EXPERIMENTAL INVESTIGATIONS ON THE MIXED-MODE ESSENTIAL FRACTURE WORK OF PC/ABS ALLOY

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Summary The mixed-mode fracture toughness of PC/ABS alloy is investigated by essential work of fracture (EWF) method. The results show the essential fracture work increases with the decreasing of loading angles. Crack initiation angles measured directly indicate the deviation of crack growth direction from the initial crack plane also increases with the decreasing of loading angles. The micro processes are observed *in situ* by a scanning electron microscope (SEM).

INTRODUCTION

Essential work of fracture (EWF) method is a simple and effective method to measure the fracture toughness of ductile polymers [1]. It was first introduced by Broberg [2] and later used by Cotterell et al. [3] and Mai [4] in ductile materials. It was considered that the deformation at crack tip could be divided into two components, i.e. the process zone and the plastic zone. The energy consumed in the process zone is called the work of fracture W_e, which increases linearly with the ligament length. The energy needed to form the plastic zone is called the plastic energy W_p, which is proportional to the square of the ligament length. The relationship between them can be written

$$W_f = W_e lt + \beta W_p l^2 t \quad (1)$$

Divided by lt, Eq. (1) can be rewritten as

$$w_f = w_e + \beta w_p l \quad (2)$$

where l is ligament length, t is specimen thickness, β is the plastic shape factor, w_f、w_e and w_p represent total specific work, specific essential fracture work and specific non-essential fracture work, respectively. It is seen from Eq.(2) that the specific essential work of fracture w_e can be easily obtained when the ligament length approaches zero.

The essential fracture work of polymers measured under mode I crack has been investigated by many researchers [5-6]. But more often, the structure components made of polymer materials suffered complex loading in practical conditions. Therefore, it is of great importance to study the fracture behaviours of polymer materials under mixed-mode loading conditions. In this paper, EWF method is employed to study the mixed-mode essential fracture work of PC/ABS alloy by DENT specimens with slant cracks on both sides. Crack initiation angles are measured on the fractured specimens. *In situ* observations are carried out to investigate the micro-mechanism of fracture processes of PC/ABS alloy.

EXPERIMENTAL PROCEDURE

The material used in this investigation is an alloy of polycarbonate and acrylonitrile-butadiene-styrene (PC/ABS). The yield strength of PC/ABS is 60 MPa. The dimensions are 60mm×30mm×1.5mm. Sharp razors are used to produce artificial crack tips with different length. Different loading angles are introduced with different φ values from 90^o, 75^o, 45^o to 30^o.All the tests are preformed on Instron 5848 material testing machine. The crosshead speed is 1mm/min and the room temperature is about 16℃. Quanta 400 SEM is used to investigate the deformation micromechanism of the specimens. With the Microtest 2000N tensile machine mounted in the sample room of SEM, the fracture processes of specimens with different crack angles can be observed *in situ*.

RESULTS AND DISCUSSIONS

As an example, Figs 1 show typical load-displacement curves for $\varphi=45^o$ with different ligament length and different φ values with approximately the same ligament length. It can be seen that the load-displacement curves have similar shapes for the specimens with different ligament lengths. With the decreasing of ligament length, the areas under the load-displacement curves reduce, i.e., the energies needed to fracture the specimens reduce. Fig.1(b) indicates that at the same ligament length, $\varphi=90^o$ possesses of the maximum load but the minimum overall displacement. The maximum elongation occurs under the condition of $\varphi=30^o$ though the corresponding load reduces significantly.

The essential fracture work w_e

Calculating the areas under the load-displacement curves, the relationships between the total specific fracture work and ligament length can be obtained. Extrapolating each straight line to zero ligament length, we can easily get the essential fracture work w_e. The slopes of the straight lines reflect the plastic characterization of specimens. It is clear seen that w_e

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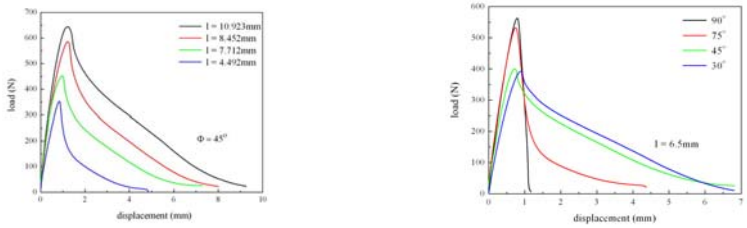

(a) (b)

Fig.1. Typical load-displacement curves for (a) φ= 45° with different ligament length, (b) different φ values with a ligament length of 6.5mm.

increases significantly with the reducing of loading angles. This means that the increasing of shear component enhance the essential fracture work of PC/ABS alloy. Therefore, the fracture works of PC/ABS alloy are greatly enhanced by the increase of shear component.

The critical initiation angle β

Also, several of the photographs of crack growth processes for different loading conditions are obtained. Crack propagation angles β are measured on the fractured specimens. It is shown that the deviation of crack growth direction from the initial crack plane increases with the reducing of loading angles φ, which is corresponding to the increasing of shear component.

SEM *in situ* observation

Using the Microtest 2000N tensile machine fixed in the sample room of SEM， the fracture processes of small EWF specimens with the loading angles of 75° are observed *in situ* as an example. Figs 2 show the typical fracture processes. It can be seen that the crack tip on the left side blunt obviously. However, for the crack on the right, it not only shows blunting but also propagates for some distance. This may be caused by the asymmetry of double-edged cracks on both sides or the inhomogeneous property of materials. Crazes are found around crack tip. It is known that crazes often initiate from the original micro defects (voids or cracks) on the surface of specimen [7]. With the increasing of load, the density and size of crazes around crack tips increase significantly, as shown in Fig. 2(a) and (b). It is seen from these figures that crazes are generally perpendicular to the tensile stress direction, and the fibrils which connect the two surfaces of crazes are oriented alone the tensile directions. It is also seen that cracks are formed with the coalescences of crazes with the increasing of loads. Crazes vanish at the crack tips once the crack growth rapidly.

(a) (b)

Fig.2. SEM *in situ* observation of the crack angle of φ= 75° at a load level of (a) 490N, (b) 300N. (The arrows denote the loading direction.)

CONCLUSIONS

Mixed-mode essential fracture work of PC/ABS alloy is investigated. The results indicate that the essential fracture work w_e increases with the decreasing of loading angles. Crack growth angles show the deviation of crack growth direction from the initial crack plane increases with the decreasing of the loading angles. By SEM *in situ* observation, the micro fracture processes are obtained. Crazing structures can be clearly seen in the fracture processes of the specimens. The crack propagation direction is determined by the macro crack that crazes were coalesced.

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