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Eliminating weldlines of an injection-molded part with the aid of high-frequency induction heating†

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Abstract

High-frequency induction is an efficient way to heat mold surface by non-contact electromagnetic induction. It has been recently applied to injection molding because of its capability to heat and cool mold surface rapidly. This study applies high-frequency induction heating to eliminate weldlines in an injection-molded plastic part. To eliminate or reduce weldlines, the mold temperature at the corresponding weld locations should be maintained higher than the glass transition temperature of the resin material. Through 3 s of induction heating, the maximum temperature of 143 °C is obtained on the mold surface around the elliptic coil, while the temperature of the mold plate is lower than 60 °C. An injection molding experiment is then performed with the aid of induction heating, and the effect of induction heating conditions on the surface appearance of the weldline is investigated. The weldline on the heated region is almost eliminated, from which we can obtain the good surface appearance of the part.

Keywords: High-frequency induction heating; Injection molding; Rapid mold heating; Weldline

1. Introduction

Weldlines are generated during the injection molding process when two or more melt flows are brought into contact. Weldlines are unavoidable in cases of: the presence of holes or inserts, multi-gated delivery systems, significant thickness change, and so on [1]. At the welded contact region, a "V"-shaped notch is formed on the surface of the molded part. This "V"-notch deteriorates not only the surface appearance but also the mechanical strength of the molded part [2, 3].

Many studies have investigated the effect of injection-molding parameters on the weldline formation and the relevant strength degradation [4-6]. Among various process parameters, the mold temperature is known as the most important in reducing weldline [6]. That is, weldlines can be greatly reduced by increasing mold temperature as high as the glass transition temperature. However, an increase in mold temperature results in a great increase in cooling time to solidify the molten polymer inside the mold.

In recent years, rapid mold heating has enabled dynamic mold temperature control in injection molding. Induction heating is an efficient means to heat the mold surface by electromagnetic induction in a non-contact procedure. The mold surface can be rapidly heated by utilizing a high-frequency proximity effect [7]. Chen et al. [8] applied induction heating to improve the surface appearance of weldlines. Kim et al. [9] used induction heating in a procedure that rapidly raises the surface temperature of a nickel stamp with nanoscale-grating structures. Park et al. [10] improved the moldability of micro-features by applying high-frequency induction heating.

The present study applies induction heating to the elimination of weldlines in an injection-molded mobile phone cover. To predict the weldline locations, numerical analyses and experimental investigations are conducted. An induction coil is then designed and fabricated to heat the mold surface around the predicted weld locations efficiently. Injection molding experiments are then performed with the aid of high-frequency induction heating. The effect of induction heating conditions on the surface appearance of the weldline is investigated.

2. Investigation of weldlines for a mobile phone cover

2.1 Mold-filling analysis to predict weld line

In the present study, a mobile phone cover with multiple holes was selected as an example. To predict the weld locations, a mold-filling analysis using Moldflow Plastic Insight® was carried out. A three-dimensional analysis based on solid

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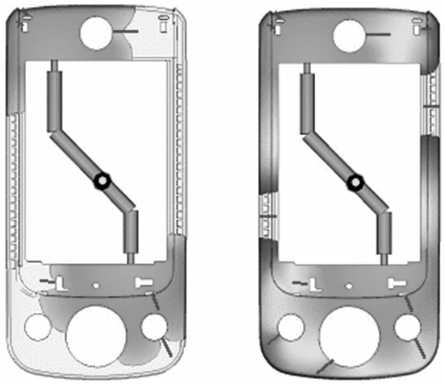


(a) 50% filling (b) 90% filling

Fig. 1. Estimated filling patterns and the resulting weldline locations.

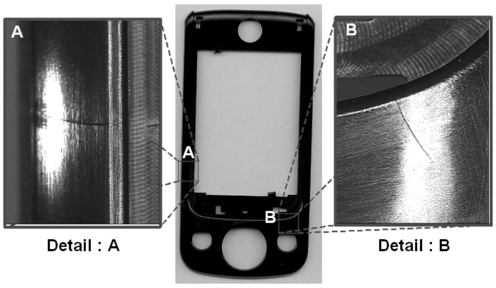


Fig. 2. Enlarged photographs of weldlines (mold temperature: 100°C).

elements was performed to consider the flow characteristics effectively [11]. Cheil Industries Starex® HF-1023I (PC) was used as the molding material. The nozzle temperature and mold temperature were set to 310°C and 100°C, respectively.

Fig. 1 presents the filling patterns and the resulting weldline locations obtained from the numerical analysis. Numerous hot weldlines were generated around all the holes, and two cold weldlines occurred at both sides where two melt flows were brought into contact (see Fig. 1(b)).

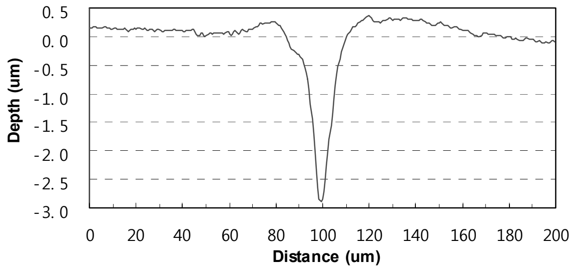
2.2 Experimental observations

Injection molding experiments were performed for the mobile phone cover. Fig. 2 demonstrates two enlarged photographs of a cold weldline (A) and a hot weldline (B) when mold temperature was set to 100 °C. To quantify the size of the weldline, surface profiles across two weldlines were measured. Figs. 3(a) and (b) show the measured profiles of the cold weldline (A) and the hot weldline (B), respectively. The depth of the cold weldline was measured as 2.943 μm, while that of the hot weldline was measured as 1.103 μm. This result indicates that the V-notch in the cold weldline is more severe than that in the hot weldline.

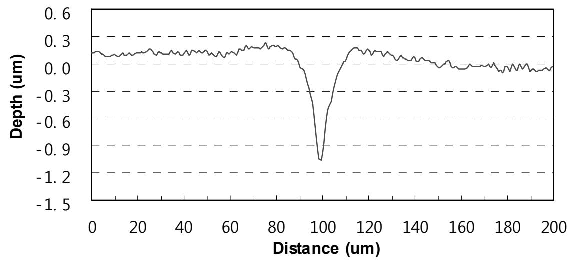
To investigate the effect of mold temperature on the weldline, additional injection molding experiments were performed with variations of mold temperature at 110 °C and 120 °C. The resulting depth and width of two weldlines at various mold temperatures are compared in Table 1. The weld depth and width decrease on the whole as the mold temperature increases. However, the rate of weld reduction is more dominant in the hot weldlines (B) than in the cold weldlines (A), which means that the mold surface of the side regions have to be maintained higher than the other regions.

Table 1. Comparison of weldlines with various mold temperatures.

Mold temperature (°C)		100	110	120
Weld depth (μm)	Weld (A)	2.943	2.772	2.399
	Weld (B)	1.103	0.797	0.501
Weld width (μm)	Weld (A)	19.89	18.21	17.18
	Weld (B)	16.02	14.98	10.72



(a) The cold weldline (“A” location)



(b) The hot weldline (“B” location)

Fig. 3. Surface profiles of the weldlines (mold temperature: 100°C).

3. Application of high-frequency induction heating

3.1 High-frequency induction for rapid mold heating

High-frequency induction heating was applied to reduce weldlines. To raise the mold temperatures of the side regions where the cold weldlines are generated, an elliptic coil was designed as shown in Fig. 4. The coil is 8 mm in diameter and is located 2.0 mm from the mold plate. The heating power, heating time, and current frequency were set to 2.5 kW, 3 s, and 160 kHz, respectively.

Fig. 5 shows the measured temperature distributions during the induction heating stage, that is, 3 s heating and 3 s cooling. The distribution of the mold surface temperature was measured by an infrared thermal imaging system. Fig. 5(a) indicates that the mold heating concentrates on the side regions, showing the maximum mold temperature of 143.5°C at the weld location (A). Fig. 5(b) shows that the mold temperature rapidly falls to 80 °C after 3 s of cooling under natural convection condition. Accordingly, it was possible to heat the mold surface efficiently and adaptively over a short period while not raising the temperature of the entire mold.

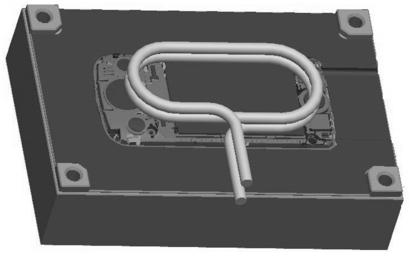
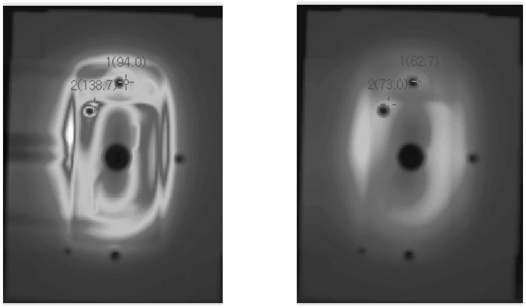


Fig. 4. An elliptically-turned induction coil to heat the mold surface.



(a) After 3 s heating (b) After 3 s cooling

Fig. 5. Temperature distributions of the mold surface.

3.2 Application to injection molding of a mobile phone cover

The high-frequency induction heating was then applied to the injection molding of the mobile phone cover. Fig. 6 demonstrates enlarged photographs of the cold weldline (A) and the hot weldline (B) when induction heating was applied for 3 s with a power of 2.5 kW. Comparing these photographs with Fig. 2, it can be concluded that the weldlines have been successfully removed from the hot-weld region (B). In the case of the cold-weld region (A), on the other hand, a weldline remains, but its size is much smaller than that of the results in Fig. 2.

To investigate the effect of heating condition on the size of weldlines, injection molding experiments were performed with variations of heating power and heating time. Fig. 7 compares the surface profiles of the cold weldline with a variation of heating power, showing that the weld depth decreases significantly with an increase in the heating power.

For quantitative analysis, the weld depth at the cold weldline location (A) was compared with a variation of the heating power, that is, from 2.0 kW to 3.0 kW. Heating time and current frequency were set to 3 s and 160 kHz, respectively. Fig. 8 plots the measured weld depth with an increase in heating power. The previous results in Section 2.2 under various mold temperatures without induction heating (see Table 1) were - also compared to clarify the effect of induction heating on the weldline improvement. As the heating power increases from 2.0 kW to 2.5 kW, the weld depth considerably decreases from 1.169 μm to 0.405 μm. On the other hand, the amount of reduction in the weld depth is relatively small in the case of 3.0 kW heating, showing a weld depth of 0.298 μm. These results indicate that the most efficient heating power is 2.5 kW under the given injection molding conditions.

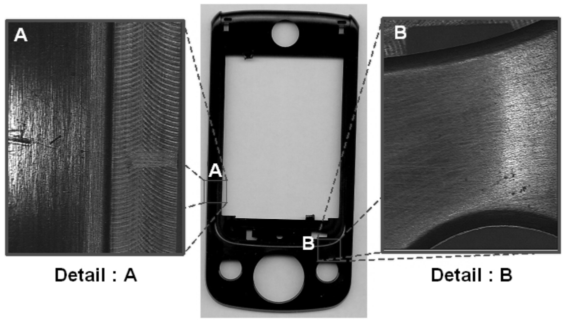
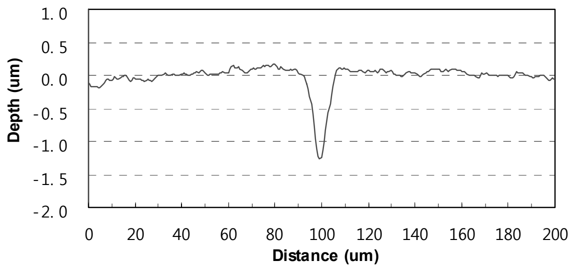
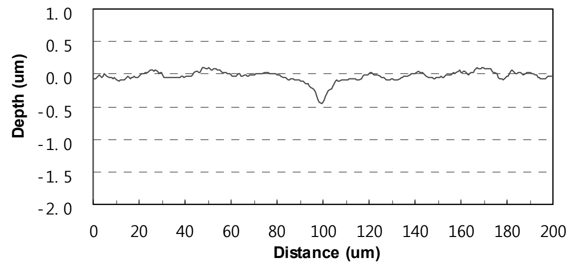


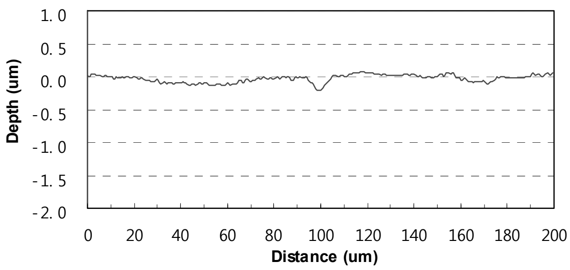
Fig. 6. Enlarged photographs of weldlines with 3s of induction heating.



(a) Weldline profile (power: 2.0kW)



(b) Weldline profile (power: 2.5kW)



(c) Weldline profile (power: 3.0kW)

Fig. 7. Surface profiles of the weldline with various heating powers.

The heating power was then set to 2.5 kW, and another injection molding experiment was performed with a variation in heating time from 3 s to 5 s with an increment of 1 s. Fig. 9 plots the measured weld depth with an increase in heating time. The weld depth considerably decreases when the induction heating is applied. As heating time increases from 3 s to 5 s, the weld depth slightly decreases from 0.405 μm to 0.328 μm. These results indicate that heating time is a less dominant factor than heating power, from which we can conclude that the heating time of 3 s has moderate influence in reducing the weldlines without a significant increase in cycle time.

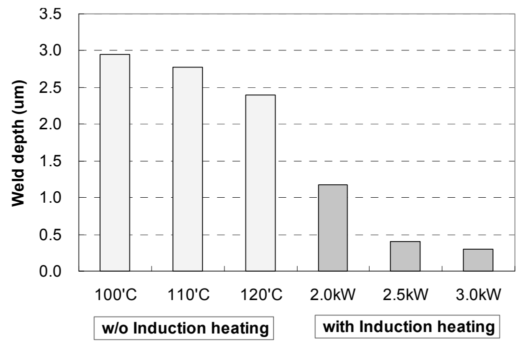


Fig. 8. Comparison of the weld depth with a variation in heating power.

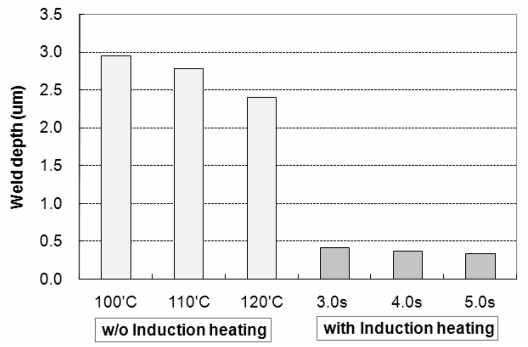


Fig. 9. Comparison of the weld depth with a variation in heating time.

4. Conclusions

High-frequency induction heating can rapidly heat the mold surface prior to the injection stage, such that a hot mold cavity can be obtained without significant increase in cycle time. In this study, the high-frequency induction heating was applied to eliminate weldlines in an injection-molded part. An elliptically-turned induction coil was proposed to heat the weld locations of the mold surface efficiently. The proposed induction heating enabled rapid and adaptive mold heating, showing the heating rate of 40 °C/s. This induction heating was then implemented on the injection molding of a mobile phone cover. Experimental observation indicated that weld depth was greatly reduced with the aid of induction heating, from 2.943 μm to 0.298 μm at most. Through these results, it can be concluded that the proposed induction heating is very effective in reducing the weldlines of an injection-molded part by heating the mold surface rapidly and adaptively.

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