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Core-material penetration in multi-cavity co-injection molding

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A high core-material ratio and slow injection speed allow for good penetration, but leading behavior during the runner-filling stage can result in unsatisfactory material distribution in the molded parts.

Multicomponent co-injection molding, which enables the development of parts with different skin and core materials, has been used in manufacturing across a variety of industries for many years (e.g., for the development of automotive parts and structural-reinforcement products).[1–5] The biggest advantages provided by co-injection molding are reduced cost, the ability to reuse material, and increased production efficiency. Because the strength of a structural-reinforcement product is correlated to its core-material distribution, control over this distribution is important. Furthermore, multi-cavity molding systems are often installed to enhance the production of co-injection products.

The combination of a uniform skin ratio and good core-material distribution is key to obtaining fabricated parts with good structural integrity. In multi-cavity systems, e.g., those with a fork structure, the material distribution can be poor.[6] Managing the skin/core ratio in these systems can be challenging due to both the complicated geometrical product design and the dynamic behavior of molten plastic as it flows through the runner and gate into the cavities.[6–8]

We have theoretically examined the dynamic core-material penetration behavior in multi-cavity co-injection molding. To determine the sensitivity of the injection-molded-part properties to the design and process conditions, we employed simulations based on experimental results.[6] The benchmark geometry and dimensions of the runners and cavities that we employed in our simulations are shown in Figure 1(a) and (b), and the process conditions are given in Table 1. The diameter and thickness of each cavity is 60 and 3.5mm, respectively, and we used Polyrex PG-22 (a general-purpose polystyrene) as the injection material (both core and skin).

To understand the flow behavior of each branch, we measured the material penetration length in the runner at the point at which the material in one of the branches reaches a cavity. When the filling

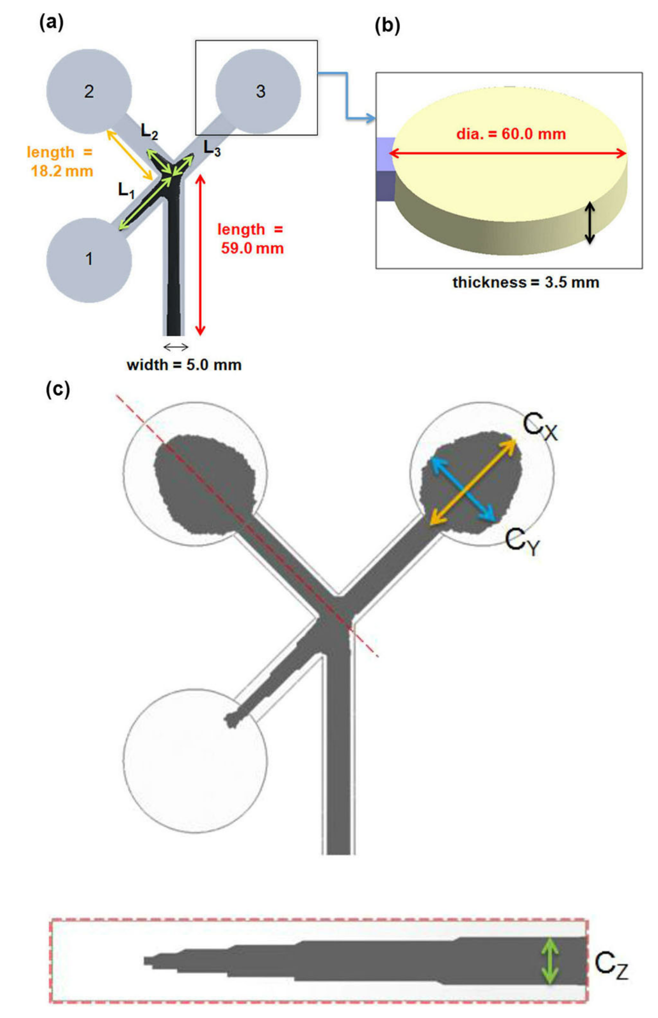

Figure 1. (a) Geometry of the co-injection multi-cavity system. L_1, L_2, and L_3: Runners through which the material travels to get to the cavities 1, 2, and 3, respectively. (b) Cavity dimensions. (c) Core material penetration length at the end of filling. C_X, C_Y, and C_Z: Core penetration lengths in the X, Y, and Z directions, respectively.

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Table 1. The process conditions that we used in our simulation, taken from experimental work.[6] *GPPS: General-purpose polystyrene.*

Filling time	0.60 (s)
Melt temperature	220.0 (°C)
Mold temperature	60.0 (°C)
Maximum injection pressure	250.0 (MPa)
Material	GPPS Polyrex PG-22
Packing time	0.05 (s)
Maximum packing pressure	250.0 (MPa)
Mold opening time	5.0 (s)
Ejection temperature	97.0 (°C)
Air temperature	25.0 (°C)
Core enter time (by volume filled)	72 (%)

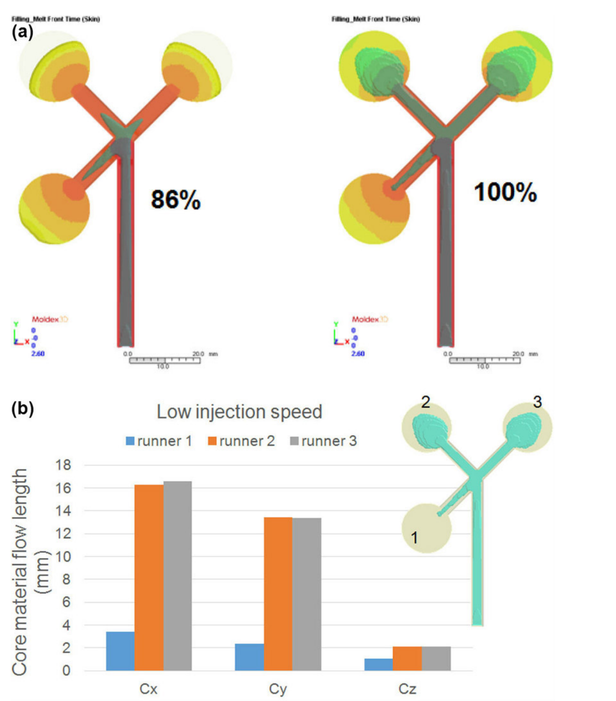

Figure 2. *(a) Filling behavior and core penetration during injection molding at various total volume ratios. The yellow and orange represent the skin-layer material, which is injected first. The greens represent the subsequently injected core material. (b) Core penetration in three directions (C_X, C_Y, and C_Z) at injection speeds of $10cm^3/s$.*

reached completion, we measured the final penetration length in the cavity: see Figure 1(c). Figure 2(a) shows the core penetration shape achieved with a skin/core ratio of 72/28. At an injection speed of $10cm^3/s$, the material in branch one touches the cavity first. The total filling ratio in this branch reaches about 86%. Beyond this point, the core material prefers to enter the second and third cavities. The leading penetration behavior during the runner-filling stage does not ensure adequate core distribution in the final product. In fact, improper core material distribution is shown to be a serious problem in the first cavity: see Figure 2(b).

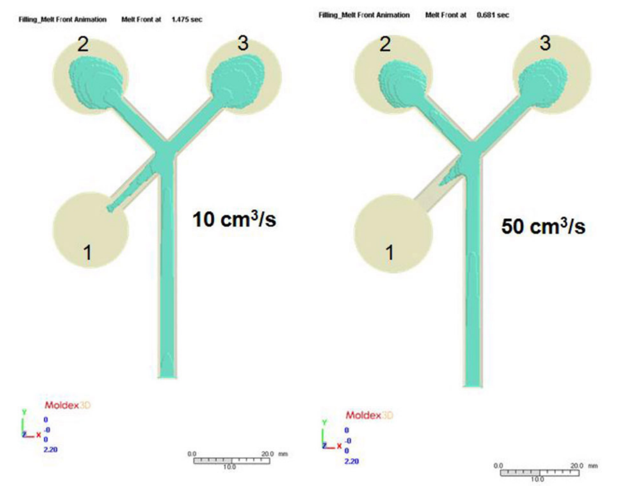

Figure 3. *The effect of different injection speeds on core-penetration behavior. The first-shot material (skin layer, cream) is injected first, followed by the second-shot material (core material, green).*

The way in which core penetration phenomena are sensitive to processing conditions is significant in the manufacture of plastic parts. Figure 3 shows the final core penetration behavior of each branch at different flow rates. At a high injection speed, the first-shot material (i.e., the skin-layer material, which is injected first) occupies more of the runner and cavity in branch one, causing the subsequently injected second-shot material (i.e., the core material) to be stopped in the runner. After 72% of the volume is filled, no room remains in the first cavity for the core material to enter. This is because the core material prefers to penetrate in the thickness (Z) direction from runner to cavity under higher flow rates. As a result, the already poor core-material distribution is worsened.

We used computer-aided engineering (CAE) to visualize the flow patterns and core penetration during multi-cavity co-injection molding. Figure 4(a) shows the core-material penetration at various skin/core ratios. When the core ratio is 28% or higher, the penetration length in the first branch reaches the cavity first. However, with a lower core ratio (e.g., skin/core=84/16), the core penetration length of the second and third branches reaches the cavity first. Figure 4(b) shows the core penetration at the end of filling. The greater the core ratio, the longer

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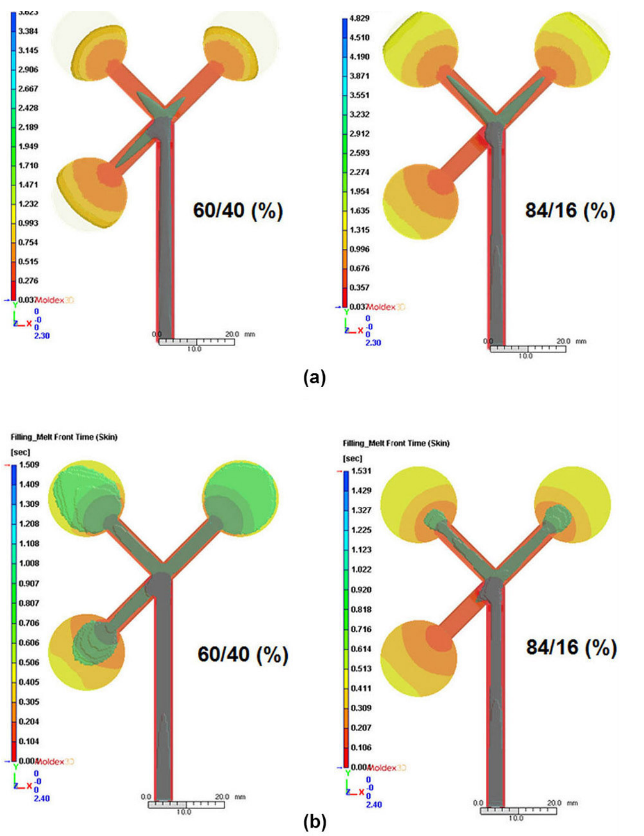

Figure 4. *The simulated melt front under different skin/core material volume ratios. Core-material penetration length when (a) one of the branches first reaches a cavity and (b) at the end of filling.*

the penetration of the core material through the runner to the cavity. Due to the multi-cavity geometrical structure and the complex stress interaction between the skin and core materials, the core penetration is unbalanced for each cavity.

In co-injection multi-cavity molding, the core material can penetrate longer at a higher core ratio and slower injection speed, but leading penetration behavior during the runner-filling stage does not ensure the core distribution of final product. Indeed, due to the geometrical structure of multi-cavity systems, the balance of the core penetration for multi-cavity molding remains highly challenging. To maintain good quality with suitable core-material penetration and distribution, the flow of the molten plastic through the full geometry (runners, gates, and cavities) should be considered simultaneously. Fortunately, current CAE technology can assist us in quantitatively determining these details. In our future work, we intend to investigate the detailed driving forces that influence the interface between the skin and core materials.

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Chao-Tsai Huang, an assistant professor, received his PhD in chemical engineering from Washington University in St. Louis, MO. Over the past several years he has focused on special injection molding technologies, including hot runner, conformal cooling, microcellular foam-injection molding, injection-compression molding, multi-component molding (including over-molding, co-injection, and bi-injection), injection stretch blow molding, in-mold decoration, fiber orientation and its effect, and variotherm technology.

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