

Numerical analysis on foam reaction injection molding of polyurethane, part B: Parametric study and real application

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Abstract Foam reaction injection molding (FRIM) is a widely used process for manufacturing polyurethane foam with complex shapes. The modified theoretical model for polyurethane foam forming reaction during FRIM process was established in our previous work. In this study, using the modified model, parametric study for FRIM process was performed in order to optimize experimental conditions of FRIM process such as initial temperature of mold, thickness of mold, and injection amount of polymerizing mixture. In addition, we applied the modified model to real application of refrigerator cabinet to determine optimal manufacturing conditions for polyurethane FRIM process.

Key words Reaction injection molding, Polyurethane foam, Numerical simulation, Refrigerator design

1. Introduction

Polyurethane foam is a cost-effective, lightweight material with low thermal and electrical conductivities, and therefore it is widely adopted in various applications such as thermal insulators and shock absorbers. Foam reaction injection molding (FRIM) is generally used for the production of polyurethane foams to fabricate complex parts of machineries [1-3]. Thermal conductivity, elastic modulus, strength, and density are the most important material properties of polyurethane foam for real applications. During FRIM process, polyurethane foams are fabricated via chemical reactions of various chemical compounds. Crude chemicals in the reservoir are sent into the mixing head with high pressure and speed. Then the mixed chemicals are injected into a mold where polymerization occurs. Microbubbles are generated and grown by saturation reaction during polymerization: chemical or physical foam agents are normally for the micro bubbles generation. FRIM process involves various physical phenomena including chemical reaction, mass transfer, thermal transport, mechanical mixing, microbubble nucleation

and growth.

In our previous work, FRIM for polyurethane was numerically studied with the considerations of chemical reactions, heat transfer, mold filling, and foaming phenomena associated with crude chemicals and mixed liquids. The numerical formulations for FRIM process were developed based on the previously proposed model by Baser and Khakhar [4, 5] to predict density and temperature of polyurethane foam during the FRIM. Along with our previous work, we applied the developed model to determine optimal experimental conditions, such as initial temperature of mold, thickness of mold, and injection amount of polymerizing mixture, for FRIM process of polyurethane foam. Also, we used the developed model to predict polyurethane foam forming reaction in the real processes of manufacturing refrigerator cabinet.

2. Theoretical Model and Numerical Method

Theoretical model and numerical method which used in this work can be found in our previous work, “*Numerical Analysis on Foam Reaction Injection Molding of Polyurethane, Part A: Considering Re-condensation of Physical Foam Agent*”.

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3. Results and Discussion

3.1. Parametric study: Optimize experimental conditions for FRIM

In order to optimize experimental conditions for polyurethane foam forming, a variety of experimental parameters, such as initial temperature of mold, initial injection amount of polymerizing mixture, and thickness of mold, were tested using the developed numerical methods. Fig. 1 represents density of foams fabricated at different initial temperature of mold. It is shown in Fig. 1 that density difference between surface and core parts of foam can be minimized by increasing initial mold temperature. The density difference was calculated as 10 kg/m^3 , 7 kg/m^3 , and 3 kg/m^3 for the foams fabricated by using molds with initial temperatures of 35°C , 40°C , and 45°C , respectively. Thus, high initial mold temperature, however below the ignition temperature of foam, is favorable in order to achieve homogenous density distribution in the final foam. Moreover, as shown in Fig. 2, it

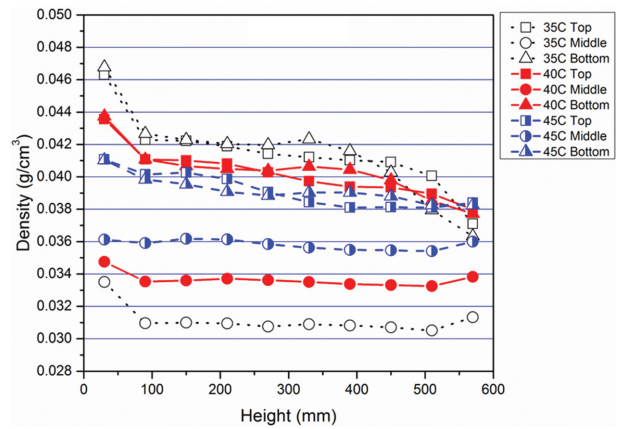


Fig. 1. Calculated density of polyurethane foam fabricated at different initial temperature of mold.

was observed that overall density of foam was increased as increases the initial injection amount of mixture, however it does not significantly affect distribution of density in final foam. It was also confirmed that by comparing computational results with experimental results, the modified numerical method can well predict density

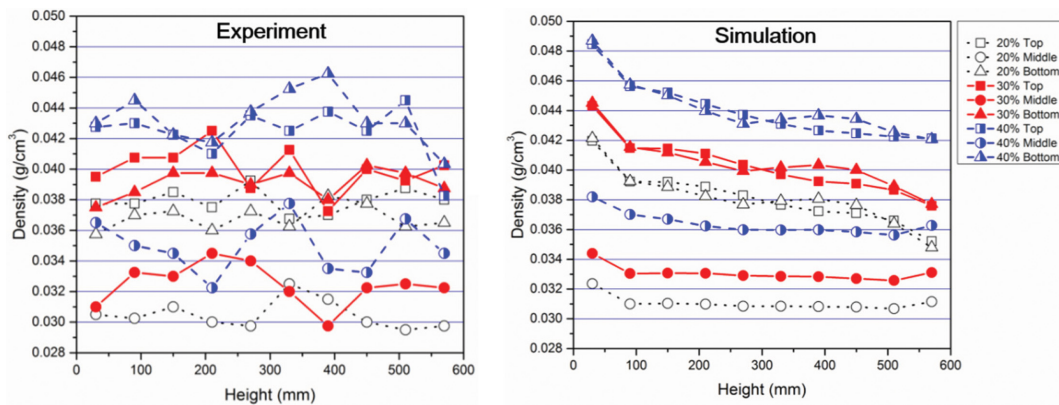


Fig. 2. Density of polyurethane foam formed with different initial injection amount of polymerizing mixture. Left and right figures are experimental and computational results, respectively.

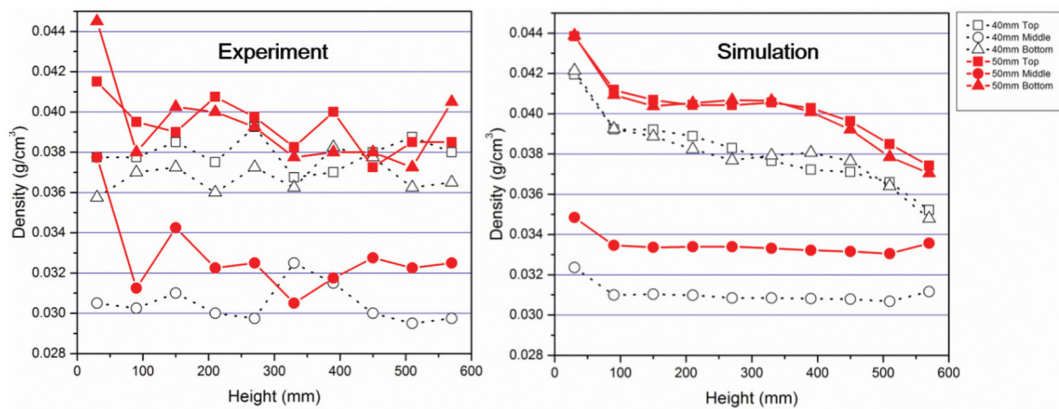


Fig. 3. Density of polyurethane foam fabricated at the molds with different thickness. Left and right figures are experimental and computational results, respectively.

of foams formed with different amount of injection. Lastly, density variation of foams as a function of thickness of mold was investigated (Fig. 3). There was no significant difference in density of foams prepared by molds with different thickness, implying that thickness of mold has a negligible effect on density of foam.

3.2. Real application of the modified numerical methods

The developed numerical method is used for real application of refrigerator cabinet in order to determine optimal manufacturing conditions. Two different geometries of cabinet (i.e., face up and down) with different configurations of nozzle heads were tested as shown in Fig. 4. For the case of ‘face up’, one nozzle head is placed at the bottom of cabinet, while four different nozzle heads are used for the case of ‘face down’. Fig. 5

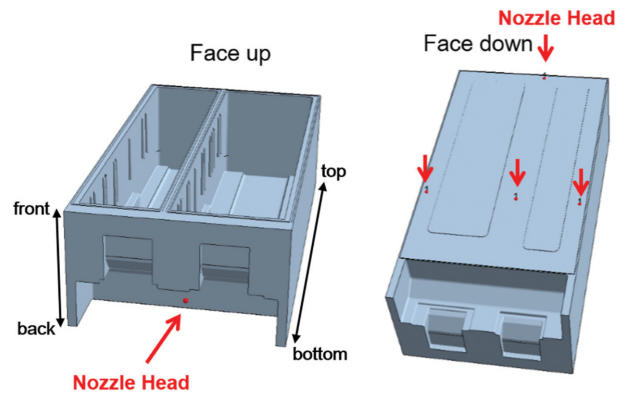


Fig. 4. Two different geometries (‘face up’ and ‘face down’) of refrigerator cabinet for FRIM process.

zle heads are used for the case of ‘face down’. Fig. 5 represents the simulation results of temperature, density, and

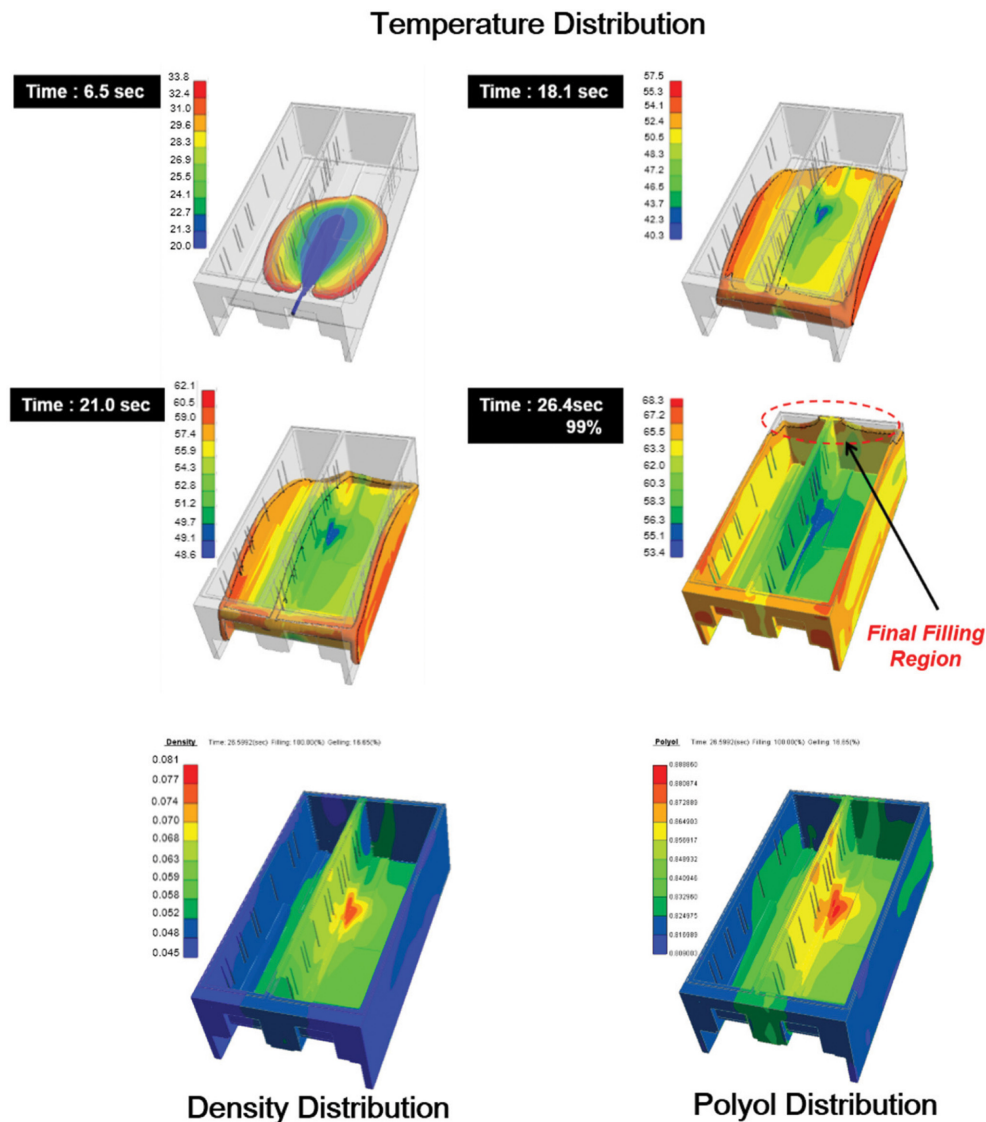


Fig. 5. Temperature, density, and polyol distributions of refrigerator cabinet during FRIM process with ‘face up’ geometry.

and polyol distributions for the case of ‘face up’. As can be seen in Fig. 5, initial filling was started from the back side of cabinet. Initial temperature was lower near at the nozzle head possibly due to the injecting mixture with low temperature. After the reaction passes about 18 s, the back side of cabinet was almost completely filled with polyurethane foams, and it starts to fill upper parts of the cabinet. Most of cabinet (up to 99 %) was filled with polyurethane foams after the reaction occurred about 26 s. The final filling region is marked with red dotted line in Fig. 5, which is determined at top-front

part of the cabinet. Density and polyol distributions are also illustrated in Fig. 5. Lower density and lower concentration of polyol were predicted at the side parts of cabinet compared to the back part, which might be attributed to higher temperature at the side parts than the back part. Density distribution was almost similar to polyol distribution in this case.

Fig. 6 shows temperature, density, and polyol distributions of the cabinet for the case of ‘face down’ as polyurethane foam forming reaction proceeds. In this case, polymerizing mixture was injected through four differ-

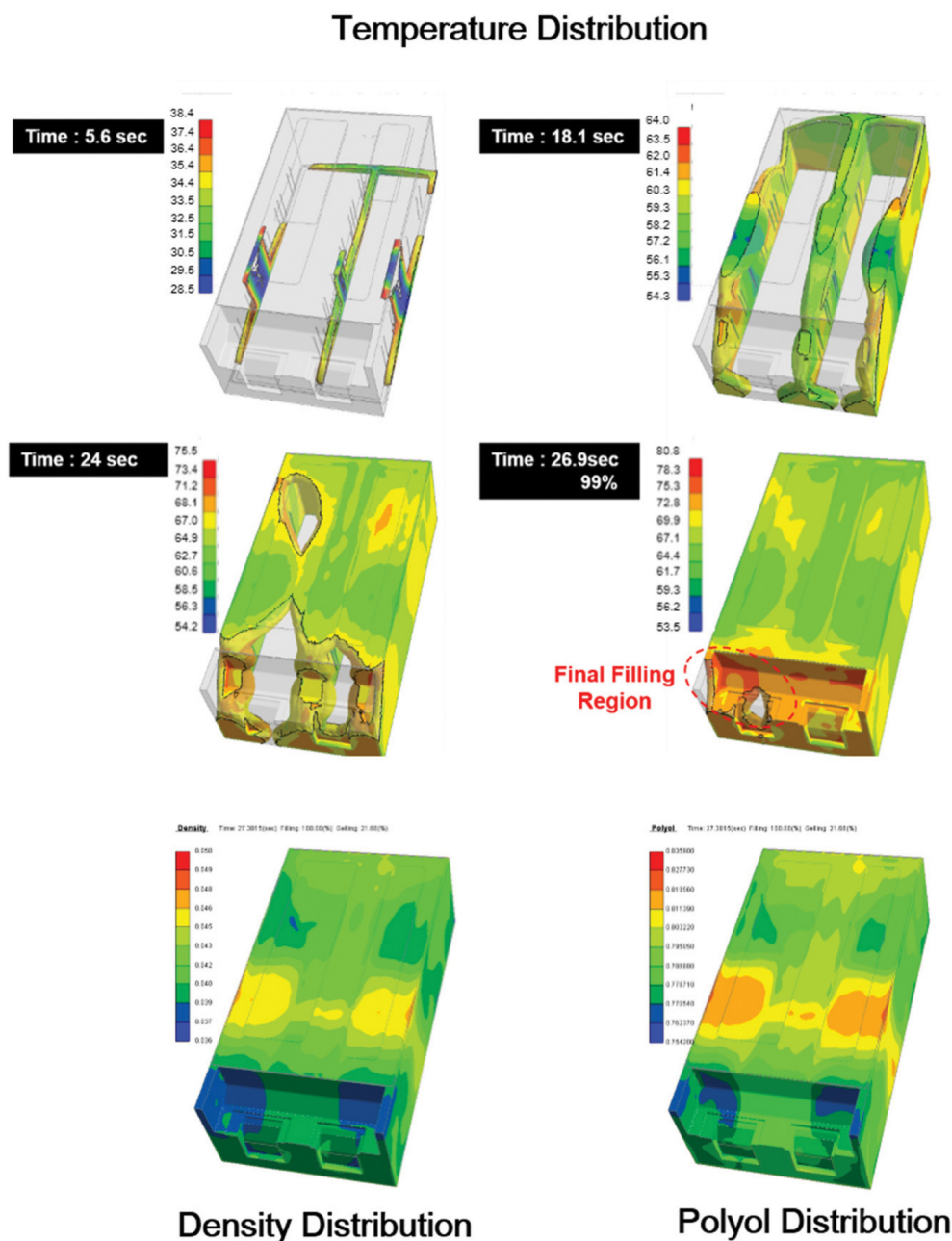


Fig. 6. Temperature, density, and polyol distributions of refrigerator cabinet during FRIM process with ‘face down’ geometry.

ent nozzle heads as shown in Fig. 4. Initially, the places near nozzle heads were firstly filled with foams where the temperature was lower than the places far from the nozzle heads. The most of side parts were filled with foams after reaction proceeded about 18 s. At this moment, temperature was still lower at places near the nozzle heads. Side parts were completely filled with foams and then the back side of the cabinet was partially filled when the reaction continued for 24 s. It took about 27 s to fill almost all parts of the cabinet (up to 99 %). The final filling region was located at bottom left part of the cabinet as marked in Fig. 6. Density distribution indicated that the cabinet has the lowest density at the bottom part, while the side and back parts have high density. As identical to the case of 'face up', polyol distribution was almost equal to density distribution in 'face down' case. However, density and polyol distributions in the cabinet were much more homogeneous for the 'face up' case compared to 'face down'. Also, overall density was higher for the 'face down' case. Therefore, it can be concluded that 'face down' geometry using four different nozzle heads are favored to manufacture the refrigerator cabinet with high density of polyurethane foams and homogeneous density distribution.

4. Conclusion

Experimental parameters for polyurethane foam forming, such as initial temperature of mold, initial injection amount of polymerizing mixture, and thickness of mold, were optimized by using simulations based on the developed model. Based on the parametric study, higher initial temperature of mold and larger amount of initial injection are favorable to achieve homogeneous density

distribution and higher density of the foam, respectively, while thickness of mold has no significant effect on density of the foam. In addition, the developed model was applied to real application of refrigerator cabinet for investigating polyurethane foam forming during FRIM process. The results indicated that 'face down' geometry using four different nozzles is necessary to manufacture refrigerator cabinet with higher density and homogeneous density distribution.

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