SIMULATING THE POLYPROPYLENE FILLING OF A DISPENSING CLOSURE MOLD WITH INJECTION MOLDING SOFTWARE

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1. INTRODUCTION TO MOLD CAVITY FILLING SIMULATIONS

In the study of plastics molding processes, injection molding is one of the first methods encountered by technology and engineering students. The process consists of heating and melting the plastic pellets (resin); injecting the melt under high pressure by a screw-type auger into a closed mold; cooling the melt inside the mold to form the part; and ejecting the finished part. Due to the elevated pressures and temperatures, great effort is needed in the design of the mold. The mold must accommodate not only the part cavity but also a runner system to distribute the melt throughout the entire part (or parts) as well as water cooling channels fabricated within the body of the mold. Commonly, the mold is tool steel and represents a significant initial cost to the plastics manufacturer. Thus any mold rework, if the cavity does not fill properly or produces defective parts, is undesirable.

The process of filling a mold cavity with a polymer melt is complex. The melt entering the cavity, via the sprue, must be evenly distributed by the runner system to the gates of the part cavity or cavities. Figure 1 presents a simplified sprue, runner, gate, and part system.

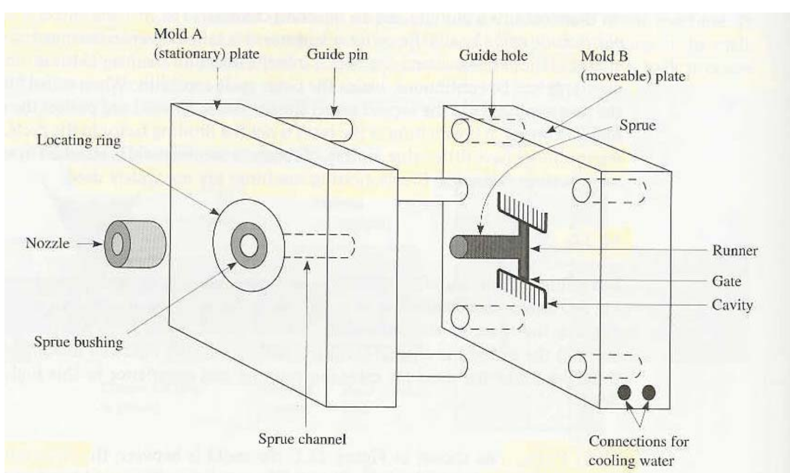

Figure 1: Typical plastics injection mold (Strong, 2000).

Compounding the flow problem, the melt is a non-Newtonian fluid experiencing a phase change with its physical and transport properties changing with location in the cavity, temperature, and time. (For example, the viscosity can vary greatly as the melt cools from several hundred degrees Centigrade to room temperature.) Thus, predicting the filling of a mold cavity is difficult and it becomes useful to computer simulate the process. In this way, the manufacturability of a plastic part may be checked, when the cost of change is the least, in the design process.

Mold filling software can optimize the final design as to part wall thicknesses, gate locations, materials, or part geometry. In addition, such software documents the cavity filling pattern along with pressure and temperature distributions in the part cavity to identify and eliminate product appearance issues such as weld lines, air traps, and sink marks.

Clearly such a program is a useful and instructive tool for the designer as well as students. In fact this type of software package ought to be included in any group of computer aided engineering (CAE) tools and be an integral part of a student's curriculum, perhaps in the last year (Kitto, 1995). It should be further emphasized to the student that such software be utilized as early as possible in the design process (Austin, 1994; Zou, *et al*., 1996). Several commercial software packages are available and suitable for use by students, and the present effort utilized MOLDFLOW which generates results quickly with a minimal amount of technical input to the model. Processing parameters may be adjusted in a series of simulations to determine the best molding conditions.

One phenomenon of interest is exactly how the polymer melt takes shape and flows, advancing from the gate to fill the cavity. The flow may be complicated by the presence of solid obstructions, such as inserts, which cause the front to split around the obstruction and later rejoin, potentially forming a weld line. Even without any obstructions, the flow may split to fill the cavity rather than advancing as a single, uniform front. Among many recent flow front studies, Ozdemir, *et al*., (2004) used MOLDFLOW results as a comparison to experimental melt front advancements in a simple, U-shaped cavity; it was found that although filling time predictions differed from experiments, the software accurately simulated the flow front profiles as the cavity was filled. In the case of inserts, Ray and Costa (2003) found qualitative agreement between MOLDFLOW and actual molding as long as the heat transfer effects at the insert/melt interfaces were accounted for.

Thus, software for use by students is available and can describe the process of manufacturing a plastic product through filling an injection mold cavity. Furthermore, in this paper, a sample case study is presented. Such a study represents a reasonable effort for the student and provides an introduction to this type of software as well as an understanding of a plastics molding process.

2. MANUFACTURING OF DISPENSING CLOSURES

The most common way to manufacture dispensing closures is by injection molding. (In recent years compression molding has been reintroduced and is also quite popular.) It is economical to use multi-cavity molds to manufacture many closures simultaneously; the molds can range from as low as 2 cavities to 128 cavities and higher. To create the threads inside the closure, many of the molds have unscrewing thread cores. Or the closures themselves may be twisted off thread cores although these threads are generally not as precise. Other features within the mold are possible including injecting a second color or material into the same cavities. Dispensing closures with a hinge can even be closed in the mold as part of the manufacturing process although this will increase the molding cycle time in most cases.

3. MODELING OF THE 38 mm DISPENSING CLOSURE

The present analysis simulated, using MOLDFLOW, the filling of a closed mold with polypropylene resin; the mold is a dispensing closure having a nominal diameter and height of 38 mm. The one-piece closure consists of a main body that would be screwed onto a bottle, as well as its integral cap or lid and an integral hinge connecting the body with its cap. Figure 2 presents the solid model of the part**; t**he actual injection gate position is located by the cone near the bottom of the left image. For the MOLDFLOW simulation, students are required to first create a solid, three-dimensional model with a program such as SOLIDWORKS. This model is then converted to an STL file for input to MOLDLFOW.

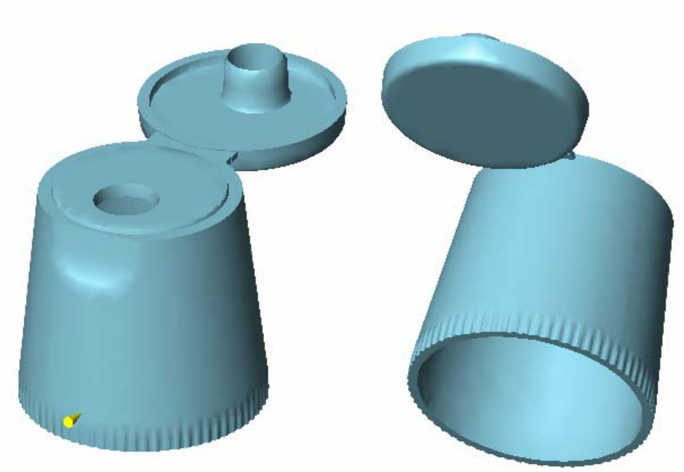

Figure 2: Solid model of 38 mm dispensing closure.

4. MOLDFLOW FILLING SIMULATION OF THE 38 mm DISPENSING CLOSURE

The material simulated is ordinary polypropylene (PP) injected at standard melt processing conditions of an injection pressure of 9.5 MPa, a melt temperature of 230 ^{o}C, and a mold temperature of 50 ^{o}C. The filling is predicted to take 0.71 seconds. Using these conditions, the following sequence of illustrations (Figure 3) represents the filling process. The closure is shown in a front and back view for each fill increment. The process is modeled at filling increments of 10%.

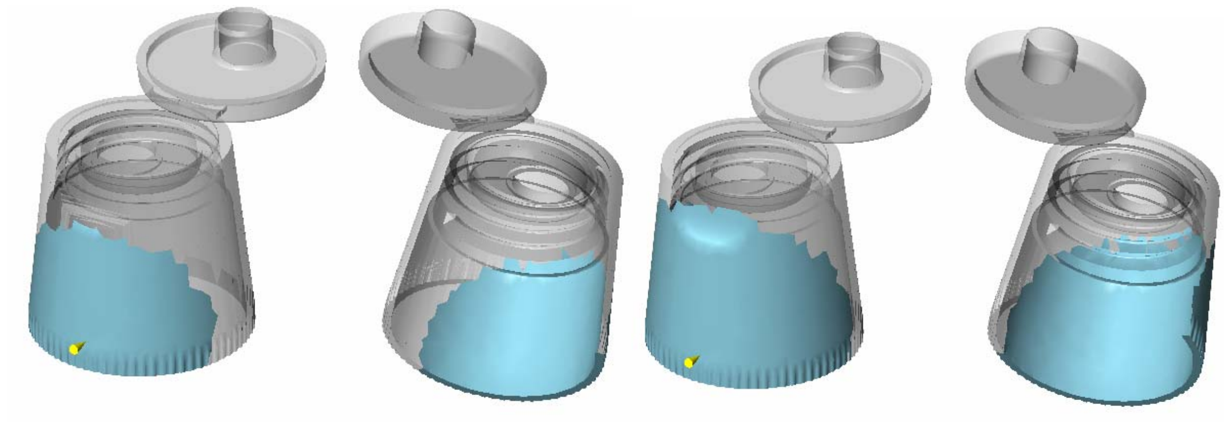

Figure 3.a: 10% fill. Figure 3.b: 20% fill.

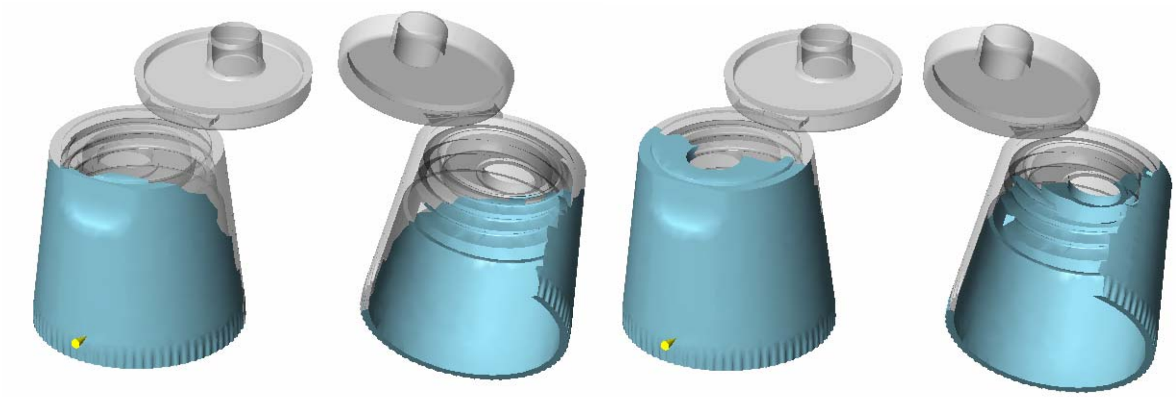

Figure 3.c: 30% fill. Figure 3.d: 40% fill.

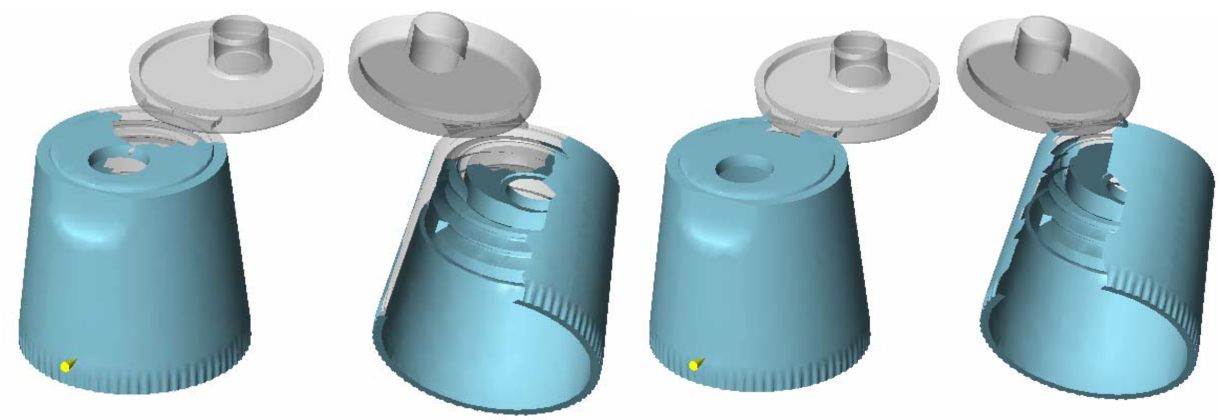

Figure 3.e: 50% fill. Figure 3.f: 60% fill.

At 10% to 20% filled, the flow front extends as a solid, uniform front to fill the front side of the closure, up to its top. The flow is confined to the front side and only at 30% fill does it begin to wrap around to the back side (side away from the gate) of the closure body. For the 40% to 50% filling stages, the flow front continues, dividing around the mold obstruction that forms the hole in the top of the closure body. At 50%, the top of the body is nearly complete while a substantial portion of the rear side of the body remains unfilled. The top is completed at 60% fill as the divided flow front has merged around the hole while the back side is still substantially incomplete and the melt begins to enter the hinge cavity.

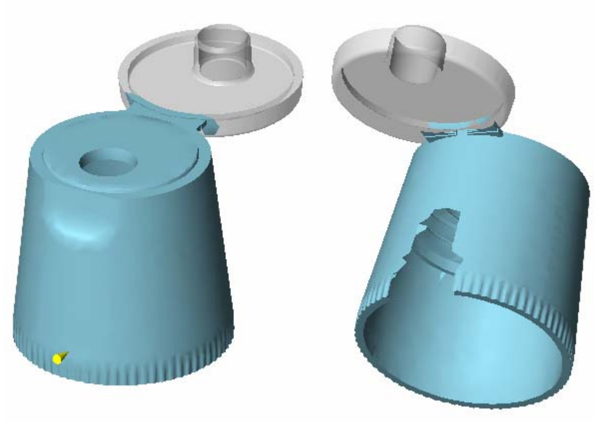

Figure 3.g: 70% fill.

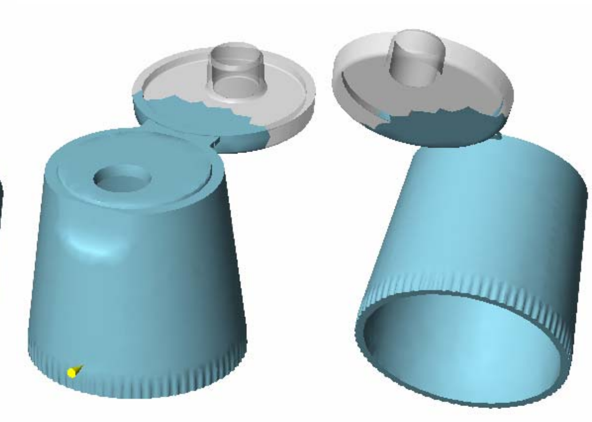

Figure 3.h: 80% fill.

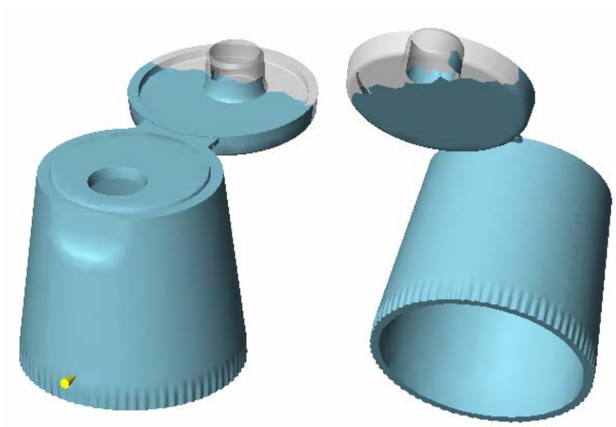

Figure 3.i: 90% fill.

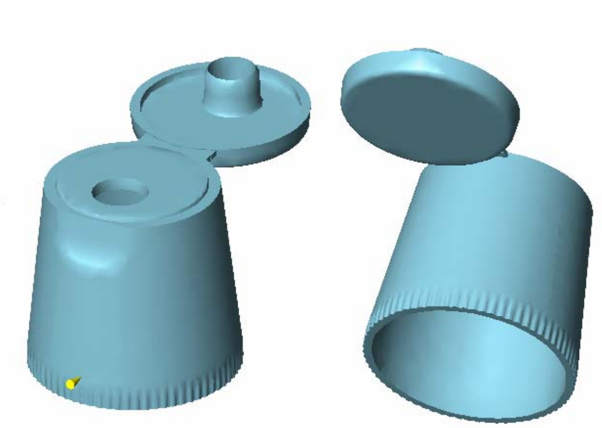

Figure 3.j: 100% fill.

At the 70% level, the back side is largely complete while the melt front has also passed through the hinge and into the cap. Finally, at the 80% mark, the back side of the body becomes solid while about 1/4 of the integral cap has filled. For the 90% fill level, the flow front extends about halfway into the cap/lid.

In addition to the quantitative filling analysis, MOLDFLOW judges the appearance and mechanical properties of the part by consideration of temperatures, pressures, shear stresses, molecular chain orientation, residual stresses, etc. and presents a qualitative quality assessment. This result is presented in Figure 4; three views of the closure are presented: front, back, and bottom. Figure 4 indicates that although, in general, the closure will have adequate quality, the region near the top of the closure body as well as the entire cap are areas that may need special attention. Most of the closure body is considered of high quality; some upper portions of the body along with the integral hinge and most of the cap are considered medium quality regions. The lid represents a region of lower quality compared to the rest of the closure components.

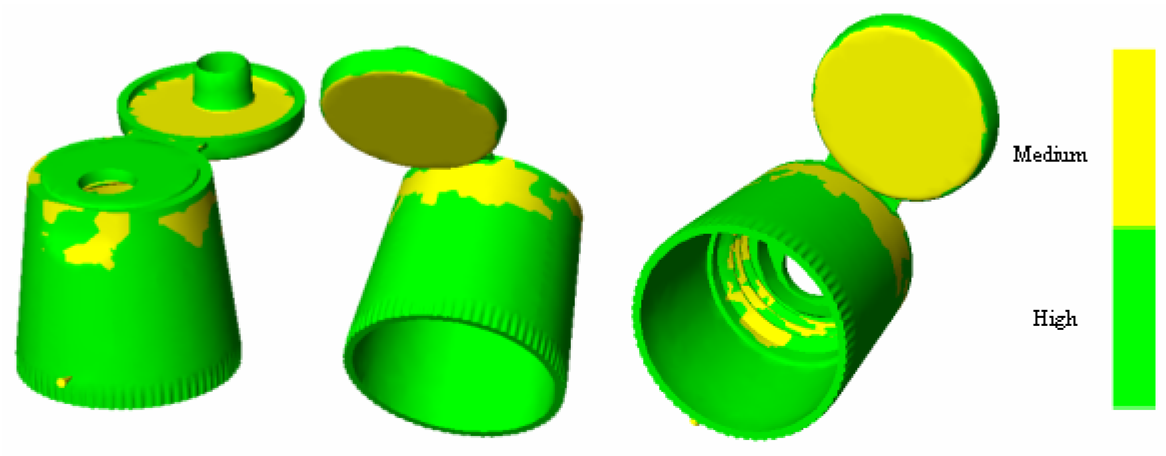

Figure 4: Quality prediction front, back, and bottom views.

It is clear that, with minimal input, students are able to perform a relatively sophisticated analysis of a plastics injection molding process. Further analysis of this closure could involve other quality issues such as weld lines, air traps, and sink marks. Students gain a clear understanding of mold filling and the effects of processing variables.

5. REFERENCES

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