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Thermal Effect Characterization of a Hand-operated Plastic Injection Molding Machine

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***Abstract*— Thermal conditions play a pivotal role during the injection molding of plastic products. This work aims at characterizing the thermal effects on the plastic injection molding process in order to produce dimensionally and structurally consistent products. For this purpose, six temperature sensors were installed at various locations appropriately selected on the barrel of a hand-operated in-house designed and fabricated plastic injection molding machine and on the product mold of a hoisting hook. The temperature data from the sensors was recorded during the injection molding of a commercially known ABS plastic to manufacture the product samples. The analysis of the measured data was then carried out to identify different phases of the injection molding process and to evaluate the temperature influence on the product quality. Also, a parametric study is conducted to find out the optimal temperature conditions for the barrel of injection molding machine and the product mold to manufacture a better quality ABS plastic product.**

***Index Terms*— ABS plastic; Hoisting hook; Injection Molding; Temperature sensors; Thermal effect.**

I. INTRODUCTION

Plastic injection molding is considered as a well-established manufacturing process by the plastic industry worldwide. According to an estimate, it is the most commonly used process of manufacturing plastic products after extrusion process. It also exhibits more benefits over traditional compression and transfer molding processes. Moreover, lower labor cost, improved dimensional stability of the products and short cycle time make it a suitable manufacturing process [1] [2] [3] [4] [5] [6].

An injection molding process comprises the injection of melting polymers into the mold cavities. Due to its suitability for mass production, the plastic injection molding has witnessed a perpetual growth since its early development. Apparently, it seems to attain the status of a standardized technology, however, with advancement in the plastic materials and the product requirements, the injection molding process is still being investigated, improved and optimized [7] [8].

The plastic injection molding process can be divided into several phases like melting, injection, cooling and finally the product ejection. The time consumed to complete a full injection process is called cycle time, and typically one-half to two-third of the cycle time involves the part cooling which is crucial to achieve a quality product but costly from mass production point of view [2] [3] [4]. It should be noted that a significant lower cycle time for the product cooling phase may result in undesired distortion leading to compromise the product quality [9]. Several attempts have been made by the researchers to lower the cycle time related to the product cooling phase as the cycle time for the rest of process phases is already reached its lowest possible levels and cannot be further reduced. Generally, the cooling channels (CC) that follow the shape of cavities of the mold have been used to shorten the product cooling time [9] [10] [11] [12]. However, the implementation of such cooling channels inside the mold is cumbersome and expensive and may only be feasible for large complicate plastic products.

For small plastic products made from manual injection molding machines, the mold cooling at the room temperature is the only feasible solution. However, considering the lower cost involved in manual injection molding, the process is generally neglected and solemnly left over the experience and judgment of the operators. In this paper, the thermal investigation of a hand operated injection molding machine is carried out in order to produce dimensionally and structurally consistent products while lowering the cycle time. The temperatures at various locations on the machine barrel and the mold are monitored and analyzed during injection molding of plastic products. It should be noted that the mold is kept at room temperature in order to lower the manufacturing as well as production cost.

The paper begins with a brief description of the problem statement followed by the methodology section where installation of temperature sensors and development of a cost effect data acquisition is discussed, and, finally, the result and discussion section is presented before the conclusion section.

II. Problem Statement

Figure 1 shows an in-house built hand-operated plastic injection molding machine to be investigated to characterize the thermal effects on the molding process. The machine comprised injection plunger, barrel, hopper, handle, nozzle and a band heater. The injection plunger and barrel were made of medium carbon steel, while, mild steel was used for hopper, handle and nozzle components. The band heater of 300W capacity wound over the barrel was used for uniformly heating the barrel to melt the polymer deposited inside. The length of injection stroke was 400 mm long. The maximum temperature of barrel achieved was 320 ºC that can be maintained by an AC power supply of 110V/60 Hz.

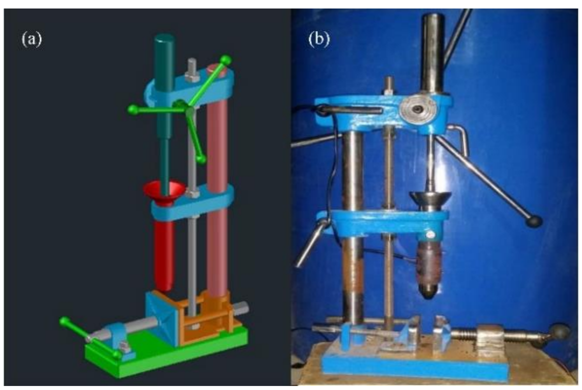

Figure 1 Plastic injection molding machine: (a) CAD model, (b) built model.

Table 1 Dimensions of injection molding machine parts.

Description	Dimensions (mm)
Injection plunger	$\phi 22 \times 900$
Barrel	$\phi 45 \times 470$
Nozzle	R10
Hopper	$90 \times 92 \times 115$
Handle	$\phi 124 \times 260$
Mold	$80 \times 60 \times 24$

The whole machine weighed approximately 48 kg. The product mold, consisting of two halves, was made of Aluminum material and was designed to mold a plastic hoisting hook. The plastic used was a commercially known ABS plastic to manufacture the samples of hoisting hook. ABS plastic was selected as it belongs the family of thermoplastics and is used for a wide range of everyday plastic products. It has the specific gravity of 1.06 and a glass transition temperature of 105 ºC [13]. Moreover, the dimensions of injection molding machine components and the mold are listed in table 1.

III. Methodology

In order to investigate the injection molding process, six different location were identified at the barrel of injection molding machine and at the product mold, as shown in figure 2. Considering the space constraints and installation difficulties, the two temperature sensors at the barrel nozzle were mounted at a distance of 10 mm, 12 mm and 25 mm from barrel bottom surface. In case of the product mold, one temperature sensor was mounted near the inlet port and while the remaining two temperature sensors were mounted close to the ends of the hoisting hook. The temperature sensors used were LM35 precision centigrade temperature sensors. This kind of sensor has an operating range of -55 ºC to 250 ºC and with a resolution of 0.5 ºC [14].

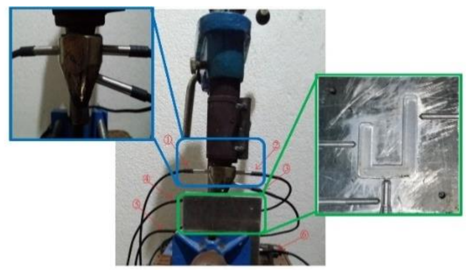

Figure 2 Temperature sensors installation on the injection molding machine and plastic hoist mold.

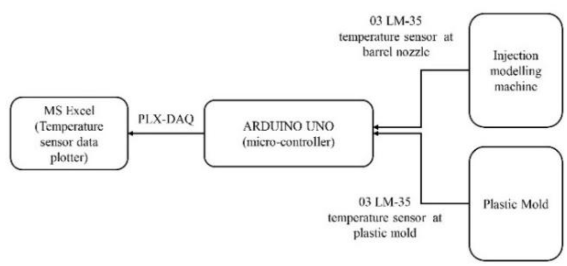

Figure 3 Schematic of temperature monitoring of plastic injection molding machine and plastic mold.

To monitor the temperature distribution along the barrel and the product mold a low cost data acquisition scheme as developed, as shown in figure 3. The analog temperature sensor data was collected using Arduino UNO, an open-source microcontroller board. It should be noted that a single Arduino UNO board can process up to fourteen digital inputs and six analog inputs by using C programming language, for further details see [15]. Since, Arduino UNO possess limited data analyzing and displaying capacities, therefore, it was interfaced with Microsoft Excel using Parallax Data

Acquisition tool (PLX-DAQ) a free software add-in which can support up to 26 data channels [16].

IV. RESULTS AND DISCUSSION

Figure 4a-b shows the temperature distributions at the barrel of injection molding machine and the mold during running empty and injection molding. In case of the empty run, it takes approximately 27 minutes by the band heater to heat the barrel until it reaches the saturation temperature (see figure 4a). On reaching the saturation temperature, a thermal equilibrium is established between the barrel and the surrounding environment as consequence the temperatures at various locations of barrel do not rise further. Moreover, there exists a temperature gradient along the barrel as can be seen by the temperature measurements from sensors 1, 2 and 3.

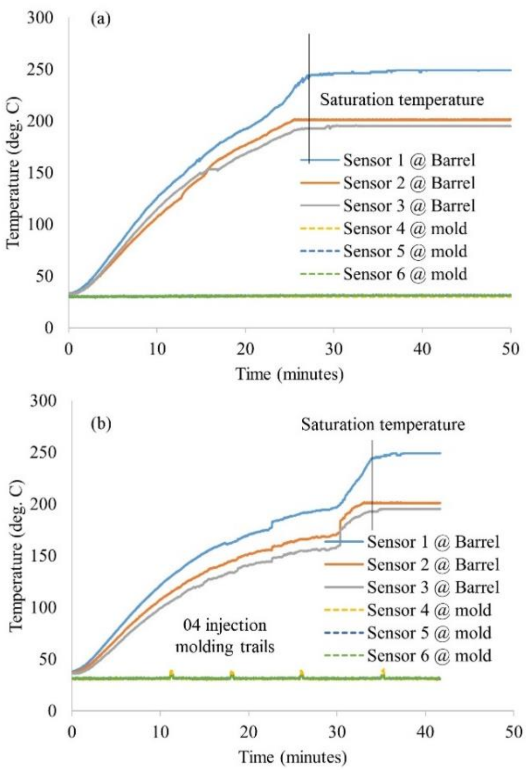

Figure 5 Temperature monitoring of the barrel of injection molding machine and the mold: (a) while running empty, (b) during injection molding.

For example, beyond the saturation limit, the measured temperature of senor 1, 2 and 3 is 250 °C, 201 °C and 194.4 °C, respectively, showing that the barrel is non-uniformly heated. On the other hand, the temperature of mold is approximately 30 °C which was consist with the environment as no molten polymer is being injected yet. In case of injection molding run, the time to reach the saturation temperature is increased to 35 minutes as more heat is required to heat the barrel and to melt the ABS plastic polymer (see figure 4b). Also, the presence of four spikes in the mold sensor data represents the four trial sets of injection molding of the hoist hook products.

Figure 5 shows the temperature distributions of the product mold during injection molding. The temperature data was collected at various locations of the mold, nevertheless, the measured data from all sensors is overlapping, depicting that the mold temperature during the injection molding is well distributed as the mold is made of Aluminum material which exhibits a good thermal conductivity.

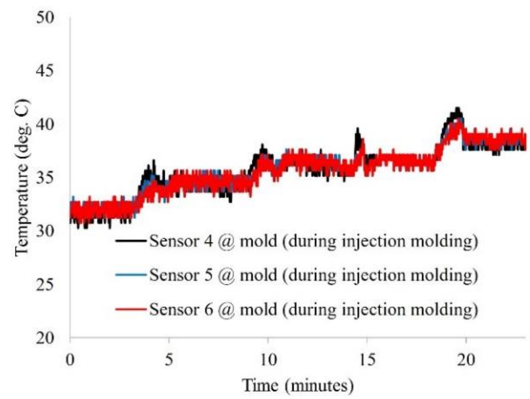

Figure 5 Mold temperature distribution

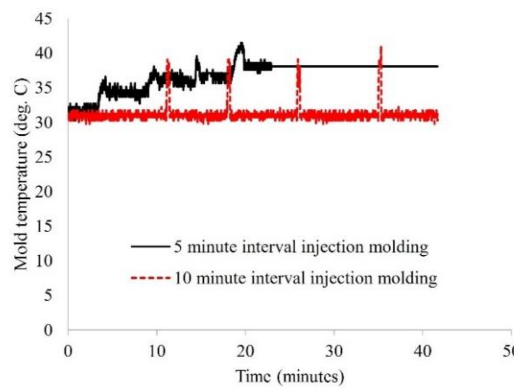

Figure 6 Effect of cycle time on mold temperature distribution.

In order to investigate the effect of cycle time on the mold temperature, several injection molding trials with two different cycle times i.e. 5 minutes and 10 minutes, were carried out. In figure 6, the solid black line refers to injection molding with a 5-minute cycle time and the dotted red line refers to injection molding with a 10-minute cycle time. The sharp temperature spikes on each graph refer to the injection phase of the molding process when the molten ABS plastic is being injected into the mold cavity. In case of a 5-minute cycle time, the mold temperature increased as time required to dissipate heat from mold was relatively short. As a results the mold temperature rises from a room temperature of approximately 30 ºC to 38.02 ºC. On the other hand, for a 10-minute cycle time, the mold temperature rises during the injection molding but it returns to the room temperature as there is now sufficient time available for mold to dissipate heat to the environment.

Figure 7 shows results of a parametric study to evaluate the effect of barrel heating and mold heating on the quality of injection molded ABS product. The Trial sets 1 and 2 refer to the thermal condition when insufficient heat was supplied and such under heating resulted in incomplete products. On the other end, the excessive heating resulted in excessive distortion of the product as represented by the results of Trial set 4. When ABS plastic was heated and injected at the proper barrel and mold temperatures, the product quality was greatly improved as can be seen by the results of Trial set 3. The optimum barral and mold temperatures found to be was 210 ºC and 38.5 ºC.

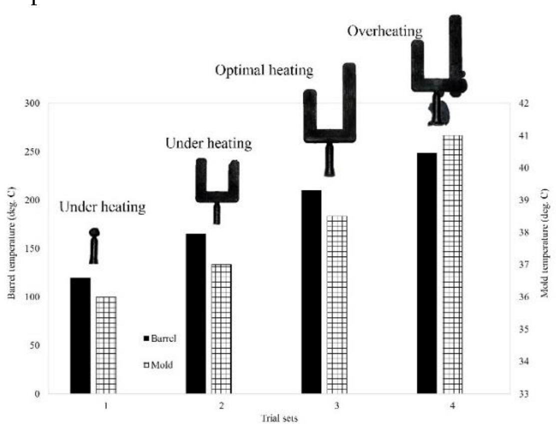

Figure 7. Heating effect on the quality of injection molded product.

V. CONCLUSIONS

Thermal characterization of injection molding process for ABS plastic is carried out using temperature sensors installed at various locations of the barrel of in-house developed injection molding machine and at the product mold. A cost effective data acquisition was built to gather the sensor data using ARUDINO UNO microcontroller and PAQ-DAQ software add-in to Microsoft Excel.

The measured results showed that the barrel of injection molding machine was non-uniformly heated as there exists a thermal gradient along the nozzle length. A uniformly heated barrel may results in a short melting time of ABS plastic, subsequently, leading to lower a cycle time. On the other hand, the sensor data from the mold showed that the mold got uniformed heated when molten plastic was injected to it. Also, when the cycle time was made short, then, the mold temperature started to rise due to lower heat dissipation and vice versa. Lastly, a parametric study was conducted and the optimum temperature for the injection machine barrel and mold were identified to be 210 ºC and 38.5 ºC that provided a dimensionally stable product.

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