ICF1009740R

FRACTURE BEHAVIOUR OF INJECTION MOLDINGS WITH WELD LINE

H. Hamada[1], K. Yamada[2], K. Tomari[2] and T. Harada[2]

[1] Advanced Fibro-Science, Kyoto Institute of Technology,
Matsugasaki, Sakyo-ku, Kyoto, 606-8585, JAPAN
[2] Plastics Department, Osaka Municipal Technical Research Institute,
Morinomiya, Joto-ku, Osaka, 536-8553, JAPAN

ABSTRACT

Weld lines are fatal defects in many injection moldings. Fracture behaviour of weld line is investigated in double torsion (DT) test using injection-molded polystyrene plates with a circular hole. The load-displacement curve showed irregular fluctuation corresponding to the alternate slow and rapid crack propagation. When the crack propagated rapidly, ripple marks appeared on the fracture surface, which were affected by the weld line. The ripple marks could be classified into two patterns, pattern I the ripple marks indicate that the crack propagated inwardly from the surface, and pattern II the ripple marks indicate the crack propagated from the mechanically introduced pre-notch. Pattern I was assumed to show the effect of V-notch on the weld line surface because the pattern was observed only in the fracture surface with a weld line. However, it was found that pattern I appeared even where there was no V-notch on the surface. It can be concluded that V-notch on the weld line surface does not affect the fracture behaviour, while it affects the visual defects of injection moldings.

KEY WORDS

Injection molding, weld line, polystyrene, fracture toughness, double torsion

INTRODUCTION

Weld lines that occur wherever two or more melt fronts meet cause reduced mechanical properties and visual defects of injection moldings. The reduction of mechanical properties is considered to be caused by poor intermolecular entanglement at the weld line, molecular orientation induced by the fountain flow, and the stress concentration effect of surface V-notch. Although the effect of weld line on the strength of injection moldings can be easily evaluated using dumbbell specimens which are molded in two-gate mold, the effect on the fracture behaviour in practical injection moldings can not be estimated only by the dumbbell data because there are many types of weld lines and their generation mechanism is not so simple as that in dumbbell specimen. In the case of the dumbbell, as soon as two flow fronts collide head-on at the center of the specimen, a weld line occurs so that the property of weld line is not much affected by the flow behaviour. In the case of injection molded product on the market, after a weld line occurs behind an obstacle, polymer continues to flow and the pressure and temperature at the weld line region varies during the filling process. This means that pressure and temperature histories affect the properties of weld line occurring in injection molded products. The tests using the dumbbell that were used in previous studies are not sufficient to investigate the fracture behaviour of weld lines occurring in complicated mechanism.

In the present study, fracture behaviour of weld line is investigated in double torsion (DT) test using injection-molded polystyrene plates with a circular hole, which is structurally more complicated than a dumbbell. This is because DT test has many advantages, for example, the specimen is simple, crack speed can be easily controlled by loading rate and so on. The influence of V-notch, a factor affecting visual defects as well as mechanical properties, on the behaviour of crack propagation is discussed in particular.

EXPERIMENTAL

Injection Molding

The material in this study was general purpose polystyrene (GPPS), Styron 666, from A & M Styrene Co. Rectangular plates with and without a weld line were injection molded using the mold shown in Fig. 1. The plate dimensions were 100 x 50 x 3 mm^3. When an insert pin whose diameter was 20 mm was located in the center of the cavity, the plate with a weld line can be obtained. When the pin is removed, the plate without a weld line can be obtained. An injection molding machine, TP-80, manufactured by Toyo Machinery and Metal Co., was used, the performance of which was 80 tons in clamping force and 200 MPa at the maximum injection pressure. Molding conditions are listed in Table 1.

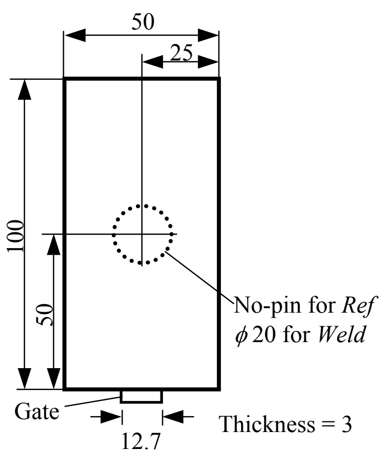

Figure 1: Specimens for double torsion test.

TABLE 1

MOLDING CONDITIONS

Run	Resin temp. (deg. C)	Mold temp. (deg. C)	Injection Speed (%)
1	180	40	30
2	200	40	30
3	220	40	30
4	200	80	30
5	200	40	10
6	200	40	90

Double Torsion Test

Fracture behaviour was investigated in double torsion (DT) test. The specimens were cut from the injection molded plates shown in Fig. 2(a). The specimens without weld lines were called *Ref* and those with a weld line were called *Weld*, respectively. A sharp pre-notch was introduced just at the pin side of the weld line for *Weld* as shown in the circle marked A in Fig. 2(b). A pre-notch was also introduced at an equivalent position for *Ref*. The fracture tests were conducted at a crosshead speed of 0.1 mm/min. at 23±2 ℃ and 60±5% with universal test machine, Autograph AG-50kNE, from Shimadzu Co. The specimen was supported by steel spheres (ϕ 11 mm) at each corner of the specimen and loaded by two spheres positioned over the notch (Fig. 3).

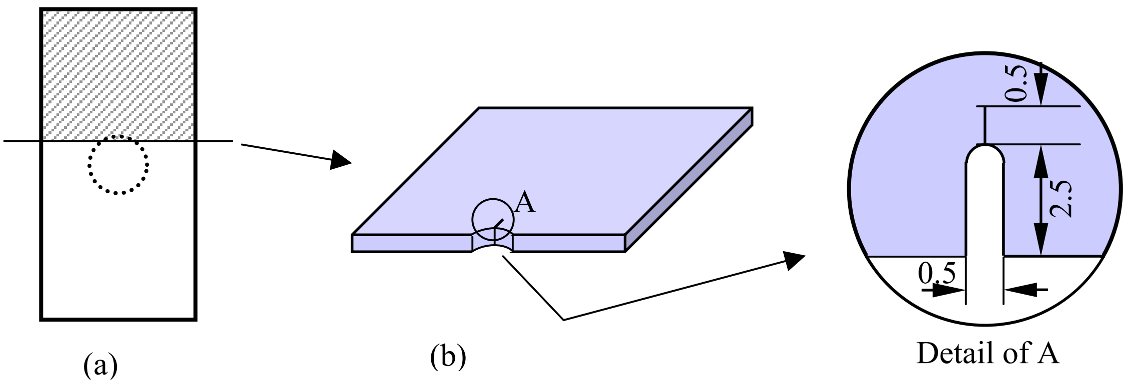

Figure 2: Specimen for double torsion test.

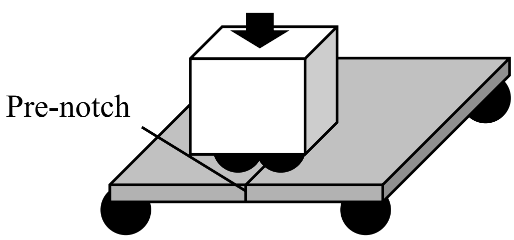

Figure 3: Schematic diagram of double torsion test.

RESULTS AND DISCUSSION

Fig. 4 shows typical load-displacement curves for both *Ref* and *Weld* obtained from the DT test. They exhibited a stick-slip mode. At start of the test the load rose linearly until the pre-notch opens, and rapid fall and linear increase in load were observed alternately. They were found to correspond to unstable crack propagation and crack arrest, respectively. In addition, slow crack propagation was observed with gradual falls in load. Fig. 5(A) shows the micrograph of the whole fracture surface of *Ref*. The fracture surface could be classified into two regions, mirror regions with no marks, and rough regions with ripple marks, indicating that the crack propagated in two kinds of manner. Tracing the crack propagation in the

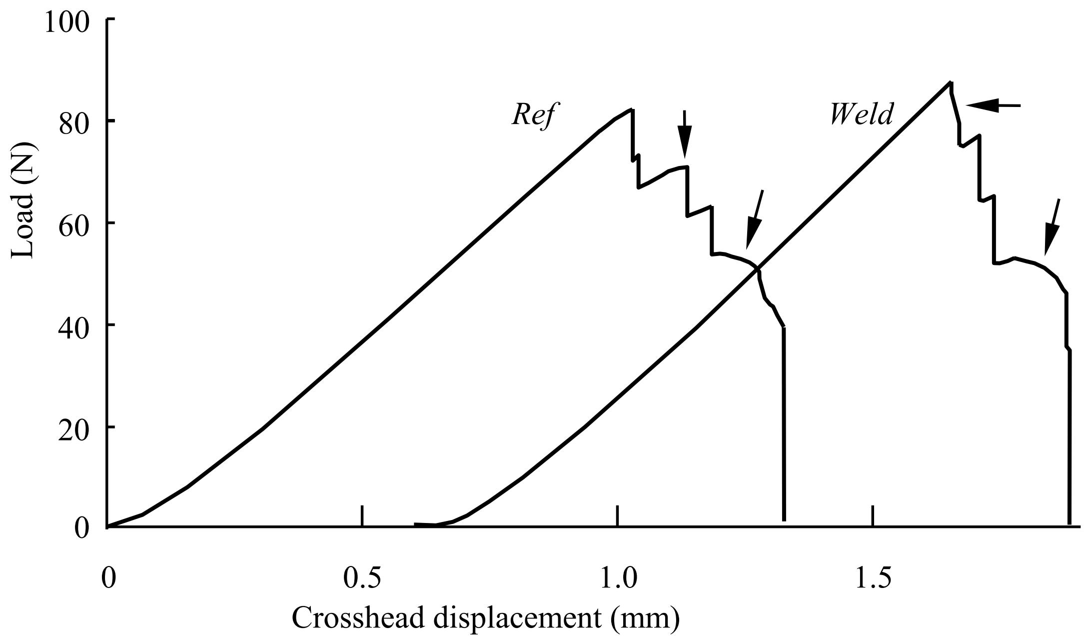

Figure 4: Load-displacement curves of *Ref* and *Weld* in DT test.
Arrows indicate slow crack propagation region.

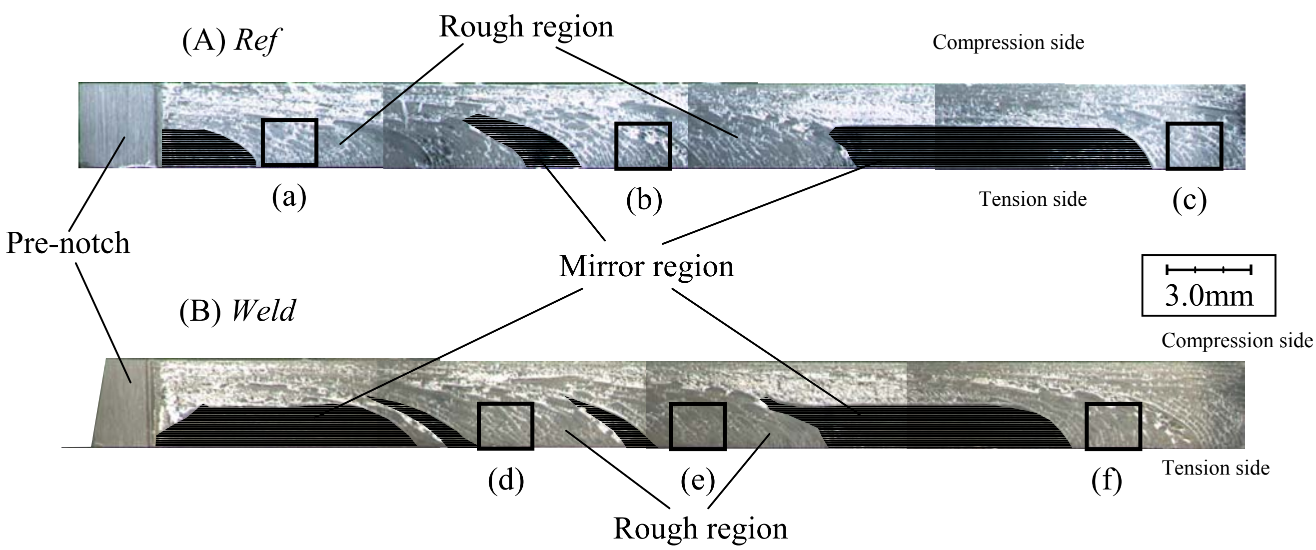

Figure 5: overviews of fracture surfaces. (A) *Ref* and (B) *Weld*.
Six rectangles (a), (b), (c), (d), (e) and (f) correspond to magnified images in Figure 6.

specimen during DT test clarified that the former corresponded to the area in which the crack propagated slowly (0.1 – 1.0 mm/s) and the latter corresponded to the area in which the crack propagated rapidly (ca. 200 mm/s).

Although the fracture surface of *Weld* seemed to be the same as that of *Ref* as shown in Fig 5(B), two different patterns of ripple marks were recognized in the rough region near the tension side surface as can be seen in Fig 6:

Pattern I: Ripple marks were parallel to the tension side surface. This pattern was observed only in the region close to the insert pin of *Weld* as shown in Fig. 6(d).

Pattern II: Ripple marks were perpendicular to the tension side surface. This pattern was observed in the whole of *Ref* and the region remote from the pin of *Weld* as shown in Fig. 6(a)-(c) and (f), respectively.

The fracture surface of *Weld* could be obviously divided into two areas, one having a rough surface with pattern I and the other having one with pattern II. Pattern I implied that the crack propagated inwardly from the tension side surface, while pattern II indicated that the crack propagated simultaneously with the surface crack. It is assumed that pattern I appears where there is a deep V-notch on the surface and pattern II appears where there is little V-notch.

Fig. 7 shows the relationship between the V-notch length and the length of pattern I. The V-notch length was not always equal to the length of pattern I. In particularly, when the mold temperature was 80 deg. C (No. 4 in Fig. 7), the V-notch length was only 6.0 mm, while the length of pattern I was 40 mm. This indicates that pattern I appears even where there is no V-notch on the surface. In other words, the other factors could affect the fracture behavior except V-notch. Although V-notch affects visual defects, it does not affect fracture behaviour.

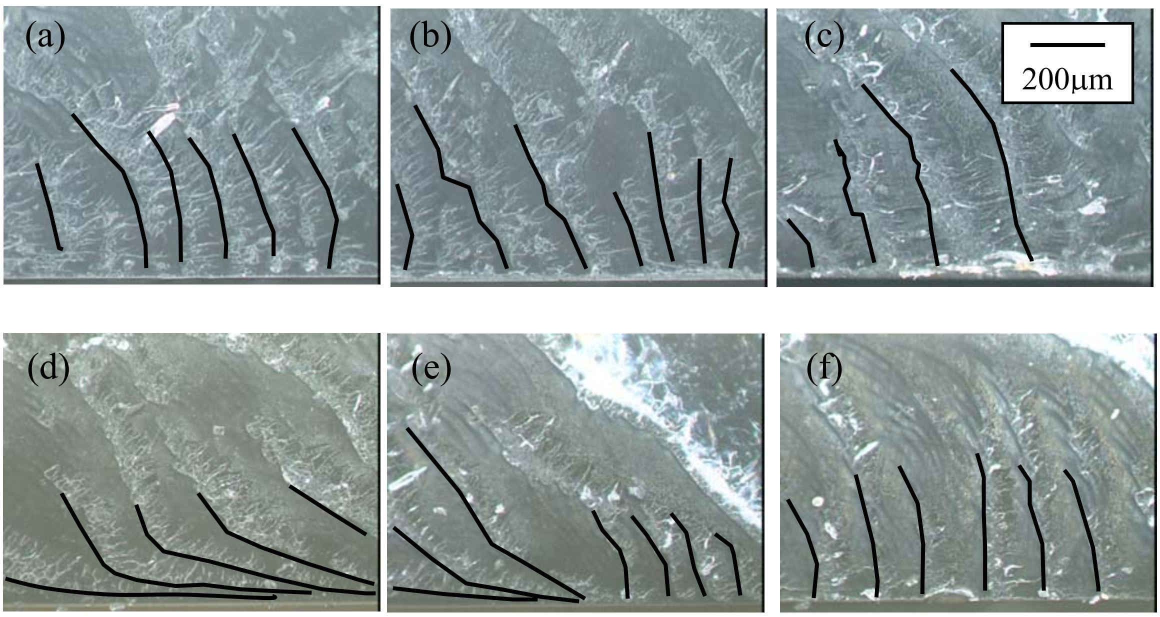

Figure 6: Optical micrographs of fracture surface of *Ref* and *Weld*. The alphabets correspond to those in Fig. 5 (a), (b) and (c) are from *Ref.* and (d), (e) and (f) are from *Weld.* Ripple marks are emphasized by black lines.

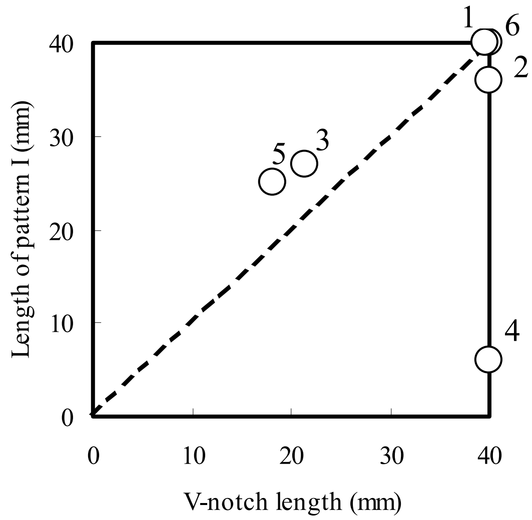

Figure 7: The relationship between the V-notch length and the length of pattern I. The numbers correspond to the run numbers in Table 1.

CONCLUSIONS

The influence of weld line on the fracture behaviour was investigated by tracing the ripple mark patterns appearing on the fracture surface from double torsion test. One of the patterns indicated that the crack propagated inwardly from the surface of specimen. Although the pattern was assumed to show the effect of V-notch on the weld line surface, the pattern was found to appear even where there was no V-notch on the surface. It can be concluded that V-notch on the weld line surface does not affect the fracture behaviour, while it affects the visual defects of injection moldings.