EFFECT OF PACKING PRESSURE AND MOLD TEMPERATURE ON FIBER ORIENTATION IN INJECTION MOLDING OF REINFORCED PLASTICS

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ABSTRACT: Injection molding of fiber reinforced polymeric composites is increasing with demands of complex products possessing superior mechanical properties of high specific strength, high specific stiffness, good fatigue strength and high impact resistance. Complex state of fiber orientation exists in injection molding of short fiber reinforced polymers. The orientation of fibers can vary significantly across the thickness of injection-molded parts and can become a key feature of the finished products. Improving the mechanical properties of molded parts by managing the orientation of fibers during the process of injection molding is the basic motivation of this study. This experimental work reveals the importance of packing pressure and mold temperature in orienting the fibers.

KEYWORDS: Injection Molding, Fiber orientation, Packing Pressure, Mold Temperature, Reinforced Thermoplastics

INTRODUCTION

Injection molding process is capable of producing intricate net shapes without any secondary processing and is thus being widely used in the electronic, automotive, aerospace and various other industries. Recently, the demand is increasing for geometrically complex and precision products, possessing superior mechanical properties. Thermoplastics coupled with fibers, as reinforcement, offer a number of advantages in terms of end-use performance to meet the desired demand. However, their use can also create several processing-related problems. The differential shrinkage between the in-flow and cross-flow directions of fiber-reinforced polymers can make it more difficult to determine the appropriate cavity dimensions and to prevent warpage. Anisotropic behavior of fiber-reinforced polymers can be attributed to the fact that the fibers become oriented during the injection molding process. The orientation of fibers varies significantly across the thickness of injection-molded part and can become a key feature of the finished product. Improving the mechanical properties of molded parts by managing the orientation of fibers during the process of injection molding was concerned in many studies. The effects of different parameters such as melt and mold temperature, flow rate, matrix and fiber properties, volume fraction of fibers, molding geometry, gate type and gate location on the detailed distribution and orientation of fibers in the final products have already been presented in many studies. In spite of all of these investigations still the process offer challenges on a fundamental level to the understanding of the relations between material parameters, processing, structure development, and final properties.

There are confusions in the conclusions of many studies [1, 2, 3, 4, 5] in explaining the state of fiber orientation at core layer of the molded parts. Fischer [1] explained that at the core layer of the part, the melt being pushed forward develops a flattened profile and fibers within this region do not orient without a well-developed shear flow. But Malzahn & Schultz [2] believed on the rotation of fibers at core region and concluded that the complete transverse alignment at the core region develops only after the instant of fill. It can be seen in the study of Gupta & Wang [3] who concluded that the in-plane stretching flow causes the fibers at the mid-plane to align transverse to the flow direction and the authors [3] in contrast to the study of Malzahn & Schultz [2] believed that the fiber orientation is only weakly dependent upon the post-filling stage of injection molding process due to a decreased flow field. Bay & Tucker [4] concluded that if there is significant in-plane stretching, the core is aligned in the principal stretching direction and in the case of no in-plane stretching, the core orientation is generated by the flow just inside the gate and is carried down the cavity with little change and these cores are more likely to have random-in-plane orientation. Another completely different expression can be seen in the study of Folkes & Russell [5] who concluded that the major contribution to the condition of the core comes not from flow induced molecular alignment but from columnar spherulitic growth that is known to occur around fibers in the absence of an externally applied flow field.

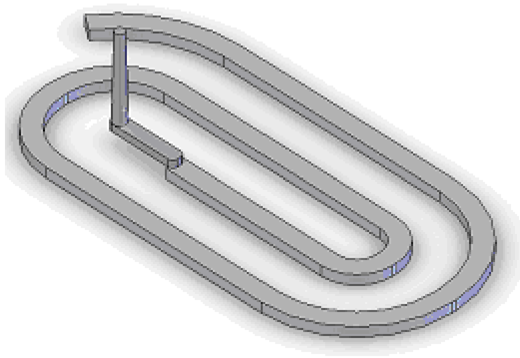
Contradictory explanations for the effect of mold temperature on the state of fiber orientation can also be seen in the conclusion of a few related studies [3,4, 6]. Gupta & Wang [3] believed that under isothermal condition, which means replacing the cold-wall temperature with the injection melt temperature; a change in injection speed has no effect on fiber orientation. In other words high mold temperature can eliminate the effect of injection speed; While Bay & Tucker [4] found that the mold wall temperature has little effect on the fiber orientation, even though they believed that the mold temperature could have a large effect on molecular orientation or crystallinity in some polymers. It can also be seen in the study of Vincent et al. [6] that variation in mold temperature did not affect the fiber orientation distribution in the products of their experiments.

In this study, a spiral mold was designed and fabricated to study the effect of packing pressure and mold wall temperature on the final orientation pattern of short fibers in injection molded parts.

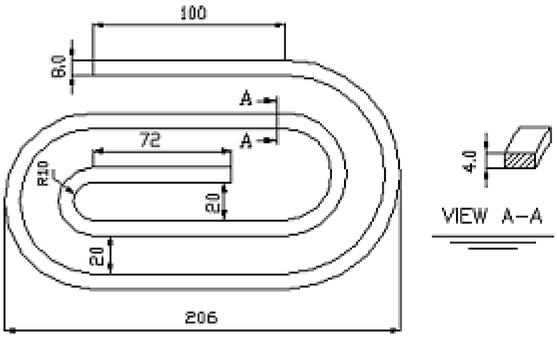
EXPERIMENTS

The mold used for this work and the geometry of its products is shown in Fig. 1.

a. Spiral mold cavity plate



b. The product of spiral mold



c. Geometry of the product

Fig. 1 Spiral mold and the solid model with geometry of its product

RGF33 NATURAL (TUFNYL, SRF Made), a 33% by weight short glass fiber reinforced in Nylon 66 in natural shade, was used in the experiments of this study. Recommended injection pressure for RGF33 NATURAL is 1000 -1250 Kg / cm^2 (10-12.5 MPa) or sufficient to fill the cavities. For this grade predrying of the granules in a vacuum oven at 100 ºC for 2 hours was done prior to molding as recommended by the supplier. Recommended temperature setting at nozzle was 290ºC for RGF33 NATURAL.

For analyzing the effects of packing pressure and mold temperature on the state of fiber orientation, three different Cases I, II, and III were studied. Injection pressure was set at 70% of maximum available pressure and injection speed was constant for all the Cases of this study. Packing pressure and the mold wall temperature for the three Cases was set according to Table 1.

Table 1 Process conditions

Case	Packing Pressure (%Max Injection pressure)	Mold Wall Temperature (ºC)
I	0%	35
II	40%	35
III	40%	70

The parts were molded on a L&T Demag PFY40-LNC4P injection molding machine of a screw diameter 28 mm, a maximum hydraulic pressure of 16 MPa, a maximum specific melt pressure of 175 MPa at the tip of the nozzle and a clamping force of 40 tons ($4x10^5$ N) for an injection capacity of 60 g.

For analyzing the state of fiber orientation at the core layer, cut-sections parallel to the plane of flow at locations A & B as shown in Fig. 2, were prepared.

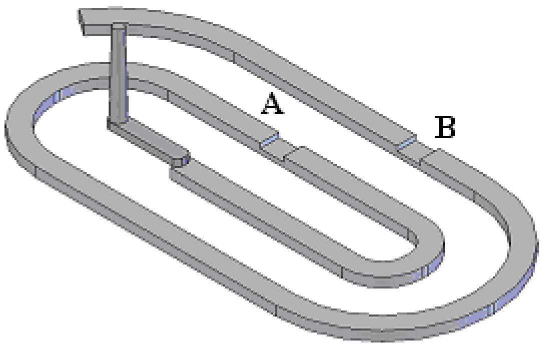
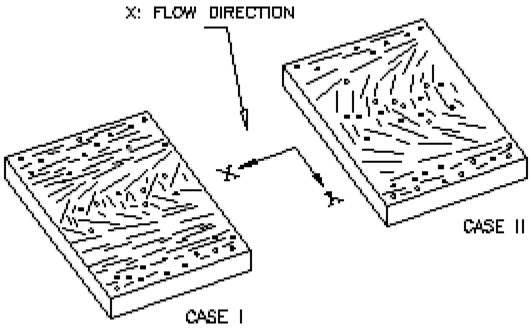


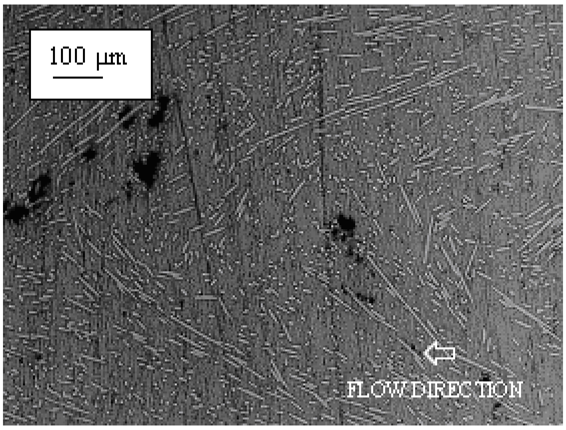
Fig. 2. Cut-sections parallel to the plane of flow at locations A & B for analyzing the state of fiber orientation in the mid-plane (Core layer)

RESULTS

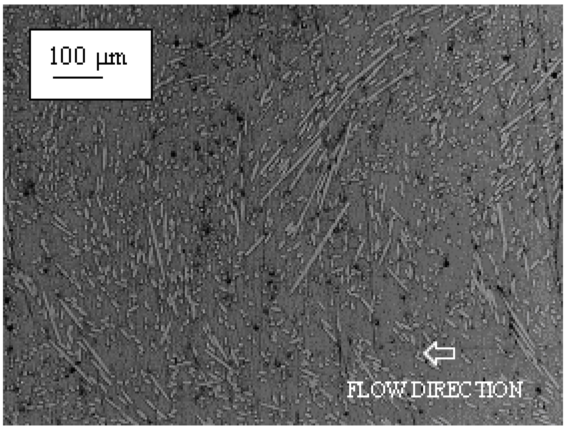
In the first step of this study, the states of fiber orientation at the core layer in the plane of flow for Cases I and II are compared. In Fig. 3a schematic pattern of observed fiber orientation and in Fig. 3b and 3c the micrographs of cut-sections for Cases I & II are shown. Comparing these micrographs shows higher alignment of fibers in the flow direction at the midplane for Case I. However, due to applied packing pressure for Case II, fibers get more transverse orientation. Moreover, as can be seen the fibers follow a specific pattern as depicted schematically in Fig. 3a such that implying random state of fiber orientation at the core layer as understood in earlier works [4, 7], where the specimens were cut at the thickness wise cross section, could not be judged appropriately.



a. Schematic pattern of fiber orientation at location A (Cases I & II)



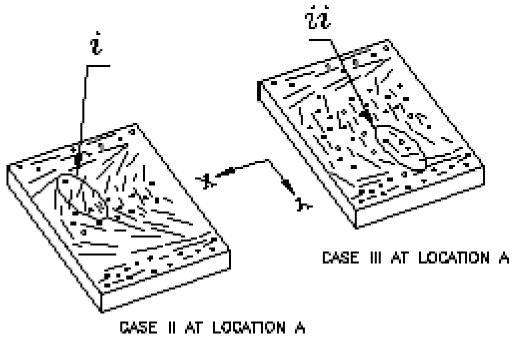
b. Lower degree of transverse orientation of fibers at the centerline (Case I)



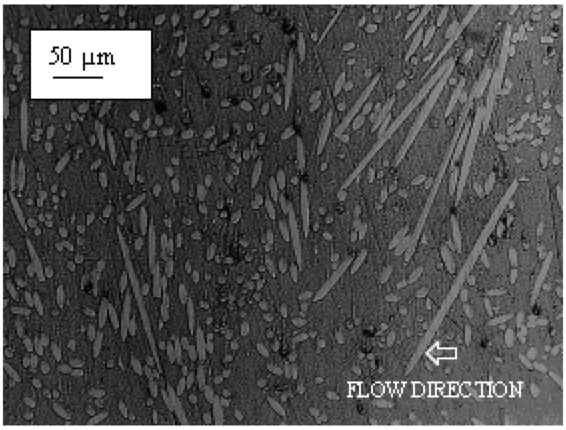
c. Higher degree of transverse orientation of fibers at the centerline (Case II)

Fig. 3 State of fiber orientation in the mid-plane of flow at location A (Cases I & II)

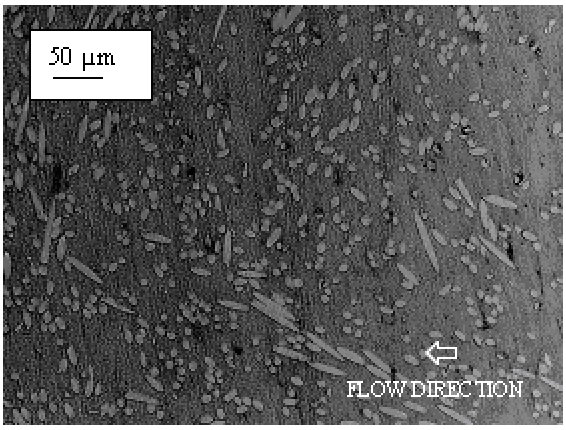
In the second step, for analyzing the effect of mold wall temperature, the state of fiber orientation is compared between Cases II (cold and packed) & III (hot and packed) at locations A & B. Schematic pattern of observed fiber orientation at location A (close to gate) along with related micrographs are shown in Fig. 4.



a. Schematic pattern of fiber orientation at location A (Cases II & III)



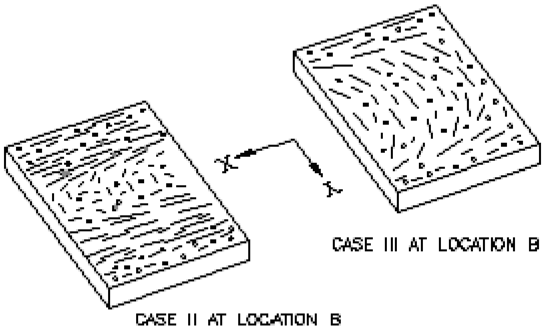
b. Higher degree of in-plane transverse orientation of fibers at location A_i (Case II)



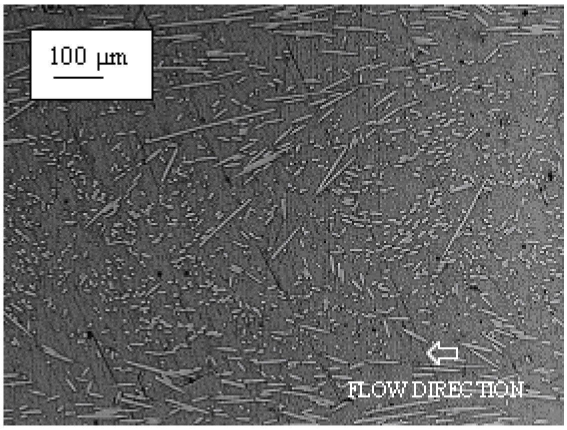
c. Higher degree of out of plane orientation of fibers at location A_{ii} (Case III)

Fig. 4 State of fiber orientation in the mid-plane of flow at location A with higher magnification (Cases II & III)

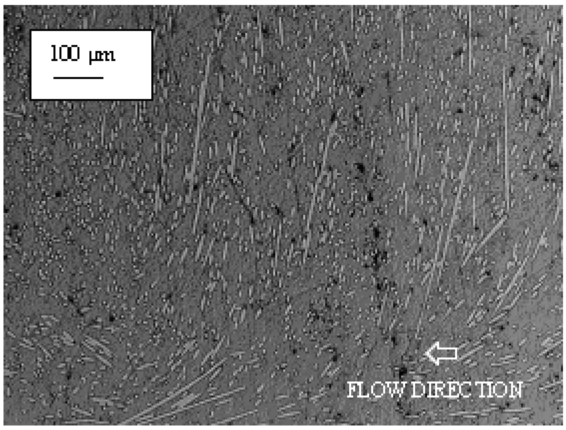
Comparing these micrographs shown in Fig. 4b and 4c indicates higher circular cut-sections of the fibers in Case III that from top view represents more out of plane orientation of fibers. Since increasing the mold temperature delays heat transfer from the melt to the mold walls, the authors attribute the observed state of fiber orientation to the reduction in the viscosity of melt, which facilitates the rotation of fibers for getting more out of plane orientation during the packing stage. It should be noted that out of plane orientation of fibers could also be considered a kind of transverse orientation of fibers with respect to the flow direction.



a. Schematic pattern of fiber orientation at location B (Case II & III)



b. Lower degree of transverse orientation of fibers at location B (Case II)



c. Higher degree of transverse orientation of fibers at location B (Case III)

Fig. 5 State of fiber orientation at centerline of mid-plane at location B (Case II & III)

In Fig. 5 schematic pattern of observed fiber orientation at location B for Cases II & III along with the related micrographs are shown. The micrographs shown in Fig. 5b and 5c show higher degree of transverse orientation of fibers at the core layer of Case III which is the product of the hot mold compared to Case II, which is the result of the cold mold. The difference in the state of fiber orientation in these two Cases is quite significant and reveals the importance of mold temperature as an important parameter in orienting the fibers in the final product.

CONCLUSIONS

- Packing pressure increases the degree of transverse orientation of fibers at the core layer.
- Increasing mold wall temperature affects the state of fiber orientation by increasing further the degree of transverse alignment of fibers at the core layer during packing stage.
- Fibers follow specific patterns at the core layer in the plane of flow such that implying random state for expressing the orientation of fibers at the core layer seems incomplete.

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