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Efficiency improvement for injection molded direct joining by dynamic control of mold temperature

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Abstract

Injection molded direct joining (IMDJ) is an in-mold process to directly join a metal piece, whose surface is fine-structured, and an injection molded polymer part. A fine-structure at the polymer–metal interface contributes micro-/nano-scale interlocking and resultant direct joining. The interlocking is formed when melt polymer flows in a mold by injection molding. To produce better interlocking and high joining performance, controlling the physical state of melt polymer is important. One of the most effective physical quantities is temperature, which is usually controlled by changing temperature of an injection nozzle and a mold. This study presents an advanced temperature control, dynamic control of mold temperature (DCMT), to control temperature of melt polymer during injection molding. DCMT is constructed with a local heating system of mold. The experimental results show that a system of DCMT produces high joining strength and improves efficiency of the IMDJ process.

Polymer–metal direct joining, Injection molding, Mold temperature, Joining strength

1. Introduction

A polymer-metal direct joining technology, which does not use any joining parts or materials such as screws and adhesives, can enhance productivity and reduce weight of products. One of the proposed direct joining methods is injection molded direct joining (IMDJ) that consists of a surface fine-structuring of metals and injection molding. An injection-molded polymer is joined with a metal piece via fine-structured surface (Fig. 1). One of joining mechanisms is micro-/nano-scale interlocking between materials.

Joining performance or productivity is determined by physical states of melt polymer during molding, which is affected by molding condition. Some previous studies investigated effects of molding conditions [1-3] to achieve strong joint. One of the most effective physical quantities is temperature, which is controlled by temperature of a mold or an injection nozzle. The higher temperature may provide both better and worse effects for the IMDJ process and product. The better effect is, for example, improvement of mechanical interlocking between a polymer and a metal, which can improve joining strength as performance. Whereas, the higher temperature causes the longer cooling (solidifying) time period, which results in the lower productivity. To avoid the tradeoff, this study presents dynamic control of mold temperature (DCMT) to change temperature of melt polymer during molding process dynamically. The effect of DCMT is experimentally validated in this paper.

2. Experimental procedure

2.1. Surface fine-structuring for metal pieces

To form fine-structures, metal pieces (A5052 aluminum alloy) were surface processed by short-pulse laser (FLS-IRM-50, IPG photonics) [4]. The condition of the laser was as follows; power: 0.375 mJ; wavelength: 1 064 µm; pulse width: 100 ns. Figure 2 shows the fine-structured metal. The laser processing formed a micro dimple array on a square grid with pitch of 60 µm. The size of each dimple was 47 µm in diameter and 108 µm in depth.

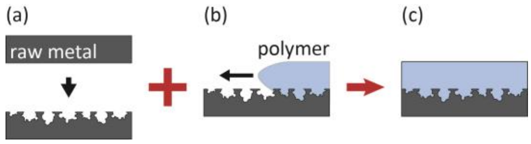

Figure 1. Process overview of injection molded direct joining.

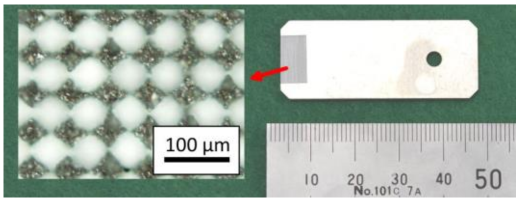

Figure 2. Laser processed metal piece. A micro dimple array was formed.

Table 1. Molding condition.

Injection speed [mm/s]	Polymer temperature [°C]	Packing pressure [MPa]	Holding pressure [MPa]
10, 100	260	60	30

2.2. Injection molding

Injection molding was carried out to join an injection molded polymer part (PBT: polybutylene terephthalate) with a surface fine-structured metal piece placed in a mold in advance. Table 1 shows the molding condition. In this experiment, two different values were used for injection speed. Otherwise, constant values were used for the condition parameters. The molding machine was a horizontal type with clamping force of 1 000 kN (α-S100iA, Fanuc). The mold was a newly developed and had a function of DCMT; the detail is described in the next section.

2.3 Dynamic control of mold temperature

Figure 3 shows a schematic illustration of the mold that was designed to produce a single-lap joint (ISO19095) and to have

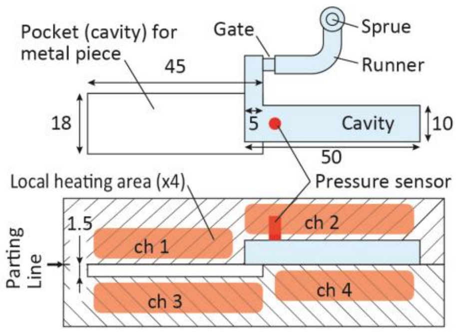

Figure 3. Schematic of mold (top view and front view).

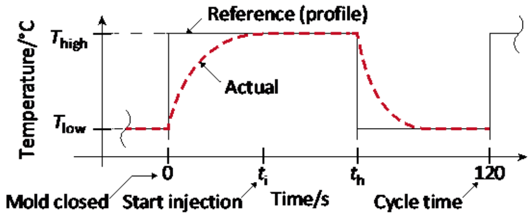

Figure 4. Reference of time course variation of temperature for DCMT and timing chart for injection molding process.

Table 2. Process parameters for IMDJ using DCMT.

T_{low}/°C	140	140	140
T_{high}/°C	140	160	200
t_i/s	NA	15	32
t_h/s	NA	20	38

the function of DCMT. There was a pressure sensor (6158A, Kistler) to measure pressure in a mold cavity, which is applied by injected melt polymer. DCMT was achieved by a local temperature controller (Y-HeaT system, Yamashita Electric) that consists of tiny heaters. The temperature-controlled part is divided into four local areas. Since this study did not investigate spatial distribution of temperature control, the temperature of the four areas were controlled by the same reference.

Figure 4 shows a reference of DCMT and timing of an action on the injection molding. In this profile, when the mold closes (t = 0 s), the reference of DCMT is changed from low temperature, T_{low}, to high temperature, T_{high}. After heating time, t_h, the temperature is changed to low temperature again. The injection process starts after the actual temperature reaches T_{high}, at $t = t_i$. In this study, the parameters of temperature were as: T_{low} = 140 °C; T_{high} = 140, 160, and 200 °C. The condition of T_{high} = 140 °C means the temperature keeps constant. The parameters of time, t_i and t_h, were determined by a pilot experiment and are shown in Table 2. Figure 5 shows an example of time course measurements of mold temperature and cavity pressure.

2.4 Evaluation of joining performance

The joining specimens were evaluated by a tensile shear test. The test applied strain to a specimen with a constant tensile speed of 1 mm/min and measured the applied load. The maximum load until failure occurred was divided by joining area of 5 mm^2 to obtain tensile shear strength. In each condition, five samples were tested.

3. Results and discussion

Figure 6 shows relationships between joining strength and high temperature T_{high} under different injection speed (v) conditions. If the mold temperature was constant (T_{high} = 140 °C), the higher injection speed provided the higher strength. The reason is because the high speed kept high temperature and

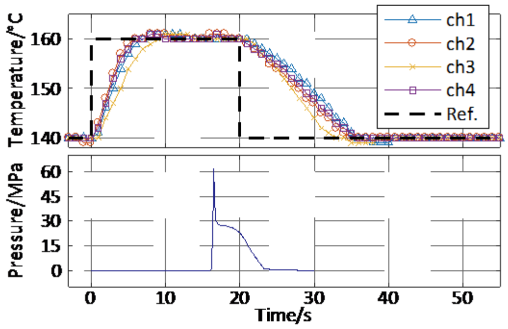

Figure 5. Time course measurement of temperature controlled by DCMT and cavity pressure.

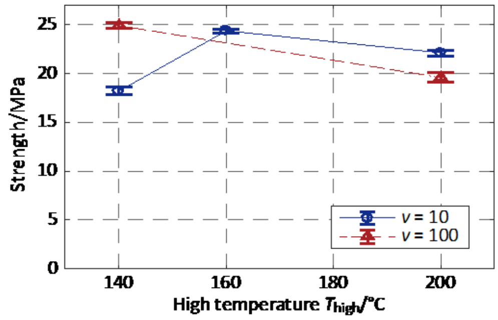

Figure 6. Relationship between joining strength and high temperature of DCMT, T_{high}. Marker: average. Error bar: standard deviation.

fluidity of flowing polymer, which causes high infiltration of polymer into micro dimples. The strength under the condition T_{high} = 160 °C was much higher than the condition T_{high} = 140 °C, which can be also due to high infiltration. However, the condition T_{high} = 200 °C provided quite lower strength. This could be caused by thermal degradation of polymer. Overheating by DCMT can provide the degradation and resultant weak joining.

4. Conclusion

This study investigated the effect of dynamic control of mold temperature (DCMT) on injection molded direct joining (IMDJ). IMDJ specimens were produced under different DCMT conditions and evaluated by a tensile shear test. The results showed that the joining strength increased if the mold was heated during melt polymer was flowing. Even if the injection speed was low, which is not suitable condition, the joining got high strength. It means that DCMT improved the efficiency of the IMDJ process. However, the overheating by DCMT provided low strength, which might be provided by thermal degradation of polymer. Future work will confirm the degradation and investigate effects of DCMT under various conditions.

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