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The use of IR thermography to show the mold and part temperature evolution in injection molding

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ABSTRACT

This study concerns the application of infrared camera for injection molding analysis by measuring temperatures of both injection molded parts and injection mold cavities in a function of injection cycles. The mold with two cavities, differing in thickness (1 and 3 mm), and a cold direct runner was used. Isotactic polypropylene homopolymer was utilized to produce parts. Mold temperature was set at 22^{0}C and controlled by a water chiller. Five measuring points were determined: SP1, SP2 (placed in the 3 mm cavity), SP3, SP4 (located in the 1 mm cavity) and SP5 around an injection molding gate. Our investigations showed that the highest temperature is localized around SP2 point and the lowest at SP4. Also, it was proved that even after 62 injection molding cycles, temperatures of cavities were not stable, revealing their further increase with each cycle.

1. INTRODUCTION

Parameters such as: polymer melt temperature, mold temperature, injection pressure and cooling conditions are the most important during injection molding process and affect sample microstructure and properties. Injection of polymer melt into a cavity starts heat transfer between a mold and a plastic part which in turn, determines products quality, structural aspects and important physico-chemical parameters. Therefore, during plastic flow and solidification time polymer rheology and heat transfer play a key role in formation of structure [1-3]. To maintain quality of plastic parts, injection molding should be monitored and analysed by modern detecting systems. One of the fastest, the most useful and precise technique is infrared thermography (IR). IR is very often used for thermal visualisation of cavities, hot injection molded parts and flow channels [4-6]. This technique is an important tool for analyzing mold temperature maps which shows unexpected "hot spots" in plastic parts indicating distribution of unbalanced cooling zones [5-8]. As a result, optimization of cooling procedure as well as reduction of injection cycle time are enabled and in turn cause further increase in product quality [7]. Moreover, thermal scans, taken just after demolding of plastic parts, provide important information on possible sources of plastic part warpage [8-9]. This work presents application of infrared thermography technique for investigations of mold temperature during injection molding process. The main purpose is to determine temperature rise of mold surface and plastic part in a function of injection molding cycle.

2. EXPERIMENTAL PROCEDURE

Temperature measurements of mold surface and plastic parts were carried out using IR camera FLIR T620. Injection molding grade polypropylene homopolymer PP HP 648T with a mass melt flow rate of 54 g/10min was used [10]. The plasticizing temperature ranged between 185 ^{0}C and 210^{0}C and injection speed was 75 mm/s. Mold temperature was stabilised by an external chiller with water output set at

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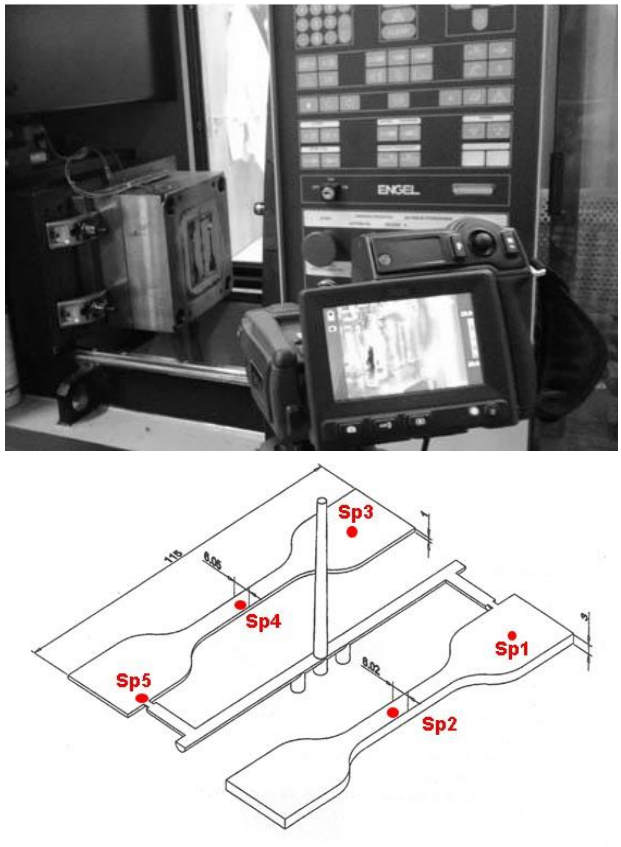
22^{0}C. Injection molding process was realised by ENGEL 80/20 HLS injection molding machine with 200 kN clamping force. A two cavity mold with cold runner system was applied in this process. Thickness of the cavities varied form 1mm to 3 mm and injection flow path was 115 mm. The injection molding machine was operated in a semi-automatic mode to enable taking IR scans after mold opening and before part ejection (5 seconds delay). Next, plastic parts were removed from the cavity and the second IR scan was made. The experimental procedure was set in the following way: a) after cooling phase the mold was opened and the IR scans of plastic parts and cavity were taken after each of 31 injection molding cycles, b) after 31st molding cycle a 15 minute break was introduced (without switching the barrel heating off), c) next, the machine was started and again 31 molding cycles were done (combined with taking of IR scans). Estimated cycle time for the first run was 35 s (procedure a). After 15 minutes break, the cycle time decreased to final value of 25 s for the procedure c. In total, 62 injection cycles were executed during the experimental part.



a)

b)

Fig. 1. a) View of IR camera position versus mold face, b) 3D view of dumble shaped parts with flow channel and temperature measuring points (red dots)

Marked areas on plastic part surfaces were used for detection of local temperature (see Fig. 1 b). The selected points were located in area of the highest width of the samples (SP1, SP3) and in the middle part of the sample (SP2, SP4). The last detecting point was located directly in the gate position into the plastic part with 1 mm of thickness (SP5). The same measuring points, except SP5, were placed in the mold to control its temperature. Emission factors for temperature detection of mold cavity and plastic part were set at 0.2 and 0.95, respectively.

3. RESULTS AND DISCUSSION

For better understanding and clear presentation of experimental results, the IR scans of plastic parts (before domolding) and face of shaping plate (after part demolding) were taken as displayed in Fig. 2. This Figure presents selected IR scans i.e. after the 12th, 32nd, and 62nd injection molding cycle. The record of the first 11 scans was not realized due to technical issues, hence data analysed in this paper include scans from 12th to 62nd.

Visible changes in surface temperature of 3 mm thick sample are noticed for first 31 injection molding cycles (Fig. 3). The highest temperature is observed for the sample with thickness of 3 mm in the area localised in front of the gate (marked as SP1). This action could be connected with relatively small distance from the gate and prolonged flowing time of polymer melt in the cavity. Moreover, this area is the widest part of the sample and therefore, promotes local heating up of the surface. For the 1 mm sample, the temperature is almost constant during all experimental cycles. SP5 measuring point reveals temperature value higher by about 10°C in comparision with the 1mm thick sample. This is due to the heating up process activated by friction when polymer flows through very narrow gate. After the break, a noticeable change is observed only for the thicker sample (red and dark blue curves in Fig. 3). A shift in the temperature of the points located on the thicker sample surface is connected with shortened time of injection cycle. Shorter time of cooling phase leads to a local increase in the sample temperature. Probably, this may cause warpage and shrinkage after demolding. Observations of the mold surface temperature changes lead to the conclusion that during all injection molding cycles, mold temperature constantly rises (see Fig. 4). For this reason, even after 62nd injection molding cycle the temperature is not stable and the mold is still warming up. This phenomenon occurs for both cavities, however higher increase is observed in case of the thicker one. Figure 5 presents shrinkage of the samples after 24 hours measured along flow direction. Higher shrinkage is observed for the thicker sample which is probably due to increased crystallinity degree of polypropylene. Shorter cycle time applied after the break leads to substantial increase in shrinkage for the 3 mm sample. This is in a good agreement with previous measurements presented in Fig. 3.

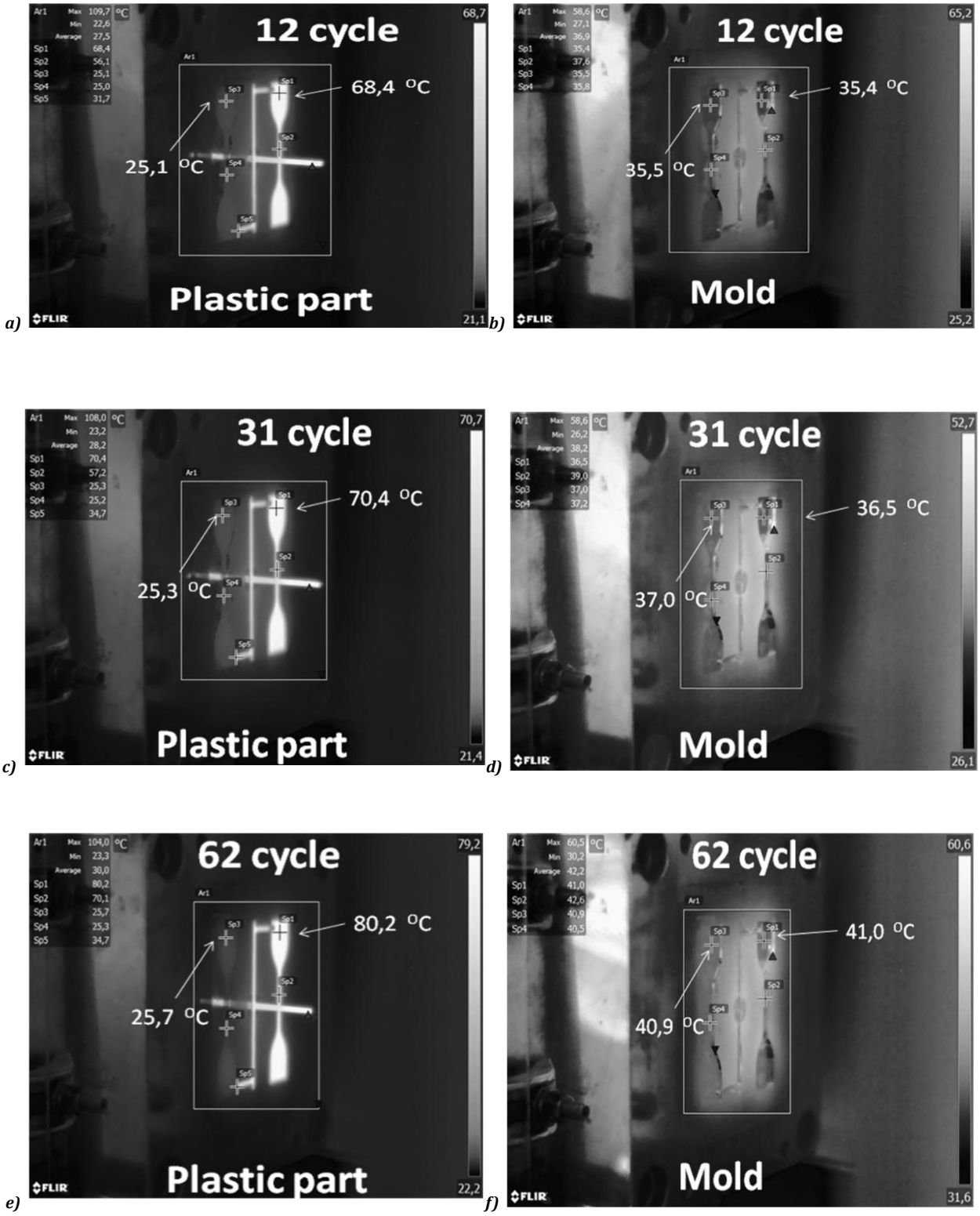


Fig. 2. IR scans recorded in selected injection cycles, a),c),e) plastic part before demolding, b), d), f) shaping plate face (picture taken just after part demolding)

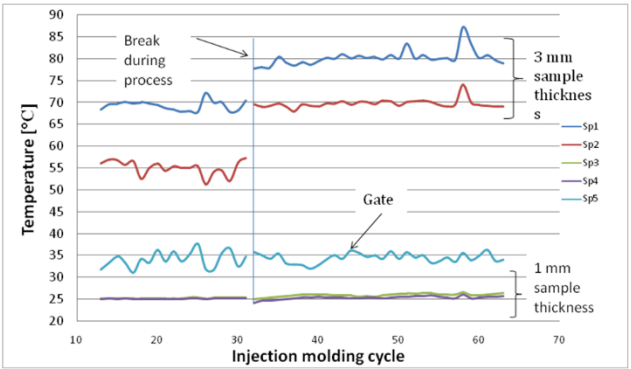


Fig. 3. Graphical interpretation of plastic part temperature in a function of molding cycle number

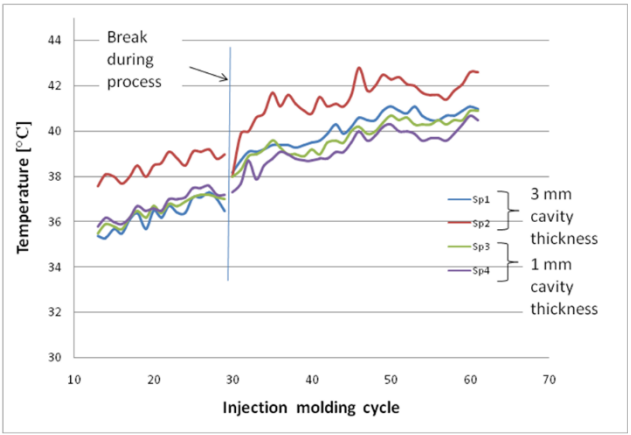


Fig. 4. Graphical interpretation of mold surface temperature in a function of molding cycles

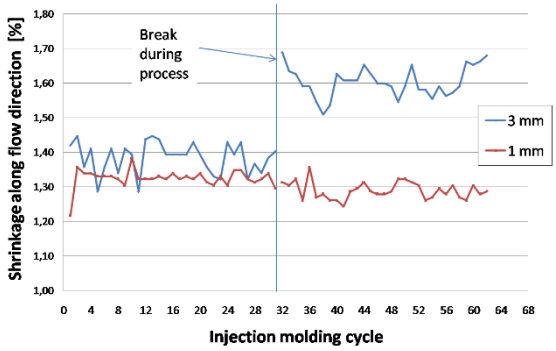


Fig. 5. Graphical interpretation of shrinkage, measured along flow direction, in a function of molding cycles

CONCLUSIONS

1. Scans of infrared camera, taken to monitor plastic part and mold surface temperatures, revealed that after 62 cycles the cavity temperature is still rising. From practical point of view it means that even 61 injection molding cycles may not guarantee production of repeatable polypropylene parts. This could be connected with too short cycle time, introduced after the break during injection molding. Moreover, shorter cycle time led to a noticeable increase in mold surface temperature for the 3 mm sample.

Based on above information, if the cooling time decreases, the flow rate of coolant should increase or its temperature should be lower. In opposite case, a rapid shift in shrinkage of molded parts will appear (especially in longitudinal direction, as it was observed for 3 mm sample thickness).

2. The results are affected by reflection of thermal radiation from the opposite mold plate (made of polished stainless steel) and by the all reflected heat sources in the surroundings.

3. To make future measurements more reliable, in next experiments, the opposite mold plate should be painted in black as well as the polymer should be colored with carbon black.

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