Wood fiber/high-density polyethylene composites: ability of additives to enhance mechanical properties

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Abstract

Improvement of mechanical properties for a composite of aspen hardwood fibers and recycled high-density polyethylene (HDPE) can be achieved by the inclusion of additives. The four additives investigated in this study were: ionomer modified polyethylene (ION), maleic anhydride modified polypropylene (MAPP), and two low molecular weight polypropylenes (LMWPP). Each additive was combined with recycled HDPE and aspen fibers in a twin-screw extruder to form the composite, and then compression molded. Creep, water sorption, tensile properties, and impact strength were evaluated. All composites were approximately 40 percent by weight aspen hardwood fibers. The effects of ION and MAPP were studied at 1, 3, and 5 percent weight ratios. The effects of the two LMWPPs were studied utilizing 5 percent additive. The inclusion of MAPP in the composite improved overall mechanical properties. Addition of ION produced some positive effects but not at a statistically significant level. The inclusion of both LMWPPs generally decreased the mechanical properties of the composite.

Introduction

Current solid waste disposal problems have led to an ever-increasing interest in recycling. Collection programs are burgeoning, but in some cases markets have not kept pace with supply. This has not yet become a significant problem for plastics, mostly because the rate of collection is still so low. However, as plastics recycling grows, markets are sure to be more of a concern. PET and HDPE are currently the most widely recycled plastics, and are likely to remain so. HDPE is limited in use for structural applications by its low stiffness and high creep properties. By reinforcing the polymer with a stiff and strong filler this limitation could be overcome for some applications, thus increasing the marketability of the recycled polymer.

Wood fiber has been recognized as a possible filler because of its low cost, stiff and strong fibers, ease of processing and its availability. Unfortunately lack of adhesion between the polar hydrophilic fibers and the nonpolar hydrophobic matrix results in decreased effectiveness of reinforcement by the fibers. Nonetheless, composite materials formed from wood fibers and recycled HDPE have been shown to have improved stiffness as determined by both tensile and flexural modulus, and improved creep resistance (1). Efforts to further improve these properties, as well as tensile strength, have focused on attempts to improve either the adhesion between the fibers and the matrix, or the dispersion of fibers within the matrix with less fiber damage. Screening of several additives resulted in the selection of MAPP and ION as promising candidates for improvement of adhesion and resultant improvement in mechanical properties (2). The present study further examines these two additives, and also examines LMWPP as a potential dispersion improver.

Materials and methods

HDPE dairy bottles were collected, cleaned, labels and caps removed, cut into quarters, and granulated using a Polymer Machinery Corp. Lowline Granulator Model 68-913. Aspen hardwood fibers from a thermomechanical pulping process were supplied by Lionite Hardboard, Phillips, Wis. The air-dried fibers were conditioned for at least 40 hours at 22°C and 50 percent RH before combining them with HDPE. The four additives studied were 1) MAPP — Hercoprime, supplied by Himont; 2) ION — Surlyn 1605, supplied by DuPont; 3) LMWPP1 — Proflow 1000, supplied by Polyvisions; and 4) LMWPP2 — Proflow 3000, supplied by Polyvisions.

A Baker Perkins Model MPC/V-30DE, 38-mm, 131 intermeshing self-wiping co-rotating twin-screw extruder was used to mix the polymer and wood fibers. The temperature in the feed, transition, and metering zones was 150°C, and compounder speed was 200 rpm. HDPE and the additive were premelted in the feed zone, and then the wood fibers added to the premelted polymer using the second feed port. This was done to minimize fiber damage and gain better dispersion. The extruded material was cut into approximately 12-cm lengths, cooled to room temperature, and then compression molded into sheets, using a Carver laboratory press, model M25 ton. Molding conditions were approximately 10 minutes at 150°C and 30,000 psi, followed by about 15 minutes of cooling in the mold. Mylar was used between the composite and the chrome plates to minimize sticking. Specimens were cut from the molded plates for testing, and then conditioned at 23°C and 50 percent RH for not less than 40 hours.

ASTM Standard P638-86 was followed for tensile testing on an Instron Tester Model 4201, using dumbbell-shape Type 1 specimens prepared on a Tensilekut Model 10-13 specimen cutter. Izod impact strength determination was done on a TMI 43-1 Impact Tester with a 5 ft.-lb. pendulum, following ASTM Standard D 256-81, with specimens notched on a TMI Notching Cutter Model TMI 2205. Water sorption determination followed the 2-hour boiling water immersion procedure of ASTM standard D 570-81, using 2-inch diameter disks. Creep analysis was done in accord with ASTM Standard D-2990-77, using 50-lb. weights attached to grips holding specimens identical to those used for tensile properties. Creep extension was measured by grip separation at specified increments up to 700 hours.

MAPP and ION were examined at concentrations of 1, 3, and 5 percent by weight. LMWPP1 and LMWPP2 were studied at a 5 percent concentration by weight. In all cases, the weight percent of wood fiber was approximately 40 percent (actual range 40.77 to 41.66%). Two batches were prepared of each combination. Statistical analysis revealed no difference between batches, so they were combined for all further data analysis. Complete details are available in Childress's M.S. thesis (3).

Results

Tensile strength

Figure 1 shows the results of tensile strength determination. As can be seen, the addition of MAPP increased tensile strength at all levels, which statistical analysis showed to be highly significant. Addition of ION produced some suggestive positive results at the 5 percent concentration, but this was not found to be statistically significant. Similarly the apparent decrease for LMWPP1 was not significant. However LMWPP2 produced a statistically significant decrease in tensile strength.

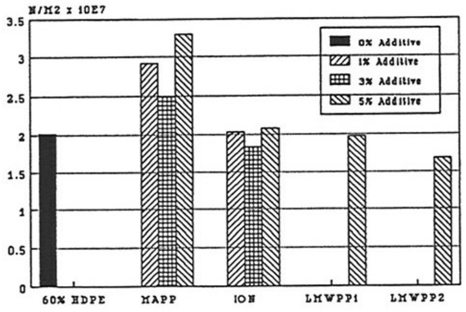

Figure 1. — Tensile strength.

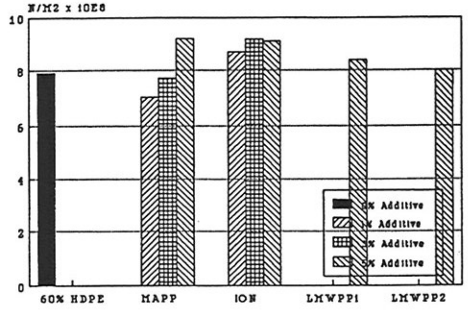

Figure 2. — Modulus of elasticity.

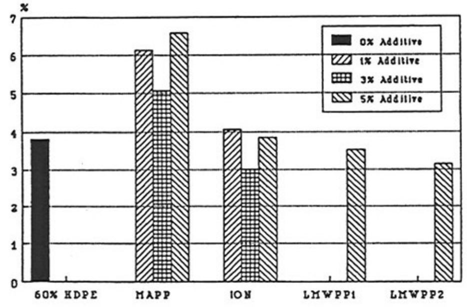

Figure 3. — Elongation at break.

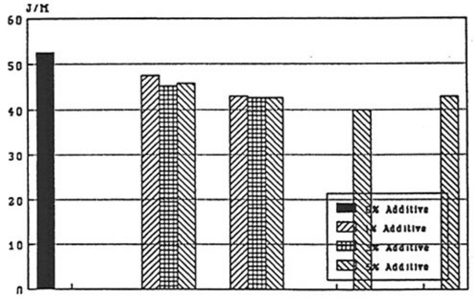

Figure 4. — Izod impact strength.

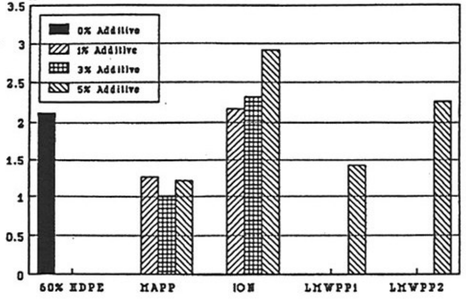

Figure 5. — Water sorption.

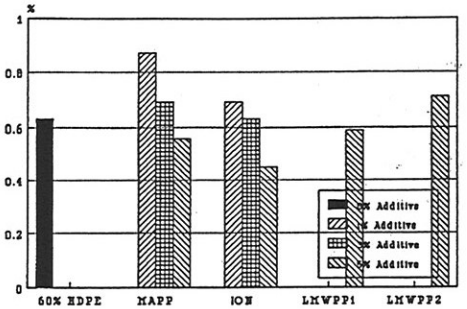

Figure 6. — Creep extension.

Modulus of elasticity

Figure 2 shows the effect of the additives on modulus of elasticity. For MAPP the apparent decrease at 1 and 3 percent levels was not statistically significant, while the increase at 5 percent was significant. For ION, the increases at 3 percent and 5 percent were both statistically significant. The apparent increases at 1 percent for ION and for LMWPP1 and LMWPP2 were not statistically significant.

Elongation at break

Values determined for elongation at break are presented in Figure 3. MAPP at all levels resulted in a significant increase at elongation. ION at 1 and 5 percent showed an apparent increase which was not statistically significant, but the decrease at 3 percent was statistically significant. This confusing result needs verification. LMWPP1 and LMWPP2 resulted in no significant change.

Izod impact strength

Figure 4 shows the results of Izod impact strength determination. As can be seen, all additives resulted in a decrease in impact strength, and this decrease was statistically significant in all cases.

Water sorption

Effects of the additives on water sorption are presented in Figure 5. MAPP and LMWPP1 significantly reduced water sorption by the specimens. ION and LMWPP2 appeared to increase water sorption, although this result was statistically significant only for 5 percent ION.

Creep

Figure 6 presents the results for creep extension. In contrast to the other tests, the number of samples tested was not sufficient for a reliable statistical analysis. These results are presented, therefore, as suggestive rather than conclusive. MAPP and ION appear to increase creep at low concentrations, but decrease creep at higher levels. LMWPP1 appears to slightly decrease creep, while LMWPP2 appears to increase it.

Summary and conclusions

The inclusion of MAPP in the composite improved overall mechanical properties. In general, the improvement increased with increasing concentration of MAPP. Water sorption was also impeded. These results are consistent with earlier findings, and reinforce the view that MAPP is improving the adhesion between the wood fibers and HDPE.

The inclusion of ION produced some positive effects and some negative ones. ION appears to promote water sorption. The inclusion of LMWPP1 and LMWPP2 did not show promising results. In fact, mechanical properties were in general poorer than without the additive. Any improvement offered by better fiber dispersion is not evident.

The decrease in impact strength which was found was not unexpected. While the relationship between reinforcement and impact strength is not entirely understood, reinforced materials are often more brittle than their more easily deformable unreinforced counterparts.

In summary, MAPP can be used to improve the properties of wood fiber/HDPE composites, and appears to act by improving adhesion between the matrix and the fiber. A drawback of using MAPP is its cost, which at $12 per pound is a significant factor (3).

Literature cited

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