EFFECT OF 2D AND 3D COIL ON THE DYNAMIC MOLD TEMPERATURE CONTROL BY INDUCTION HEATING

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ABSTRACT

Electromagnetic induction heating has many advantages such as fast heating, low energy consumption and reduced environmental pollution. Using induction heating for rapid tool heating is more economical and efficient than any of the current tool heating techniques. In this research, using both experiment and simulation, the 2D and 3D design of induction coil were applied to verify the heating capacity of mold plate. With the 2D coil, after 2 s for heating, the temperature of mold plate can increase from 40 °C to 108 °C. However, the low temperature area appears at the center of the mold plate. On the contrary, when the 3D design was used, the max temperature reached to 89 °C at the end of heating period, and the low temperature area was removed.

Keywords: injection molding, dynamic mold temperature control, induction heating, coil design.

1. INTRODUCTION

Injection molding technology has been widely used in almost all fields of plastic product manufacture. The mold surface temperature has great influence for plastic injection molding. With high mold surface temperature, the surface quality of part will be better, but the cooling time will increase and accordingly the cycle time will rise as well. Maintaining high mold temperature during the filling process and lowering the mold temperature to below deflection temperature during the post-filling process without greatly increasing cycle time and energy consumption are not easy. In recently researches, before the filling of the melt into the cavity, the mold surface has a heating step for raising the temperature up to the glass transition temperature of the plastic. This process was called "Rapid Heat Cycle Molding – RHCM". In injection molding field, the RHCM has some requirements as fast heating rate, low energy consumption, and the cooling step of the injection molding can operate easily…

For the heating process in RHCM, there are two main types of heating systems in use, surface heating and volume heating. With the surface heating method, several techniques have been researched. An insulation layer is coated onto the mold surface then a heating layer is applied to the insulation layer as the cavity surface. The heating layer can be quickly heated with a pair of electrodes and the insulation layer is used to enhance heating efficiency and decrease consumption [1, 2]. On the other hand, for raising the mold surface temperature in the filling process, a coating on the cavity surface with TiN and Teflon has reduced the heat transfer from the melt to the mold material, which increased the temperature on the cavity surface to 25 °C [3, 4]. In another research project, on the heating surface, an electromagnetic induction coil with different configuration was used to heat the cavity surface to reduce the weld line, shrinkage and other defects of the part surface [5, 6]. Furthermore, an infrared heating system was also applied for heating the mold surface. This system can heat the surface of one or two mold halves using a suitable design [7, 8]. For the newest application of surface heating, the hot air flowed into the cavity and heat convection from the hot air can directly heat the surface of the cavity [9]. The advantage of surface heating is the high rate in heating, so, the cycle time can be reduced. However, the user must have a special mold design when the mold is complex, and more equipment is needed to calculate the parameters for a high quality product. For volume heating, the most inexpensive way to achieve high mold temperature is to use hot water at a temperature as high as 90 °C or 100 °C for both heating and cooling. If the mold temperature needs to be higher than 100 °C, either a high pressure water supply system or a hot oil may be used [10]. The former may damage the channel connection and safety may be an issue after long-term use. Also, the latter may not be energy-efficient due to the low heat transfer coefficient of the oil. Local mold heating using an electric heating element is sometimes used to assist in high mold temperature control, especially for a thin-wall product. However, this still requires extra design and tool costs [11].

In our recent investigation series [5, 6, 12], with the requirement of high heating rate and low energy consumption, we had suggested the application of induction heating combined with low coolant temperature for dynamic mold temperature control. Figure 1 shows the principle of induction heating for injection mold plate. In this method, after the part was rejected, the inductor will be moved to the gap of the core plate and the cavity plate. This coil will stand by that location for heating the mold to the target temperature. After that, the coil will be removed and the mold will close for the filling step of the melt. By experiment, the time of 3 s to 4 s were needed for the mold surface temperature to increase from 110 °C to 180 °C and 200 °C. The shorter heating time required for induction heating is due to the fact that the heat generated from induction is basically appeared on the mold surface, about 0.1 mm in depth, due to the skin penetration of the electromagnetic wave. In that case, the induction heating speed was about 30 °C/s.

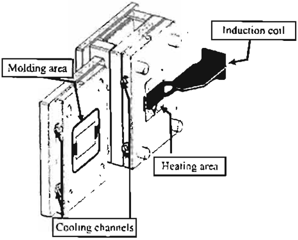

Figure 1. Induction heating for injection mold plate.

The heating rate of induction heating method is total satisfy the requirement of the injection mold field. However, the application of induction heating is still quite complicated. There are many aspects that had a big influence on the induction heating process. The most important element in the induction heating system is the induction coil, because it impacts strongly on the heating effect as well as the temperature distribution of mold surface. For improving the induction heating period in injection molding cycle, this research will focus on the geometry design of the induction coil. This study will make comparison of heating effect with two types: the 2D coil and the 3D coil. In addition, the simulation and the experiment will be compared for verifying the accuracy of simulation results.

2. SIMULATION AND EXPERIMENTAL WORKS

The mold temperature control process using external coil induction heating consists of an induction heating machine (IHTC-02) from INER Technology Co., LTD., a water mold temperature control system, a control and monitoring unit for operating the heating / cooling process and observing the mold temperature change, a mold plate ($32 \times 100 \times 100$ mm^3), and an externally coil system. The induction heating machine supports a high-frequency current flows through the conductor and the mold plate with a full power of 80 kW. This machine can support a maximum current of 1500 A, and the frequency of 75 kHz. Figure 2a shows the mold design with the cooling channel insert system. This system controls the plate temperature, which includes pre-heating the plates to the initial temperature at the beginning of the experiment, and cooling them after the heating period by receiving the water from the mold temperature control. During each case of the experiment, the mold surface temperature will be measured and collected at points T1, T2 and T3. The location of these measuring points is shown in Figure 2b. In this study, there are two types of coil were designed: 2D and 3D coil. The coil design is based on the mold plate size. The coil dimension and the heating position of coil are shown in Figure 3. The inductor coil has the diameter of 8 mm. With both designs, the distance from the coil to the mold surface will be set at 3 mm. To cool the coil, a hollow channel is fashioned inside each coil. The coils are made of copper.

To observe temperature at the plate surface, an infrared thermal imaging system (Avio NEO THERMO TVS-700) and thermal couples were used to measure the mold temperature. The experimental results were collected to verify the simulated predictions. In this study, the mold plate will be pre-heated to 40 °C by the 40 °C water flows through the cooling channel. The induction heating machine will then be turned on to heat the mold surface. The heating rate and temperature distribution of the mold surface will be observed by the infrared camera and the sensors. All material properties are shown in Table 1.

In all cases, the mold plate made of stainless steel 420 was used to study the effect of coil design on the heating rate and the temperature distribution. Because the induction heating has a high heating rate, therefore, in every case, by experiment and simulation, the temperatures at points T1, T2 and T3 will be collected after 2 s of heating. These results will be compared to study the differences in heating rate and temperature distribution when the coil design was changed.

In this study, with the same heating parameters and material properties of experiment, the ANSYS software will be used for running the simulation of the induction heating process. After that, the simulation results will be compared by the experiment result to estimate the accuracy. The mesh model of the 2D coil and the mold plate were shown in Figure 4.

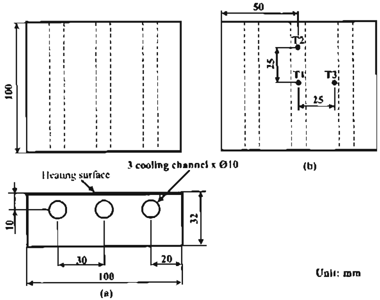

Figure 2. Mold design (a) and temperature measurement point (b).

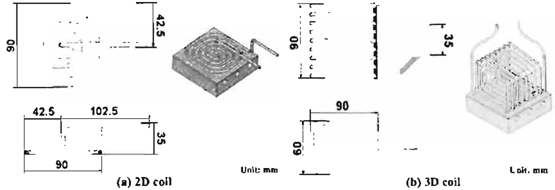

Figure 3. The coil designs.

Table 1. Material properties.

Physical property	Density	Electrical Resistivity	Relative Permeability (μ)	Specific heat	Thermal Conductivity
Unit	Kg/m^3	Ωm	-	J/kg K	W/m K
Air at 25 °C	1.18	-	1	1000	0,0256
Stainless steel 420 (ISO 683/134)	7700	5.50E-07	200	448	14
Copper (Cu)	8940	1.71E-07	0.99	392	400

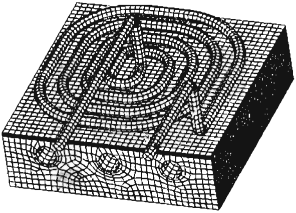

Figure 4. The simulation mesh model of 2D coil.

3. RESULTS AND DISCUSSION

Comparisons of heating temperature using a 2D and 3D coil with the initial mold temperature of 40 °C are illustrated in Figures 5 and 6. By experiment and simulation, Figure 5 shows the temperature of point T1, T2 and T3 with a heating time of 2 s using 2D coil. Base on this result, by experiment, after 2 s for heating, the temperature of point T1, T2 and T3 is 64 °C, 108 °C, 105 °C, respectively. This shows that temperatures at point T2 and T3 are almost the same. However, the heating effect at the center plate (point T1) is significant lower. The different temperature between 3 points is about 41 °C. This is a trouble for the heating process in injection molding field because it will increase the warpage of the molding product due to the unbalance shrink in the cooling process. Figure 6 shows a comparison of temperature at point T1, T2 and T3 with the 3D coil in the simulation and experiment. The same boundary conditions with the 2D coil, in this case, the temperature of point T1, T2 and T3 are 89 °C, 78.5 °C, 66.1 °C, respectively. Although the max temperature in this case is lower than the case of 2D coil, but the temperature difference between three points was decreased to 23°C. This improvement is a great meaning in the injection molding field because it can reduce the part warpage clearly [12 – 14], moreover, with the heating rate of the 3D coil (about 13.0 °C/s to 24.5 °C/s), it can easily satisfy the target temperature of heating process in the injection molding field within a short time.

For estimating the heating uniformity, the temperature distribution was observed by the infrared thermal camera in experiment. This result was compared with the simulation result in Figure 7. According to this figure, the lower temperature is located clearly at the center area of the heating surface when the 2D coil was used. This temperature distribution is very difficult to apply for the heating process in injection molding field, especially with the flat product. On the contrary, with the 3D coil, the heating effect appears as a rectangular area with the higher temperature locates at the center. This temperature distribution is a great improvement, and it could be easily applied for the heating step in the injection molding field. Figures 5, 6 and 7 also show that the simulation can predict the temperature distribution with different coil design. The improvement of temperature distribution with the 3D coil could be explained by the change of magnetic fluid. These cases were studied by simulation and the results were compared in Figure 8. At the center area of 2D coil design, the magnetic fluid is perpendicular with the molding surface, so, the heating effect is very weak. In the other hand, the magnetic fluid is parallel with the heating area when the 3D coil was used, so, the heating effect appears on all this face. The magnetic distribution is fit with the temperature distribution in Figure 7.

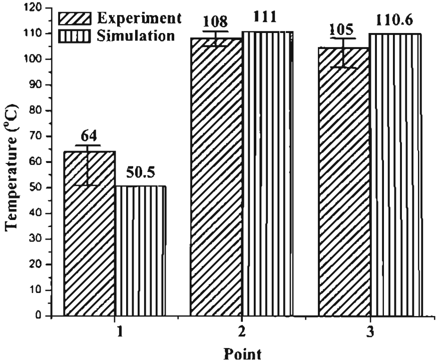

Figure 5. Comparison of temperature at T1, T2 and T3 on the surface of plate with the 2D coil design.

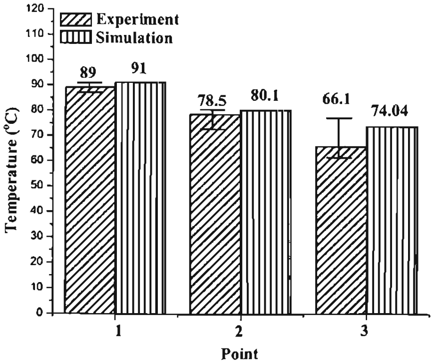

Figure 6 Comparison of temperature at T1, T2 and T3 on the surface of plate with the 3D coil design.

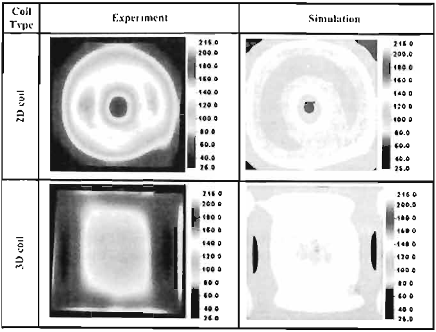

Figure 7. Temperature distribution with the 2D coil (a) and 3D coil (b).

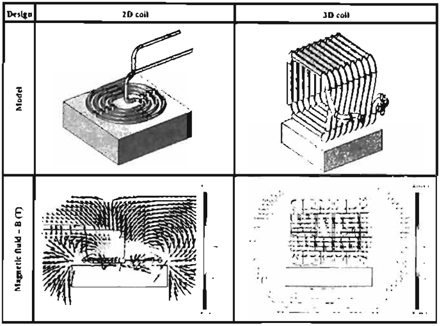

Figure 8. The magnetic fluid comparison by simulation.

4. CONCLUSIONS

In this study, a mold temperature control system using induction heating with two designs of coil was established. The advantage of 3D coil was evaluated. Using both experiment and simulation, temperature at the heating surface was investigated. Based on the results, the following conclusions were obtained.

The heating rate of point T2 and T3 will be higher when the 2D coil was used. However, the temperature at point T1 is lower than T2 and T3. With this coil type, by simulation and experiment, the lower temperature area appears clearly at the center of the mold plate.

In general, the heating rate of point T2 and T3 is slower when the 3D coil was used. On the contrary, the heating effect at the center point was significant improved with the 3D coil. In addition, the temperature difference between 3 points was reduced from 41 °C to 23 °C when the 3D coil was used.

In both type of coil designs, the ANSYS simulation can predict quite accuracy the heating process with the temperature value of three points and the temperature distribution at the mold surface

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TÓM TẮT

ẢNH HƯỞNG CỦA CUỘN DÂY 2D VÀ 3D ĐẾN QUÁ TRÌNH ĐIỀU KHIỂN NHIỆT ĐỘ CHO KHUÔN THEO PHƯƠNG PHÁP CẢM ỨNG TỪ

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Phương pháp gia nhiệt bằng cảm ứng từ (Electromagnetic induction heating) có nhiều ưu điểm như: tốc độ gia nhiệt nhanh, tiết kiệm năng lượng và hầu như không gây ô nhiễm môi trường. Hiện nay, đây là một trong những phương pháp hiệu quả và tiết kiệm nhất trong quá trình gia nhiệt bằng điện năng. Trong nghiên cứu này, bằng phương pháp thực nghiệm và mô phỏng, thiết kế 2D và 3D của cuộn dây gia nhiệt (Induction coil) được sử dụng nhằm đánh giá khả năng gia nhiệt cho bề mặt của khuôn. Với cuộn dây 2D, thời gian gia nhiệt 2 s, nhiệt độ bề mặt khuôn đã tăng từ 40 °C đến 108 °C. Tuy nhiên, vùng nhiệt độ thấp vẫn tồn tại tại trung tâm của bề mặt khuôn. Ngược lại, với thiết kế 3D, nhiệt độ cao nhất tại cuối quá trình gia nhiệt là 89 °C, và vùng nhiệt độ thấp đã được khắc phục.

Từ khóa: khuôn phun ép, điều khiển nhiệt độ khuôn, gia nhiệt bằng từ trường, thiết kế cuộn dây gia nhiệt.