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Characterization of Fiber Length Distribution in Short andLong-Glass-Fiber Reinforced Polypropylene during Injection Molding Process

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ABSTRACT

The reduction in fiber length during injection molding of two commercial glass-fiber reinforced polypropylene (PP) granules was studied. The first containing 20 percent by weight (wt%) of short-glass-fibers with the average fiber length around 350 μm and the other filled with 40 wt% of relatively much longer fibers mostly around 7,000 mm. The fiber length distribution (FLD) was measured along the screw channels and after the molten composite was injected through a nozzle of an injection unit. The results indicated that the FLD moved to shorter fiber lengths along the screw channels further from the hopper. In both cases, fiber attrition occurred predominately in the feed and the compression zones, particularly in long-glass-fiber reinforced polypropylene. More severe fiber attrition in this finding can be assumed due to higher fiber concentration and longer fiber length which result in a higher degree of fiber-fiber interaction and increased fiber-wall contacts.

Key words: glass-fiber reinforced polypropylene, fiber attrition, fiber length distribution, injection molding process

INTRODUCTION

The use of reinforced thermoplastics in engineering applications is increasing and diversifying. Glass-fibers have been extensively used in the automotive industry for many years because of their high strength-to-weight ratio, high stiffness, corrosion resistance and design flexibility, and so on. In general, the mechanical properties of fiber reinforced thermoplastics depend not only on the properties of raw materials used and their compositions but also on processing methods (Ramos and Belmontes, 1991; Thomason, 2002). Several factors affect the mechanical behavior of fiber reinforced thermoplastics such as the characteristics of matrix and fiber, interfacial bonding, fiber content, void volume, fiber orientation distribution and fiber length distribution (Akay and Barkley, 1985; Singh and Kamal, 1989; Akay and O'Regan, 1995; Barbosa and Kenny, 1999). Injection molding process is the most common processing technique used to manufacture fiber reinforced thermoplastic products. Severe fiber breakage occurs in this process, and resulting composites have short fiber length distribution (Turkovic and Erwin, 1983; Gupta *et al*., 1989). It is well known that fiber reinforced thermoplastics do not achieve their maximum possible stiffness, strength, and toughness properties, because of many factors and

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one of the main reasons for this is the short fiber length within the composites. Hence, in the past decade, a trend has developed to use long fiber reinforced plastic pellets as molding compounds (Denault *et al.*, 1989; Bailey and Rzepka, 1991). Some benefits of long fiber products, such as better mechanical properties, better impact resistance, and enhanced creep performance, have been reported (Karger-Kocsis and Friedrich, 1988; Denault *et al.*, 1989; Thomason, 2002b and 2005).

In the present study, fiber attrition was investigated during injection molding process in detail along the screw channels and after the molten composite was injected through a nozzle of an injection unit. The first starting sample was a commercial product in which most of the fibers were around 350 μm while the second was another commercial sample containing 7,000 μm long fiber strands.

MATERIALS AND METHODS

The materials used in this study were polypropylene filled with 20 wt% of short-glass-fibers and 40 wt% of long-glass-fibers; both materials were supplied in granular form by Chisso Polypro and Verton, respectively. An Arburg Allrounder 320C injection molding machine was used to prepare helices from the two commercial glass-fiber reinforced PP granules described above. The nozzle diameter was 2 mm and the nozzle temperature was set at 240 °C. The screw rotation speed and injection flow rate were kept at 12 rpm and 25 cm^3/s respectively. The screw profile is schematically demonstrated in Figure 1(a). The starting material was fed through the feed hopper of injection unit. As the screw rotated (driven by an electric motor) the granules moved forward in the screw channel to the screw tip. The granules were undergone extreme pressure and friction which generated most of the heat needed to melt the granules. After the shot size has been reached, the screw pushed the molten material through the nozzle of the injection unit, as illustrated in Figure 1(b). The injection molding machine was then stopped and cooled down rapidly. The screw was removed and the frozen content of the screw channel was taken out as a helix; a typical helix is shown in Figure 2.

Short and long-glass-fibers were isolated from the composite material using an incineration

A

B

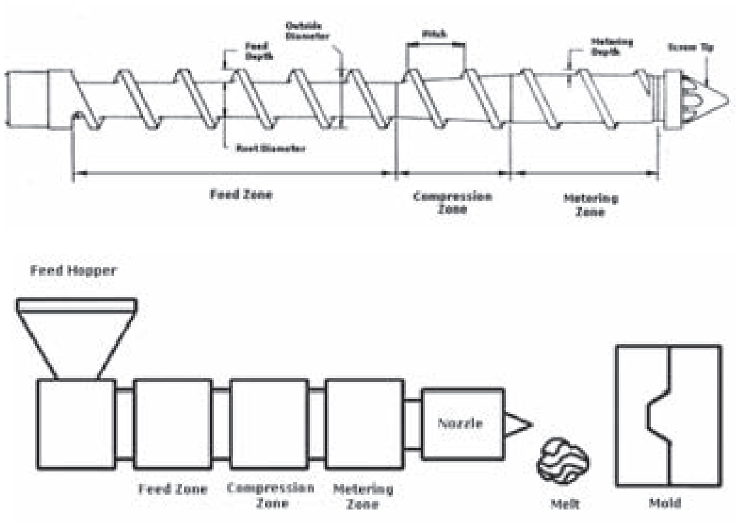

Figure 1 (a) Schematic drawing of a screw profile (b) typical injection molding machine (b).

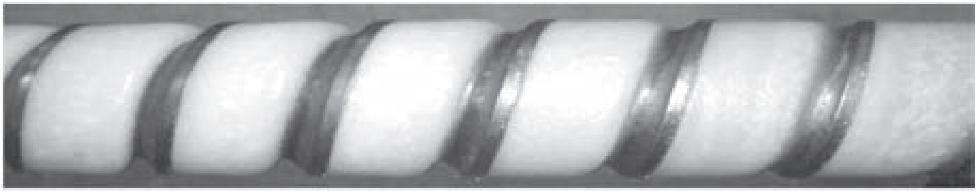

Figure 2 Photograph of helix.

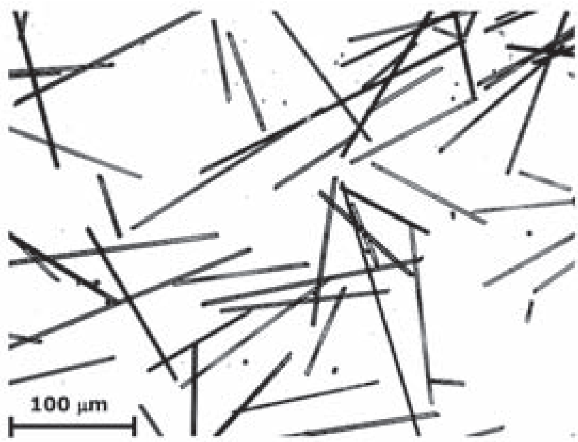

Figure 3 Digital image of fibers.

method, according to DIN EN 60. Small sections of the helices were kept in crucibles, and the PP matrix was removed by burning off in a muffle furnace maintained at 650°C for a period of 2 hours. The fiber length measurements were made with the help of polarized light microscopy (OLYMPUS model PMG3) and computer aided image analysis (Image-Pro Plus), as shown in Figure 3. The fiber length distribution (FLD) was determined by the average fiber length, which calculated from a minimum of 500 length measurements on fibers recovered from the incineration. From the fiber length distribution, the following average length was derived:

$$\text{Average fiber length } \bar{l}_n = \frac{\sum n_i l_i}{\sum n_i}$$

where n_i is the number of fibers of length l_i

The percentage difference between the average fiber length inside the granules and the overall glass-fiber length inside the sample ($\%\Delta l$) was used to describe the results. For this purpose the following equation was employed:

$$\%\Delta l = \left[\frac{\bar{l}_G - \bar{l}_i}{\bar{l}_G}\right] \times 100$$

with $\bar{l}_G$ being the average fiber length inside the granules and $\bar{l}_i$ the average fiber length inside the samples.

RESULTS AND DISCUSSION

The length distribution of the short and long-glass-fibers in the starting commercial granules are shown in Figure 4(a) and (b). The reduction in fiber length as the material progressively moves in the screw channels is clearly brought out in Figure 5(a) and (b) which show the percent differences between each stages

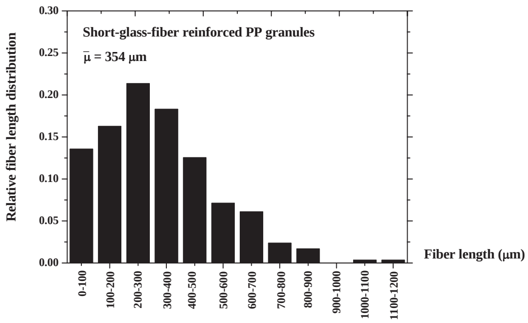

Figure 4 (a) Fiber length distribution of granules PP with 20 wt% short-glass-fibers.

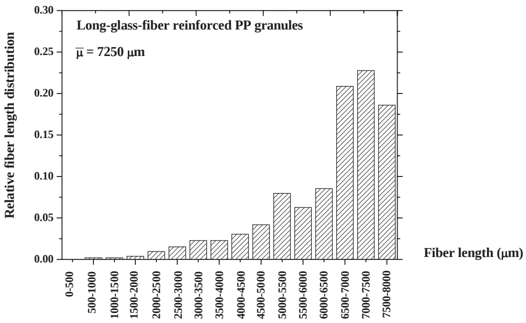

Figure 4 (b) Fiber length distribution of granules PP with 40 wt% long-glass-fibers.

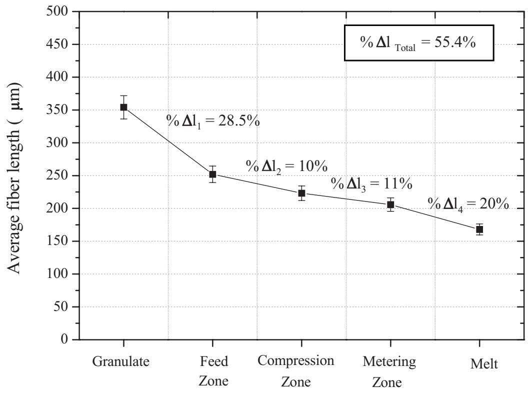

Figure 5 (a) Fiber attrition at various stages of injection unit of PP filled with 20 wt% short-glass-fibers.

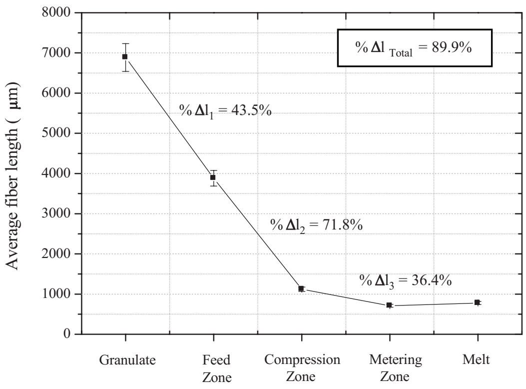

Figure 5 (b) Fiber attrition at various stages of injection unit of PP filled with 40 wt% long-glass-fibers.

for both materials. Our experiments showed that the total reduction of fiber length ($\%\Delta l_{total}$) is approximately 50-55% for short-glass-fiber filled PP granules and 85-90% for long-glass-fiber filled PP granules. The explanation of the fiber attrition phenomena are all based on the analysis of the forces and moments experienced by fibers in a shearing flow (Czarnecki and White, 1980; Salinas and Pittman, 1981; Turkovic and Erwin, 1983). However, it should be noted that extensive breakage of fibers takes place in the feed zone ($\%\Delta l_1 \sim 30\%$ for short-glass-fibers and ~ 40% for long-glass-fibers). In the compression zone, where the initiation of the melting of the polymer occurred, there is a significant continuing reduction in length particularly in the case of the long fiber granules ($\%\Delta l_2 \sim 70\%$) while the short fiber granules showed little reduction in fiber length ($\%\Delta l_2 \sim 10\%$). The occurrence of more pronounced fiber length degradation for long-glass-fibers is believed to arise from an increased fiber-fiber and fiber-wall interactions in the more viscous melt. A further fragmentation of fibers also occurred in metering zone ($\%\Delta l_3$) and during injection process ($\%\Delta l_4$). This is due to the melt containing the glass fibers has to pass through the narrow channels in the metering zone and the nozzle of the injection unit which result in further breakage. The average fiber length in the injected melt is ~ 160 mm for short-glass-fiber filled PP granules and ~ 750 μm for long-glass-fiber filled PP granules. A dramatic reduction of the fiber length can also occurred in the mold cavity which in turn depends on the geometrical shape of the mold such as gating, insert, and section thickness, as have been reported by many authors (Sanou *et al.,* 1985; O'Regan and Akay, 1996; Larsen, 2000).

CONCLUSIONS

As amply documented in the available literature, and also as evident from the results obtained in the present investigation, glass-fibers used to reinforce common thermoplastics are degraded to such a degree that their ultimate shape almost makes them resemble particulate filler, with all the adverse effects in the mechanical properties. The breakage of fibers occurs predominantly in the feed and compression zones, such that the final length of long-glass-fibers reduces to 10% of its initial length. Fiber attrition can thus be minimized by decreasing the residence time (shorter screw) and/or screw design, thereby decreasing fiber-fiber and fiber-wall interactions which were found to control the attrition process. This will, however, be done at the expense of the quality of the melt to be injected.

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LITTERATURE CITED

Akay, M. and D. Barkley. 1985. Processing-structure-property interaction in injection molded glass-fiber-reinforced polypropylene. **Composite Structure** 3(3-4): 269-293.

Akay, M. and D. O'Regan. 1995. Generation of voids in fiber reinforced thermoplastic injection moldings. **Plastics, Rubber and Composites Processing and Applications** 24(2): 97-102.

Bailey, R. and B. Rzepka. 1991. Fiber orientation mechanisms for injection molding of long fiber composites. **International Polymer Processing** 6(1): 35-41.

Barbosa, S.E. and J.M. Kenny. 1999. Analysis of the relationship between processing conditions fiber orientation-final properties in short fiber reinforced polypropylene. **J. Reinforced Plastic and Composites** 18(5): 413-420.

Czarnecki, L. and J.L. White. 1980. Shear flow rheological properties: Fiber damage and mastication characteristics of aramid-, glass-, and cellulose-fiber reinforced polystyrene melts. **J. Applied Polymer Science**. 25: 1217-1244.

Denault, J., T. Vu-Khanh and B. Foster. 1989. Tensile properties of injection molded long fiber thermoplastic composites. **Polymer Composites** 10(5): 313-321.

Gupta, V.B., R.K. Mittal, P.K. Sharma, G. Mennig and J. Wolters. 1989. Some studies on glass-fiber-reinforced polypropylene, Part 1: Reduction in fiber length during processing. **Polymer Composites**. 10(1): 8-15.

Karger-Kocsis, J. and K. Friedrich. 1988. Fatigue crack propagation in short and long fiber-reinforced injection-molded PA 6.6 composites. **Composites** 19(2): 105-114.

Larsen, A. 2000. Injection molding of short fiber reinforced thermoplastics in a center-gated mold. **Polymer Composites** 21(1): 51-64.

O'Regan, D. and M. Akay. 1996. The distribution of fiber lengths in injection molded polyamide composite components. **J. Material Processing Technology** 56(1-4): 282-291.

Ramos, M.A. and F.A. Belmontes. 1991. Polypropylene/low density polyethylene blend matrices and short glass fiber based composites III: Morphology and fiber orientation. **Polymer Composites** 12(1): 7-12.

Salinas, A. and J.F.T. Pittman. 1981. Bending and breaking fibers in sheared suspension. **Polymer Engineering and Science** 21: 23-31.

Sanou, M., B. Chung and C. Cohen. 1985. Glass fiber-filled thermoplastics, Part 2: Cavity filling and fiber orientation in injection molding. **Polymer Engineering and Science** 25(16):1008-1016.

Singh, P. and M.R. Kamal. 1989. The effect of processing variables on microstructure of injection molded short fiber reinforced polypropylene composites. **Polymer Composites**10(5): 344-351.

Thomason, J.L. 2002a. Interfacial strength in thermoplastic composites. **Composites Part A: Applied Science and Manufacturing** 33(10): 1283-1288.

___________ . 2002b. The influence of fiber length and concentration on the properties of glass fiber reinforced polypropylene: 5. Injection molded long and short fiber PP. **Composites Part A: Applied Science and Manufacturing**. 33(12): 1641-1652.

___________ . 2005. The influence of fiber length and concentration on the properties of glass fiber reinforced polypropylene: 6. The properties of injection molded long fiber PP at high fiber content. **Composites Part A: Applied Science and Manufacturing**. 36(7): 995-1003.

Turkovic, R. and L. Erwin. 1983. Fiber fracture in reinforced thermoplastic processing. **Polymer Engineering and Science**. 23(13): 743-749.