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Effect of the Post-Filling Stage on Fiber Orientation at the Mid-Plane in Injection Molding of Reinforced Thermoplastics

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Abstract

Injection molding of fiber-reinforced thermoplastics is able to open a new dimension in the area of mass production of complicated net-shaped parts with accurate dimensions while the new target could be to produce parts with tailored properties. Since the properties of the composite products highly depend on the orientation of fibers, this experimental study concentrates on analyzing the state of fiber orientation during the process. By revealing the complex flow behavior of polymeric melt in the filling and packing phases of injection molding process, the results of this study show the important effect of packing pressure on fiber orientation in the final products.

Keywords: Injection Molding; Fiber Reinforced Thermoplastics; Finer Orientation; Flow behavior

1. Introduction

Plastics coupled with fibers, as reinforcements, offer a number of advantages in terms of end-use performance of the products. In injection molding process, the properties of the final products are strongly affected by the fiber orientation field set up during processing. Depending on the selected process conditions, the orientation of fibers varies significantly at the mid-plane and across the thickness of injection-molded parts. Many studies concentrated on analyzing the effects of various process conditions on the final state of fiber orientation and the conclusions of some of them in explaining the effect of

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packing pressure [1,2,3,4,5] show a few disagreements and reveal the necessity for further analysis in this area.

In injection molding process, once the mold is completely filled with plastic, the packing (holding) phase of the cycle begins. Pressure is maintained on the melt inside the cavity until the gate freezes. During this phase, a small amount of plastic flows into the mold as the melt in the mold cools and shrinks. This packing pressure and the related packing time have a significant effect on compensating in-mold shrinkage such that the packing phase becomes an inevitable step in every injection molding cycle.

In studying the flow behavior in injection molding of reinforced plastics for predicting the final state of fiber orientation, it is common [1, 2, 4, 6, 7, 8, 9, 10, 11], to consider the dependence of final orientation pattern just to the velocity field set up during the mold filling phase. However, there are a few studies such as the work of Lee et al. [3] and Malzahn & Schultz [5] in which possible changes in the orientation of fibers after complete filling of a cavity and during the post filling stage of injection molding process have been expected.

The present work is concentrated on analyzing and comparing the state of fiber orientation at the mid-plane during the filling and packing phases of injection molding process and shows clearly the important effect of packing pressure on the final state of fiber orientation.

2. Materials and Methods

RGF33 NATURAL (TUFNYL, SRF Made), a 33% by weight short glass fiber reinforced in PA66, was used in the experiments of this study. For analyzing the orientation of fibers in injection molding process, two molds namely Spiral Mold and Test Specimens Mold were used. Seven cases with different packing pressure were analyzed in this study, as shown in Table 1.

Table 1. Process conditions

Case	Packing Pressure (%Max Hydraulic Pressure)
I DF , I JF	0
I P	40
J DF , J JF, J CF	0
J P	20

In this nomenclature "I" refers to the products of spiral mold and "J" refers to the products of Test Specimens mold while "DF" is the abbreviation of "During Flow", "JF" refers to "Just Filled", "CF" stands for "completely Filled" and "P" represents "Packed" samples. Injection pressure was set at 70% of the maximum available pressure and injection speed was constant for all the Cases of this study. Melt and mold temperature were set at 290 ºC and 35 ºC respectively.

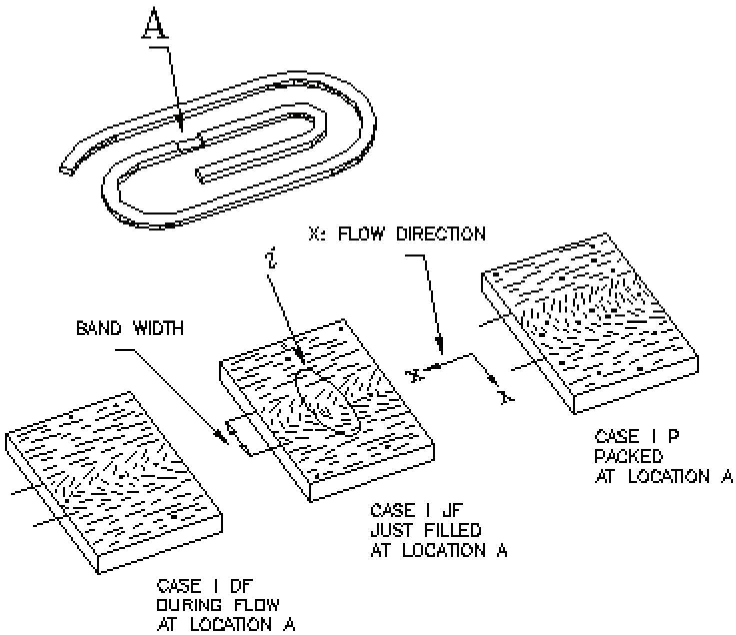
To avoid any change in the state of fiber orientation due to the sudden increase of pressure after complete filling of the cavities, short shot products of each mold were used for studying fiber patterns during the filling phase. In addition to analyzing the effect of packing pressure, due to the specific geometry of the Test Specimens Mold and because of the unbalance filling of its cavities, studying the effect of further injection pressure after complete filling of a cavity (cavity no. 2) till the complete filling of the mold was also possible. In this particular case, which can be considered a primary step in any packing phase, the melt in the cavity no. 2 is under further pressure after its complete filling while there are other passages and cavities in the mold, where the melt can flow in simultaneously.

3. Results and Discussion

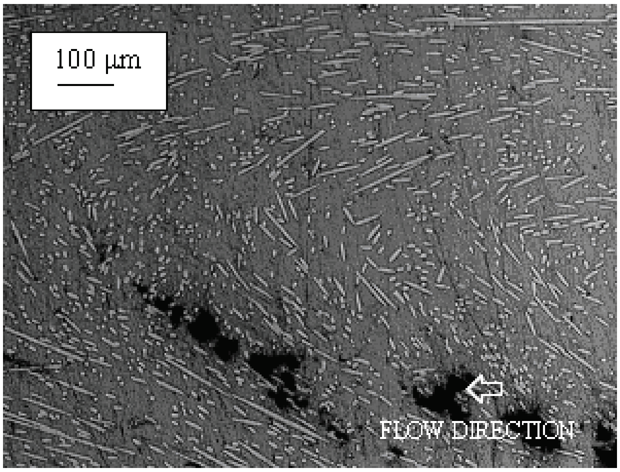
For analyzing the effect of packing pressure, patterns of fiber orientation at the mid-plane of location A in Case I, for its three different conditions (I DF, I JF and I P), are shown and compared in Fig. 1.

Presence of aligned fibers along with the parabolic distribution of fibers verifies the combined effectiveness of shear flow and extensional flow (stretching flow) at the mid-plane of location A. Comparing the bandwidth of parabolic patterns of fibers shows a higher degree in transverse orientation of fibers with respect to the flow direction at the mid-plane of Case I P which is the packed sample.

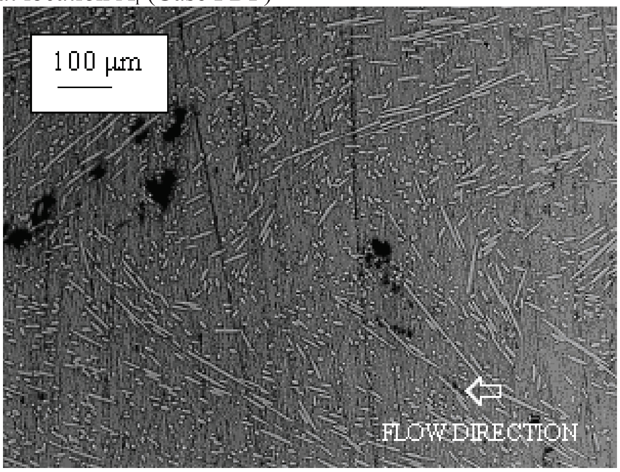
These results which verify the important role of packing pressure in orienting the fibers, were achieved easily just because of the type of selected cut-sections. In the packing phase, in contrast to the filling phase, thickness-wise (gap-wise) cut-sections cannot always provide proper information about the state of fiber orientation and may lead to confusing results. This is discussed in more details in the results of the next experiment.



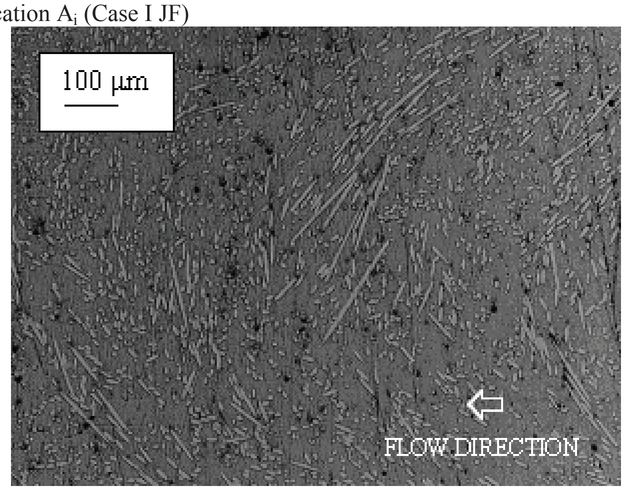
(a) Patterns of fiber orientation at location A (Cases I DF, I JF, and I P)



(b) Fiber orientation at location A_i (Case I DF)



(c) Fiber orientation at location A_i (Case I JF)



(d) Fiber orientation at location A_i (Case I P)

Fig.1.Fiber orientation at the mid-plane of location A-Spiral Mold (Cases I DF, I JF, and I P)

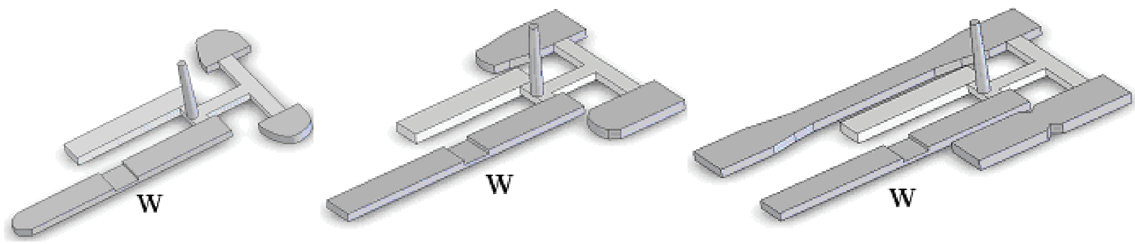
For having a better understanding of flow behavior during the packing phase, cut-sections at location W in different cases of Test Specimens Mold were also studied. The patterns of fibers at the mid-plane of this location in Cases J DF, J JF, J CF and J P are presented in Fig 2.

Arrangement of fibers in Case J P, shown schematically in Fig. 2b, reveals the presence of a kind of backward flow of melt during the packing phase. Presence of backward flow is the most important effect of packing pressure which can be observed clearly in the packed sample of this mold.

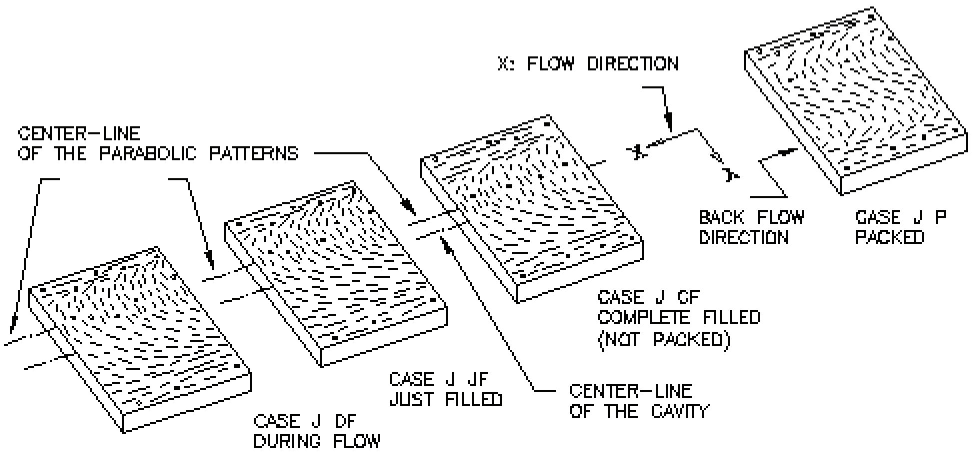
The micrographs, shown in Fig. 2c, should be studied from left to right and from top to bottom. The last micrograph of each column is the same as the first micrograph of the following column. Putting the columns along each other results in having a survey of the width of the cavity at the mid-plane of Case JP.

Having flow streams in opposite directions at one location verifies that packing pressure does not pressurize melt hydrostatically and the cavity is not being filled volumetrically. The unsymmetrical gate location causes an asymmetric state of viscosity with respect to the center-line of the cavity and results into asymmetric patterns of fibers in the plane of flow. This observation emphasizes further the importance of heat conduction in the y-direction, width of the cavity, which is an ignoring parameter in simplified energy equation for modeling the flow behavior in the packing phase by Kennedy [12].

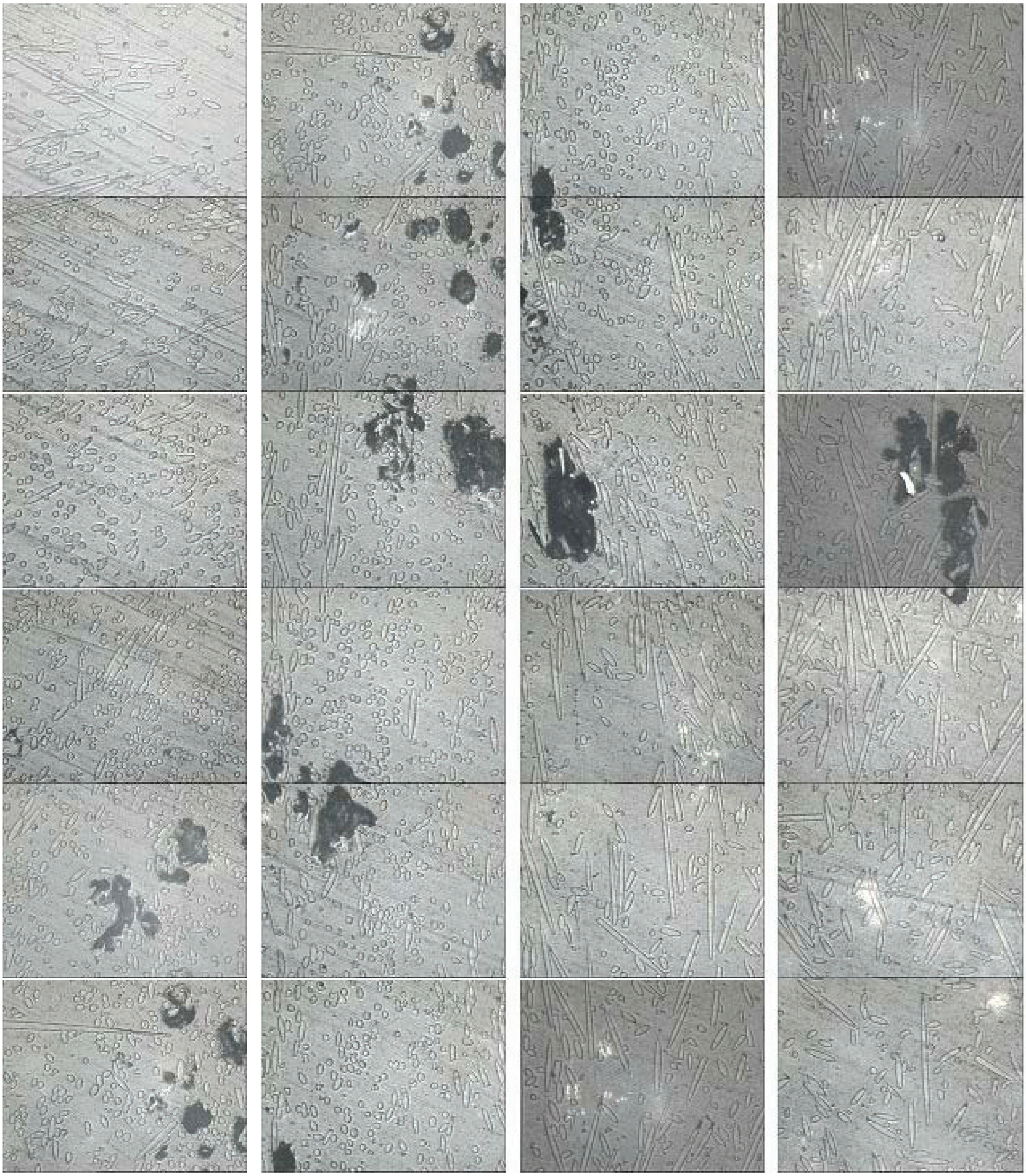
Due to the presence of backward flow of melt and the resulted shear at its interface with the forward flow during the packing phase, analyzing the state of fiber orientation just by observing the gap-wise cut-sections may lead to a set of contradictory results.



(a) Cut section W at the same location of various products - Test Specimens Mold



(b) Patterns of fiber orientation at the mid-plane of location W



(c) Fiber orientation at the mid-plane of location W (Case J P)

Fig.2. Part conditions, location of cut-sections, and patterns of fiber orientation at the mid-plane of location W - Test Specimens Mold (Cases J DF, J JF, J CF, and J P)

4. Conclusions

- Fibers follow specific patterns according to the velocity field set up at the mid-plane of a cavity which is a combination of shearing flow and diverging flow (stretching flow); therefore the state of fiber orientation at the mid-plane cannot be considered generally random.
- Fibers tend to get more transverse orientation along the centerline of the stretching flow (extensional flow) at the mid-plane during the packing phase of injection molding process.
- Flow streams in the opposite directions co-exist at one location during the packing phase and the presence of backward flow verifies that, packing pressure does not pressurize melt hydrostatically and the cavity is not being filled volumetrically.
- The results of this study emphasize the importance of heat conduction in the y -direction (width of the cavity) and show its effect on fiber orientation during the packing phase.

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