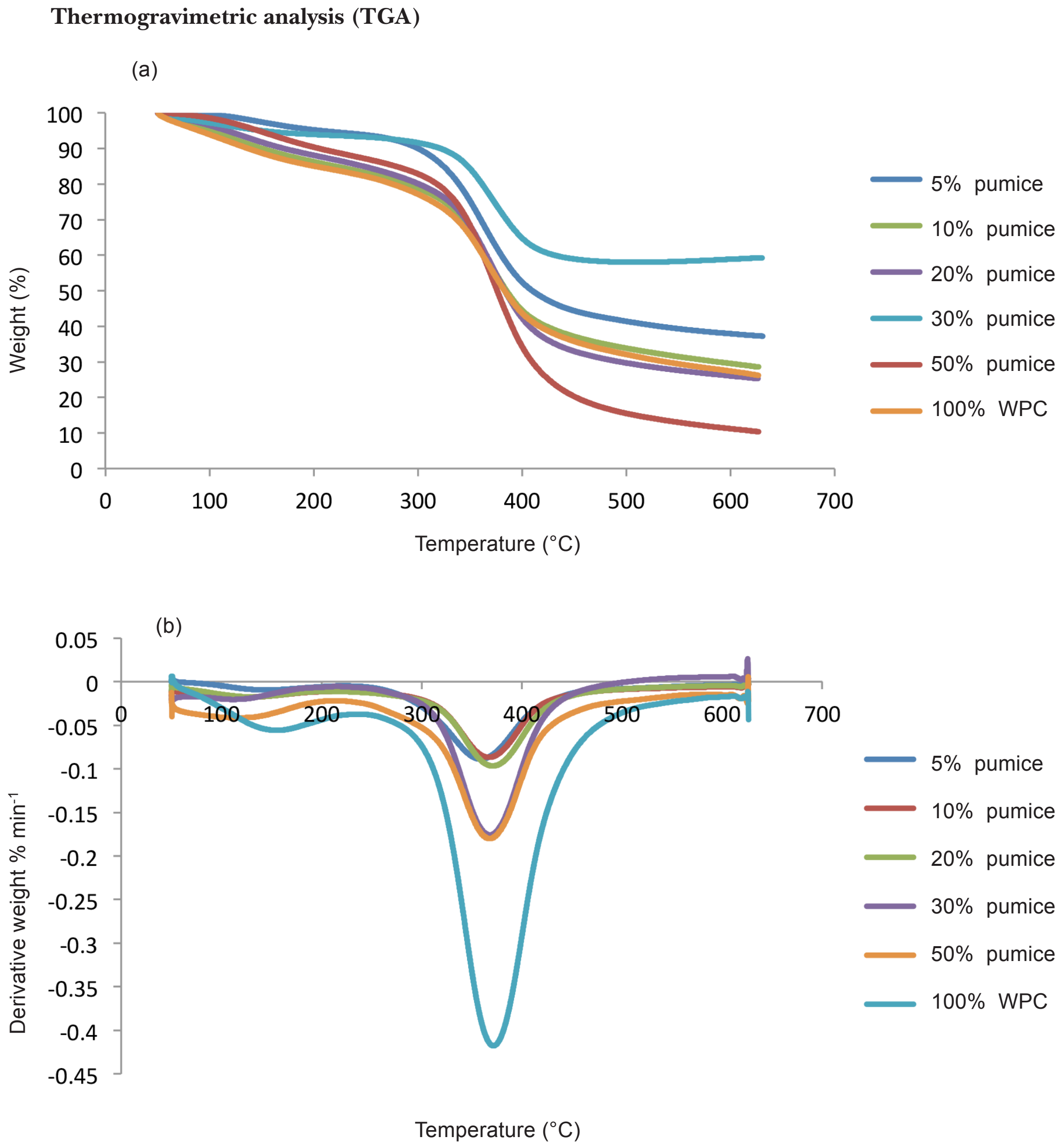

Figure 3 a = TGA thermograms of pumice dust/wood flour composites and b = differential peak temperature of pumice dust/wood flour composites

The TGA spectra showed 1–2% weight loss in treated composites at 100 °C and untreated composites at 100–150 °C, due to dehydroxylation of WPC (Figure 1). Initially the treated an untreated composites had sharp weight loss at around 200 °C due to decomposition of lignocellulose. The weight loss then slowed down to 20% and 30% at 300–330 °C. Another dramatic weight loss occurred at 400–450 °C due to decomposition and chain scissor of WPC macromolecules. The WPC was finally carbonised over 500 °C and the total weight loss was 80–90% (Figure 1). Similar results were demostrated by John et al. (2008) and Bin & He (2004). Addition of pumice dust improved thermal stability of the resultant wood composites and retarded the decomposition of wood flour.

CONCLUSIONS

Tensile strength and shore A stiffness in WPC were significantly affected by pumice dust treatment of wood flour. The WPC produced, loaded with pumice dust, had both upper tensile strength and shore A stiffness, than unfilled WPC. However, only a small increase of stiffness value was observed beyond 10% of pumice powder. Pumice dust was utilisable as a filler for manufacturing of wood flour composites, and showed flame retardant properties, compared to unfilled composites. Flammability of WPCs with pumice dust were evaluated by burning tests based on UL94. WPC with increased percentage weight of pumice powder showed best fire performance (flammability class V0), showing self-extinguishing property at vertical burning test, confirmed by TGA test. Loading pumice powder at different percentage improved tensile strength of WPC composites, where the tensile strength increased with the addition of pumice dust, compared to neat wood flour strength. It considerably improved with the use of 50% weight of pumice dust. Consequently, this study showed that pumice dust is a potential alternative filler for structural application and development of composite.

REFERENCES

Akkuş M, Ulay G & Ayrilmiş N. 2016. Characterzation of wood polypropylene composites by reinforced pumice's powder. Paper presented at the International Conference on Material Science and Technology in Cappadocia, Nevşehir.

Arwinfar F, Khalil S, Hosseinihashemi A, Jahan-Latibari-Lashgari A & Ayrilmiş N. 2016. Mechanical properties and morphology of wood plastic composites produced with thermally treated beech wood. *Bioresources* 11: 1494–1504.

Ashori A. 2008. Wood-plastic composites as promising green composites for automative industries. *Bioresoure Technology* 99: 4661–4667.

Deka BK & Maji TK. 2010. Effect of coupling agent and nanoclay on properties of HDPE, LDDE, PP, PVC blend pharpamites karka nanocomposite. *Composites Science and Technology* 70: 1755.

Devi̇ Rr & Maji T. 2007. Effect of glycidyl methacrylate on the physical properties of wood- polymer composite. *Polymer Composites* 28: 1.

Hosseinaei̇ O, Wrang S, Enayati AA & Ri̇als T. 2012. Effects on hemicellulose extraction on properties of wood flour and wood plastic composite. *Composites Part A* 43: 686–694.

Hu LYH, Chen CY & Wang CC. 2004. Viscoelastic properties and thermal degradation kinetics of silica/PMMA nanocomposites. *Polymer Degradation and Stability* 84: 545–553.

Huang NH, Chen ZJ, Yi CH. & Wan JQ. 2010. Synergistic flame retardant effects between sepiolite and magnesium hydroxide in ethylene vinyl acetate (EVA) matrix. *Express Polymer Letters* 4: 227–233.

John Z, Xifang-Duan L, Wu Q & Lian K. 2008. Chelating efficiency and thermal, mechanical and decay resistance performances of chitosan copper complex in wood–polymer composites. *Bioresource Technology* 99 : 5906–5914.

Kazayawoko M, Balatinecs J & Matuana LM. 1999. Surface modification and adhesion mechanisms in wood fibre-polypropylene composites. *Journal of Materials Science* 34: 6189–6199.

Li B & He J. 2004. Investigation of mechanical property flame retardancy and thermal degradation of LLDPE-wood fibre composites. *Polymer Degradation and Stability* 83: 241–246.

Liu W, Mohanty AK, Askeland P, Drzal LT & Misra M. 2004. Effects of alkali treatment on the structure, morphology and thermal properties of native grass fibers as reinforcements for polymer matrix composites. *Journal of Materials Science* 39: 1051–4.

Mi̇nelli̇ M, Angelis MGD, Doghieri F, Rocchetti̇ M & Montener. 2010. Effect of silica nanopowder on the properties of wood flour/ polymer composite. *Polymer Engineering and Science* 50: 144.

Oi̇u W, Zhang F, Endo T & Hirotsu T. 2005. Polymer effect of maleated polypropylene on the performance of polypropylene/cellulose composite. *Composites* 26: 448.

Rashid M, Hamid Y & Ahmet S. 2011. Effect of flame retardants on wood plastic composites HDPE based. *Engineering Materials* 471–472: 640–645.

Sain M, Park SH, Suhara F & Law S. 2004. Flame retardant and mechanical properties of natural fibre-pp composites containning magnesium hydroxide. *Polymer Degradation and Stability* 83: 363–367.

Selke SE & Wi̇chman I. 2004. Wood fiber/polyolefin composites. *Composites Part A* 35: 321–326.

Shaker K, Munir A, Madeha J, Salma S, Yasir N, Jasim Z & Abdur R. 2016. Bioactive woven flax-based composites: development and characterisation. *Journal of Industrial Textiles* 46: 549–561.

Song GJ. 1996. Mechanical property of nano-particle reinforced epoxy composite. *Materials Report* 4: 57.

Sultana-Mi̇r S, Nafsin N, Hasan M, Hasan N & Hassan. 2013. Improvement of physico mechanical properties of coir polypropylene biocomposites by fiber chemical treatment. *Materials and Design* 52: 251–257.

Turkmenoglu F, Kilinc M & Depci̇ T. 2015. Investigation of Mechanical Properties of Self Compacting Lightweight Concretes Produced Using Van Pumice and Waste Marble Dust. *Çukurova University Journal of the Faculty of Engineering and Architecture* 30: 105–116.

Umemura T, Arao Y, Nakamura S & Tomita Y. 2004. Synergy effect of wood flour and fire retardants in flammability of wood-plastic composites. *Energy Procedia* 56: 48–56.

Zheng Y & Ning R. 2003. Effects of nanoparticles SiO_2 on the performance of nanocomposites. *Materials Letters* 57: 2940–44.