Influence of Wood Flour on the Mechanical Properties of Polyethylene

INTRODUCTION

Wood flour is an inexpensive filler which reduces the overall cost of the wood flour/polymer composite material with a little loss in some properties and gain in other properties. The impact-modifying role of wood flour in thermoset polymer compositions is well known.[1] Its use as a filler in thermoplastic polymer composites has also been reported recently.[2–5] In the study of polypropylene-wood flour composites Ishihara et al.[5] reported decreased shrinkage after moulding, increase in elastic modulus, and increase in creep resistance with increasing wood flour content of the composite.

In the present communication we report a study of the mechanical properties of high-density polyethylene (HDPE)/wood flour composites. Tensile, impact, and hardness properties of these composites with two ranges of particle sizes of the wood flour (less than 180 μm and 355–425 μm) and varying filler content (0 to 14 v%) are reported.

EXPERIMENTAL

Materials

HDPE Hostalen G (density 0.949 g cm^{-3}) of Hoechst India Ltd. was used in this study. Wood flour from Deodar wood (also known as Cedrus Deodara-Indian Cedar) was sieved into various particle size ranges and the two ranges of particle sizes, (i) less than 180 μm and (ii) 355 to 425 μm, were used in the study.

COMPOUNDING AND PROCESSING

Wood flour dried in a vacuum oven, was mixed with HDPE in a plasticating extruder (Betol BM-1820). Thick strands of the material extruded were cut into small granules in a granulator. Test samples were prepared by injection moulding of the dried granules at moulding temperature 180–200°C.

MEASUREMENTS

Tensile measurements on an Instron (Model 1121) were done at an extension rate 100% (initial crosshead separation 5 cm and crosshead speed 50 mm/min) on dumbbell-shaped specimens according to ASTM D638-82 test procedure. Izod impact strength measurements on notched samples were carried out using an FIE impact tester (Model IT-042) according to ASTM D256-73 test procedure. Shore A hardness values were determined on a Durometer of Instruments and Manufacturing Co., USA (Model 26419-A). All tests were performed at ambient temperature of 30 ± 2°C.

Journal of Applied Polymer Science, Vol. 32, 4285–4289 (1986)

CCC 0021-8995/86/034285-05$04.00

RESULTS AND DISCUSSION

Tensile Properties

Results of tensile properties are presented in Figures 1-3 in terms of the relative values of the various properties of the composite (subscript c) to those of the pure polymer (subscript p). Variations of the properties are shown as function of the volume fraction ϕ_F of the filler (wood flour) in the composite.

Variation of the relative value of the elastic modulus (E_c/E_p) with filler content (Fig. 1) shows initially an increase at low wood flour loading showing a maximum at about 1% filler loading, (ϕ_F = 0.007) with increasing ϕ_F. Wood flour of fine particle size (< 180 μm) is apparently superior to that of coarse particle size (355–425 μm), since the elastic modulus of the composite in the former case remains superior to that of the parent HDPE up to the highest value of ϕ_F (i.e., 0.14) studied, whereas in the latter case the modulus of the composite drops to nearly 0.9 times the value of the parent HDPE. The modulus decrease curve appears to flatten toward the upper limit of ϕ_F, indicating the possibility of going to higher filler content without much loss in elastic modulus.

The relative yield stress (σ_c/σ_p) of the composite varies with filler loading (ϕ_F) in a manner shown in Figure 2. The yield stress decreases with increasing filler loading, the decrease being very slow above 5% wood flour. The overall decrease of yield stress in the case of fine particle filler (< 180 μm) is much less than in the case of coarse particle filler (355–425 μm). The limiting value at 14% filler content of the yield stress of the composite is quite close to that of the unfilled HDPE in the case of fine filler particle composite, whereas in cases of the coarse filler particle composite it is nearly 0.8 times the value of unfilled HDPE.

Figure 2 also presents a comparison of these data with Nicolais and Narkis[6] equation for no-adhesion-type composites, viz.

$$\frac{\sigma_c}{\sigma_p} = 1 - 1.21\,\phi_F^{2/3} \qquad (1)$$

The agreement of the data with the Nicolais and Narkis equation is apparently superior in the coarse particle-filled composite than the fine particle-filled composite. This suggests greater

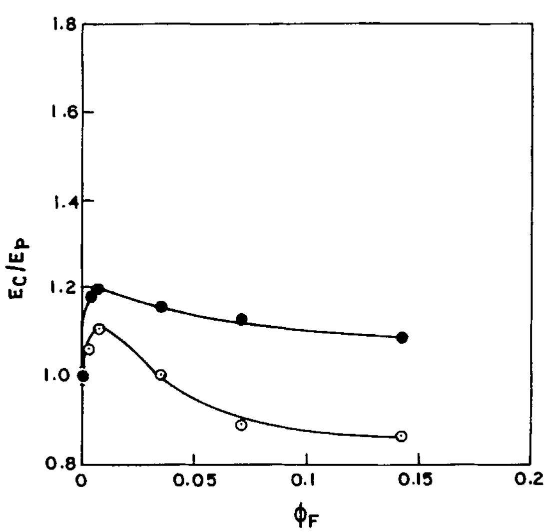

Fig. 1. Plot of relative modulus of HDPE-wood flour (particle size less than 180 μm) (●) and HDPE-wood flour (particle size 355 to 425 μm) (⊙) composites against ϕ_F.

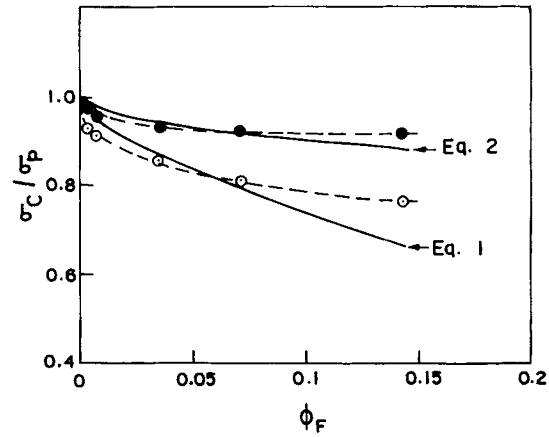

Fig. 2. Relative yield stress of HDPE-wood flour (particle size less than 180 μm) (●) and HDPE-wood flour (particle size 355 to 425 μm) (⊙) composites against ϕ_F. Dotted curves represent variation of experimental data. Solid curves represent predicted behavior according to equations indicated.

resemblance with the no-adhesion-type of model of Nicolais and Narkis of these coarse particle-filled composites than the fine particle-filled composites.

An estimation of the extent of adhesion at the interface of the two components of these composites is possible by the method of Nicolais and Nicodemo.[7] According to these authors the data must fit an empirical equation

$$\frac{\sigma_c}{\sigma_p} = 1 - K\,\phi_F^{2/3} \tag{2}$$

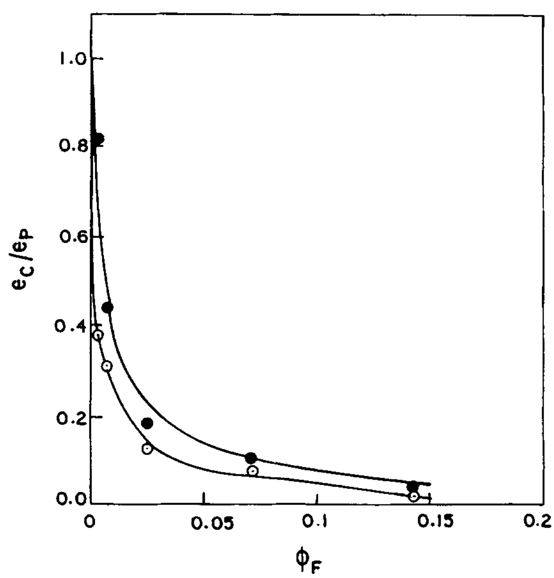

Fig. 3. Relative strain-at-break of HDPE-wood flour (particle size less than 180 μm) (●) and HDPE-wood flour (particle size 355 to 425 μm) (⊙) composites vs. ϕ_F.

where K is a parameter whose value is indicative of the extent of adhesion. These data for fine particle-filled composites fit very well with Eq. 2 with $K = 0.45$ (as shown by predicted curve in Fig. 2). Similar values of K are reported for the adhesion of iron powder with styrene-acrylonitrile (SAN) copolymer.[8]

Elongation at break ($\varepsilon_c/\varepsilon_p$) decreases considerably with increasing filler content, as shown in Figure 3, the decrease being rapid at low filler content and quite slow at $\phi_F > 0.05$. In the region of low ϕ_F the elongation at break of the fine particle-filled composites is distinctly higher than that of the coarse particle-filled composites at any given ϕ_F; at higher ϕ_F this difference, however, becomes insignificantly small. Presence of fillers causes discontinuities in stress transfer, hence the stress concentrations and weakening of the structure which explains the occurrence of failure at an early stage of extension. Smaller elongation at break in the coarse particle-filled composites than fine particle-filled composites implies a weaker structure of the former than the latter composites, which is also in agreement with the higher modulus and higher yield stress of the latter (i.e., fine particle-filled composites).

IMPACT STRENGTH

Izod impact strength (I) of the composite decreases with increasing filler content as shown by the variation of (I_c/I_p) as function of ϕ_F in Figure 4. Initially at low filler content, the decrease in impact strength is very rapid and thereafter the decrease becomes slow with increasing ϕ_F. The impact strength of the composite at 14% wood flour loading is nearly 0.3 and 0.4 times the value for unfilled HDPE in the fine and coarse particle-filled composites, respectively. It may be noted, that unlike the tensile properties, the impact performance of the fine particle-filled composites is poorer than that of the coarse particle-filled composites. Thus, it may be stated that wood flour filler does not provide the energy dissipation mechanism in HDPE necessary for impact toughening. This is contrary to the reported[1] role of wood flour as an impact modifier in thermoset compositions.

HARDNESS

Shore A hardness (H) values of these composites are shown in Figure 5 as the variation of (H_c/H_p) as a function of ϕ_F. There is an improvement in the hardness of HDPE on incorporation

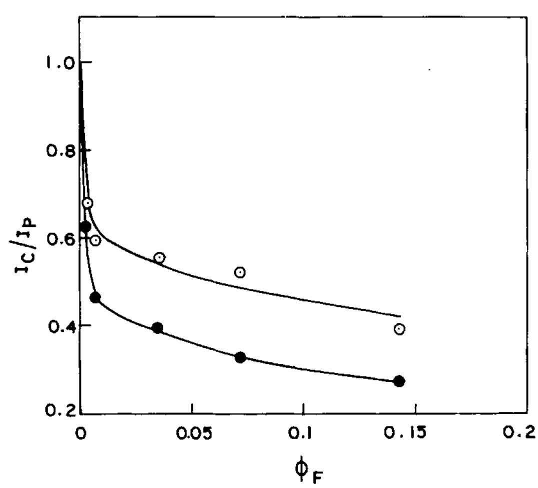

Fig. 4. Relative izod impact strength of HDPE-wood flour (particle size less than 180 μm) (●) and HDPE-wood flour (particle size 355 to 425 μm) (⊙) composites against ϕ_F.

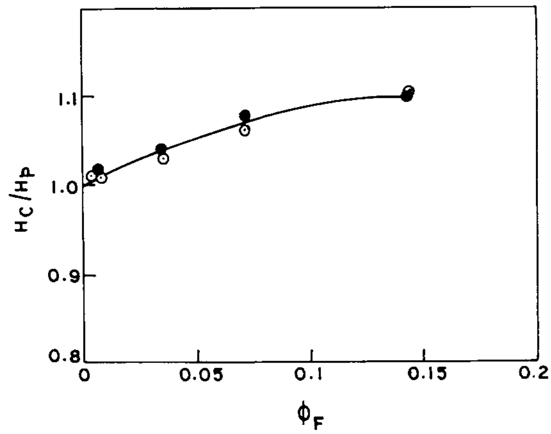

Fig. 5. Relative shore A hardness of HDPE-wood flour (particle size less than 180 μm) (●) and HDPE-wood flour (particle size 355 to 425 μm) (⊙) composites against ϕ_F.

of wood flour which increases on increasing filler loading. Hardness values in case of fine particle composites are slightly superior than those of coarse particle-filled composites.

CONCLUSION

This study suggests that wood flour can be successfully used as filler in HDPE for applications where impact properties of the material are not of prime importance. The cost of the material can be reduced without too much loss of elastic modulus, thus not affecting the usefulness of the material for various end uses. Potential end uses include moulded furnitures, domestic hollow ware, handles of various tools, etc. The hardness of HDPE is improved with the use of wood flour filler. Wood flour of fine particle size is preferable to the coarse particle wood flour for incorporation with HDPE.

References

1. P. D. Ritchie, ed., *Plasticisers, Stabilisers & Fillers,* Iliffe Books Ltd., London, Part 3, 1972.
2. H. Ohkaha and coworkers, *Chem. Abstr.,* **86,** 172521n (1977).
3. H. Pfannmueller and coworkers, *Chem. Abstr.,* **75,** 64905e (1971).
4. H. Matsukawa et al., *Chem. Abstr.,* **85,** 6675a (1976).
5. S. Ishihara et al., *Chem. Abstr.,* **92,** 130969h (1980).
6. L. Nicolais and M. Narkis, *Polym. Eng. Sci.,* **11,** 194 (1971).
7. L. Nicolais and L. Nicodemo, *Int. J. Polym. Mater.,* **4,** 229 (1974).
8. L. Nicodemo and L. Nicolais, *J. Mat. Sci. Letters,* **2,** 201 (1983).

S. N. MAITI and K. SINGH

Centre for Materials Science & Technology
Indian Institute of Technology
Delhi, New Delhi 110016
India

Received March 8, 1985
Accepted September 23, 1985