

Effect of Hot Air Heating on The Cavity Temperature Distribution of Injection Mold

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ABSTRACT

In this paper, the air-assisted mold temperature control (AMTC) is applied for heating the mold in the injection molding process. The simulation is run with the same boundary conditions in the experiment. The results show that the AMTC can heat the surface mold plate to 171.6 °C. This temperature value is higher than the glass transition temperature of almost thermoplastic materials that used in the injection molding process. With the product thickness values of 0.1 mm, 0.3 mm and 0.5 mm, the heating rates were 6.3 °C/s, 6.39 °C/s and 6.58 °C/s, respectively. The increase in heating rate can be explained by the need for thermal energy to heat up the stamp volume that is inserted in the mold cavity for changing the product thickness. Also, the highest temperature at the top of the stamp which is nearest to the hot air gate, and the temperature is smaller when the area is far from the hot air gate.

KEYWORDS

Hot air heating;
Injection molding;
Temperature distribution;
Heating rate;
Tamp thickness.

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1. Introduction

Nowadays, the mold temperature control is one of the solutions to improve efficiency in injection molding process. With a high mold surface temperature, the quality of the part will be better although the cooling time and the cycle time will increase. Decreasing the surface temperature of the mold reduces the cooling time, but there is no benefit to the surface quality of the part [1–3]. Therefore, a critical requirement for current studies is to increase the mold surface temperature and to maintain a cycle time that is not too long. The thin wall and micro injection molding are used to manufacture a variety of polymer products because of their low cost and potential for high-volume production. Most applications of thin wall and micro injection molding are in the field of micro optics (as CDs and DVDs) and micro fluidic devices. Production of other molded micro optical components, including optical gratings, optical witches, and waveguides [4–6] as well as a variety of molded micro fluidic devices including pumps, capillary analysis system, and lab-on-a-chip applications [7, 8], is ongoing.

Besides the traditional heating of the water heating method that is the volumetric heating, the surface heating method is being studied for increasing the mold surface temperature such as the induction heating process [9, 10], high-frequency proximity heating, and gas-assisted mold temperature control. The first two methods can support a high heating rate with a quite good prediction ability. By applying the high frequency current on a coil, the magnetic will create an eddy current on the heating surface. This current will create the heating source on the heating surface and increase the temperature of this face. This method can heat the mold to over 170 °C. However, the type of induction heating is just used for the steel mold with a high permeability property. Besides the advancement of rapid heating, the induction heating method may lead the mold plate to overheating troubles, particularly in the edge area. For the real application in mold industry, the controlling of magnetic in this heating method is still a challenge because the mold material and other equipment are steel so the heating can be appeared on the other surface, so, the equipment close to the coil can be broken. In addition, with the gas heating method, the hot gas is sprayed into the heating position, the heat convection between the hot gas and the mold surface will let the thermal energy transfer from the hot gas to the mold surface. Therefore, the surface temperature will be increased. In general, the heating rate is not as high as the induction heating, but it can be used for almost the mold material as steel, aluminum, or copper. Additionally, owing to the properties of heat convection between the hot gas and the mold surface, the gas heating method can save the mold from overheating. In our

previous researches, the gas heating method can increase the mold temperature to improve the flow in the mold [11-14].

In this study, the hot air is applied in injection molding process for mold surface temperature control within the air temperature ranges from 200 °C to 400 °C. The hot air can be used as a heat source to increase the temperature of mold. For the heating process of this method, first, by opening the mold, two mold plates shift from the closing position to the opening position. Second, the hot air drier will be shifted to the heating position. Then, the air will be heated when flowing through the air drier, and the outside of the air drier will provide the hot air, which will contact directly to the cavity surface. This hot air will heat the cavity surface to the target temperature. Third, when the mold reaches the needed temperature, the air supplier will be shut down. Then, the mold will completely close in preparation for the filling process of melt. Therefore, the effect of hot air heating on the cavity temperature distribution will be examined.

2. Simulation Method

For observing the temperature distribution, the air-assisted mold temperature control (AMTC) and the mold plate are designed as shown in Figure 1. The AMTC system has an air drier with a dimension of 240 mm × 100 mm × 80 mm, consisting of two halves of plates jointed together. The thermistors are placed into these two plates for air heating. The air channel is cut inside the air drier with a width of 5 mm and a depth of 10 mm. In former researches [11–14], with the mold surface heating method, the structure of the stamp insert is often used for increasing the heating efficiency. The stamp thickness is one of the most essential parameters of mold design according to the results of these researches. Therefore, in this paper, for estimating the heating ability of AMTC, the stamp with a dimension of 77.4 mm × 70 mm is inserted into the cavity as show in Figure 2. For observing the heating effect of AMTC on the stamp temperature, five temperature sensors are used as S1, S2, S3, S4 and S5 where the temperature values need to be determined. The location of sensor S1 is placed at the top point, which is closed to the outlet of the air drier, for considering the effect of heating time on the mold temperature distribution. In order to consider the effect of the stamp thickness on the heating process, the stamp plates with different thicknesses for producing the thickness products of 0.1 mm, 0.3 mm and 0.5 mm are designed. Also, the gap between the hot air gate and the heating surface is a constant value of 3.5 mm (Figure 3). As in the experiment, the simulation model is developed in order to study the temperature distribution of the heating area. Since the stamp is inserted into the mold, the small air gap existed between the stamp and the mold. In a short time, this air gap will act as an insulation layer. Hence, the simulation model just includes two volumes as the air volume and the stamp volume with boundary conditions are showed in Table I. In this AMTC model, the hot air is sprayed directly on the surface of the mold cavity in a direction perpendicular with the several temperature values of 200 °C, 300 °C, 400 °C and the pressure of 7 atm. The initial temperature and the initial pressure of mold cavity are 40 °C and 1 atm, respectively. To improve simulation accuracy, the heating plate is meshed with the hex dominant mesh due to its simple structure and the air mass is meshed with the tetrahedrons mesh due to the complex structure, as well as increasing the number of elements in the regions where high precision is required.

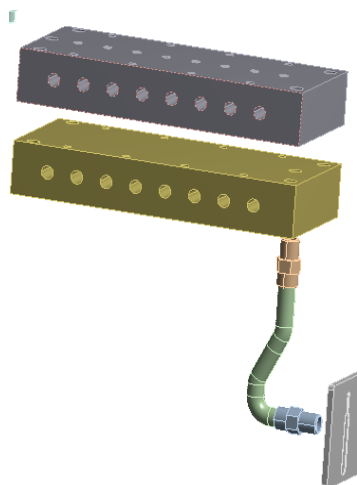


Fig. 1. The model of AMTC system and mold plate

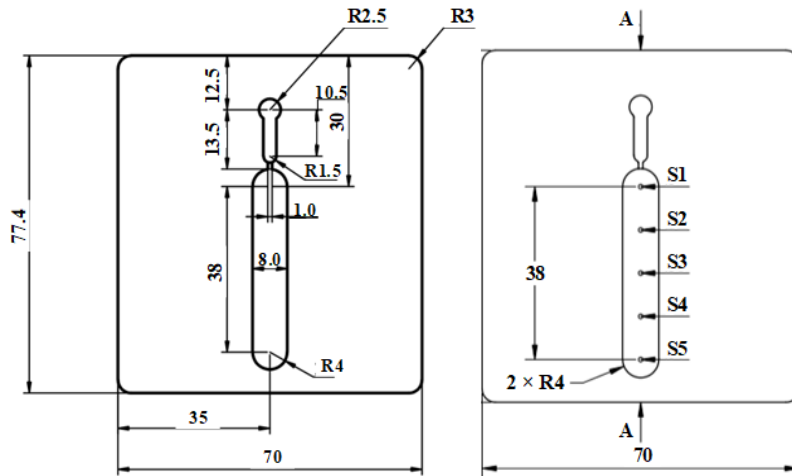
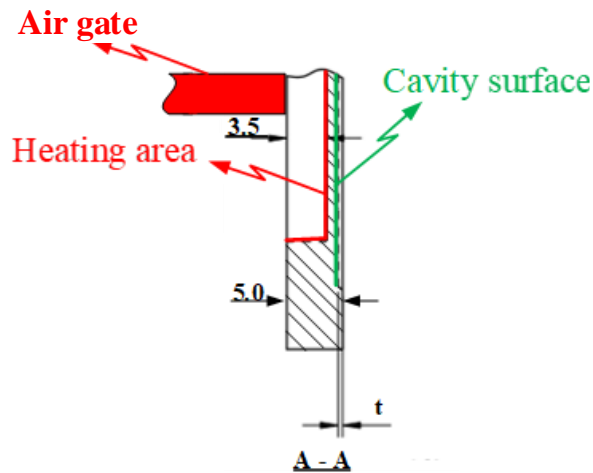


Fig. 2. The geometry and dimension of stamp plate in mold



(*) t : part thickness

Fig. 3. The location of air gate for heating cavity surface

Table 1. Simulation Parameters

Material	Property	Value
Air	Molecular mass	28.96 kg/kmol
	Density	1.185 kg/m ³
	Specific heat capacity	1004.4 J/kg ^o K
	Dynamic viscosity	1.831e-5 kg/ms
	Thermal conductivity	0.0261 W/m ^o K
Steel	Molecular mass	55.85 kg/kmol
	Density	7854 kg/m ³
	Specific heat capacity	434 J/kg ^o K
	Thermal conductivity	60.5 W/m ^o K

3. Results and Discussion

Table 2. *The Temperature Distribution for The Product Thickness of 0.1 mm*

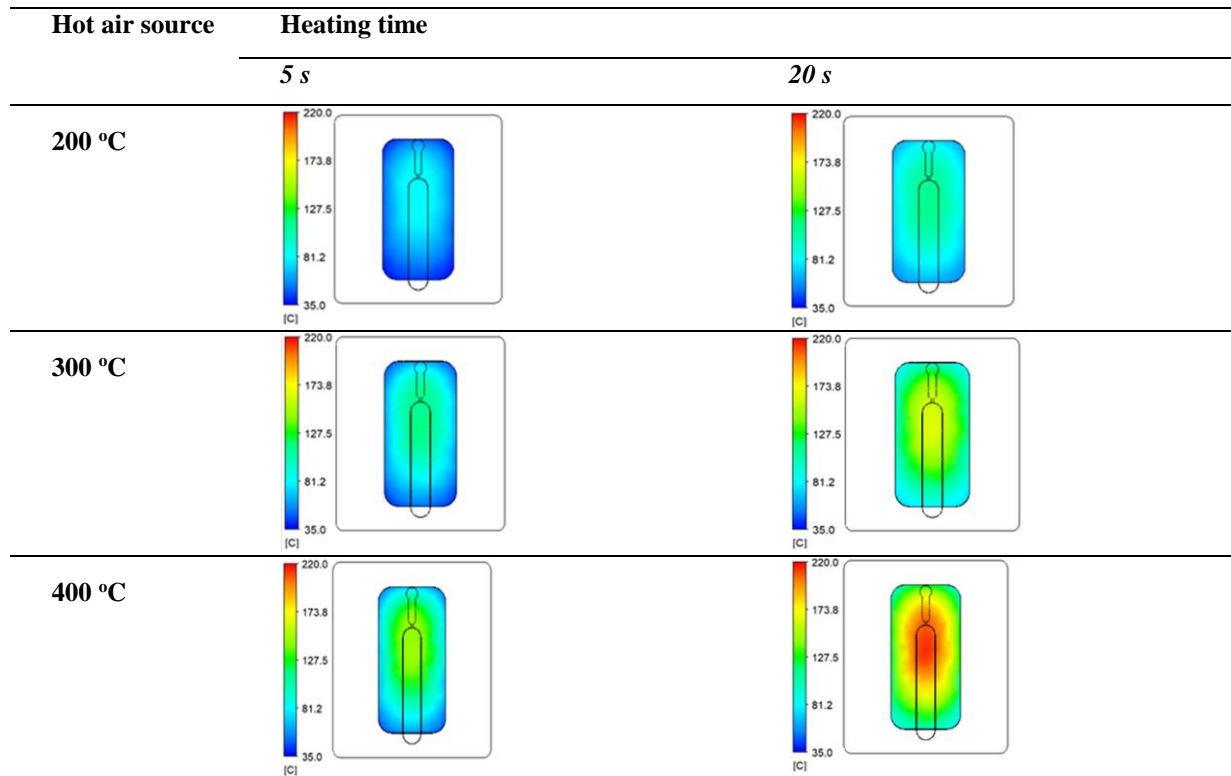


Table 3. *The Temperature Distribution for The Product Thickness of 0.3 mm*

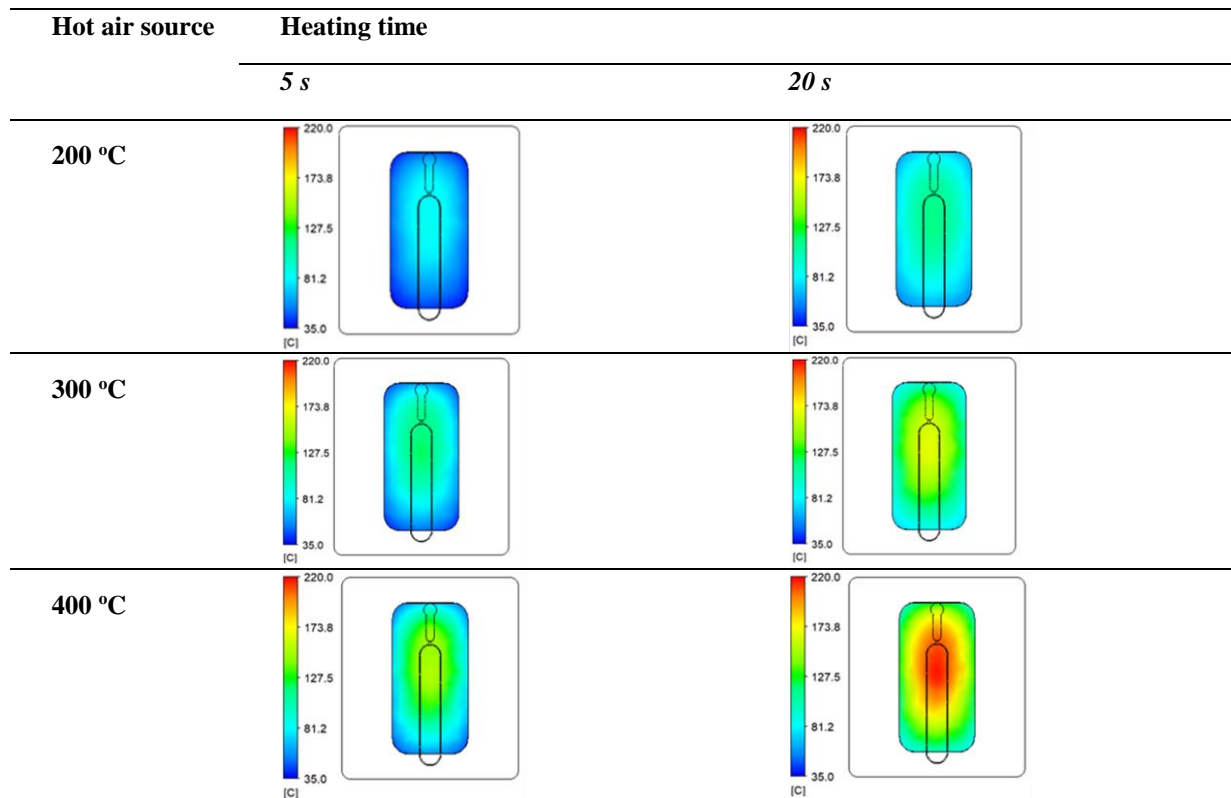
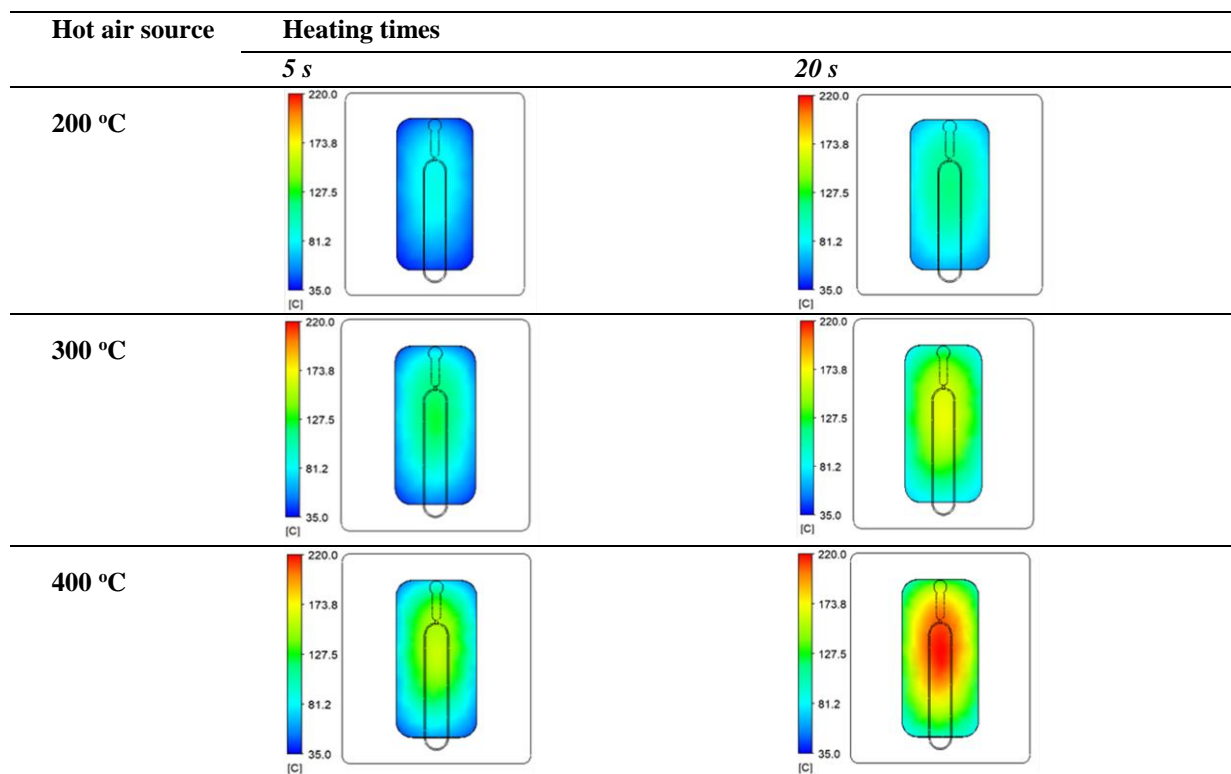


Table 4. The Temperature Distribution for The Product Thickness of 0.5 mm



The temperature distributions for the product thicknesses of 0.1 mm, 0.2 mm and 0.3 mm were showed in Table II, Table III and Table IV, respectively. The hot air sources were investigated in cases of 200 °C, 300 °C and 400 °C, and the heating times were considered at 5 s and 20 s. The results showed that the region near the hot air gate had the largest temperature and the mold surface temperature improved significantly when the heating time and hot air temperature source increased. To see more clearly the effects of different heating conditions including the product thickness on the surface mold temperature at S1, the heating process was done with the hot air temperature of 300°C during the heating time of 20 s and showed in Table V. The results showed that the AMTC could heat the surface mold to 166.1 °C, 167.7 °C and 171.6 °C corresponding to the product thicknesses of 0.1 mm, 0.3 mm and 0.5 mm, respectively, when the initial mold temperature was 40°C. It was clear that the temperature value was larger than the glass transition temperature of almost thermoplastic materials that used in the injection molding process. Compared to another research [15], when the hot air was used for the heating area of 58 mm × 30 mm, the gas flow rate of 500 l/min and the gas temperature of 300°C, the maximum heating rate was only about 2.2°C/s. It meant that the AMTC method had a great advantage in terms of surface heating efficiency but depended on each model.

Figure 4 showed that when the product thickness increased from 0.1 mm to 0.5 mm, the temperature of mold surface increased from 166.1 °C to 171.6 °C after 20 s of heating. It meant that the heating rate increased from 6.3 °C/s to 6.58 °C/s. It increased as a function of the product thickness that could be explained in relation to the thermal energy required to heat the insert plate volume (stamp plate volume). Since the insert plate and the mold plate were separated by a heat-insulating layer, the heating result mainly depended on the insert volume when having the same heating source. According to Figure 3, the product thickness became thinner as the stamp thickness increased. Therefore, a greater heating rate was achieved with thinner stamp. However, the difference in heating rate was negligible when the product thickness varied from 0.1 mm to 0.5 mm. In addition, Figure 4 also showed a very high heating rate for the first 5 s, with the heating rate changing between 15.2 °C/s and 17.9 °C/s. This heating rate was higher than that of many previously studied heating methods [1, 2, 6]. At the same time, at the heating time of 20 s, the temperature plots had shown to still increase, which was not limited as in other studies [15]. Thus, the temperature at the mold surface was still increasing with longer heating time or higher power heating source. However, the temperature at 20 s was high enough for most thermoplastic materials in injection molding. In our previous studies, when the hot air was used for mold surface heating, the temperature

distribution was depending on many factors [11-14]. Thus, in this study, for evaluating the uniformity of the heating process with different stamp thicknesses, the temperature at the centerline of the stamp was collected and analyzed. Figure 5 showed the simulation results of the temperature distribution for the hot air of 300 °C and the heating time of 20 s. It was clear that the temperature distribution on the mold surface was different and dependable on the location of hot air gate. This was the advantage of AMTC for the local heating of mold.

Table 5. *The Comparison of Temperature at Point S1 with Different Heating Times and Different Product Thickness ES*

Heating time (s)	Product thickness		
	0.1 mm	0.3 mm	0.5 mm
	<i>Mold surface temperature (°C)</i>		
1	54.2	57.6	60.9
2	87.5	89.9	90.4
3	91.1	96.0	101.5
4	108.9	109.1	114.7
5	118.2	120.2	124.9
6	121.5	131.3	138.1
7	132.0	135.3	140.1
8	135.5	140.4	145.2
9	141.4	144.4	149.3
10	144.5	148.5	152.3
11	147.7	150.5	154.3
12	151.2	153.5	157.4
13	153.5	155.5	159.4
14	156.3	157.6	161.4
15	156.4	159.6	163.5
16	158.7	161.6	165.5
17	160.1	163.6	166.5
18	161.4	164.6	167.5
19	163.4	165.6	169.6
20	166.1	167.7	171.6

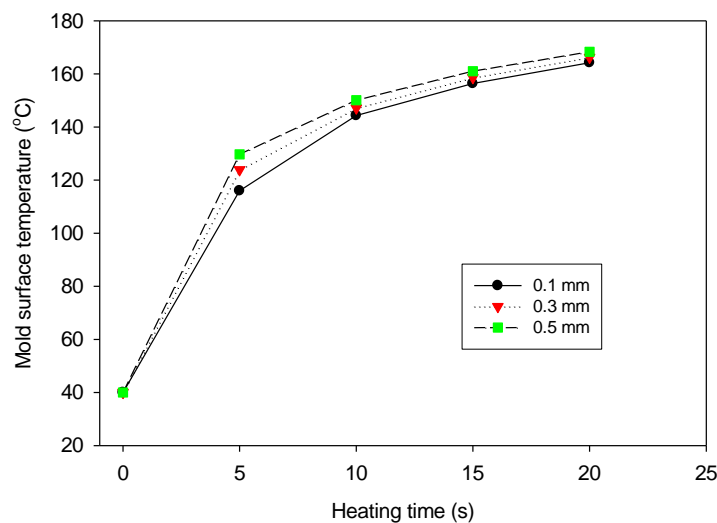


Fig. 4. *The mold surface temperature as a function of heating time for different product thicknesses at the sensor location S1*

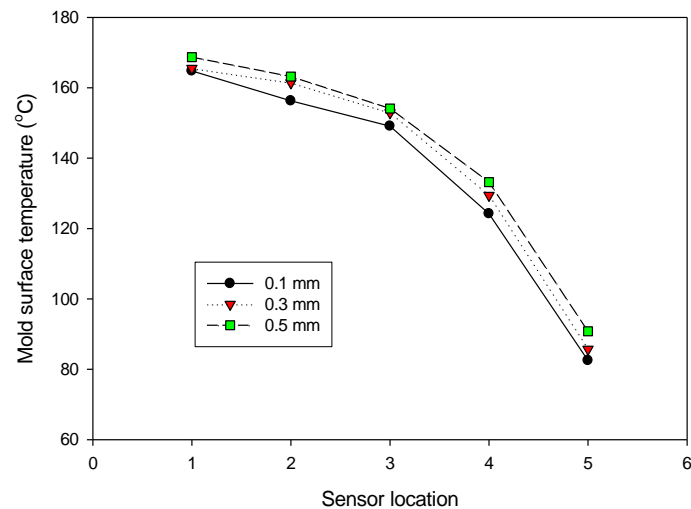


Fig. 5. The mold surface temperature with the hot air of 300 °C and the heating time of 20s

4. Conclusions

In this study, the following results are observed:

- The hot air could heat the mold plate to 171.6 °C and the heating rate of AMTC could reach to 6.39 °C/s. This temperature value was larger than the glass transition temperature of almost thermoplastic materials used in the injection molding process.
- With the product thickness values of 0.1 mm, 0.3 mm and 0.5 mm, the heating rates were 6.3 °C/s, 6.39 °C/s and 6.58 °C/s, respectively. The increase of heating rate could be explained by the thermal energy required for heating the stamp volume.
- The temperature distribution on the mold surface by AMTC was different and could be controlled through the heating source, heating time and location of hot air gate.

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