Experimental Investigation of Infrared Rapid Surface Heating for Injection Molding

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ABSTRACT: A low cost and practical infrared rapid surface heating system for injection molding is designed and investigated. The system was designed to assemble on the mold and a control system was used to operate the motion of the lamp holder. Four infrared halogen lamps (1 kW each) were used as the radiative source to heat the surface of mold insert. The temperature increase is verified on the mold plate with a thermal video system. Two types of specular reflectors combined with different bulb configurations were applied to study the heating ability of radiation heating. A modified spiral flow mold was used to test the enhancing filling ability of the rapid surface heating system. Three resins, PP, PMMA and PC were molded in the spiral flow injection molding experiments. If spherical reflector and centralized lamp configuration are used, the temperature at the center of the mold surface is the highest. The temperature of mold center surface is raised from 83°C to 188°C with 15 s of infrared heating. Because the surface temperature of the mold insert is higher than the glass transition temperature of resins before filling, the flow distance of resins in the modified spiral flow mold will be increased. The location effect of the infrared surface heating system on a thin-long cavity was studied to demonstrate the possibility of using smaller infrared heating area on a large mold surface. A microprobe cavity also demonstrated that with the assistance of infrared heating technology the formability of a microprobe can be greatly improved. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 102: 3704–3713, 2006

Key words: injection molding; variotherm; infrared; rapid surface heating

INTRODUCTION

Microinjection molding is one of the most promising fabrication technologies for thermoplastic polymer microparts. Microinjection molding can be classified as microfeatured parts and microparts. The volume of microfeatured parts could be normal but there are many microfeatures on it. Aspect ratio of microfeature is the main molding ability concern for injection molding. Typical microfeatured parts are DVD, light guide plate of LCD and the aspect ratio of their microfeatures is less than 1. The size of the microparts is very small and the weight of the microparts is usually dozen of milligrams, for example, microgear of watches and optical fiber connectors.

Molding microfeatured parts or microparts is always a challenge for engineers. Auxiliary technologies have been applied to help the microinjection molding process. Some of the well-known auxiliary technologies are variotherm process and vacuum assisted molding process.[1–3] Depending on the type of variotherm system, the variotherm process could be applied before or after mold clamping. With proper variotherm heating process, the surface temperature of the microstructured mold insert will be higher than the resin heat deflection or glass transition temperature. When filling the cavity of the mold insert, higher mold temperature will delay the solidification process of the resin and keep the resin in liquid or flowable state. Thus the microfeatures in a microinjection molded part can be well maintained. However, with higher mold temperature, the cycle time of the injection molding will be longer. Despa et al.[4] have molded high aspect ratio microfeatures and studied the injection molding processes. They demonstrated that high mold temperature, generally higher than the resin heat deflection temperature, is helpful for molding microfeatured parts. Besides, it is difficult to fabricate air ventilation channels in a micromold insert because the size of air ventilation channels can be larger than that of microfeatures. If high injection rate is used to prevent the unwanted solidification and no suitable air vent or vacuum system exists, the air in the cavity of the mold insert will cause burned marks under high injection rate and blunt corner of the microfeatures.[5]

In general, practical variotherm system is a rapid surface heating technology, which raises the surface temperature of the mold insert before resin injection. Chen et al.[6] have studied the electromagnetic induction heating on a mold plate. The power of the induction system is 30 kW. The maximum temperature of the mold plate can be raised from 40°C to 140°C in 14 s and the maximum temperature is located near the

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inductive coils. Therefore, the geometry of inductive coils is important and it should be operated by a robotic arm. Yao and Kim.[7] have developed a rapid thermal response molding technique by coating two layers, one metallic heating layer and one oxide insulation layer, on the mold insert surface. The surface temperature of the mold insert could be raised from 25°C to 250°C in 2 s. The thermal stresses built up due to thermal mismatch between the heating layers during heating and cooling will influence the surface reliability of the mold insert. So, the material and the quality of the coating layers are very important on this technology. Saito and Satoh.[8] have developed an active temperature control for injection molding process. A Zinc-selenite transparent mold window and CO_2 laser radiation energy source were used to heat molten resin during filling stage. With this special technique, the quality of microfeatured parts can be improved. But most microfabrication techniques are exerted on silicon substrate or using electroforming (electrodeposition) to form Nickel-based microfeatured mold insert. It is not easy to fabricate microfeature on glass-based substrates and this will limit the practicality of this type variotherm technique.

Rapid thermal processing (RTP) using radiation heat transfer is a popular technology that is widely used in the semiconductor manufacturing processes such as chemical vapor deposition (CVD) on silicon substrates. Because of vacuum environment in the CVD chamber, radiation is a more efficient way to heat the silicon substrates rapidly. Some researchers have studied the temperature control of the RTPCVD system.[9–12] Short wavelength ($\sim 1\ \mu m$) halogen lamps are used as the infrared source. Silicon substrate is insulated by quartz pillars and the temperature of silicon substrate can be raised from 300 K to 1300 K in 10 s. Kim et al.[13] have demonstrated that infrared surface heating process can enhance the molding ability of microchannel components. The surface temperature can be raised from 110°C to 350°C in 20 s. But they did not mention the geometry and surface properties of reflector or the power of the infrared lamps. The depth of the channels is 100 μm but the maximum aspect ratio is unknown. Krauss-Maffei Corp. has applied the infrared variotherm system in the injection molding processes. (http://www.krauss-maffei.de/k/english/) The surface temperature can be raised from 60°C to 115°C in 20 s. For all the referred papers mentioned above, there have been no quantitative studies on the effects of infrared aided surface heating technology. There's no report on the effect of using reflector on an IR surface heating system, either.

For microinjection molding, a practical and economic rapid mold surface heating system is needed. In this study, an infrared heating system for injection molding is designed and fabricated. The system was designed to assemble on the mold and a control system was used to operate the motion of the lamp holder. Four infrared halogen lamps (1 kW each) were used as the radiation heating source to heat the mold surface. At the beginning of this research, the authors were wondering whether it is necessary to heat the whole mold for large microfeatured parts such as backlight panels. If the answer is ''yes,'' then the power needed to heat the whole model would be enormous, and the applications of the rapid surface heating technology would be very much limited. If the answer is ''no,'' then how to implement a small area rapid surface heating system to a large mold will be a very important job. Since uniform temperature distribution is not possible for any rapid surface heated mold surface no matter what type of heating technology is applied, the necessity of using reflector to focus the energy on key points such as runners, sprue or gates is raised. Thus, all the experiments executed in this paper are intented to answer all the questions. A modified spiral flow mold was used to study the enhancement ability of various designs of the rapid mold surface heating technique. By injection molding experiments on the spiral flow mold, the heating enhancement ability of the radiation heating can be identified. Since, the reflector geometry and lamp configuration can affect the resin filling capability of a mold, two types of specular reflectors and two different configurations of lamps were applied to study the filling enhancement ability of the rapid surface heating system and determine which design is better.

INFRARED HEATING SYSTEM AND THE MODIFIED SPIRAL FLOW MOLD

In this study, a frame and a guided pneumatic cylinder are the main components of the infrared heating system (Fig. 1). The infrared heating system is assembled

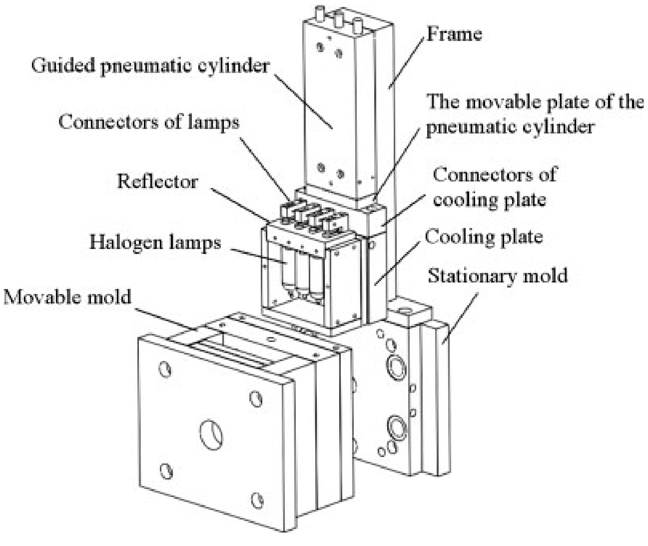


Figure 1 Assembled schematic of the infrared heating system and spiral flow mold.

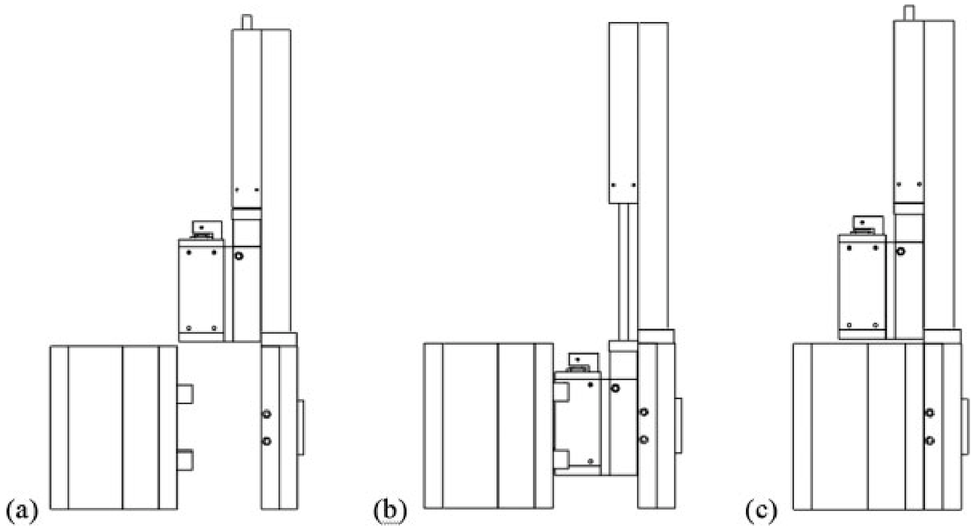


Figure 2 Schematic of the infrared heating processes (a) mold is open and lamp holder is standby (b) lamp holder moves between the mold and lamps are turned on (c) mold is closed and resin is injected.

with the stationary mold. The movable plate of the pneumatic cylinder is fixed to a cooling plate and the cooling plate is connected to the reflector. The cooling plate is used to lower the temperature of the guided compressed pneumatic cylinder and protect the switch sensors and the rubber piston inside the cylinder from over heating. The coolant of the cooling plate is water and the temperature of the coolant is around 25°C. The temperature of the pneumatic cylinder is maintained to be lower than 50°C.

Four infrared halogen lamps are placed in a lamp holder and the power of each lamp is 1 kW (PHILIPS 6990P). The temperature of the lamp filament will reach 3100 K at 120 V. The diameter of the lamp is 20 mm and

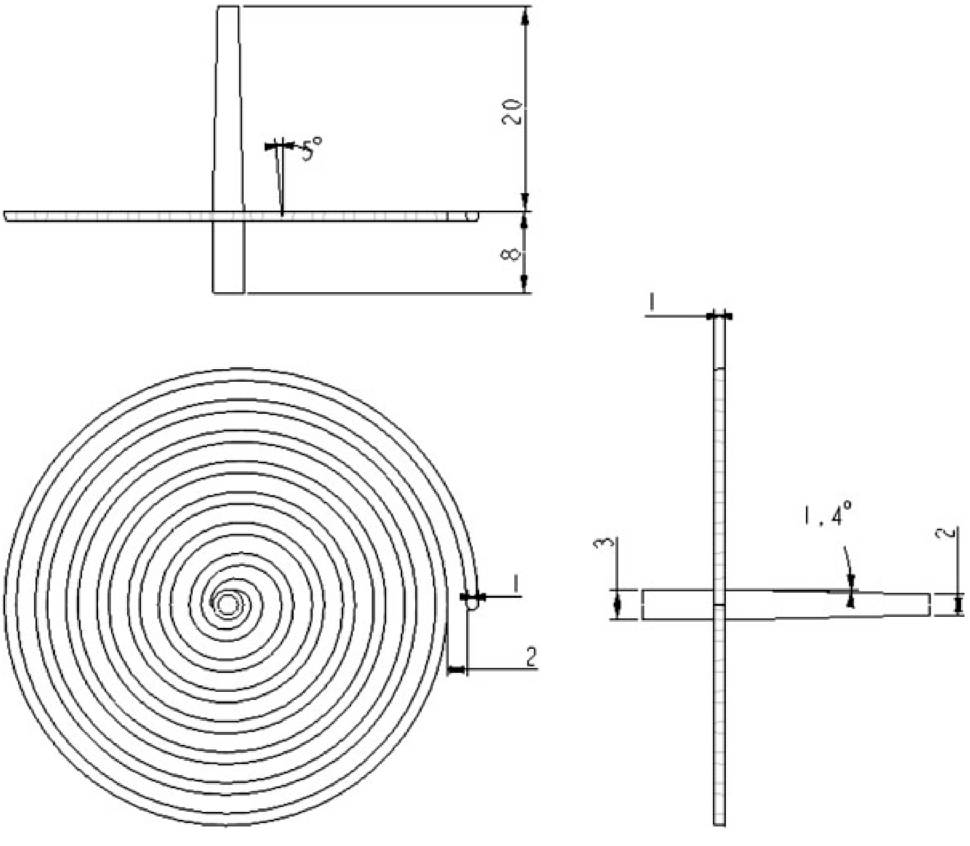


Figure 3 Dimensions of the modified spiral flow molded part (unit : mm).

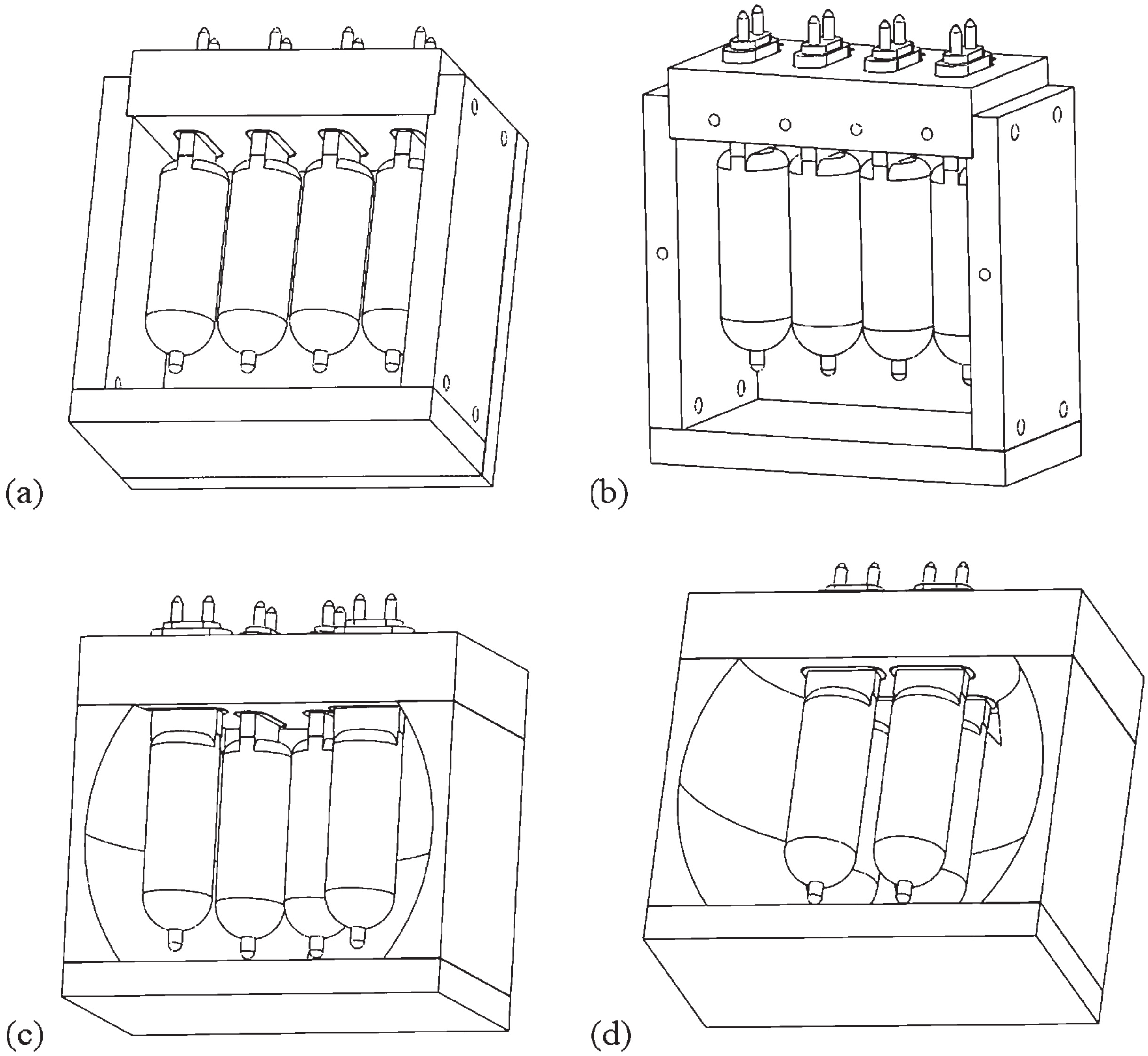


Figure 4 Types of the reflectors and lamps configuration (a) flat reflector for single side irradiation (b) double side irradiation without reflector (c) spherical reflector and scattered lamp configuration (d) spherical reflector and centralized lamp configuration.

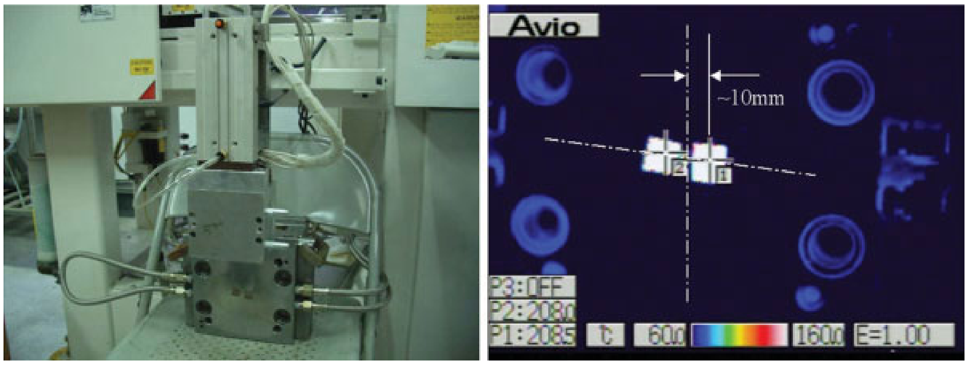


Figure 5 Pictures of infrared heating system and surface temperature of the stationary mold plate measured by thermal video system (AVIO TVS-600). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

TABLE I
Central Temperature of the Stationary Mold Surface Measured by Thermal Video System

	Mold temperature (°C)		
	Spherical reflector centralized lamp configuration	Spherical reflector scattered lamp configuration	Flat reflector
15-s heating	184.5	170.35	145.65
15-s Heating (no coolant circulation)	188.15	180.7	143.05
20-s Heating	188.3	185.15	151.5
20-s Heating (no coolant circulation)	208.25	194.05	156.85
5 s after heating			
15-s heating	136	132.55	116.7
15-s heating (no coolant circulation)	143.1	144.55	118.55
20-s heating	141.3	143.4	124.2
20-s heating (no coolant circulation)	159.65	156.65	131.65

the length is 105 mm. The stable time of filament irradiation is about one second after supplying power. To fix the lamps stably on the reflector, each lamp is connected to a special phenolic connector and heat-resistant electric wires are clipped with the electrodes of the lamps. A variable-volt power supply was used to provide 120 V for full intensity of the infrared. The schematics of the infrared heating system are shown in Figure 2. When mold is open, the lamp holder is standby at the upper stage. Then, the lamp holder moves between the mold and lamps are turned on for heating. At the end of heating cycle, the lamp holder moves upward and the mold clamped for injection. A personal computer based control system was established for infrared heating system. The motion of the pneumatic cylinder is controlled by IO card (input-output card), magnetic switch, relay, and electromagnet valve. The power supply of the lamps is operated by IO card and solid stage relay (SSR). Also, a friendly user interface was designed to operate the infrared heating system.

To study the mold filling ability improvement of the infrared heating system, a spiral flow mold was modified in according to ASTM D569-82 and ASTM D3123-72 standards. ASTM D569-82 is the standard method for measuring the flow properties of thermoplastic molding material and ASTM D3123-72 is the standard test method for spiral flow of low-pressure thermosetting molding compounds. Because the infrared heating system is designed for injection molding small parts or microfeatured parts, the size of spiral flow test part cannot be large. In Figure 3, the width of the spiral flow is 1 mm with draft angle 5° and the pitch is 2 mm. If the temperature rise of the infrared heating system is obvious, the length of the spiral flow part will be longer than that without heating. For easy measurement of the spiral flow length, the spiral flow mold cavity is marked every 3 mm along the flow direction. A standard mold base (180 mm × 180 mm) is used for the test spiral flow mold. The prehardened tool steel (AISI P21) is adopted as the material of the mold insert.

Two types of reflector surface, flat and sphere, were used to observe the reflective ability of infrared surface heating. The flat reflector with scattered lamps is shown in Figure 4(a). If the flat reflective plate is removed, the infrared could irradiate both sides of the mold [Fig. 4(b)]. The spherical reflector with scattered lamp configuration [Fig. 4(c)] and centralized lamp configuration [Fig. 4(d)] were used to experiment the heating ability. The reflector material is aluminum alloy and polished for high reflectivity.

ANALYSIS AND MEASUREMENT OF THE MOLD SURFACE TEMPERATURE

To observe the thermal condition of the mold surface, an AVIO TVS-600 thermal video system was set up to

TABLE II
The Properties of the Resins Used in the Experiments

Property	Test method	FU-GE PP PT231	Chi Mei PMMA CM-205	GE PC Lexan HF1130
Heat deflection temperature (°C)	ASTM D-648	104	100	127
Melt flow rate (g/10 min)	ASTM D-1238	25	1.8	25
Density (g/cm^3)	ASTM D-792	0.904	1.19	1.2
Shrinkage (%)	ASTM D-955	1.25	0.2–0.6	0.5–0.7
Window of injection temperature (°C)	–	200–280	210–250	271–293
Injection temperature of the spiral flow mold experiment (°C)		215	245	275

TABLE III
The Molded Lengths and Increased Flow Length of Spiral Flow Parts

Length of spiral flow part (mm)\ Increased flow length (%)	Material		
	PP	PMMA	PC
Without heating	57.3 (0)	10.9 (0)	10.2 (0)
Double side (15 s)	65.1 (13.5)		
Double side (20 s)	66.2 (15.5)		
Flat (15 s)	70.1 (22.2)		
Flat (20 s)	73.2 (27.5)		
Spherical scattered (15) s	77.8 (35.5)		
Spherical scattered (20 s)	82.0 (42.9)		
Spherical centralized (15 s)	80.1 (39.6)	15.4 (41.5)	11.9 (16.3)
Spherical centralized (20 s)	83.9 (46.2)	16.5 (51.6)	13.0 (27.1)

The values given in parentheses are percentages

measure the central temperature of the mold surface (Fig. 5) The resolution of thermal video system is 0.15°C and the resolution of image is 320 × 240 pixels. Because the temperature of specular mold surface cannot be measured precisely by thermal video system, two heat-resistant tapes were glued on the center of the mold surface for thermal video measurement. The emissivity of heat-resistant tape is around 1 and the measured temperature is verified with thermal couple temperature measurement results. It is difficult to measure the temperature distribution of the whole mold surface. If the tape is glued on the whole surface of the mold, the emissivity condition deviates a lot from the original infrared heating. Thus, there is no alternative but using small tape to measure the central temperature on the mold surface.

When under stable condition, the temperature of the mold surface is maintained at 83 ± 1°C before infrared heating process. Owing to the uneven spiral flow mold insert surface structure, the temperature measurement of the spiral flow mold insert surface is difficult. Therefore, the temperature measurement of the infrared surface rapid heating was done only on the stationary mold plate, which is a flat plate. The results of measured temperature shown in Table I are averaged from Point 1 and Point 2 temperature measurements at the center of the mold surface (Fig. 5). In Table I, the temperature of the mold center surface was observed with or without coolant circulation at the moment when the lamp holder is lifted. The heating time is including the stable time of the halogen lamp ($\sim$ 1 s). Besides, the temperature after 5 s from heating was observed. In generally, the duration of mold closing process, from lamp holder lifting to mold clamping, is about 4–5 s. The clearance between reflector and mold surface is around 2 mm. Thus, some infrared rays will irradiate out from the clearance.

From the result of the measurement, it is observed that increased temperature is proportional to heating time. The mold surface temperature will be higher with coolant circulation closed during heating period. The temperature at the central surface of the mold heated by spherical reflector with centralized lamp configuration is better than the other two cases. 5 s after heating, the central temperatures of spherical reflectors with centralized and scattered lamp configurations are very close but are higher than that of flat reflector.

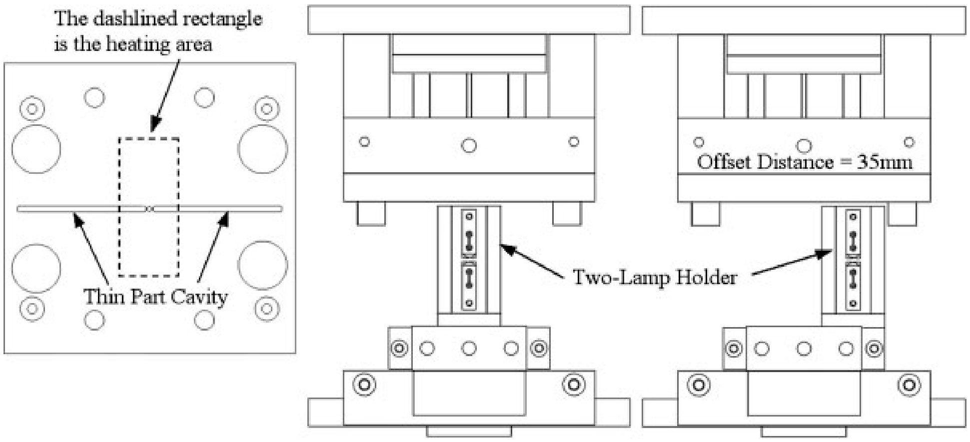


Figure 6 Schematics of the thin part mold cavity and the offset condition of IR lamps.

RAPID SURFACE HEATING ASSISTED MOLDING TEST OF THE SPIRAL MOLD

The injection molding experiments of the modified spiral flow mold were executed on a Sodick TR30EH injection molding machine, which is an electric-hydraulic hybrid preplasticating injection molding machine. The injection speed and pressure were set as 80 mm/s and 40 MPa, respectively. Because the filling ability of the resins is the main concern in the experiment, the packing pressure is unnecessary for the spiral flow molding. The clearance between the reflector and mold surface is also 2 mm. The cycle time of injection molding includes infrared heating processes is less than 1 min.

Three resins, PP, PMMA and PC were chosen to investigate the heating ability of the infrared heating system in spiral flow injection molding. The properties of the resins are listed in Table II. The heat deflection temperatures of PP, PMMA and PC are 104°C, 100°C, and 127°C, respectively. Five seconds after heating, the central temperature of mold surface is higher than the heat deflection temperature from the experimental result except for the flat reflector (Table I). The melt index of PP and PC are both 25 g/min and the melt index of PMMA is only 1.8 g/min. Generally, the resin with higher melt flow rate has better filling ability.

From the results of the experiments with PP (Table III), the heating ability of spherical reflector and centralized lamp configuration is the best (increased flow length = 46.2% with 20 s. heating). The spherical reflector could focus the infrared at the center area of the mold surface, but flat reflector could not. Since the gate of the spiral flow part is at the center of the mold, focused heating can raise the gate temperature to a higher level and thus has better flow enhancement ability. The phenomenon is the same for PMMA and PC resins (increased flow length = 51.6% and 27.1% respectively, with 20 s. heating). The lengths of spiral flow parts of PMMA and PC without infrared heating are very close. Although the melt index of PMMA is much smaller than PC, the increased flow length of PMMA is almost twice as that of PC under the same injection conditions. One of the possible reasons for this phenomenon is that PC has higher injection temperature and narrower window of injection temperature.

TABLE IV
Process Conditions of the Heating Location Injection Molding Experiment

Process	Value
Injection speed	20 mm/s
Injection pressure	30 MPa
Resin	FU-GE PP (PT231)
Cooling time	15 s
Mold temp.	80°C
Nozzle temp.	215°C
IR power	2 kW
Heating time	20 s

TABLE V
The Filling Length of a Thin Part Enhanced by Flat Reflector IR Heating

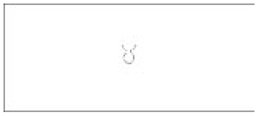
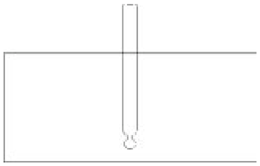
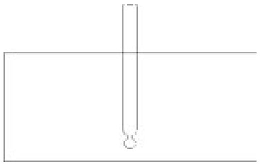
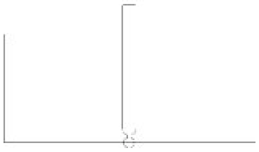
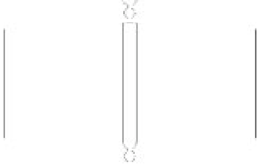
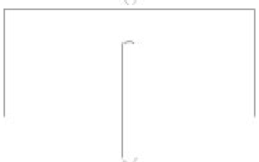
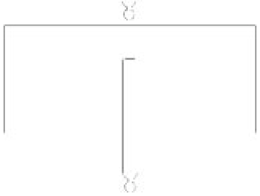
		Offset distance of lamps from center				Offset distance from center			
	No heating	0	5	10	15	20	25	30	35
Filling length (mm) & Increased rate (%)	30.85	34 (10.2)	34.4 (11.5)	35.5 (15.1)	36.3 (17.6)	34.9 (13.1)	34.2 (10.8)	33.8 (9.6)	33 (6.9)
Schematics of heating area (rectangle) & Filling part									

TABLE VI
The Filling Length of a Thin Part Enhanced by Spherical Reflector IR Heating

	Offset distance of lamps from center					Offset distance from center			
	No Heating	0	5	10	15	20	25	30	35
Filling length (mm) & Increased rate (%)	31.25	34.9 (11.7)	35.9 (14.9)	36.3 (16.1)	36.8 (17.8)	36.7 (17.4)	36.1 (15.5)	34.7 (11)	34.2 (9.4)

The heating ability of the centralized lamp configuration is better than that of the scattered lamp configuration. Because the gate of the spiral flow part is at the center of the mold, the centralized lamp configuration has better flow enhancement ability. If the infrared irradiates both side of the mold surface, the energy absorption of mold surface is less than single side heating. That is why the heating ability of the flat reflector is better than that of the double side irradiation with PP. If the mold need double side irradiation, two set of lamp holder are required for better surface heating.

HEATING LOCATION STUDY OF RAPID SURFACE HEATING

Another injection molding experiment was executed to study the effect of heating location of the mold insert. From the result of pervious experiment, it is known that the infrared rapid surface heating process will increase the filling length of the thin or long parts. If the mold cavity area is larger than the infrared heating area, the heating location of the mold surface will have significant effect on the resin filling length.

To study the effect of infrared heating location of the mold cavity, a thin and narrow mold cavity was fabricated and a set of two-lamp holder was prepared. The width, thickness, and length of thin mold cavity are 4 mm, 0.8 mm, and 75 mm respectively. The schematics of thin mold cavity and the two-lamp holder assembled on the mold are shown in Figure 6. The dimension of the lamp heating area is 30 mm × 75 mm. The two-lamp holder can be adjusted to lateral locations with a distance of every 5 mm and the maximum offset distance from mold center is 35 mm. Besides, two types of reflectors, flat and spherical, were applied to compare the heating ability. In this experiment, only one side of the thin part was heated. The filling length of the thin part was recorded for each lamp location. Also, the packing process was omitted to observe the filling length of the thin part. The detailed process conditions are shown in Table IV.

The filling length and the increased length percentage of the thin part enhanced by flat reflector IR heating process are shown in Table V. The schematics of heating area (inside of rectangle) and filling part are also shown in Table V. The filling length and the increased length percentage of the thin part enhanced by spherical reflector IR heating process are shown in Table VI. Because the experiments were not executed at the same time, the filling lengths of thin part without heating were not the same in Table V and Table VI. It can be observed that the heating ability of spherical reflector is better than that of the flat one and the best location of the heating lamps is not at the gate (offset distance of lamps = 0). The molding results of the thin part are compared in Figure 7 and Figure 8. It is obvious that the best offset distance of infrared lamps is around 15 mm from mold center. That's the location where maximum energy is focused on the beginning stage of heating. The results are useful information for

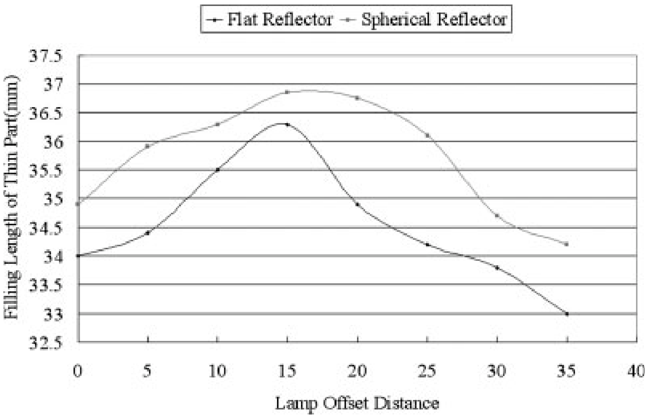


Figure 7 Filling length of thin part enhanced by IR rapid surface heating process.

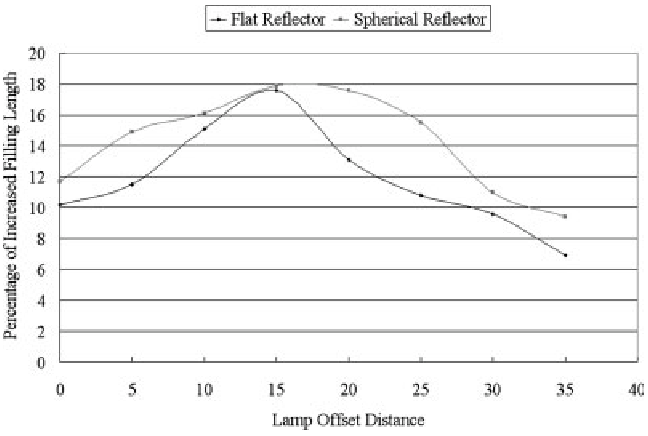


Figure 8 Percentage of increased filling length of thin part enhanced by IR rapid surface heating process.

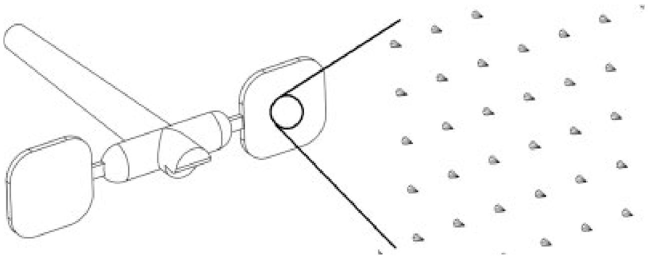


Figure 9 Schematics of microfeatured part with sharp probes.

engineers to design the location of the heating lamps if a smaller lamp is designed to use in a big mold.

DEMONSTRATION ON MICROFEATURED INJECTION MOLDING

In our pervious study,[5] the formability of microprobe array was studied. Although the formability of microprobe can be improved by injection compression molding process, the tips of microprobe are not sharp enough for most practical applications. Thus, it is meaningful to demonstrate the benefit of infrared rapid surface heating process on microfeatured injection molding. The molded part of this experiment is shown in Figure 9. The thickness of the part is 0.6 mm and there are hundreds of microprobe on the part surface. The height of microprobe is about 80 μm and the aspect ratio is 1.7. The spherical reflector with centralized four-lamp configuration was adopted in this experiment. The detailed process conditions are shown in Table VII. Figure 10 shows the schematics of microprobe mold cavity surface and the infrared heating area. The center of the infrared heating area is very close to the microprobe cavity.

Figure 11 shows the picture of the injection molded part without IR rapid surface heating. Most tips of the microprobe are not sharp and some microprobe are very short obviously. Comparing with the result of microprobe injection molding assisted by IR heating process (Fig. 12), all the tips of microprobes are much sharper. All microprobes are molded completely, and the worried air trap phenomenon is gone. Therefore, it is obvious that the infrared rapid surface heating technology can improve the fidelity of the microfeatured injection molded parts. IF flat reflector is used, more than 20 s of heating time is required to achieve the same results as 20 s heating with spherical reflector.

TABLE VII
Process Conditions of Heating Location Injection Molding Experiment

Process	Value
Injection speed	60 mm/s
Injection pressure	30 MPa
Packing pressure	15 MPa
Packing time	4 s
Cooling time	15 s
Mold temp.	80°C
Resin	FU-GE PP (PT231)
Nozzle temp.	215°C
IR power	4 Kw
Heating time	20 s

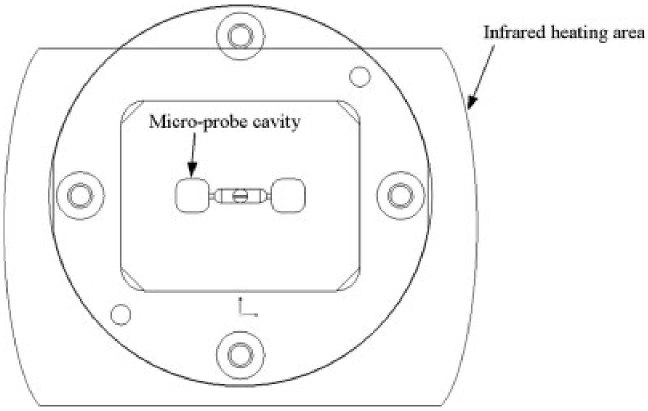


Figure 10 Schematics of microprobe mold cavity and the infrared heating area.

CONCLUSIONS

In this study, a low cost and practical infrared rapid surface heating system for injection molding was investigated. The heating ability of the infrared heating system was examined on the mold plate by thermal video system. A modified spiral flow mold was used to test the enhanced filling ability due to rapid heating of mold surface. The temperature at the mold center surface heated by spherical reflector and centralized lamp configuration is the highest. Because the surface

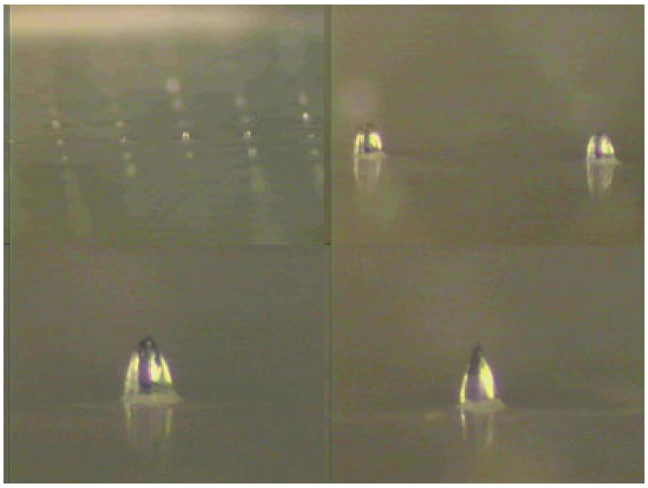


Figure 11 Results of microprobe injection molding without IR rapid surface heating. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

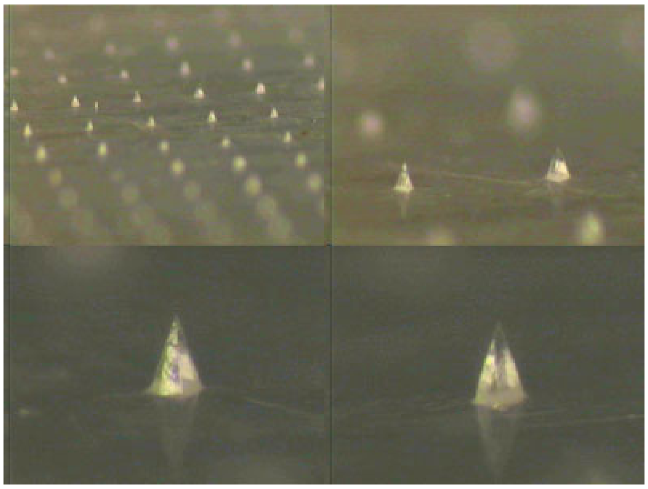


Figure 12 Results of microprobe injection molding assisted by IR heating process. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

temperature of mold insert is higher than that of the heat deflection temperature of the resins after heating, the filling ability of resins are improved. Although the filling process of the spiral flow part is dependent on the injection molding parameters, the results of the experiment do show great improvement in filling ability. The results of thermal video measurement also match the spiral flow injection molding experiments.

As for the location study of the infrared rapid surface heating, it could be summarized that the best rapid surface heating location is dependent on the geometry of the molded part and the condition of the infrared lamps. For example, if a part is very thin and with large area, the better location of the surface heating is near the gate. The determination of the IR rapid heating lamp location would be a challenge for engineers for a complex and large mold. This paper used the microprobe injection molding to demonstrate the practical applications of the IR rapid surface heating technology. The infrared surface heating technology really provides an option for better duplication of sharp microfeatures in the microprobe array part.

From the results mentioned above, it is possible to use a smaller heating area on a large mold. The strategy would be to install IR heaters with a reflector to focus the energy around some key areas such as gate, sprue or runners. This would raise the temperature around these areas. The determination of the heating location would also be critical. The proper locations would be runner, gate or sprue etc. Heating these areas is more or less functionally similar to a hot runner to maintain the resin flow at a high temperature. One of the problems induced by rapid surface heating is its uneven temperature distribution on the mold surface. Since the amount of input energy is small and only a thin mold surface layer is heated, the even temperature distribution can be minimized. If the heater is applied at the locations near gate, runner or sprue, the uneven temperature induced residual stress would be even less.

The main disadvantage of the variotherm system is its increase in cycle time of the injection molding process. Therefore, the variotherm system should include rapid surface heating and special cooling system to reduce the cycle time. Another disadvantage of the infrared rapid mold surface heating system is the possibility of causing the residual mold clean liquid, oil or resin particles to burn. The unwanted burned black may decrease the quality of optical products. Therefore, the cleanness or special coating of the mold surface for infrared heating technology is an important work for practical industrial applications.

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