On-line temperature recording in a multi cooling channel injection molding tool

Przemyslaw Postawa[1), *)], Tomasz Stachowiak[1)], Dominik Grzesiczak[1)]

DOI: dx.doi.org/10.14314/polimery.2015.351

Abstract: In this paper the temperature distribution in injection mold was investigated. For this purpose a special experimental mold was designed and made. This mold has eight independent cooling circuits which were connected to a temperature controller using two rotameters. In order to register temperature changes, four thermocouples placed in various points of the mold under the cavity surface and connected to a recorder. It allowed to transmit the data in real time during the injection process and to determine the temperature profile in various areas of injection molding. The infrared thermal images and temperature distribution profiles of the mold cavity and molded parts were also determined.

Keywords: thermoplastic polymer, injection molding, process control, mold temperature, infrared camera.

Monitorowanie temperatury w procesie wtryskiwania tworzywa do formy z wieloma kanałami chłodzącymi

Streszczenie: Zbadano rozkład temperatury w formie wtryskowej oraz zaprojektowano i wykonano eksperymentalną formę wtryskową wyposażoną w osiem niezależnych obiegów chłodzących, podłączonych do termostatu za pośrednictwem dwóch rotametrów. W celu rejestracji zmian temperatury w różnych punktach formy tuż pod powierzchnią gniazda umieszczono cztery termopary połączone z rejestratorem, które umożliwiały przesyłanie danych, w czasie rzeczywistym, podczas trwania procesu i wyznaczenie profilu temperatury w różnych obszarach formy wtryskowej. Sporządzono też termogramy w podczerwieni i profile rozkładu temperatury gniazda formy oraz wypraski.

Słowa kluczowe: polimer termoplastyczny, formowanie wtryskowe, sterowanie procesem, temperatura formy, kamera termowizyjna.

Mold temperature is one of the most important parameters in the injection molding process of thermoplastic polymers — in particular semi-crystalline polymers. It has very big impact on many different properties of injection molded parts, *e.g.*: stiffness, impact strength, residual stresses, and deformation [1—5]. There are lots of methods to control the mold temperature but it is neither simple nor easy to measure it precisely. Injection molding tools usually have a large mass what is strictly related to their high heat capacity and thermal inertia. Measurement of temperature by contact equipment leads to errors, because this method is based on heat transfer between the thermocouple and the measured area of the mold.

In industrial processes temperature measurements are difficult due to the dynamics of their changes as well as the corrosive and destructive properties of a melted polymer at high temperatures. Polymer materials have a very high viscosity and high values of shear stress during the flow along the channels of the mold and the plasticizing unit of the injection molding machine.

Furthermore, polymers have a very low (in comparison to metals) coefficient of thermal conductivity which hinders the heat exchange processes between the melted polymer and the measuring elements (thermocouples). Therefore, errors often appear in the machine control due to incorrect temperature readings in the plasticizing unit of the injection molding machines.

The temperature should preferably be measured in the exact place where we want to estimate it, but in plastics processing technology this is very difficult due to the above mentioned significant phenomenon (shear stresses that could destroy any thermocouple mounted directly in the flow channel). Therefore, most of the temperature measurements in plastic processing are indirect and are susceptible to some errors [6—8]. Many methods of temperature measurement can be used to estimate the temperature of the melt polymer. The shape of sensors and place it can be installed depend on the method of measurement and the possibility to install them in a specific location in the mold or plasticizing unit.

[1)] Czestochowa University of Technology, Faculty of Mechanical Engineering and Computer Science, Department of Polymer Processing, Al. Armii Krajowej 19C, 42-201 Czestochowa, POLAND.

[*)] Author for correspondence; e-mail: postawa@ipp.pcz.pl

The most commonly used temperature measuring instruments are as follows:

— liquid thermometers,

— resistance elements (thermocouple),

— semiconductor elements,

— pyrometers and infrared cameras — very modern but still expensive.

The last of the above mentioned instruments, despite the high cost, is very convenient in terms of speed, giving the possibility of rapid measurements of the temperature field over a large area in a very short time. These features are highly valued in industrial conditions.

The main purpose of the research was to estimate the temperature gradient on the surface of the mold and its effect on the temperature field of the injection molded parts.

EXPERIMENTAL PART

Material

A semi-crystalline polyoxymethylene (POM) of Delrin 500 PNC010 type made by DuPont was used in the experiment. It is very popular technical material for advanced applications with very good flow ability in the mold cavity and high impact of mold temperature on molding structure.

Construction of the test stand

The test stand, presented in the article, consists of the following parts:

— a special experimental mold equipped with eight independent cooling circuits (four on each part of the mold),

— a two circuit thermostat (temperature controller),

— equipment for data acquisition from thermocouples.

Each cooling channel of the mold can be connected to a thermostat independently, so it offers the possibility of a free configuration of the temperature field on the mold surface (within the capabilities of the thermal conductivity of its individual parts). A diagram of the mold with separate cooling channels is presented in Fig. 1.

The experimental mold was equipped with four thermocouples (T1, T2, T3, T4) located about 2 mm under the mold cavity in specially drilled holes and using thermoconduct paste. The thermocouples were connected *via* a controller to a microcomputer by a USB data link. Pico Technology Software was used for data acquisition from the temperature sensors. The mold was mounted in an injection molding machine type Krauss Maffei KM65 C4.

The mold is connected to dual circuit temperature controller TP Plus2 made by Wittmann. A stream of thermostatic liquid (water) is divided into two 4-way rotameters (Shini Company), then, after equalization of

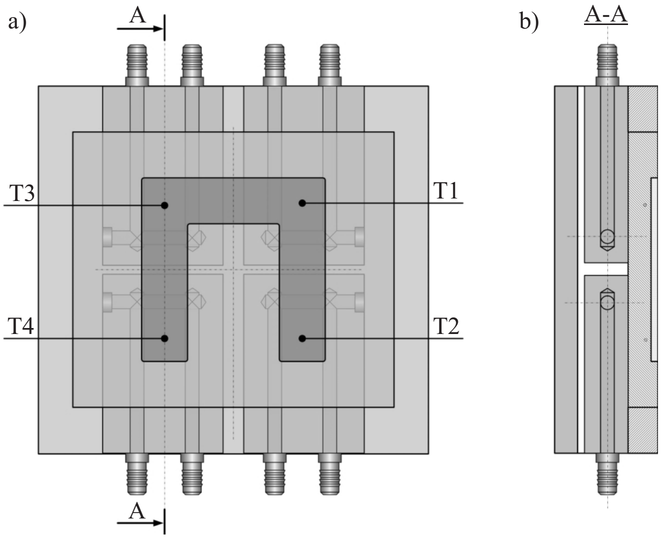

Fig. 1. Cavity part of the experimental injection mold: a) mold plate with molding, b) top view of the mold with cooling inserts

the flow, water is fed into the individual circuits in the mold. A picture of this research stand is presented in Fig. 2.

That kind of mold apparatus gives possibilities of many different setups of the cooling/heating circuit which has an influence on specific field of temperature on the mold surface [9]. Three of possible settings for the coolant flow were presented in Fig. 3.

The main purpose of the research was to estimate the temperature gradient on the mold surface and its effect on the temperature field of the injection molded parts. The temperature of the experimental mold was set to intentionally obtain the difference between the parts of the mold cavity.

The temperature controller was set in such a way that the left half-part of the mold was heated to 30 °C and the right half-part to 100 °C. Then, after thermal stabilization of the mold, the injection test took place. The sample is square in shape, and the molten polymer is injected through two gates into the cavity (Fig. 4).

Tests of injection molding were carried out under the conditions listed in Table 1.

T a b l e 1. Conditions of investigated injection molding process

Injection temperature	200 °C
Injection time	0,52 s
Injection speed	40 cm^3/s
Injection pressure	80 MPa
Hold pressure	20 MPa
Hold time	12 s
Cooling time	15 s
Settings of the mold temperature controller:	
– hot circuit	100 °C
– cold circuit	20 °C

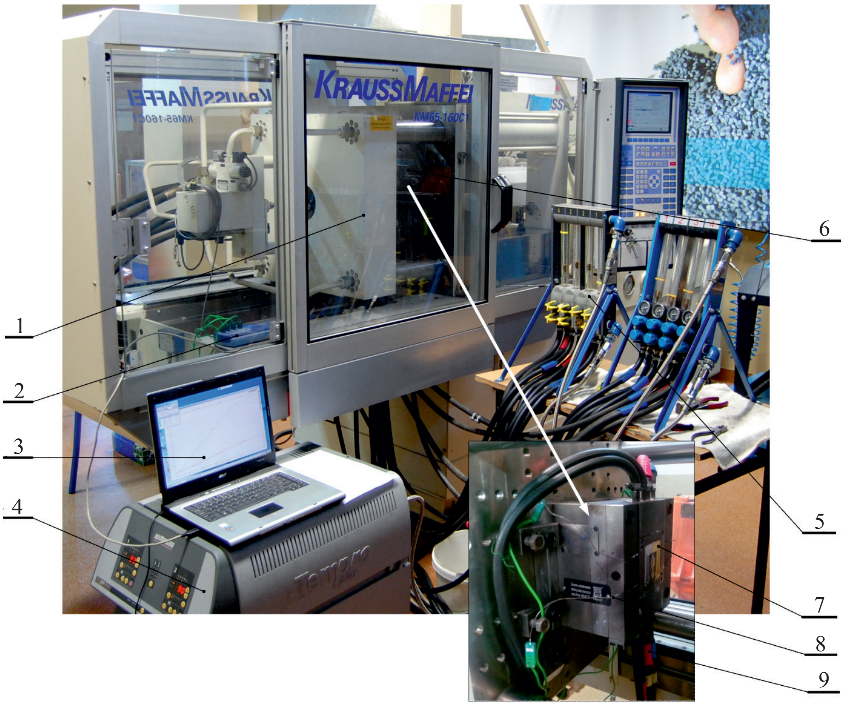

Fig. 2. A view of the research stand: 1 — injection molding machine, 2 — temperature recorder, 3 — computer, 4 — temperature controller, 5 — rotameter, 6 — mold, 7 — molding, 8 — thermocouple, 9 — water pipes

The locations of thermocouple elements for temperature measurement were present in Fig. 4.

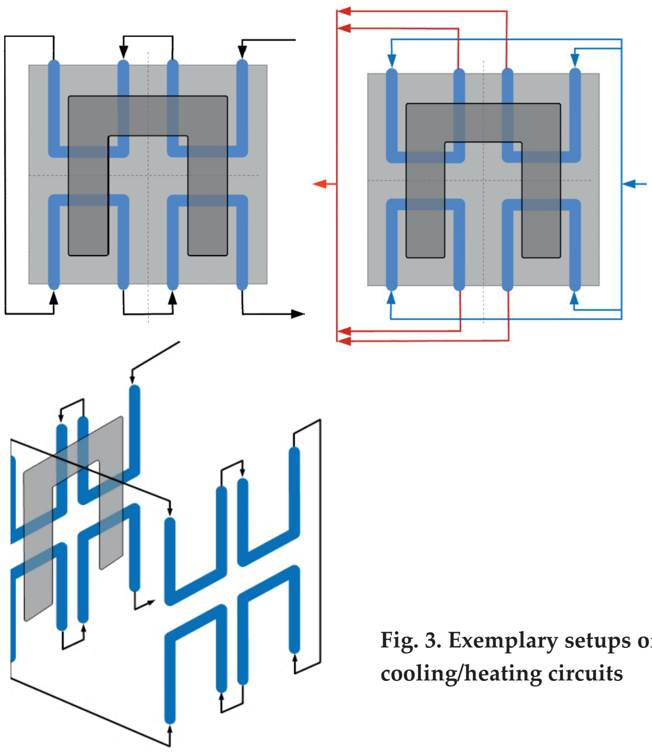

Fig. 3. Exemplary setups of cooling/heating circuits

RESULTS AND DISCUSSION

In order to determine the temperature variation during the injection molding process the following measurements were made:

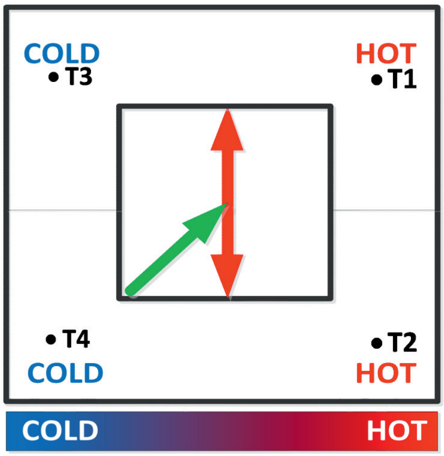

Fig. 4. A diagram of the injection molded part (red arrow — location of injection gates, green arrow — main flow channel) with marked hot and cold mold areas and the location of temperature sensors (T1—T4)

— measurement of the temperature at the outlet from the temperature controller by means of thermocouples,

— temperature measurements directly under the mold cavity (four thermocouples),

— infrared measurements of the experimental injection mold (infrared camera),

— infrared measurements of moldings immediately after demolding (infrared camera).

As mentioned above, there were two sets of different temperature values for the mold: 100 °C for the hot circuit and 20 °C for the cold circuit. The measured temperatures at the outlet of the temperature controller (measured by

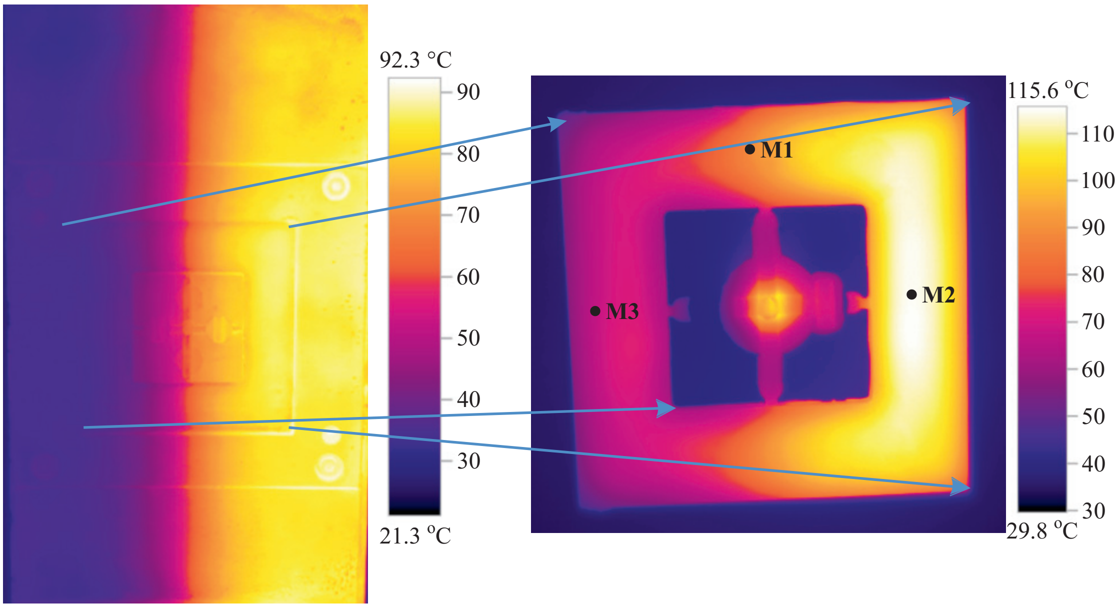

Fig. 5. Infrared thermograms of the mold cavity and injection molded parts with a visible profile of the temperature distribution

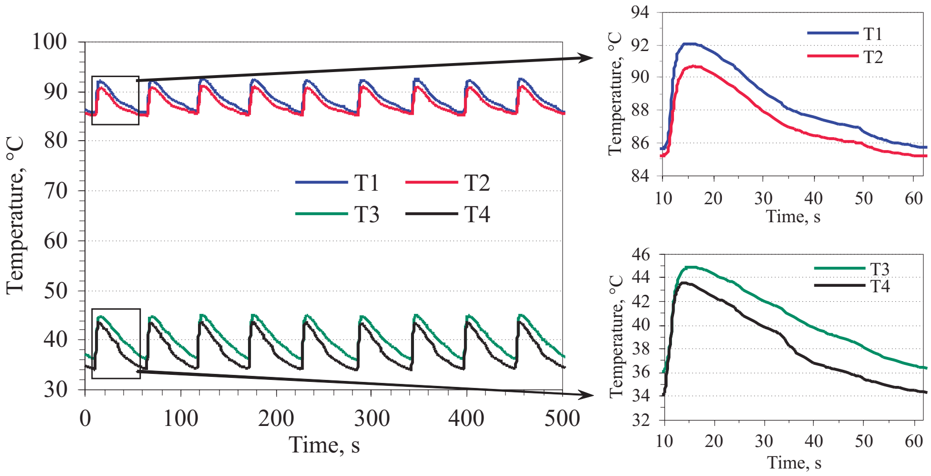

Fig. 6. Change in the temperature profile in various areas of the injection mold

thermocouples) were equal to 99 °C for hot circuit and 20 °C for cold circuit. However, the temperature set on the temperature-controller was not obtained due to losses caused by heat transfer to the environment and the lack of thermal insulation of the mold and pipes.

The temperatures were measured by the infrared camera in specific areas of molded parts as it is presented in Fig. 5.

The temperature values observed in points marked in this figure are as follows:

— M1 at the injection area 91,4 °C,

— M2 at the hot part of the mold 114,4 °C,

— M3 at the cold part of the mold 68,8 °C.

The temperature changes during the injection of ten consecutive moldings recorded by the thermocouple located under the mold cavity are presented in Fig. 6. The main graph shows temperature changes recorded by four thermocouples (T1, T2, T3, T4) and the reduced graph shows a single molding.

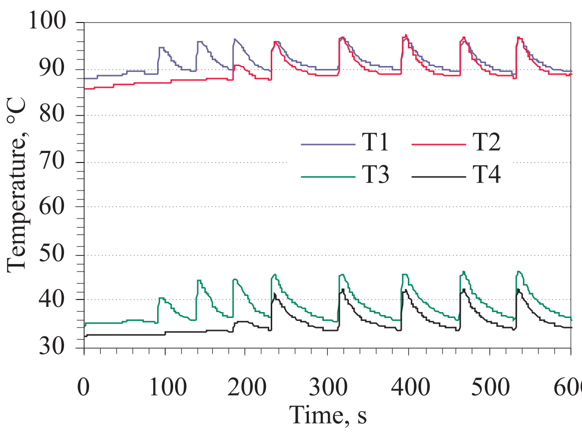

Fig. 7. Temperature profile in specific part of the mold during short shot tests

A collapse in the temperature profile is clearly visible for the measurements recorded in the cold part of the mold when the molding is ejected from the mold cavity. It is at this point that a sudden drop in temperature is observed. The same effect is not clearly visible in the hot part of the mold due to the smaller temperature gradient between the mold and injected polymer material (Fig. 6).

The short shot test was also conducted to determine temperature signals during the filling stage in different parts of mold. For that test the mold with one injection point was used. Injection point was localized in the top part of the mold between hot and cold area. The temperature profile of eight cycles recorded during short shot test was shown in Fig. 7. It can be seen the times when there appear signals from the individual thermocouples located under the surface of the cavity. This means that the polymer flowed to the specific thermocouple. The average value of temperature increasing during short shots tests, and after 6 shots the average temperature stabilized at 93 °C for the hot circuit and at 38 °C for the cold circuit. It is due to larger mass of melted polymer which increases the heat capacity of the molding and a higher heat flux transferred to the mold. Constant value of the average temperature in various circuits demonstrates the stability of the injection molding process.

CONCLUSIONS

— In the case of temperature measurement by contact devices, the appropriate positioning of the sensors is crucial (for this purpose, sensors with the smallest heat capacity should be used and mounted with thermoconductive paste).

— Temperature variation in the injection molding is dependent on the gradient between the temperature of melted polymer and the cavity mold temperature.

— A varied mold temperature affects the temperature in different areas of the injection molded material and differences in the flow of polymer inside the cavity.

— Usage of mold temperature control circuits, separated from each other by an air gap, allowed to obtain the distribution of the temperature field of the mold and the distribution of the temperature of the molding.

ACKNOWLEDGMENTS

The research was performed within project No. N N508 630740 funded by the Polish National Science Centre. Special acknowledgment is extended to Plastigo sp. z o.o. for providing two rotameters for the research stand and a molecular dryer to prepare raw material for testing.

REFERENCES

[1] Hamdy H., Regnier N., Lebot C. *et al.*: *Applied Thermal Enineering* **2009**, *29*, 1786.

[2] Yan C., Nakao C., Go T. *et al.*: *Microsystem Technologies* **2003**, *9*, 188. http://dx.doi.org/10.1007/s00542-002-0262-y

[3] Bociąga E., Jaruga T.: *Polimery* **2009**, *54*, 342.

[4] Bociąga E., Jaruga T., Sikora R.: *Polimery* **2009**, *54*, 522.

[5] Postawa P., Kwiatkowski D.: *Journal of Achievements in Materials and Manufacturing Engineering* **2006**, *18*, 171.

[6] Zhaoa G., Wanga G., Guana Y., Lia H.: *Polymers for Advanced Technologies* **2011**, *22*, 476.

[7] Qiao H.: *International Journal of Mechanical Sciences* **2006**, *48*, 430. http://dx.doi.org/10.1016/j.ijmecsci.2005.11.001

[8] Masse H., Arquis E., Delaunay D. *et al.*: *International Journal of Heat and Mass Transfer* **2004**, *47*, 2015.

[9] *Pol. Pat. Appl.* 408 480 (2014).

Received 17 VI 2014.

Rapid Communications

Przypominamy P.T. Autorom, że publikujemy artykuły typu **Rapid Communications**. **Prace oryginalne wyłącznie w języku angielskim** o objętości 3—4 stron maszynopisu z podwójną interlinią (plus ewentualnie 2—3 rysunki lub 1—2 tabele), którym umożliwiamy szybką ścieżkę druku (ok. 4—5 miesięcy od chwili ich otrzymania przez Redakcję). Artykuł należy przygotować wg wytycznych zamieszczonych we wskazówkach dla Autorów.