EFFECTS OF SPECIMEN SIZE AND SIDE GROOVES ON THE FRACTURE TOUGHNESS, J_{IC}, OF A HIGH DENSITY POLYETHYLENE

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The effect of specimen size and side grooving on the fracture toughness, J_{IC}, and the R curve was investigated. The multiple specimen technique and the unloading compliance method were applied and the results from the two methods were compared. The J_{IC} was found to be size independent but the R curve rose with decreasing thickness. The validity of the ASTM size criteria for this material and the difference in J_{IC} evaluated using the E813-81 and E813-87 protocols are discussed. Side grooving provided a lower R curve and a slightly lower J_{IC} value.

INTRODUCTION

The fracture toughness of a variety of toughened polymers has been characterised successfully using the J integral technique (1,2,3,4). The concept was first proposed by Rice (5) and the testing procedure was developed by Landes and Begley (6) and was later established as a standard test method, designated ASTM E813, by the ASTM. The effect of specimen size has been investigated by Huang (4) and an artificial thickness dependence on J_{IC} value was observed when the E813-81 procedure was used. However, the use of the E813-87 protocol provided a more consistent J_{IC} value. In all the previous studies, the multiple specimen method was adopted and most of the tested specimens were not side grooved. The application of the unloading compliance method to polymers has been demonstrated to be successful (7) and this technique is used in this study and the results are compared with those obtained from the multiple specimen method. Specimens of various sizes, both with and without side grooves were tested and the results were analysed using both the E813-81 and E813-87 procedures.

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EXPERIMENTAL DETAILS

The material tested here was a compression moulded high density polyethylene with σ_Y=27MPa and elastic modulus E=1.7GPa. The sheet thickness was the same as the specimen thickness. Notches were introduced by a single point flycutter with a tip radius of 16μm. Side grooves were machined on both sides of the specimen after the notching had taken place. The dimensions of the specimens are shown in Table 1. The specimens were loaded in three point bending with a span to width ratio of 4. For the multiple specimen tests, nine or more specimens were prepared and loaded to various pre-determined displacements to obtain different amounts of crack extension. In the case of the single specimen tests, the crack extension was estimated from the change of the crack mouth opening compliance. The J value at the point of unloading is given as:

$$J=\frac{2U}{B_N b_o} \qquad (1)$$

where U is the area under the load versus the load line displacement curve. The details of the test procedures for the multiple and single specimen tests are given in reference (7).

TABLE 1 - Specimen Dimensions

W (mm)	B (mm)	Span (mm)	Side Grooves, each side(mm)	a/W
40	12	160	0.75	0.6
30	12	120	0.75	0.6
25	12	100	0.75	0.6
20	12	80	0.75	0.6
15	12	60	0.75	0.6
30	5	120	0.5	0.6
30	7.5	120	0.6	0.6
30	9	120	0.75	0.6

RESULTS AND DISCUSSION

The J-R curves for the side grooved and non side grooved samples with various widths are shown in fig.1 and fig.2 respectively. It can be observed that the R curves virtually show no width dependence and an unique R curve can be suggested for each type of specimens within the limits of experimental scatter. The effect of the specimen thickness on the R curve is illustrated in fig.3 and fig.4 for side grooved and non side grooved specimens respectively. The results show that the slope of the R curve increases slightly with decreasing specimen thickness. For the 5mm thick samples, necking at the ligament was observed during the experiment after the crack had grown more than 0.6mm and the R curve rose steeply at this point, therefore the J_{IC} value could not be determined from the multiple specimen test data for this set of specimens. The J_{IC} values evaluated according to the E813-81 and E813-87 methods are summarised in Table 2. It should be noted that the theoretical blunting line did not depict the data near the blunting region adequately and this has also been observed before in the other studies (2,7,8). As a result, the theoretical blunting line was replaced by a straight line through the data near the blunting region and the data from the side grooved and non side grooved specimens agreed well in this region. For the range of specimen size used, no effect on the J_{IC} value is observed, see Table 2, except for the thinnest specimens. The J_{IC} values determined using the E813-87 procedures tended to be higher than the ones obtained from the old standard. This is because the 0.2mm offset blunting line actually describes the fracture toughness at 0.2mm ductile crack growth which will always give a higher J_{IC} value. The amount of offset, 0.2mm in this case, was determined empirically for metals, and the suitability of using the same offset line for determining the initiation point for polymers is questionable. However, the 0.2mm offset line provided a more consistent J_{IC} value since the data in the blunting region were excluded.

TABLE 2 - Summary of the Results
(MJ=Multiple Specimen Tests, SJ=Single Specimen Tests)

		J_{IC} (KJ/m^2)							
		E813-81 Method				E813-81 Method			
		Non side-grooved		Side-grooved		Non side-grooved		Side-grooved	
B (mm)	W (mm)	MJ	SJ	MJ	SJ	MJ	SJ	MJ	SJ
5	30	-	4.2	2.1	2.1	-	5.5	2.8	2.8
7	30	2.4	2.5	1.5	2.0	3.2	5.3	2.1	2.25
9	30	2.15	2.3	1.7	2.3	2.3	2.8	1.81	2.3
12	30	2.6	2.7	2.0	2.1	2.9	2.8	1.7	2.3
12	15	2.8	-	2.5	-	3.2	-	2.7	-
12	20	2.4	-	1.8	-	2.8	-	2.1	-
12	25	2.3	2.4	2.2	2.3	2.4	2.7	2.3	2.4
12	40	2.5	2.6	2.0	2.4	2.8	3.1	2.0	2.4

From fig.1 and 3, it can be seen that side grooving gives a lower R curve and the amount of scatter is reduced. The flattening of the R curve indicates that the plastic deformation at the shear lips accounts for a substantial part of the total energy input into the system and the lower R curve will cause a lower J_{IC} value, as shown in Table 2. The J_{IC} evaluated using the side grooved specimens should reflect the actual initiation point more closely since the blunting process for both types of the samples is the same. Side grooving also tends to promote triaxiality of the stress at the crack tip which in turn will reduce the crack front curvature. This minimises the uncertainty in crack length measurement and the amount of scatter in the data will be reduced.

According the ASTM standard, the minimum required thickness for the measured J_{IC} to be valid is approximately 2.5mm for this material and all the specimens satisfied this requirement. However, severe plastic deformation was observed for the 5mm thick specimens and a steeply rising R curve was obtained. It is suspected that the ASTM size criteria is not appropriate for this material. By examining the results shown in fig.3 and 4, little changes on the slope of the R curves is observed for specimen thickness greater than 5mm. If the required thickness is assumed to be 5mm, the specimens with the shortest ligament will still satisfy this requirement. It is believed that if the ligament is further reduced to less than 5mm, a steep rising R curve may be obtained.

It can be seen that the results from the single specimen tests and the multiple specimen tests are in good agreement except for the 5 and 7mm thick non side grooved samples. The discrepancies are due to the large size of the shear lips relative to the specimen thickness since the results from the side grooved specimen do not show the same effect. The unloading response is controlled by the material at the shear lips rather than that at the crack tip and the compliance measurement will be subjected to error.

CONCLUSIONS

The R curve was found to be thickness dependent and the slope increased with decreasing thickness but it was insensitive to the variation in specimen width. It is suspected that the ASTM size criteria is not appropriate for this material. The use of the 0.2mm offset blunting line did not describe the initiation point adequately but it tended to give a more consistent J_{IC} value. Side grooving provided a lower R curve and a lower J_{IC} value. It also reduced the uncertainty in crack length measurement due to crack front curvature so the amount of scatter in the data was less.

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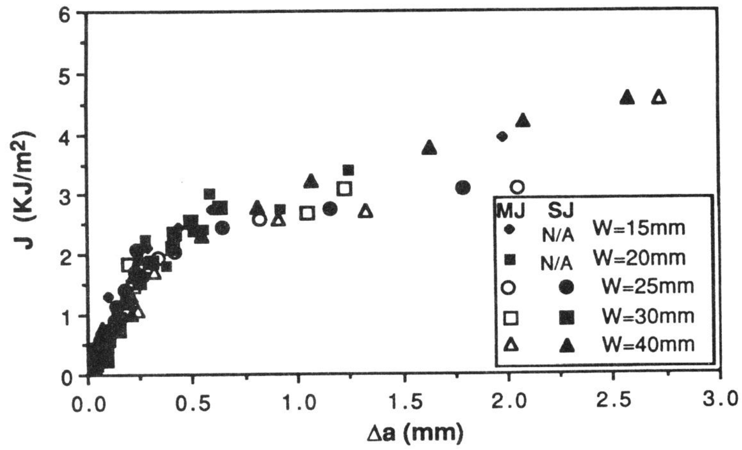

Fig. 1 Effect of Specimen Width on the J-R curves for the Side Grooved Specimens(MJ=multiple specimen, SJ=Single Specimen)

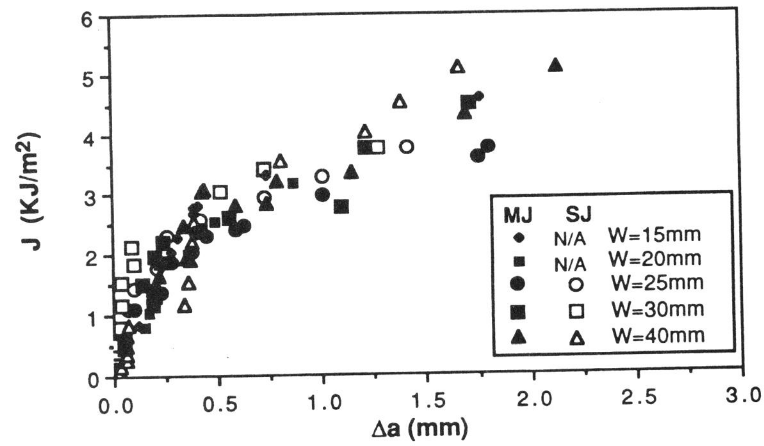

Fig. 2 Effect of Specimen Width on the J-R curves for the Non Side Grooved Specimens(MJ=multiple specimen, SJ=Single Specimen)

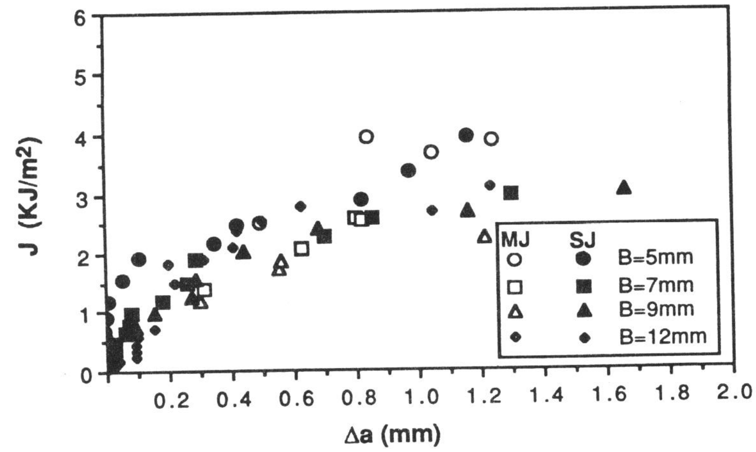

Fig. 3 Effect of Specimen Thickness on the J-R curves for the Side Grooved Specimens(MJ=multiple specimen, SJ=Single Specimen)

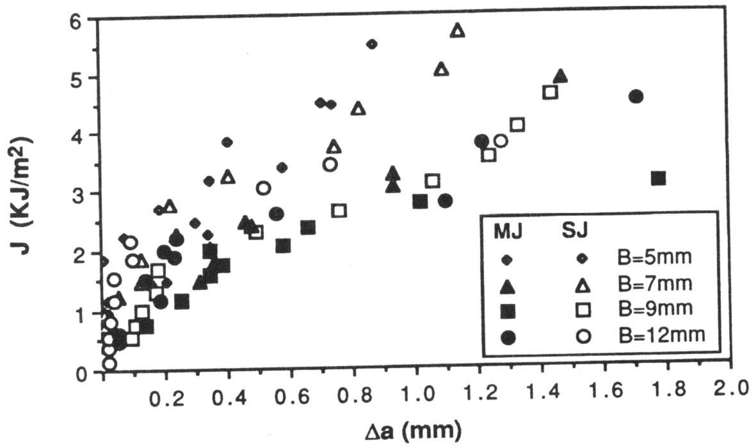

Fig. 4 Effect of Specimen Thickness on the J-R curves for the Non Side Grooved Specimens(MJ=multiple specimen, SJ=Single Specimen)