Test method development for corner deformation of injection moulded plastic parts

Kovács J. G., Sikló B.

Test Method

Test method development for deformation analysis of injection moulded plastic parts

[*]J. G. Kovács, B. Sikló

[1]Department of Polymer Engineering, Budapest University of Technology and Economics, H-1111 Budapest, Műegyetem rkp. 3., Hungary, e-mail: siklo@pt.bme.hu
[*]Corresponding author J. G. Kovács, e-mail: kovacs@pt.bme.hu

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.

Key-words: warpage, corner effect, injection moulding, deformation, injection mould

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 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 characterise. 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 (Figure 1.). The constructed insert mould slides into a quick-change frame and has two cavities with a variable runner system. The stationary side of the mould contains only the changeable cavity inserts; changing these inserts allows the part's wall thickness to be varied. In this way, the wall thickness can be chosen as either 1 mm or 2 mm. Top locks guarantee the perfect closing of the two mould halves assuring a uniform part thickness.

The orientation of the material and the positioning of the injection location have significant effects on the deformation. Therefore, three different gate types can be used by changing the gate inserts in the mould (Figure 2.): a standard gate at the front of the edge, a standard gate at the middle of the edge or a film gate along the whole edge.

The sides of the V-top specimen close an angle of 90°, and the deformation caused by the technological or other parameters can be quantified by changing this angle. In addition to unidirectional cavity filling, bidirectional filling can be achieved with the application of rotatable inserts (Figure 3.). This feature allows investigation of the influence of the weld lines [20, 21] at the corners.

Warpage is highly influenced by cooling and is very significant at corners. The core of the mould has to dissipate heat faster than the cavity; otherwise the internal area of the part's corner solidifies slower and causes a sharpening of the corner itself. To meet the high requirements of warpage tests, an efficient cooling system is required

(Figure 4.). For the highest control precision, temperature sensors were installed into both the core and the cavity of the mould. Not only the temperature but also the pressure control is important. For this reason, two pressure sensors were mounted; one at a distance of 5 mm from the gate (PGS; post-gate-sensor) and one at a distance of 5 mm before the end of the flow path (EOC; end-of-cavity sensor). With the help of these sensors, the switchover point can be controlled precisely, which is of fundamental importance for a stable and consistent cycle.

To evaluate the warpage of the V-top specimen, special image analysis software was developed. The software analysed scanned images of the side of the specimens and calculated the closing angle along the edge length from the corner point (Figure 5.) in 5% steps.

3. Experimental

In this study, experiments were carried out to prove the efficiency of the novel measuring technique. Neat polypropylene and polypropylene reinforced with glass fibre of different weight contents (10, 20, 30 wt%) were examined to comprehensively evaluate the new method in a wide range of deformed parts. The matrix (Borealis, HD120MO) and the glass fibres were mixed on a Brabender Plasticorder twin-screw extruder, and a Brabender pelletizer was used to produce pellets from the extrudate. From these materials, V-top specimens were injection moulded on an Arburg Allrounder 320C 600-250 injection moulding machine. The specimens were moulded with a thickness of 2 mm using all 3 gate types. The effects of glass fibre content, temperature of the moving side of the mould (30, 50, 70°C) and holding pressure (100, 300, 500 bar) were analysed. All other technological parameters were kept constant. The melt temperature was 230°C, the temperature of the stationary side of the mould was 50°C, the holding time was 5 s, the injection rate was 50 cm^3/s and the cooling time was 15 s. The switchover took place when the end-of-cavity pressure sensor reached 25 bar.

4. Results and discussion

The difference between the cavities was controlled with weight measurements, showing that the correlation between the weights of the samples from the different cavities was 0.994. Therefore, it was concluded that specimen weight is independent of the cavity, and deformation was analysed on the outer edge of the specimens produced in the upper cavity.

A typical result of the experiments is shown in Figure 6, with the closing angle as a function of the relative edge length. It can be seen that the measurement is accurate and the standard deviation is relatively small at each measurement point. The influence of gate type was analysed, and it was shown that the melt entrance point and type cannot be neglected because they influenced the results through the orientation of the material (Figure 6.).

Below, some results will be presented to demonstrate the wide applicability of the method. The experimental results showed that the holding pressure had a considerable effect on the deformation of neat PP (Figure 7.). Close to the corner the holding pressure had a minor effect, whereas further away from the corner the angle increased with increase in holding pressure.

Fibre content decreased warpage independently of holding pressure (Figure 8.). However, the temperature difference between the two mould halves had the biggest effect on warpage. When higher mould temperatures on the movable mould side were used, the closing angle between the faces of the specimen was decreased as a result of a larger deformation. Analysing the deformation as a function of relative position along the edge, it was observed that the closing angle decreased monotonically, with the slope of the angle depending on the temperature of the moving mould side (Figure 9.).

5. Conclusions

In this paper, a new measurement method was introduced for the deformation analysis of injection moulded plastic parts. The newly introduced V-top specimen allows investigation of the effects of different technological parameters and material properties on its deformation. Moreover a novel transformable injection mould was designed and built for the V-top specimen’s production. The new method was tested and analysed with experimental research, in which the effects of gate type and location, glass fibre content of the material, mould temperature difference and holding pressure were investigated. Based on the experimental data, it was concluded that warpage strongly depended on the fibre content and on mould temperatures, but that it was nearly independent of the holding pressure when using PP with glass fibre. These experiments strongly support the new warpage analysis technique in having a significant advantage over previously used warpage measuring methods.

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Figure Captions

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

Figure 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

Figure 3. V-top specimen with rotatable inserts

Figure 4. The cooling system of the mould

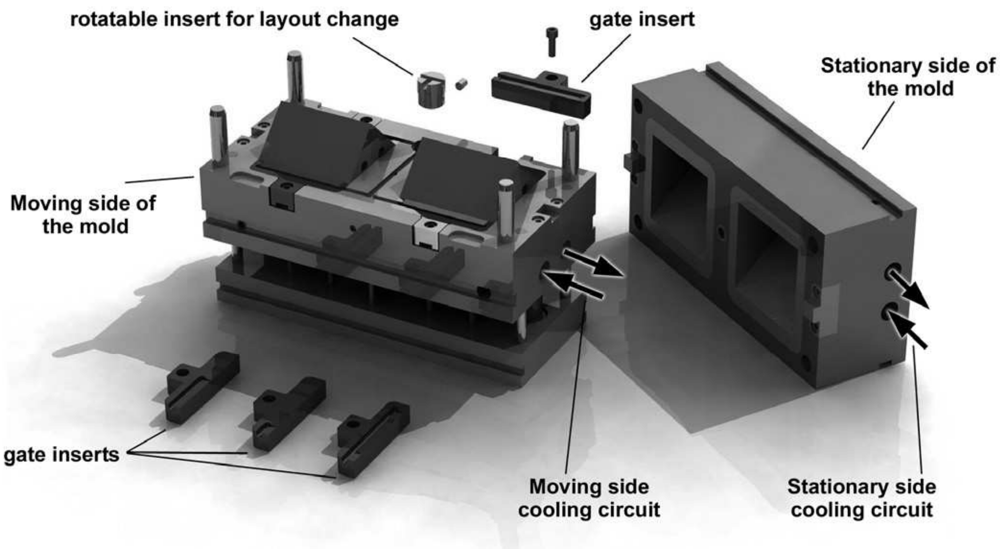
Figure 5. Theoretical image for the closing angle calculation

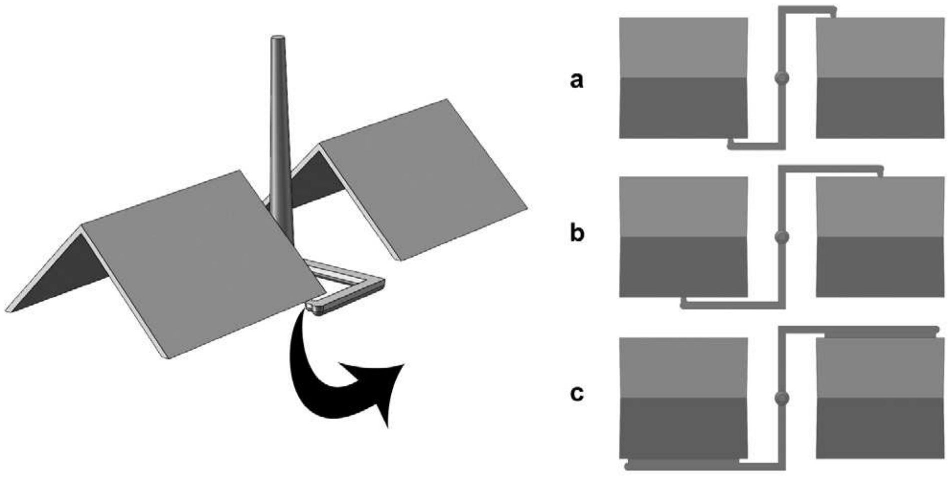
Figure 6. The influence of injection location on the closing angle as a function of the relative position along the edge (mould temperature: 70°C, fibre content: 20%, holding pressure: 300 bar)

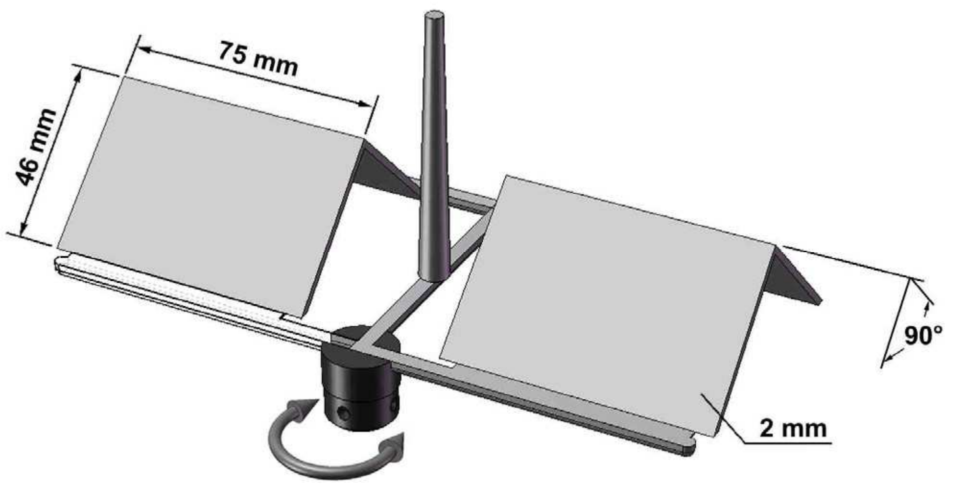
Figure 7. Corner angle as a function of holding pressure at 5% and 85% position using neat PP

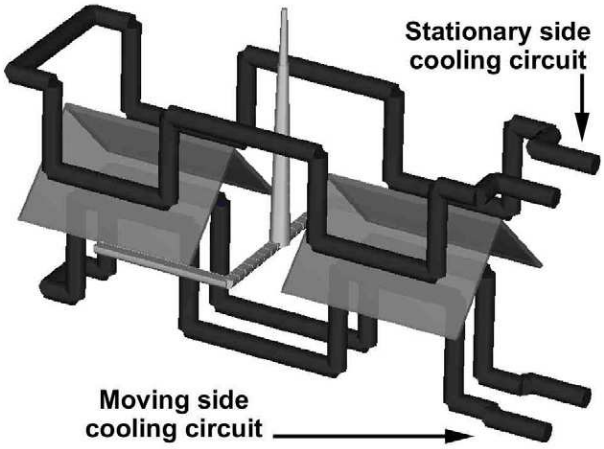
Figure 8. The influence of the holding pressure on the closing angle as a function of the fibre content (mould temperature: 50°C, relative position along the edge: 50%)

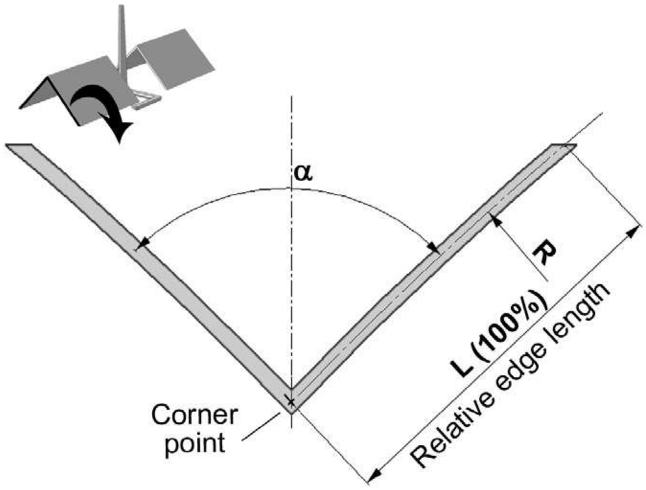
Figure 9. The influence of the moving mould side's temperature on the closing angle as a function of the relative position along the edge (holding pressure: 100 bar)

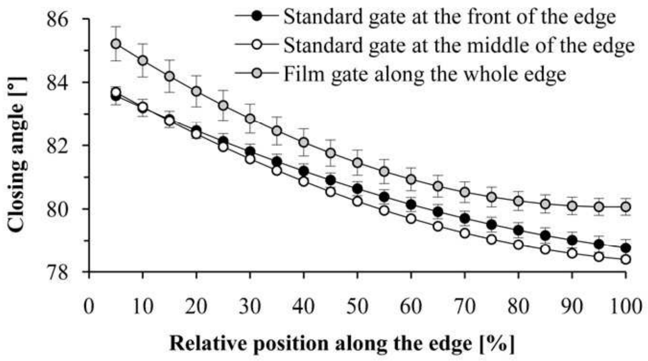

rotatable insert for layout change
gate insert
Stationary side of
the mold
Moving side of
the mold
gate inserts
Moving side
cooling circuit
Stationary side
cooling circuit


a
b
c

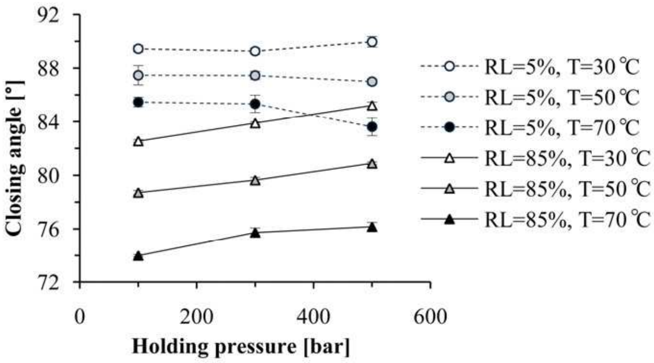

75 mm
46 mm
90°
2 mm


Stationary side
cooling circuit
Moving side
cooling circuit

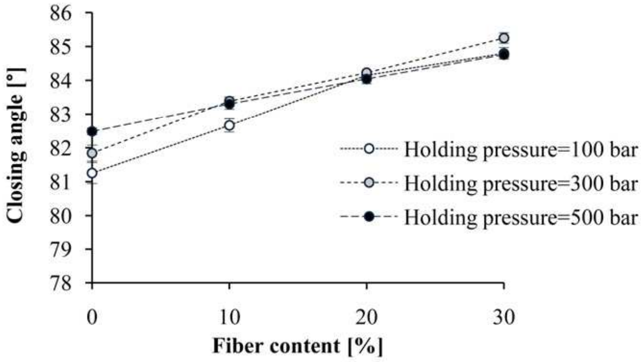

α
R
L (100%)
Relative edge length
Corner
point



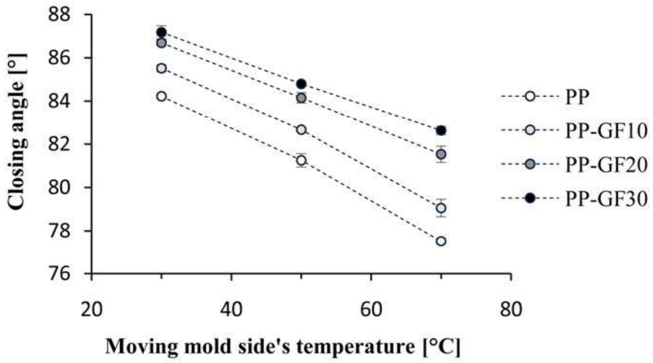
Standard gate at the front of the edge
Standard gate at the middle of the edge
Film gate along the whole edge
Closing angle [°]
86
84
82
80
78
0
10
20
30
40
50
60
70
80
90
100
Relative position along the edge [%]



Closing angle [°]
92
88
84
80
76
72
0
200
400
600
Holding pressure [bar]
RL=5%, T=30 ℃
RL=5%, T=50 ℃
RL=5%, T=70 ℃
RL=85%, T=30 ℃
RL=85%, T=50 ℃
RL=85%, T=70 ℃



86
85
84
83
82
81
80
79
78
Closing angle [°]
0
10
20
30
Fiber content [%]
Holding pressure=100 bar
Holding pressure=300 bar
Holding pressure=500 bar



88
86
84
82
80
78
76
Closing angle [°]
20
40
60
80
Moving mold side's temperature [°C]
PP
PP-GF10
PP-GF20
PP-GF30