

**THERMAL STRESS OF SURFACE OF MOLD CAVITIES
AND PARTING LINE OF SILICONE MOLDS**

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Abstract

The paper is focused on the study of thermal stress of surface of mold cavities and parting line of silicone molds after pouring. The silicone mold White SD – THT was thermally stressed by pouring of ZnAl4Cu3 zinc alloy with pouring cycle 20, 30 and 40 seconds. The most thermally stressed part of surface at each pouring cycle is gating system and mold cavities. It could be further concluded that linear increase of the pouring cycle time leads to the exponential increasing of the maximum temperature of mold surface after its cooling. The elongated pouring cycle increases the temperature accumulated on the surface of cavities and the ability of silicone mold to conduct the heat on its surface decreases, because the low thermal conductivity of silicone molds enables the conduction of larger amount of heat into ambient environment.

Key words

silicone mold, thermal stress, spin casting

INTRODUCTION

Polymer structural materials have undergone recently rapid development and they are used in many branches of industry, including foundry. They more and more replace classical materials (metal, wood, ceramics, glass, etc.) due to their price, properties, production and processing. One of them, silicone rubber, is used in foundries (1, 2) for low melting point alloys spin casting into silicone molds. These mold materials enable to cast especially zinc, tin alloys and some kinds of plastics (3). Their main disadvantage in comparison with classical mold materials is low thermal conductivity. Table 1 compares thermal conductivity and other physical properties of chosen materials. The low thermal conductivity of silicone molds influences the heat distribution in mold, cooling of mold and solidification of casting.

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THERMAL PROPERTIES: COMPARISON OF DIFFERENT METALS AND SILICONE (4)

Table 1

Material	Silicone	Pure aluminum	Pure copper	Plain carbon steel
Specific heat [J/kg.K]	~1250	903	385	434
Density [kg/m ³]	1535	2702	8933	7854
Thermal conductivity [W/m. °C]	0,71–1,0	237	401	60,5

From the previously published data about the silicone molds thermal stress or their cooling during casting (4 – 6), it can be concluded that the main disadvantage of various published cooling methods is a longer mold production process and increased complexity of molds due to various complex shape inserts to increase thermal conduction from the surfaces of molds cavities. The next disadvantage is the lacking information about the influence of the pouring cycles number and the time of thermal stress of silicone molds cavities, because these parameters significantly influence the lifetime of silicone molds.

MATERIALS AND METHODOLOGY OF EXPERIMENT

For experimental molds, TEKSIL White SD – THT silicone material (Fig. 1) was used. It was vulcanized at the temperature of 170 °C and pressure 25 MPa for 140 minutes. The mold material was thermally stressed by ZnAl4Cu3 zinc alloy pouring (pouring temperature 430 °C) into mold preheated to 50 °C. The pouring cycles were 20, 30 and 40 seconds long. After removal of castings, the open mold was put on the pad under the infrared camera, where the cooling of its surface was observed.

The cooling process of mold after pouring was observed by TI 160 infrared camera in 30 seconds intervals. The interval between the removal of mold from the casting machine (subsequent removal of castings from mold cavities, putting the mold on rubber pad) and the first shot of infrared camera was 30 seconds. The results documented by infrared camera were processed by IRSee Report software. The processing consists of the determination of percentage distribution of the areas of the mold cooled on certain temperature, considering the total area of the mold parting line.



Fig. 1 Silicone mold used for thermal stress measurement

RESULTS

The cooling of silicone molds after the pouring cycle of 20, 30 and 40 s can be followed in Figs. 2, 4 and 6. The highest measured mold surface temperature is usually only a point, and therefore the temperature distribution is from the range of lower temperatures, than the highest measured temperature on the infrared photoshot. The highest thermal stress is concentrated on the surface of cavities and gating system of the mold. The maximum measured temperature after 0.5 min of cooling at the pouring cycle of 20 seconds reached 151.3 °C. The pouring cycle 10 seconds longer increases this temperature by about 8 °C to 159.3 °C. Further prolongation of the pouring cycle to 40 seconds leads to the increased maximum temperature of 172.3 °C, which means a 13 °C difference between the 30 and 40 second-long pouring cycle.

Visible difference of the mold cavity and parting line surface temperature is caused by low thermal conductivity of mold, and therefore the highest thermal stress is concentrated on the locations of the molten metal flow and solidification.

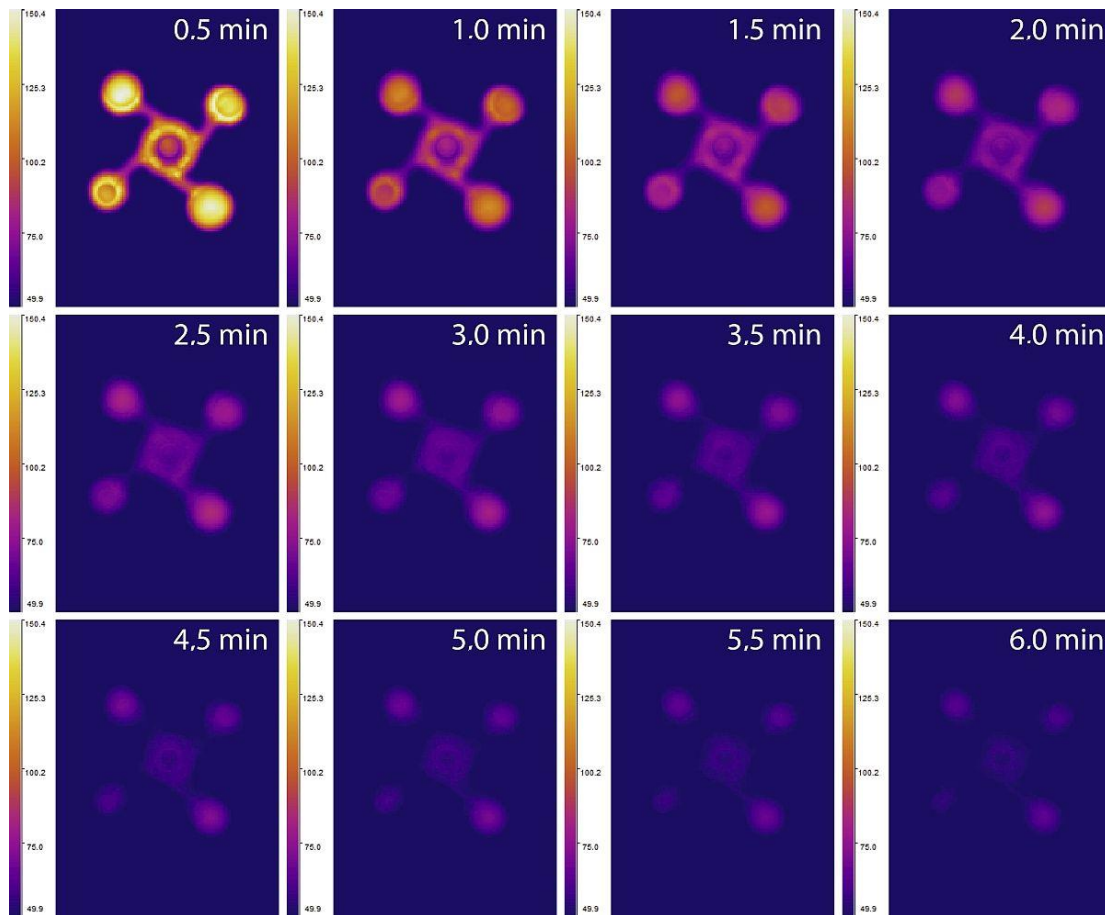


Fig. 2 Thermal stress of mold (pouring cycle 20 s)

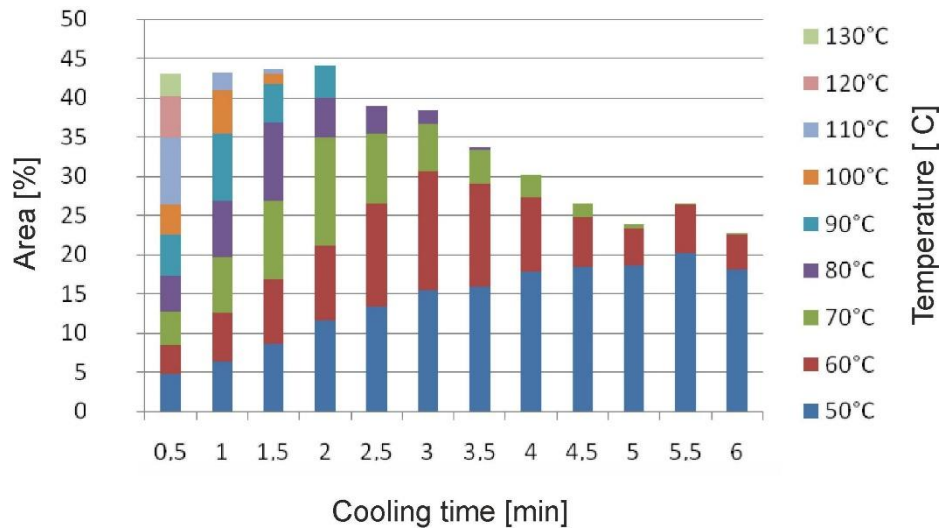


Fig. 3 Percentage distribution of temperatures on mold surface (pouring cycle 20 s)

Fig. 3 shows percentage distribution of the temperatures on mold surface with the pouring cycle 20 seconds. The areas with the temperatures higher than 100 °C represented more than 20 % of the observed surface after 0.5 min of cooling. The areas with such temperatures were observed on surface until 1.5 min of cooling, when they represented 2 % of the observed surface. After 1 min of cooling, the areas with the temperatures in the range 90 – 99 °C and 100 – 109 °C reached their maximum. For the temperature range 90 – 99 °C, it was approximately 9 %, and for the temperature range 100 – 109 °C, approximately 6 %. The areas with the temperatures in the range 80 – 89 °C reached maximum 10% after 1.5 minutes of cooling. The areas with temperatures in range 70 – 79 °C reached their maximum approximately 14 % after 2 minutes of cooling. There were present only the areas with the temperature below 79 °C after 4 minutes of cooling. These areas formed approximately 30 % of the observed area.

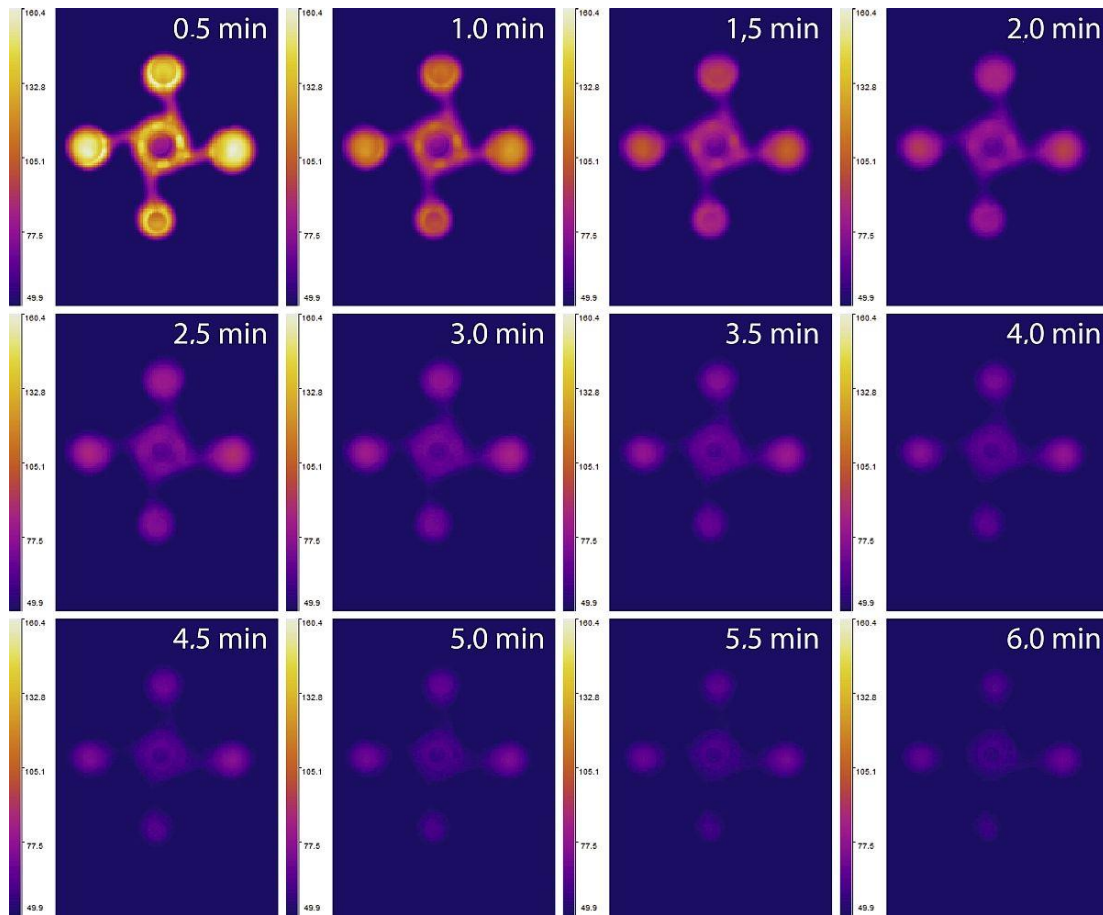


Fig. 4 Thermal stress of mold (pouring cycle 30 s)

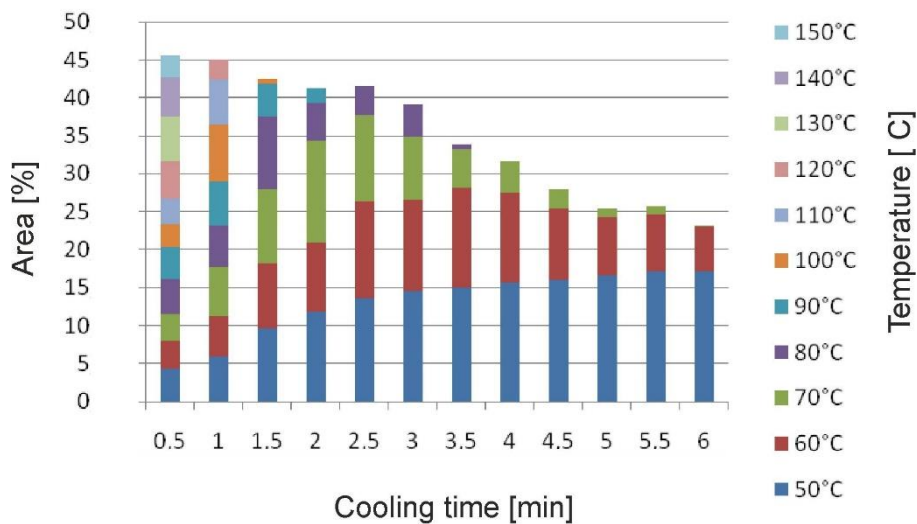


Fig. 5 Percentage distribution of temperatures on mold surface (pouring cycle 30 s)

Percentage distribution of the temperatures on mold surface at the pouring cycle 30 s can be seen in Fig. 5. The areas with the temperatures higher than 100 °C formed approximately 25 % of the observed surface after 0.5 min of cooling, which was by 5 % more than at the mold surface cast with the pouring cycle 20 s. The areas with these temperatures were present on the observed surface up to 1.5 min of cooling, when they are only 1 % from observed surface. After 1 min of cooling the areas with the temperatures in the range 90 – 99 °C and 100 – 109 °C

reached their maximum. For the temperature range 90 – 99 °C, it was approximately 6 %, and for the temperature range 100 – 109 °C, approximately 7 %. The areas with the temperature range 80 – 89 °C reached their maximum 9 % after 1.5 min of cooling. The areas with temperatures in the range 70 – 79 °C reached their maximum approximately 13 % after 2 min. of cooling. There were present only the areas with the temperature below 79 °C after 4 minutes of cooling. These areas formed approximately 31 % of the observed area.

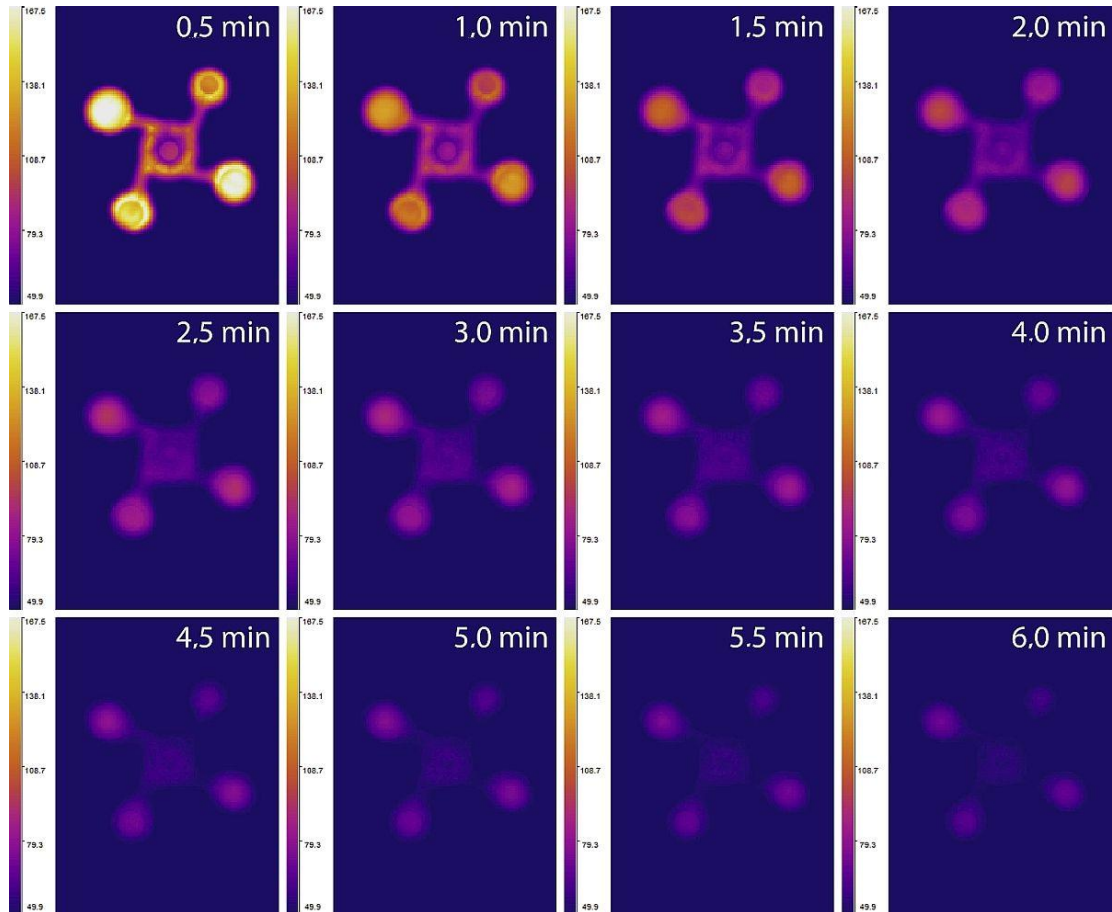


Fig. 6 Thermal stress of mold (pouring cycle 40 s)

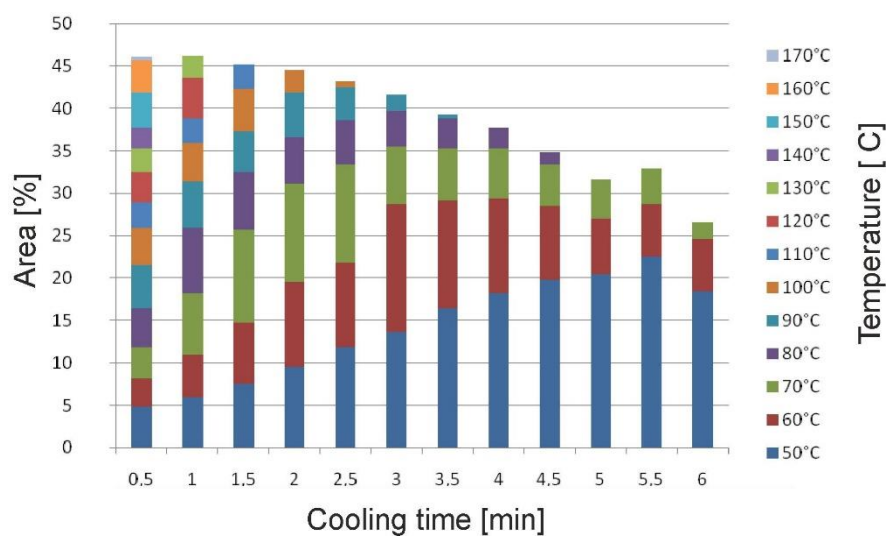


Fig. 7 Percentage distribution of temperatures on mold surface (pouring cycle 40 s)

Fig. 7 shows percentage distribution of temperatures on the mold surface at pouring cycle 40 s. The areas with the temperatures higher than 100 °C formed approximately 25 % of the total area after 0.5 min of cooling. The areas with such temperatures can be found until 2.5 min of cooling, when they formed only 1 % of the total area. The maximum of 8 % for areas with the temperatures in the range from 80 to 89 °C was reached after 1 min of cooling. The maximum of 12 % for areas with the temperatures in the range from 70 to 99 °C was reached after 2 min. The areas with temperatures in the range from 60 to 69 °C reached the maximum of 15 % after 3 min of cooling. After 5 min of cooling, only the areas with the temperatures below 79 °C were observed on the surface. These areas represented approximately 31 % of the total area. On contrary to molds with pouring cycles 20 and 30 s, there were also the areas with higher surface temperature up to 89 °C after 4 min. of cooling.

DISCUSSION

The results of experiments show low thermal conductivity of silicone molds, which can be seen from the similar percentage distribution of the areas with the temperature higher than 100 °C for molds with pouring cycle 30 and 40 s. These areas formed more than 25 % of the total area of parting line in spite of the different maximum surface temperatures after 0.5 min of mold cooling. The difference of these temperatures was 13 °C (159.3 °C for pouring cycle 30 s, and 172.3 °C for pouring cycle 40 s).

It is also obvious, that the decrease of surface temperature is not regular, because, during the cooling time, there was initial increase of the percentage distribution of areas in certain range of temperatures, considering the total area of the observed mold parting line, followed by decrease of the percentage distribution of areas in certain range of temperatures.

The decrease of percentage of the area fraction heated over 50 °C during the whole period of cooling was caused by low thermal conductivity of mold, which was not heated from castings after their removal. The low thermal conductivity of mold obstructs the thermal conduction by volume of mold, so the mold was cooled only through the surface of parting line. Thus, larger number of subsequent pouring cycles can significantly heat the mold.

CONCLUSION

The analysis of temperature distribution of the mold parting line surface at the pouring cycles of 20, 30 and 40 seconds shows increased stress of the silicone molds. The thermal stress decreases its thermal conduction and changes the physical properties of material. This is caused also by lower thermal conductivity of silicone molds because of the decreasing intermolecular bonding forces under thermal stress of material.

It was experimentally established, that the time of pouring cycle influences the cooling of mold in such way, that the increasing time of pouring cycle increases the temperature of mold parting line surface and vice versa. On the base of the maximum measured temperatures, it can be concluded that the linear increase of time of pouring cycle leads to the exponential increase of the maximum temperature of mold surface during cooling.

The longer pouring cycle and repeated use of silicone mold increases the thermal stress of silicone mold. In practice, this means that each subsequent pouring into silicone mold significantly increases its wear and decreases its lifetime.

References:

1. GATTO, A., IULIANO, L. 2001. Evaluation of inserts for modular thermoplastic injection moulds produced by spin casting. *Journal of Materials Processing Technology*, pp. 411-416.
2. WANG, J., et al. 2004. Rapid tooling for zinc spin casting using arc metal spray technology. *Journal of Materials Processing Technology*, pp. 283–288.
3. FETECAU, C. 2006. Applications of silicone rubber for Spin casting of ZnAl alloys. *Materiale Plastice*, pp. 190-193.
4. HUAN, Z., JORDAAN, G.D. 2003. Investigation of the cooling of spin-casting moulds. *Applied Thermal Engineering*, pp. 17–27.
5. HUAN, Z., JORDAAN, G.D. 2005. Air-cooling induced from spinning of spin-casting moulds. *Applied Thermal Engineering*, pp. 1183–1194.
6. HUAN, Z., JORDAAN, G.D. 2004. Galerkin finite element analysis of spin casting cooling process. *Applied Thermal Engineering*, pp. 95–110.

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