Fracturre toughness evaluation of adjacent flow weldline by SENB method

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Abstract:

Fracture toughness of adjacent flow weldline occurring around an obstructive pin was evaluated by single edge notched bend (SENB) method. The fracture toughness near the pin was higher than any other part of the weldline. The fracture toughness decreased drastically along the weldline and then increased gradually toward the end on the specimen. These characteristic features could be explained by flow-induced molecular orientation at the weldline interface. The material flow beside the pin stopped in the middle of the filling process. Molecular orientation parallel to the weldline due to the fountain flow relaxed since no shear stress affected the area, resulting in high molecular entanglement across the weldline. On the contrary, at the downstream side the material kept on flowing during the filling process. This indicated that the molecular orientation could not relax due to flow-induced stress during the process. The magnitude of these two areas was dependent on the position of first collision point (FCP) at which two melt fronts collided first behind the pin. The V-notch depth on the surface of the specimens was also dependent on the distance from FCP.

Introduction

Weldlines that occur wherever two or more melt fronts meet cause reduction of mechanical properties and visual defects in injection moldings. The reduction of mechanical properties is considered to be caused by several factors such as poor intermolecular entanglement at the weldline, molecular orientation induced by the fountain flow, and the stress concentration effect of surface V-notch and so on [1-4]. Two main types of weldlines are usually distinguished; opposite flow weldlines and adjacent flow weldlines. Opposite flow weldlines are formed when two flow fronts collide head-on. In such cases, no additional flow occurs after the collision. The effect of such weldline on the strength of injection moldings can be easily evaluated using dumbbell specimens that are molded in a two-gate mold since the weldline has uniform structure. On the other hand, adjacent flow weldlines are formed when two melt streams flow in parallel and there is an additional flow after the weldline formed. Then the weldline is affected by the flow behavior during the process. However, there were few researchers investigating the relationship between flow behavior and mechnical properties of such weldlines [5-7].

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In the present study, plates having a weldline were injection-molded using three different shaped obstacles to influence the flow behavior at the weldline. Then single edge notched bend (SENB) tests were conducted for evaluating the fracture toughness of the specimens prepared from the plates. The influence of flow behavior on the fracture toughness was discussed. In addition, the shape of the V-notch occurring at the weldline surface was also discussed.

Experimental

Injection Molding

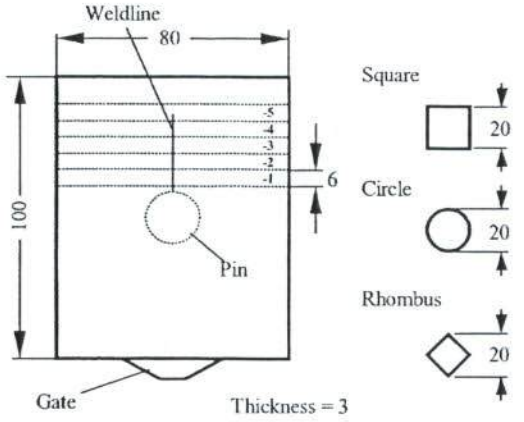
Material in this study was general purpose polystyrene (GPPS) with a melt flow rate of 7.5 g (FR-200/5.0). Rectangular plates with a weldline were injection-molded using the mold shown in Fig. 1a. The cavity dimensions were 100 × 80 × 3 mm and three different shaped pins, a square, a circle, and a rhombus, were located at the center of the cavity. An injection molding machine, N-100BII, manufactured by Nissei Plastic Industrial Co., Ltd. was used. It has a clamping force of 100 tons and a maximum injection pressure of 250 MPa. Molding conditions are listed in Table 1. Plates having no weldlines were also molded without the pins.

Table 1 *Molding conditions*

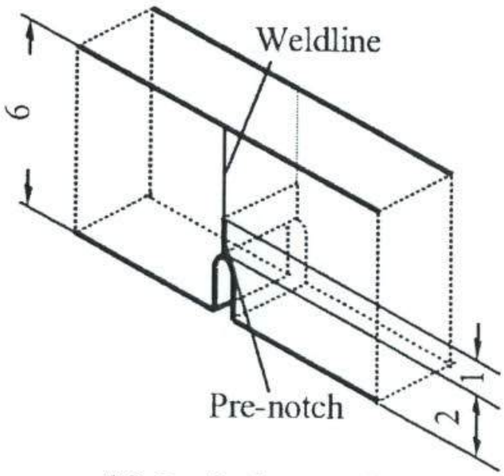
Cylinder temperature	200 °C
Mold temperature	40 °C
Injection speed	19 cm^3/s
Holding pressure	30 MPa
Holding time	10 s

Single Edge Notched Bend Test

Fracture toughness was measured in SENB test. Five specimens were cut from each plate so that the cutting lines were perpendicular to the flow direction and the widths were 6 mm, as shown in Fig.1a. Pre-notches were introduced as illustrated in Fig.1b. After a groove with a depth of 2 mm was machined, a keen notch with a depth of 1 mm was hammered just into the weldline. Specimens were also prepared from the corresponding positions of the plates having no weldlines.



(a) Molded parts



(b) Details of pre-notching

Fig. 1 *Geometry of molded parts and pre-notch. All dimensions are in mm.*

SENB tests were conducted at a crosshead speed of 10 mm/min. and a support span of 24 mm at 23+/-2°C and 65 +/-2 %RH with a universal test machine, Autograph AG-50kNE, from Shimadzu Co., Ltd. Five specimens were tested at each position, and mean values were calculated. The critical stress intensity factor as the fracture toughness is given by:

$$K_{IC} = \frac{PSf(a/W)}{BW^{3/2}}$$

Where P is the peak load, S the support span, B the specimen thickness, and W the specimen width. For the SENB specimen with S/W ratio of 4.0, $f\ (a/W)$ is given by:

$$f(a/W) = 3x^{1/2}\frac{1.99 - x(1-x)(2.15 - 3.93x + 2.7x^2)}{2(1+2x)(1-x)^{3/2}}.$$

where $x = a/W$.

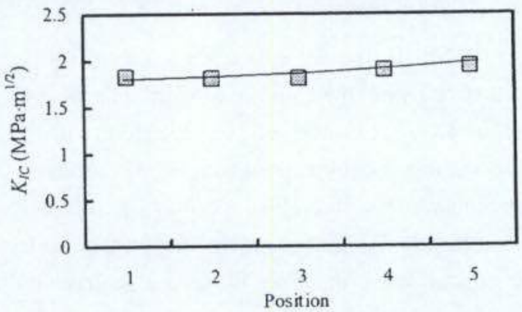
Results and Discussion

Fracture toughness of weldline

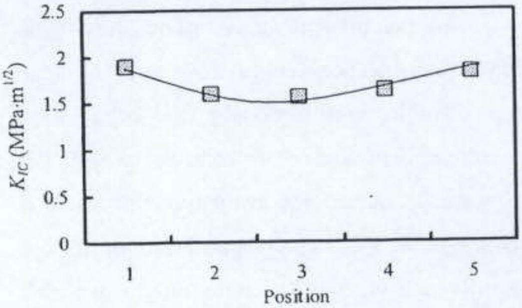
Results obtained from SENB tests are summarized in Table 2 and Fig. 2. The fracture toughness, K_{IC}, of the specimens having no weldlines gradually increased from 1.74 MPa.m$^{1/2}$ of 1 to 2.04 MPa.m$^{1/2}$ of 5 as shown in Fig. 2a. Fig. 2b, c, and d show K_{IC} when the square, circular and rhombus pin is used, respectively. For the square pin, the toughness decreased drastically from 1 (1.90 MPa.m$^{1/2}$) to 2 (1.58) and recovered gradually along the flow direction. Similar behavior was observed when using the circular pin. But in the case of the rhombus, the tendency was much different from those for the other pins. The toughness was gradually increased from 1 (1.54) to 5 (1.74).

***Table 2** Fracture toughness* (MPa·m$^{1/2}$)

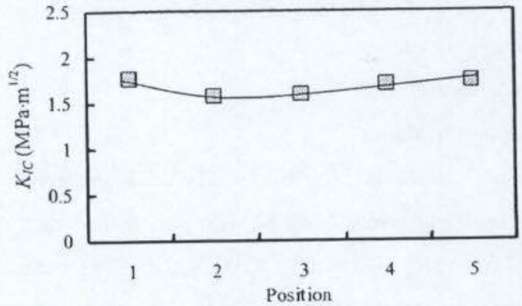
Pin shape	Specimen position				
	-1	-2	-3	-4	-5
Non-weld	1.82	1.80	1.81	1.90	1.93
Square	1.90	1.58	1.55	1.63	1.82
Circle	1.76	1.56	1.58	1.70	1.73
Rhombus	1.54	1.58	1.51	1.74	1.74



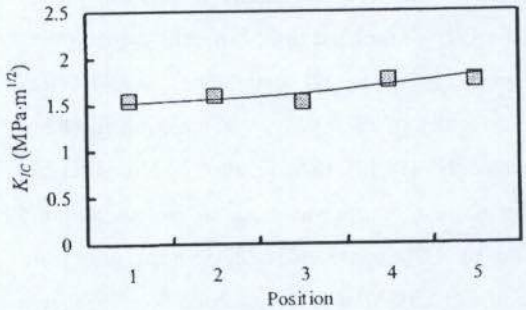
(a) Non-weld



(b) Square pin



(c) Circular pin



(d) Rhombus pin

***Fig. 2** Fracture toughness vs. position*

Flow behavior at weldline

These differences of fracture toughness are considered to be closely related to the flow behavior around the pins. Then the flow behavior was studied by observation of short shots molded with various amount of the material. Fig.3 shows a photograph of a short shot just after two flow fronts collided at the point away from the circular pin. We call the point first collision point (FCP). The position of FCP was determined by the following method. The merging length l_m and the flow length l_f of each short shot were measured respectively.

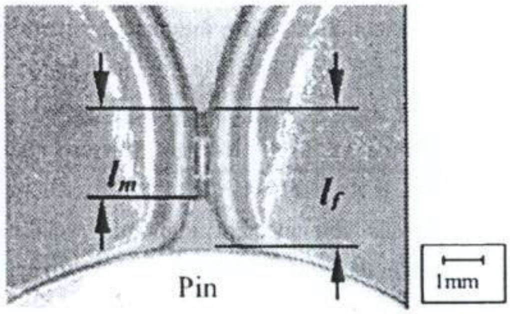


Fig. 3 *A photograph of flow fronts behind the circular pin*

As shown in Fig. 4, l_f was found to be linear with respect to l_m. The y-intercept of the line, which represented the flow length when the merging length was zero, means the distance from the pin to FCP. By this method the distances from the pin to FCP were estimated 3.1, 2.0, and 0.6 mm for the square, circular and rhombus pin, respectively.

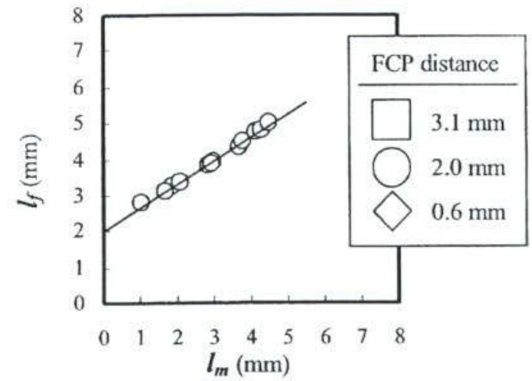


Fig. 4 *Relationship between l_f and l_m in the case of the circular pin*

Influence o flow behavior on fracture toughness

The material filled in the area between the pin and FCP stops to flow despite the fact that the filling process has not been completed. On the contrary, at the downstream side of FCP, the material keeps on flowing during the filling process. In all pins, these two flow patterns are considered to be dependent only on the position of FCP. The obtained fracture toughness values were replotted as a function of the distance from FCP to the pre-notch tip. As shown in Fig. 5,

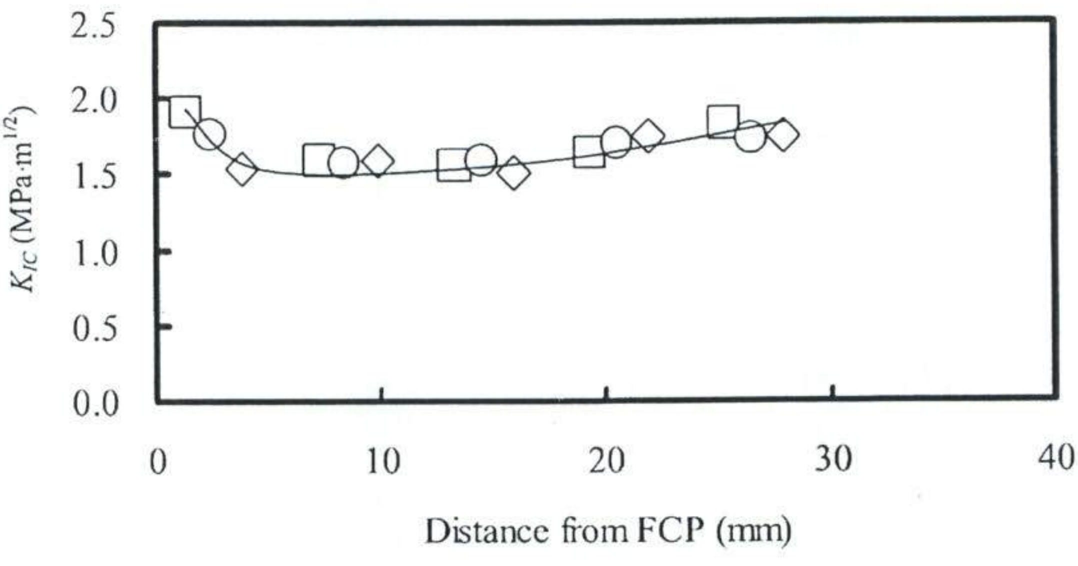


Fig. 5 *Fracture toughness replotted against the distance from FCP*

the values were located on a curve, implying that fracture toughness of weldline is dependent upon the distance from FCP. The fracture toughness was decreased drastically at a range of 4 mm from FCP. After remaining constant at 1.6 MPa.m$^{1/2}$ from 4 mm to 15 mm distance, the fracture toughness increased gradually along the flow direction. This tendency can be explained by molecular orientation deeply influenced by the flow behavior at the weldline interface as illustrated in Fig. 6. As mentioned before the material filled in the upstream side of FCP stop to flow in the middle of the filling process. Molecular orientation parallel to the weldline due to the fountain flow can relax since no shear stress affects the area. It results in high molecular entanglement across the weldline interface. On the contrary, in the downstream side of FCP, the molecular orientation connot relax due to flow-induced stress during the filling process, resulting in the drastic decrease in fracture toughness.

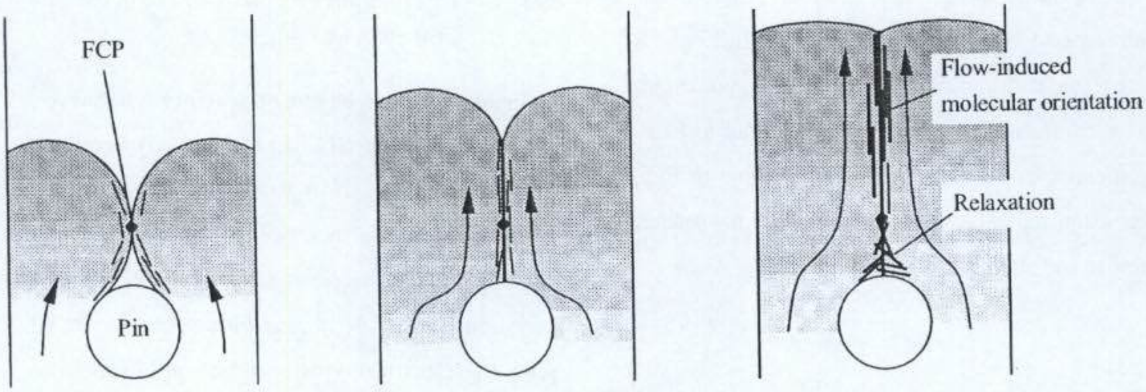


Fig. 6 *Flow behavior around an obstructive pin*

V-notch depth of weldline

Surface V-notch at weldline is also a problem in injection moldings as mentioned before. The shape of V-notch should reflect flow behavior at the weldline. Fig. 4 shows the relationship between the V-notch depth and the distance from the pin. For each pin the depth of the V-notch dropped steeply after a gradual decrease along the flow direction. The distances from the pin to the inflection point were approx. 19, 17, and 15 mm, for the square, circular and rhombus pin, respectively. This indicates the inflection point is dependent on the pin shape, implying the flow behavior along the weldline influenced on the V-notch shape. In Fig. 7

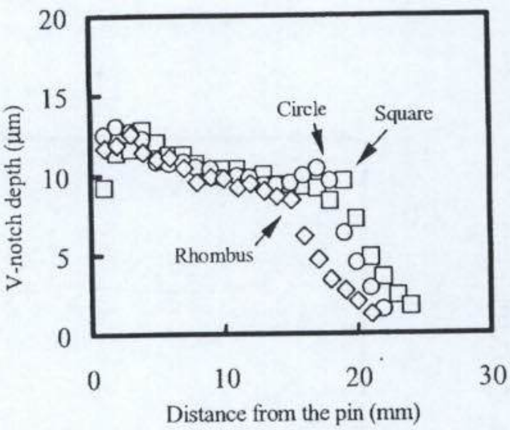


Fig. 7 *V-notch depth variation against the distance form the pin*
(Arrows indicate the inflection points)

the V-notch depth is replotted against the distance from FCP. All the three curves agreed with each other, showing the V-notch depth is dependent only on the distance from FCP.

As shown in Fig. 8, the values were located on a curve, implying that fracture toughness of weldline is dependent upon the distance from FCP.

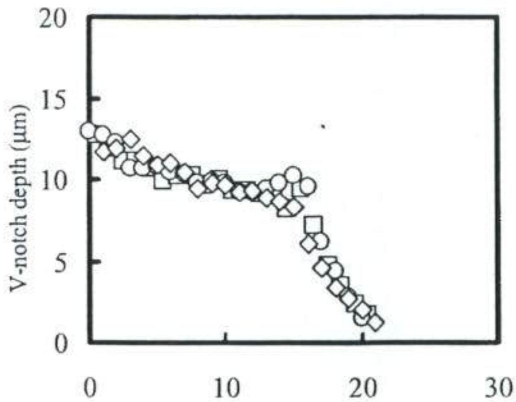


Fig. 8 *V-notch depth variation against the distance from FCP*

Conclusion

Fracture toughness of adjacent flow weldline occurring around an obstructive pin injection-molded polystyrene plates was evaluated using SENB test. Flow behavior behind the pin was investigated using short shot moldings. The following conclusions apply to the results presented above:

FCP played an important role in flow behavior of adjacent flow weldline. The V-notch depth and the fracture toughness were dependent only on the position of FCP.

The fracture toughness decreased steeply behind FCP. This tendency was due to flow-induced molecular orientation at the weldline interface.

References

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