World Applied Sciences Journal 19 (3): 395-398, 2012
ISSN 1818-4952;

DOI: 10.5829/idosi.wasj.2012.19.03.1973

The Relationship Between Plastic Virginity and Engineering Properties of Wood Plastic Composites

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Abstract: This study attempted to investigate the relationship between plastic virginity and physico-mechanical properties of wood plastic composites. To meet this objective, wood flour was mixed with either virgin or recycled polypropylene at 40%, 50% and 60% by weight fiber loading. The samples were made by melt compounding and then injection molding. The amount of coupling agent was fixed at 2% for all formulations. Then physical and mechanical properties of composites were measured according to ASTM standard. Then, all the experimental data were collected and analyzed with the analysis of variance techniques and suitable model was selected with the simple's linear regression model. Results indicated that the flexural strength, flexural modulus, tensile strength and tensile modulus of composites of recycled plastic composites were higher than those of virgin plastics. Also, the water absorption and thickness swelling of samples decreased with the increase of recycled plastic loading. Furthermore, optimization processes have been carried out to determine the suitable combinations of plastic virginity variables in order to attain desirable physical and mechanical properties of wood plastic composites.

Key words: Optimization · Recycled Plastic · Mechanical Strength · Physical Properties

INTRODUCTION

Global ecological concern has resulted in a renewed interest in natural materials. Natural organic fibers from renewable natural resources offer the potential to act as biodegradable reinforcing materials alternative for the use of glass or carbon fiber and inorganic fillers, in plastic industry. The fibers have several advantages, such as their high specific strength and modulus, low cost, low density, renewable nature, absence of associated health hazards, easy fiber surface modification, wide availability and relative non abrasiveness. Much work has been done in studying and developing thermoplastic/natural fibers composites, especially wood plastic composites (WPCs), which have successfully proven their high qualities in various fields of technical application, especially in load-bearing applications. The main applications of WPCs are in building products, such as fencing, rails, decking, door and window profiles, decorative trims and so on. These composites are also gaining acceptance in automotive, industrial and marine applications [1].

Plastic waste is one of the major components of global municipal solid waste and annually, thousands of tons of post-consumed polymeric material wastes are generated all over the world. For example, waste plastics accounted for 11.2% of the 82.3 thousand tones of municipal solid waste generated in Tehran in 2006 [2]. The increasing quantities of plastic wastes and the effective and safe disposal of them have become serious public concerns. Reutilization of the post-consumed polymeric materials reduces the environmental impact and dependence on virgin plastics. Because of their large volume and low cost, plastic wastes are promising raw material sources for WPCs. By using recycled plastics rather than virgin resin, these wood/ recycled plastic composites provide an additional market for recycled

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plastics. Hence, the development of new value added products using wood flour and recycled plastic is assuming greater importance [2-3]

Due to the significant increase in global oil prices, using recycled plastics for the production of WPCs has recently attracted considerable attention and now it is a major task for researchers and industries. The use of recycled plastics in wood plastic campsite is increasing in developed and developing countries. It allows producers to make more cost-competitive products. It is obvious that the price of recycled plastics strongly depends on logistical solutions but the price of virgin plastics depends on the global prices of crude oil [2-3]. The utilization of recycled plastic for the manufacture of wood-fiber-reinforced recycled plastic composites has been studied by a number of authors [4-8].

The objective of the present study is the relationship between plastic virginity and physico-mechanical properties of wood plastic composites.

MATERIALS AND METHODS

Pine wood flour (WF) is used as the reinforcing fiber material was from Cellulose Aria Co. (Iran); the average particle size of wood flour was 60 meshes. Virgin polypropylene (VPP) and recycled polypropylene (RPP) were used as plastic matrix in wood plastic composites. Virgin polypropylene (VPP) was purchased from Arak Petrochemical Company with a melt flow index of 18 g/10 min with the trade name V30S. Recycled polypropylene (RPP) was obtained from waste spindle with a melt flow index of 31.5 g/10 min. PP-g-MA provided by Solvay with trade name of Priex 20070 (MFI=64 gr/10min, grafted maleic anhydride 1 Wt. %) was used as a coupling agent.

Before preparation of samples, wood flour was dried in an oven at (65 ± 2)°C for 24 hours. Then virgin and recycled plastics, wood flour and coupling agent were weighed and bagged according to formulations given in Table 1. The mixing was carried out by a hake internal mixer (HBI System 90, USA). First the plastics were fed to mixing chamber, after melting of plastics, coupling agent was added. At the two minute, the wood flour fed and the total mixing time was 12 min. The compounded materials 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 a temperature of 23°C and relative humidity of 50% for at least 40 hours according to ASTM D618 prior to testing.

Table 1: Composition of the studied formulations

Sample Code	Polypropylene (Wt. %) Virgin	Polypropylene (Wt. %) Recycled	Wood flour (Wt. %)	Coupling agent (Wt. %)
58VPP/40WF/2M	58	-	40	2
48VPP/50WF/2M	48	-	50	2
38VPP/60WF/2M	38	-	60	2
58RPP/40WF/2M	-	58	40	2
48RPP/50WF/2M	-	48	50	2
38RPP/60WF/2M	-	38	60	2

The flexural and tensile tests were measured according to the ASTM D 790 and D 638, respectively, using an Instron machine (Model 1186, England); the tests were performed at crosshead speeds of 5 mm/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 the ASTM D 256. For each treatment level, five replications were tested.

Water uptake tests were carried out according to ASTM D 7031 specification. Specimens with a dimension of 20 × 20 × 20 mm were cut for the water uptake measurement. Five replicates were used for each sample code. To ensure the same moisture content for the specimens before each test, all the specimens were oven-dried at 102±3°C. The weight and thickness of dried specimens was measured to a precision of 0.001 mm. The specimens were then placed in distilled water and kept at room temperature for one month. For each measurement, specimens were removed from the water and the surface water was wiped off using blotting paper. Then, the values of the water absorption in percentage were calculated equation 1.

$$WA(t) = \frac{W(t) - W_0}{W_0} \times 100 \qquad (1)$$

Where WA (t) is the water absorption at time t, W_o is the oven dried weight and W (t) is the weight of specimen at a given immersion time t.

Also the values of the thickness swelling in percentage were calculated using the equation 2.

$$TS(t) = \frac{T(t) - T_0}{T_0} \times 100 \qquad (2)$$

Where TS (t) is the thickness swelling at time *t*, To is the initial thickness of specimens and T (t) is the thickness at time *t*.

The statistical analysis was conducted using SPSS programming (Version 16) method in conjunction with the analysis of variance techniques. Duncan multiply range test was used to test the statistical significance at α = 0.05 level. The simple's linear regression model (REG procedure) was used to analyze the relationship between plastic virginity and physico-mechanical properties of wood plastic composites.

RESULTS AND DISCUSSION

The values of mechanical properties of polypropylene-wood flour composites from either virgin or recycled plastic are given in Table 2. As can be seen, the mechanical properties of wood plastic composites were affected by plastic virginity. The flexural strength, flexural modulus, tensile strength and tensile modulus of composites containing made of recycled plastic is higher than those of virgin plastics. It is well known that the different mechanical properties between all manufactured composites can be attributed to the virginity of plastics. During the recycling process of plastics there is a generation on the crystalline structure and degradation of the mechanical properties of recycled plastics is possible [4-8]. Therefore, the flexural strength, flexural modulus, tensile strength and tensile modulus of composites of recycled plastic composites were higher than those of virgin plastics. It seems that melt high melt flow rate corresponding to low molecular weight, which showed that recycled plastic, had higher molecular weight than virgin plastic. The flexural strength, flexural modulus, tensile strength and tensile modulus of composites increase with molecular weight due to the effect of better entanglement.

From these mechanical properties results, suitable model was selected. The adequacy of the model was established by ANOVA, Normal Probability plot and Residual Analysis. Through the estimation of all regression coefficients, the experimental response can be modeled as a polynomial equation that shows the effect of plastic virginity variables on the mechanical properties of wood plastic composites. The linear function equation and correlation coefficient obtained is given in Table 3.

The values of physical properties of polypropylene-wood flour composites from either virgin or recycled plastic are given in Table 4. As can be seen, the physical properties of wood plastic composites were affected by plastic virginity. The water absorption and thickness swelling of composites containing made of recycled plastic is lower than those of virgin plastics. The possible reason is the enhanced dispersion and interfacial adhesion due to the presence of chemical impurities, different molecular and compositional differences (MFI and crystallinity) between virgin and recycled plastics. So, in the composites with recycled plastics, plastic penetrated into the fiber lumens, pit holes and other void spaces in the matrix. The composites with the virgin plastics showed more isolated fibers and some gaps and flaws which provided more water residence sites.

Table 2: Effect of plastic virginity on mechanical properties of wood plastic composite

Sample Code	Flexural strength (MPa)	Flexural modulus (MPa)	Tensile strength (MPa)	Tensile modulus (MPa)
58VPP/40WF/2M	49.53	19045	24.82	2345.89
48VPP/50WF/2M	50.03	2127.22	26.53	2434.33
38VPP/60WF/2M	50.76	2201.89	27.34	2521.78
58RPP/40WF/2M	51.84	2138.22	26.03	2480.33
48RPP/50WF/2M	52.43	2216.08	28.79	2532.22
38RPP/60WF/2M	53.46	2356	29.54	2636.44

Table 3: The relationship between plastic virginity and mechanical properties of wood plastic composites

Mechanical properties	Virgin Polypropylene (VPP)	Recycled Polypropylene (RPP)
Flexural strength (MPa)	$Y= 0.6135 X + 48.878$; $R^2= 0.9877$	$Y= 0.545 X + 52.309$; $R^2= 0.9972$
Flexural modulus (MPa)	$Y= 328.44 X + 1501.1$; $R^2= 0.9934$	$Y= 312.11 X + 1611.8$; $R^2= 0.9862$
Tensile strength (MPa)	$Y= 1.259 X + 23.715$; $R^2= 0.9614$	$Y= 1.9605 X + 24.67$; $R^2= 0.7806$
Tensile modulus (MPa)	$Y= 327.94 X + 2524.8$; $R^2= 0.9926$	$Y= 327.56 X + 2660.9$; $R^2= 0.9982$

Table 4: Effect of plastic virginity on physical properties of wood plastic composite

Sample Code	Water absorption (%)	Thickness swelling (%)
58VPP/40WF/2M	10.93	2.78
48VPP/50WF/2M	11.23	2.96
38VPP/60WF/2M	11.81	3.17
58RPP/40WF/2M	9.58	2.23
48RPP/50WF/2M	10.43	2.49
38RPP/60WF/2M	10.90	2.75

Table 5: The relationship between plastic virginity and physical properties of wood plastic composites

Mechanical properties	Virgin Polypropylene (VPP)	Recycled Polypropylene (RPP)
Water absorption (%)	$Y= 0.065 X + 10.865; R^2= 0.9922$	$Y= 0.0965 X + 10.497; R^2= 0.9366$
Thickness swelling (%)	$Y= 0.119 X + 2.548; R^2= 0.994$	$Y= 0.117 X + 2.298; R^2= 0.9786$

From physical properties results, suitable model was selected. The adequacy of the model was established by ANOVA, Normal Probability plot and Residual Analysis. Through the estimation of all regression coefficients, the experimental response can be modeled as a polynomial equation that shows the effect of plastic virginity variables on the physical properties of wood plastic composites. The linear function equation and correlation coefficient obtained is given in Table 5.

CONCLUSION

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

- The flexural strength, flexural modulus, tensile strength and tensile modulus of composites of recycled plastic composites were higher than those of virgin plastics.
- The water absorption and thickness swelling of samples decreased with the increase of recycled plastic loading.
- Optimization processes have been carried out to determine the suitable combinations of plastic virginity variables in order to attain desirable physical and mechanical properties of wood plastic composites.

ACKNOWLEDGMENT

The authors have a special thanks to Islamic Azad University, Malayer Branch for providing financial support for this project No: 110.

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