NEW METHOD FOR WARPAGE CHARACTERIZATION OF INJECTED PARTS

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ABSTRACT

In this study we examined the nylon (PA6) filled with glass fiber and glass bead for warpage and shrinkage measurements. Sixteen different mixtures were produced with different fiber and bead contents. Shrinkage was measured in five different places on these composites. We introduced three special warpage parameters, and a holding pressure parameter. The shrinkage and warpage were examined in the function of the holding pressure. It was concluded that the holding pressure decreased all the measured shrinkage, but it increased the warpage because the shrinkage was uneven. We reduced this effect by applying glass beads into the composites, which made the shrinkages more uniform. We also created mathematical models for these effects.

KEYWORDS
injection molding, shrinkage, warpage, reinforcement

1 INTRODUCTION

For thermoplastic polymers, the injection molding is one of the most important processing technologies. During the process, the polymer melt is injected into the mold, where its shape is being formed, and fixed. Several defects can be occurred because the improper mold design or incorrect machine setup. One of the main errors is that the shrinkage is not handled properly, and the uneven shrinkage causes warpage in the injected parts [1-4].

1.1 Shrinkage

Shrinkage derives form the decreasing volume of the injected part caused by the cooling process. One of the most important quality features is the dimensional accuracy. The raw material and the technology have influence on it. The technology development and the every day requirements need more and more accurate parts which can keep there quality during aging [2].

We can distinguish linear and volumetric shrinkage [4]. The total volume change is

$$\Delta V = V_C - V_T, \tag{1}$$

where V_C is the volume of the mold, V_T is the volume of the part. The volumetric shrinkage can be expressed as follows:

$$S_V = \frac{\Delta V}{V_C} = \frac{V_C - V_T}{V_C} = 1 - \frac{V_T}{V_C} = 1 - \frac{L_x(1-S_x)L_y(1-S_y)L_z(1-S_z)}{L_x L_y L_z}, \tag{2}$$

$$S_V = 1 - (1 - S_x)(1 - S_y)(1 - S_z), \tag{3}$$

where S_V is the volumetric shrinkage, S_x, S_y, S_z are the linear shrinkages, L_x, L_y, L_z are the dimensions of the mold cavity. The S_i, the shrinkage can be calculated by the corresponding dimensions of the mold cavity and the part:

$$S_i = \frac{L_C - L_i}{L_C} * 100 \ [\%], \tag{4}$$

where L_C is the dimension of the cavity, L_i is the dimension of the part [3, 4]. Nowadays the shrinkage of the injection molded parts is still problem, because it cannot be estimated exactly, and the costs of a possible mold fixing are high. This phenomenon can only be reduced, but not eliminated. The volume of polymers decreases during the cooling process because of their structures. The shrinkage can be compensated until the gate freezes off, but afterwards the process cannot be influenced. With precise mold design, the shrinkage can be compensated. However, the common way is simply to ‘scale up’ the cavity, so the part shrinks to the desired geometry. With this procedure, almost perfect parts can be produced.

1.2 Warpage

Warpage occurs because of the different shrinkage of the part. It is a deformation from the original shape, the plane of the part becomes deformed [4].

Using fiber reinforcements, the in-flow shrinkage decreases dramatically and the ratio of the in-flow and cross-flow shrinkage increases. While the in-flow shrinkage reduced below 0.5%, the cross-flow shrinkage does not change much in most cases (Fig.1.). This leads to the warpage of the part.

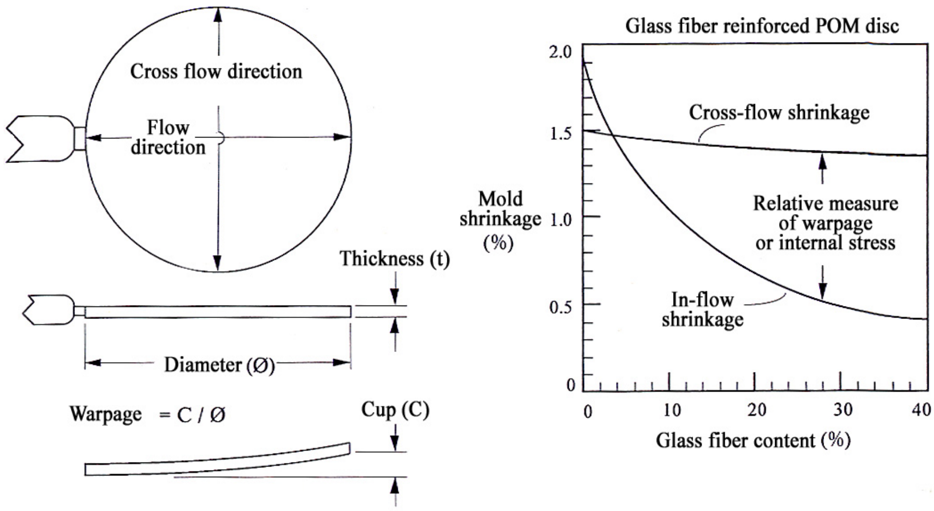

Fig.1. Fiber reinforcement content influence on differential shrinkage [4]

It can be seen that the fiber content increases the warpage, as the shrinkage difference increases in the in-flow and cross-flow directions (Fig.1.). The geometry of the fillers has significant effect on the uniformity of the shrinkage. Sanschagrin studied the effects of the 30% of glass fiber, glass bead and glass flake content on the in-flow and cross-flow shrinkage characteristics of PP [5]. Galucci et. al. measured the shrinkage in hybrid composites in which it was more uniform because of the special fillers and the special cross sections of the fibers [6].

2 EXPERIMENTAL

During the experiments 0, 10, 20, 30 weight percent (wt%) glass fibers and 0, 1, 2, 3 weight percent (wt%) glass beads were mixed with nylon (PA6) type Durethan B 30 S obtained from Lanxess (Deutschland). The mixture was homogenized in a double-screw extruder type Brabender 814402 and a pre-product with the diameter of 3 mm was drawn and later ground with the granulating machine type Brabender 881203.

Special specimens – for the falling weight tests – were injection molded from the pellet in an injection molding machine type ARBURG Allrounder 420 C 1000-250 Advance. The injection pressure varied according to the filler and reinforcement content (Fig.2.) and the holding pressure was examined between 200 to 1000 bar.

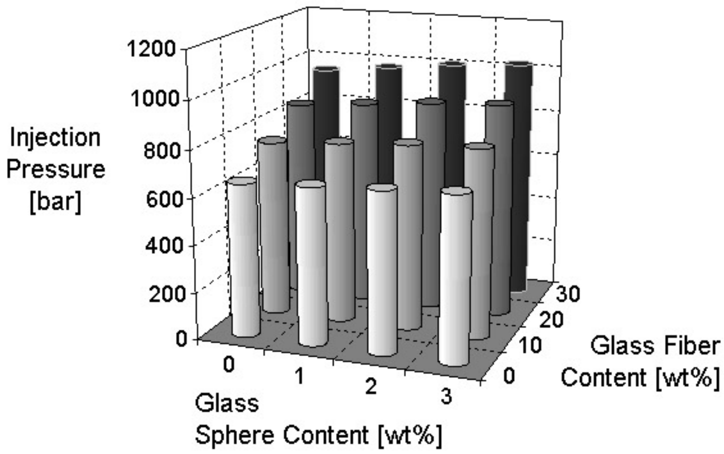

Fig.2. Injection pressures for different fiber and filler content materials

The different fiber and filler material content specimens were measured in different places (H0 – longitudinal shrinkage in the middle , HSZ – longitudinal shrinkage at the edge, KE – cross-flow shrinkage close to the gate, KH – cross-flow shrinkage far from the gate) (Fig.3.), and the warpage parameters were determined to show the uneven shrinkage.

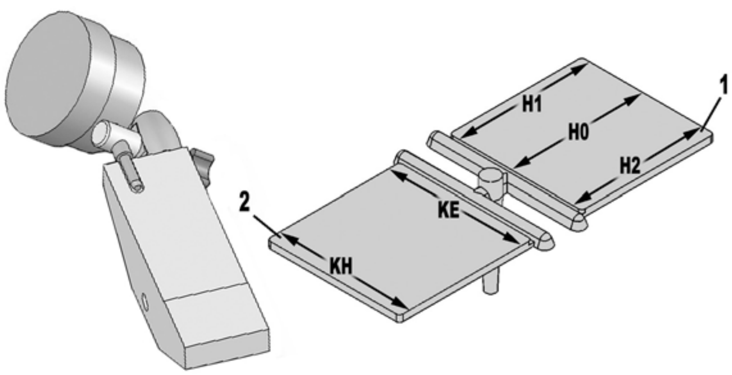

Fig.3. Samples for the shrinkage measurement (right) with the measured dimensions and measuring equipment (left)

With the introduced warpage parameters, we can monitor (i) the runner position dependence of the in flow shrinkage (H0/HSZ), (ii) the pressure (KE/KH) and (iii) the flow direction dependence of the shrinkage ($K_{average}/H_{average}$). The optimum for the warpage parameter is one, which refers to uniform shrinkage, therefore the parts will not deform.

3 RESULTS AND DISCUSSION

From viewpoint of the shrinkage the most important technological parameter is the holding pressure, therefore all newly introduced warpage parameters were examined as a function of the holding pressure. Independently from the reinforcements and fillers – almost in all cases – the increasing holding pressure leads the in-flow shrinkages smoother, and the uneven shrinkage caused by the pressure drop becomes smaller, but it increased the in-flow and cross-flow shrinkages ratio (Fig.4.).

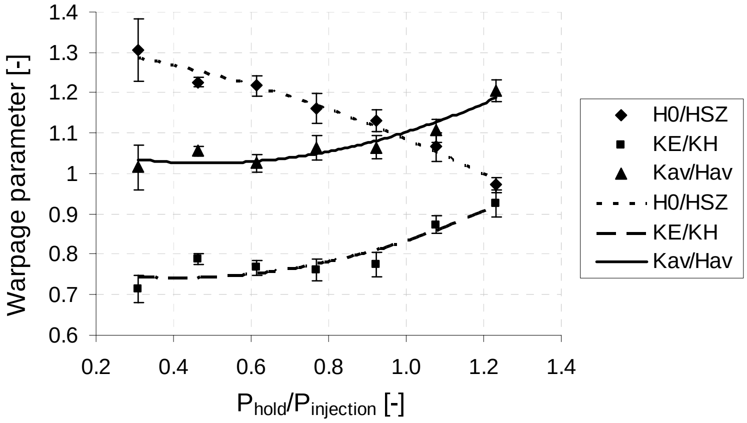

Fig.4. Warpage parameters for nylon filled with 3wt% of glass beads

It can be concluded that the ratio of the in-flow and cross-flow shrinkages increases exponentially as the fiber content or the holding pressure increase (Fig.5.).

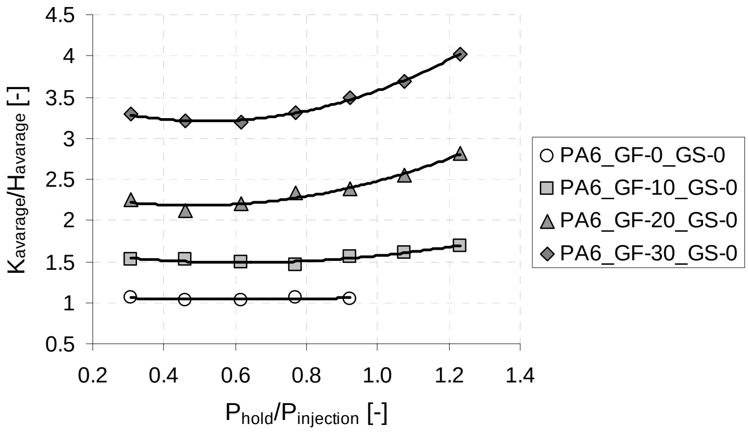

Fig.5. K/H warpage results

The mathematical model for the K/H warpage parameter is:

$$W = W_0 \cdot e^{B \cdot C}, \tag{5}$$

where W is the in-flow/cross-flow shrinkage indicated warpage parameter, the W_0 is the same warpage parameter for the unfilled material, B is a constant for the given material, and C is the fiber content.

4 CONCLUSIONS

In this study we examined the nylon (PA6) filled with glass fiber and glass bead for warpage and shrinkage measurements. Sixteen different mixtures were produced with different fiber and bead contents. Shrinkage was measured in five different places on these composites. We introduced three special warpage parameters, and a holding pressure parameter. The shrinkage and warpage were examined in the function of the holding pressure. It was concluded that the holding pressure decreased all the measured shrinkage, but it increased the warpage because the shrinkage was uneven. We reduced this effect by applying glass beads into the composites, which made the shrinkages more uniform. We also created mathematical models for these effects, such as for the in-flow/cross-flow shrinkage indicated warpage parameter (5). The ratio of the in-flow and cross-flow shrinkages increases exponentially as the fiber content or the holding pressure increase.

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