OPTIMIZING CHEMICAL BLOWING AGENT CONTENT IN FOAM INJECTION MOLDING PROCESS OF POLYPROPYLENE

Eunse Chang, Mayesha B. Mahmud, Xiping Li, Abolfazl Mohebbi, Chul B. Park

Microcellular Plastics Manufacturing Laboratory, Department of Mechanical and Industrial Engineering, University of Toronto, 5 King’s College Road, Toronto, Ontario, Canada M5S 3G8 - eunse@mie.utoronto.ca; park@mie.utoronto.ca

Abstract

Use of chemical blowing agent in foam injection molding process is appealing to industries owing to its low implementation cost. If chosen properly, chemical blowing agent can help produce foams with very uniform cellular structure and good surface quality. However, it also presents many processing challenges. Relatively high processing temperature is required to induce chemical reaction or decomposition, which narrows down the foam processing window to reduce the cell size. It may lead to degradation of resins in some cases, and compatibility with resins is also very crucial. In this work, we examined the processing parameters in foam injection molding process of polypropylene, particularly the chemical blowing agent content, to find out its effect on foam, mechanical, and surface properties.

Introduction

The increasing cost of raw materials and the environmental pollution concerns urges industries to find effective ways to produce lightweight products by using less material while obtaining desirable properties. In this context, foamed materials can be used as a substitute to their solid counterparts because foaming reduces the consumption of materials which also results in the reduction of production cost. In addition, they give very high strength-to-weight ratio without compromising the mechanical properties and also offer high insulation properties [1].

Polypropylene (PP) is a member of polyolefin family. Owing to its good processability and comprehensive mechanical properties, PP is one of the most widely used commodity thermoplastics, especially in structural, automotive, and packaging applications as it gives firm structure. Also, it provides a higher service temperature compared to other commonly used polymers such as polystyrene and polyethylene [1, 2]. However, PP is brittle at room temperature and at low temperatures, and this fact limits the application of pure PP as an engineering thermoplastic. For improved impact toughness and an extension of its range of use, rubber materials have been added since the 1970s [3-6] to impact-modify PP as rubber has excellent elasticity and toughness.

To manufacture polymeric foams, blowing agents are used to produce stabilized bubble structures inside the matrix of polymer to reduce weight. Introducing such cellular structures in PP injection molding can be achieved by using either a physical blowing agent (PBA) or a chemical blowing agent (CBA). The use of PBA requires additional accessories to produce polymeric foams (e.g. MuCell® technology owned by Trexel, Inc.), hence, CBA can be the preferable option to industries as it does not require any significant modification of their existing injection system to introduce voids in their products. For these reasons, the popularity of CBA has been rapidly increased in the past few years [7-11]. CBAs generate gases under specific conditions through chemical reaction or thermal decomposition and may react in both endothermic or exothermic process.

The content of CBA to achieve the desired foam density and void fraction is a critical factor because it can affect the production cost of the foamed material, yet few efforts had been made by researchers to investigate its effects to the full extent. Andalib et al. studied the effect of the CBA content to increase the void fraction of PP foam for high temperature extrusion process, and claimed that up to a certain point void fractions and cell density gave an upward trend, but after crossing that point void fraction reduced with the increase of gas content [12]. They attributed the mountain shape curve of cell density and void fraction to the plasticization effect and nucleating agents. An experimental study and modeling of the polypropylene foam blown with three different kinds of CBAs was performed by Ruiz et al., where the expansion ratio and final foam structure derived both by directional observation and optical analysis were compared [13]. In addition, the mechanical properties of PP foam reinforced by different amounts of fibers and blown with various amount of CBA has been investigated by Mechraoui et al., and they demonstrated the effect of skin layer thickness and composition, and density of core section on the mechanical properties of PP foams with sandwich structure [14]. The skin layers were produced using polypropylene-hemp fiber composite while the core was kept as the same polypropylene foam using different contents of CBA.

In this study, we aim to examine the effects of CBA content on foam morphology, mechanical properties, and surface quality of foam injection-molded parts. The
findings in this work may help find the optimal processing window for high mechanical strength PP foams such as in structural or automotive applications.

**Materials**

In this study, a high crystallinity block copolymer polypropylene manufactured by PolyMirae was used. This resin is characterized by its good balance of stiffness and impact performance intended for automotive parts applications. It had a solid density of 0.9 g/cm³ and melt flow rate of 60 dg/min (230°C, 2.16 kg). Ecocell®L supplied by Polyfill Corp. and Trexel was selected as a CBA to study its effects on the morphological and mechanical properties of the foamed PP parts. Ecocell®L is an endothermic type CBA that releases carbon dioxide when heated above 200°C. It was provided as a masterbatch with 7% active content. PP and different concentrations of solid CBA pellets were dry-blended prior to the injection molding process.

**Experimental**

Foam injection molding experiments were performed using a 50-ton Arburg ALLROUNDER 270 injection molding machine. A rectangular mold cavity with nominal dimensions of 11.1 cm x 13.5 cm x 0.32 cm was used, and samples for IZOD impact tests, tensile tests, and SEM imaging were taken from the injection-molded part as shown in Figure 1.

![Figure 1. Injection-molded part geometry and sample preparation for characterizations](image)

Temperature profile in the feeding zone was kept well below 200°C to prevent any pre-activation of CBA, while the temperatures at the metering zone and the nozzle were set at 220°C to accelerate the chemical reaction.

To minimize premature cell nucleation during the filling stage which causes formation of shear-induced elongated cells along the mold cavity, it is crucial that a high injection flow rate is maintained. However, too high an injection flow rate could lead to surface defects such as silver streaks especially when high melt temperature is required for activation of CBA. For this reason, a relatively high injection flow rate of 70 cm³/s was employed.

5 different contents of CBA masterbatch (1%, 3%, 5%, 7%, 9% wt.) were dry-blended with PP resin to investigate the effects of gas content on the cell morphology, mechanical properties, and surface roughness values. Other processing parameters such as the mold temperature and cooling time were also fixed throughout the experiments at 30°C and 30 seconds, respectively, for comparison purposes.

**Discussion**

**Effect of CBA Content on Foaming**

SEM micrographs were taken at locations A, B, and C following the foam injection molding experiments with different CBA content. Figure 2 displays a set of SEM images taken at the core region of location B and the skin layer region of location C.
Figure 2. Cell morphology of injection-molded parts with varying contents of CBA at different locations along the flow direction (location B and C) and the normal direction (core and skin region).

It is noticeable from Figure 2 that the cells in general are fairly spherical for all cases. One interesting aspect was that at location A and B the cells near the skin layers were also very spherical without major signs of cell coalescence. The SEM images on the right column of Figure 2 show that even at location C where the morphology and sizes are quite uniform although some coalescence of cells and gas pockets are observed with increasing content of CBA. This suggests that the undesirable premature foaming actions during the mold-filling stage have been successfully suppressed to an extent, thereby eliminating the elongated cell structure caused by shear flow.

It can also be witnessed that the cell density at the core region follows an upward trend in general. Further analysis of cell density in the core at location B was carried out by measuring the cell density 3 times each using the following equation:

\[
\text{Cell density} = \left( \frac{\text{number of cells}}{\text{area (cm}^2)\right)^{\frac{3}{2}} \cdot \frac{1}{1 - \text{v.f.}}}
\]  

(2)

The average cell size at location B was also measured and plotted in Figure 3, which suggests that as CBA content increased from 1% to 3% the foaming behavior was significantly improved. With further increase of CBA content, the average cell density continued to gradually grow while the average cell size also seemed to increase slightly beyond 5% CBA loading. Moreover, the growing number of large voids or gas pockets detected near the skin region at C indicates that although the foam properties of samples with 9% CBA loading near gate region may seem desirable, the overall cell uniformity across the entire injection-molded part may not be excellent with potential danger of over-saturation.

Effect of CBA Content on Mechanical Properties

Impact performance and stiffness, which are two of the most important mechanical properties in industrial applications, were evaluated at various CBA content via IZOD impact tester (92T, Tinius Olsen), and tensile tester (2710-102, Instron), respectively. 10 impact samples and 4 tensile samples were tested for each experimental condition as per ASTM D256 and D638, respectively, to calculate the average IZOD impact strength and Young’s Modulus as shown in Figure 4.

Figure 4. Young’s modulus and IZOD impact strength of foamed samples with varying CBA contents

The IZOD impact strength plot as a function of CBA content depicts that there is no clear correlation between CBA content (i.e. cell structure) and impact strength at a fixed void fraction. It has been reported in numerous publications that several parameters govern the impact strength of foamed parts, including skin thickness, cell size, and void fraction. Therefore, further study is required to find out their individual effects.

More notably, the Young’s modulus decreased linearly with higher CBA content. This behavior could be attributed to the location from which tensile specimens were cut out. As hypothesized in the previous section, samples with higher concentration of CBA seem to be more heavily influenced by the fountain flow effect, resulting in generation of larger voids as they travel further away from the gate. These voids behave as crack generation sites that may severely damage mechanical properties of the samples. However, further investigation is also necessary to verify these findings.

Effect of CBA Content on Surface Roughness

To outline the effect of foam processing on the surface quality of injection molded products, PP foam samples were investigated in terms of surface roughness using a surface roughness tester (TR200, Qualitest). Figure 5 displays the average roughness, Rₐ, measured 10 times
along the reverse flow direction near the location B of the PP foams with varying CBA concentrations.

![Graph showing surface roughness parameter Rₐ as a function of CBA content near location B](image)

Figure 5. Surface roughness parameter $R_\alpha$ as a function of CBA content near location B

As anticipated, the foamed samples compared to the solid counterpart yielded poorer surface qualities with approximately doubled surface roughness. While the solid sample was measured to have the surface roughness of 1.71µm, the sample of the highest CBA concentration (9%) exhibited the average roughness of 4.13µm.

Furthermore, based on Figure 5, surface roughness appeared to be linearly dependent on the CBA concentration. Imperfections on the surface of the solid injection-molded part was attributed to normal wear and machining marks of the mold used in the experiments. The increase in the roughness observed from the foamed samples indicate that the presence of gas was a critical factor controlling the surface quality. The phenomenon can be explained by the fountain flow effects: bubbles forming at the advancing melt front during the mold filling stage are pushed to the mold surface by the incoming polymer melt [15]. The bubbles are subjected to stretching and dragging against the mold which subsequently have a detrimental effect on the surface quality of the final product. Based on the nucleation theory, the activation energy for cell nucleation is inversely proportional to the degree of supersaturation. Thus, the samples with higher CBA contents having lower activation energy should experience more intensive cell nucleation, which will induce a higher degree of the fountain flow effect. The experimental results closely followed the phenomenon, as the samples of higher CBA contents had larger cell densities and also higher surface roughness values.

Conclusions

A foam injection molding process of PP with CBA was carried out and the role of CBA concentration as an injection parameter was investigated. Overall foam morphology of 20% void fraction injection-molded PP foams was optimal with the best cell uniformity and smallest average cell size at 5% concentration of CBA masterbatch, which contains around 0.35% active blowing agent content. Cell density was measured to be the highest at 9% CBA concentration or 0.63% active content, however. In addition, tensile properties and surface roughness values also suggested that excessive use of CBA may bring detrimental effects to foamed plastics.

Acknowledgement

This work was supported by the Korean Ministry of Trade, Industry and Energy (MOTIE), and Korea Evaluation Institute of Industrial Technology (KEIT) as part of their Global Convergence ATC project [ATC-10053160].

References