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Effect of Screw Speed on Mechanical and Morphological Properties of PP/Sawdust Flour/Montmorillonite Hybrid Nanocomposite

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Abstract: The aim of this study was to understand the role of screw speed as processing parameter (in five levels of 60, 90, 120, 150 and 180 rpm) on the clay dispersion and mechanical properties of wood plastic composite. Composites based on polypropylene, sawdust flour, montmorillonite and coupling agent were prepared by melt mixing using a brabender co-rotating twin-screw extruder. Then, the resulting granules were manufactured using injection molding. The mass ratio of sawdust flour to polypropylene was controlled at 50:50 for all blends. The amount of nanoclay and coupling agent at 3 phc and 4phc was fixed respectively for all formulations. The results indicated that all mechanical properties of hybrid composites were significantly affected by screw speed. The tensile strength, tensile modulus and impact strength of nanocomposites increased with increasing of the screw speed from 60 to 180 rpm. Furthermore, the higher screw speed generates a higher shear stress, which leads to a higher degree of clay dispersion.

Key words: Screw Speed · Sawdust Flour · Montmorillonite · Mechanical Properties · Clay dispersion

INTRODUCTION

The term “nanocomposite” is widely employed to describe an extremely broad range of materials, where one of the components has a dimension in the sub-micron scale. A better and far more restrictive definition would require that a true nanocomposite should be a fundamentally new material (hybrid) in which the nanometer scale component or structure gives rise to intrinsically new properties, which are not present in the respective macroscopic composites or the pure components. This latter definition necessitates that the nanostructure has dimensions smaller than a characteristic scale that underlies a physical property of the material. For example, for the mechanical properties of a polymer it would relate to the size of the polymer coil or crystal (again ranging from a few nanometers to hundreds of nanometers) and for the thermodynamic properties of a polymer glass it would relate to the cooperativity length (a few nanometers) [1-4].

In recent years, the organically modified layered silicates (organoclay) are increasingly used for reinforcement of polymeric materials. It has been reported that the dispersion of such minerals at the level of a few nanometers induces a significant improvement in mechanical properties, flame resistance and barrier properties, compared with the pure polymer [5]. In addition, these improvements may be obtained with low clay loading (typically less than 5%). There are several techniques used for dispersing organoclay at a nanoscopic scale, including the addition of organoclay during polymerization (in situ method), or to a solvent swollen polymer (solution blending), or to a polymer melt (melt intercalation method), as described in recent reviews [5]. One of the most commonly used organically layered silicates is derived from montmorillonite (MMT). Its structure is made of several stacked layers, with a layer thickness around 0.96 nm and a lateral dimension of 100-200 nm [1-5].

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Many efforts have been made in the formation of wood polymer composite (WPC), to improve such properties so as to meet specific end-use requirements. Both thermoplastic and thermosetting systems have been used and have achieved certain improvements in wood properties, but both showed limitations [6-7]. Nanotechnological preparation of WPCs could represent a promising new approach to obtain better products. Using nanoclay filler in WPC composite has been reported in many literatures [6-12].

Furthermore, Morphology type and disperse phase size of blends could be affected by composition, melt viscosity, interfacial interactions and processing parameters. There are several reports in the literature studying the effect of blend composition, melt viscosity or interfacial interactions [5, 13-15] but less attention has been paid to the processing parameters. The purpose of this work is to examine the influence of screw speed as processing parameter on clay dispersion and mechanical properties of polypropylene/sawdust flour/montmorillonite hybrid nanocomposite.

MATERIALS AND METHOD

The nanoclay used in this study was natural montmorillonite modified with a quaternary ammonium salt (trimethyl ammonium chloride) of bis-2-hydroxyethyl tallow as an organic modifier, having a cationic exchange capacity (CEC) of 90 mequiv/100 g clay, a density of 1.98 g/cc and a d-spacing of d_{001}=18.5 nm was obtained from Southern Clay Products Co. USA, with the trade name Cloisite 30B. Polypropylene is used as the polymer matrix which was got from Arak Petrochemical Co (Iran); with a density of 0.92 g/cm^3 and the melt flow index of 18 g/10 min. Maleic anhydride grafted polypropylene (PP-g-MA) provided by Solvay with trade name of Priex 20070 (MFI=64 g/min, grafted maleic anhydride 0.1 Wt. %) was used as coupling agent. Sawdust flour is used as the reinforcing fiber material was from Cellulose Aria Co. (Iran).

Raw materials were dried in an oven at (65 ± 2)°C for 24 hours prior to processing. The mass ratio of sawdust flour to polypropylene was controlled at 50:50 for all blends. The amount of nanoclay and coupling agent at 3 phc and 4phc was fixed respectively for all formulations. The oven-dried sawdust flour, polypropylene, PP-g-MA and nanoclay were prepared by melt mixing using a brabender co-rotating twin-screw extruder (Brabender Plastic Corder Co.) equipped with a circular die. The temperature profile was selected as 140-160°C. The effect of screw speed as process parameters in five levels of 60, 90, 120, 150 and 180 rpm were examined. The resulting granules were then ground using a pilot scale grinder (WIESER, WGLS 200/200 Model). The resulted granules were dried at 105°C for 4 hours. Test specimens were prepared by injection molding (Eman machine, Iran). Finally, specimens were conditioned at 23°C and 50% relative humidity over 40 hours according to ASTM D618-99.

The flexural and tensile tests were measured according to ASTM D790-03 and D638-03, respectively, using an Instron machine (Model 1186, England); the tests were performed at crosshead speeds of 2mm/min. A Zwick impact tester (Model 5102, Germany) was used for the Izod impact test. All the samples were notched on the center of one longitudinal side according to ASTM D256. For each treatment level, five replicate samples were tested.

Wide angle X-ray diffraction (XRD) analysis was carried out with a Seifert-3003 PTS (Germany) with 2CuKα radiation (λ=1.54 nm, 50kV, 50mA) at room temperature. The scanning rate was 1° /min.

The statistical analysis was conducted using SPSS programming (Version 16) method in conjunction with the analysis of variance (ANOVA) techniques. Duncan multiply range test (DMRT) was used to test the statistical significance at α=0.05 level.

RESULT AND DISCUSSION

Characterization of the morphological state of the composites was accomplished using X-ray diffraction. To verify a homogeneous dispersion of nanoparticles (so-called intercalation and exfoliation) in a polymer matrix, the interlayer spacing in nanolayered silicates (Bragg's law) and the relative intercalation (RI) of the polymer in nanoclay were quantified using the following equations:

$$n\,\lambda = 2d \sin\theta \quad (1)$$

$$RI = [(d - d_0) \div d_0] \times 100 \quad (2)$$

Where n is the integer number of wavelength (n = 1), λ is the wavelength of X-ray, d is the interlayer or d-spacing of the clay in the nanocomposite, θ is half of the angle of diffraction and d_0 is the do is the of the clay in the pristine clay.

The d-spacing and relative intercalation of the clay in the nanocomposites calculated from equations (1) and (2) is listed in Table 2. This table shows that that as the mixing time increases, the peak intensity decreases, which

Table 1: Effect of screw speed on the gallery spacing and relative intercalation in the polypropylene/sawdust flour/montmorillonite hybrid nanocomposite

Screw Speed (rpm)	2θ (°)	d-spacing (nm)	Relative Intercalation (%)
60	4.47	19.73	-
90	4.17	21.18	8.89
120	3.91	22.56	16.19
150	3.76	23.49	21.90
180	3.70	23.88	19.05

means better dispersion, thereby leading to improved diffusion. In other words, formation of the intercalation morphology and better dispersion was shown in screw speed at 180 rpm, because the peak of that was shifted to a lower angle. The higher screw speed generates a higher shear stress, which leads to a higher degree of clay dispersion [5]. It can be concluded that the intercalation/exfoliation behavior depends on the shear stress as well as on the diffusion time of the polymer. It is not clearly distinguished which characteristic is dominant, because Table 1 is not based on a quantitative discussion. However, it can be believed that the overall exfoliation increased even though the shear stress had increased [5, 13-15].

Statistical analysis indicated that screw speed had significant effect on the mechanical properties of polypropylene/sawdust flour/montmorillonite hybrid nanocomposite. The tensile strength and modulus which affected by screw speed is shown in figures 1 and 2. As can be seen, tensile strength and modulus of nanocomposites increased with increase of screw speed. It seems that increasing screw speed and applying higher shear on the melt, promotes better dispersion of nanoclay resulting in improved mechanical properties. It is known that the major factor which controls the enhancement of mechanical properties in polymer nanocomposites is the aspect ratio of dispersed organoclay [5, 13-15]. Results depicted in Figures 1 and 2 also show that screw speed of 180 rpm overall leads to better tensile properties which shows the important influence of shear stress on the dispersion state of the nanocomposites.

Figure 3 shows the effect of screw speed on the impact strength of polypropylene/ sawdust /montmorillonite hybrid nanocomposite. As can be seen, the impact strength of composites increased with increasing of the screw speed from 60 to 180 rpm. This might be ascribed to the better break up of viscous sawdust flour and nanoclay particles during the extrusion in the melt compound which would obviously increase the fracture toughness of the polypropylene/sawdust flour/montmorillonite nanocomposite.

CONCLUSION

The following conclusions could be drawn from the results of the present study:

- The mechanical properties of polypropylene/sawdust flour/montmorillonite hybrid nanocomposite were significantly affected by screw speed.
- The tensile strength, tensile modulus and impact strength of nanocomposites increased with increasing of the screw speed from 60 to 180 rpm.
- The higher screw speed generates a higher shear stress, which leads to a higher degree of clay dispersion.

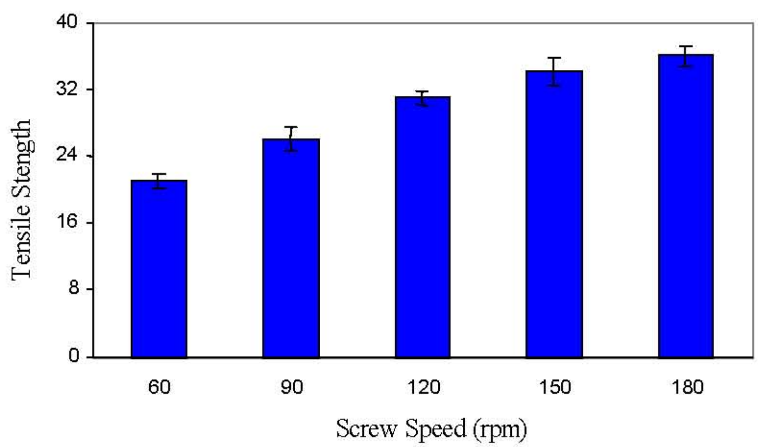

Fig. 1: Effect of screw speed on the tensile strength of polypropylene/sawdust flour/montmorillonite hybrid nanocomposite

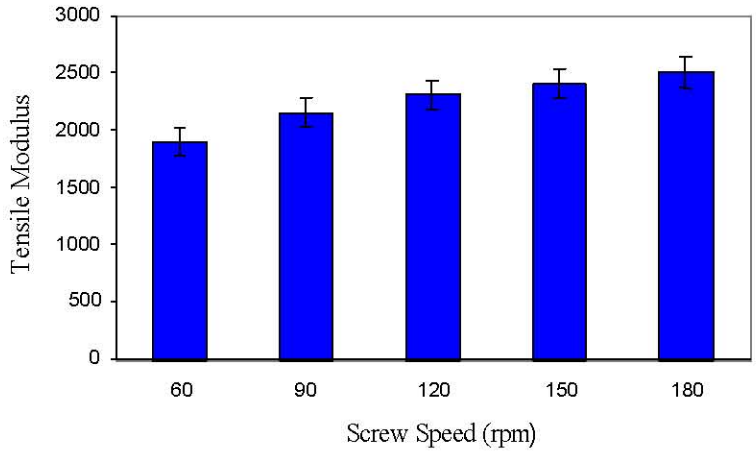

Fig. 2: Effect of screw speed on the tensile modulus of polypropylene/sawdust flour/montmorillonite hybrid nanocomposite

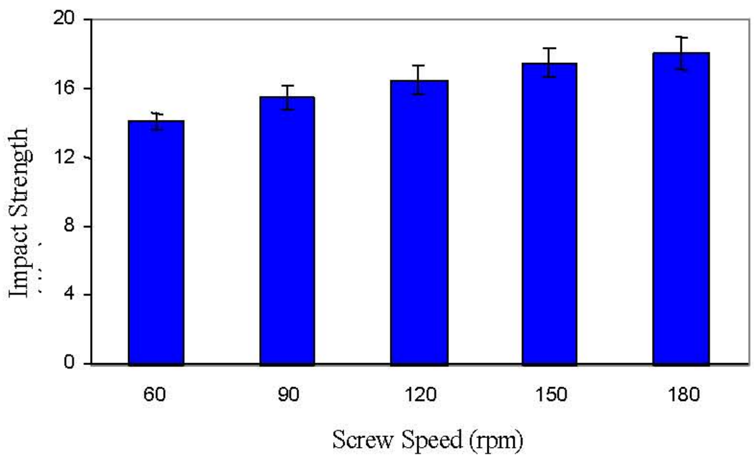

Fig. 3: Effect of screw speed on the impact strength of polypropylene/sawdust flour/montmorillonite hybrid nanocomposite

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