Polymer Bulletin 25, 253–255 (1991)

Polymer Bulletin

On the J-integral blunting line applied to linear amorphous polymers

I.-Chung Tung

Department of Mechanics and Materials Science, Rutgers University, Piscataway, NJ 08854, USA

SUMMARY

The development of crazes of linear amorphous polymers competes with the occurrence of general yielding in the plastic zone in tensile deformation. For toughened semi-ductile linear amorphous polymers, general yielding in the plastic zone is suppressed by the development of crazes. This suppresion prevents the crack tip from being blunt. Therefore it is recommended that the blunting line be neglected for the evaluation of J_{IC}. For semi-ductile linear amorphous polymers, general yielding in the plastic zone takes place and blunts the crack tip. Thus the blunting line cannot be neglected for the evaluation of J_{IC}.

INTRODUCTION

Most of the commercially useful products of linear amorphous polymers, such as PC, PMMA, PS, and PC/PBT blend etc., usually have long enough molecular chains for the development of crazes around the crack tip and are able to yield above a specific temperature in tensile deformation. When the energy stored by the plastic deformation can compete with or exceed the energy stored by the elastic deformation, the J-integral comes to be a proper criterion for the evaluation of fracture toughness, instead of the Kc value criterion determined by linear elastic fracture mechanics.

Accordind to ASTM E813-87 (1), J_{IC} is determined by the intersection of two lines, a power law fit of the J–Δa curve and a 0.2mm offset line parallel to the blunting line. However for linear amorphous polymers, the chain structures are rather different from the rigid-ball structures of metals, in which the molecular entanglements inhibit general yielding (in contrast to localized yielding arising from the formation of crazes) to a varying degree. Recently, Narisawa and Takemori even stated that the use of crack blunting lines for impact-modified polymers may be misleading and quite possibly incorrect (2). From the microstructural diference between linear amorphous polymers and metals, the blunting lines for linear amorphous polymers could be taken into account in a different way which will be discussed below.

BLUNTING LINE IN THE J-INTEGRAL PROCEDURE

The ASTM E813-87 assumes that the crack tip profile is semicircular due to the blunting of the crack caused by general yielding in the plastic zone. This blunting process leads to the increase in the apparant crack length which is taken into account and expressed as a blunting line. Then a 0.2mm offset line is plotted parallel to the blunting line for the evaluation of J_{IC}.

It has been pointed out that the blunting of the crack tip has an important effect on the chage in crack geometry (3, 4). In metallic materials, until now there has been no literature investigating the possibility of inhibition of general yielding in the plastic zone. However in polymeric materials, there exists a possibility of inhibition of general yielding in the plastic zone caused by the formation of crazes.

FRACTURE MODES FOR LINEAR AMORPHOUS POLYMERS

Commercial linear amorphous polymers usually develop crazes before fracture, excepting the conditions of very low temperature, preorientation of molecular chains, plasticization of specimen surface, or any other conditions that inhibit the formation of crazes. Due to the effect of crazes, there exist two obvious fracture modes for linear amorphous polymers. One is the semi-brittle mode in which polymers are loaded far below the glass transition temperature, and the other one is the semi-ductile mode in which polymers are loaded at the temperature closer to the glass transition temperature than that in the former (5).

For the semi-brittle mode, tensile deformation causes crazes to grow locally. This results from localized stress concentration naturally distributed within the polymer. Then the formation of cavities and subcritical cracks follows. Crazes continue to develop until the polymer fails catastrophically before general yielding.

For the semi-ductile mode, crazes grow locally first in tensile deformation. But until the applied stress is greater than the tensile flow stress, general yielding replaces localized yielding of crazes. The fracture process is therefore controlled by general yielding.

CRAZING AROUND THE SHARP CRACK TIP

(1) Semi-brittle mode

In this mode crazes exist during the whole fracture process.

Crazes grow first around the sharp crack tip due to stress concentration before crack growth in tensile deformation. When the stress around the crack tip reaches the tensile flow stress, a plastic zone starts to develop, and the size of the plastic zone becomes gradually larger with the increase in the applied stress. But most of the molecular chains in the plastic zone have been stretched as fibrils. This stretching leads to a low rate of orientation hardening. Therefore general yielding is suppressed and replaced by the formation of a craze zone (6).

(2) Semi-ductile mode

In this mode crazes are usually eliminated by general yielding before fracture.

Crazes grow around the sharp crack tip (7) due to stress concentration before the crack growth in tensile deformation. When the stress around the crack tip reaches the tensile flow stress, the plastic zone starts to develop and grows gradually larger with the increase in the applied stress. Because the molecular entanglements can be released in the plastic zone, it is favorable to replace localized yielding of crazes by general yielding. As a result, the crack tip is blunted by this general yielding in the plastic zone.

Considering rubber toughened semi-ductile linear amorphous polymers, the soft rubber particles are stress raisers and nucleate a copious number of crazes. Rubber particles in the plastic zone can elongate elastically which results in a stress-relieving effect and delays the breakdown of crazes. Additionally, the fibrils crazes need some time to reach their equilibrium lengths (8). Since the stress around the crack tip increases very fast due to the effect of stress concentration, these fibrils cannot reach the equilibrium length prior to the formation of cavities and subcritical cracks which form during the rupture of the interface between the rubber particles and the polymer matrix (2). In this case, the chain entanglements are not released since the fibrils have not grown to the equlibrium length. Thus general yielding is suppressed and replaced by the development of crazes , cavities, and subcritical cracks.

DISCUSSION

Considering polymer chain motion around the sharp crack tip, the fact that no general yielding occurs for semi-brittle linear amorphous polymers leads to the situation that one is not able to obtain values of yield stress for construction of the blunting line. It is easier to determine the K_{IC} value for fracture toughness criterion in tensile deformation.

For toughened linear amorphous polymers, it is realized that general yielding in the plastic zone is suppressed and localized yielding caused by the formation of crazes is more favorable to occur. In crazes, the fibrils are streched only to a level less than the equilibrium length which blunts the crack tip very little. In tensile deformation, crazes continue to grow and form a damage zone(2, 9). This damage zone stores much more energy than that stored by the elastic deformation. Therefore, under this condition the application of J-integral is necessary to obtain the appropriate fracture criterion.

In the damage zone, a lot of microvoids exist. However these microvoids do not affect the geometry of the crack(10). The crack keeps its initial shape until the beginning of the crack growth. Since the blunting of the crack does not take place in this toughened semi-ductile linear amorphous polymers in tensile deformation, it is reasonable to state that the blunting line is not quite needed for evaluating J_{IC}.

For semi-ductile linear amorphous polymers, general yielding is more favorable to occur in the plastic zone(11). The crack tip is blunted by this general yielding in the plastic zone. The blunting line therefore cannot be neglected for evaluating J_{IC}.

REFERENCES

1. Annual Book of ASTM Standards (1989) : Standard E813-87, Am. Soc. for Testing and Materials, Philadelphia.
2. I. Narisawa and M. T. Takemori (1989) : Polym. Eng. Sci., 29, 671-678.
3. J. R. Rice and M. A. Johnson (1970) : Inelastic Behavior of Solids, (Eds.) M. F. Kanninen, W. Adler, A. Rosenfield, and R. Jaffee, McGraw-Hill, 641-672.
4. R. M. McMeeking (1977) : J. Mech. Phys. Solids, 25, 357-381.
5. S. Rabinowitz, P. Beardmore (1972) : CRC Crit. Rew. Macromol. Sci., 1-45, Jan.
6. H. R. Brown and I. M. Ward (1973) : Polymer, 14, 469-475.
7. Zhen-bang Kuang (1984) : Advances in Fracture Research (ICF6), Pergamon Press, Vol. 2, 1011-1019.
8. J. A. Sauer and C. C. Hsiao (1953) : Trans. ASME, 75, 895-902.
9. J. L. Bassani, N. Brown, and X. Lu (1988) : Int. J. Fracture, 38, 43-59.
10. S. Aoki, K. Kishimoto, A. Takeya and M. Sakata (1984) : Int. J. Fracture, 24, 267-278.
11. M. Kitagawa (1982) : J. Mater. Sci., 17, 2154-2524.

Accepted November 26, 1990 K