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Evaluation of Heating Performance and Its Impact on Surface Transcription by Rapid Heating Mold using Thin Electric Heater

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Abstract. By installing a thin heating layer to the surface of injection molds, it can be expected that the reduction of required energy for the mold temperature control and the minimization of elongation of the process cycle time. The experimental mold used in this study consisted of a top heating layer of Nickel-Phosphor (NiP) and thermal insulation layer of Zirconium ceramics, and they were firmly fixed on the mold base. In the experiment, the heating performance of the NiP layer was investigated first by using an infrared thermography, then the transcription level against the microscale structure on the mold surface was evaluated by measuring the surface geometry of the molded plates made of polycarbonate.

Keywords: Injection molding, Rapid heating mold, Temperature distribution, Surface transcription
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INTRODUCTION

The electric heaters or pressurized steam are often used to actively control the temperature of the injection molds. In these techniques, large amount of thermal energy is consumed to rapidly heat and cool the mold which has large thermal capacity. It is also noted that large amount of thermal energy exchange tends to extend the process cycle time. There is one approach to solve these difficulties; that is the rapid mold heating system using thin electric heaters (1).

The structure of this rapid mold heating system consists of two laminated layers firmly fixed on the mold block. The first layer is Zirconium ceramics of several millimeters thickness installed on the mold base, and the second layer is a thin Nickel-phosphor (NiP) layer about ten microns which is coated on the ceramics layer by electroless plating. Electrodes for electric power supply are fixed on the both ends of the NiP layer, then the top surface of the mold (NiP layer) can be heated by Joule heating. The mold surface temperature will be efficiently heated because the thermal energy dissipation is effectively reduced by the thermal insulation effect of Zirconium layer.

In this study, the performance of injection molds with thin heating element was quantitatively evaluated. The temperature distribution of the NiP layer surface was investigated using an infrared thermography, and the reason for the inhomogeneous temperature distribution was discussed through the numerical simulation. In addition, the transcription variation of the injection molded polycarbonate plate was examined by introducing microscale structure on the NiP layer surface.

EXPERIMENTAL MOLDS AND CONDITIONS

Detailed Structure of the Molds

Figures 1 shows the schematics of the molds used in this study. The numbers indicated in the figures mean;

1. Base mold made of steel
2. Thermal/electric insulator made of polyphenylene sulfide inserted between the base mold and electrodes

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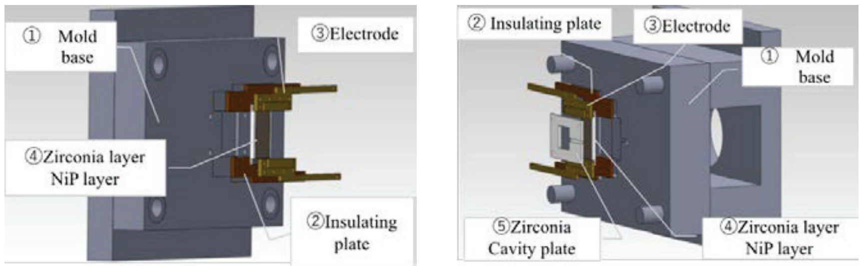
3. Brass electrodes providing the electricity to the thin heating layer of NiP
4. Thin heating element consisting of NiP top layer and Zirconium oxide base layer
5. Zirconium oxide plate for the cavity spacer attached to the fixed mold half

The thickness of thin NiP layer prepared in this study had two variations; 3 μm and 15 μm. The first one is for the checking of the heating performance of the mold surface temperature and the second one is for the surface transcription study of the molded sample.



(a) Movable half (b) Fixed half

FIGURE 1 Schematic structure of the test molds used in this study

Experimental Conditions for the Injection Molding

The experiments were done using an injection molding machine (ROBOSHOT α-15iA, FANUC Corp.). The test material was polycarbonate and the tested pellets were dried at 120°C for 6 hours prior to the molding. Evaluation of microscale transcription was carried out by shape evaluation of a fine groove structure on the NiP layer surface. In this case, the thickness of the NiP layer was set at 15 μm and the design depth of the groove was 3 μm. The microstructures were formed by making a crossing of five grooves (Figure 2). The molding conditions used in this study are summarized in TABLE 1.

TABLE 1 Molding conditions used in this study

Melt temperature [°C]	270
Injection pressure [MPa]	15
Injection rate [mm/s]	12, 20, 30, 40, 50, 60
Mold temperature [°C]	50°C, heating for 60 seconds at 20 A 80°C, heating for 60 seconds at 30 A 120°C, heating for 90 seconds at 30 A 150°C, heating for 60 seconds at 40 A 180°C, heating for 45 seconds at 40 A

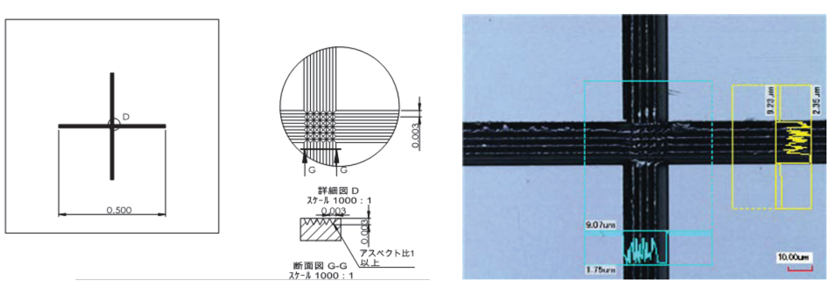


FIGURE 2 Design of microstructure on the NiP layer surface and its appearance observed by optical microscope

RESULTS AND DISCUSSION

Investigation of the Heating and Cooling Performance

Time change of the surface temperature distribution was measured by infrared thermography. Figure 3 shows a snapshot of the surface temperature distribution of the NiP layer with 3 μm in thickness. A relatively high temperature region was observed around the electrodes (left and right ends) and center of the NiP layer. Further, Figure 4 shows the temperature change of the central position of the NiP layer; heating stage (left) and cooling stage (right). The target temperature of this study was 150°C, which was slightly higher than the glass transition temperature of polycarbonate. As shown in the time dependent graph of the surface temperature, the temperature of 150°C could be achieved by heating for 10 seconds at 10 A and 20 seconds at 9 A. It was also shown that the mold temperature rapidly decreased by stopping the electric power supply, and the expected demolding temperature of 50°C was achieved less than 25 seconds even without an active cooling device.

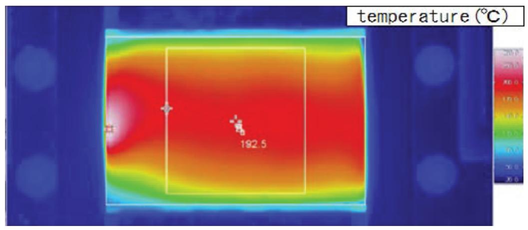


FIGURE 3 Surface temperature distribution detected by infrared thermal camera (60 s after the start of heating)

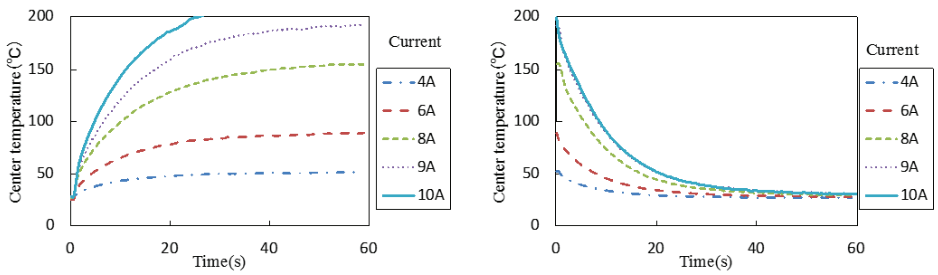


FIGURE 4 Temperature change of the NiP layer (3 µm) during the heating (left) and after the heating (right)

The surface temperature of the NiP layer of the mold for surface transcription was also measured by thin thermocouples (Figure 5). Because the thickness of NiP layer was 15 µm in this case, the required amount of electric current was larger than that of the mold with the NiP layer of 3 µm (Figure 4). By supplying an appropriate electric current, however, it was able to heat up to the target temperature in a short time; the target temperature of 150°C was achieved in about 30 seconds by the condition of 3.0 V and 40 A. Moreover, the right graph in Figure 5 tells that the mold could be cooled to 50°C within 30 seconds by natural cooling.

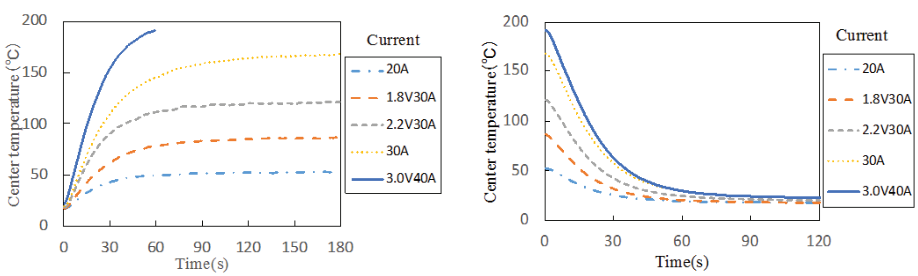


FIGURE 5 Temperature change of the NiP layer (15 µm) during the heating (left) and after the heating (right)

Mold Temperature Analysis by Numerical Simulation

The surface temperature of the NiP layer (3 µm) was numerically estimated using ANSYS®. The physical properties of materials for simulation were assumed to be equivalent to those of the previous work (2, 3), but the volumetric resistance of NiP (ρ [Ωm]) was independently measured by the four-terminal sensing. The result considering the temperature dependence in the unit of Kelvin is given below. The obtained value reasonably matched with the reference value (4).

$$\rho = 9.99 \times 10^{-7} \times \left\{1 + 1.78 \times 10^{-4} \times \left(T - 273\right)\right\} \quad (1)$$

Figure 6 indicates the simulation results of temperature distribution under different conditions. The upper left graph shows the result of not considering the thermal resistance between the mold and thermal insulation (Zirconium) layer, and the upper right graph is the result of considering the thermal resistance. The lower left graph shows the result when the NiP layer contacting with the electrodes were thinned from 3 μm to 2 μm, and the lower right shows the result of adding the thermal resistance effect to the lower left case. Because the estimated temperature distribution at the lower right was the best match with the experimental result (Figure 3), the interfacial conditions assumed in the case was considered to be the closest to the actual situation that causes the uneven heating.

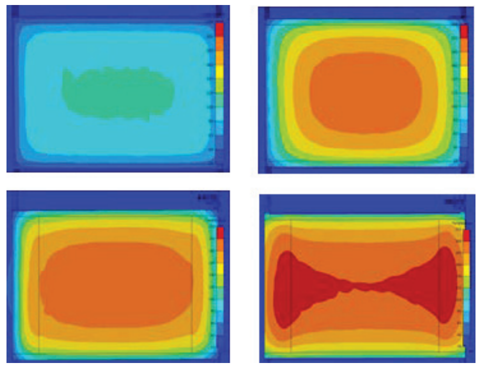


FIGURE 6 Numerically estimated temperature distribution of the NiP layer surface

Evaluation of Energy Efficiency and Effect on the Cooling Time

The performance of conventional mold temperature control system using electric heater and cooling water was estimated using ANSYS® and compared with the method of this study. In the model of conventional system, two electric heaters with a diameter of 10 mm and a length of 120 mm were inserted at 9 mm below the cavity surface, and a cooling channel with a diameter of 10 mm was provided between the heaters. Figure 7 shows the amount of thermal energy required to raise to the target temperature (150°C) after heating for 60 seconds. By using the thin electric heating element, energy consumption was suppressed to about 1/50. Figure 8 shows the temperature change during the cooling, and the present method showed a sufficient cooling rate even with natural cooling.

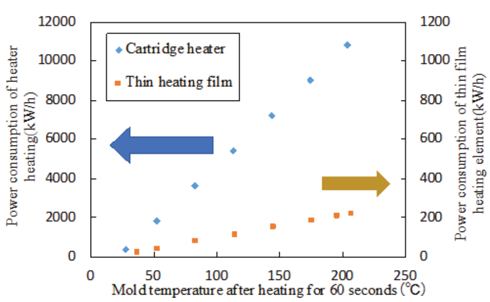


FIGURE 7 Required energy for the mold heating

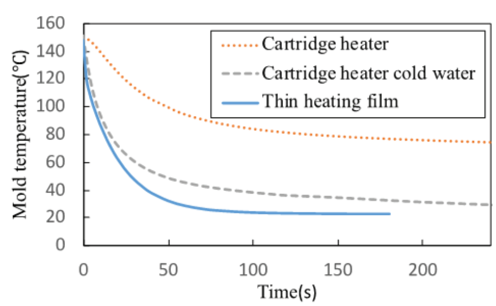


FIGURE 8 Comparison of the temperature change in cooling

Surface Transcription of Molded Sample

As shown in Figure 9, the surface geometry of injection molded plate was investigated by a confocal laser microscope (VK-X100, KEYENCE Corp.). The microscale transcription situation in the vicinity of the crossing section was examined, and it was shown that the improvement of transcription was obtained by increasing the mold temperature. Although the transcription conditions were insufficient below 80°C, the condition was significantly improved at 120°C. Of course, good transcription was obtained at the mold temperature of 150°C and 180°C, but it was observed that the structure of the protruded part deformed towards the melt flow direction especially under the condition of 180°C. This result was considered to be caused by the sticking phenomena between the microstructure on the mold surface and the molded material. In other words, the present method can provide very good transcription that can deform the microstructure of the molded.

Assuming that the transcription volume of the microstructure did not change as long as the surface of the molded products did not deform much, the transcription situation was evaluated by calculating the cross-sectional area of the microstructure on the molded surface. The measurement position was set to be closer to the gate by 10 μm than the crossing. The cross-sectional area to the microstructure given on the NiP layer was about 80 μm^2. Figure 10 shows the variation of cross-sectional areas at each mold temperature and injection speed. As the mold temperature increased, the cross-sectional area of the microstructure increased. The cross-sectional area of the fine structure reached the maximum at the glass transition temperature (150°C) or higher. It was observed that the microstructure of the molded product had a larger cross-sectional area than the original size of structure. This was brought by the plastic deformation due to the tension at the demolding. From this result, it was suggested that appropriate use of the release agent was necessary for the efficient process.

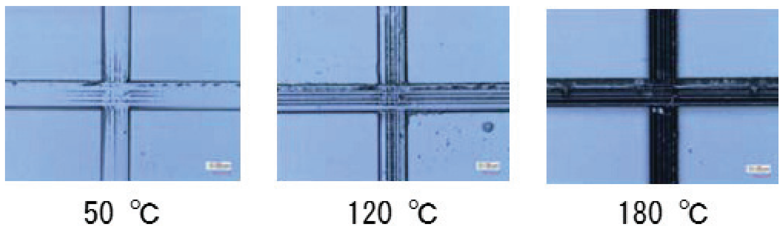


FIGURE 9 Surface transcription situation of the molded surface at different mold temperature (The direction of melt flow was from the top to down in each photo.)

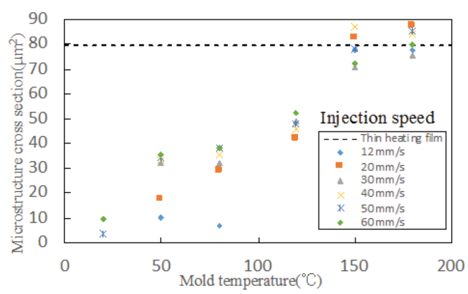


FIGURE 10 Variation of the measured cross-sectional area on the molded surface

CONCLUSIONS

In this study, a temperature measurement of the entire heating layer and evaluation of the transcription of the molded product were conducted for a rapid heating mold system using thin heating element. Rapid heating and cooling of the mold could be successfully achieved by using test molds specially designed. The numerical simulation results for the mold surface temperature pointed out that the thermal resistance management between the heating element and the mold base was important for minimizing the surface temperature inhomogeneity of the heating element. The evaluation of energy efficiency and the impact on cycle time were also examined by the numerical simulation. By using polycarbonate as the molding material, it was confirmed that the surface of the mold was heated to the glass transition temperature of the material within a short time period, and good transcription was obtained. However, plastic deformation of the microstructure on the molded surface was observed when the transcription condition was exceedingly good.

REFERENCES

1. JP4973351, Patent in Japan (2012)
2. H. Nishida, et al., *Preprints of Seikei-kakou Annual Meeting 2015* (in Japanese), 155-156 (2015)
3. H. Nishida, et al., *Preprints of Seikei-kakou Annual Meeting 2016* (in Japanese), pp. 135-136 (2016)
4. T. Osaka, et al., *Japanese Journal of Applied Physics*, **27**, 1885-1889 (1988)