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A new core-back foam injection molding method with chemical blowing agents

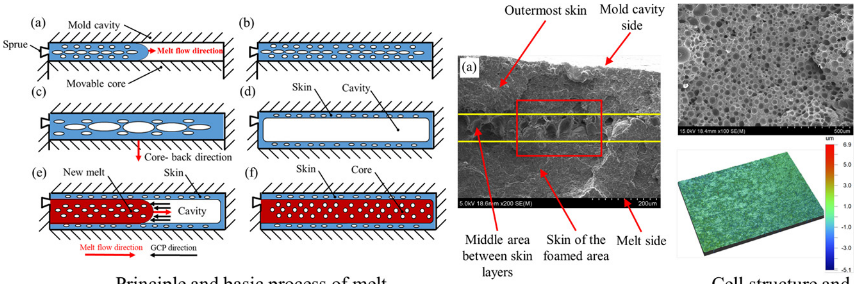
Hao Wu [a], Guoqun Zhao [a,*], Guilong Wang [a], Weilun Zhang [b], Yang Li [b]

[a] *Key Laboratory for Liquid-Solid Structural Evolution and Processing of Materials (Ministry of Education), Shandong University, Jinan, Shandong 250061, PR China*
[b] *Qingdao Hisense Mould Co., Ltd. Qingdao, Shandong 266114, PR China*

HIGHLIGHTS

- The new core-back chemical foam injection molding samples have a special sandwich structure with a unique dense skin.
- A naturally formed gas counter pressure well restrains the melt's fountain effect and improves the samples' cell structure.
- The new core-back chemical foam injection molding method reduces the surface defects of samples obviously.
- The new core-back chemical foam injection molding samples have excellent mechanical properties under the same weight reduction conditions.

GRAPHICAL ABSTRACT



Principle and basic process of melt filling of the novel core-back FIM

Unique skin structure

Cell structure and surface profile

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ABSTRACT

This paper presented a new core-back chemical foam injection molding (CFIM) method. Different from the conventional method, the new method has a unique secondary filling stage right after core-back operation. By combining core-back and secondary filling, a closed shell composed of dense polymer skins can be created right before melt filling. This closed shell can prevent the gas loss from the melt flow front, and act as the gas counter pressure to reduce cell coalescence and collapse, thus leading to significant improvement of cell structure. The mechanical testing results show that the new technology can produce plastic foam with simultaneously enhanced tensile strength, elastic modulus, and notch impact strength. Moreover, this technology can also improve the surface appearance of the foamed sample. Thus, it shows a promising future in offering lightweight structural components with improved mechanical strength and enhanced surface appearance.

1. Introduction

Light weight has become a trend of modern industry with the intensification of the energy crisis and the improvement of the awareness of environmental protection. The weight reduction of the products plays an important role in energy saving and emission reduction, for example, when the vehicle curb weight is reduced by 10%, fuel consumption can be reduced by about 7%. In this context, plastic materials are more and more used to replace metal materials, and the weight ratio of plastics in automobiles is now more than 18% [1]. Among plastic materials, polypropylene (PP) in one of the most widely used thermoplastics, due to its excellent heat resistance, high mechanical properties and low thermal conductivity. Notably, the amount of PP material has accounted for more than 47% of the total automotive plastic material consumption [2]. Therefore, it is of great significance to study how to reduce the

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* Corresponding author.
E-mail address: zhaogq@sdu.edu.cn (G. Zhao).

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weight of plastic parts for saving materials and energy, reducing greenhouse gas emission and plastic wastes.

Foam injection molding (FIM) is an effective method to reduce the weight of plastic parts, in which blowing agents are added into the barrel at the storage stage to form polymer/gas homogeneous system, and then the homogeneous system is injected into the mold cavity for foaming. Compared with other foaming technologies, FIM process exhibits several advantages including its high production efficiency and design flexibility, and its capacity to fabricate complex geometries [3,4]. Despite these advantages, the FIM technology suffers from several obvious shortcomings. Firstly, due to the strongly confined foaming by the closed mold cavity, the foam's weight reduction is very limited. Secondly, the plastic foam has very poor surface appearance due to many surface defects including swirl marks, silver streaks and surface blistering. Thirdly, in most cases, the plastic foam shows inferior mechanical properties than the unfoamed plastic part.

Core-back FIM process is an advanced technology to further increase the plastic foam's weight reduction. In the core-back FIM process, an extra core-back operation is involved to provide a free space for foaming, and thus the finally molded foam's weight reduction can be increased significantly [5–19]. Ameli et al. [16,17] fabricated PLA and its composites with a high porosity of 65% by using core-back FIM. The results showed that the core-back FIM can improve the cell morphology, and increase the specific modulus, strength and impact resistance. Zhao et al. [18] prepared PP/PTFE nanocomposite foams with an expansion ratio up to 25-fold by using core-back FIM. The PP-based nanocomposite foams exhibit outstanding thermal insulation and compressive mechanical performance. Miyamoto et al. [19] also prepared a kind of PP composite with an expansion ratio up to 5-fold by using core-back FIM with PBA. The PP composite has good cell morphology. In addition, it is found through previous experiments that when the commonly used PBAs in the field of FIM [20–25] are used for core-back FIM, the foaming effects are usually good because of high foaming power, but when the same commonly used chemical blowing agents (CBA) [26,27] are used, it is difficult to obtain a complete piece of parts because of relatively low foaming power.

Towards fabricating lightweight plastic parts simultaneously with good mechanical properties and surface appearance, a new core-back foam injection molding (FIM) strategy using chemical blowing agent was presented in this paper. In this strategy, a secondary filling operation was employed right after the core-back operation. By combining the core-back and secondary filling, a closed shell composed of dense polymer skins can be created right before melt filling. This closed shell can prevent the gas loss from the melt flow front in secondary filling, and act as the gas counter pressure to reduce cell coalescence and collapse, thus leading to significant improvement of cell structure. For comparison, both the conventional CFIM and the new core-back CFIM were conducted in this paper to fabricate PP foams. The mechanism of the improved cellular structure in the new core-back CFIM process was discussed and analyzed. The tensile tests, flexural tests and impact tests were conducted to characterize the foam's strength, rigidity and toughness, respectively. In addition, a white light interferometer was employed to analyze the foam's surface appearance. The results show that the technology can produce plastic foam with improved cell structure, enhanced mechanical properties and surface appearance.

2. New Core-back foam injection molding method

The new core-back FIM method is fundamentally different from the existing methods. The existing core-back FIM [5–17] firstly injects the melt into the mold cavity, then removes the cells produced during the filling process by high holding pressure, and finally does core-back to make the melt foaming. While the core-back FIM presented in this paper does core-back immediately once the melt injection has finished. In the core-back process, the melt foams immediately and forms a special “skin” structure with a cavity under the negative pressure of the mold cavity wall. Once the core-back is finished, a unique “secondary filling stage” begins immediately, new melt is filled into the cavity of this special “skin” structure in this stage. Finally, a “sandwich” structure with dense skin, uniform and small internal cells is obtained. Fig. 1 gives the principle and basic process of melt filling of the core-back FIM. The whole process includes conventional injection stage, core-back stage, and the newly added secondary filling stage.

Stage I: conventional injection stage, Stage II: core-back stage, Stage III: secondary filling stage.

Stage I: conventional injection stage. In this stage, the core of the mold is always at the front end. The melt filling process in this stage is the same as that of the conventional FIM, as shown in Fig. 1 (a), where the direction of the red arrow is the direction of the melt flow. In the conventional injection stage, the position of the core remains unchanged until the melt is filled completely, as shown in Fig. 1 (b).

Stage II: core-back stage. Once the stage I is finished, the core-back is started immediately, as shown in Fig. 1 (c). The direction of the red arrow in Fig. 1(c) is the core-back direction. After core-back, a closed shell structure wrapped by a “skin” is formed, as shown in Fig. 1 (d).

Stage III: secondary filling stage. This stage is a step that the conventional core-back method does not have. The secondary filling is started immediately once the core-back is completed. In this stage, new melt is filled through the sprue into the cavity of the “skin” structure formed in Stage II, as shown in Fig. 1 (e), where the direction of the red arrow is the direction of the melt flow. In addition, because the “skin” structure is a closed structure, the gas inside the cavity is compressed and the pressure is increased with the filling of melt. Thus, the front of the melt is subjected to a pressure opposite to the flow direction, which naturally forms a GCP, as shown in Fig. 1 (e), where the direction of the black arrow is the direction of the natural GCP. This naturally formed GCP can improve the morphology of the melt flow front, inhibit the melt foaming in the filling process, and finally uniform cell structure. In addition, because the skin is very thin, when the pressure of gas in the cavity rises to a certain extent, the gas will break through and spill at a weak position of the skin, and is discharged through the exhaust system of the mold. Finally, a “sandwich” structure is formed, as shown in Fig. 1 (f).

Based on the above core-back FIM method and its unique characteristic in melt filling process, a set of experimental core-back FIM mold was designed and manufactured in this paper. Fig. 2 shows the diagram of mold cavity plate, core plate, and specimens. The cavity plate is mainly consists of the specimen cavity, the hot runner sprue, and the flow channel. The mold cavity is divided into four cavities to obtain impact specimen, bending specimen, tensile specimen, and a special shaped part with a groove. The specimen size used to test the mechanical properties was designed by referencing the ASTM mechanical performance test standard, and the dimensions of them are shown in Fig. 3. Since the initial depth of the cavity used in this experiment is 1.5 mm and core-back distance is 3.5 mm, the final thickness of the specimen is 5 mm. The core plate is mainly composed of variable core, flow channel, piece gate and exhaust system.

The cavity depth control structure is the core of the core-back FIM mold. In this paper, a new type of cavity depth control structure was designed. The major difference between the mold designed and manufactured in this manuscript and other core-back molds is that since each cavity depth control structure is independent, each cavity of the mold can do core-back independently, and the core-back FIM experiments with different core-back distance, core-back timing, and core-back speed can be carried out at the same time. Its basic structure and composition is shown in Fig. 4, which mainly consists of bi-directional hydraulic cylinder and mechanical coordination structure. The mechanical coordination structure includes a sliding block, a chute, and a mechanical limit structure. An inclined plane is used to match the chute and sliding block to ensure that the movement direction of the chute and the sliding block is perpendicular to each other.