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Effects of thickness of the flow channel, melt temperature and mold temperature on the flow behavior of polypropylene/silicon carbide composites using injection molding simulation

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Abstract

Computer-aided engineering tools for plastic injection molding have been used to resolve problems of material, part, and mold design. This work analyses the flow behaviour of polypropylene/silicon carbide composites simulated by the injection molding simulation software, Moldex3D, using the spiral flow mold. The spiral flow mold was initially modelled by CATIA, and then the part model was imported into the Moldex3D for the simulation of the injection molding process. The effect of injection parameters, such as thickness of the flow channel (i.e., 2, 3 and 4 mm), melt temperature (i.e., 190, 210 and 230 °C), and mold temperature (i.e., 40, 55 and 70 °C) on the process were investigated. The tested material is polypropylene filled with silicon carbide 15% by weight. The flow ability is expressed as the length of the characterization mold filled under a specified set of parameters. Results showed that the flow length of polymer composites increased with increasing thickness of the flow channel. The rate of change decreased with increasing thickness of the flow channel from 2 mm to 3 mm, and 3 mm to 4 mm, respectively. The flow length of polymer composites increased with increasing melt temperature from 190 °C to 210 °C , and mold temperature also exhibited improvement in flow ability. Furthermore, the effect of injection parameters on shrinkage of the parts of the samples was also investigated. Results indicate that the melt temperature had an influence on the shrinkage. Shrinkage of polymer composites increases with increased melt temperature, whereas thickness of flow channel and mold temperature had no significant effect on shrinkage.

Keywords: Polymer composites; Flow channel thickness; Flow ability; Injection molding simulation

1. Introduction

Injection molding is a manufacturing technique used to produce complex parts from plastic. The filling stage is the most important stage in the injection molding process. There are many defects such as short shot, shrinkage, and warpage which may occur in this stage leading to rejection of the products when they reach quality control. The defects may be prevented if the injection molding takes place under optimal processing conditions using a properly designed mold. Injection molding often requires time for trial and error methods to find a solution to design problems related to raw materials, product dimensions, and process problems during manufacturing. Therefore, nowadays computer-aided engineering software (CAE) for plastic injection molding has shown to be useful in resolving problems of material, parts, and mold design. Several CAE software types for injection molding are available such as Moldflow® and Moldex3D® [1]. Previous authors have studied the injection molding simulation analysis of materials including natural fiber composites, biodegradable polymers, rubber seals, polypropylene, ABS, and high viscosity PC [1 – 5].

Polypropylene is one of the most important commodity plastics in a wide variety of applications and easy processing by injection molding. However, the properties of polypropylene do not reach typical properties of technical or engineering polymer. Using silicon carbide as reinforcement in commodity thermoplastic composites reduces costs and modifies their physical and mechanical properties. In previous studies, the incorporation of waste silicon carbide into polypropylene led to an increase of flexural strength, flexural modulus, tensile strength, tensile modulus, and impact strength [6, 7]. The understanding of polymer composite flow ability is necessary for an accurate mold design and for processing parameter selection. Based on the achievements previously reported, this study focused on analyzing the effects of thickness of the flow channel, melt temperature, and mold temperature on the flow behaviour of polypropylene/silicon carbide composites using an injection molding simulation. The Moldex3D software was applied to simulate the injection molding process of polypropylene/silicon carbide composites.

2. Materials and methods

Materials

In this study, polypropylene was filled with waste silicon carbide 15% by weight. Polypropylene-grafted-maleic anhydride (PP-g-MA) 5% by weight was introduced into a blending system as a compatibilizer [6]. The materials used in this study are as follows: high density polyethylene (1100NK-grade) at 0.90 g cm^{-3} was purchased from IRPC Public Company Limited (Thailand). This had a melt flow index of 11 g/10 min at 230 °C. The waste silicon carbide (SiC) powder from abrasive industry was produced by Kyocera Kinseki (Thailand) Company Limited, and was filtered with a 400 mesh screen panel. The maleic anhydride grafted polypropylene (PP-g-MA) with a melt flow index of 19.24 g/10 min was supplied by Creative Polymer Limited.

Methods

To compare different processing parameters, a spiral flow mold was designed in accordance with ASTM D3123. Different thicknesses of the flow channel of the mold (i.e., 2, 3 and 4 mm) were created. The length and width of the flow channel were 1,270 mm and 6 mm. CATIA™ 3D Software was used to draw the spiral flow mold layout. Fig. 1 shows the modelling of the spiral flow mold. Then, the part model was imported into the Moldex3D software for injection molding simulation analysis as shown in Fig. 2.

Moldex3D is a computer aided engineering (CAE) software suitable for injection molding simulation because of the true 3D model simulation. In the present study, the commercially available CAE software for injection molding, Moldex3D R14.0 (CoreTech System, Hsinchu, Taiwan) was used to simulate the polymer composites filling and shrinking of the part model. The material properties of Moldex3D include the rheological data (viscosity over the shear rate), PVT data, thermal conductivity and specific heat. This data was measured specifically for each material. The processing conditions of polypropylene filled with silicon carbide were approximated due to the unavailability of polypropylene/silicon carbide composites in Moldex3D software. Several models have been developed to predict the rheological behaviour of thermoplastic polymers for injection molding purposes, including the Newtonian, Power-Law, Cross, and Carreau models, which relate to temperature, shear rate and pressure [8]. Normally, polymers exhibited a Newtonian plateau at low shear rate, a transition region, and then a power law region is well modelled by the Cross-WLF model. Therefore, in this study the Cross-WLF model is used for numerical simulation. The Cross-Model is defined as:

$$\eta = \frac{\eta_0}{1 + \left(\frac{\eta_0 \gamma}{\tau^*}\right)^{1-n}} \qquad (1)$$

where η_0 is the zero-shear viscosity, τ^* is the model constant that shows the shear stress from which the pseudoplastic behaviour of the polymer starts, γ is the shear rate and n is the power law index [9]. The Cross-WLF model of the rheological data for the materials is shown in Fig. 3.

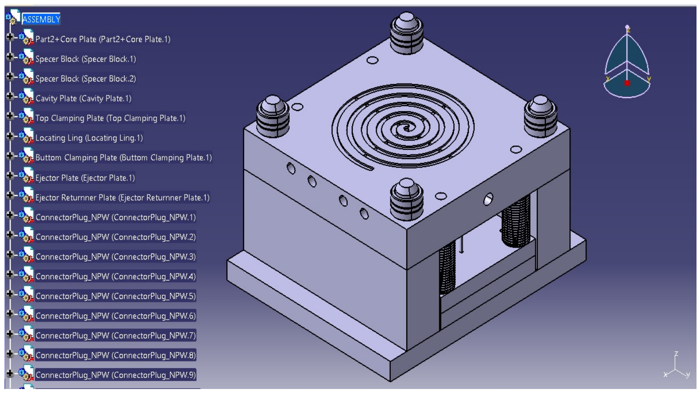

Fig. 1 Modelling of the spiral flow mold

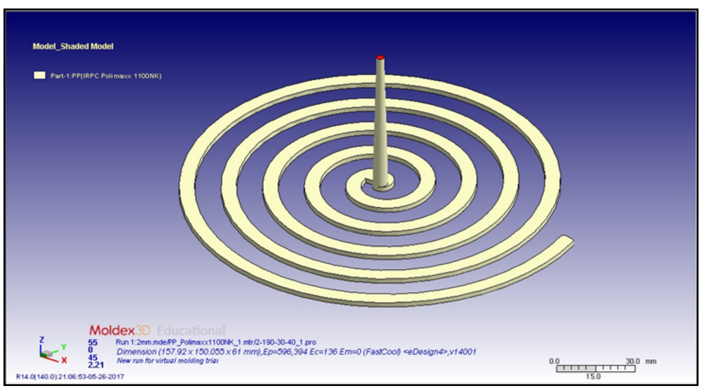

Fig. 2 Mold model in the Moldex3D software

The measured properties of the polypropylene/silicon carbide composites used as material data for the simulation are presented in Table 1. For other information such as PVT data, heat capacity was approximated to neat polypropylene 1100Nk manufactured by Polimaxx as in the Moldex3D software database.

Based on the experimental parameters of the injection molding simulation as specified in Table 2, the polypropylene/silicon carbide composites with different parameters were used in the injection molding simulation to investigate the effects of processing parameters (i.e., thickness of the flow channel, melt temperature, and mold temperature) on the flow length and shrinkage. The injection pressure was fixed at 60 MPa. The injection molding experiments were conducted on the injection molding machine (model ES 200/50 HL, ENGEL). The experimental runs were performed in the same way for all the different parameters to get comparable results. Flow ability is expressed as the length of the characterization mold filled under a particular set of conditions. Examples of simulation results at the end of filling, with mold temperatures of 190 °C and 40 °C are shown in Fig. 4.

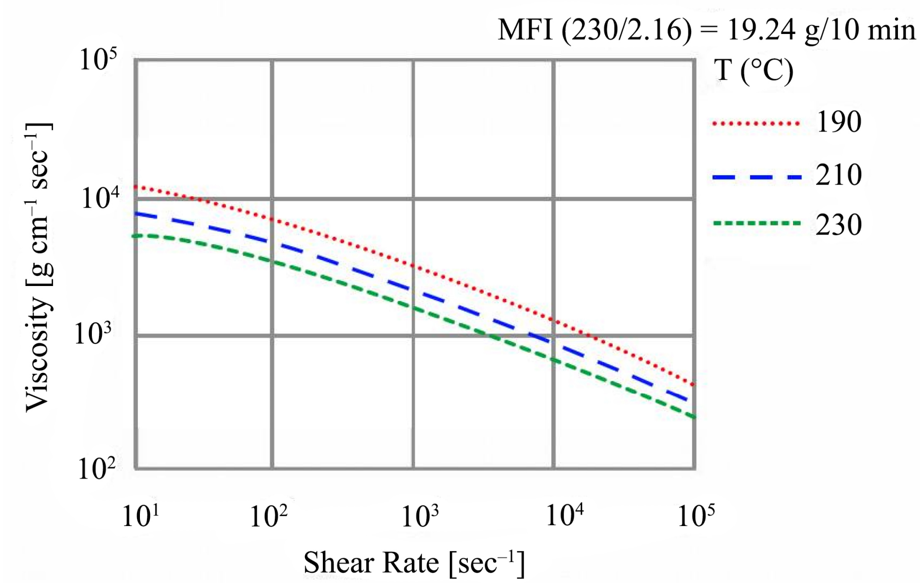

Fig. 3 Shear viscosity Cross-WLF model for polypropylene/silicon carbide composites

Table 1 Input data of polypropylene/silicon carbide composites for injection molding simulation

MFI (Melt flow index)	19.14 g/10 min (2.16 kg/ 230 °C)
Density	1.02 g cm^{-3}
n (Power law index)	0.38 (at 190 °C), 0.46 (at 210 °C), 0.56 (at 230 °C)
k (Consistency index)	5,649.30 (at 190 °C), 2,964.40 (at 210 °C), 1,449.00 (at 230 °C)

Table 2 Experimental parameters of injection molding simulation

Thickness of the flow channel (mm)	2	3	4
Melt temperature (°C)	190	210	230
Mold temperature (°C)	40	55	70

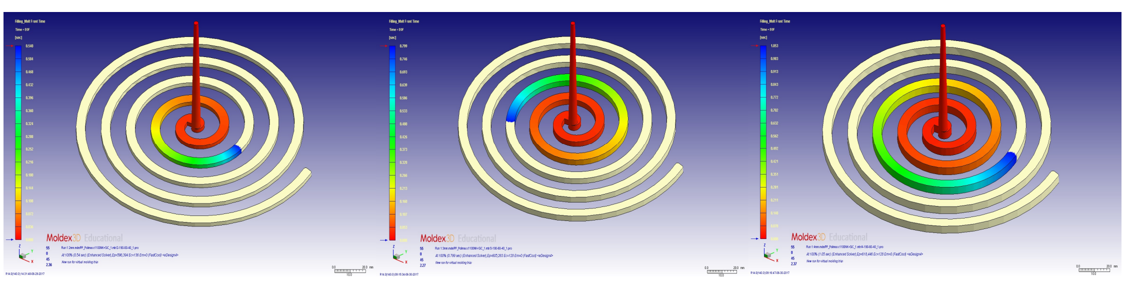

Fig.4 Simulation results at the end of filling, with mold temperatures of 190 °C and 40 °C at differing thicknesses of the flow channel: (a) 2 mm; (b) 3 mm; (c) 4 mm

3. Results and Discussion

Effect of the thickness of the flow channel

Fig. 5 shows the length of flow of polypropylene/silicon carbide composites as a function of the thickness of the flow channel with different melt and mold temperatures. It was found that the length of flow increased with an increase in the thickness of the flow channel. The rate of change decreased as the flow channel increased from 2 mm to 3 mm, and 3 mm to 4 mm, respectively. The increases in length of flow with increased thickness of the flow channel were explained in association with the frozen layer. The greater the thickness of the flow channel, the slower the frozen layer continuously forms along the mold wall, in contrast to the situation when the thickness of the flow channel is reduced. The shrinkage of polypropylene/silicon carbide composites as a function of the thickness of flow channel with different melt and mold temperatures is presented in Fig. 6. It was observed that the thickness of the flow channel had no significant effect on shrinkage.

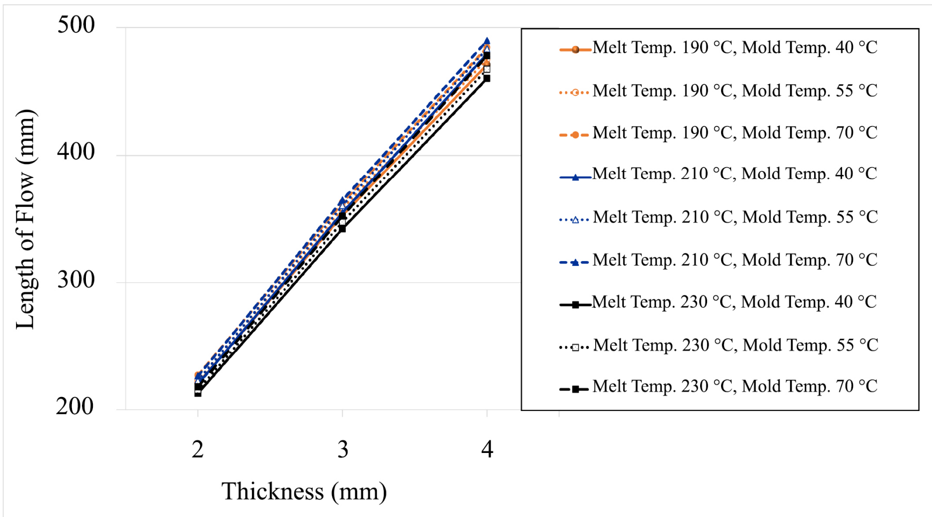

Fig. 5 Length of flow as a function of thickness of the flow channel of polypropylene/silicon carbide composites

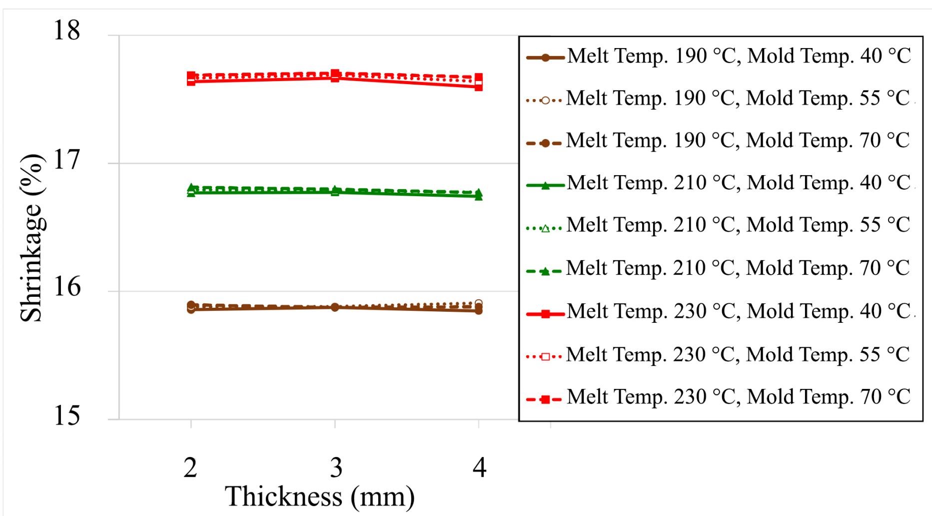

Fig. 6 Shrinkage as a function of thickness of the flow channel of polypropylene/silicon carbide composites

Effects of melt temperature

The effect of melt temperature on the viscosity of polymer composites is important for considering temperature changes during their processing. Therefore, the length of flow of polypropylene/silicon carbide composites after injection molding simulations at melt temperatures of 190 °C, 210 °C and 230 °C were investigated. The results are shown in Fig. 7. It was found that the length of flow gradually increased as the melt temperature increased from 190 °C to 210 °C. This is due to the greater free volume and the decreasing entanglement density at high temperatures. On other hand, the length of flow decreased as the melt temperature increased from 210 °C to 230 °C. The decrease in length of flow occurs because at 230 °C the viscosity is governed by filler melt interaction that increases the viscosity [10]. Fig. 8 shows the shrinkage of polypropylene/silicon carbide composites as a function of the melt temperature with different thickness of the flow channel and mold temperature. It was observed that shrinkage increased with an increasing melt temperature. At higher temperatures, the increase in shrinkage is due to difficulty in removing heat of solidification from the molten polymer and due to polypropylene crystallization upon cooling to a solid phase. It is commonly accepted that semi-crystalline polymers have less resistance to shrinkage because of the closer packing of the crystalline structure. Higher shrinkage indicates that the material has an extensive crystallization process taking place in the course of solidification of the molten material during the cooling process [2].

Effects of mold temperature

The effects of mold temperature on the length of flow and shrinkage of PP/SiC composites were presented in Fig. 9 and Fig. 10. Because of the fact that during the injection molding process the mold is cold, a frozen layer continuously forms along the mold wall. Therefore, the continued filling of the mold depends on the flow through the frozen channel. The moldability results show that when the mold temperatures increase, the length of flow is greater. The increase in mold temperature did not significantly affect the shrinkage value when observed at same thickness of flow channel and melt temperature.

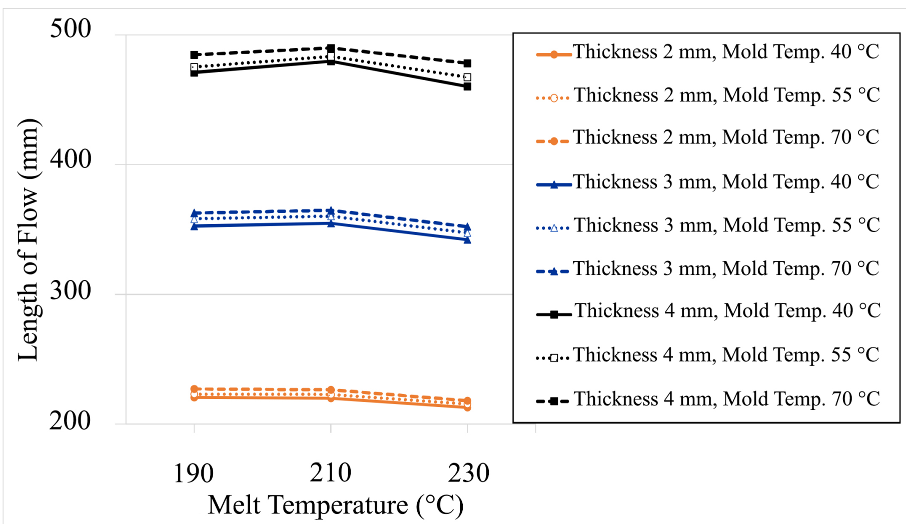

Fig. 7 Length of flow as a function of melt temperature of polypropylene/silicon carbide composites

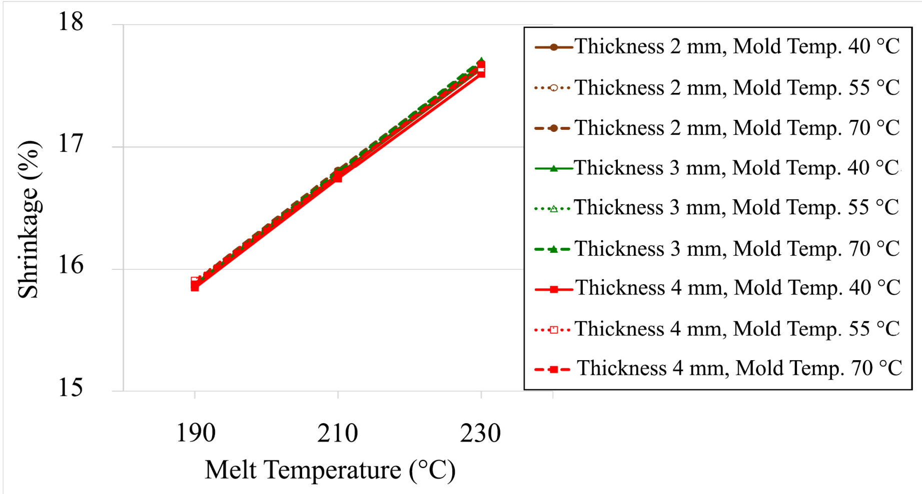

Fig. 8 Shrinkage as a function of melt temperature of polypropylene/silicon carbide composites

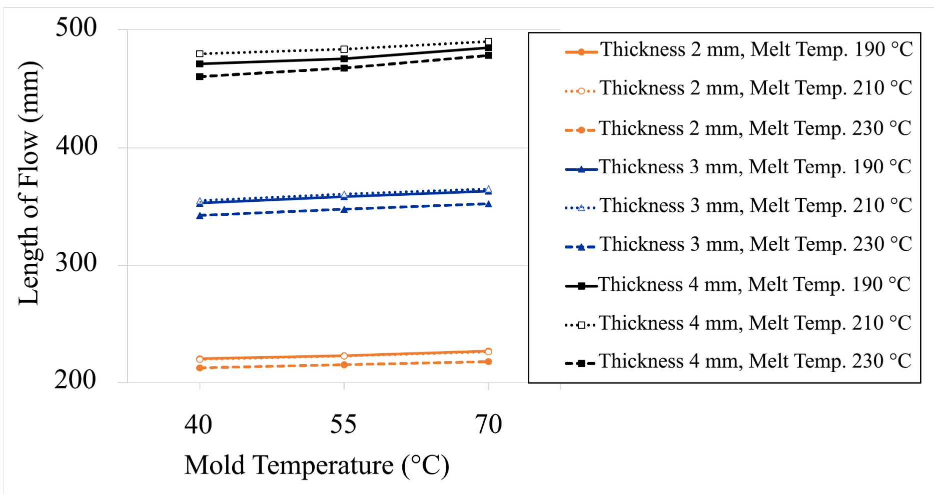

Fig. 9 Length of flow as a function of mold temperature of polypropylene/silicon carbide composites

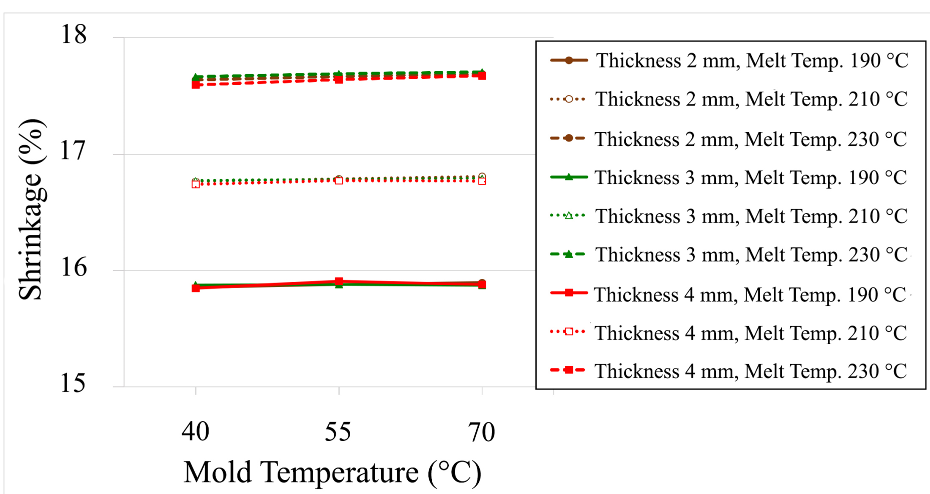

Fig. 10 Shrinkage as a function of mold temperature of polypropylene/silicon carbide composites

4. Conclusion

Polypropylene filled with silicon carbide 15% by weight was considered as the injection molding material to a spiral flow mold using Moldex3D. The effect of thickness of flow channel, melt temperature, and mold temperature on flow ability and shrinkage of the injection part were studied. Results indicate that the length of flow increased with increasing thickness of flow channel and mold temperature, while the length of flow increased as the melt temperature increased from 190 °C to 210 °C. On other hand, the length of flow decreased as the melt temperature increased from 210 °C to 230 °C. The thickness of the melt temperature had an influence on the shrinkage. The shrinkage of polymer composites increases with increasing melt temperature, whereas thickness of flow channel and mold temperature did not significantly affect the shrinkage. Overall, this study indicated that injection molding simulation software helps to study the flow patterns inside the mold during injection. The output results can be used as guidance to design the mold with current operation parameters, and the most important benefit is the control of expenses in building a mold.

5. Acknowledgement

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6. References

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