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Investigation on the Mechanical Properties of Nanocomposite based on Wood flour/ Recycle polystyrene and Nanoclay

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ABSTRACT

Mechanical properties of wood plastic composites made from wood flour, recycled polystyrene and Nanoclay have been investigated in this study. The wood flour was mixed with the recycled polystyrene at three weight ratios of 40, 50 and 60% for the experiments, while the nanoclay was used in 0, 3 and 5 Phc. Meanwhile, the coupling agent was used in all composite samples for 3 wt%. Wood plastic samples were prepared using injection molding then mechanical properties were evaluated including tensile and bending Tests. The obtained results indicated that the tensile strength and flexural strength were increased by raising nanoclay content in the composites.

KEYWORDS: wood plastic nanocomposite, mechanical properties, Nanoclay, Tensile Strength, flexural Strength.

1. INTRODUCTION

In order to produce wood polymer composites, natural fibers are added to thermoplastic polymers. During the last decade, wood plastic composites (WPC) have gained extensive applications in construction materials and automobile parts. The natural fibers which are used to reinforce the thermoplastics are basically comprised of wood, cotton, cotton fibers, hemp (cannabis fiber), jute (Indian cotton), sisal fiber and cane fibers. Advantages of using these fibers in composites are their light weight, high quality, low cost, annual renewability, good mechanical properties, reduced energy consumption and environmental friendliness (Ziaei et al., 2012). Polymer-clay nanocomposites have attracted much attention due to their improved mechanical, thermal and flammability properties. A great deal of experiments which have been done recently in laboratory have shown that the polymer-clay nanocomposites provide decreased flammability and improved mechanical properties at a rather small cost. Many types of polymeric resins have been used to artificially build polymer-clay nanocomposites. (Alexander et al., 2002) In fact, nanoclays improve properties of the polymeric composites due to their special dimensions and great apparent coefficient in comparison with other fillers (Tjong 2006). Wood plastic composites are probably one of the most dynamic segments of today's plastic industry. Although this technology is not that much new, there is a growing tendency to design new possibilities by integration of these materials. Polystyrene (PS) is the third most used thermoplastic in the world after polyethylene (PE) and polypropylene (PP. Introduction of wood fibers is a method used to enhance impact strength of this material due to some of the potential advantages it has. Therefore, this technique is known as an appropriate candidate for the polymeric composites armed by fibers (Justo et al., 2007).

Fu and Naguib (2006) in their research on the effect of nanoclay filler on mechanical properties of composites declared that only 0.5% of montmorillonite can significantly increase elasticity modulus, tensile strength, flexural strength and elongation at break for the composite. They however argued that an excessive addition of the nanoparticles could reduce their mechanical strength with the optimal value of addition being 4-5%.

Deshmane et al., (2007) in studied morphological and mechanical properties of polypropylene reinforced with nanoclay filler. They stated that this filler treatment would enhance mechanical strength due to formation of strong connection with polymer matrix.

Han et al. (2008) examined the effect of using nanoclay and coupling agent on mechanical and thermal properties of composites obtained from bamboo fibers-heavy polyethylene. Their examinations revealed that flexural elasticity modulus, dynamic elasticity modulus and crystallinity degree were increased upon addition of 1% nanoclay, though impact strength of the samples was decreased. X-ray diffraction (XRD) data confirmed this observation as well since exfoliation structure is created in the composite. They also declared that all the mechanical properties were improved by addition of the coupling agent due to the increased interface area between polymer matrix and filler phase.

METHODOLOGY

Materials

Polystyrene (PS) produced in Tabriz Petrochemical Company was used.

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Preparation of Recycled Polystyrene

Raw polystyrene is poured into extruder according to the conditions listed in Table 1 and it was granulated in milling apparatus.

Table1. Process conditions for recycling raw polystyrene by extruder

Process Conditions	Value
Temperature (°C)	180
Rotation Speed	100

Wood flour was employed as matrix reinforcement of the polymeric powder. For this purpose, wood flour of pine produce in Aria Cellulose Industry with particles of 150 µm size was used.

Maleic acid polypropylene (MAPP) manufactured by Javid Kimiya Sepahan Co. with melt flow index (MFI) of 12.67 g/10min and 1.1% grafted anhydride maleic was employed as coupling agent in order to improve adherence between hydrophobic polystyrene (non-polar) and hydrophilic wood fibers (polar).

In this research, nanoclay powder made in Southern-Clay Co. (US) with Cloisite 30B trademark was used. Cloisite 30B clay is one type of natural montmorillonites which has been modified by 4^{th} ammonium salt.

Mixing Process

It is very important to mix lignocellulosic material with thermosoft polymers while being dry, because the hydrophilic nature of the wood fibers will limit filling distribution in the polymeric matrix during processing. On the other hand, existence of moisture in the lignocellulosic material and steam generation upon processing and casting will create delamination structure in the final product. Wood flour and nanoclay were used in three levels, while coupling agent was added in one level. Mixing process was implemented for 13 min using HAAKE internal mixer apparatus in Iran Polymer Institute at 190°C temperature, 60 rpm speed until reaching constant torque. After mixing the produced amorphous composite materials, they were re-milled after being cooled down and then injected into the casting machine to prepare the mechanical samples.

Mechanical Properties

All standard test samples prepared prior to mechanical experiments were kept for 48 h in conditioning room at 23°C temperature and 50% relative humidity to get in equilibrium with ambient moisture and temperature. Thereby, one can ensure uniform temperature and moisture conditions and ineffectiveness of these factors (temperature, moisture and etc.) on mechanical properties. Mechanical properties of the composites were measured for three times based on regulations of ASTM standard. Bending test was done according to ASTM D790 standard using loading rate of 2 mm/min on the samples. INSTRON Model 186 was utilized for this purpose. Computer attached to the instrument provided some information including strength (MPa) maximum load (KN) after testing samples of each treatment. Tensile test was conducted based on ASTM D638 standard on the samples and experienced loading at 2 mm/min rate.

RESULTS

Tensile Strength

Table2. Analysis variance on independent and mutual effects of manufacturing variables on tensile strength

Source of variations	Degree of freedom	Sum square	Mean square	F	Sig.
wood flour	3	264.59	88.197	581.582	0.000
nanoclay	2	7.169	3.585	23.638	0.000
wood flour*nanoclay	6	0.753	0.125	0.827	0.000
error	24	3.640			
total (modified)	35	276.152			

The results of variance analysis show that the independent effect of wood flour on tensile strength of the wood plastic composite is significant at 95% confidence level (Table 1). It is possible to improve tensile strength of wood plastic composite by increasing the amount of wood flour from 40 to 60%, such that the minimum tensile strength of the composites (31.81 MPa) is associated with addition of 40% wood flour and their maximum tensile strength (33.50 MPa) belongs to addition of 60% wood flour.

Fig.1. Effect of wood flour content on tensile strength of WPC

Flexural Strength

Table3. Analysis variance on independent and mutual effects of manufacturing variables on flexural strength

Source of variations	Degree of freedom	Sum square	Mean square	F	Sig.
wood flour	3	64.890	21.630	140.455	0.000
nanoclay	2	36.039	18.020	117.011	0.000
wood flour*nanoclay	6	21.361	3.560	23.118	0.000
error	24	3.696	0.019	-	-
total (modified)	35	125.986	0.078	-	-

The results of variance analysis demonstrate that the independent effect of wood flour on flexural strength of the wood plastic composite is significant at 95% confidence level (Table 2). The flexural strength of wood plastic composite can be improved by increasing the amount of wood flour from 40 to 60%. Thereby, the minimum flexural strength of the composites (48.33 MPa) is related to addition of 40% wood flour, while their maximum flexural strength (49.72 MPa) belongs to addition of 60% wood flour. Furthermore, these it can be inferred from the obtained result that the independent effect of nanoclay on flexural strength of the wood plastic composite is significant at 95% confidence level (Table 2). Duncan test categorized various levels of the means under three groups (Figure 2). It can be observed that raising the nanoclay content from 0 to 3 phc improves the flexural strength of the wood plastic composite though this value is decreased by further addition of the nanoclay up to 5 phc.

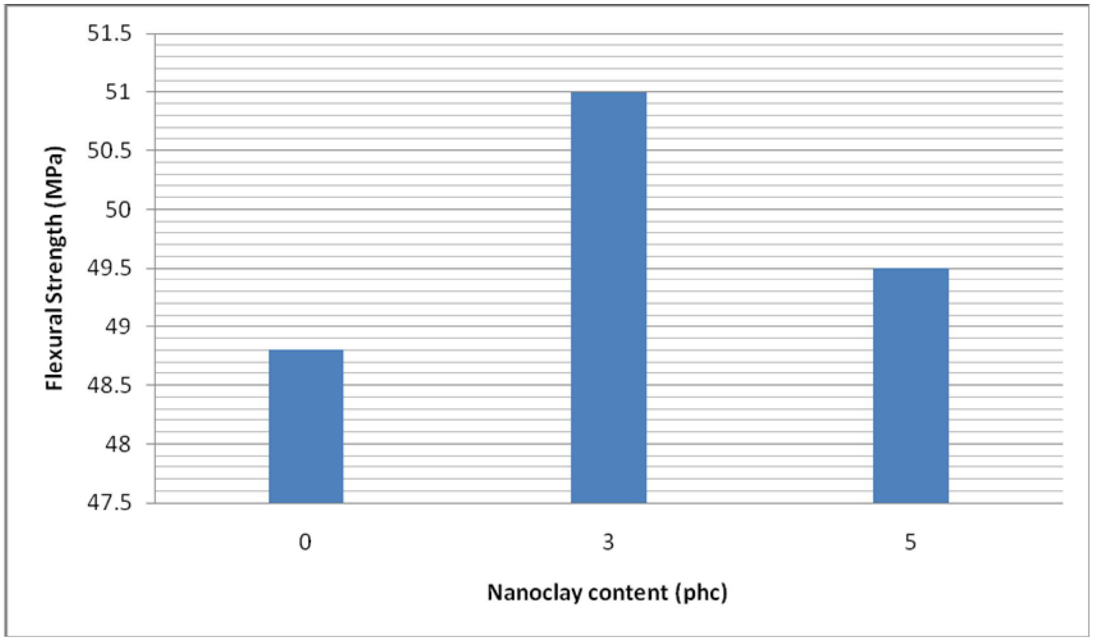

Fig.2. Effect of wood flour content on tensile strength of WPC

DISCUSSION AND CONCLUSION

Generally speaking, mechanical properties of the composite materials are greatly dependent on quality of the interface between two phases of the composite material since the stress is transferred from the matrix phase (polymer) to the fibers (reinforcement). The role of matrix phase is principally to keep the fibers in addition to transfer force to the secondary phase, while the secondary phase is responsible to physically and mechanically reinforce the matrix. The extent of tolerable stress is increased in the composite material due to existence of the reinforcement phase. Therefore, the extent of tolerable stress would be enhanced by increasing the wood flour content (Kord et al., 2010; Tajvidi, 2005; Nourbakhsh et al., 2008; Yang et al.,2004). Both tensile and flexural strengths of the wood plastic composite are improved by increasing the wood flour content from 40 to 60%. Meanwhile, taking into account the greater strength of the wood flour considering its molecular structure (lignination) in comparison with the polymer, the values of tensile and flexural strengths will be enhanced by raising addition of the wood flour due to improved stress transfer characteristics (Kord, 2010).

In bending test, resistance against being bent is indeed determined upon application of vertical force to the sample. During plastic bending, polymeric chains are compressed and compacted at the point of applying force. At the same time, polymeric chains are stretched and moved at the other side. When the cellulosic filler is added to matrix of the composite material, it inhibits motion of the polymeric chain and thus improves strength of the composite against being fractured and bent (Khosravian, 2010).

The effect of Nanoparticles on mechanical properties of the polymeric nanocomposites depends on various factors such as shape, size, apparent coefficient, type, content, crystallographic structure, quality and distribution of the nanoclay particles, and their connection to the polymer. The increased tensile strength of the composite for 3 phc nanoclay can be attributed to the high apparent coefficient of the nanoclay particles which extends the interface area between two phases. The increased nanoclay content and existence of exfoliation morphologies in the nanocomposite improves its strength due to the interfacial effect of organic chains and nanoclay particles as well as arrangement of the layered silicate particles (Korabi et al., 2007).

Kord (2010) adopted to explore the effect of nanoclay particles on mechanical properties f the wood plastic composites produced from heavy polyethylene-wood flour. The study showed that increasing weight percent of the nanoclay up to 3 phc would improve tensile strength, whereas addition of 5 phc of nanoclay could deteriorate this property.

Jayaraman et al. (2004) studied flexural and tensile properties of the composites made from fiberboard powder and recycled plastics. They declared that tensile and flexural strengths and moduli show an ascending trend up to addition of 40% fiberboard powder.

It was noticed in this paper that increasing the nanoclay content from 0 to 3 phc will improve tensile and flexural strengths of the wood plastic composite and then further addition of it up to 5 phc will reduce this strength. As a result, one can assign the improved tensile strength of the nanocomposite upon 3 phc of nanoclay addition to the high apparent coefficient of the nanoclay particles the wood plastic nanocomposite as well. The great apparent coefficient of the nanoclay particles plays the key role in the reinforcement capability of the nanoclay particles in this composite. It also increases the interface area between two phases and thus improves both tensile and flexural strengths of the composite. On the other hand, increasing the amount of nanoclay to 5 phc will reduce tensile and flexural strengths of the composite due to aggregation and compaction of the nanoclay particles as well as formation of the intercalated aggregates (Alexander and Dubis, 2000).

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