Autodesk® Simulation Moldflow Insight 2014

3D Injection-Compression Molding

Executive summary

In this report, the injection-compression molding process is analyzed using a three dimensional simulation program. The injection-compression process is often used to produce parts with relatively small warpage at a low clamp force. An example case will be used to test the analysis. The program can be used to compare regular injection molded parts and injection-compression molded parts in terms of injection pressure, clamp force and dimensional stability. In this report, one example case of thermoplastics injection compression molding will be shown.

Contents

Introduction

An injection-compression molding process is illustrated in Figure 1. As can be seen from this figure, the molding cavity initially has an enlarged cross section. Generally, the cavity thickness is initially oversized by several millimeters more than the nominal thickness. This allows flow to proceed readily to the extremities of the cavity under relatively low pressure and stress. At some time during or after filling, the mold cavity thickness is reduced by a compressive force. This forces the resin into the unfilled portions of the cavity and produces a more uniform pressure across the cavity than would be achieved by conventional injection molding. The compression by the press (also called the plunger, moving mold half, or moving platen) is generally done at a controlled speed until a maximum force is reached. The press motion is then gradually decreased. The press motion is determined by the maximum force and the pressure required to squeeze the polymer melt. After the cavity is filled and the material settles in the mold and cools down, additional press movement may be required to compensate for polymer shrinkage. This results in more homogeneous physical properties and less molded-in stresses compared to conventional injection molding [1].

In this report, a three-dimensional injection-compression analysis program developed for a thermoplastic material and a thermoset material will be described. The three dimensional analysis of injection compression has the following advantages compared to two dimensional analysis. First, it can produce more accurate results for thick parts or parts with complicated geometry. Second, the velocity and pressure in the compression direction can be calculated more accurately. Third, it can be readily extended to compression analysis because the initial charge geometry can be modeled more accurately. Designers and engineers can use the results from the program developed in this study to minimize the press force, the injection pressure, shrinkage, warpage and residual stress.

In the next sections, an analysis method for the injection-compression process will be given. This will be followed by some results from a case study.

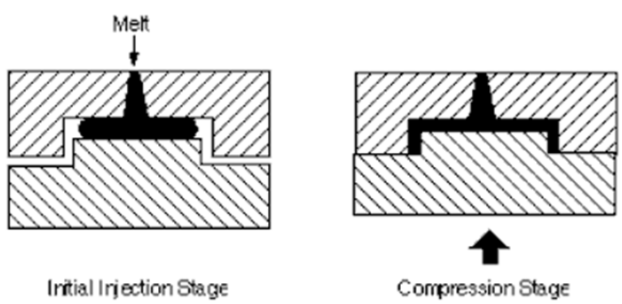


Figure 1: The injection-compression molding cycle.

Governing Equations for Flow Analysis

We need to solve the following set of equations to analyze the injection-compression molding process for thermoplastic materials [2]:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \quad (1)$$

$$\rho \frac{D\mathbf{v}}{Dt} = -\nabla p + \nabla \cdot \boldsymbol{\tau} + \rho g \quad (2)$$

$$\rho C_p \frac{DT}{Dt} = \nabla \cdot (k \nabla T) + \eta \dot{\gamma}^2 + \beta T \frac{Dp}{Dt} \quad (3)$$

where (1) is the mass continuity equation, (2) the momentum equation and (3) the energy equation. A finite element method is used to solve the above set of equations as in [3].

For thermoset materials, the energy equation needs to include a heat generation term due to curing. This is represented by the last term in equation (4).

$$\rho C_p \frac{DT}{Dt} = \nabla \cdot (k \nabla T) + \eta \dot{\gamma}^2 + \beta T \frac{DP}{Dt} + H \frac{D\alpha}{Dt} \quad (4)$$

We also need to solve for the following curing kinetics equation for thermoset materials [4].

$$\frac{D\alpha}{Dt} = (K_1 + K_2 \alpha^{\mu})(1-\alpha)^{\nu} \quad (5)$$

$$K_1 = A_1 e^{(-(\frac{E_1}{T}))} \qquad K_2 = A_2 e^{(-(\frac{E_2}{T}))} \quad (6)$$

Tetrahedral elements are used in the current simulation. A no-slip boundary condition can be applied at the fixed non-compression mold wall as in regular injection molding analysis. However, unlike regular injection molding, a specified speed boundary condition needs to be applied at the compression mold wall when the press is moving under speed control. When the press is moving under force control, the press speed needs to be calculated based on the press force.

Material Properties

The simulation requires various material properties. For thermoplastic materials, the viscosity can be represented by the Cross-WLF model. For pvT (pressure – volume – temperature) data, we use 2-domain Tait equations [5]. We also need values for the thermal conductivity and heat capacity.

For thermoset materials, the viscosity is represented by the reactive viscosity model. It also requires parameters for curing kinetics.

Thermoplastic Injection Compression Molding Example Case

In the example, the software developed is used to simulate the molding of a light guide plate used in LCD panel. Figure 2 shows a model of the part. The model shown in Figure 2 includes runner, gate and part. In this figure, the gray area is where compression is applied. The length of the part is 90 mm, the width is 120 mm and the thickness is 1mm. The finite-element mesh has about 144,000 tetrahedral elements and about 28,000 nodes.

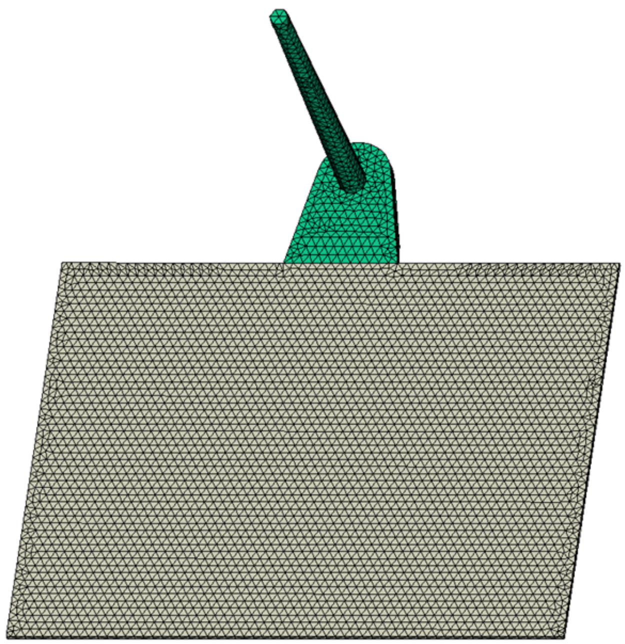


Figure 2: Finite-element mesh of a LCD light guide plate used in the simulation.

Injection molding as well as injection compression molding simulations were run for comparison. The following process conditions are used in this example. The melt temperature is 290 C, and the mold temperature is 80 C.

For the injection molding case, the nominal fill time is about 0.3 second, and the packing pressure is 80% of the switch-over value with 2 seconds of packing time. The cooling time is 10 seconds.

For the injection-compression case, the injection flow rate during the injection stage is the same as the injection-molding case. Injection is stopped when 107% of the final cavity volume (or about 55% of the initial cavity volume before compression) is filled, and the process is then switched to compression. The maximum press force (compression tonnage) is 50 tons and press compression time is 10 seconds. The press open distance is 1 mm. For injection compression, 2 different press speed profiles were used (constant and variable speed profile). For the constant press speed case, the press speed was constant at 12 mm/sec. For variable press speed case, the press speed was initially at 12 mm/sec, but was decreased with time. The press moves at a controlled speed until maximum press force is reached. When the maximum press force is reached, the press moves at a constant press force. The polymer used is polycarbonate.

The simulation results are shown in Figures 3 - 14.

Figure 3 – 5 show the results from injection molding simulation. Figure 3 is the pressure at the injection location. Figure 4 is the clamp force. Figure 5 shows the

warpage result in z coordinate.

Figure 6 – 14 are injection-compression simulation results. Figure 6 shows press speed profile for a constant speed case (a) and a variable speed case (b). Figure 7 shows the pressure history at the injection location during the filling and post-filling stage. As can be seen, the pressures at injection location for constant and variable speed cases are similar during injection period, but the value for the variable speed case is much smaller during compression stage. Figure 8 shows the clamp force history. The clamp force with variable press speed is much smaller than the constant press speed case. Figure 9 shows fill time. Figure 10 the pressure distribution in the cavity during filling and Figure 11 during post-filling. The pressure during filling with variable press speed case is smaller than the constant press speed case. The pressure distribution during post-filling with variable press speed case is much smaller than the constant press speed case. Figure 12 shows pressure history at some points within the cavity.

Figure 13 shows the volumetric shrinkage results at the end of molding for injection compression cases. As can be seen from this figure, the volumetric shrinkage for variable press speed case is much more uniform than the constant press speed case. Figure 14 shows the warpage in z coordinate. We can see that the warpage in z-coordinate for variable press speed case is much smaller than the constant press speed case.

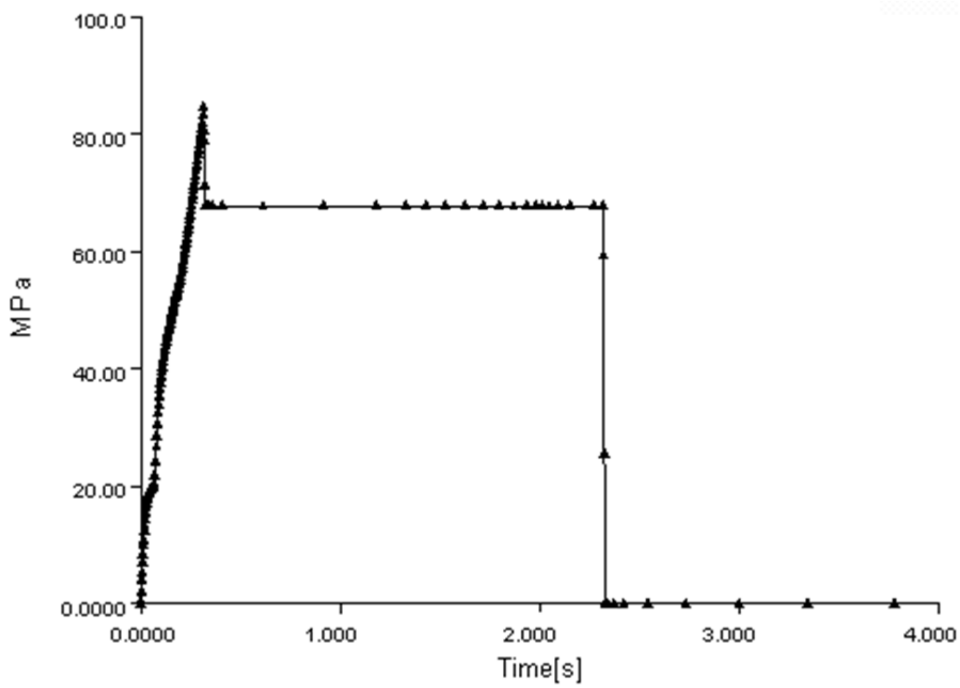


Figure 3: Calculated pressure at the injection location during filling and post-filling for injection molding.

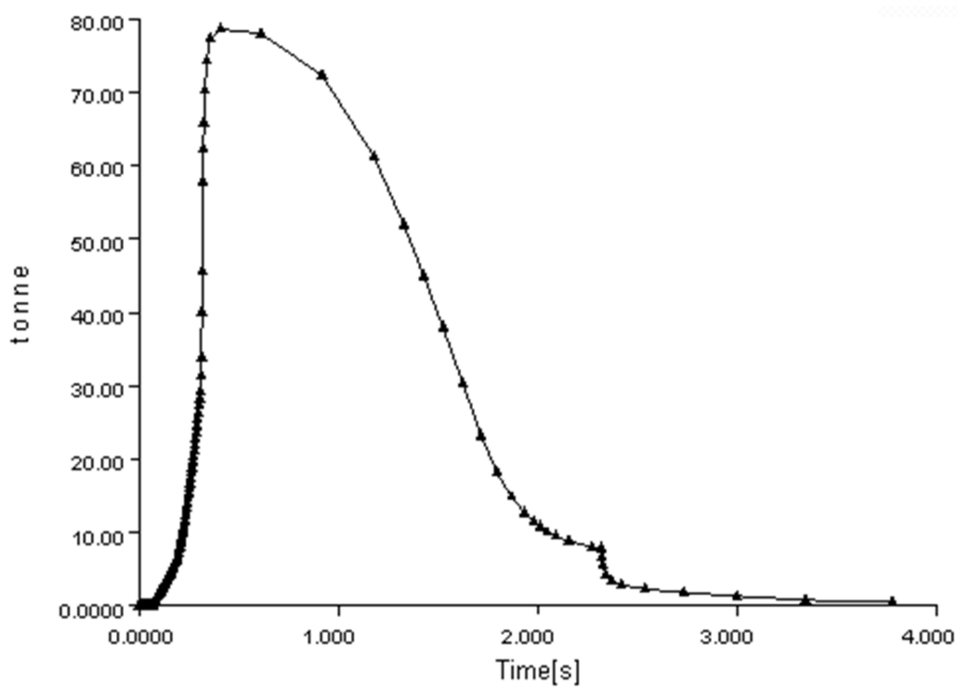


Figure 4: Calculated clamp force during filling and post-filling for injection molding.

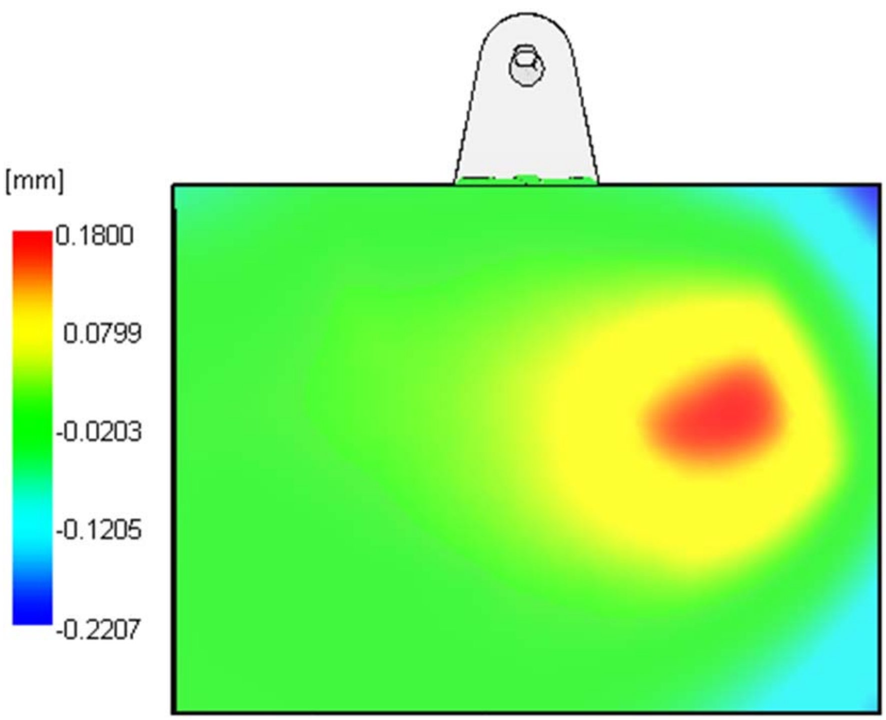
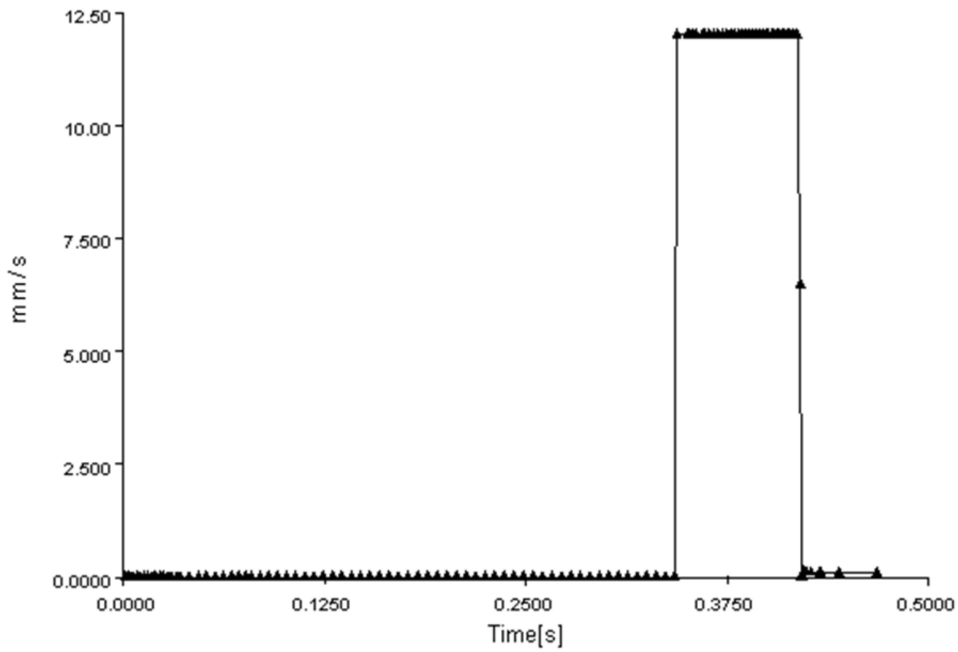
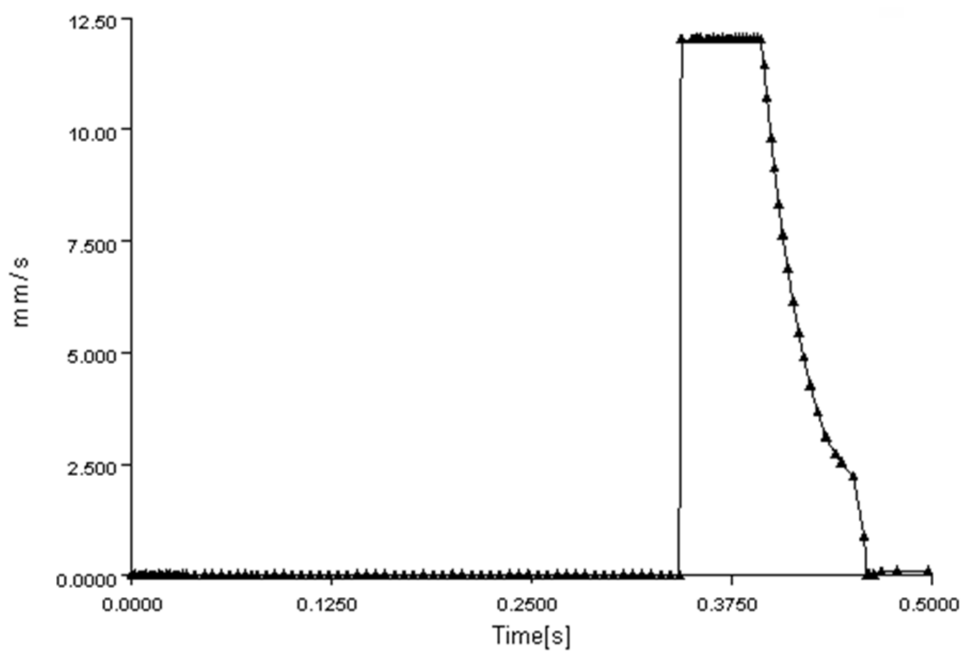


Figure 5: Calculated warpage in z-coordinate for injection molding.

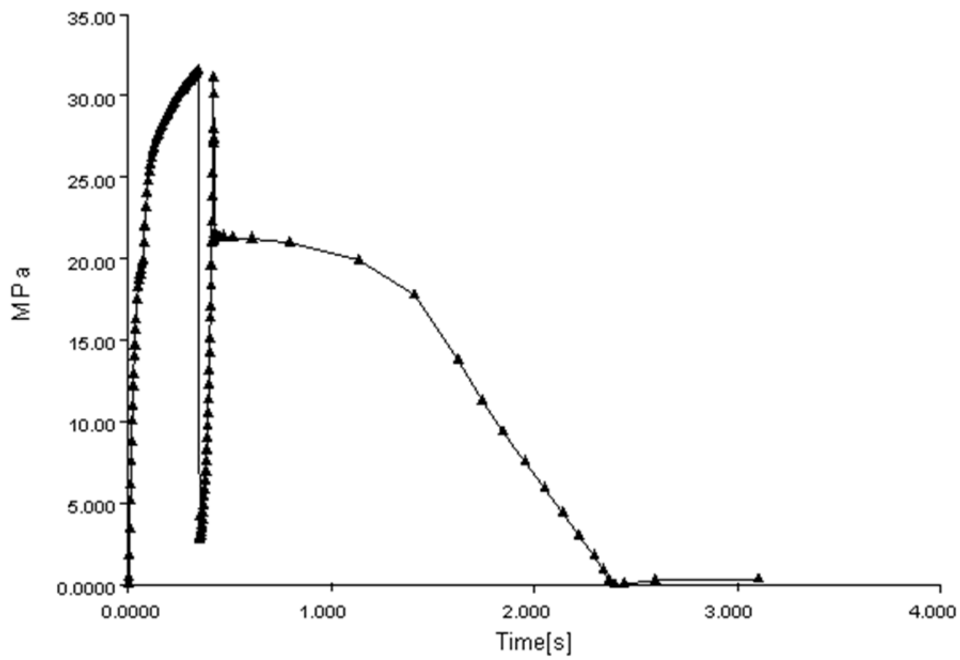


(a)



(b)

Figure 6: Press speed profile for injection-compression molding: (a) constant press speed, (b) variable press speed.



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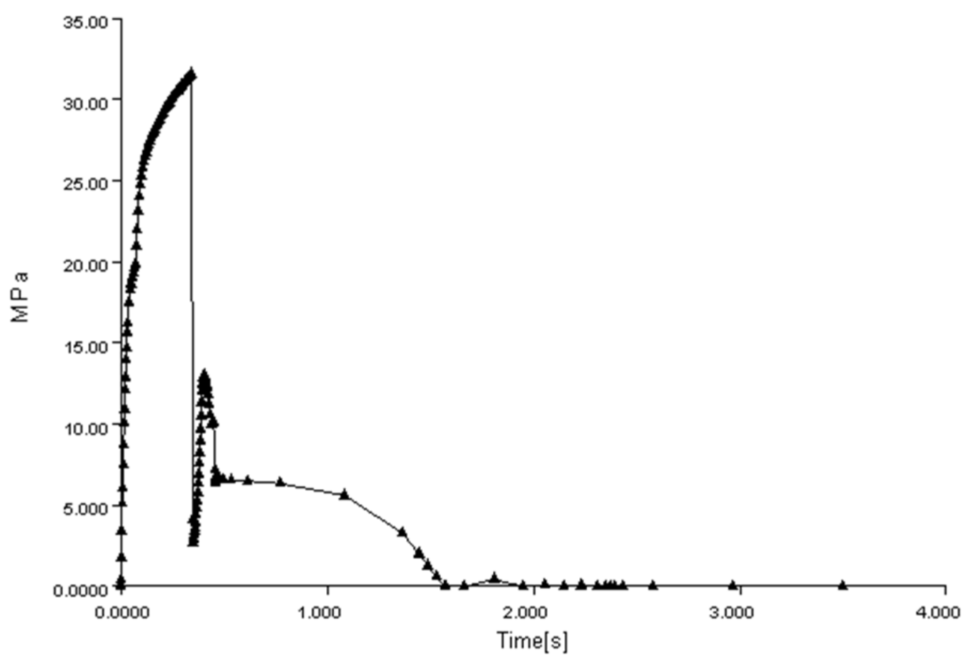
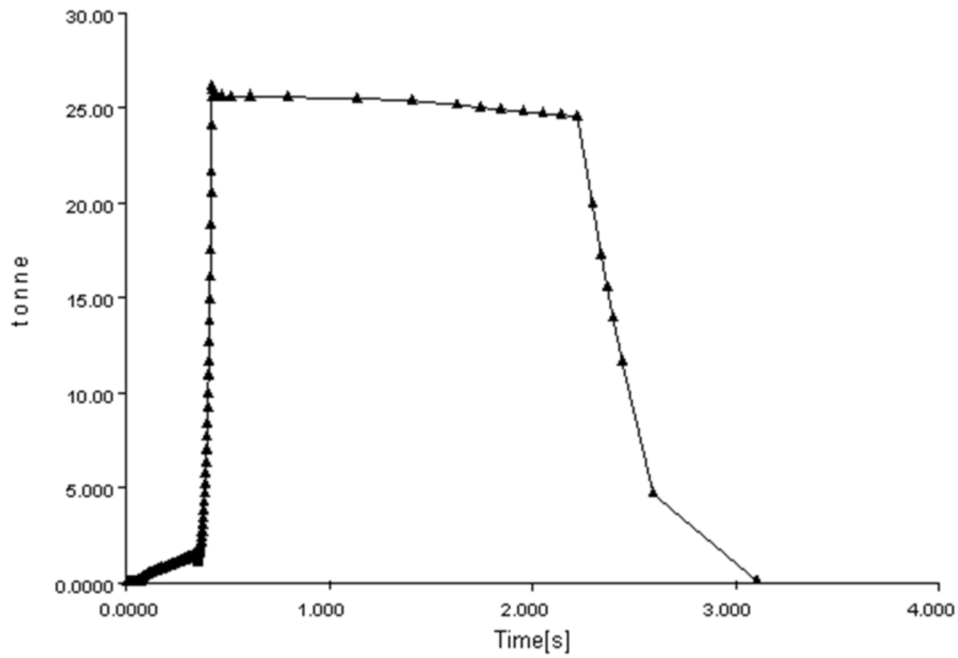


(b)

Figure 7: Calculated pressure at the injection location during filling and post-filling for injection-compression molding: (a) constant press speed, (b) variable press speed.



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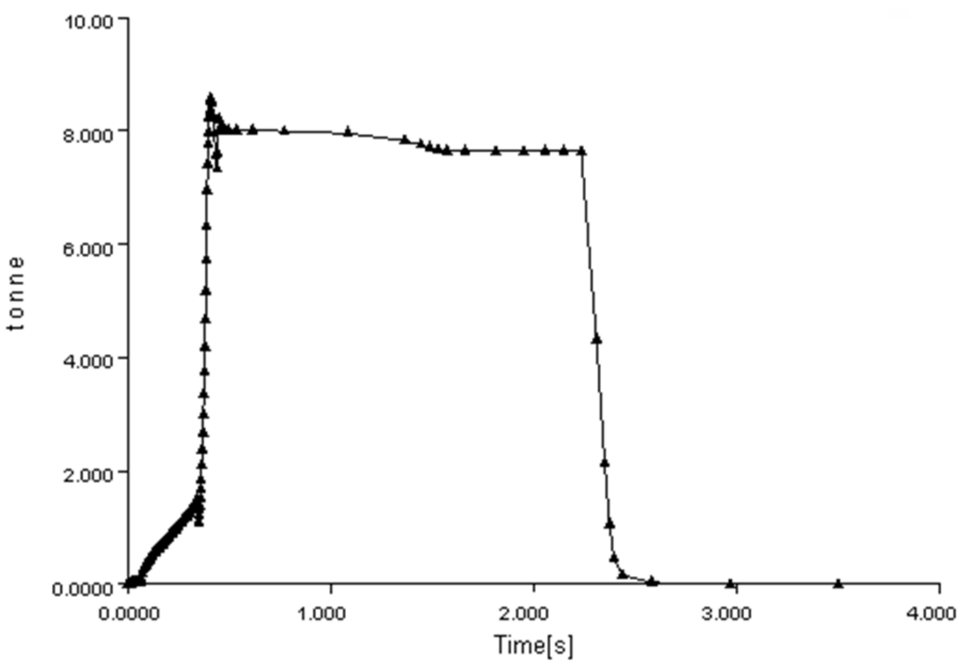


(b)

Figure 8: Calculated clamp force during filling and post-filling for injection-compression molding: (a) constant press speed, (b) variable press speed.

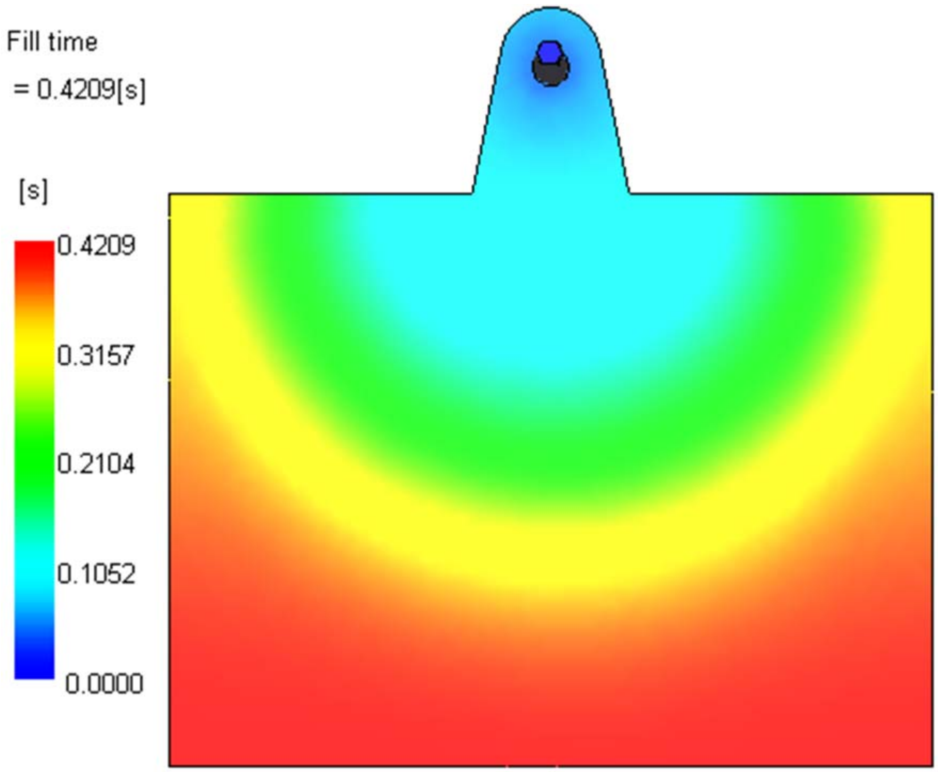
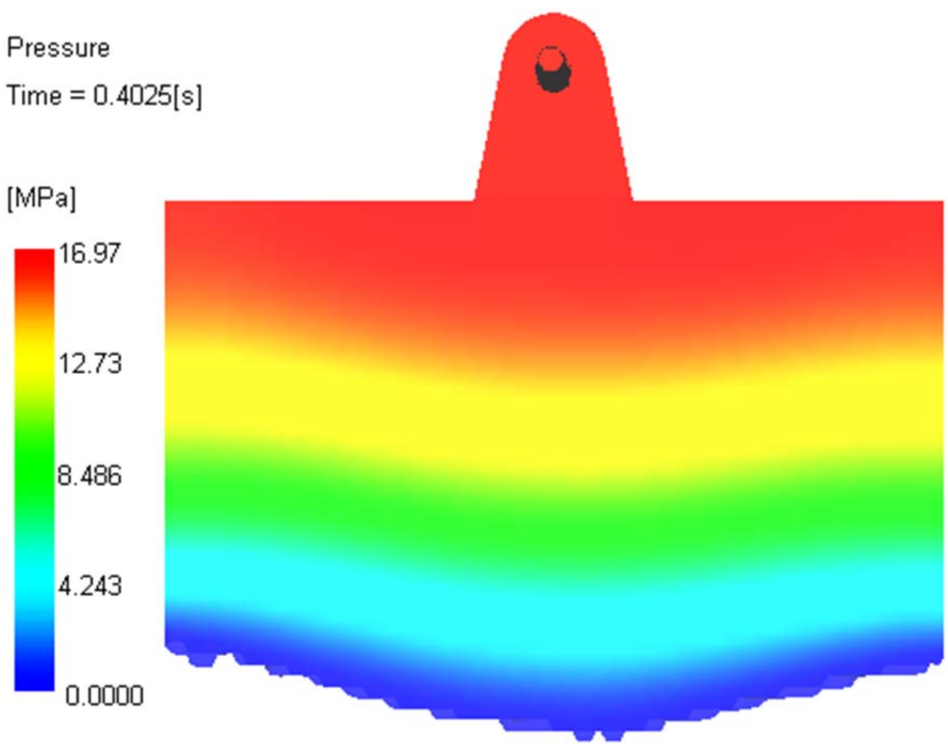


Figure 9: Fill time plot for injection-compression molding for a constant press speed case.



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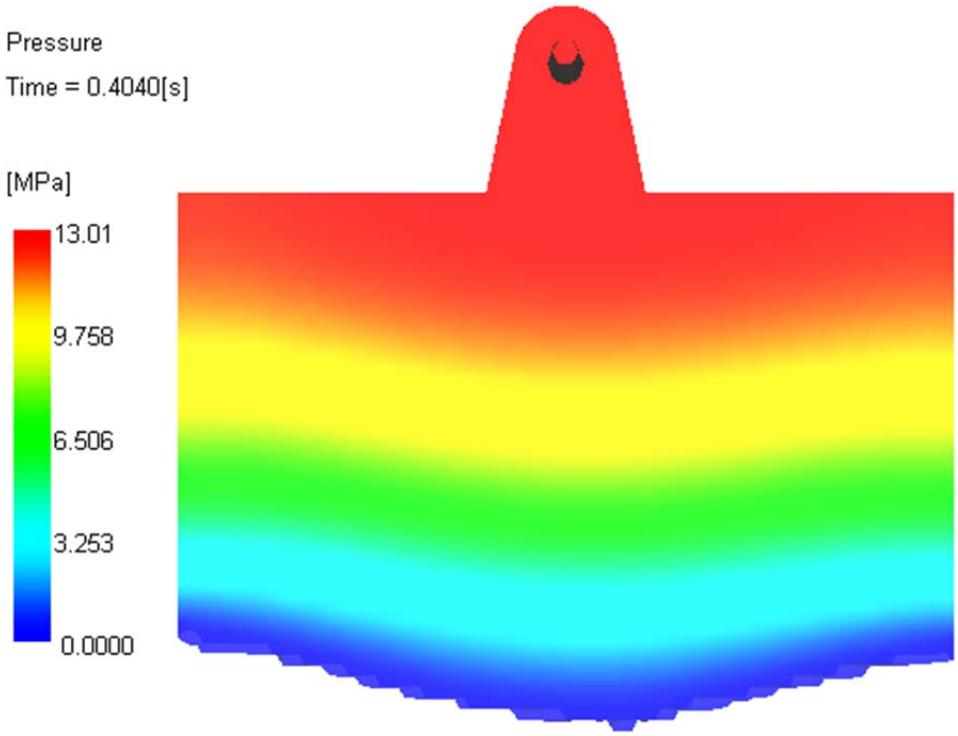
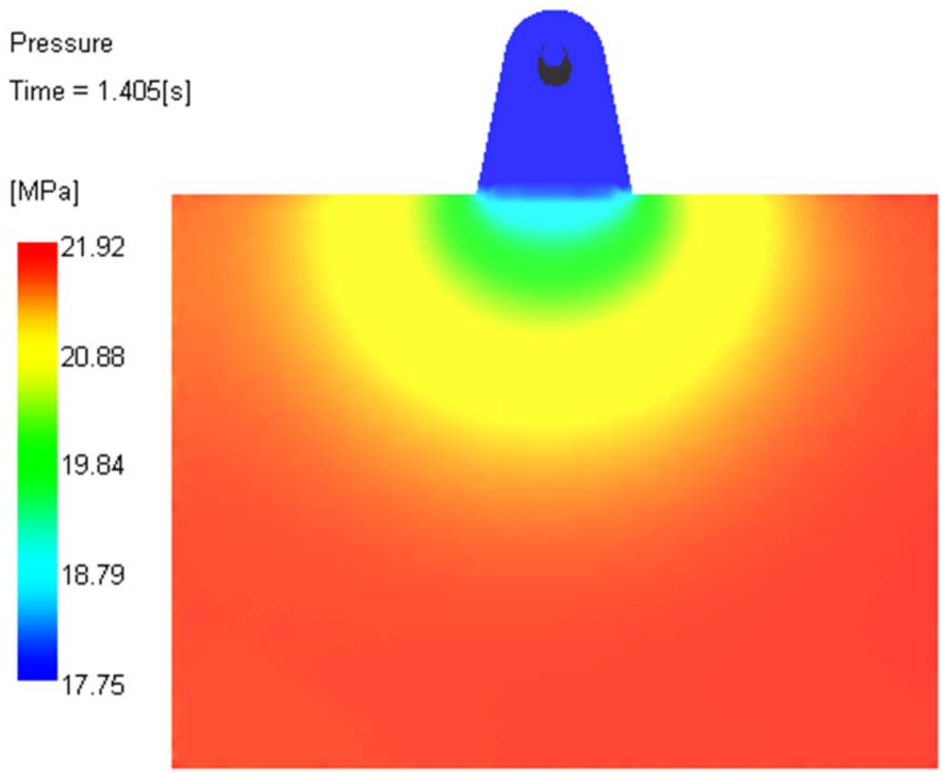


(b)

Figure 10: Cavity pressure during filling for injection-compression molding (a) constant press speed, (b) variable press speed.



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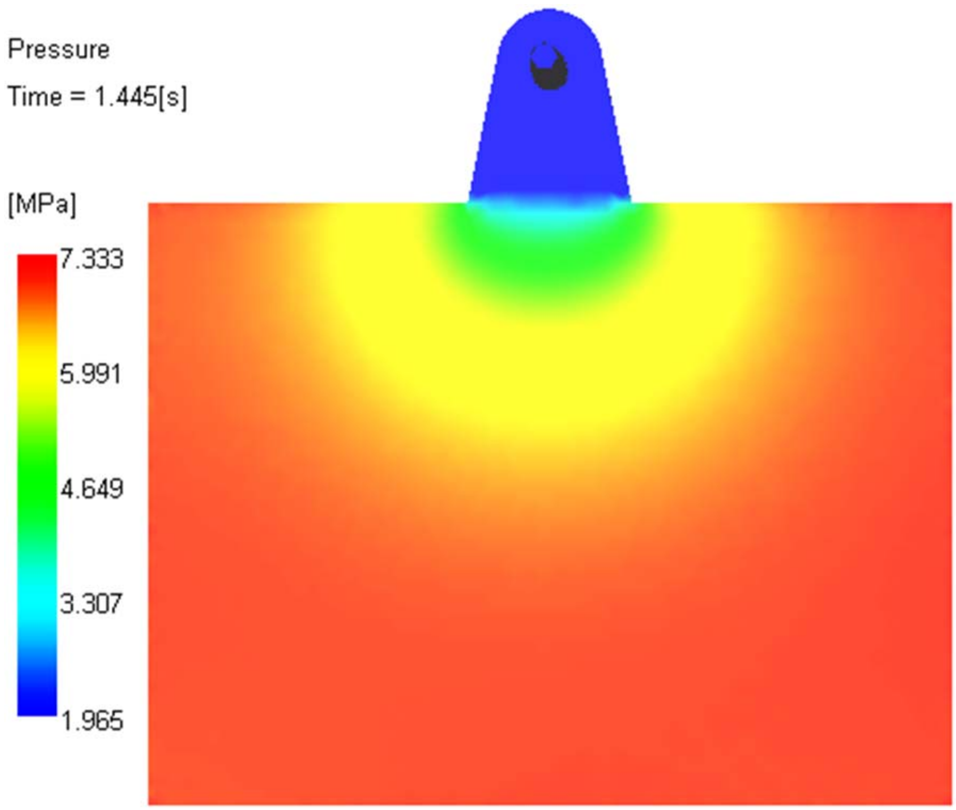
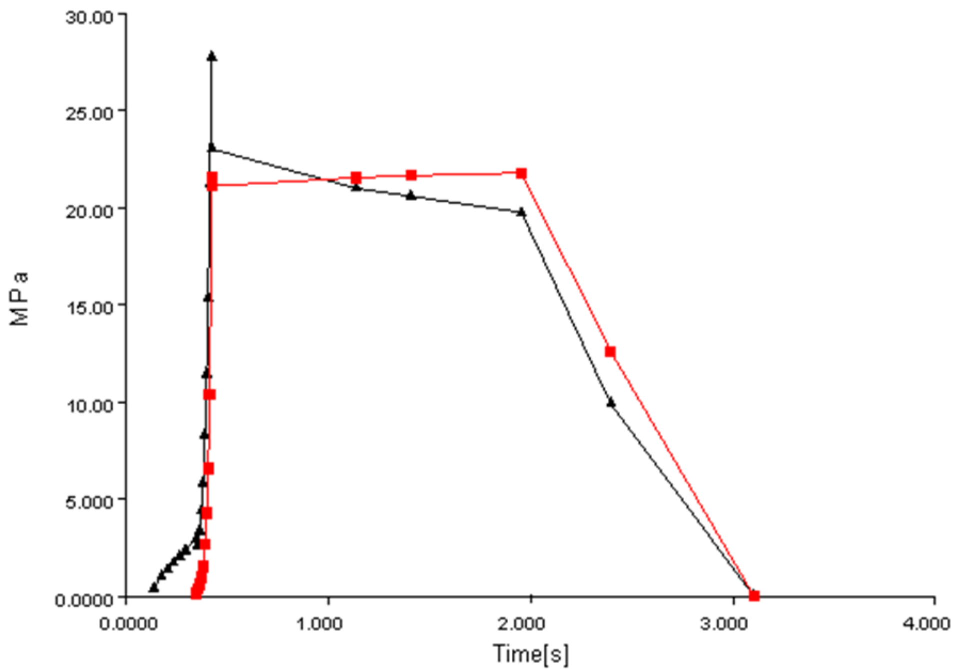


(b)

Figure 11: Cavity pressure during post-filling for injection-compression molding (a) constant press speed, (b) variable press speed.



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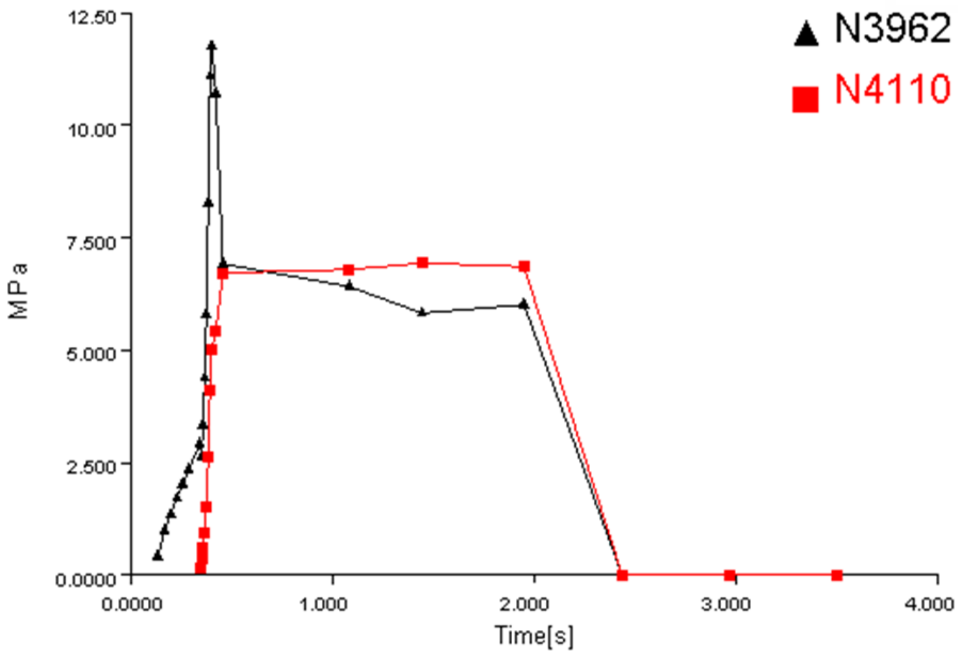

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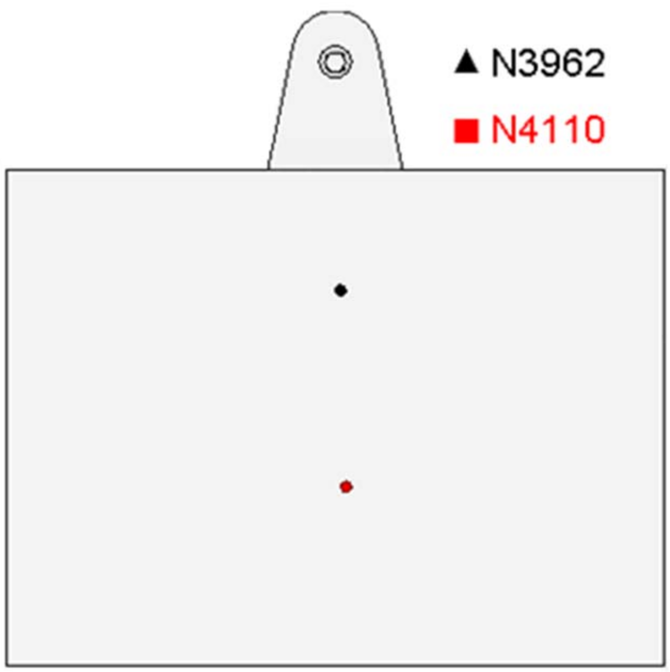
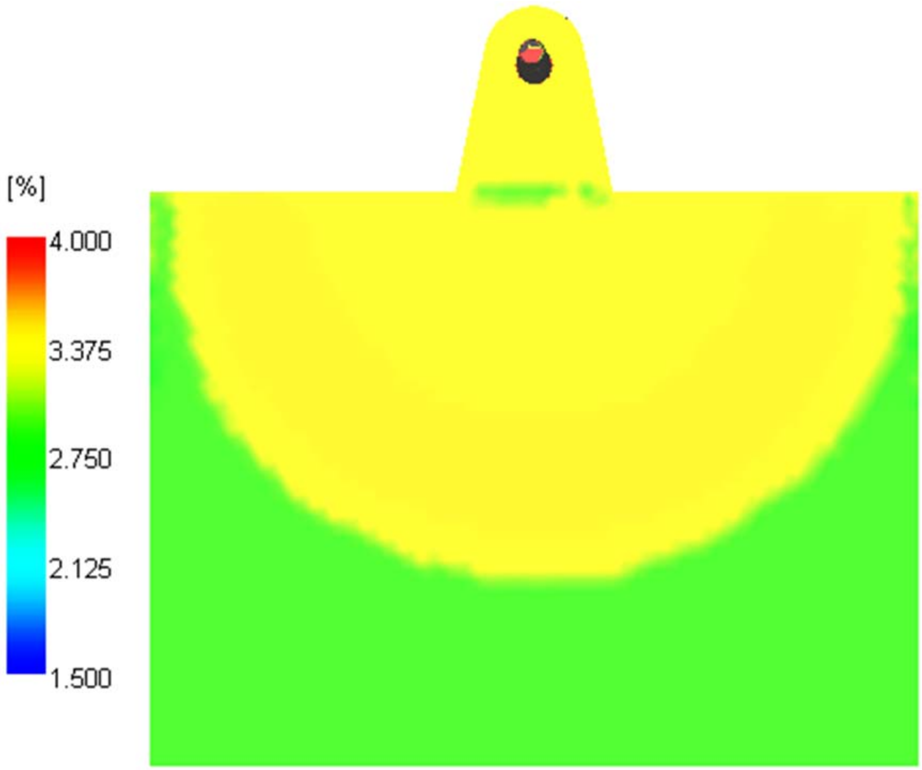


Figure 12: Pressure history during molding at two locations in the cavity for injection-compression molding: (a) constant press speed, (b) variable press speed ((c) shows the locations for these two pressure plots).



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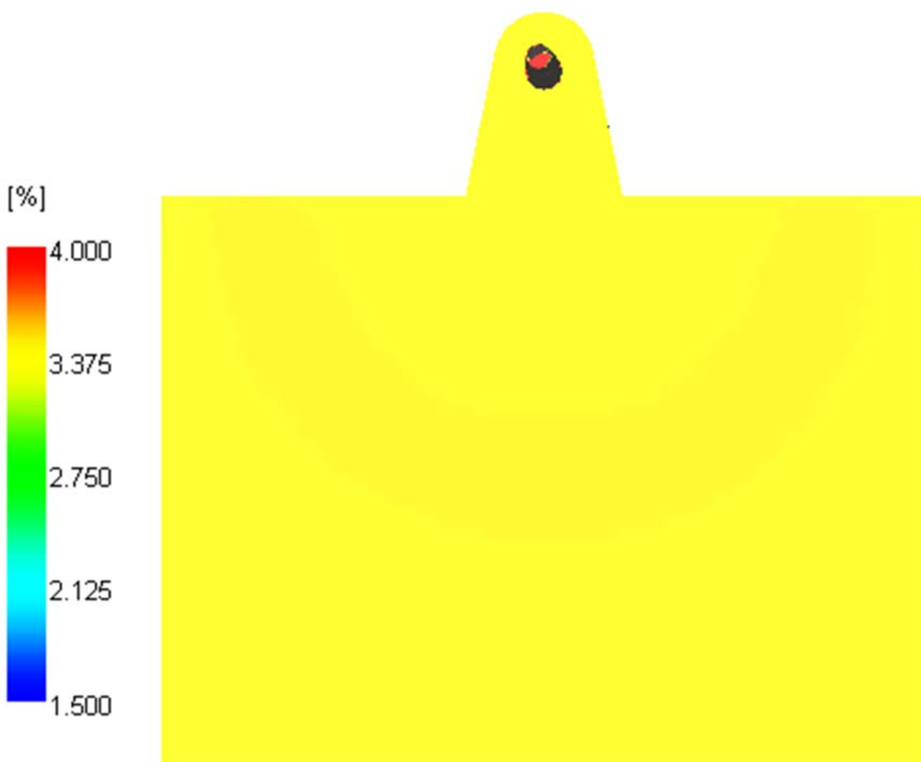
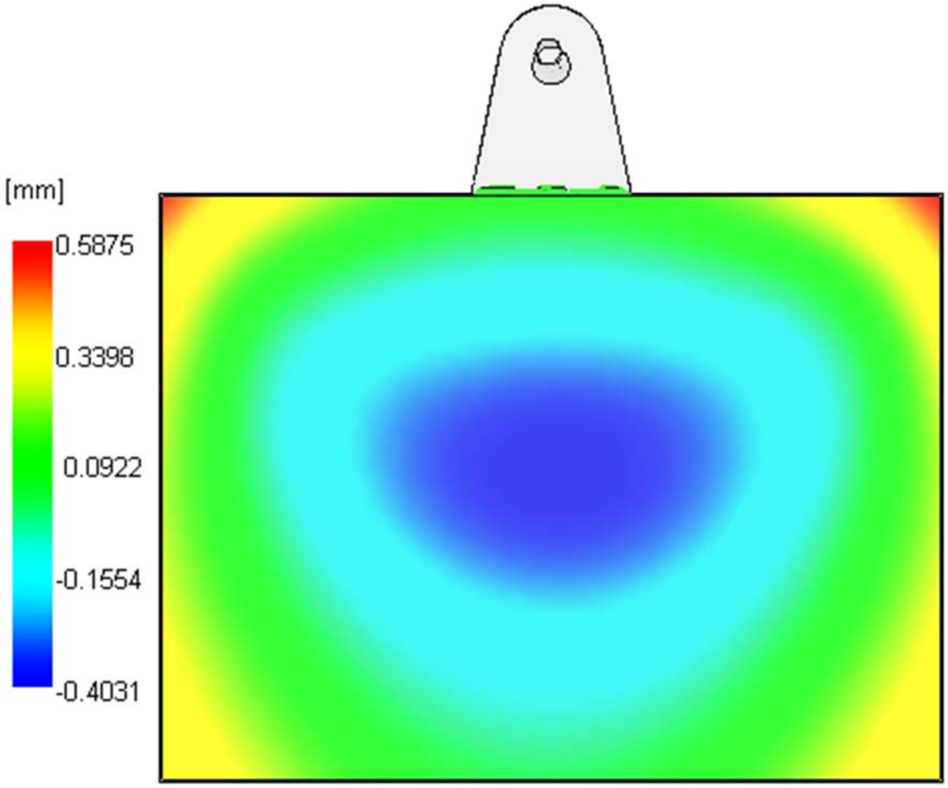
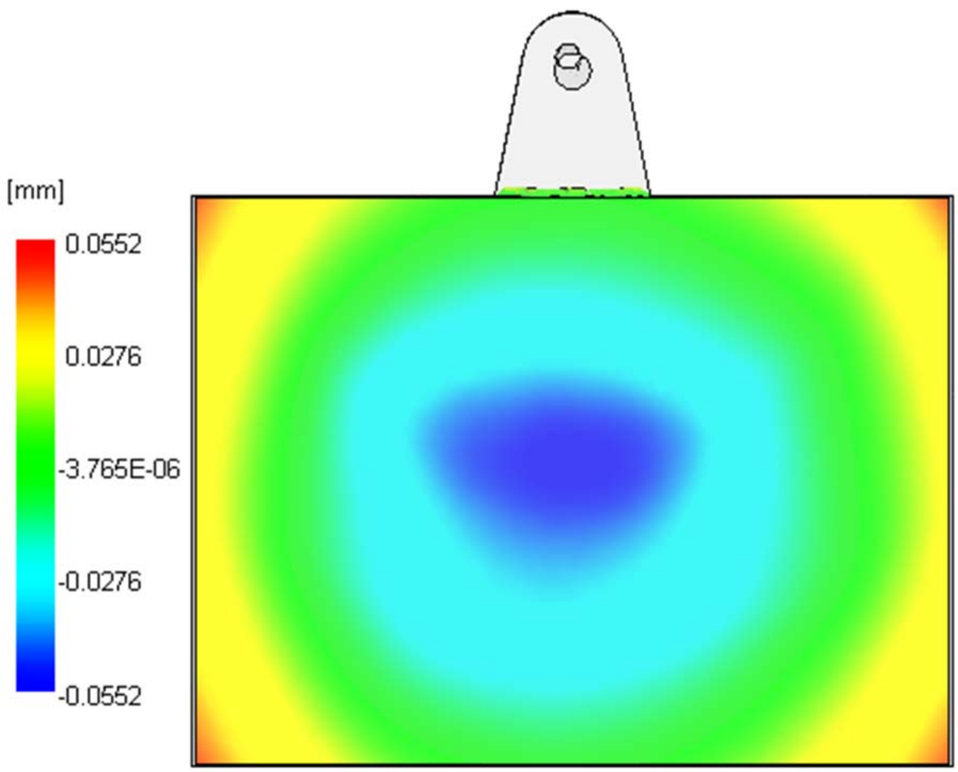


(b)

Figure 13: Volumetric shrinkage at the end of molding for injection-compression molding: (a) constant press speed, (b) variable press speed.



(a)



(b)

Figure 14: Warpage in z-coordinate for injection-compression molding: (a) constant press speed, (b) variable press speed.

Nomenclature

C_P	specific heat capacity
g	gravitational constant
k	thermal conductivity
p	pressure
T	temperature
t	time
v	velocity vector
v	specific volume
β	expansivity
$\dot{\gamma}$	shear rate
η	viscosity
ρ	density
τ	stress tensor

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