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Test Method

Test method development for deformation analysis of injection moulded plastic parts

J.G. Kovács*, B. Sikló

Department of Polymer Engineering, Budapest University of Technology and Economics, H-1111 Budapest, Műegyetem rkp. 3, Hungary

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ABSTRACT

The characterisation of warpage of injection moulded plastic parts is not standardised and is extremely problematic due to the complex nature of the warping process. This paper presents a novel method for the analysis and measurement of the deformation of injection moulded plastic parts. A specific part with a special mould design was introduced for the characterisation of the effect of different technological parameters and different mould element design on warpage. The applicability of the system was demonstrated via its experimental use. The effects of mould temperature, mould temperature difference, holding pressure and the glass fibre content of the material were investigated using different gate types in the mould. Additionally, new software was developed to evaluate warpage. Based on the results, it was concluded that the deformation of the corner along the edge length can be described by a curve.

1. Introduction

The quality of injection moulded thermoplastic parts is largely determined by the process parameters and the mould design used. One of the main problems with injection moulded plastic parts is warpage caused by non-uniform shrinkage. This deformation is strongly influenced by non-uniform cooling, differential shrinkage and orientation effects [1].

Several researchers have investigated the formation and characteristics of warpage using various methods, particularly multiple types of specimen geometries. Many studies have investigated shrinkage using rectangular plate specimens [2,3], and the application of this geometry was extended to warpage measurements [4–9].

Tang et al. [10,11] introduced a two-cavity, two-plate injection mould producing acrylonitrile butadiene styrene (ABS) plates for warpage testing, with deformation of the parts being determined with a dial gauge. The authors concluded that warpage was mostly influenced by melt temperature, followed by packing time and packing pressure. Thermal analysis was performed to check the effect of any thermal residual stress in the mould.

Fahy [12] investigated the warpage of reinforced thermoplastics on a circular disk and showed that different orientation caused various deformations; namely, they observed cup- and saddle-shaped conformations. Kikuchi and Koyama [13,14] also analysed disk specimens and plates, and they introduced a warpage index as a means of recording the characteristics of injection moulded parts.

Zheng et al. [15] acknowledged that plate-like specimens were incapable of measuring warpage of injection moulded parts because of their simple geometry, and proposed that a more complex shape should be used. They continued to perform measurements with the injection moulding simulation on a ribbed plate model, but they were only able to visualise the effect of the rib and not the entire deformation [15].

Jansen [8] studied the warpage of amorphous materials not only on plates but also on L-shaped specimens with different corner radii and sharp corners. The warpage of flat plate products was assessed by positioning the plate on

* Corresponding author. Tel.: +36 14631440.
E-mail addresses: kovacs@pt.bme.hu (J.G. Kovács), siklo@pt.bme.hu (B. Sikló).

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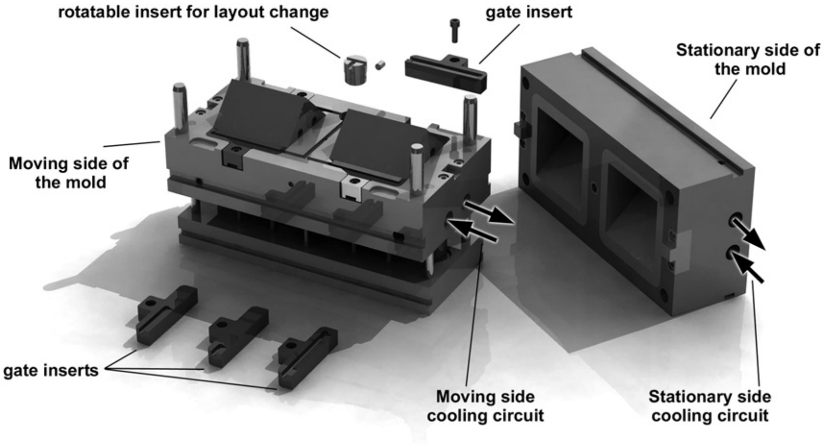

Fig. 1. The moving and stationary sides of the mould with the 3 + 1 gate inserts.

three supporting pins and measuring the vertical displacement as a function of the length coordinate. The experiments showed that deformation linearly increased with the difference between the temperatures of the mould halves when using amorphous polymers. The results also showed that at low holding pressure the plates curved towards the hot side, whereas at high holding pressure the plates curved towards the cold side. The corners with larger radii were more sensitive to mould temperature differences than were specimens with smaller radii. The result was explained by the proportionality of the angle deflection to the length of the radial section.

Akay et al. [9] also analysed the relationship between warpage and the temperature difference of the two halves of the mould. The deformation of both the flat plate and the L-shaped specimens was measured and calculated with finite element software and a coordinate-measuring machine. Then, it was analysed using uniform cooling and also with temperature difference between the two mould halves. It was observed that a higher mould temperature on the cavity side resulted in increase of the angle in the corner of the part.

Some investigations used box geometry for warpage analysis [16,17]. Kabanemi et al. [17] analysed warpage on box-like parts. Different cases were presented to show the influence of the geometrical complexity of the shape on the deformations and residual stresses. It was concluded that the asymmetrical thermal profile was responsible for the bending moment that caused warpage.

Mlekusch [18] analysed the warpage on a specifically designed part with various types of corners. The effect of short-fibre-reinforcement was studied and attributed to the anisotropy of the material. A multi-layer model was used to calculate the cooling of a cylindrical segment. The model predictions were compared with experimental measurements showing that the additional warpage observed for short-fibre-reinforced materials could be attributed to the anisotropy of the material.

Ammar et al. [19] used a specimen with four corners with different radii. They concluded that two phenomena caused warpage: the first was asymmetrical cooling and the second was the spring forward effect. The spring forward effect was generated in fibre-reinforced materials due to the higher thermal expansion coefficient in the thickness direction. The deformation around the corner and the deformation of the initially flat surfaces were distinguished. Using polypropylene (PP) in their experiments, equal mould temperatures in both mould halves induced a significant angle deformation of 3°and 5°. A difference of 40 °C between the two mould halves caused an angle variation of about 1.5°.

The aim of this research was to create not only a specimen but also a complex method for warpage characterisation. The main goal was to design and create a specific sample and mould, which allows deformation measurements to be obtained in different manners.

2. Methodology and measuring equipment

To characterise the warpage at the corners of injection moulded parts, a special part was designed. The main goal was to measure the effect of varying technological parameters, mould design or material properties on warpage.

To produce the so called V-top specimens, a special mould was designed with changeable and variable inserts (Fig. 1.). The constructed insert mould slides into a quick-change frame and has two cavities with a variable runner

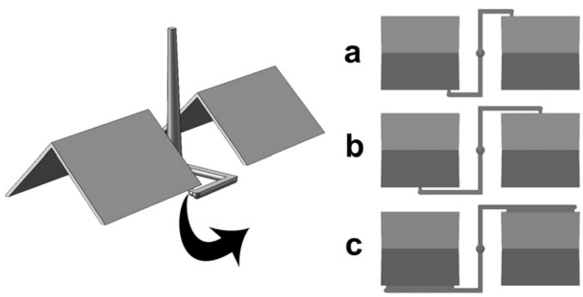

Fig. 2. Gate designs: a) standard gate at the front of the edge, b) standard gate at the middle of the edge and c) film gate along the whole edge.