THE EFFECT OF THE STRAIN RATE ON THE J-R CURVE OF POLYETHYLENE

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The usefulness of the J-integral concept for the characterisation of the fracture behaviour of polyethylene is determined by studying the effect of the strain rate on the J-R curve of three different brands of polyethylene. The CTOD during the experiments is also measured to determine the applicability of EPFM fracture mechanics by comparing the J and the CTOD.

INTRODUCTION

Since thermoplastic polymers become more frequently used in critical applications it is of interest to characterise the fracture behaviour of thermoplastic polymers. The chain structure with possible side branches produces visco-elastic behaviour of thermoplastic polymers. Another phenomenon caused by the chain structure is crazing. Crack growth in thermoplastic polymers is a process of formation and breakdown of a craze(s). The growth of crazes, especially in the thickness direction, is a time dependent process. The experiments described in this paper were performed to determine the usefulness of the J-integral concept to characterise the fracture behaviour of Polyethylene. Three different brands of Polyethylene, commonly used as gas pipe material, were tested at three different strain rates. The three brands of Polyethylene used in the test are marked as TUB70, TUB121 and Finatheen

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EXPERIMENTS

In table 1 properties of the materials are given.

TABLE 1 Material properties, yield stress 20 °C 0.1 mm/min

Material	Monomers	Density(kg/dm^3)	Yield stress(MPa)
TUB70	Etheen-buteen	0.943	23
TUB121	Etheen-buteen	0.96	25
Finatheen	Etheen-hexeen	0.96	19

The experiments were performed on Single Edged Notched Bend (SENB) specimens with a machined notch and side grooving. The dimensions of the specimens were: length L 162 mm, thickness B 18 mm, width W 36 mm and a/W 0.5. A sharp crack tip was obtained by pressing a razor blade in the root of the machined notch at 200 μm/min until a/W was 0.55. The ligament b was 16.2 mm. The specimen dimensions and bending rig were according to the requirements of the ESIS protocol (1).

The multiple specimen method was used to determine the J-R curves of the three brands according to the ESIS protocol (1) with correction for indention. Eight specimen were tested during one test series. The materials were tested at the following crosshead rates: 0.1, 1, 10 mm/min. The test temperature was 20 °C. The load displacement curve and crack mouth opening were recorded. The energy U was determined by calculating the area under the load displacement curve. This leads to J with the following equation for a SENB configuration:

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

The CTOD was calculated from the recorded crack mouth opening.

After the loading the specimens were sectioned near the middle perpendicular to the notch plane. The larger part was cooled in liquid nitrogen and broken open. The fracture surface was studied using SEM and light microscopy to determine the damage zone length Δa caused by the loading. The other part was used to obtain a sideview of the damage zone. The crack could be opened to the CTOD from the test using a device similar to a vice. After coating with gold the damage zone, i.e. the craze/crack could be studied with a SEM.

The J-R curves were constructed using the J values and Δa obtained from the fracture surface.

RESULTS AND DISCUSSION

The effect of the strain rate on the J-R curves of the three tested materials is that an increase in strain rate causes a downshift in the J-R curve. This can be seen in figures 1-3. This means the fracture toughness decreases if the strain rate increases. An increase in strain rate makes it more difficult for the craze at the crack tip to grow in the thickness direction. This craze growth involves chains being pulled in the craze. This is a time dependent process. A higher stain rate means less time and consequently craze thickness growth is limited. Blunting at the crack tip is controlled by this craze thickness growth. A increase in strain rate leads to less craze thickness growth with consequently less blunting of the crack tip. This causes the downshift of the J-R curves with increasing strain rate.

The slope of the J-R curves increases as Δa increases. From the sideview it was found that during the tests no crack growth had occurred. The damage zone consisted entirely of a craze or multiple crazes at the crack tip. A growing craze increases its volume instead of a growing crack that increases its surface. The increasing energy needed for craze growth with increasing damage zone causes the increasing slope. Figures 1-3 show that $J_{0.2}$ is virtually independent of the strain rate This is caused by the fact that $J_{0.2}$ was not the start of crack growth but of craze growth. The start of craze growth is less influenced by the strain rate. The strain rate gets its effect when it is necessary for craze thickness growth to pull chains into the craze.

From the sideview it was found that Δa obtained from the fracture surface overestimated Δa by approximately 30 %. This was caused by the brittle fracture after the cooling in liquid nitrogen. During this procedure the craze apparently grows further in its original plane before the crack reaches the original craze tip. Subsequently the process becomes unstable and brittle fracture markings are formed

In EPFM there is a linear relation between J and CTOD. Figure 4 shows the relation between J and the CTOD for Finatheen. It is apparent that the relation is not linear. This was to be expected since there was no actual crack growth during the tests. EPFM does not apply.

Comparison of the J-R curves for the three materials showed that Finatheen had the most favourable J-R curves at all three strain rates. TUB121 had the lowest fracture toughness. This is the same order as the order in yield stress (table 1). The yield stress is an indication of the chain mobility. A lower yield stress correlates to higher chain mobility. As was discussed before this causes easier craze thickness growth which leads to more blunting and consequently a higher fracture toughness

CONCLUSIONS

The effect of the strain rate on the J-R curves of the three tested materials is that a increase in strain rate causes a downshift in the J-R curve.

The increasing slope of the J-R curves is caused by the fact that only craze(s) were formed during testing.

The brittle fracture procedure can cause an overestimation of the damage zone length by 30%.

Using the J-integral to determine the fracture behaviour of thermoplastics which exhibit a large degree of crazing seems doubtful.

SYMBOLS USED

a = precrack length (mm)
Δa = damage zone length (mm)
b = length of ligament (mm)
B = specimen thickness (mm)
L = specimen length (mm)
J = value J-integral (J/mm^2)
W = specimen width (mm)
U = energy from area load displacement curve (N*mm)

REFERENCES

(1) A testing protocol for conducting J-crack growth resistance curve tests on plastics. May 1995. Prepared on behalf of the ESIS technical committee on Polymers and Composites.

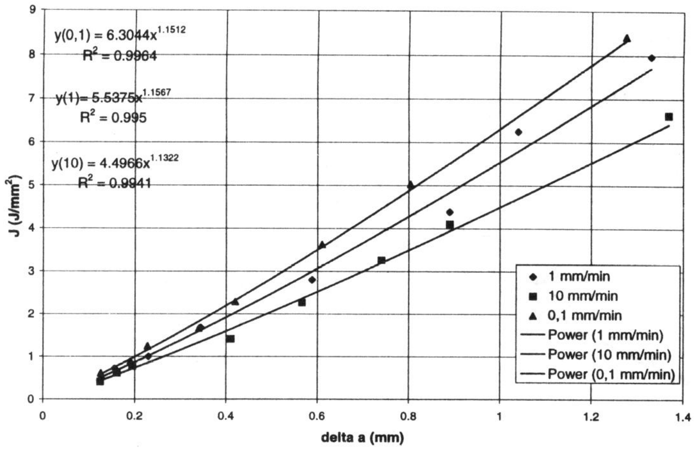

Figure 1 The J-R curves of Finatheen

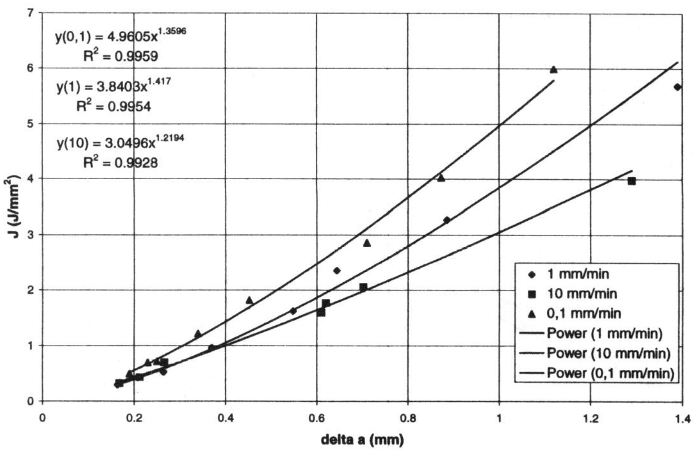

Figure 2 The J-R curves of TUB121

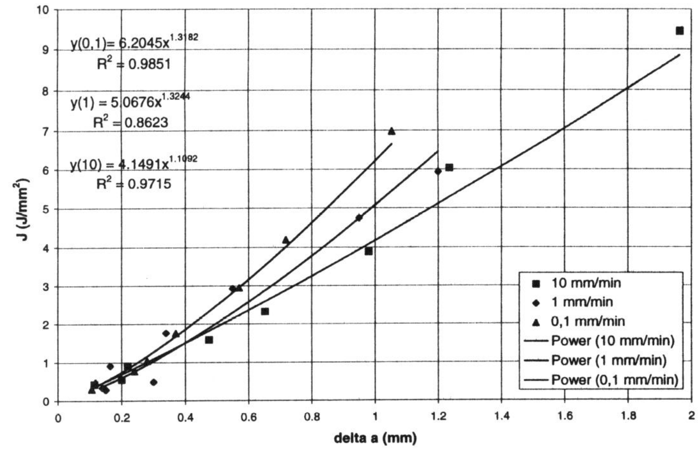

Figure 3 The J-R curves of TUB70

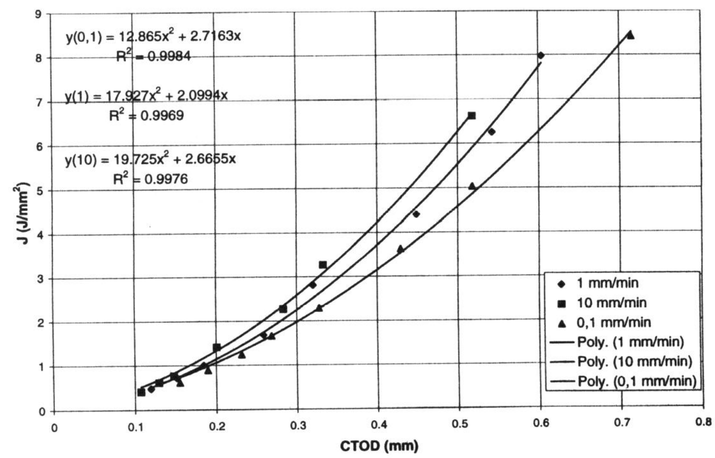

Figure 4 The relation between J and the CTOD for Finatheen.