

THE EFFECT OF VAPOR CHAMBER IN AN INJECTION MOLDING PROCESS ON PART TENSILE STRENGTH

There are many reasons for welding lines in plastic injection molded parts. During the filling step of the injection molding process, the plastic melt drives the air out of the mold cavity through the vent. If the air is not completely exhausted before the plastic melt fronts meet, then a V-notch will form between the plastic and the mold wall. These common defects are often found on the exterior surfaces of welding lines. Not only are they appearance defects, but they also decrease the mechanical strength of the parts. The locations of the welding lines are usually determined by the part shapes and the gate locations.¹⁻⁵

Weld lines can be eliminated using three methods. First, the melt temperature may be increased. The viscosity of the molten plastic decreases with increasing temperature, which improves the flow pattern of the plastic, and reduces the depth of the V-notch of the welding lines. However, degradation of the material strength sometimes occurs if the melt temperature is too high. The second method involves increasing the number of vents. Increasing the number of vents (ejecting pins or inserts) at the vicinity of the weld line will enable air to be dispelled from the mold cavity more easily. Nevertheless, extra vents will leave marks on the product surfaces, especially with transparent plastics. Finally, the mold temperature can be raised. Raising the mold temperature increases the viscosity of the material, which in turn can reduce the depth of the V-notch. However, increased mold temperature also increases the cycle time of the injection molding process, thus increasing production costs.

If increased cycle time is not a problem, then raising the mold temperature is the simplest of the three methods for eliminating weld lines discussed above. There are several methods for raising the mold temperature. Replacing the water in the mold temperature controller with oil can increase the mold temperature roughly 100°C. But the time required for the mold to reach the designated temperature is often too long to be practical. Kim et al.⁶ investigated heating the mold with a gas flame, but the temperature of the heated cavity and core are not easy to control. Yao et al.⁷ coated a heating layer and an insulation layer on the mold surface in order to control the mold temperature. However, the thickness of the coating layer was difficult to control uniformly. In addition, the coated layers affected the product appearance. Electromagnetic induction heating⁸ can raise the mold temperature rapidly. However, the design of the induction coil is limited by the mold shape. Ono Sangyo Co., Ltd., Tokyo, developed a mass production method called rapid heat cycle molding (RHCM)⁹ in which mold heating is achieved using high pressure vapor as a media. When

the filling stage in the injection molding process is finished, high pressure vapor is introduced for cooling. The technology enables a short heating and cooling cycle, but its application is limited by the size of the mold.

A vapor chamber with a two-phase flow heat transfer device consists of sealed container, a wick structure, and a working fluid. Its underlying mathematical model is the same as that of a heat pipe, and, like the RHCM, generates high pressure vapor.^{10,11} Xuan et al.¹² found through experiment that the temperature difference between the center and the edge of a vapor chamber-based thermal module is within 1°C, while this temperature difference for the copper integral heat spreader (IHS) of identical size under identical experimental parameters is more than 6°C. The vapor chamber thus appears to achieve better temperature homogeneity.

In this paper, a heating and cooling system using a vapor chamber was developed. The vapor chamber was installed between the mold cavity and the heating block as shown in Fig. 1. Two electrical heating tubes are provided. A P20 mold steel block and a thermocouple are embedded to measure the temperature of the heat insert device. The mold temperature was raised above the glass transition temperature of the plastic prior to the filling stage. Cooling of the mold was then initiated at the beginning of the packing stage. The entire heating and cooling device was incorporated within the mold. The capacity and size of the heating and cooling system can be changed to accommodate a variety of mold shapes.

EXPERIMENTAL PROCEDURE

The vapor chamber investigated in this study, manufactured by Taiwan MicroLoops Corp., (Taoyuan Hsien, Taiwan) is essentially a flat-plate type heat pipe made of copper. Water is used as the working fluid. Copper mesh composed of 50- μ m wire with a 100/200-mesh pore and a solid copper cylinder 2 mm in diameter supporting vacuum and loading forces are used to circulate the working fluid. The loading force will support an injection pressure of roughly 100 atm. The copper meshes are bonded to the top, bottom, and sides of the internal surface to ensure the circulation of the working fluid.

At the beginning of a cycle, the vapor chamber is in a vacuum. After the wall surface of the cavity absorbs the heat from its source, the working fluid in the interior will be rapidly transformed into a high-pressure vapor which fills the entire interior of the cavity. During the cooling phase, vapor is condensed into liquid by the cooling action, and flows back to the location of the heat source along the capillary structure. The upper and lower copper covers of the vapor chamber are made from C1100 oxygen-free copper, whereas the wick structure inside the chamber is composed of copper wire mesh with a uniform mesh spacer and copper walls of 50- μ m diameter, which are tightly structured using diffusion

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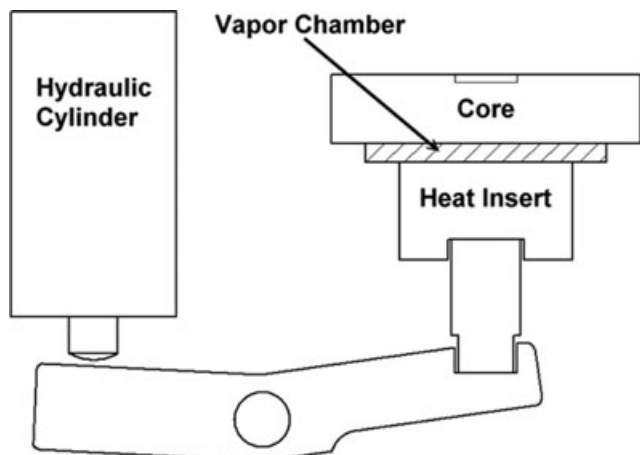


Fig. 1: Mechanics of heating and cooling cycle system with vapor chamber

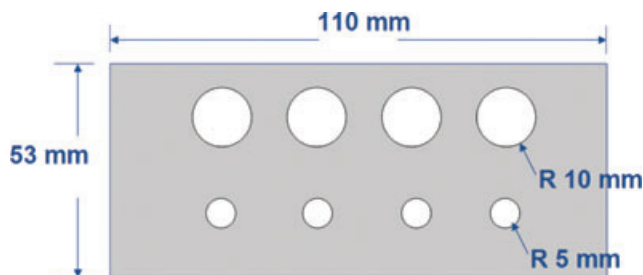


Fig. 4: Specification of the eight holes test part

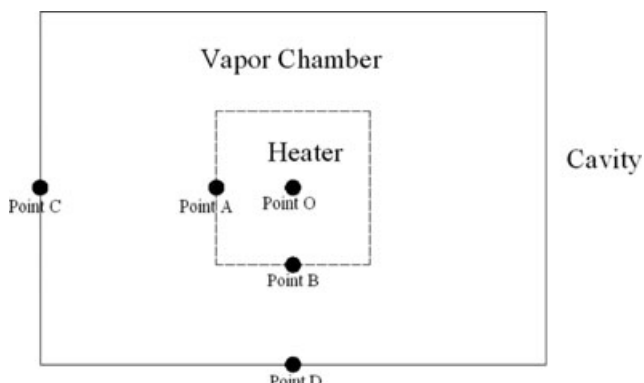


Fig. 2: Measured temperature position on the surface of cavity

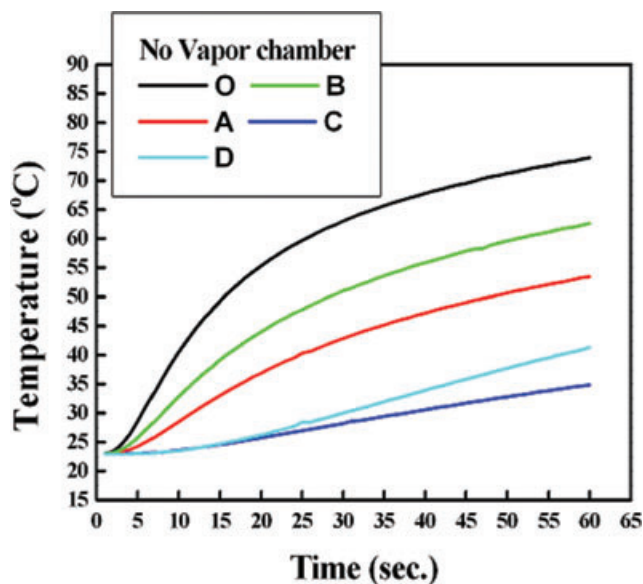


Fig. 5: Relationship of the temperature with the heating time without vapor chamber



Fig. 3: Different design for tensile test specimen

bounding, and have no soldering materials. The working fluid is pure water with a low oxygen content. The plastic used in the experiment is ABS (Chi-Mei PA-758), with a glass transition temperature of 109°C. The material for the moldbase is JIS S50C, whereas the material for the mold core is ASSAB 718.

The heating cycle is activated by a lever mechanism which pushes the vapor chamber into contact with the mold at the beginning of the filling stage (Fig. 1). The heating and cooling system used in the experiment was 50 × 50 × 80 mm. It can be incorporated within the mold at any location regardless of

the mold size. The lever pusher is a hydraulic cylinder. The heat source for the vapor chamber is a low-density cartridge heater which contacts the vapor chamber only when the lever is activated. When the filling is completed, the heat source separates from the vapor chamber, and a vortex tube blows in low temperature air (−20°C) to cool the vapor chamber. In this way, the mechanism provides a rapid heating and cooling cycle for the injection mold. Five thermocouples are placed on the surface of cavity to measure the temperature of the vapor chamber as shown in Fig. 2. Point O measures the central temperature of the cavity at the interface of cavity and vapor chamber. Points A and B measure the temperature opposite the position of the heat insert device on the surface of the cavity. Points C and D measure the temperature opposite the position of the vapor chamber on the surface of the cavity. For the experiment without the vapor chamber, they measure the surface temperature of the cavity.

Two different mold designs, a mold with one gate, and a mold with two opposite gates, were selected for the experiments as shown in Fig. 3. The injection molding experiments

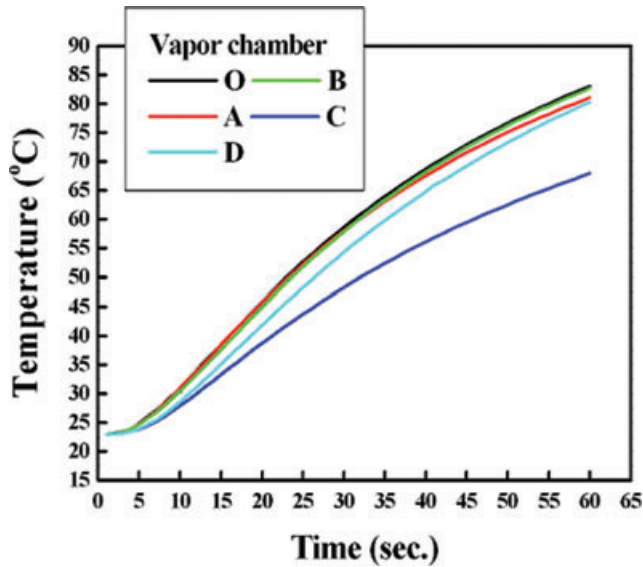


Fig. 6: Relationship of the temperature with the heating time with vapor chamber

tested the tensile strength of the parts. They evaluate the effectiveness of the proposed heating and cooling system with and without the vapor chamber. The dimensions of

Table I—Tensile test results

CONDITION	MAX. STRESS (KGF/CM ²)	STRENGTH (%)
Two gates, cavity temp = 75°C, no vapor chamber	165	88.9
Two gates, cavity temp = 75°C, with vapor chamber	178	95.7
Two gates, cavity temp = 110°C, with vapor chamber	184	98.9
One gate, cavity temp = 75°C, no vapor chamber	186	100.0

the parts are 215.9 × 12.7 × 25.4 mm, with a thickness of 3.175 mm. Figure 4 shows the multiholed products tested to evaluate the effectiveness of the system with vapor chamber under different cavity situations and core temperatures. The multiholed products have eight holes in total, four 10 mm in diameter and four 5 mm in diameter, respectively. The dimensions of the multiholed products are 110 × 53 × 3.175 mm. Three temperature combinations were tested in the experiments. Case 1 sets both cavity temperature and core temperature to 60°C. In Case 2, cavity temperature is 60°C while core temperature is 130°C. In Case 3, cavity temperature is 80°C while core temperature is 130°C.

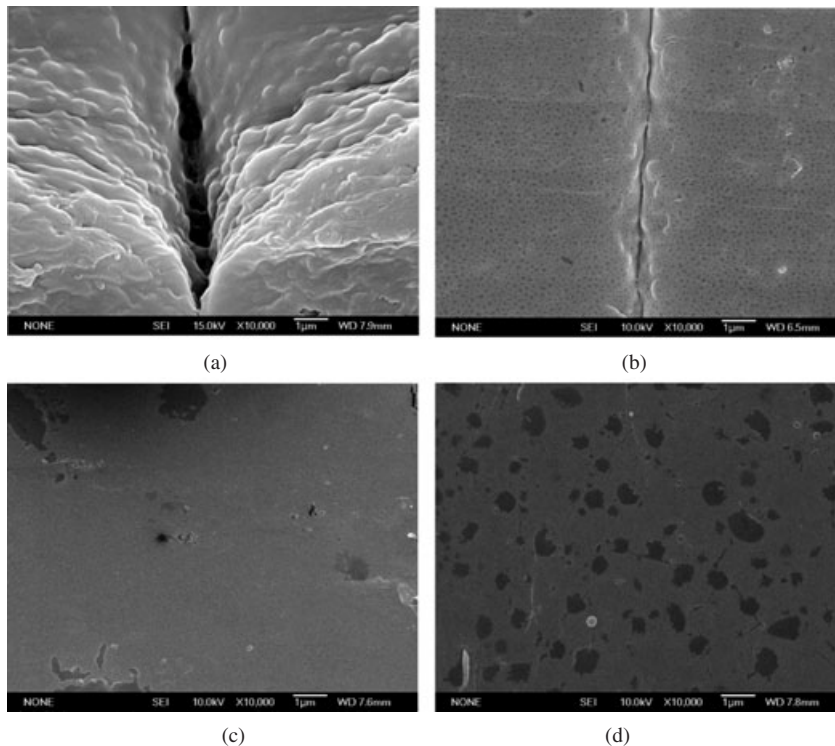


Fig. 7: SEM pictures of one gate and two opposite gates (a) Two opposite gates at the temperature of Point O is 75°C without vapor chamber system, (b) Two opposite gates at the temperature of Point O is 75°C with vapor chamber system, (c) Two opposite gates at the temperature of Point O is 110°C with vapor chamber system, and (d) One gate at the temperature of Point O is 75°C without vapor chamber system

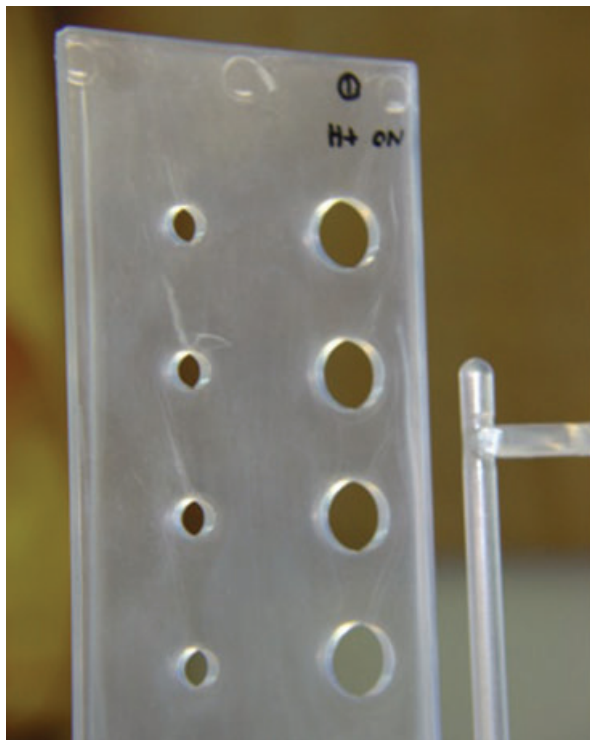


Fig. 8: The picture of the eight-hole plate without vapor chamber heating system

RESULTS AND DISCUSSIONS

These temperature curves for 0–60 s with and without the vapor chamber are shown in Figs. 5 and 6. In Fig. 5, the temperature at point O is 73.9°C, while the farthest corner away from point O is point C at 34.7°C at 60 s. Furthermore, the temperature differences of points A, B, and D are high values, about 10°C greater, at 60 s. In Fig. 6, the temperatures of point O and point C are 83.7°C and 67.8°C at 60 s, respectively. In addition, the temperatures of points A, B, and D are nearly 80°C at 60 s. The temperature curve of point O in Fig. 5 is rising more rapidly than that of Fig. 6 at 0–30 s due to the heater being in direct contact with cavity. The temperature rise slows after 30 s. In other words, the temperature at point O of Fig. 5 is higher than that of Fig. 6 prior to the 30-second mark. The mean temperature of these five points with and without the vapor chamber is 78.3°C and 56.1°C, respectively. The rapid uniform temperature increase employing a vapor chamber heating system is better even if the heater is in direct contact with point O on the surface of the cavity when no vapor chamber is used.

Table 1 shows the tensile strength of the products for one gate and two opposite gates, with and without the vapor chamber. The tensile strength reaches its maximum for one gate without vapor chamber heating system because of the weld line(Fig. 7). Figure 7 shows the SEM images of the weld line. One gate/no vapor chamber experiments resulted in test parts without any weld lines. The two gate/no vapor chamber system shows an obvious weld line, and the tensile strength of the resultant testing part is 11.1% lower

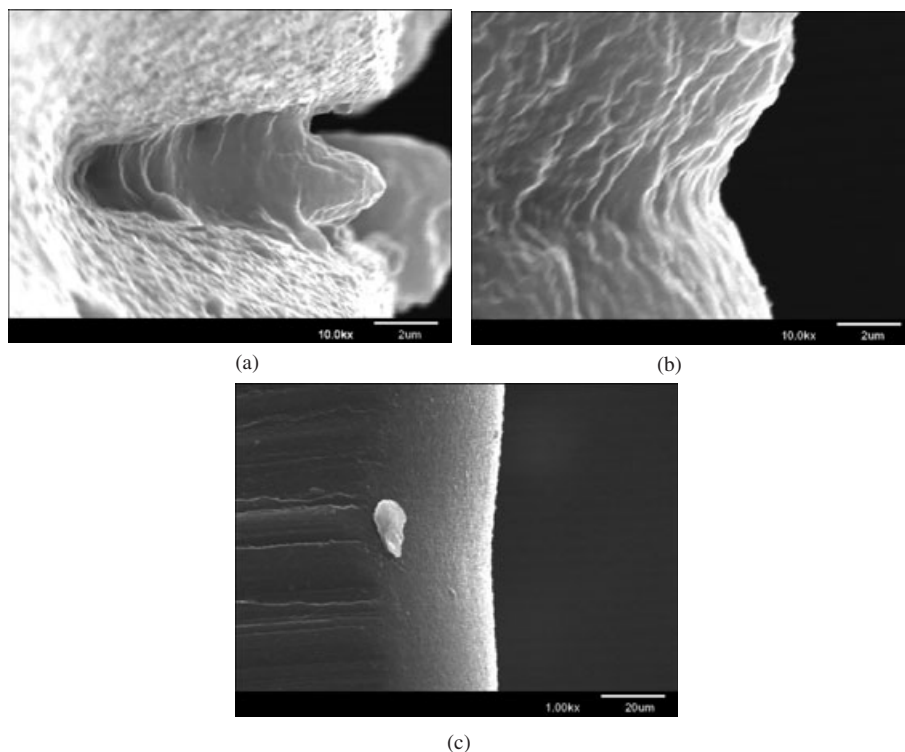


Fig. 9: SEM picture of the eight-hole plate (a) Case 1, (b) Case 2, and (c) Case 3

than that of the part from the one gate/no vapor chamber system (Table 1 and Fig. 7). The two gate/vapor chamber system yielded a light weld line and a tensile strength of the tested part 6.8% higher than that of the part molded in the two gate/no vapor chamber system. When increasing the preheating temperature from 75 to 110°C in the two gate/vapor chamber system, the tensile strength increases 3.2%. It appears that using a vapor chamber heating system and increasing the preheating temperature can increase the tensile strength of parts molded using two opposite gates, due to the extended fluid flow.

Figure 8 shows a picture of the injected products using conventional methods. There are many weld lines on the surface of the transparent parts. The depth of the V-notch is deeper and the weld lines are more obvious. Figure 9 gives the depths of the V-notch found in each case: 12, 2, and 0.5 μm , respectively. The part made in Case 1 shows a V-notch 24 times deeper than the part made in Case 3. The effects of cavity and core temperatures are also important in weld line outcomes. The depth of the V-notch is decided by the polymer temperature. Higher temperature can decrease the viscosity of the polymer and the polymer can flow more easily. A vapor chamber with heating device can control the polymer melt front temperature, decrease the polymer viscosity, and decrease the depth of the V-notch.

CONCLUSIONS

In this study, a vapor chamber-based rapid heating and cooling system for injection molding to reduce the welding lines of the transparent plastic products is proposed. Tensile test parts and multiholed plates were test-molded with this heating and cooling system. The results indicate that the new heating and cooling system can reduce the depth of the V-notch as much as 24 times.

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