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Micro Injection Molding of Thin Walled Geometries with Induction Heating System

ICOMM 2014 No.

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Abstract

To eliminate defects and improve the quality of molded parts, increasing the mold temperature is one of the applicable solutions. A high mold temperature can increase the path flow of the polymer inside the cavity allowing reduction of the number of injection points, reduction of part thickness and moulding of smaller and more complex geometries. The last two aspects are very important in micro injection molding.
In this paper a new embedded induction heating system is proposed and validated. An experimental investigation was performed based on a test geometry integrating different aspect ratios of small structures. ABS was used as material and different combinations of injection velocity, pressure and mold temperature were tested. The replicated test objects were measured by means of an optical CMM machine. On the basis of the experimental investigation the efficacy of the embedded induction heating system with respect to improvement of replication quality, reduction of injection pressure and injection velocity as well as reduction of cycle time has been verified.

Keywords: Micro injection molding, Tooling, Induction heating system, Optical CMM.

1. Introduction

In recent years the requirements on geometrical accuracy of plastic products has increased while products got smaller and thinner [1]. Not always conventional injection molding could satisfy the requirements. For that reason different companies have developed and introduced heating systems to increase the mold temperature to obtain a better quality of the molded objects. The most common heating technologies used nowadays are resistive heating, hot fluid/steam in the cooling channels, infrared lamp heating, laser light, external induction heating [2, 3, 4, 5]. At the same time an increase of the mold temperature has the drawback to prolong the total cycle time for the single molding.

In this study a new embedded induction system was designed and investigated with focus on improvement of replication quality and reduction of injection pressure and injection velocity while maintaining short total cycle time. For the validation of the system an experimental investigation was performed based on a test geometry integrating different aspect ratios of small structures in ABS.

2. Induction Heating System

In the fixed mold part an electrical induction coil is installed to heat the surface of a small defined area of the cavity, and on the movable side conventional cooling channels are set.

The induction heating system is mainly consisting of a power supply to increase the frequency of the AC from 50 Hz up to 10 KHz, a transformer, a capacitor and an induction coil to be positioned inside the block mold just behind the test geometry Fig. 1.

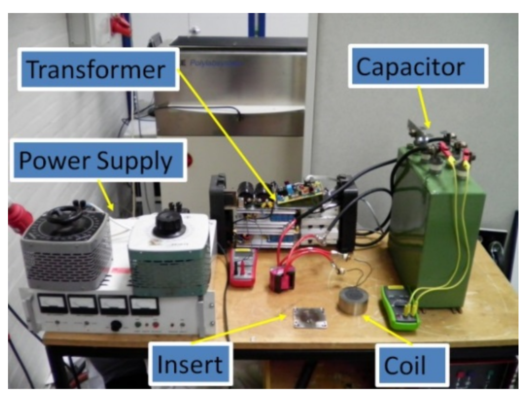

Fig. 1: Layout of the induction system

The induction coil assembly is made of a hollow copper insulated tube for the circulation of cooling water. The coil is inserted in a ferrite core to concentrate the magnetic field in a specific area, the connection between the coil and the ferrite core is provided by a thermally conductive concrete powder Fig. 2.

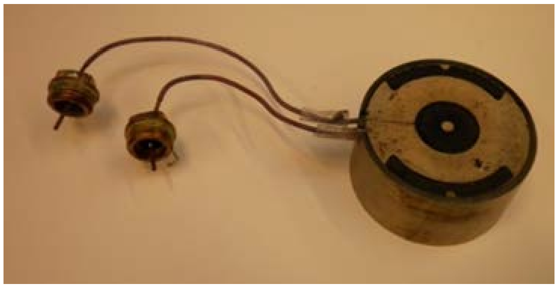

Fig. 2: Embedded coil

This new induction heating experimental setup has the characteristic of working in a completely automatic manner to ensure a high repeatability of the process conditions. The main steps of the process are the following. First the injection machine closes the two parts of the mold and at the same time it sends an electrical signal to the induction system that activates the heating time. When the predetermined time is over, the machine injects the polymer in the cavity. At this point the cooling time starts and when the ejection temperature is reached, the test part is ejected. After that the cycle starts over again. The adjustable parameters on the external induction system are the heating time and the inlet power. The power can vary changing the voltage on the power supply. In the following experiments the inlet power was fixed at 3335 W.

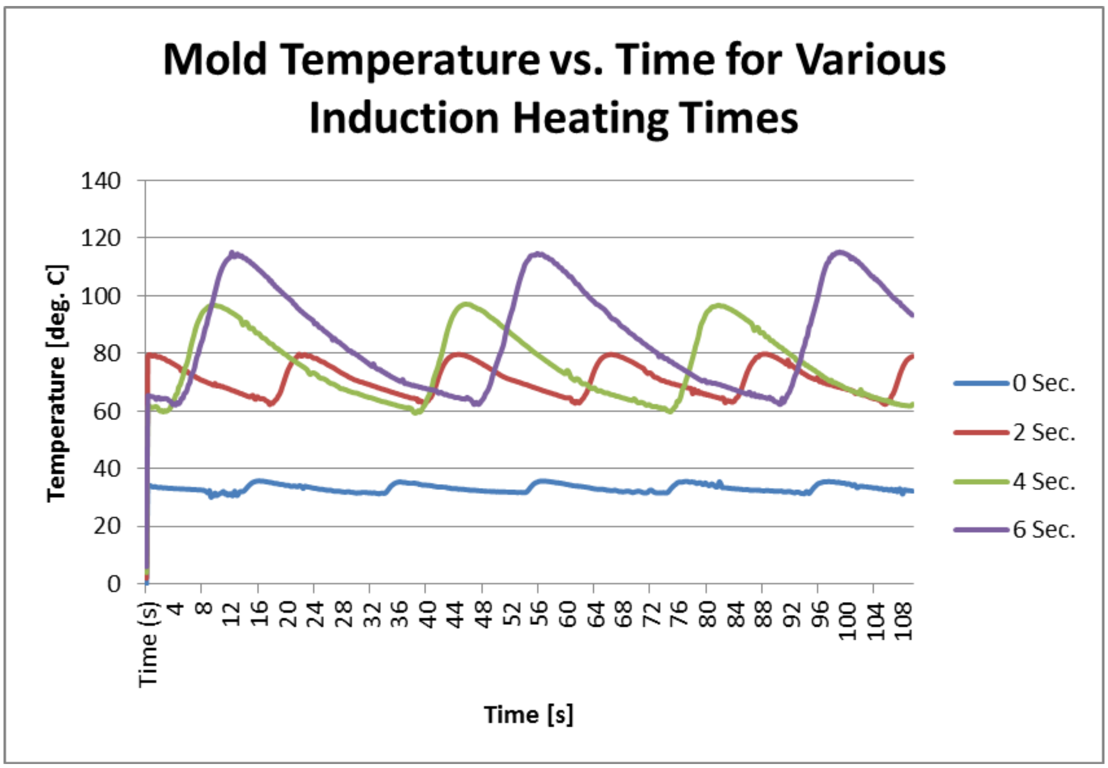

Fig. 3: Example of cavity mold temperature during the process at different heating time.

In Fig. 3 an example of the cavity mold temperature profile during the injection process is shown. In the figure, temperature profiles for 4 different heating times are shown, with constant injection velocity of 20 mm/s and cooling temperature of 20-25°C. The cooling time was varied together with the heating time to compensate for the different mold cavity temperatures reached.

It is possible to notice that an increase of the heating time of 2 seconds corresponds at an increase of the mold temperature of approximately 20°C. The cooling time in this specific series of experiments was increased from 0 to 15 seconds when the heating time was set at 4 sec to reach the correct demolding temperature.

3. Test geometry

In Fig. 4 a representation of the test part is reported.

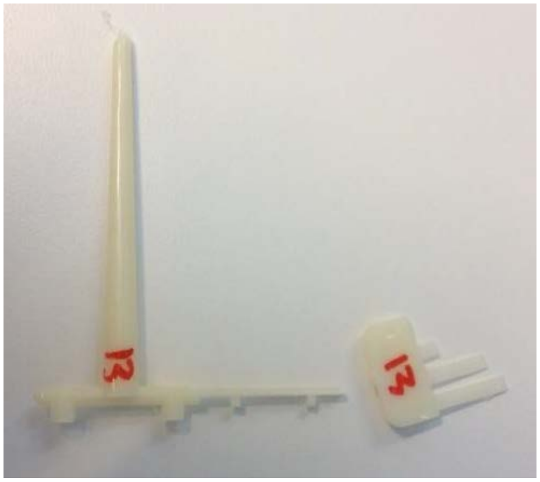

Fig. 4: Example of molded part

The selected feature for these experiments is a simple comb with 4 cantilevers of 15 mm length and 3 mm wide. The four cantilevers have different thickness 0.1 mm, 0.3 mm, 0.5 mm and 0.7 mm respectively (Fig. 5). The test geometry was designed to give a quick characterization of the polymer melt behavior in the cavity and also to allow a relatively simple measurement procedure.

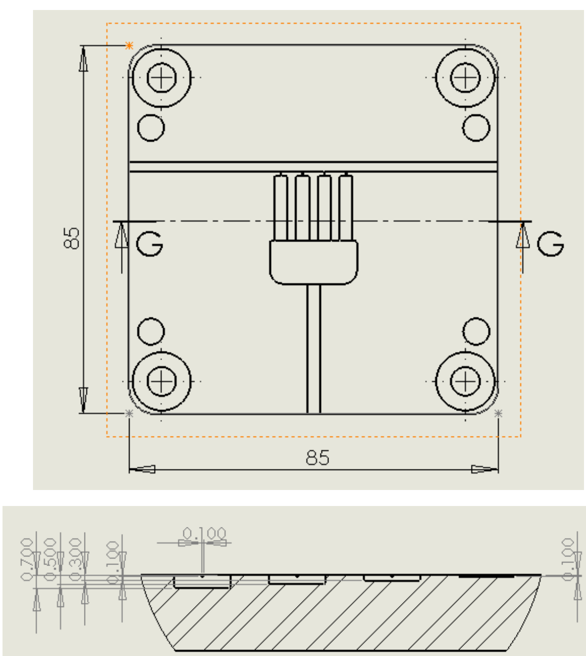

Fig. 5: Front and Cross section view of the insert

The main body just before the 4 cantilevers has a depth of 1.5 mm where the material could be expanded and homogenized before entering into the cantilevers. Four venting channels were manufactured at each cantilever end to improve air evacuation. A milling process was used to generate the cavities. The outside dimension of the insert are 85 mm x 85 mm x 4 mm and the material is an pre-hardened tool steel (IMPAX). Fig. 6 shows the manufactured insert.

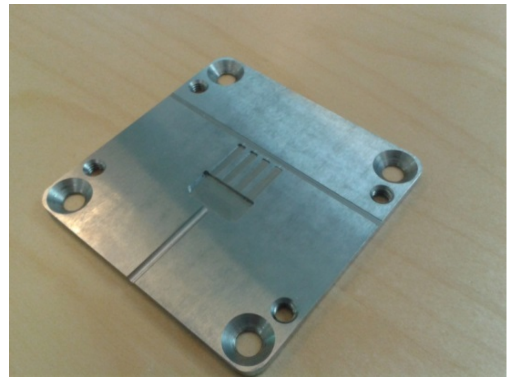

Fig. 6: Mold insert

4. Experimental micro injection molding

The experimental plan for validation of the developed induction heating system is reported in Table 1. The process parameters varied in the experimental plan were the injection velocity (and consequently the max pressure), packing pressure, lower mold temperature and heating time.
For the injection velocity three levels were selected: a low value of 20 mm/s a medium value of 100 mm/s and a high value equal to 200 mm/s. The max pressure value was a dependent variable varying with the velocity. The packing pressure was set as half of the injection pressure value.

Regarding the heating/cooling system different combinations of heating time, cooling time and temperature of cold/hot water were tested. A first set of experiments were carried out with the base mold temperature indicated in the data sheet of the polymer (70°C) [6], after that the mold cooling temperature was decreased to 32°C and finally set at the lowest temperature reachable from the system of approximately 22°C.
The induction heating time was increased from 0 s up to a max value of 10 s with steps of two seconds.

The molding experiments were carried out on an Arburg Allrounder 370A 600-70 all drive injection machine with a diameter of the screw of 18 mm.

Table 1: Experimental plan

Velocity [mm/s]	**Cooling T[°C]**	***Cooling Time [sec.]***	**Heating Time [sec.]**
20	20-25	*0*	**0**
20	20-25	*0*	**2**
20	20-25	*15*	**4**
20	20-25	*20*	**6**
20	32	*0*	**0**
20	32	*20*	**2**

20	32	*20*	**4**
20	32	*20*	**6**
20	70	40	**10**
20	70	*0*	**0**
20	70	*40*	**2**
20	70	*50*	**4**
100	20-25	*0*	**0**
100	20-25	*0*	**2**
100	20-25	*15*	**4**
100	20-25	*20*	**6**
100	32	*0*	**0**
100	32	*0*	**2**
100	32	*15*	**4**
100	32	*20*	**6**
100	70	*0*	**0**
100	70	*35*	**2**
100	70	*45*	**4**
100	70	*50*	**6**
200	20-25	*0*	**0**
200	20-25	*0*	**2**
200	20-25	*10*	**4**
200	20-25	*15*	**6**
200	32	*0*	**0**
200	32	*0*	**2**
200	32	*15*	**4**
200	32	*25*	**6**
200	70	*0*	**0**
200	70	*40*	**2**
200	70	*50*	**4**

In all the experiments the packing time was set constant at the value of six seconds. The material used in the experiments was ABS (Acrylonitrile Butadiene Styrene) with the following properties (Table 2)

Table 2: Material Properties as indicated in the material data sheet [6]

Property	Value
Commercial Name	Novodur P2H-AT
Producer	Styrolution
Density	1.05 g/mm^3
Drying Temperature	80 °C
Drying Time	2 to 4 hours
Processing temperature	220 to 260 °C

5. Measurement strategy

To compare the effect of different process settings on filling of the part, the length of each sample's cantilever was measured. An optical measurement device, DeMeet 220 by Schut Geometrical Metrology, was used to perform these measurements. A combination of user inputs and program defined measurements was used to perform length measurements.

Prior to the measurements, each sample was labeled and the runner system was removed. The samples were then attached to a fixture using double tape for consistent placement on the device platform Fig. 6.

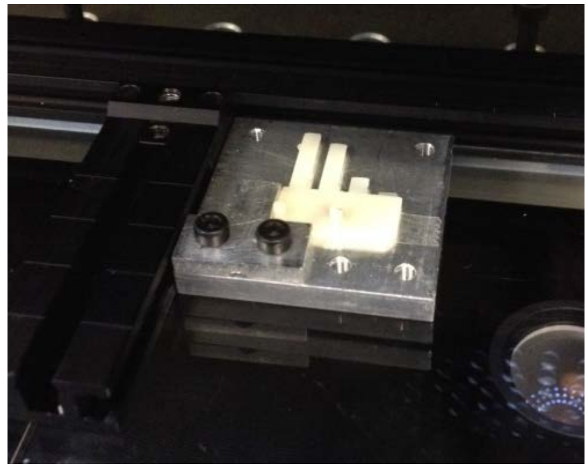

Fig. 7: Position of the test geometry on the optical CMM

Before running the program to collect length measurements, references were defined for each cantilever. The camera of the device was focused on the top surface of each cantilever. The measurement locations remained consistent across the width of the cantilevers, while the Z focal position was adjusted to find the ending edge along the length.

The program searched for two points at the end of each cantilever. The user verified that these points were at the edge of each cantilever. The program was run for each of the twenty samples. Adjustments were made to measurement planes and locations when the program failed to locate a point along the cantilever's end or when the program located a point incorrectly.

6. Results and discussion

Fig. 8, Fig. 9, Fig. 10 report the measured lengths of the four cantilevers at different processing conditions divided in macro groups. In each macro group the injection molding machine parameters are kept constant.

In all the three graphs it is easily possible to observe that a higher heating time leads to an increase of the length of the cantilevers.

If we consider the length of the cantilever with thickness 0.5 mm in the experiment VIII in Fig. 10, with no heating time and injection speed of 200 mm/s and the experiment V in Fig. 9 with heating time of 10 s and injection velocity of 20 mm/s it is possible to observe that they are the same. The latter was carried out with an injection speed ten times lower than the former. This shows that, by introducing effective induction heating of the cavity, it is possible to obtain the same replication quality with a machine size that is much smaller or alternatively have more cavities for the same machine size. It is possible to observe the same behavior when comparing experiment IV in Fig. 10 and experiment VII in Fig. 8 for the smallest cantilever thickness of 0.1 mm.

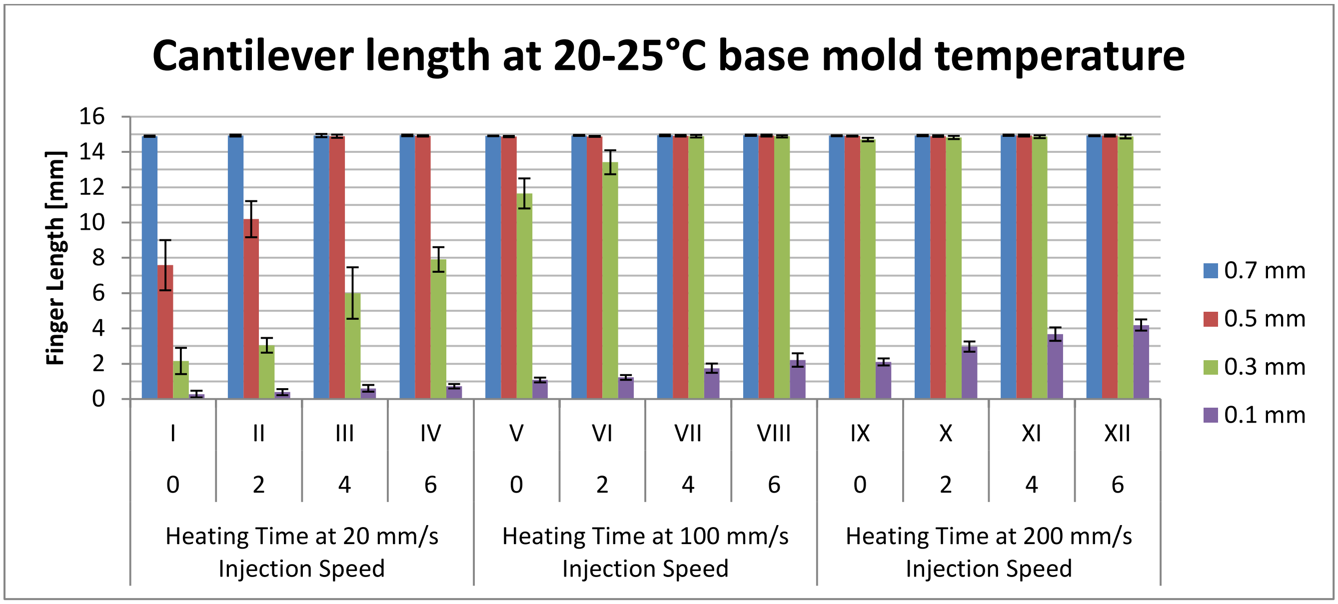

Fig. 8: Cantilever length value reached by the polymer at 20-25°C base mold temperature.

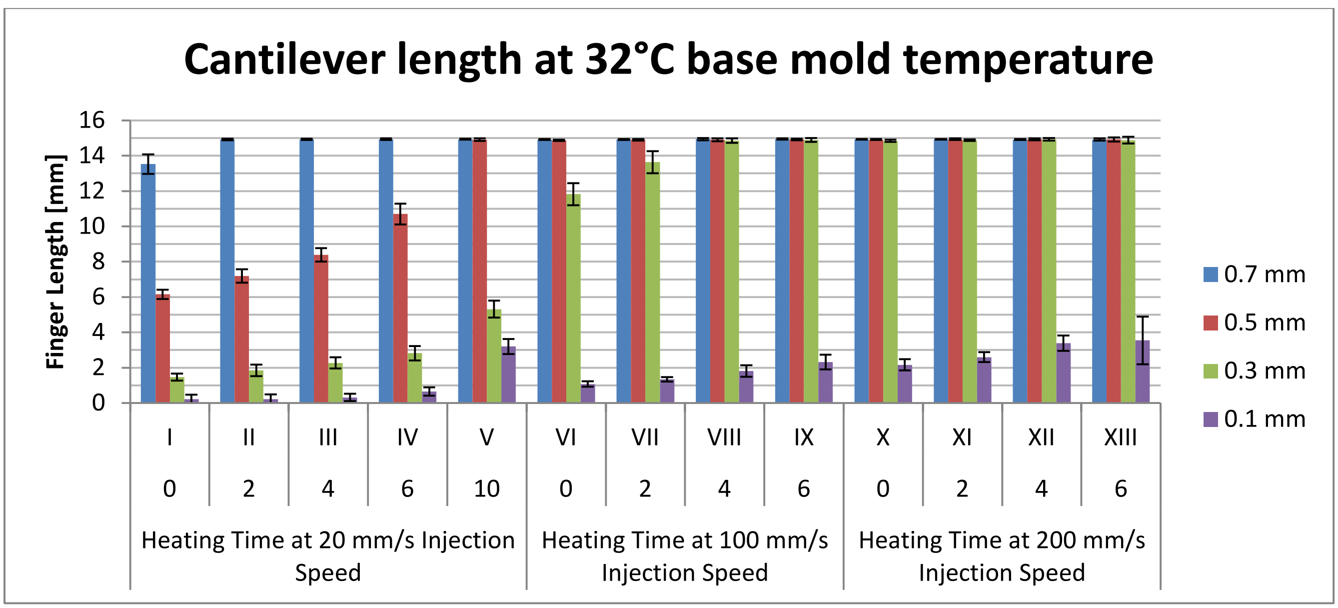

Fig. 9: Cantilever length value reached by the polymer at 32°C base mold temperature.

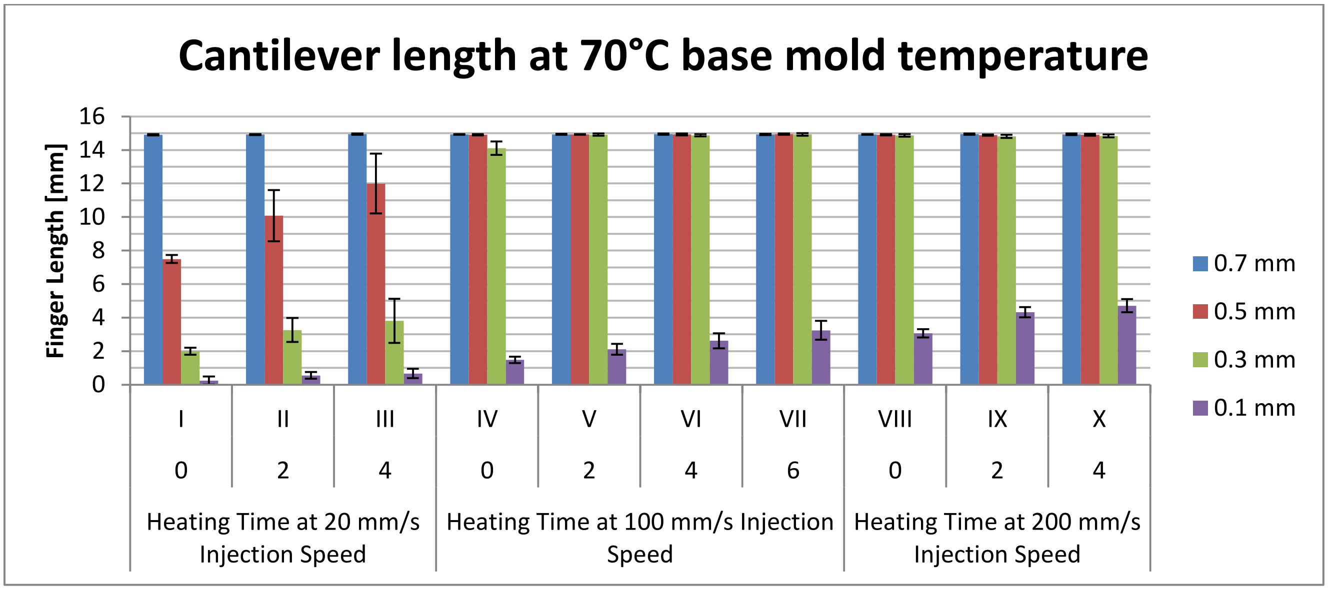

Fig. 10: Cantilever length value reached by the polymer at 70°C base mold temperature.

The comparison of experiments VIII in Fig. 11 and X in Fig. 9 shows also another interesting aspect. In these experiments the length of the cantilever with thickness 0.1 mm is the same. This result was obtained decreasing the base mold temperature from 70 °C to 20-25 °C and adding external induction heating for a time of 2 s. Another interesting observation regarding this last comparison is that the total cycle time for the two process condition is the same.

7. Uncertainty analysis on the optical measurement

An uncertainty analysis was completed in order to assess the accuracy of the cantilever length measurements. One sample was measured twenty times to determine the repeatability of the measurements. The sample was fully removed from the fixture and platform and then replaced. Another source of uncertainty considered in this analysis was from the measuring instrument. The maximum permissible error of the machine was used for the measuring instrument uncertainty. Using the polymer part thermal expansion coefficient, the bias in length from the environmental temperature was removed [7]. The calculated expanded uncertainty with a confidence level of 95% is reported in Table 3.

Table 3: Uncertainties for the 4 fingers

Finger [mm]	Average Length [mm]	Measuring after compensation [mm]	Expanded uncertainty at 95% [mm]
0.7	14.926	14.925	0.029
0.5	11.899	11.898	0.057
0.3	3.787	3.787	0.141
0.1	0.731	0.731	0.231

8. Conclusions

An experimental plan, varying injection velocity and heating/cooling parameters, was carried out on a test geometry with thin and long features. The results show a clear trend regarding the improvement of the replica quality adding an external heating source during the molding. The work shows also that with the aid of the induction heating is possible to reduce the injection pressure and injection velocity, maintaining the same replica quality and cooling time.

Acknowledgements

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References

[1] G.R. Berger, G.A. Pacher, A. Pichler, W. Friesenbichler, D.P. Gruber, "Influence of mold surface temperature on polymer part warpage in rapid heat cycle molding", Proceeding of the Polymer Processing Society 29th Annual Meeting 2013.
[2] W. Michaeli, M. Schongart, F. Klaiber, S.Beckemper, "Variothermal Moulding of Superhydrophobic Surfaces", Proceeding of the 7th International Conference on Multi-Material Micro Manufacture 2010.
[3] D. Yao, S.C.Chen, B. H. KIM, "Rapid Thermal Cycling of Injection Molds: An Overview on Technical approaches and Applications", Advances in Polymer Technology, Vol.27, No.4 233-255 (2008).
[4] S. Menotti, H. N. Hansen, G. Bissacco, P. T. Tang, C. Ravn, "Initial verification of an induction heating set-up for injection molding", Proceeding of ANTEC (2013), April 21-24, 2013 Cincinnati (USA).

[5] C. T. Huang, I. S. Hsieh, C. H. Tsai, "The effects of various variotherm processes and their mechanisms on injection molding", Proceedings of the Polymer Processing Society 26th Annual Meeting, July 4-8, 2010 Banff (Canada)
[6] http://www.styrolution.com/Product/ABS_Novodur-P2H-AT_SKU401200140442.html, access November 2013
[7] L. De Chiffre, "Geometrical Metrology and Machine Testing", DTU Mekanik, 2011.