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DESIGN OF AN INSERT TYPE INDUCTION HEATING AND COOLING SYSTEM FOR INJECTION MOULDING PROCESSES

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Preliminary notes
For some injection moulding processes, the tool must be kept at high temperature when injecting plastic melt. Conventionally, this is achieved by heating the tool with hot oil or water, but heating the entire tool will cause unnecessary energy consumption. Previous studies show that using external induction in order to heat the surface of injection moulding tools is both rapid and energy efficient. However, while using a robot to put the heating coil in front of a tool cavity is very convenient, the tool must be open until heating is finished, making the injection cycle time longer. In addition, repeatedly making the tool surface exposed to too high and low temperatures may quickly damage it. The use of an insert type induction heating coil has thus been proposed to address this issue. Since the heated mass with insert type induction heating is a lot greater than with coil of external induction heating, the former has a slower heating rate on the tool surface, thus extending the life of the tool. In this approach, a coil can heat the tool during the tool opening and ejection process and a cooling channel can also be used to avoid interference with the coil inside the tool, as well as to enable cooling on the cavity surface. This study thus proposes a new tool structure, and a two-cavity tool was fabricated to verify the design concept. The results of a set of experiments show that the coil could heat the tool and achieve temperature uniformity of about 91 %, while the heating rate was about 3 °C/s.

Keywords: *electromagnetic induction heating, insert type coil, temperature uniformity, tool surface temperature*

Projekt sustava zagrijavanja i hlađenja umetanjem indukcijske zavojnice u postupcima kalupljenja uštrcavanjem

Prethodno priopćenje
Kod nekih postupaka kalupljenja uštrcavanjem temperatura alata kod uštrcavanja plastične rastopine mora biti visoka. Uobičajeno se to postiže zagrijavanjem alata toplim uljem ili vodom, ali će zagrijavanje čitavog alata dovesti do nepotrebnog trošenja energije. Ranija istraživanja pokazuju da je primjena vanjske indukcije za zagrijavanje površine alata kod kalupljenja uštrcavanjem i brza i energetski učinkovita. Ipak, iako je vrlo prikladna primjena robota za postavljanje zavojnice za zagrijavanje ispred šupljine alata, alat mora biti otvoren do kraja zagrijavanja, produžujući na taj način vrijeme ciklusa uštrcavanja. Uz to, učestalo izlaganje površine alata veoma visokim i niskim temperaturama može ubrzo dovesti do njegovog oštećenja. Stoga se za zagrijavanje predlaže primjena indukcijske zavojnice tipa umetka. Budući da je masa zagrijana indukcijskim zagrijavanjem umetanjem zavojnice puno veća nego primjenom zavojnice vanjskog indukcijskog zagrijavanja, prvim se načinom postiže sporija brzina zagrijavanja na površini alata i tako produžuje vijek trajanja alata. Kod ovog pristupa zavojnica može grijati alat tijekom otvaranja alata i postupka izbacivanja, a može se također upotrijebiti kanal za hlađenje da se izbjegne interferencija sa zavojnicom unutar alata kao i da se omogući hlađenje na površini šupljine. Stoga se u ovom radu predlaže nova konstrukcija alata te je izrađen alat s dvije šupljine u svrhu provjere koncepta projekta. Rezultati niza eksperimenata pokazuju da se zavojnicom može grijati alat i postići ujednačenost temperature od otprilike 91 %, dok je brzina zagrijavanja bila oko 3 °C/s.

Ključne riječi: *electromagnetsko indukcijsko zagrijavanje, temperatura površine alata, ujednačenost temperature, zavojnica tipa umetka*

1 Introduction

Due to concerns over rising energy cost it is necessary to not only work to enhance production quality in injection moulding processes, but also to reduce energy consumption. An injection process can be divided into four major steps, which are metering, injecting, packing and ejecting. First the solid plastic becomes liquid due to heating and friction, and then the screw injects the melted plastic into the tool. The screw maintains a high pressure in order to prevent the plastic melt shrinking after the tool cavity is filled. The plastic in the tool then cools and solidifies. Tool opens and ejects the product. Plastic melt is a non-Newtonian fluid with high viscosity, although this decreases at higher temperatures. Fig. 1 shows that when injecting the plastic melt into the tool cavity, it flows through the lower temperature tool cavity and creates solidified layer on the cavity and channel surfaces.

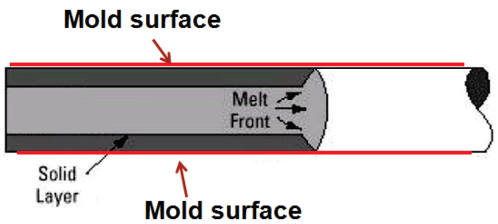


Figure 1 The solidified layer on tool surface

A lower tool surface temperature causes the plastic melt to solidify when filling the tool cavity, and the resulting solidified layer can cause problems with regard to poor replicability, warpage and so on. One way to delay the solidification process is to keep the cavity surface temperature high during filling [1]. Johannaber [2] found that a high tool temperature can decrease injection pressure loss. Chen et al. [3] applied induction heating to injection moulding, in which the tool temperature was raised to 140 °C in 3 s. Fujita et al. [4] showed that the induction heating temperature in different zones can be controlled, and that a higher tool temperature can increase micro-structure transcription. RocTool [5] a moulding technology company developed a tool heating system, called Cage System, which uses differences in the magnetic permeability of materials to cause different induction heating effects in different areas of the tool.

Previous studies have shown that high tool temperature can improve replicability. Most current induction heating methods use a robot to put the heating coil near the tool cavity surface, when opening the tool. In practice, the injection process cycle time is an important factor in the cost of this process, and using a robot to put a coil inside the tool will increase this. The present study thus developed an insert type coil to heat cavity inside the tool base. However, when placing a coil inside the tool base it is necessary to consider both the tool thickness and the cooling system of the tool base. The current study presents details of this innovative cooling system.

Induction heating is based on using a magnetic field to induce an eddy current on the workpiece, which is then heated by resistance, similar to the basic concept of a transformer. Fig. 2 shows a schematic diagram of an example of induction heating process. The induction coil is on the primary side and the workpiece is on the secondary side. An alternating current flows in the primary side and produces an alternating magnetic field. The secondary side is thus induced, and also produces an alternating magnetic field. According to Faraday's Law, the alternating magnetic field on the secondary side will then induce a current, called an eddy current. This eddy current flows through the workpiece which is then heated by electrical resistance.

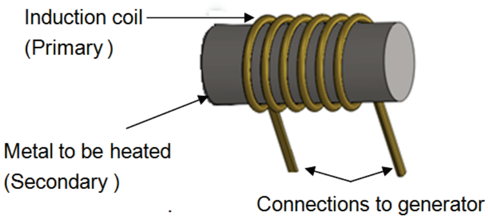


Figure 2 A schematic of induction heating

2 Experiment

Previous studies have shown that the tool temperature is a very important parameter for high quality injection molding, and so induction heating can provide advantages such as rapid heating. In the present experiment a coil was inserted in the tool base, thus avoiding interference, and a novel cooling system design was also applied.

The aim of this study was to develop an insert type induction heating coil capable of uniformly heating the tool. This was achieved with the use of magnetic flux concentrators, which controlled the magnetic field that was applied during this process.

The apparatus used in the present study was a high frequency power generator, a transducer, and a cooling machine. The high frequency power generator provided current output with a maximum frequency of 50 kHz. The cooling machine provided water to cool the temperature of the induction heating coil.

2.1 Carrier

A business card case was designed as the carrier, as shown in Fig. 3. This case can be separated into two parts, with marks on the top cover of the logo of the related university department and a hole on bottom. The top cover was 97,76 mm long, 60,76 mm wide and 8 mm high. The case bottom was 95,56 mm long, 58,56 mm wide and 8 mm high. The case was 1 mm thick. The hole on the case bottom was used to examine whether the welding line decreased due to the high moulding temperature that was used.

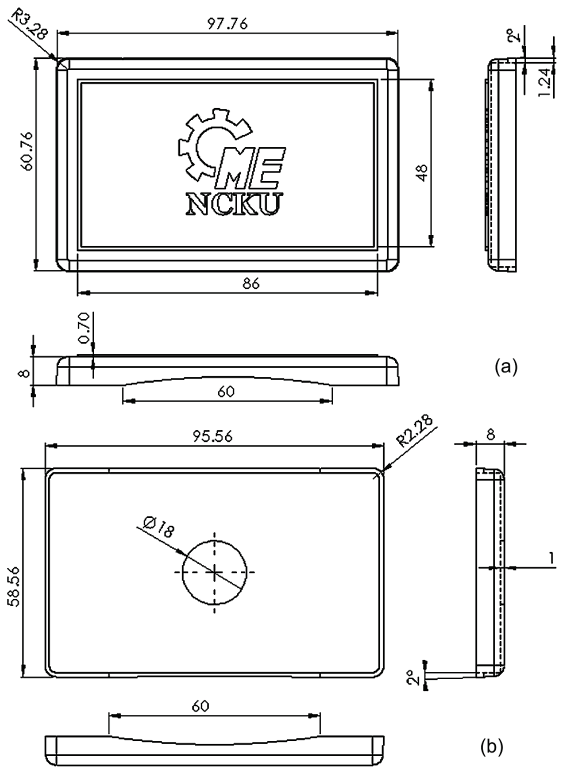


Figure 3 (a) Dimension of the top of the business card case, (b) Dimension of the bottom of the business card case

2.2 Heating Coil Design

Fig. 4 shows the induction heating coil. Since the tool was designed as a two-cavity tool, it was designed to fit into two areas to heat two different cavities. According to Fan [6], a planar spiral coil for which each coil has identical current direction, can induce uneven magnetic fields. Therefore, each coil had the opposite current direction, and magnetic flux concentrators were used to increase the magnetic field toward the heating direction and thus improve heating efficiency.

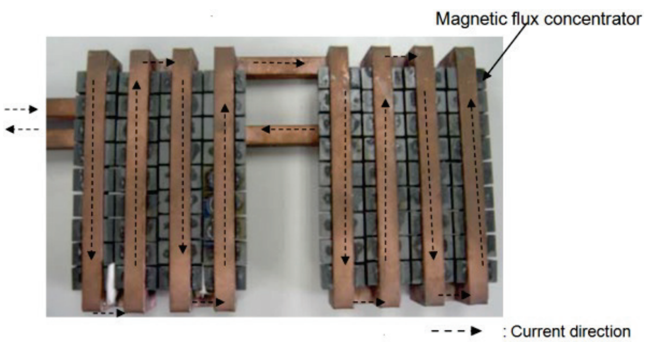


Figure 4 Induction heating coil

2.3 Tool Design

In general, the outer surface of a product requires better surface quality, and thus the insert type coil should be designed to heat the cavities of the tool. The fixed tool base must have one two-cavity base for setting the insert coil unit. The insert coil unit consists of a heating coil, a Teflon plastic base, a PEEK plate and a copper plate. When the coil is inside the tool it should not come into contact with any conductive material in order to avoid short circuiting. For this reason, the coil was set up with a

Teflon plastic base. In addition, a PEEK plate was set up between the coil and the heated tool base. The PEEK plate thickness was 5 mm, so that the coil could maintain a 5 mm distance from the heated tool base. The plastic base bottom was set up with a copper plate to shield the magnetic field and avoid inducting the eddy current in the non-heating direction. The entire insert heating coil unit is shown in Fig. 5. The basic design concept of the tool in this study is to use an additional tool base for internal coil, positioned behind the cavity tool base.

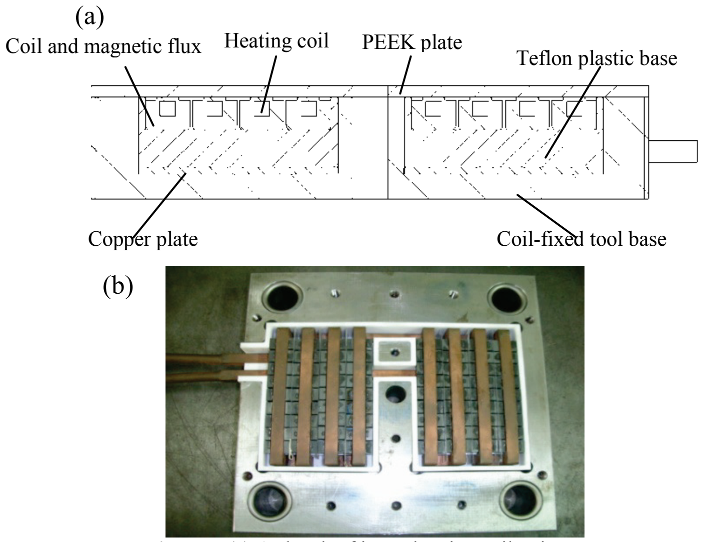


Figure 5 (a) A sketch of insert heating coil unit, (b) A photo of the heating coil in the tool base

Because the cavity needs to be cooled after the packing stage of the injection moulding process, cooling channels were designed in the tool base. The cavity tool base thickness was 22 mm, and the cavity depth was 9 mm. In order to deal with the thermal fatigue on the cavity surface, planar cooling channels were designed and fabricated on the back surface of the cavity tool base. The planar cooling channels are shown in Fig. 6, the depth of the channel is 5 mm, while the tool is shown in Fig. 7. The depth of the cooling channels is 3 mm, and an O-ring was used to avoid cooling water leakage.

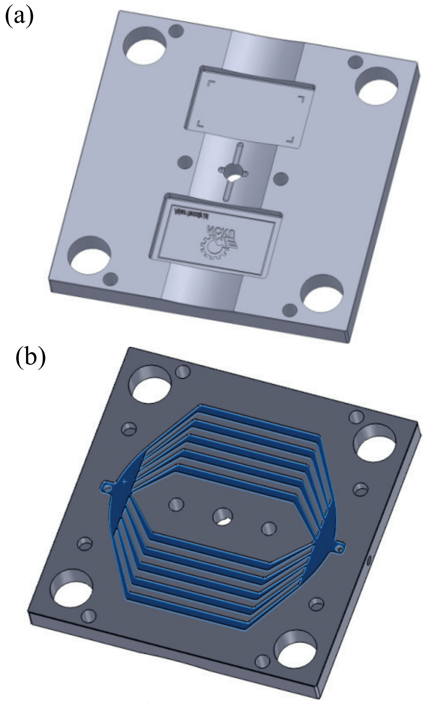


Figure 6 (a) Cavity side of cavity tool base, (b) Planar cooling channel side of cavity tool base

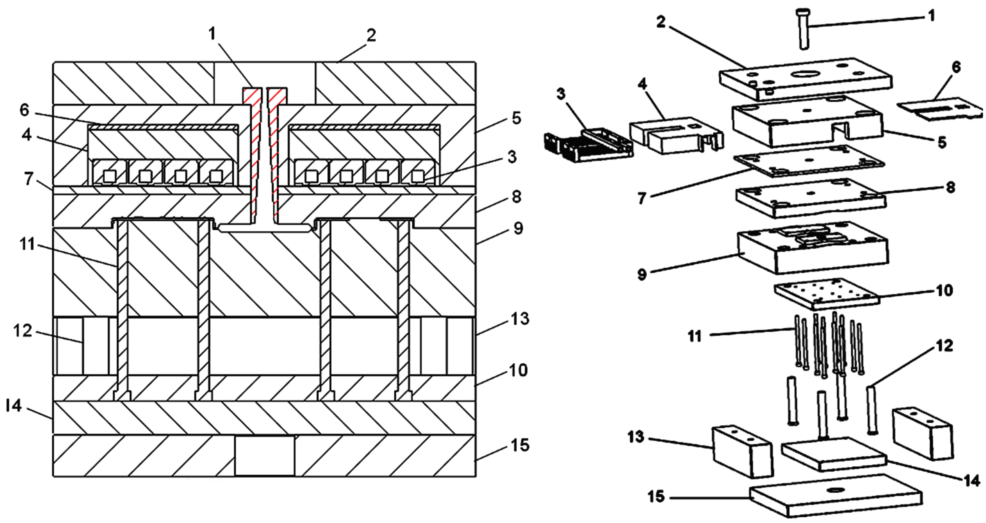


Figure 7 Insert type induction heating tool (1 - Sprue bushing, 2 - Top fixed plate, 3 - Heating coil, 4 - Teflon plastic base, 5 - Coil tool base, 6 - Copper plate, 7 - PEEK plate, 8 - Cavity tool base, 9 - Core tool base, 10 - Ejector retainer plate, 11 - Ejector pin, 12 - Ejector guide pin, 13 - Spacer block, 14 - Ejector plate, 15 - Bottom fixed plate)

2.4 Experiments

(1) A coating was applied on the surface of planar workpiece, so that the emissivity piece surface was close to 0,94.

(2) Heating experiments. Different initial tool temperatures, heating times and heating powers were used, and heat fixed tool base was heated for 15 s. The experimental parameters are shown in Tab. 1. Thermal images were obtained at 0, 5, 15 and 25 s using an

infrared thermal imaging system. The flow of cooling water was turned off during the heating process.

(3) Cooling experiments. The temperature of the cooling water was set at 25 °C. After heating the tool for 25 s, the cooling system was turned on for 45 s. Thermal images were then taken to detect any temperature variations. The experimental parameters are shown in Tab. 2.

(4) Injection moulding with induction heating. In the moulding experiment, all the induction heating apparatus was integrated into the injection moulding process. The coil heated the tool base when the tool was opening and ejecting the product. The injection machine used in the experiment was an Arburg 320C, while the injection material was nylon. The experimental parameters are shown in Tab. 3.

Table 1 Heating experiment parameters

Initial tool temp. / °C	80	90	100
Heating power / kW	16,5 22,5 25,5	16,5 22,5 25,5	16,5 22,5 25,5
Recording time / s	0/ 5/15/25	0/ 5/15/25	0/ 5/15/25

Table 2 Cooling experiment parameters

Initial tool temp. / °C	70
Heating power / kW	21
Heating time / s	25
Cooling time / s	45
Cooling water temp. /°C	25
Recording time / s	0/25/30/35/40/45/50/55/60/65/70

Table 3 Injection moulding experiment parameters

Initial tool temp. / °C	70
Heating power / kW	30
Heating time / s	15
Cooling time / s	25
Cooling water temp. /°C	25
Recording time / s	0/25/30/35/40/45/50/55/60/65/70

3 Experiment Results

Fig. 8 shows the two cavities, the area marked "A" is 95 mm long and 58 mm wide, while that marked "B" is 97 mm long and 60 mm wide. Infrared thermal imaging was used to obtain the temperature measurements. The average temperature and standard deviation of each area were calculated. Temperature uniformity X was calculated by averaging the average temperatures and standard deviations.

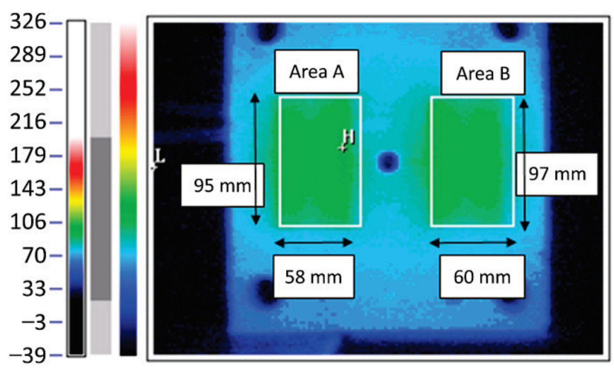
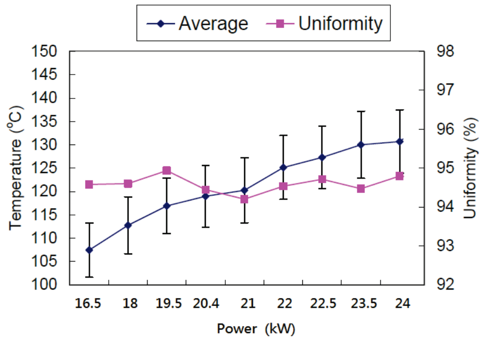


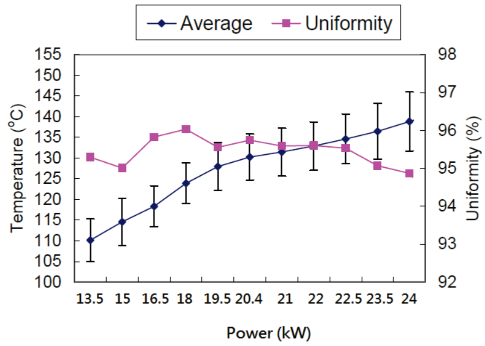
Figure 8 The infrared thermal imaging of two cavities

Table 4 Heating results with different tool initial temperature and heating power levels (at the end of 15 s heating)

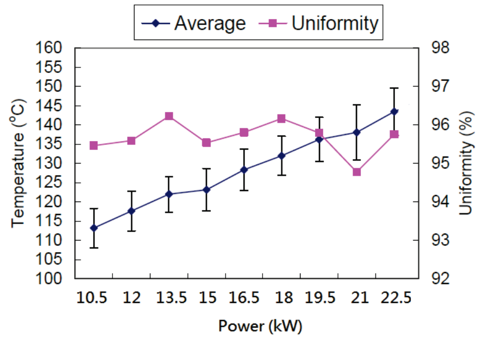
Initial temp. / °C	Heating power / kW	Average temp. / °C	Standard deviation	Temp. uniformity / %
80	16,5	107,45	5,82	94,58
	18	112,79	6,09	94,60
	19,5	116,94	5,92	94,94
	21	120,27	6,97	94,20
	22,5	127,30	6,73	94,71
	24	136,82	7,24	94,71
90	16,5	118,33	4,94	95,83
	18	123,87	4,91	96,03
	19,5	127,95	5,69	95,55
	21	131,43	5,80	95,60
	22,5	134,60	6,01	95,53
	24	138,82	7,12	94,87
100	16,5	128,34	5,38	95,81
	18	132,00	5,06	96,17
	19,5	136,22	5,73	95,80
	21	138,05	7,21	94,78
	22,5	143,45	6,79	95,75
	24	147,60	6,62	95,51



(a) Heating results with initial temperature of 80 °C



(b) Heating results with initial temperature of 90 °C



(c) Heating results with initial temperature of 100 °C

Figure 9 Heating results with initial temperatures of 80 °C, 90 °C and 100 °C at 15 s of heating

Tab. 4 shows the heating results with different initial temperatures and heating powers. The heating time for each case was 15 s. The results show that, at the end of heating, the temperature uniformity was about 94~95 %

with an initial temperature of 80 °C, and uniformity was about 95~96 % with initial temperatures of 90 °C and 100 °C. The uniformity was thus better at a higher initial temperature. However, the heating power levels had no significant effects on temperature uniformity.

Figs. 9 (a), (b), (c) show the heating results with initial temperatures of 80 °C, 90 °C and 100 °C, respectively.

The temperature variation after heating 15 s was also calculated, and the heating rates for each initial temperature with heating powers 16,5 kW, 18 kW, 19,5 kW, 21 kW, 22,5 kW and 24 kW are shown in Tab. 5. The heating rate increased at higher power levels, but the initial tool temperature had no significant effects on this.

Table 5 Heating rates under different conditions

	Heating power / kW	Initial temp. 80 °C	Initial temp. 90 °C	Initial temp. 100 °C
Heating rate / °C/s	16,5	1,83	1,89	1,89
	18	2,23	2,26	2,13
	19,5	2,46	2,53	2,41
	21	2,68	2,76	2,54
	22,5	3,15	2,97	2,90
	24	3,38	3,25	3,17

Fig. 10 shows the thermal images taken at 0, 25, 35, 45, 55 and 65 s for the cooling experiment.

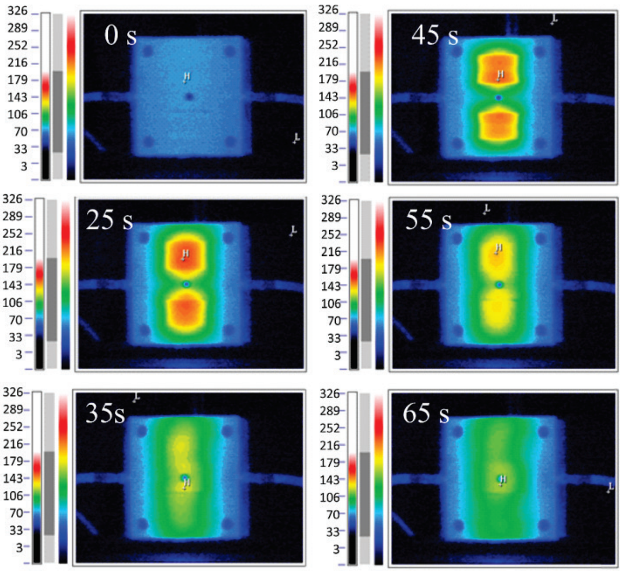


Figure 10 Thermal images obtained at 0, 25, 35, 45, 55 and 65 s for the cooling experiment

Table 6 Results of the cooling experiment

Time / s	Average temp. / °C	Standard deviation	Temp. uniformity / %
0	69,05	1,01	98,54
25	137,47	11,23	91,83
30	145,52	12,33	91,53
35	139,79	11,89	91,50
40	132,05	11,28	91,46
45	124,76	10,40	91,67
50	118,79	9,46	92,04
55	113,05	8,46	92,52
60	107,76	6,97	93,53
65	104,34	6,39	93,88
70	101,15	5,72	94,35

Tab. 6 shows the result of cooling experiment, including average temperature, standard deviation and uniformity. The initial mould temperature was 70 °C and the power level was 21 kW.

Fig. 11 shows the average temperature and uniformity for the cooling experiments, with the maximum temperature being 145 °C at 30 s. The temperature continued to increase for 5 s after the heating was turned off, because heat was conducted from the tool base to the surface.

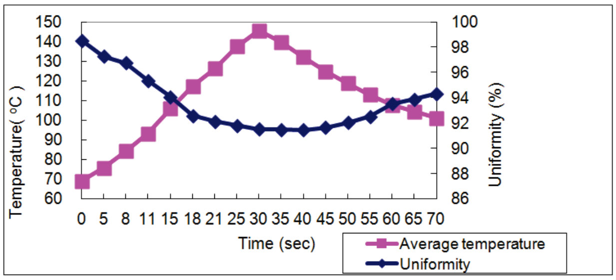


Figure 11 Average temperature and uniformity in the cooling experiments

Fig. 12 shows the tool setup in an Arbuge 320C machine. The induction heating process was included in the control sequence of the injection cycle, and thus was fully automatic. After opening the tool and ejecting the moulded product, the induction heating process was carried out for 15 s, and the tool was then closed and ready for the next injection moulding. During the heating and injection processes, the cooling system was turned off.

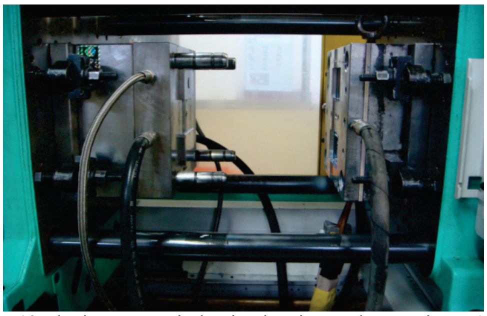


Figure 12 The insert type induction heating tool set up in an Arbuge 320C machine

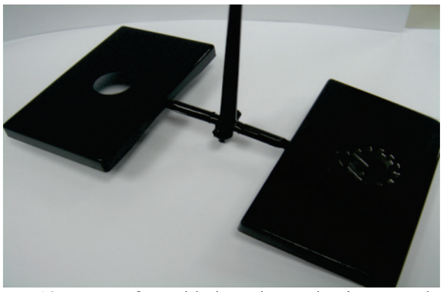


Figure 13 Image of moulded product, a business card case

Fig. 13 shows an image of the injection moulded product, with no welding line on surface. In the injection moulding experiment the induction heating power was set at 30 kW and the tool for 15 s. After heating, the temperature of the tool surface reached 125 °C.

4 Conclusions

Based on the results presented in this study, the following conclusions are made:

1) Insert type induction heating has a number of advantages, such as uniform heating, high heating rate and lower injection cycle time, even for a multi-cavity tool. The use of cooling channels also means that the cooling process can be very uniform.
2) Although the heating power had no significant effects on temperature uniformity, the heating rate increased along with the heating power. The average temperature also increased due to an increase in heating power.
3) The heating test results with the cooling system setup showed that the heat uniformity was higher than 91 %, and the heating rate was about 3 °C/s.
4) The results of injection moulding showed the insert type coil could successfully heat the tool. The injection moulding products produced in this way had high-gloss surface without welding lines.

In addition to improving the quality of the moulded product, the use of an insert type coil was also able to reduce the cycle time, while the use of cooling channels enabled more uniform tool cooling.

Remark

The article was presented at and recommended by the ASPEC2013 Conference.

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