# Causes and Analysis of Warpage in Injection Molding

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**Abstract:** This paper contains the basics of injection molding technology and describes some problems and defects which can occur during the injection process. The increased attention is paid to the field of residual stresses and its influence on shape of the injected part. Residual stresses are divided into groups and described. Injection process of the sample is then run in simulation software, the results are explored and compared with real measurements.

**Keywords:** Injection Molding; Shrinkage; Residual Stress; Warpage.

## 1 Introduction

In these days we are surrounded by the products which are made of plastic in many ways. With improving product quality and increasing batch sizes there is a need for suitable production technology. The technology, which meets high requirements is injection molding. This technology is based on injection of plastic melt into mold cavity, where it solidifies into cavity shape. As the flow of the melt is forced through the cavity and it is rapidly cooled then, there remain internal stresses, called residual stresses. As a result, residual stresses can introduce warpage, cracking or long-term deformations.

## 2 Shrinkage

It is generally known that the injection molding technology is accompanied by problems with high thermal expansion of plastics. Since plastics are exposed to wide temperature range, the volumetric changes may achieve up to 20 % by volume. The compressibility of plastics and volumetric changes of crystallization transitions has to be taken in account as well. These changes are generally called shrinkage. Shrinkage occurs as a result of higher temperature dependence of specific volume. When a crystalline polymer melt is cooled down below its transition temperature, the molecules start to clump together which has higher influence on volumetric changes than it would have with amorphous polymers.

The amount of shrinkage can be affected by various factors and injection process is usually modified in order to minimize shrinkage. Shrinkage may be influenced by injection and packing pressure, packing and cooling time, mold and melt temperatures and by the shape of the product.

## 3 Residual Stresses

Residual stresses are undesirable effect which occurs even in the material without external loads. Residual stresses are the main cause of warpage of the injected parts. If their values overcome certain level, collapsed walls or cracks can occur. Residual stresses can be divided into two groups according to their origin.

- Flow-induced residual stresses.
- Thermal-induced residual stresses.

### 3.1 Flow-Induced Residual Stresses

When a polymer is melted, polymer molecules tend to agglomerate into patterns, which are natural and represent their steady-state. While a polymer is forced into cavity of mold, polymer molecules are oriented in the direction of the flow against their will. As a polymer is rapidly cooled down in contact with the mold, molecules are kept frozen in their unnatural positions. This is called flow-induced residual stress. The properties even differ in the direction of the flow and in the perpendicular direction. Exposing the part to heat can cause stress release which is accompanied by dimension changes.

### 3.2 Thermal-Induced Residual Stresses

The first special case of thermal-induced residual stress is described in the following section. It is presented in the Fig. 1. Residual stresses are induced by uneven solidification across the wall cross-section. In the beginning of cooling process when the melt solidifies in contact with cavity, the middle layer is still liquid. The middle layer starts to shrink then but the frozen layers constrain the movement. This generates compression in lateral layers whereas the middle layer is tensioned.

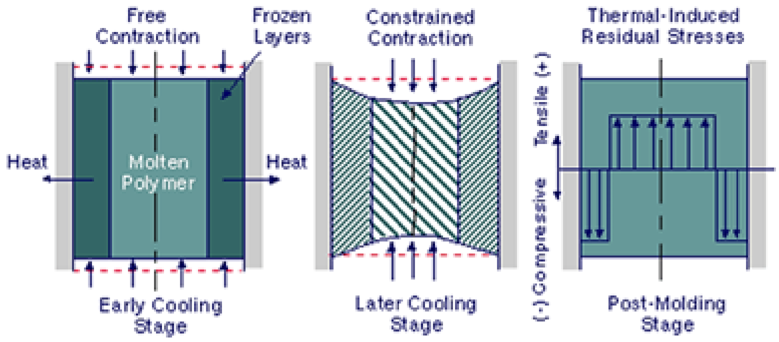



Fig. 1: The development of residual thermal stress due to variations in cooling across the molded part [1].

The biggest influence appears when the rate of cooling channels is unbalanced. This type of cooling inducts asymmetric solidification resulting in generation of bending moment. As one side of cross-section is efficiently cooled down and solidifies in thick wall, the second poorly cooled layer is still thin. When the middle layer begins to solidify and shrink, it overcomes the stability of the thinner side and the cross-section bends. This is the main cause of warping. This problem is described in Fig. 2.

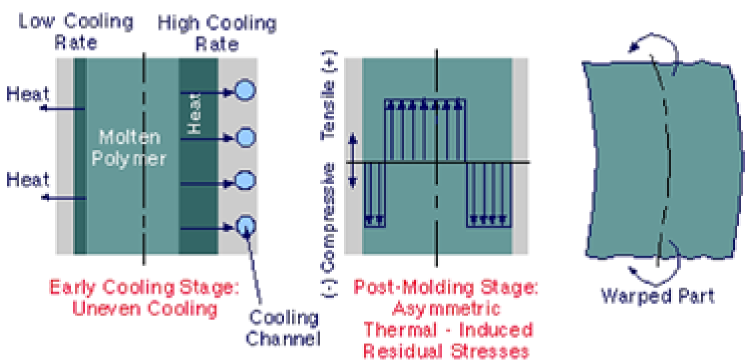



Fig. 2: Thermal-induced residual stress caused by unbalanced cooling across the molded part thickness introduces part warpage [1].

## 4 Case Study

In reality, the dimensions of each injected part are influenced by residual stresses. In this example the influence of each cause of warpage was examined and its influence was evaluated.

A deformed plastic housing was chosen as an example. This part is used as an electromagnetic shield and its function is to block electromagnetic field from the outside world. The housing is made of polybutylene terephthalate reinforced with 20 % of glass fiber. Stainless steel fiber in 10 % content is added to make the polymer electrically conductive, which is necessary for the shielding function.

The problem is that the injected product is warped and differs from the desired shape. Injection molding process was simulated and the calculated warpage was compared with real shape of the sample.

(a) view from the top (b) view from the bottom

Fig. 3: Examined injected plastic part.

### 4.1 Boundary Conditions

As the injection mold was provided by the producer, its pre-deformed cavity was transformed to its negative solid, which was used for the analysis in simulation software. Small radii were deleted from the cavity representation to get a better discretized model. Dual domain mesh was used for discretization of the cavity volume, because in comparison with 3D mesh, it offers more results related to residual stresses and deflection. It consists of two 2D triangular layers of surface meshes which are analyzed simultaneously.

The cavity is surrounded by the cooling channels which were transformed from the mold into the simulation as well. Hot runner gate was replaced with the injection location. The parameters of injection molding were set according to real values provided and used by the producer.

### 4.2 Results

The analysis was performed. The causes of the warpage were divided to 4 effects:

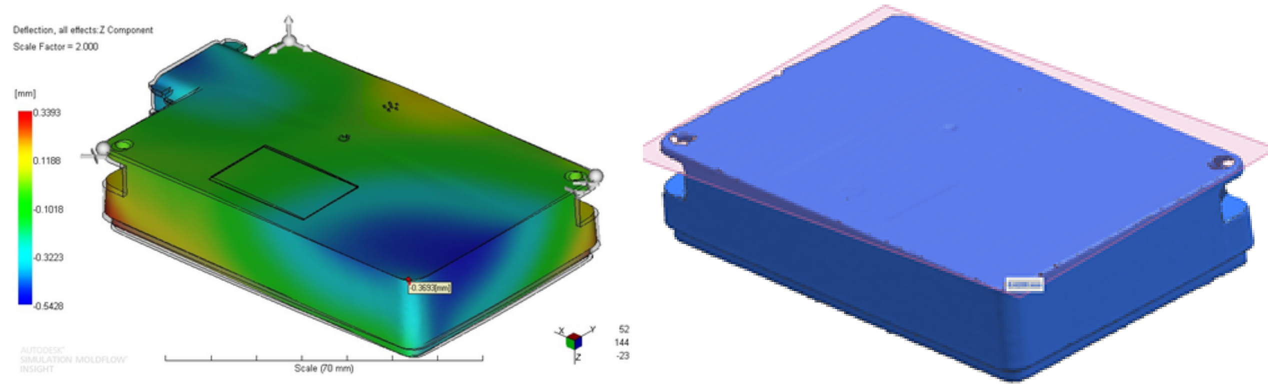
- Deflection, differential cooling.
- Deflection, differential shrinkage.
- Deflection, orientation effects.
- Deflection, corner effect.
- Deflection, all effects.

The flat bottom face of the sample showed the biggest deformation which was therefore investigated. The value of deflection was measured in one direction through the corners of the bottom. Three corners were fitted to the anchor plane and maximal deformation was measured by the displacement of fourth node along Z axis.

Calculated deflections were compared with real deflections for evaluating the simulation. The real sample was scanned to 3D representation with the 3D scanner Leica Laser Tracker LT840. The principle of measurement was the same as in simulation. An anchor plane was fitted to three nodes in bottom corners. The scanned model was examined and the maximal deflection of fourth node was measured along Z axis.

## 5 Conclusion

This paper described warpage defects which can occur during injection molding process. The causes and consequences of residual stresses were reported. The obtained knowledge was applied to the real case study and the injection process was simulated. The simulation showed the maximal deflection of the bottom as 0.37 mm. The measurement of the scanned sample determined the value 0.42 mm. The deviation between obtained values




(a) measurement of simulated deflection

(b) measurement of scanned sample

Fig. 4: Maximal deflection of the bottom along Z axis, influence of all effects.

Tab. 1: Comparison of warpage effects of simulation and experiment.

| | Effect | Displacement [mm] | Percentage [%] |
|---|---|---|---|
| Simulation | Differential cooling | 0.14 | 37.8 |
| | Differential shrinkage | -0.09 | -24.3 |
| | Corner effect | -0.87 | -235.1 |
| | Orientation effects | 0.45 | 121.6 |
| | All effects | 0.37 | 100 |
| | Experiment - All effects | 0.42 | 113.5 |

can be affected by accuracy of 3D scanning and precision of the mold machining. Although there is 13.5 % deviation from the experimental value, the nature of deflections is realistic and the results of simulation were confirmed. Furthermore, the causes of warpage can be isolated in simulation, which allows to determine causes with biggest influence and to optimize them. The simulation can be then rerun to check the improvements.

Based on the made study, simulation software can be used in the pre-production phase for optimization of injection mold and injection molding process. Alternatively, it can also help to find main causes of injection defects during production process but the value of deflection must be evaluated carefully.

## Acknowledgement

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