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Examining foaming technology for long-fiber-reinforced polypropylene composites

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Novel injection molding technology can reduce the level of fiber breakage during processing and the degree of fiber alignment along the flow direction.

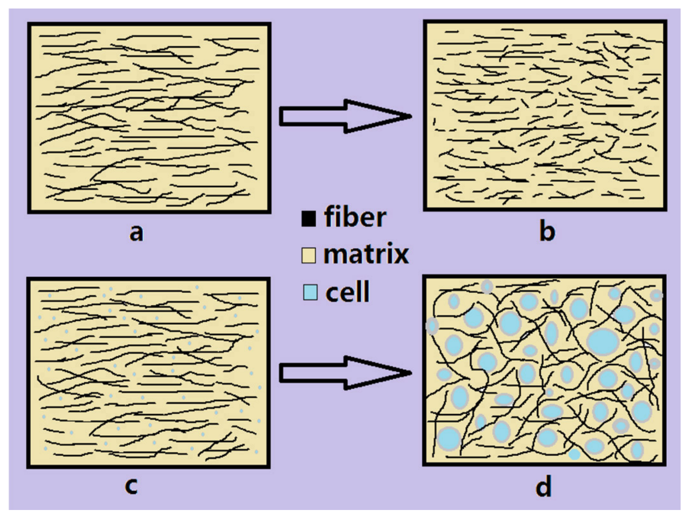

Figure 1. *Model illustrating the influence of gas bubbles on glass-fiber orientation and breakage in the long-glass-fiber-reinforced polypropylene samples fabricated via a conventional injection molding (top) and water-foaming injection molding (bottom) process.*

Although polypropylene (PP) is one of the most widely used plastics (because of its low density, ease of processing, high softening temperature, and low cost), its application is somewhat limited because of its relatively poor mechanical properties. Frequently, therefore, glass fiber (GF)—offering good tensile strength and moduli, stiffness, impact resistance, chemical resistance, and thermal stability, all at low cost—is used to reinforce PP matrices. Indeed, combining PP and GF in this way is becoming more and more popular in fields such as the automotive and building industries. To date, short glass fiber (SGF)—with an aspect ratio of less than the critical value of 200—has been traditionally used to reinforce materials in the polymer composites industry. In more recent years, however, the use of long glass fiber (LGF) reinforcements for PP has seen a 30% per year increase in the polymer industry.[1]

Injection molding is one of the most common manufacturing techniques for GF-PP composites, because of the ability to rapidly fabricate parts with complex geometries. The mechanical properties of injection molded GF-PP composites has thus been of much interest for many years, and it is generally thought that the mechanical properties of GF-reinforced PP parts are mainly influenced by factors such as the length, length distribution, and orientation of the fibers, as well as by the interfacial adhesion between the GF and the PP matrix, and by the inherent mechanical properties of the GF and matrix materials. It has also been shown that foaming technologies can reduce the amount of fiber breakage in GF-PP molded parts[2] and can help avoid fiber attrition in SGF-PP parts.[3,4] Almost all these previous studies, however, have been focused on SGF-reinforced polymer matrices, and it is still unclear whether foaming will be equally applicable to LGF-reinforced composites.

In our work, we have therefore been motivated to explore a variety of foaming methods for improving the mechanical properties of GF-PP composites. For example, we have previously investigated the influence of processing technology on the mechanical properties and foamed structure of PP/low-density polyethylene blends.[5] We found that by carefully selecting the injection molding processing parameters, it was possible to achieve dramatic improvements in the ductility of the composites. As an extension of the previous study, in our new work we have thus examined the influence of different foaming technologies on the fiber length and fiber orientation of GF-PP composites. In particular, we investigated a variety of different processing conditions—for both conventional injection molding (CIM) and foaming injection molding (FIM)—for the fabrication of LGF-reinforced PP composite samples with different initial feedstock lengths (i.e., LGFs and SGFs).[6,7]

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As part of our experiments, we performed tensile tests to measure the mechanical properties (e.g., strength, modulus, strain-at-break) of our composites. Our results show that there is a close relationship between the residual fiber lengths and the mechanical properties of the samples, both of which are largely influenced by the processing conditions. We also find that the LGF-reinforced water-FIM samples exhibited the best fiber length and fiber-length distribution (i.e., giving rise to the best mechanical characteristics). Furthermore, these samples exhibited a lower degree of fiber orientation along the fiber direction than the CIM samples.

The results of our study also suggest that the presence of gas bubbles in LGF-reinforced composites may help reduce the amount of fiber breakage. We attribute this finding to two possible reasons. First, the embedded blowing agent and emerging bubbles can act as a plasticizer or cushioning spacer. In other words, the presence of gas bubbles in the LGF-reinforced PP composites reduced the viscosity of the melt and improved the flowability. In turn, this reduced the shear stresses in the polymer matrix and thus decreased the occurrence of fiber breakage. Second, the packing stage of the injection molding process is an important step that can substantially influence the degree of fiber breakage. That is, variations in the packing stage can lead to different fiber-length distributions in CIM and FIM samples. During the conventional packing of CIM, high pressure is used to inject melted composites into the cavity and the mold cavity is then maintained at a constant pressure to fill the remaining volume of the cavity and compensate for shrinkage of the filled materials. Breakage of LGFs may occur primarily at this packing stage, and so the packing pressure can strongly influence fiber breakage. In contrast, during water-FIM, packing of the filled material into the mold mainly relies on the effect of expansion from the growth of bubbles. The damage to fibers can thus be minimized because of the relatively small, uniform pressure and shear rate.

From the results of our study, we have formulated a model (see Figure 1) to explain the fundamental mechanism by which foaming technology helps to reduce fiber orientation along the flow direction in our LGF-reinforced PP composites. In this model, the fibers are mainly parallel to the flow direction after the composites fill the mold during the CIM process: see Figure 1(a). At this stage, the polymer composite melt is pressed continuously so that the fibers in the shell layers (near the mold walls) break up under the high pressure and shear until they are frozen into the polymer matrix. The fiber orientation in the skin layer of the mold samples—see Figure 1(b)—is therefore very noticeable. In contrast, the breakup and orientation of fibers in the core layer are generally weaker than in the skin layer. This is partly because of the smaller velocity gradient during melt filling of the core and possible disorientation of fibers when the gate freezes before the polymer composite melt. We observed a similar trend during the filling stage of water-FIM: see Figure 1(c). In the subsequent stage of bubble growth, however, the force of expansion in the water steam is gentle and uniform. Fiber breakup is therefore less likely, and the randomly oriented fibers form an interlocking network in the polymer–gas matrix, as shown in Figure 1(d).

In summary, we have investigated the mechanical properties of GF-reinforced PP parts that contain either SGFs or LGFs and that were fabricated via a conventional or water-foamed injection molding process. Our experimental results indicate that the mechanical properties (e.g., tensile strength) of the LGF-PP FIM composites were superior to the CIM equivalents. We also found that water-foaming injection molding technology can effectively reduce the amount of fiber breakage in the composites. In turn, this helps to improve the mechanical properties and fiber orientation of the samples. In the next stages of our work, we are already conducting a quantitative evaluation of the relationship between fiber residual length and the mechanical properties of LGF-PP FIM composites.

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