SIMULATION OF CORE SHIFT AND INJECTION MOLDING MACHINE CLAMP OVER-TONNAGE USING MOLDFLOW PLASTICS INSIGHT® (MPI®)

White Paper

Abstract

This document describes the recent technology developments for simulating core shift in plastics injection molded parts and predicting injection molding machine clamp over-tonnage using Moldflow Plastics Insight (MPI). A core is the part of a mold which shapes the inside of a molded part. Core shift is the spatial deviation of the position of the core and is caused by non-uniform pressure distribution over the surface of the core during the filling and packing phases. Core shift causes wall thickness variation which results in both structural and cosmetic defects. For high precision parts, the core deflection can lead to rejects or a premature service life failure. An extension of core shift analysis is used to evaluate the performance of the part when the clamp force of an injection molding machine is exceeded. The clamp over-tonnage analysis helps to determine the change in the wall thickness of the part due to the tie-bar stretch; even injection molding flash defect can be simulated. Designers can use MPI's core shift analysis results to correct the phenomenon, by adjusting process settings or modifying the mold design as necessary, reducing the costs of design-to-manufacturing process of a part and decreasing the time to market.

Moldflow Corporation • 430 Boston Post Road • Wayland, MA 01778-1824 • USA

0405

CONTENTS

INTRODUCTION

The production of injection molded parts is a complex process where, without the right combination of material, part and mold design and processing parameters, a multitude of manufacturing defects can occur, thus incurring in high costs. Computer-aided engineering (CAE) tools can be used to simulate a wide variety of phenomena such as core shift that occur during the manufacture of plastic parts. The simulation results can be used to correct the defects on the final part, for example by adjusting process settings or modifying the mold design.

Core shifts are caused by an uneven distribution of the polymer melt flow around a core pin during filling and packing phases of the cycle. The deflection of the core pin causes wall thickness variation of the part. The core shift analysis has the capability to predict the thickness changes due to core deflection, and these thickness changes are carried through to subsequent analyses; so for example, a warpage analysis can be performed to evaluate the part final form, fit and function.

Senior engineer, Paul Van Huffel, at Cascade Engineering has extended the uses of core shift analysis to evaluate the part final shape when the clamp force of the press is exceeded. The clamp over-tonnage analysis helps to determine the change in the wall thickness of the part due to the tie-bar stretch. At Cascade, engineers use core shift analysis also to evaluate the platen deflection, tie-bar stretch and even flash defects.

This white paper discusses the problems and causes of core shift, options of core shift analysis and the benefits of using the simulation program which performs a core shift analysis coupled with structural analysis all in the same environment.

PLASTICS INJECTION MOLDING INDUSTRY OVERVIEW

The complex mix of variables of the injection molding process makes it prone to many defects without the right combination of processing parameters

The plastics injection molding process is integral to many of today's mainstream manufacturing processes. Industries such as telecommunications, consumer electronics, medical devices, computers and automotive all have large, constantly increasing demands for injection molded plastic parts. The injection molding process itself is a complex mix of time, temperature and pressure variables with a multitude of manufacturing defects that can occur without the right combination of processing parameters and design components. There are thousands of different grades of commercial of plastics materials with widely varying processing characteristics and complex part and mold designs are constantly pushing the limits of the process. Because of these complexities, today's plastic part and injection mold designers are under tremendous pressure. Project timelines are being compressed; scaling to high-volume production at times occurs literally overnight; there is a push to ever thinner-walled molding; mold design, mold making and manufacturing often occur across fragmented geographic locations; and material choices are greater than they have ever been.

The usage of CAE simulation provides users with high return on investment

The above factors bring a level of complexity to injection molding that makes it necessary to use CAE tools to predict and solve potential problems before they occur. Additionally, the cost of tooling for injection molds can be very high and subsequent rework increases these already high costs. All these factors combine to make injection molding an ideal application for CAE simulation, the benefits of which provide users with a high return on investment.

CORE SHIFT OVERVIEW

What is Core Shift

A core is the part of a mold which shapes the inside of a molded part. Core shift is the spatial deviation of the position of the core and is caused by non-uniform pressure distribution over the surface of the core during the filling and packing phases. It is a pervasive problem for many types of geometries, especially in the manufacturing of thin-walled parts.

Manufacturing Problems Caused by Core Shift

For high precision parts, the core deflection can lead to rejects or a premature service life failure

Non-uniform flow around the core pin causes the pin to deform during the filling and packing phases of the cycle. This deformation causes wall thickness variation which results in both structural and cosmetic defects. For high precision parts, the core deflection can lead to rejects or a premature service life failure.

Centrifuge tubes, blood-collection tubes, test tubes, syringe barrels, vials, pen barrels, pails, drums, yogurt and other thin-walled containers, and pre-forms for blow molding are just a few examples of parts that are molded using cores that may shift, thus causing problems.

Simulation of Core Shift

Historically, it has been possible to use CAE simulation tools to predict core shift. However, few attempts were made to use them owing to the complex nature of setting up and running the analyses. Predicting core shift through these historical methods required the use of two separate analyses, each performed in entirely different CAE software programs. The first analysis was needed to predict the flow of plastic material around the core. The results of the flow analysis were used to perform a subsequent analysis of the structural deformation of the core.

Core shift analysis now can be performed completely within Moldflow Plastics Insight 5.0 using a unique, coupled structural analysis

Fortunately, the technology advances every day, and now core shift analysis can be performed completely within Moldflow Plastics Insight® (MPI®) 5.0. The MPI 5.0 release introduced a new, fully coupled structural analysis that is unique in the industry.

CORE SHIFT ANALYSIS

Designers can use core shift analysis results to correct the phenomenon, by adjusting process settings or modifying the mold design

Core shift analysis is available for all geometry types (midplane/Fusion/3D)

About Core Shift Analysis

The core shift analysis provides detailed information about the movement of the mold core and its interaction with the polymer flow process as the plastic is being injected. Designers can use this information to correct the core shift phenomenon, for example, by adjusting process settings such as injection speeds or core or mold temperatures or modifying the design of the mold such as adjusting the gate location or changing the type of gate.

To simulate the core shift phenomenon, a structural analysis of the core has been coupled with the plastic flow analysis, thus allowing the core deflection and modified wall thickness to become dynamic inputs to the filling and packing simulation. This coupling has been implemented for all geometry types supported by the MPI 5.0 release (midplane/Fusion/3D). Examples shown in this paper include long cores, part inserts and deflection of mold plates.

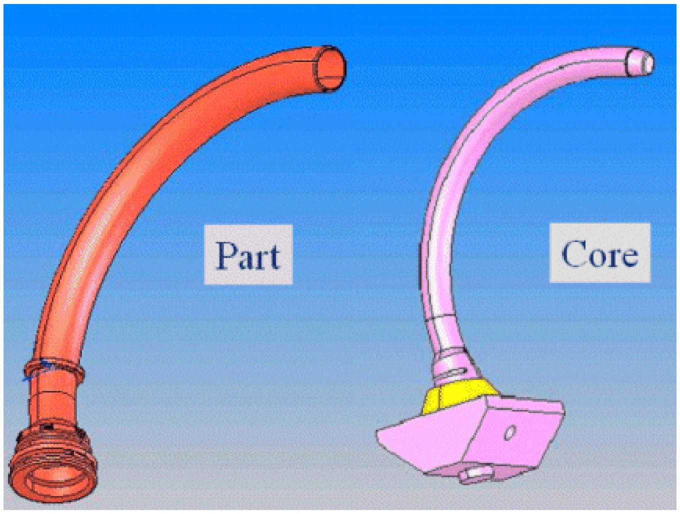

***Figure 1**, Part and Core. Model courtesy of Avenue Mould, Ireland*

When to Use Core Shift Analysis:

The following are examples of instances where a core shift analysis can be performed and will provide valuable results to the user:

- Long cantilevered cores
- Non-steel, flexible cores
- 2-shot moldings (tail lamps, etc.)
- Insert molding over sheet-metal stampings
- Clamp over-tonnage, mold and tie-bar fatigue and vent flash

The simulation of clamp over-tonnage, mold and tie-bar fatigue and vent flash is a creative way of using core shift analysis. The application of this capability was developed by Paul Van Huffel, senior engineer at Cascade Engineering.

Preparing a Model for Core Shift Analysis

The core must be modeled as 3D tetrahedral mesh

Core shift analysis is supported with midplane, MPI/Fusion and MPI/3D meshes, although the core itself always should be modeled as 3D tetrahedral mesh.

Appropriate constraints need to be applied to the fixed end of the core to prevent rigid body motion in the structural analysis. All of the nodes on the bottom face of the core should be fixed.

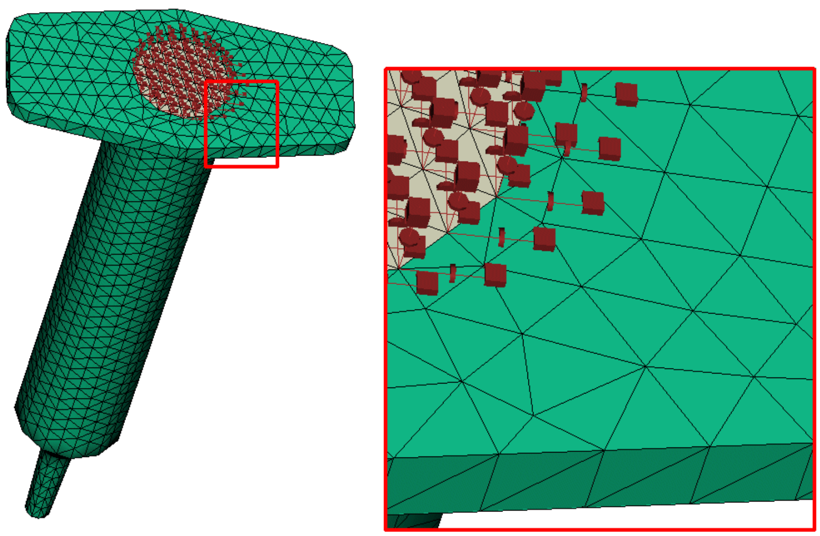

***Figure 2**, Core constraints*

Core Shift Analysis Options

Users have the option to perform core shift analysis in conjunction with a Filling or Filling + Packing (Flow) analysis. Other parameters options that control the fluid-structural interaction include:

- The **Frequency of the core shift analysis** determines at what interval the core shift analyses are performed during the flow analysis. Users can specify the *Maximum volume increment between analyses* and the *Maximum time step between analyses*.

Option to specify number of nodes on the tetrahedral elements used in the core to increase the analysis resolution

- For midplane and Fusion models the **Analyze core using** option specifies the number of nodes on the tetrahedral element used to model the core.
- The **Perform core shift analysis during pressure iteration** option specifies whether additional core shift analyses should be performed during the pressure solution iteration.

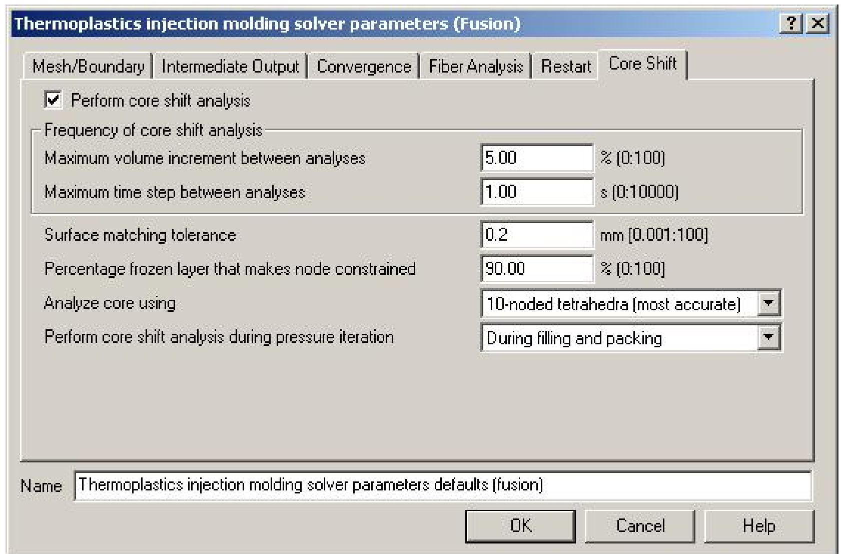

***Figure 3**, Core shift solver parameters*

Users have the option to choose between 4-noded tetrahedra or 10-noded tetrahedra to be used on the core mesh. When users select the 10-noded tetrahedra, the 4-noded tetrahedra created by MPI will be upgraded to 10-noded tetrahedra by the addition of an extra node on each tetrahedron edge. The solution with 10-noded tetrahedra provides higher resolution than with 4-noded tetrahedra; however, the memory requirement and computation times are considerably higher.

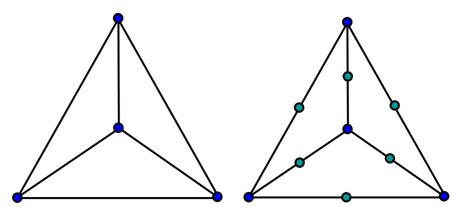

***Figure 4**, 4-noded and 10-noded tetrahedra*

Reviewing Core Shift Analysis Results

The core shift analysis will produce two results specific to this analysis:

- The **Displacements, core** result shows how far the core deflects over time. In many cases, the maximum deflection of the core will not happen at the end of the cycle but during filling or packing. The number of time steps is determined by the frequency of the core shift analysis. This result is available for midplane, Fusion and 3D mesh types.

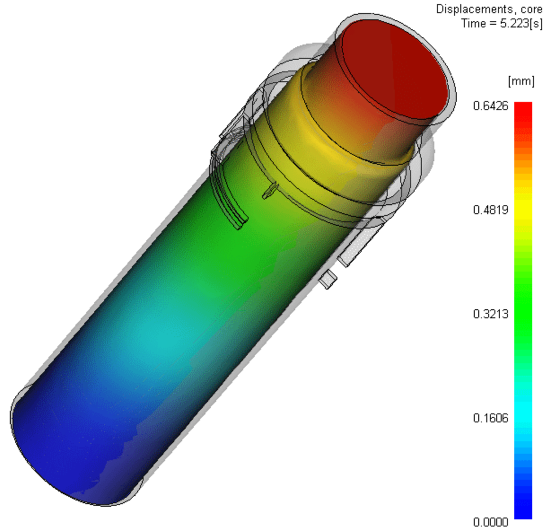

***Figure 5**, Displacements, core. Tool courtesy of S P & Associates, Australia*

- The **Real thickness, cavity** result shows the cavity thickness as a consequence of the core deflecting. This plot is available for midplane and Fusion mesh types only.

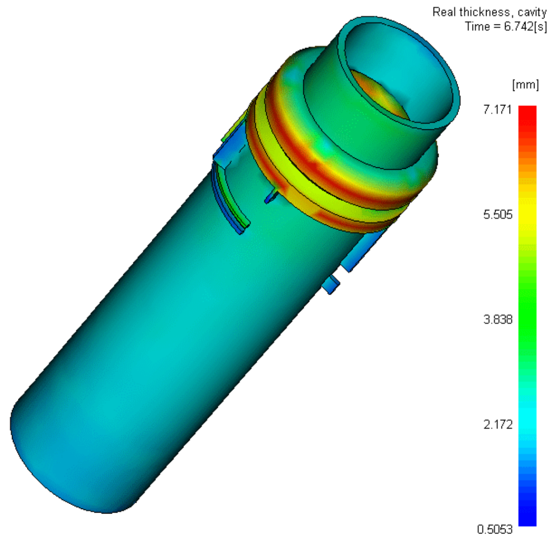

***Figure 6**, Real thickness, cavity. Tool courtesy of S P & Associates, Australia*

- The **Displacements, final shift** result shows the final position of the core as well as the plastic part. This plot as viewed on the core is the same as the **Displacements, core** plot at its last time step. However, viewed on the plastic part model, it shows how much the wall thickness has changed. This result is available for 3D mesh only.

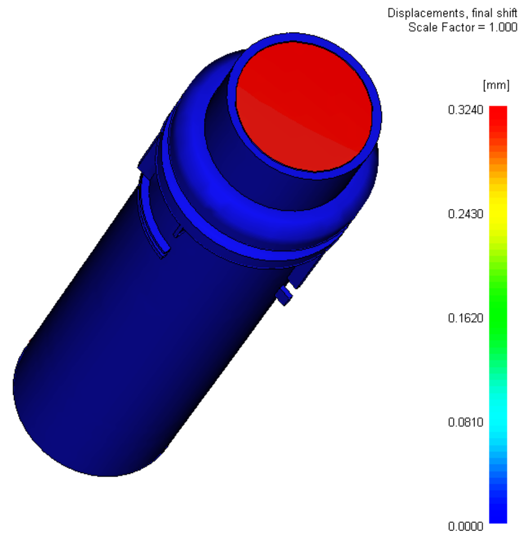

***Figure 7**, Displacements, final shift. Tool courtesy of S P & Associates, Australia*

The thickness changes are carried through to subsequent analyses so further evaluation of the part quality can be performed

The thickness changes are carried through to subsequent analyses; so for example, a warpage analysis can be performed to evaluate how the wall thickness changes influence the part final shape.

APPLICATION EXAMPLE

Experimental data and the model for simulation are courtesy of Avenue Mould, Ireland (see Figure 1). The part is a curved polyethylene tube gated on a plane of symmetry of the part.

Experimental and Analysis Settings

Due to the curved shape of the core, it is very stiff in the plane of symmetry but relatively elastic in the transverse direction. The experiment found a strong final core shift of 0.25±0.1 mm in the direction perpendicular to the plane of symmetry at the midpoint of the tube. This deformation is the criterion used to validate the core shift simulation results.

Table 1 displays the processing conditions from the molding trials which were used in the simulation.

Table 1, *Processing conditions used in the simulation*

Parameter	Value
Material	LDPE: PE 2038 from Huntsman Chemical Company
Mold surface temperature [°C]	30
Melt temperature [°C]	265
Fill time [sec]	0.43
Pack time [sec]	2
Cooling time [sec]	16

The Fusion mesh of the part and runner system used in this validation is shown in Figure 8 and mesh of the core, which is fixed on both ends, is shown in Figure 9:

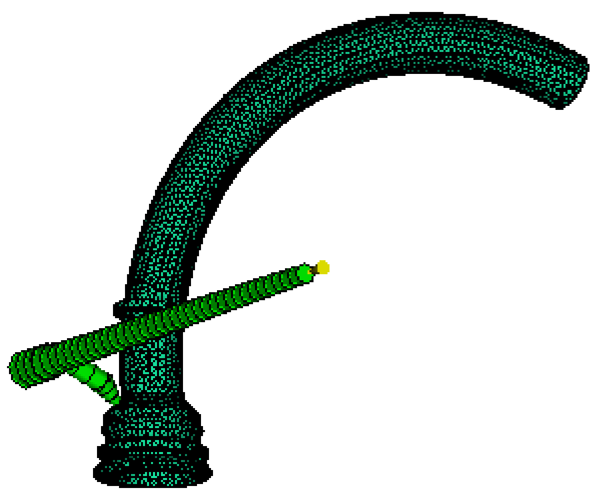

Figure 8*, Part and runner system. Model courtesy of Avenue Mould, Ireland*

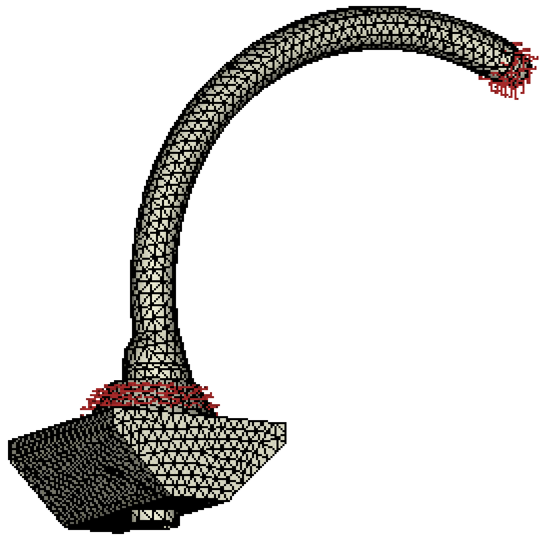

***Figure 9**, Constraints on the core. Model courtesy of Avenue Mould, Ireland*

Results

The final displacement predicted by the analysis is shown in Figure 10.

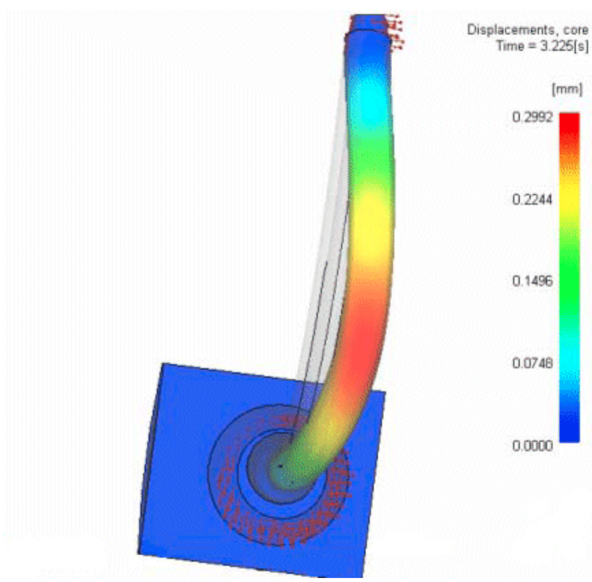

***Figure 10**, Displacements, core result. Model courtesy of Avenue Mould, Ireland*

Simulation result of 0.29 mm core displacement is close to the experimental data of 0.25±0.1 mm

The maximum displacement of 0.29 mm is mostly in the direction perpendicular to the plane of symmetry. The result is in close agreement with the experimental data of 0.25±0.1 mm of core displacement mostly in the direction perpendicular to the plane of symmetry.

CLAMP OVER-TONNAGE OVERVIEW

A creative example for using the core shift analysis is to evaluate the performance of the part when the clamp force of the press is exceeded.

What is Clamp Over-tonnage

The clamp over-tonnage analysis help to determine what will be the effect when the machine clamp force is exceeded

Clamp over-tonnage is an analysis in which the user models the machine's clamping unit as part of the core and the analysis determines what will be the effect when the machine clamp force is exceeded.

By modeling the clamping unit, the change in the wall thickness of the part due to the tie-bar stretch can be determined

When the clamp force of the machine is exceeded, the tie bars stretch. The mold will open the amount of the stretch, increasing the wall thickness of the part. As the part shrinks, the clamp force is reduced and the mold will shut. In most molds, the pressure distribution is not even, so the stretching of the tie-bars is not uniform. By modeling the clamping unit of the injection molding machine, the change in wall thickness of the part due to tie-bar stretch can be determined, even flash defects can be simulated.

Modeling for Clamp Over-tonnage Prediction

Modeling for prediction of clamp over-tonnage is quite complex compared to normal core shift analysis. In addition to the core itself, the model must include:

- Machine platen(s)
- Clamp assembly
- Tie-bars
- Tie-bar stretch force
- Flash or parting line elements

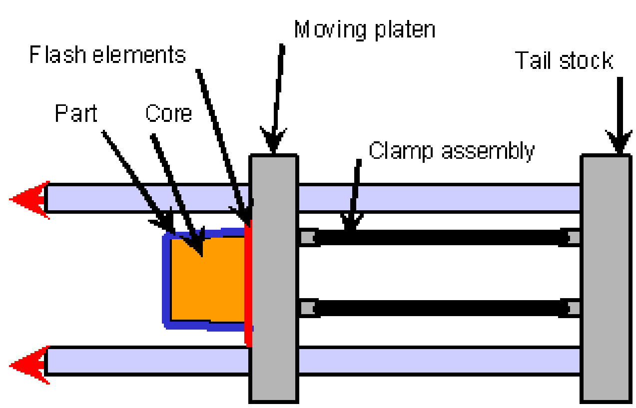

***Figure 11**, Modeled components of a three platen press*

The stretch of the tie-bars will provide the thickness of the flash on the part

For a typical three-platen press, the moving platen and tailstock platen are modeled along with the clamp unit between the platens. This is only done to describe the clamp force and how it is applied to the mold. The ends of the tie-bars that are not attached to the platen have a displacement load applied to them which represents the stretch applied to the tie-bars based on the clamp force applied to the mold. This is calculated based on the following relationship:

$$\frac{\text{clamp force * length of the tie-bars}}{\text{modulus (E) of the tie-bars * total transverse area of the tie-bars}}$$

To resist the tie-bars, elements are placed on the parting line. These elements are part surface elements which should have a small non-zero thickness, such as 1e-6. MPI is not designed to use the core deflection technology for clamp-over tonnage calculations, so there are a few things that have to be done that will cause error messages to be generated by the software. The small thickness will trigger a warning about the thin value. These elements should NOT fill, but because they are plastic elements, the flow analysis effectively will end in a short shot. During the core deflection analysis, these elements will go down to a zero thickness. This is what resists the tie-bar stretching force.

Reviewing Clamp Over-tonnage Results

Results from the clamp over-tonnage are the same as a core shift analysis. The **Displacements, core** result is used to look at how much the tie-bars stretch and the platens bend. The **Real thickness** plot is used to show how much the cavity thickness changes based on the mold opening and the bending of the platens. Figure 12 shows a simplified model of a two platen press and a sample flat plate.

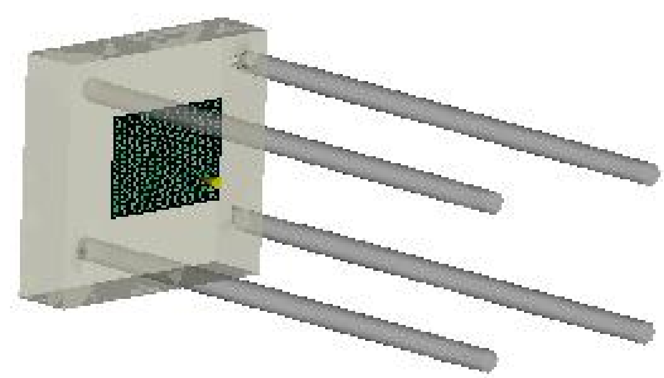

***Figure 12**, Simplified model of a two platen press*

Figure 13 shows both of the results *displacements, core* and *real thickness*. The results are shown at three times during the cycle, showing how the distribution changes due to the asymmetric gate location.

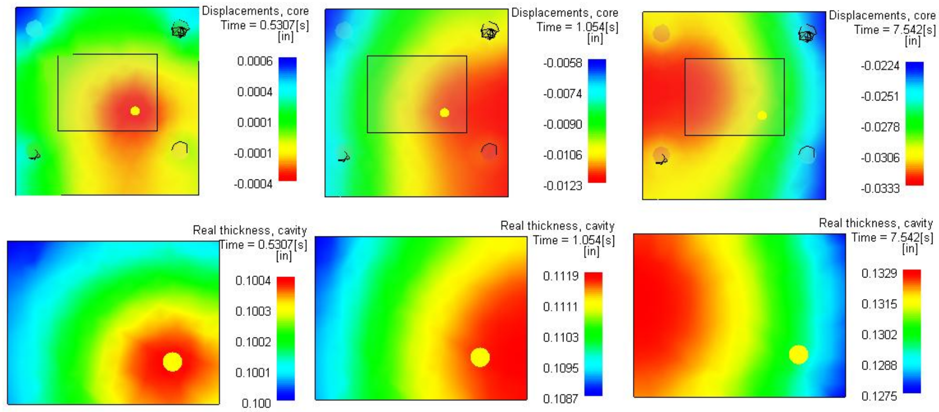

Figure 13*, Displacements, core and real thickness at 3 times during the cycle.*

CONCLUSION

The phenomenon of core shift is a well known to those involved in the design and manufacture of injection molded plastic parts. Core shift is the spatial deviation of the position of the core and is caused by non-uniform pressure distribution over the surface of the core during the filling and packing phases. Core shift causes wall thickness variation which results in both structural and cosmetic defects. For high precision parts, the core deflection can lead to rejects or a premature service life failure.

Historically, it has been possible to use CAE simulation tools to predict core shift. However, few attempts were made to use them owing to the complex nature of setting up and running the analyses. The dynamic, cause-and-effect nature of core shift makes it a very complex problem to simulate. Furthermore, predicting core shift required the use of two separate analyses, each performed in entirely different CAE software programs. The first analysis was needed to predict the flow of plastic material around the core. The results of the flow analysis were used to perform a subsequent analysis of the structural deformation of the core.

The above landscape was completely changed with the development of core shift analysis capability in Moldflow Plastics Insight (MPI) software. The MPI core shift analysis is characterized by a fully coupled, fluid-structure interaction analysis and easy-to-use tools to model the geometry and set up the analysis.

The MPI core shift analysis can be used to estimate the magnitude and orientation of the core deformation. Designers can use core shift analysis results to correct the phenomenon. Through analysis, it is possible to evaluate several alternative solutions before the mold is built.

The core shift analysis feature can be extended to perform other similar types of analyses. Paul Van Huffel, a senior engineer at Cascade Engineering, took the lead in developing a method to use core shift analysis to simulate clamp over-tonnage and the resultant platen deflection, tie-bar stretch and flash defects.

Moldflow Plastics Insight software’s core shift analysis gives designers the ability to correct the phenomenon, by adjusting process settings or modifying the mold design as necessary, reducing the costs of design-to-manufacturing process of a part and decreasing the time to market.