Mechanical Properties of Composites from Sawdust and Recycled Plastics

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ABSTRACT: Mechanical properties of wood plastic composites (WPCs) manufactured from sawdust and virgin and/or recycled plastics, namely high density polyethylene (HDPE) and polypropylene (PP), were studied. Sawdust was prepared from beech industrial sawdust by screening to the desired particle size and was mixed with different virgin or recycled plastics at 50% by weight fiber loading. The mixed materials were then compression molded into panels. Flexural and tensile properties and impact strength of the manufactured WPCs were determined according to the relevant standard specifications. Although composites containing PP (virgin and recycled) exhibited higher stiffness and strength than those made from HDPE (virgin and recycled), they had lower unnotched impact strengths. Mechanical properties of specimens containing recycled plastics (HDPE and PP) were statistically similar and comparable to those of composites made from virgin plastics. This was considered as a possibility to expand the use of recycled plastics in the manufacture of WPCs. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 100: 3641–3645, 2006

Key words: wood plastic composites; sawdust; recycled plastic; mechanical properties

INTRODUCTION

Wood plastic composites (WPCs) are defined as composite materials containing wood (in various forms) and thermoplastic materials. These materials are a relatively new family of composite materials, in which a natural fiber and/or filler (such as wood flour/fiber, kenaf fiber, hemp, sisal, etc.) is mixed with a thermoplastic such as polyethylene (PE), polypropylene (PP), poly (vinyl chloride) (PVC), etc. Compared with the traditional synthetic fillers, natural fibers present lower density, less abrasiveness, lower cost and they are renewable and biodegradable. WPCs are becoming more and more commonplace by the development of new production techniques and processing equipment. Around 100 companies involved in WPC manufacturing have been identified worldwide.[1]

In WPC manufacturing, virgin plastics such as high and low density polyethylene (HDPE and LDPE), PP, and PVC are commonly used. As for virgin plastics, any recycled plastic that melts and can be processed below the degradation temperature of wood (lignocellulosic fillers) (200°C) is usually suitable for manufacturing WPCs. Plastic wastes are one of the major components of global municipal solid waste and present a promising raw material source for WPCs (thanks to their large amount of daily generation and low cost). For example, a city in a developing country with a population of 3 million inhabitants produces around 400 tonnes plastic waste per day with an annual increase of 25%.[2] Hence, the development of new value-added products (WPCs), with the aim of utilizing the wood waste (this means no need for additional wood resources) and low cost recycled plastics (which would otherwise be added to landfills), is assuming greater importance.

The utilization of recycled plastic for the manufacture of WPCs has been studied by a number of authors.[2–6] Applications of such materials include floor parquets, flower vases, waste paper baskets, park benches, picnic tables, and plastic lumbers. Properties of some waste plastics are similar to those made from virgin materials. For instance, only slight changes in mechanical properties of recycled polyethylene have been reported.[6] The use of plastic and wood wastes seems inevitable and the present opportunities are promising.[7,8]

Because separation of waste plastics imposes additional costs, more research is needed on WPCs made from recycled plastics especially mixed plastic waste. The objective of the present study was to evaluate the

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TABLE I
Composition of Evaluated Formulations

Formulation	ID code	Sawdust (wt %)	HDPE		PP	
			Virgin	Recycled	Virgin	Recycled
1	VPE	50	50	—	—	—
2	VPE/RPE	50	25	25	—	—
3	RPE	50	—	50	—	—
4	VPP	50	—	—	50	—
5	VPP/RPP	50	—	—	25	25
6	RPP	50	—	—	—	50
7	VPE/VPP	50	25	—	25	—
8	RPE/RPP	50	—	25	—	25

mechanical properties of WPCs made from sawdust and recycled plastics (most commonly used HDPE and PP).

METHODS

Materials

Plastics

Two kinds of most commonly used virgin plastics were selected: virgin HDPE (noted as VPE with a melt flow index of 0.4 g/10 min (170°C) and virgin polypropylene (VPP) with a melt flow index of 29.2 g/10 min (190°C).

Two kinds of recycled plastics were also selected: recycled HDPE (noted as RPE) with a melt flow index of 18.4 g/10 min (170°C) and recycled polypropylene (RPP) with a melt flow index of 65 g/10 min (190°C).

Preparation of sawdust

Sawdust used in the study was obtained by screening industrial sawdust of beech (*Fagus Orientalis*) collected from local mills to 50-mesh particle size. The material was then dried in an oven for 24 h at 105 ± 2°C.

Mixing process

Plastics and sawdust were mixed in a Brabender Plasticorder (Duisburg, Germany) at 30 rpm and temperatures of 170 and 190°C for PE and PP formulations, respectively (Table I). First the polymers were added to the mixer and the sawdust was added after the polymers had reached their melting temperatures. The mixing process took 11 min on average.

Preparation of the specimens

The amorphous composites removed from the mixer were then pressed into sheets of 2-mm nominal thickness and 15 × 15 cm^2 nominal dimensions using a laboratory hydraulic hot press at 170 and 190°C for HDPE and PP formulations, respectively. Specimens for mechanical testing were cut out of these sheets.

Mechanical tests

The mechanical properties of the sawdust/plastic composites were assessed through flexural, tensile, and impact properties. Flexural and tensile properties of sawdust/waste plastic composites were determined according to ASTM D790–90[9] and ASTM D 638–89[10] specifications, respectively, using a ZWICK testing machine, Model 2/5H (Ulm, Germany). Crosshead speed was set to 5.3 and 5 mm/min for flexural and tensile tests, respectively. Unnotched impact tests were also carried out according to ASTM D256–90[11] specification using a DMG Izod testing machine (New Yorkshire, England). All tests were performed at room temperature (25°C) and constant relative humidity (65%) and six replicates for each test were performed. The specimens were conditioned at constant room temperature and relative humidity prior to testing.

Statistical analysis

The collected data have been statistically analyzed in a completely randomized design and Duncan's multiple

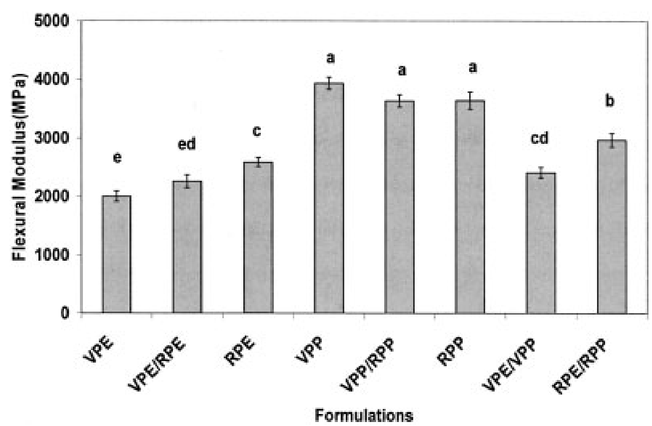

Figure 1 Flexural modulus of sawdust/plastic composites.

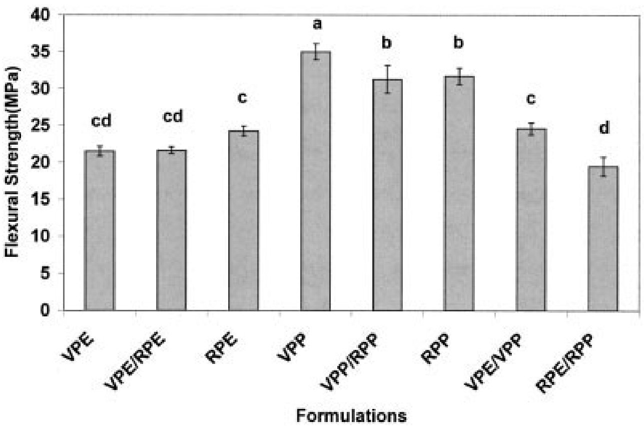

Figure 2 Flexural strength of sawdust/plastic composites.

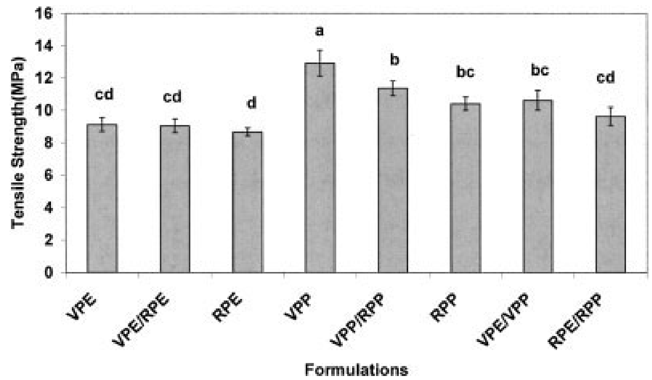

Figure 4 Tensile strength of sawdust/plastic composites.

range test was used for grouping the means. All comparisons have been made at 95% confidence level.

RESULTS AND DISCUSSION

Figures 1 and 2 illustrate the flexural modulus and strength of sawdust/recycled plastic composites, respectively. It can be observed that the flexural modulus and strength of composites containing PP is significantly higher than those of HDPE. When the RPE content increased to 50%, flexural modulus and strength significantly increased 30 and 13%, respectively, while slight decreases of 9 and 7% were observed for flexural strength and modulus of PP composites, respectively. This was not statistically significant for modulus but significant for strength.

Composites made of mixed recycled plastics (RPE/RPP) exhibited statistically higher (23%) flexural moduli compared with those of mixed virgin plastics (VPE/VPP).This was inversely observed for the flexural strength. Kamdem et al.[5] reported higher flexural modulus and strengths for composites from VPE and wood flour (at 50 : 50 by weight) than those of RPE. The values of flexural modulus and strength of samples made from mixture of plastics (HDPE and PP) are statistically similar to those made with HDPE. However, they were statistically lower than those of PP.

Figure 3 shows the tensile modulus of sawdust/plastic composites. No Statistically significant difference between composites has been observed. This means that the tensile modulus of composites made from HDPE is statistically equal to those made from PP, and tensile moduli of samples from virgin plastics are also comparable with those of recycled plastics.

Tensile strength of sawdust/plastic composites is presented in Figure 4. It can be observed that for PP composites, tensile strength statistically decreases 19% when the recycled plastic content increases to 50%, whereas for HDPE composites this decrease is slight (not significant). Generally, PP composites showed higher tensile strength and modulus than HDPE composites. The composites made from the mixture of PP and HDPE (both virgin and waste) exhibited tensile properties comparable with that of boards made from HDPE or PP.

Figure 5 shows the elongation of sawdust/plastic composites. The elongation is usually inversely pro-

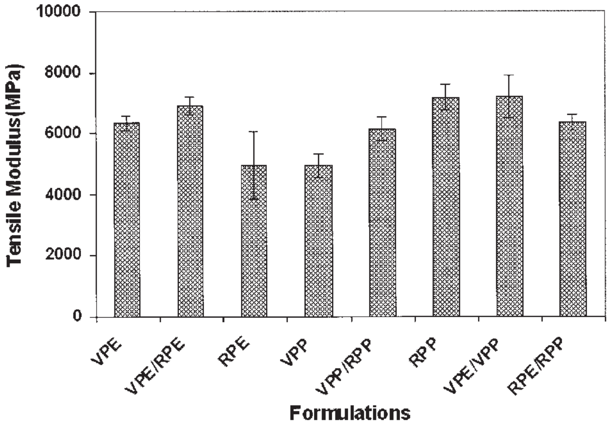

Figure 3 Tensile modulus of sawdust/plastic composites.

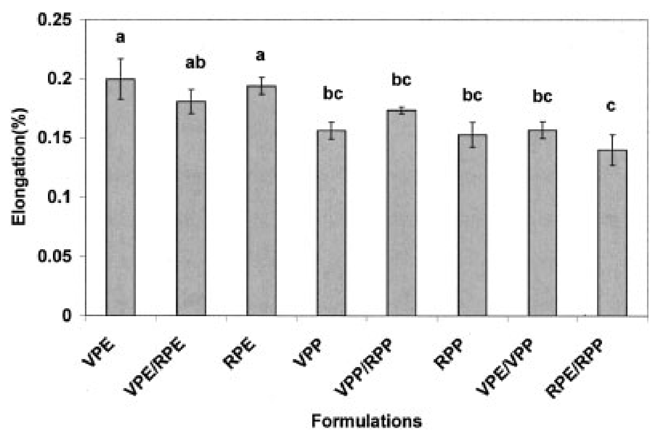

Figure 5 Elongation of sawdust/plastic composites.

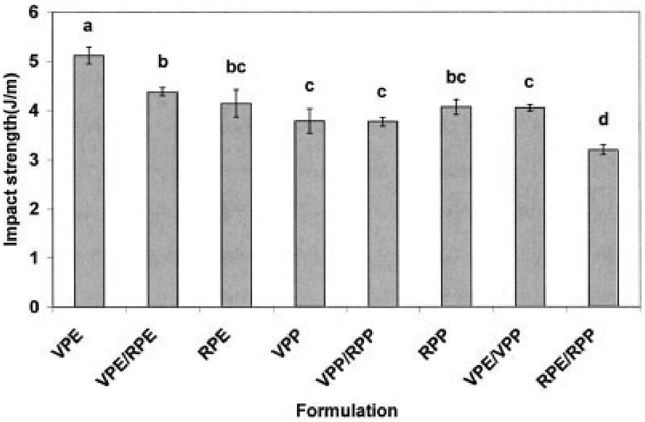

Figure 6 Impact strength of sawdust/plastic composites.

portional to tensile strength, which means that increasing the tensile strength of composites usually contributes to a decrease in elongation.[12] The composites from VPE and mixed recycled plastics (RPE/RPP) showed maximum and minimum elongations, respectively.

Composites from HDPE showed statistically higher elongation (lower tensile strength) compared with PP composites (with higher tensile strength). It was found that similar to tensile strength and modulus, the elongation also decreased in composites containing recycled plastics.

Impact strength of sawdust/plastic composites is shown in Figure 6. Composites from VPE and mixed recycled plastics (RPE/RPP) showed maximum and minimum impact strengths, respectively. For HDPE composites, impact strength significantly decreased 20% when recycled fraction increased to 50%. Also the impact strength of mixed recycled plastics is significantly lower (22%) than that of virgin plastics. For PP composites, no significant effects were observed. Kamdem et al.[5] reported no significant difference between the impact strengths of composites containing VPE and wood flour (at 50 : 50 by weight) than those of RPE.

Because the fraction of sawdust was constant in all composite formulations, the variations in the mechanical properties of sawdust/plastic composites can be related to the matrices (plastics); i.e., the properties of the composites qualitatively followed those of the matrix polymers. Generally PP (virgin and recycled) composites were stronger and stiffer than HDPE (virgin and recycled) composites but had lower unnotched impact strength. Similar results were reported by Youngquist et al.[3]

During the recycling process of plastics there is a generation on the material mechanical properties[2] and degradation of the mechanical properties of recycled plastics is possible. Therefore, the mechanical properties of the sawdust/recycled plastic composites were slightly lower than those of virgin plastics with an exception for flexural properties of RPE, which were higher than those of virgin ones. Similar higher flexural properties have been reported for recycled PET composites by Avila.[13] The higher flexural properties in recycled PET were related to an increase in crystalline structure.[14] The increase in crystallinity is the result of molecular weight reduction that can occur during recycling process.[15]

CONCLUSIONS

Mechanical properties of WPCs manufactured from sawdust and virgin and recycled plastic (HDPE and PP) were studied in this research. The following conclusions can be drawn from the results and discussions presented above:

- PP (virgin and recycled) composites were found to be stronger and stiffer than HDPE (virgin and recycled) composites, but had lower unnotched impact strengths. This was attributed to the superior mechanical properties of PP as compared with those of HDPE.
- Composites made from the mixture of PP and HDPE (both virgin and waste) exhibited tensile properties comparable to those made from HDPE or PP. Therefore, it would be possible to use both plastics in the composite without further reduction in mechanical properties.
- Composites made from mixed recycled plastics (RPE/RPP) exhibited statistically higher flexural moduli compared with those of mixed virgin plastics (VPE/VPP). This phenomenon was attributed to the possible increase in crystallinity.[15]
- Generally the mechanical properties of specimens containing recycled plastics (HDPE and PP) were statistically comparable with those of composites made from virgin plastics. This was considered as a possibility to expand the use of recycled plastics in the manufacture of WPCs.

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