Mold Filling Meta Model for Polymer Composite Heat Exchanger

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1. Introduction

In this study, we present a manufacturability analysis of polymer heat exchangers using thermally-enhanced composites. The advent of new fiber filled resins [1], which use fibers with higher thermal conductivity, has brought along new design possibilities for heat exchangers using cost-effective molding techniques. The cost of polymer heat exchangers and the energy investment in fabrication are expected to be considerably lower than their metal counterparts. The most common molding technique for thermoplastics today is injection molding. Polymer heat exchangers will involve complex geometries and thin sections. Hence we believe that injection molding will be the most suitable process for making them. The work presented here focuses on injection molding of a finned plate. This geometry was deemed to be representative of a compact heat exchanger module.

Thermally-enhanced polymers possess certain material characteristics that could pose challenges during the molding process. Specifically, these resins have high filler loadings, which increases the viscosity, and the fibers' high thermal conductivity causes the resin to cool faster in the mold. These two factors make filling the mold difficult to accomplish for long thin parts, so for this reason, successful filling of the mold is the subject of this study.

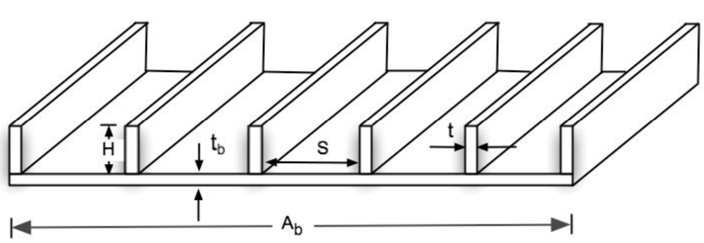
Optimizing the heat exchanger designs requires characterization of the moldability over the design space. However, molding actual parts to explore the design space would be time consuming and costly. Hence, a more suitable approach is to explore the design space using mold flow simulation software such as Moldflow. Simulation is conducted for discrete points in the design space and a meta model is constructed based on the simulation results. Moldflow filling predictions were validated using a spiral mold test. The meta model presented here can be used to predict filled volume percentage for single-gate injection, and to identify regions in the design space not suitable for injection molding.

2. Results

Multiple points in the parametric space were selected using 2-level factorial design and adaptive sampling. At the selected points, Moldflow was used to predict the percentage volume filled by single-gate injection of a commercially available thermally-enhanced PA12 resin. The finned plate geometry and the parametric space is shown below in Figure 1.

Moldflow predictions were validated experimentally using a spiral mold test. Figure 2 below shows a comparison of Moldflow predictions to spiral mold average results for unfilled and filled PA12. The predictions were within 20% of the experimental results. Figure 2 also reveals that for equal injection pressures, enhanced polymers are able to fill approximately half the volume filled by unfilled polymers.

The dataset (~60 points) obtained from Moldflow simulations was used to construct a quadratic meta model to predict the percent volume filled in the mold for single-gate injection. The quadratic model fits the dataset with residual errors of less than 10%. Figure 3 below shows a plot of the meta model, which can be used to assess the feasibility of a certain design.



A_b = 200-1000 mm
t_b = 1-4 mm
S = 3-20 mm
t = 1-5 mm

Figure 1. Finned plate geometry and parametric range.

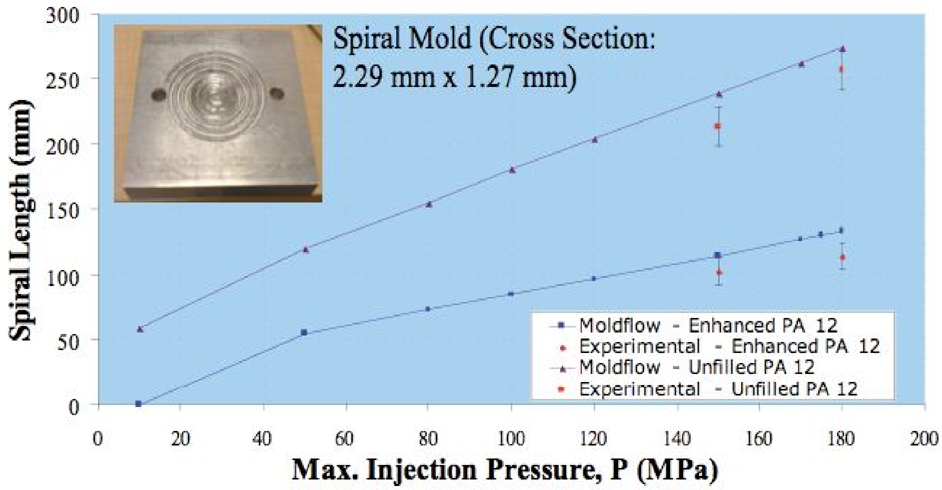


Figure 2. Experimental validation of Moldflow filling simulation.

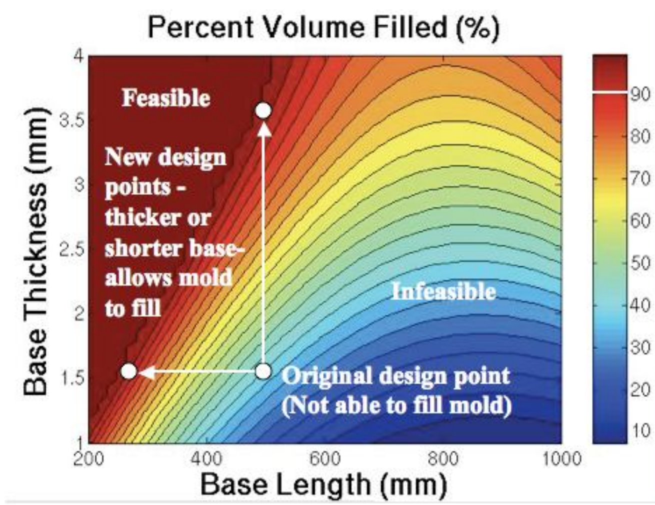


Figure 3. Percent volume filled as a function of base length and base thickness (H = 10 mm, S = 10 mm, t = 2 mm).

3. Conclusions

From the results obtained in this study, it was observed that base length and base thickness were the driving parameters in achieving successful mold filling, while fin thickness and fin spacing only had secondary effects on mold filling.

The meta model presented here can be used to identify regions of infeasible designs within the parametric space. Maps such as that of Figure 3 can be used to elucidate possible changes, which can be made to make designs feasible. This model provides a computationally fast analysis tool (running time is less than 1 second) when compared to Moldflow predictions (running time is greater than 2 hrs).

4. References and Bibliography

1. Zweben, C., 2004, "Emerging High-Volume Applications for Advanced Thermally Conductive Materials," Proceedings of the 49th International SAMPE Symposium and Exhibition, Long Beach, CA, USA, May 16-20, pp 4061-4072.

Author(s) Biographies

Dr. Avram Bar Cohen is Distinguished University Professor and Chair of Mechanical Engineering at the University of Maryland, U.S.A., where he continues his research in the thermal management of Micro/Nano systems. His interests include thermal design, ebullient heat transfer, and thermal phenomena in microelectronic, photonic, and biological systems, as well as technology forecasting and management of technology. Bar-Cohen was a founding member and currently serves on the Advisory Board of ASME's Nanotechnology Institute and represents ASME on the Assembly for International Heat Transfer Conferences (2002-2006). Prior to accepting his current position, he served as the Director of the Center for the Development of Technological Leadership and held the Sweatt Chair at the University of Minnesota, where he earlier served as Professor of Mechanical Engineering and Director of the Thermodynamics and Heat Transfer Division.

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