Deformation analysis of short glass fiber reinforced polypropylene injection molded plastic parts

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ABSTRACT

The warpage of injection molded plastic parts is a complex problem being affected by different technological parameters, material properties and mold design. Hence the description of the deformation is difficult as well. This paper presents the effect of fiber content and mold temperature difference on the deformation of polypropylene parts. Based on the measurement results, a linear approximation and a calculation method are shown which can be used to jointly determine the ideal fiber content and mold temperature difference to produce undeformed plastic parts.

Key-words: warpage, corner effect, injection molding, deformation, injection mold, mold temperature

INTRODUCTION

Injection molding is a high-speed technology to form plastic parts [1-6]. The effectiveness of the technique, and therefore the quality of the product which can be achieved, depends on the use of adequate process settings and suitable mold construction used to eliminate different kind of failures [7-10]. The occurrence and minimization of warpage in injection molded plastic parts provides a big challenge for mold designers and technologists. At the design stage of an injection mold it is required to take into consideration the physical effects ruling in the cavity. These effects will determine the dimensional accuracy and form stability of the part. The use of non-optimal technological settings results in an unequal shrinkage causing warpage in the part. The main causes of this variation in shrinkage (resulting deformation) can be material properties, mold and part design or process settings. This deformation can be attributed to three causes: anisotropic shrinkage, orientation effect and non-uniform cooling [11-13]. Anisotropic shrinkage means the presence of variation in the shrinkage from region to region in the part. Orientation effect is the difference in shrinkage parallel and perpendicular to the material orientation direction, mainly occurring in fiber reinforced thermoplastics. The third is caused by the temperature gradient through the thickness of the part generated by unequal core and cavity temperatures. This is called non-uniform cooling.

Many studies have tested the deformation of unfilled thermoplastics [14-19]. Akay and Ozden [14] analyzed polycarbonate and acrylonitrile butadiene styrene and concluded that the examined specimens injection molded with a temperature difference between the two mold halves have resulted in the final part curving towards the hotter side of the mold. Tang et al [15] using acrylonitrile butadiene styrene plates for deformation analyses analyzed how melt temperature, filling time, packing pressure and packing time affect warpage. It has been concluded that the deformation was mostly influenced by melt temperature, followed by packing time and packing pressure.

Also Jansen et al [16] analyzed the warpage of specimens made of amorphous polycarbonate. Plate like and L-shaped specimens (Figure 1/a) were used in the investigation to study the effect of holding pressure and mold temperature. The experiments showed that the deformation increased along with the increased temperature difference between the mold halves, furthermore that at low holding pressure the plates warped towards the hot side while at high holding pressure they warped towards the cold side.

Ammar et al [17] used a specimen with four corners (Figure 1/b) for their warpage measurements. It was concluded that two phenomena caused the deformation of the part: the first was the asymmetrical cooling and the second was the spring forward effect. The spring forward effect was generated in fiber reinforced polymers due to the higher thermal expansion coefficient in the thickness direction of the component. The deformation around the corner and the deformation of the plane surfaces were distinguishable. Using fiber reinforced polypropylene in their experiments, with an equal mold temperature in both mold halves they recorded a significant angle deformation of 3°and 5°. A temperature difference of 40°C between the two sides of the mold caused an angle variation of about 1.5°.

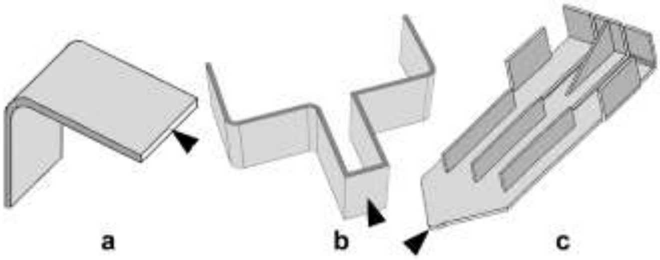

Figure 1. Specimen geometries with their injection locations for deformation measurements used by a) Jansen et al. [16], b) Ammar et al. [17] c) Mlekusch [22]

Other studies dealt with the warpage of fiber reinforced thermoplastic parts [20-24]. Kikuchi and Koyama [20] studied the orientation of fiber reinforced polymer, being the main cause of the occurring warpage. They used glass reinforced polyamide in their analyses and made a conclusion that in a case of uniform orientation there weren't any deformation while non-uniform orientation caused warpage on the specimens. In another study [21] they distinguished different deformation modes of a circular disk made of PA66-GF33, namely bowl-like, saddle-like and waves on the circumference of it.

Mlekusch [22] analyzed the effect of glass fiber on the warpage of corner-like geometries (Figure 1/c) using polyamide as the matrix material. He concluded that the warpage difference between the reinforced and the non-reinforced polymer appeared due to the orthotropy caused by the fibers and their alignment. He also concluded that the deformation increased with increasing fiber volume fraction.

Prashantha et al [25] analyzed the effect of multi-walled carbon nanotubes on the deformation of an injection molded polypropylene part. They showed that the addition of 2wt% of carbon nanotubes reduced the warpage of the parts by 55% compared to the unfilled ones.

The aim of our research was to analyze the effect of the material and of the asymmetrical cooling on the deformation of injection molded plastic parts on a specific specimen.

EXPERIMENTAL

In this study the warpage of specific specimens injection molded of unfilled polypropylene and with polypropylene reinforced with glass fiber of different weight content (10, 20, 30 wt%) were examined. The matrix (Borealis, HD120MO) and the glass fibers were mixed on a Brabender Plasticorder twin-screw extruder and a Brabender pelletizer was used to produce pellets from the extrudate. From these materials special V-top specimens (Figure 2.) were injection molded on an Arburg Allrounder 320C 600-250 injection molding machine. The sides of the V-top specimen close an angle of 90°, and the warpage caused by the technological or other parameters can be described as a change of this angle. The specimens were injection molded with a special two-cavity mold. The mold has changeable and variable inserts making it possible to alter the layout of the runner system (one directional or bidirectional cavity filling) and to inject with different gate types (standard gate at the front of the edge, standard gate at the middle of the edge, film gate along the whole edge). The stationary side of the mold contains changeable cavity inserts allowing a variation of the part's wall thickness. The wall thickness can be chosen as either 1 mm or 2 mm. The specimens were injection molded with a thickness of 2 mm using film gate type. For the highest precision of the control, temperature and pressure sensors were incorporated in the core and cavity of the mold. To evaluate the warpage of the V-top specimen special image analysis software was used.

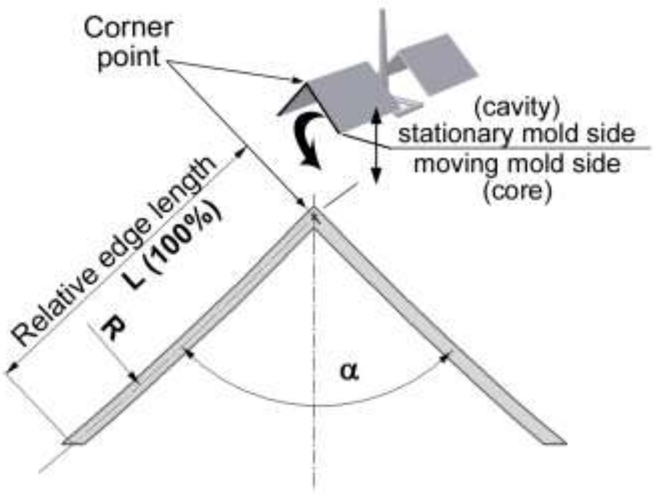

Figure 2. V-top specimen

In the experiments the effect of glass fiber content and the alteration of the temperature of the movable and stationary mold side (30, 50, 70°C) were analyzed. The rest of the technological parameters were kept constant. The holding pressure was 300 bar, the melt temperature was 230°C, the holding time was 5 s, the injection rate was 50 cm^3/s and the cooling time was 15 s. The switchover to holding pressure took place when the end-of-the-cavity pressure sensor reached the 25 bar.

RESULTS AND DISCUSSION

With design of experiment it was proved that both the temperature difference and glass fiber content influenced the deformation of the V-top specimen significantly compared to the other studied parameters like injection rate, melt temperature and holding pressure [26].

The effect of fiber content can be clearly seen on Figure 3. The addition of more fiber (whilst maintaining both core and cavity temperatures of 50°C) resulted in a smaller deformation occurring hence a larger final closing angle. It is also observable that a decided difference appeared in the deformation change along the relative edge length (Figure 2.) using different fiber weight content in the material. The use of more glass fiber in the material attenuated the warpage of the specimens.

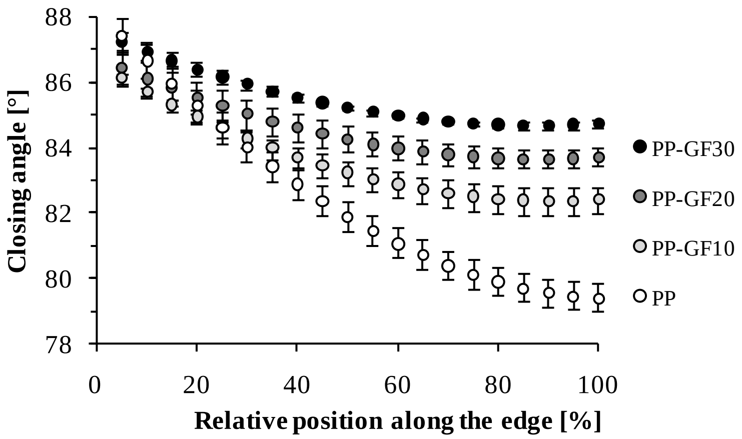

Figure 3. The effect of glass fiber content on the closing angle as a function of the relative edge length of the specimen (both core and cavity temperatures of 50°C)

Along with the fiber content, the mold temperature had an important influence on the deformation of the parts. Figure 4. shows that the alteration of the moving mold side's temperature (whilst maintaining the stationary mold side's' temperature at 50°C) changed the warpage of the specimens independently from the used holding pressure. Increasing the differential mold temperature resulted in an increase in deformation due to a reduction in the closing angle.

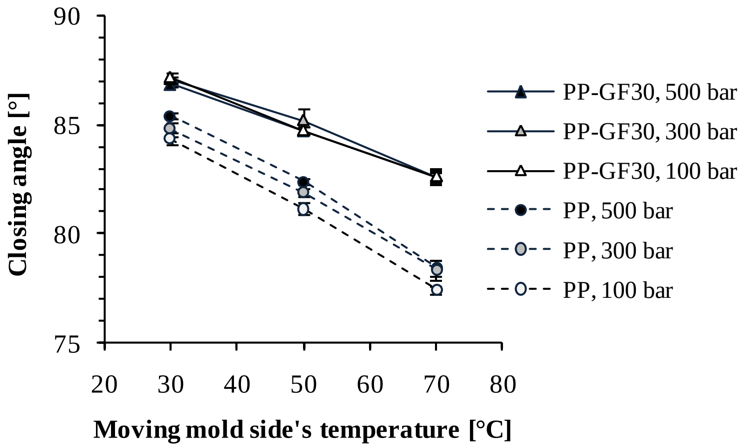

Figure 4. The influence of the holding pressure on the closing angle as a function of moving mold side's temperature (PP, PP-GF30, the stationary mold side's' temperature is 50°C)

Analysis of the effects of the application of various holding pressures alone (Figure 5) showed that it produced a minor variation on the warpage when the PP was unfilled, with this effect reducing and eventually disappearing with the increased % of glass fiber content.

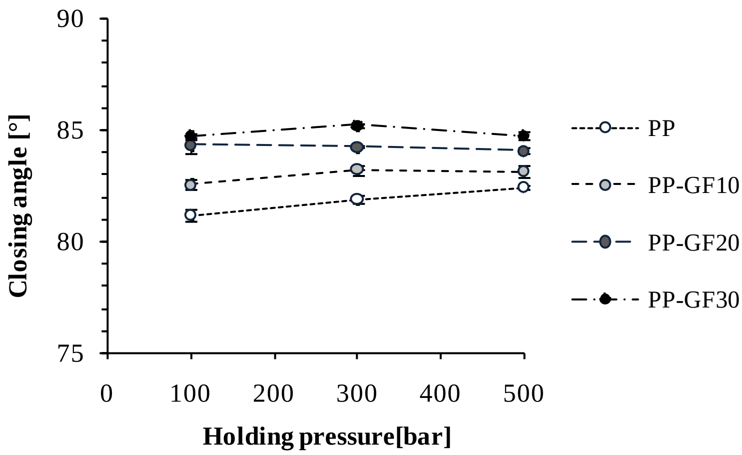

Figure 5. The effect of holding pressure on the deformation at a relative edge length of 50%

Contemplating the results as the function of the moving mold side's temperature (Figure 6.) and the stationary mold side's temperature it can be seen that the closing angle along the relative edge length showed mainly a decreasing tendency, and the degree of its change was influenced by the glass fiber content of the material. In the case of setting a higher mold temperature in the moving mold side, the deformation was significantly influenced by the glass fiber content. Whereas using a higher mold temperature in the stationary mold side there weren't any dominant differences between the specimens' deformation made from material with different weight content.

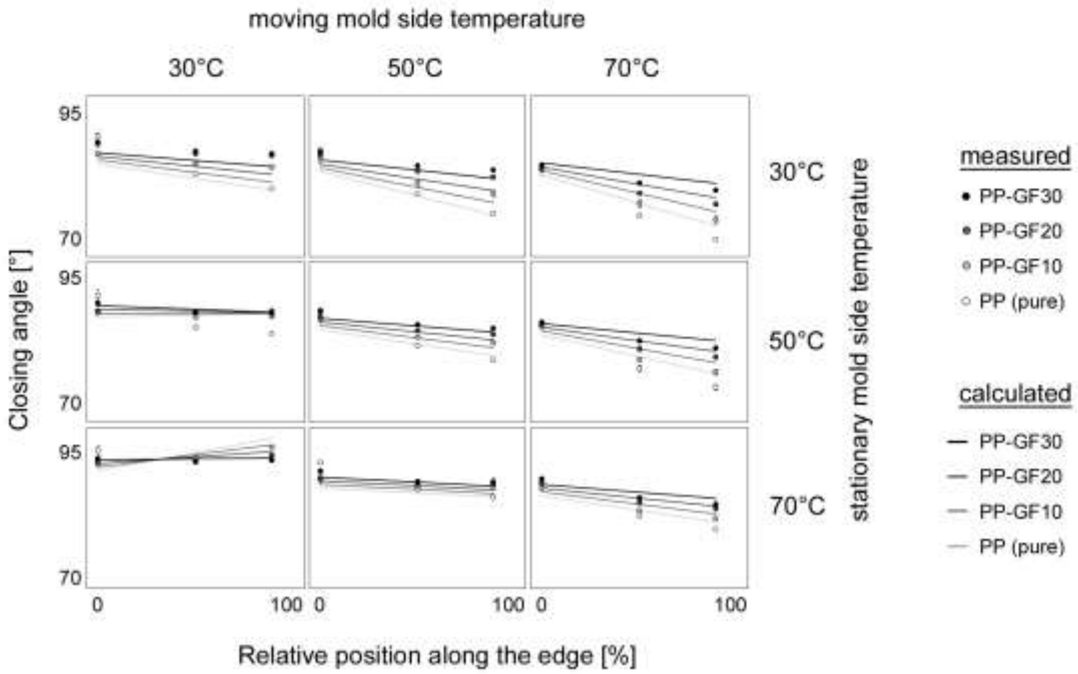

Figure 6. The effect of glass fiber content and mold temperature on the closing angle as a function of relative edge length

Based on the results of measurements taken, the closing angle along the edge length of the parts made of glass fiber reinforced polypropylene can be characterized with a linear approximation opposing a correlation of 98% as Equation (1):

$$\alpha\left(L;\Phi;\frac{T_s}{T_m}\right) = A\left(\Phi;\frac{T_s}{T_m}\right)\cdot L + B\left(\Phi;\frac{T_s}{T_m}\right), \qquad (1)$$

where α [°] is the closing angle, L [%] relative edge length, Φ [wt%] glass fiber content, T_s/T_m [-] the ratio between the temperature of the stationary mold side and the moving mold side, *A* and *B* are mathematical expressions concerning from the material's glass fiber content and from the mold temperature ratio. The exposed mathematical expression forms into Equation (2):

$$\alpha = \Phi \cdot \left(f \cdot_1 \frac{T_s}{T_m} \cdot L + f_2 \cdot L + i_1 \cdot \frac{T_s}{T_m} + i_2 \right) + g_1 \cdot \frac{T_s}{T_m} \cdot L + g_2 \cdot L + j_1 \cdot \frac{T_s}{T_m} + j_2 , \qquad (2)$$

where f_1=-0,00209°/(%·m%), f_2=0,00289°/(%·m%), g_1=0,08511°/%, g_2=-0,13576°/%, i_1=0,007821°/m%, i_2=0,04713°/m%, j_1=2,53355° and j_2=82,16° are constant parameters.

Based on Equation (2) the closing angle will be constant along the relative edge length, if Equation (3) will be true:

$$\frac{T_s}{T_m} = -\frac{\Phi \cdot f_2 + g_2}{\Phi \cdot f_1 + g_1} . \qquad (3)$$

If the closing angle would be 90°along the relative edge length, the needed mold temperature difference can be described as Equation (4) :

$$\frac{T_s}{T_m} = \frac{90 - (\Phi \cdot i_2 + j_2)}{\Phi \cdot i_1 + j_1} . \qquad (4)$$

With (3) and (4) a theoretical glass fiber content and a theoretical mold temperature difference can be determined, which allow the injection molding of specimens with a closing angle of 90° along the whole relative edge length (Figure 7.). This is at a fiber content of Φ=31.04 wt% and a mold temperature ratio of T_s/T_m=2.29, which corresponds with the measured experimental results obtained.

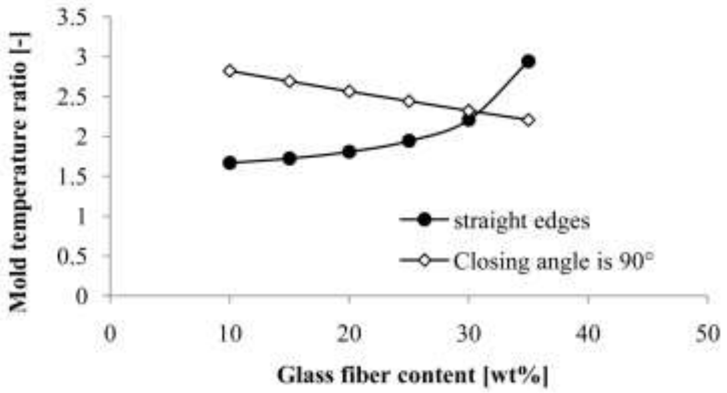

Figure 7. Required theoretical glass fiber content and mold temperature difference to enable the injection molding of a non-deformed specimen

CONCLUSIONS

Under normal circumstances, manufacturing a component containing angles, by injection molding, results in a deformation and warpage of the part. In this paper, the effect of glass fiber content and mold temperature on the deformation of an injection molded special V-top specimen was analyzed. The results showed that the addition of more fiber resulted in a smaller deformation occurring, hence a larger final closing angle, closer to that originally intended. It was also concluded that the higher the moving mold side's temperature was compared to the stationary mold side's temperature the larger was the warpage of the part. Both of these normally independent parameters have to be jointly taken into account when trying to remove any deformation and warpage. Based on the results of the measurements recorded, the closing angle along the edge length was characterized with a linear approximation. A theoretical glass fiber content and a theoretical mold temperature difference was then determined, and in practice proved, which allows the injection molding of the specimens with a closing angle of 90°along the whole relative edge length.

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