Injection Molding and Extrusion of Composites of Low Density Polyethylene (LDPE) and Plywood Grindings

Modification of the properties of thermoplastics like polyolefins by means of low density cellulosic fillers such as wood flour and cellulose pulp has aroused considerable interest during the last few years.[1-6] The properties of these composites strongly depend upon the structure and properties of filler. Wood pulps with considerable large aspect (length to diameter) ratios ($L/D > 15$) can act as reinforcing agents but their cost is usually prohibitive. On the other hand, cheaper wood flours with smaller aspect ratios (L/D usually < 2.5) typically act as fillers which strongly increase the brittleness or decrease tensile strength of polyolefins.[1,5] It can be concluded that the aspect ratio of wood flour and its tendency to increase the brittleness of composite are inversely proportional to each other.

Plywood grindings are wood flour materials with fibrous-like nature. Therefore, they may be potential fillers of thermoplastics. This communication presents our results of processing (injection molding and extrusion) and properties of composites consisting of low density polyethylene and birch plywood grindings.

EXPERIMENTAL

LDPE (Pekema LDPE B 8015; flow index 8.0 g/10 min (ASTM D 1238) and density 915 kg/m^3) was supplied by Neste Oy (Kulloo, Finland).

Plywood grindings were supplied by G.A. Serlachius Oy (Kolho, Finland). Plywood grindings consist of fibers of different dimensions. Figure 1 shows the scanning electron microscope (SEM) figure of the studied grindings.

According to SEM and stereomicroscopical estimations the aspect ratio of these grindings is >5. Figure 2 shows its fiber length distribution. Particles with length over 1 mm were separated from grindings by straining before their use to avoid disturbances during compounding. The plywood grindings were dried 4 h at 105°C before processing. Grindings and LDPE granules were first dry mixed mechanically and then compounded with the Buss-Kneader PR 46. Its compounder screw diameter was 46 mm and L/D ratio 11. The feed screw diameter was 42 mm and L/D ratio 3.5. The compounder was equipped with degassing zone. The temperature profile of compounder was 117–132–132°C and the temperature of feed screw was 128°C. The used concentration of grindings was 30 wt %.

LDPE–grindings composite granules were dried 3 h at 100°C in vacuum before processing by injection molding and extrusion.

The used injection molding machine was Ankerwerk V15-75 with the cylinder diameter of 43 mm and screw L/D ratio = 12. Its maximal injection pressure was 800 kp/cm^2 and maximal injection volume 95 cm^3. The temperature profile of injection molding machine was 110–120–135–135°C (nozzle). The mold temperature was 20°C. The prepared test samples were dumbbell-shaped with cross-sectional dimensions of 5 mm × 10 mm (narrow part) and with the length of the narrow part 10 mm.

The used extruder was a single screw extruder Nokia MP 40-24D with the screw diameter of 40 mm. The usual polyethylene screw was applied. The screw was equipped with Union Carbide (UC) mixing zone. The LDPE–grindings composite was extruded into the form of a rectangle profile with cross-sectional dimensions 1.6 mm × 14 mm by means of a crosshead nozzle. The temperature profile of extruder was 115–120–125°C and the temperature of nozzle was 125°C. The extrudate was cooled by leading it into a cooling channel filled with tap water. Four different screw rotation rates (20, 50, 100, and 120 rpm) were used.

Dumbbell-shaped tensile testing samples with cross-sectional dimensions of 1.6 mm × 4 mm (narrow part) and with the length of the narrow part 25 mm were punched from the profile manually.

The stress–strain behavior of injection-molded and extruded tensile testing samples was studied by JJ Tensile Testing Machine Type T 5003 with the test speed of 50 mm/min. The

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Fig. 1. SEM figure of the studied birch plywood grindings (magnification 32.5 ×).

number of parallel samples was varied between 6 and 12. Tensile impact tests of injection-molded samples were carried out according to standard DIN 53 448.

The morphology of fracture surfaces of test samples was studied by the SEM Microscope JEOL JSM-U3. The samples were vacuum-coated with carbon before examination.

RESULTS AND DISCUSSION

The compounding of LDPE and grindings left some gas bubbles (pores) in the granules. However, the injection-molded samples and the extruded profile were free of pores. There was also no evidence of agglomerates of wood flour in the products. The color of injection-molded and extruded samples was brown. The former were darker than the latter. In the case of extrusion the intensity of color increased with the decrease of rate of screw rotation, which indicated that the stay time of LDPE–wood flour mixture in extruder was the primary factor determining the degree of pyrolysis of wood flour at the studied extrusion conditions.

The results of mechanical tests of injection-molded and extruded samples are given in Table I, which shows that compounding of LDPE with grindings decreases by about 20% the tensile strength of LDPE. This decrease of tensile strength is emphasized by high rotation rates of extruder screw. An evident explanation to this is that the homogeneity of the product decreases with increasing screw rotation rate (which means also increasing yield), which is reflected as decreasing of tensile testing values.

Table I shows that the studied plywood grindings do not act as a reinforcing agent in LDPE because the tensile strength of LDPE decreases 20–30% as a consequence of addition of grindings. However, it is interesting to note that the elongation at break is retained to a good extent both in the case of injection-molded and extruded samples. This is clearly seen if we compare results of Table I with elongations obtained in other studies where wood flours have been

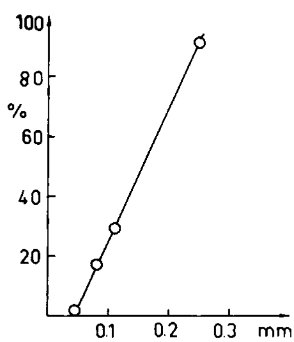

Fig. 2. Fiber length distribution of the studied birch plywood grindings.

TABLE I
Mechanical Properties of Injection Moulded and Extruded LDPE–Birch Plywood Grindings Composites

Manufacturing process	Screw rotation rate ($r \cdot min^{-1}$)	Amount of grindings (wt%)	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Tensile impact strength ($kJ \cdot m^{-2}$)
Injection molding	—	0	9.05	105	260	320
	—	30	6.95	230	68	80
Extrusion	20	0	10.1	—	460	—
	20	30	7.7	—	37	
	50	30	7.2	—	38	
	100	30	6.8	—	35	
	120	30	7.0	—	37	

compounded with LDPE. Accordingly, Blomberg et al. studied press-molded sheets of LDPE B 8015–wood flour and –ground waste fibers.[7] They obtained for 33 wt % filler samples elongations at break between 6% and 9%. Also the corresponding values of Berggren et al. for injection-molded LDPE–30 wt % wood flour composites were ~10%.[1]

We can conclude that the fibrous-like plywood grindings increase the brittleness of LDPE less strongly than the more particlelike wood flours. The good elongation at break value is also correlated with the tensile impact strength value: according to Table I LDPE–30 wt % grindings sample has a tensile impact strength which is still 25% of the value of original LDPE.

Figure 3 shows a typical fracture surface SEM figure of a test sample. According to Figure 3, there is no noteworthy adhesion between LDPE and grindings fibers because free fiber ends and holes left by pullout of fibers can be seen. On the other hand, the pullout mechanism in combination with the fibrous-like structure of grindings is an evident explanation to the moderate toughness of this composite.

Taking into account the facts that (a) the plywood grindings are a byproduct of manufacturing plywood, which means that its price is not determined by its production costs but by its energy value (~0.25 $/kg as it is now) and (b) it is a product with a very high degree of purity and fibrous-like character, it is evident that this material can be applied successfully as a filler of thermoplastics such as polyethylene.

The advantages of this composite are high modulus, moderate elongation at break, moderate tensile strength, moderate impact strength, light weight ($\rho \sim 1.030 \text{ g} \cdot \text{cm}^{-3}$), better adhesion with glues,[8] and competitive raw material costs. This combination of properties gives possibilities to apply this material, e.g., in automotive industry.

SUMMARY

Low-density polyethylene (LDPE) and birch plywood grindings (30 wt%) were compounded to granules, which were injection-molded and extruded to test samples and profiles. The mechanical testing of injection-molded samples showed that grindings increase considerably the modulus of LDPE (from 105 MPa to 230 MPa). However, the composite is still ductile (elongation at break = 68%). Also the extruded samples showed still moderate ductile behavior (elongation at break-35–38%). The loss of tensile strength of 20–30% was registered, which showed that the adhesion between LDPE and grindings was poor. The ductile behaviour of test samples was explained by the moderate high aspect (length to diameter) ratio ($L/D > 5$) of birch plywood grindings.

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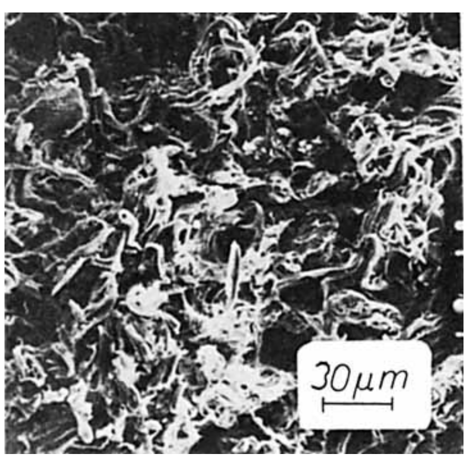

Fig. 3. A SEM figure of the fracture surface of a test sample (magnification 288 ×).

References

1. K. Berggren, C. Klason, and J. Kubát, *Kunststoffe*, **65**, 69 (1975).
2. S. A. Hider, *U.S. Pat.* 3,325,345 (1967).
3. N. G. Gaylord, *U.S. Pat.* 3,645,939 (1972).
4. J. R. Quick, *Symposium of Renewable Resources for Plastics*, American Chemical Society 169th National Meeting, Philadephia, Pa, April 1975, pp. 56–67.
5. G. R. Lightsey, P. H. Short, and V. K. K. Sinha, *Polym. Eng. Sci.*, **17**, 305 (1977).
6. A. J. Michell, J. E. Vaughan, and D. Willis, *J. Appl. Polym. Sci.*, **22**, 2047 (1978).
7. T. Blomberg, P. Lehmus, and V. Tammela, *Kemia-Kemi*, **4**, 57 (1977).
8. E. Pääkkönen, J. Laiho, and P. Törmälä, unpublished results.

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