VAPOR CHAMBER UTILIZATION FOR RAPID COOLING IN THE CONVENTIONAL PLASTIC INJECTION MOLDING PROCESS

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ABSTRACT

Injection molding is the most common process for producing plastic products. The surface quality and the cycle time of the plastic product is strongly influenced by the cooling system, which accounts for approximately 70% of cycle time. In conventional injection molds, beryllium copper (BeCu) inserts are commonly used to speed up the cooling process and to obtain a uniform temperature distribution. This study aims to compare the abilities of the vapor chamber and the BeCu insert to increase the cooling rate and provide an even temperature distribution. The experiment was conducted with variations in heat inputs, cooling temperatures, and cooling rates. The vapor chamber had a copper foam wick with a pore diameter of 0.2 mm, filling ratio of 30%, and water as the working fluid. The vapor chamber provides an effective way to speed up the heat transfer process in injection molding, with heat transfer up to 67% greater than in conventional cooling methods that use BeCu.

Keywords: Injection mold; Mold cooling process; Rapid cooling; Vapor chamber

1. INTRODUCTION

The plastics industry is one of the medium and large manufacturing industries that contribute to the growth of the national economy in Indonesia (Putri et al., 2016). The broad use of plastic products, such as in home appliances, food packaging, building materials, and the automotive industry, has resulted in the rise of plastic consumption, especially in developing countries like Indonesia. Plastic products must be made in bulk, cheap to produce, easy to set up, stable at room temperature, and have a good surface quality. The injection molding process is a widely used plastic-making process due to its suitability for mass production (Guilong et al., 2010; Huang & Tai, 2009). Injection molding enables high productivity with good surface quality. For special products such as medical equipment that require higher surface quality, other methods such as investment casting can be used (Supriadi et al., 2015).

There are four steps in the injection molding process: clamping, injection, cooling, and ejection. Half of the mold is fixed to the injection molding machine, while the other half is allowed to slide. The clamping unit pushes the mold and exerts sufficient force to keep the mold securely closed while the material is injected. The next step is to insert the plastic material, in the form of pellets, into the injection molding machine. The material is melted then cooled as it contacts the interior mold surfaces. After a sufficient amount of time has passed, the cooled product is ejected via the ejection system. During the process of injection, the temperature of the product

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from 220°C, when the plastic is melted, to 60°C, when the plastic is removed from the mold. The cooling process determines the quality of the product (Li et al., 2011). The current trend is to manufacture products that are lightweight, strong, and cheap. To achieve a cheap plastic product, one of the most important factors is cycle time. Shortening the cycle time can significantly reduce production costs; however, doing so carries the risk of failure when the product is ejected from the mold while its temperature is still high. This can cause product defects, such as deformation, non-uniform shrinkage, warpage, and bending. The requirement to increase production rate without causing defects is a challenge in plastic manufacturing.

Previous research has been conducted to overcome the disadvantages of low cycle time and temperature distribution during the injection molding process. The most common method is to use an electric heater with water as a cooling medium (25°C); however, this system carries a disadvantage in that the surface temperature distribution is uneven (Li et al., 2011). A study on pulsed cooling revealed that it can reduce the cycle time by 10% (Chen et al., 2008). Several types of coating layers were used to increase the strength of the plastic and the surface temperature, but there was no significant change in cooling time (Chen et al., 2009). A beryllium copper (BeCu) alloy was inserted into the injection mold due to its high thermal conductivity, resistance to corrosion, and its ability to absorb heat faster.

Several studies on the use of heat pipes for thermal management in electronics and batteries have been conducted (Putra et al., 2016; Putra et al., 2011). The vapor chamber is a special type of heat pipe that has several advantages, such as even temperature distribution, high thermal conductivity, and is unaffected by the inclination angle (Putra et al., 2012). Vapor chambers have been widely used to accelerate heat transfer and distribution (Wang, 2011). There are three main parameters that influence the performance of a vapor chamber: filling ratio, working fluid, and wick structure. Naphon et al. (2013) found that a filling ratio of 20% is the most appropriate for injection mold cooling. Nanofluids, such as Al_2O_3-water, can increase the heat transfer rate and improve the performance of the vapor chamber (Ji et al., 2012; Liou et al., 2010). A vapor chamber with a copper foam wick can transfer a considerably high amount of heat flux (Ji et al., 2012).

Vapor chambers have been proven to dissipate heat faster than other solid metal materials, such as iron and aluminum, with continuous load, such as in electronic cooling. Using vapor chambers in the injection mold is a solution for speeding up cycle time and ensuring uniform temperature distribution in the mold insert (Wang et al., 2008). In conventional injection molds, uniform temperature is important for preventing some defects, such as bending, twisting, and other defects caused by inconsistent shrinkage (Hassan et al., 2010). The common method used in conventional injection molding is to extend the cooling time, which ensures the product temperature is uniform and avoids shape distortion when the product is removed from the mold; however, this method certainly increases the manufacturing time, so the cost will also increase (Hassan et al., 2009; Lin & Chou, 2002).

In the present study, the vapor chamber was used to speed up the heat transfer process in the cooling system. The aim is to determine the characteristics of the vapor chamber, its temperature distribution, and its influence on the conventional plastic injection molding process, compared to the BeCu insert.

2. METHODOLOGY

The vapor chamber was manufactured using copper to the specifications shown in Figure 1. The total width and length of the vapor chamber is 34 mm and 65 mm, respectively. A 2-mm copper foam wick with a pore diameter of 0.1 mm and 50% porosity was planted inside the vapor chamber. The width of vapor chamber is 34 mm. There are two vacuum pipes used to vacuum

and inject the working fluid into the vapor chamber. The diameter of each pipe is 5 mm. The working fluid used was distilled water.
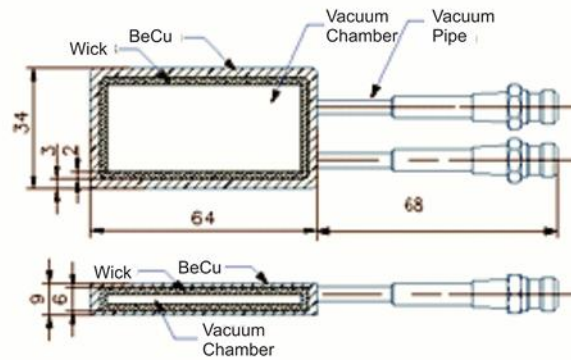

Figure 1 Vapor chamber

The temperature distribution data was obtained using the National Instruments data acquisition modules NI9137 and NI9211 for temperature measurement. The thermocouples were soldered to the top and bottom of the vapor chamber. Figure 2 shows the placement of the thermocouples. The purpose of this placement was to gain an accurate reading of the temperature difference, which would allow for the absorbed heat to be calculated. All the dimensions are shown in millimeters.
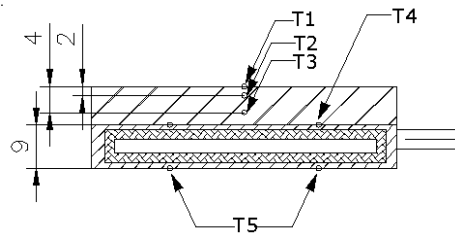

Figure 2 Thermocouple placements

The heat input calculation is based on the temperature difference between two points, T_2 and T_3, where thermocouples were placed. The heat supplied in the injection molding simulation was discontinuous, which reflects the actual conditions of the injection molding process. T_1 represents the temperature between the plastic and a cavity, which is unstable due to contact with the air, and therefore could not be used as a reference temperature.

An electric heater was used to simulate the injection molding machine so that the same temperatures could be reached as those in the molding process. The pressing machine was used to simulate a situation in the injection molding process. The voltage stabilizer and thermostat were used to control the heater. A circulating thermostatic bath was used to create a temperature difference between the heater and the bottom of the vapor chamber, therefore causing the heat to flow from the heater into the vapor chamber. The vapor chamber was placed between the heater and the cooling space. Figure 3 displays a schematic of the experimental set up.
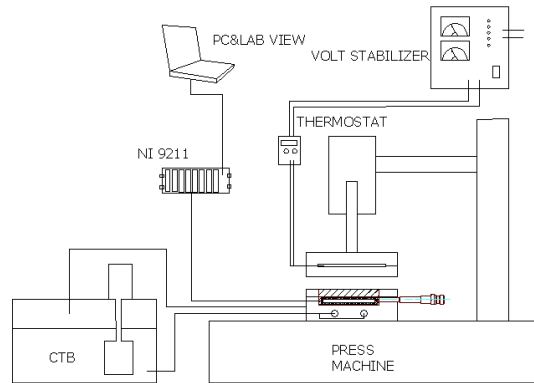
Figure 3 Experimental set up

The first searchable encryption construction was presented whereby anyone with a public key can write to the data stored on the server, but only authorized users with private keys can search (Boneh et al., 2004). Ranked keyword search in a secured manner utilizes keyword frequency to rank results instead of returning undifferentiated results (Wang et al., 2010, 2012). Data search service over encrypted content in the cloud made the work of data retrieval easy (Ning et al., 2014). Multi-keyword based ranked search over encrypted data improved the search experience with more search semantics.

3. RESULT AND DISCUSSION

3.1. Copper foam characteristics

Copper foam was used to increase the performance of the vapor chamber as a cooling system for the injection molding process. The copper foam consisted of two porous foams, small and large. Figure 4 shows the SEM result of the copper foam. The pore sizes of the copper foam were 271, 318, and 348 mm. The larger pores can increase the permeability of the working fluid in the vapor chamber. Dual pore vapor chambers can be used in high heat source applications (Semenic & Catton, 2009; Semenic et al., 2008).
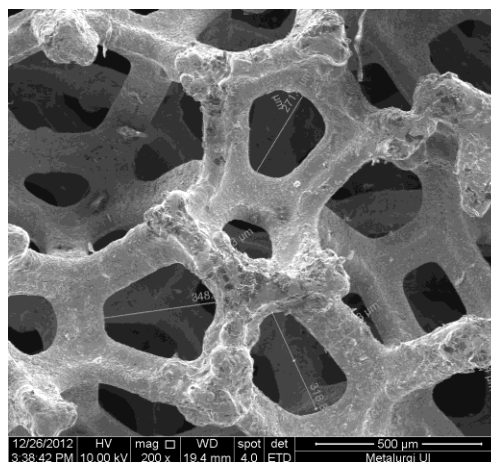

Figure 4 SEM visualization of the copper foam

3.2. Temperature Distribution in the Vapor Chamber and BeCu Cooling Systems

Thermocouples were placed at three positions to display the temperature distribution during heat transfer by the vapor chamber and BeCu cooling systems. The distance between each thermocouple was 2 mm. Figure 5 shows the temperature distribution at T_2, T_3, and T_4, with a cooling temperature of 20°C and a cooling water flow rate of 4 liters per minute. The initial

temperature (T_1) of the vapor chamber dropped dramatically compared to the BeCu insert, from 80°C to 45°C within 200 seconds. The same condition was found at T_2 and T_3 on the vapor chamber, in which the temperature dropped by 76.8% and 78.3%, respectively.
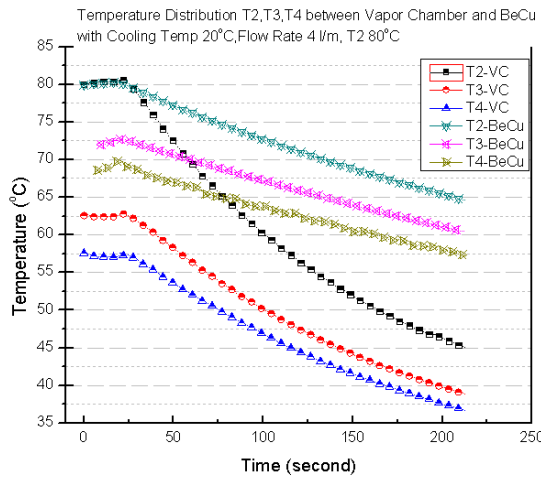

Figure 5 Temperature distributions of vapor chamber and BeCu insert

The temperature in the BeCu insert (T_1) only dropped from 80°C to 65°C within 200 seconds of operation. T_2 and T_3 on the BeCu insert showed the same tendency as T_1. This phenomenon indicates that the vapor chamber is better than the BeCu insert as a cooling system in the injection molding process. The heat transfer ability of the vapor chamber was also higher than the BeCu insert due to the vacuum pressure and wick inside the vapor chamber. This improved heat transfer will lead to higher drops in temperature.

3.3. Cooling Performance of the Vapor Chamber and the BeCu Insert

Various ejection temperatures (i.e., 40°C, 50°C, 60°C, and 70°C) were used to compare the performances of the vapor chamber and the BeCu insert, as shown in Figure 6a. The times required for the vapor chamber to reach the ejection temperatures were 290, 185, 100, and 60 seconds, respectively. At the ejection temperature of 70°C, the vapor chamber improved the heat transfer process by up to 42%. At the ejection temperature of 40°C, the heat transfer rate of the vapor chamber was 67% faster than the BeCu insert. This phenomenon is consistent with previous studies.
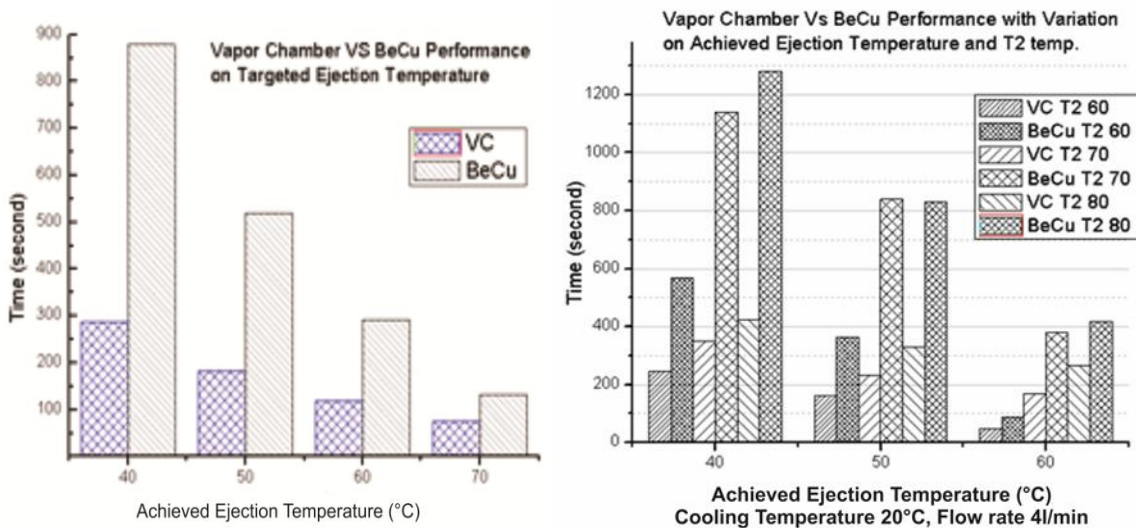

Figure 6 (a) Performance comparisons between the vapor chamber and the BeCu insert; (b) Performance comparisons between the vapor chamber and the BeCu insert with T_2 variation

The relationship between T_2 and the ejection temperatures are shown in Figure 6b. A higher T_2 value increased the time required to reach the ejection temperature. The shortest times required for the vapor chamber to reach the ejection temperatures of 60°C, 50°C, and 40°C were 30, 130, and 240 seconds, respectively. These results are better than those of the BeCu insert. When the target temperature (T_2) was 40°C, the cooling rate of the vapor chamber was 60% faster than the BeCu insert; however, for a T_2 of 50°C and 60°C, the cooling rate showed only a 50% increase compared to the BeCu insert.

3.4. Thermal Resistances of the Vapor Chamber and the BeCu Insert

After measuring the heat inputs and outputs, thermal resistances were calculated and investigated. Figure 7 shows the thermal resistance values for the vapor chamber and the BeCu insert. The thermal resistance of the vapor chamber was lower than the BeCu insert, a solid material. The performance comparison of the vapor chamber with the BeCu insert, which can be seen using the thermal resistance from both of material.
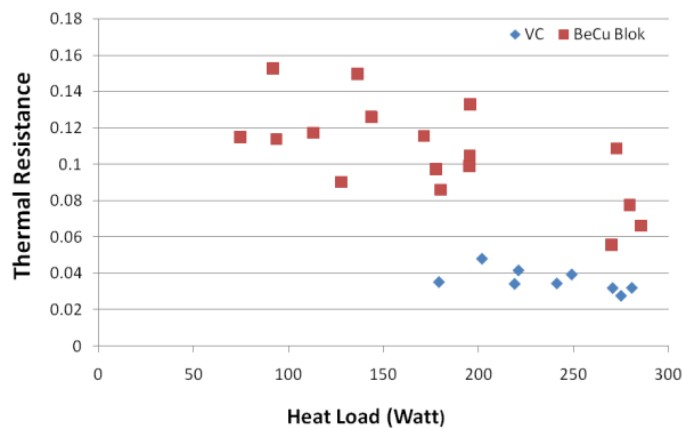

Figure 7 Thermal resistances of the vapor chamber and the BeCu insert

Different heat loads were applied to determine the relationship between the vapor chamber and the BeCu insert in terms of heat load performance. As shown in Figure 7, the thermal resistance of the vapor chamber has a minimum value of 0.028 K/W at 275 W and a maximum value of 0.048 K/W at 200 W. The BeCu insert has a maximum thermal resistance of 0.153 K/W, which is higher than the maximum thermal resistance of the vapor chamber. These results show that the vapor chamber has better thermal performance compared to the BeCu insert.

4. CONCLUSION

This study compared the cooling performances of the vapor chamber and the BeCu insert during the plastic injection molding process. It can be concluded that the vapor chamber performs better than the BeCu insert, as the vapor chamber has a lower thermal resistance. The heat transfer process of the vapor chamber is up to 60% faster compared to the BeCu insert. Within the first 3−5 seconds after heat was released from the vapor chamber, the temperature did not rapidly decrease, which is beneficial to the injection molding process as this reduces the frozen layer in the channel cavity.

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