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Injection Molding Analysis of a Needle Cover – Optimum Filling for Gate Location Design

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Abstract: Injection molding is one of the most popular manufacturing methods for the cost-effective mass production of the plastic parts. Filling analysis of the molten polymer provides useful information to investigate the process conditions to ensure successful replication. To validate appropriate gate location for a NEEDLE COVER, flow fronts and flow stresses for four different gating options and three different design options are analyzed and compared to the field results. Based on the results, the optimum gate location for the minimum flow stresses and uniform fill patterns appears to be at gate 3. Thus it also provides minimum possibility of part warpage throughout PORT HOUSING and NEEDLE HOUSING. The results of analysis on the increased wall thickness, lower melt temperature, and longer injection time indicated that higher melt temperatures were recommended to achieve successful molding. Injecting the polymer at a longer time (1.2 second) leads to a significant increase in flow stresses throughout the part and the increase of wall thickness achieve successful replication of the parts.

Keywords: Injection molding, Filling analysis, Fill pattern, Flow stress, Gate location

Introduction

Injection molding has been used to realize cost-effective mass production in the field of manufacturing. It has a wide variety of applications from housewares to automotive parts. Short cycle time, good replication accuracy, and high productivity are typical advantages of injection molding as one of the most popular manufacturing methods [1-3].

The quality of injection-molded parts primarily depends on the behavior of molten polymer in the replication process [4-6]. The behavior can be analyzed by using process parameters, including flow front, flow stress, injection time, melt and mold temperature, etc. [2]. Mold design, including gate location and wall thickness, also directly affects the flow behavior of the molten polymer. The gate location in the mold design is one of critical aspects to avoid short shot and to reduce flow stress in the advance of flow front [7,8]. The various numerical methods have been employed to help understand the flow behavior for the successful replication of the parts [11,12]. The careful design of gate location and process parameters can lead to high quality products.

Cavity filling analyses of the Needle Cover were performed to determine the appropriate gate location and to suggest any design improvements if needed. Finite element models for the numerical analysis were constructed using MOLDFLOW (Moldflow, Framingham, MA). Depending on the gate location, the flow fronts and flow stresses were quantified to avoid the incomplete filling and the hesitation of molten polymer during molding. The effect of wall thickness, melt temperature, and injection time were also investigated in conjunction with the gate location and proper processing conditions.

Analyses

Injection Molding Conditions

The material used in the analysis was polypropylene. Most of the analyses were performed at a mold temperature of 30 ^{o}C, and a melt temperature of 240 ^{o}C. One set of analyses was performed at a melt temperature of 220 ^{o}C to get a better understanding of the effects of lower melt temperature. The injection time of 0.6 second to fill the cavity was chosen primarily to minimize flow stresses in the part.

Figure 1 shows a CAE model for the simulation of cavity filling with molten polymer. The model consists of a NEEDLE HOUSING, a COLLAR, and a PORT HOUSING. Four different gating options were investigated as shown in Figure 1. The CAE model was constructed using shell

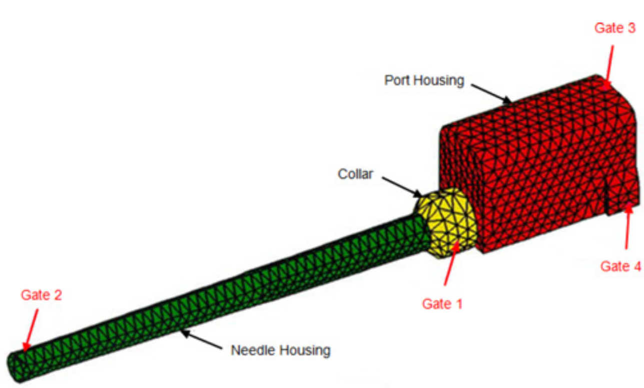

Figure 1. Finite element model and terminology of a needle cover.

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meshes with triangular elements.

Filling Analysis for the Gate Location

In order to determine the optimum gate location for the part, four different gating options were studied. The results of analyses were represented as flow front with a time scale and flow stresses, showing the fluidic resistance in advance.

Figure 2(a) shows the flow fronts in the part gated on the COLLAR, Gate 1. On close inspection of this figure, it is clear that after the PORT HOUSING fills, the polymer accelerates suddenly in the NEEDLE HOUSING (see the wide pink bands in Figure 2(a)). If possible, this type of uneven filling pattern should be avoided because it induces high flow stresses along the NEEDLE HOUSING as shown in Figure 2(b).

Light to dark pink areas, as shown in Figure 2(b), denote high flow stresses that are acceptable in small areas, but may tend to cause warpage in large areas. Areas represented in black have flow stresses that are above the degradation level of polypropylene (250,000 Pa) and are generally unacceptable except in confined regions such as the gate. The developed flow stresses in the NEEDLE HOUSING area are very high, compared to the PORT HOUSING and may cause this long and slender area to bow.

Figure 3(b) shows the flow stresses with the part gated at Gate 2. As the figure shows that the flow stresses in the NEEDLE HOUSING area are much lower than those for all other gating options studied. This gating scheme also leads to a very uniform filling pattern as shown in Figure 3(a). However, based on the experience with earlier designs of Needle Covers, molds gated at the tip of the NEEDLE HOUSING are prone to short shots during start-up, leading to damaged core pins [13].

Gate location 3 provides a uniform filling with the advance

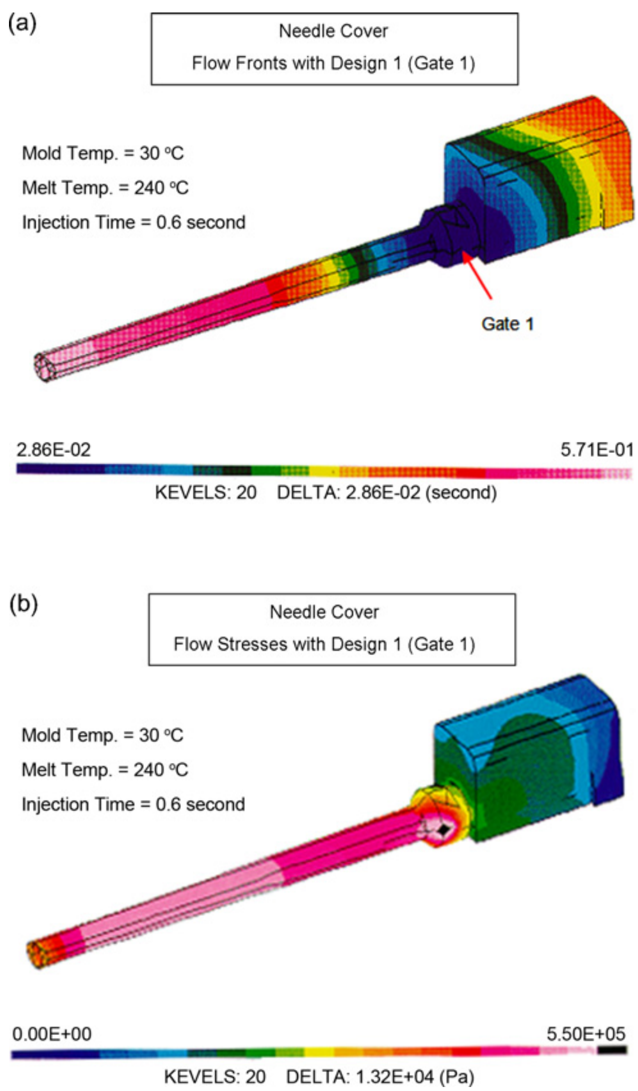

Figure 2. Cavity filling analysis of the part with gate 1: (a) flow fronts and (b) flow stresses.

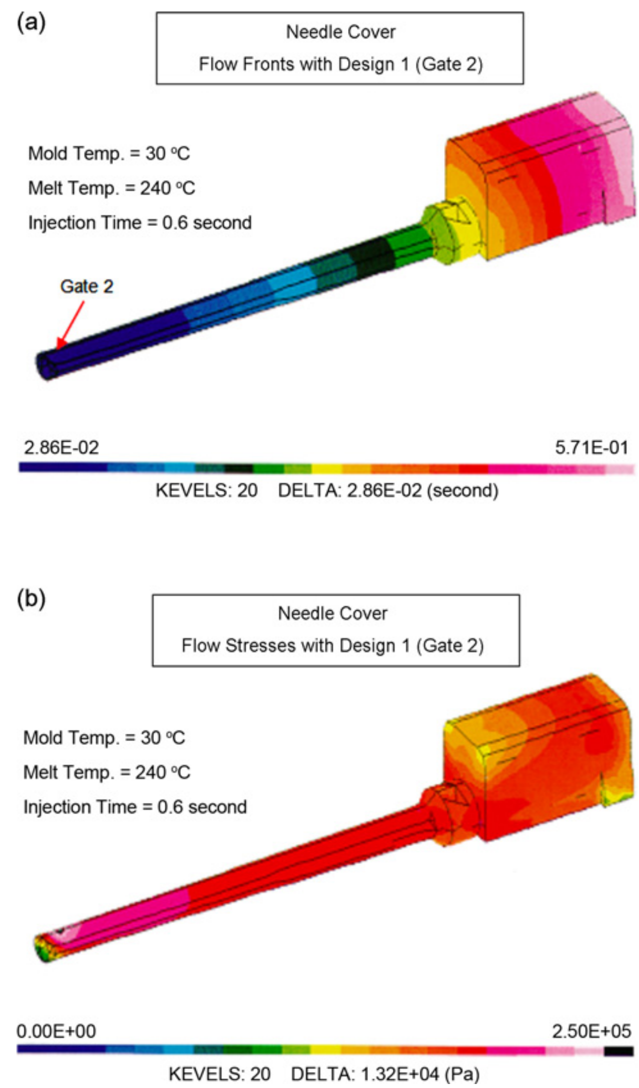

Figure 3. Cavity filling analysis of the part with gate 2: (a) flow fronts and (b) flow stresses.

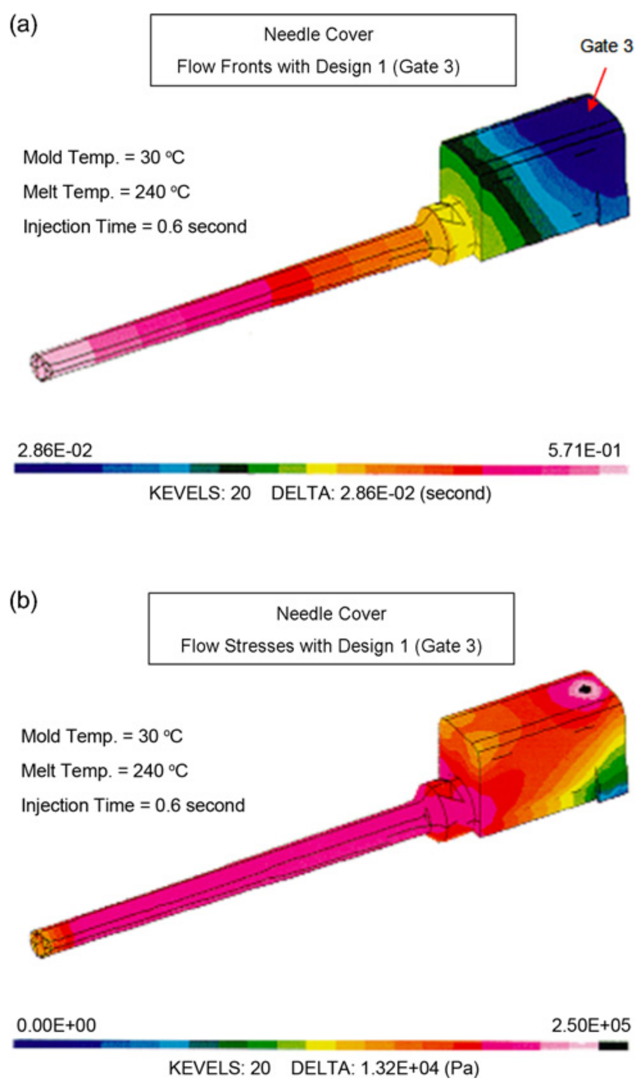

Figure 4. Cavity filling analysis of the part with gate 3: (a) flow fronts and (b) flow stresses.

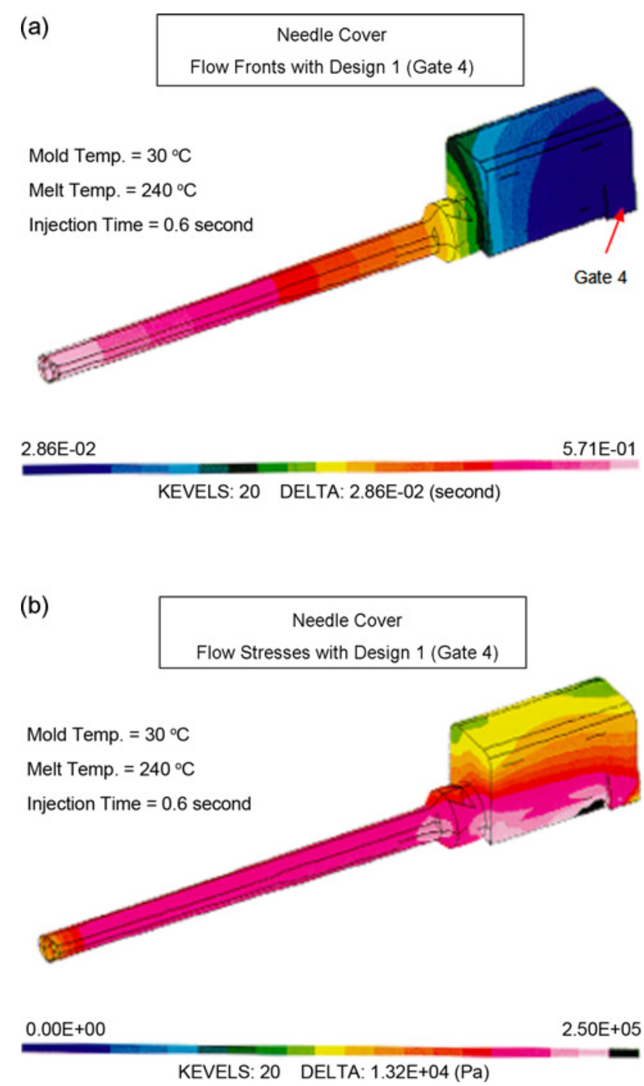

Figure 5. Cavity filling analysis of the part with gate 4: (a) flow fronts and (b) flow stresses.

of the molten polymer as shown in Figure 4(a). Figure 4(b) indicates that the flow stresses in the NEEDLE HOUSING area are slightly lower than those obtained with Gate 1, but slightly higher than those obtained with Gate 2. Although the stresses in the internal ribs are not shown in this figure, they are well within acceptable limits. This gating scheme leads to a very uniform filling pattern and would allow relatively tight dimensional tolerances in the PORT HOUSING area.

The flow stresses shown in Figure 5(b) indicate that the gating option 4 developed the stresses along the bottom portion of the PORT HOUSING and COLLAR area. The stresses are at or near the degradation level of polypropylene (250,000 Pa) and the stresses in the NEEDLE HOUSING area are essentially the same as those obtained with Gate 3. The flow pattern shown in Figure 5(a) is not very uniform. Due to the high stresses and non-uniform flow pattern, this gating scheme is the least favored.

Based on the four different gate location studied, Gate 2 and 3 are probably optimum due to the uniform fill patterns and minimization of flow stresses. As discussed earlier, Gate 3 may be preferable to Gate 2 due to the tendency of excessive short shot formation during start-up with parts gated at the tip of the needle housing.

Filling Analysis for the Wall Thickness, Lower Melt Temperature, and Longer Injection Time

Although Gate 3 might be the best alternative, this gating option still leads to high stresses in the NEEDLE HOUSING area as shown in Figure 4(b). In order to reduce the high stresses and possibility of bowing or twisting, it may be necessary to increase the wall thickness in the NEEDLE

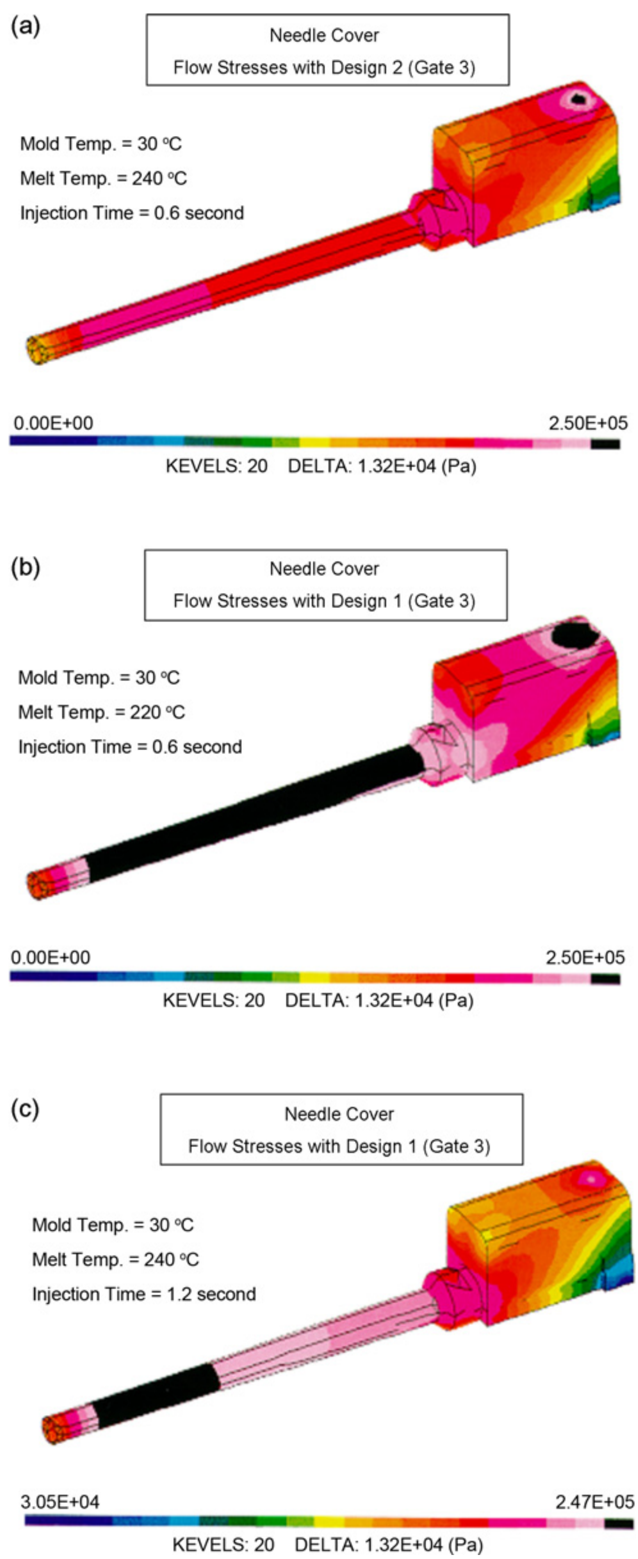

Figure 6. Cavity filling analysis for increased wall thickness, lower melt temperature, and lower injection time: (a) flow stresses for increased wall thickness (Design 2), (b) flow stresses for lower melt temperature of 220 °C, and (c) flow stresses for longer injection time of 1.2 second.

HOUSING by 0.125 mm with its original thickness of 1.25 mm. This increased wall thickness design option was studied as Design 2 and results are discussed below.

Figure 6(a) shows flow stresses in the part with the increased wall thickness of 0.125 mm. Gate location is the same as Gate 3. As Figure 6(a) shows, the flow stresses in the NEEDLE HOUSING are much lower than those obtained with the current design in Figure 4(b) (Design 1). It indicates that the increase of wall thickness considerably reduced the fluidic resistance to the advance of flow front in the cavity. The percentage increase in material utilization for Design 2 (relative to Design 1) is 5 %. This may be acceptable in terms of quality and cost for the parts because the increase of 5 % does not significantly affect entire production cost of the NEEDLE COVER.

Figure 6(b) represents the flow stresses in the part with a melt temperature of 220 °C for Design 1 in order to show the effect of a decrease in melt temperature on flow stresses. In the comparison of the flow stresses shown in Figure 6(b) and 4(b), the flow stresses shown in Figure 6(b) along the entire NEEDLE HOUSING area significantly increase to levels above the degradation level of polypropylene.

The decrease in melt temperature induces higher flow stresses because the lower melt temperature accelerated the solidification of the polymers at the mold walls. This led to degradation of replication of the parts as the temperature was decreased. The analysis result in Figure 6(b) notices that how a 20 °C decrease in melt temperature increase flow stresses.

In case of press limitations for some machinery there is a possibility that the molten polymer may not be able to fill a multiple cavity production mold at a 0.6 second injection time. In order to demonstrate the effects of longer fill times, Figure 6(c) shows flow stresses in the part (Design 1) with an injection time of 1.2 second. As the figure shows, the flow stresses in half of the NEEDLE HOUSING area increase above the degradation level of polypropylene. This can be explained by the increase of fluidic resistance of the molten polymer due to the temperature drop with longer injection time along the long and slender area in particular. The increase of injection time decreased the injection speed. The lower injection speed induced a lower injection pressure to push the melt into the cavities. The melt experienced longer cooling time and the viscosity of the melt increased while the longer injection time is applied.

From the analyses for Design 1 and 2, the maximum injection pressures required to fill the cavity for all four gate locations, are shown in Table 1. These injection pressures are approximately equal, with gate 1 requiring the lowest injection pressure of 26.4 MPa. Table 1 also shows the minimum and maximum temperatures of molten polymer at the end of the fill cycle for the different gate locations. The minimum temperatures, shown in Table 1 for all four gate locations, are well above the No-Flow temperature of

Table 1. The cavity filling analysis results with four different gate options

Gate	Injection pressure (MPa)	Maximum temperature (°C)	Minimum temperature (°C)
1	26.4	240	215
2	34.1	240	223
3	37.3 (32.7)	240 (241)	226 (226)
4	37.2	241	226

*Numbers in parentheses indicate values for Design 2, material= polypropylene, mold temperature=30 °C, melt temperature=240 °C, injection time=0.6 second.

polypropylene (152 °C) and should not cause a problem.

All of the options studied and discussed above should help to determine the appropriate combination of processing conditions, gate location and material usage for molding a high quality part.

Conclusion

Cavity filling analysis of an injection-molded needle cover was performed. Four different gating options and three different designs were studied to the identification of appropriate processing conditions, gate location, and material usage for the replication of high quality parts.

Gate 1 leads to very high flow stresses in the NEEDLE HOUSING area which may cause the part to bow. Gating the part at Gate 4 induces flow stresses that are above the degradation level of polypropylene along the bottom edge of the PORT HOUSING. This, however, is not serious enough to rule out this gating option. Although Gate 2 leads to the lowest flow stresses in the part among the four gate locations studied, this gating option is prone to excessive short shots during start-up and causes core pins to break. Based on the design, the optimum gate location for the minimum flow stresses and uniform fill pattern appears to be Gate 3.

Design 2, with wall thicknesses in the NEEDLE HOUSING increased by 0.125 mm, reduces the flow stresses, thus, decreasing the possibility of bowing. The flow stresses also significantly increases throughout the part while injecting the polymer at a lower melt temperature of 220 °C and longer injection time of 1.2 second.

In order to minimize the flow stresses in the part combined with the preference not to gate at Gate 2, it is recommended to gate at Gate 3. For the minimization of the possibility of the part bowing, it is suggested to process at higher melt temperatures and design the mold to accommodate an increased wall thickness of the part if necessary.

Cavity filling analysis, using computer-aided engineering (CAE), was employed to analyze process parameters and gate location in the replication of the part. It is shown to design process parameters and mold for the cost-effective mass production of a needle cover.

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