CHARACTERIZATION OF CRACK RESISTANCE BEHAVIOUR OF POLYMERS WITH THE JT$_J$ CONCEPT

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This paper presents dynamic crack resistance curves of polymer blends. The interpretation of the J versus Δa curves was made with a testing protocol of the ESIS Task Group TC 4 and with a physical concept for describing nonlinear R curves, named JT$_J$ concept. It can be shown, that the JT$_J$ conccept is very practicable to get informations about crack initiation and energy dissipative processes occuring during stable crack growth.

INTRODUCTION

Modern plastics are characterized by high toughness properties even under high testing velocities. The toughness of such materials is often determined by means of J-integral. If stable crack growth is dominant crack growth mechanism in a material, the toughness characterization has to be done by crack resistance curves. With the help of these J versus Δa curves it is possible to characterize the materials resistance against stable crack initiation and stable crack growth.
Anyhow, in most of materials the process of stable crack growth is accompanied by energy dissipation, which can occur by different mechanisms, in addition to that consumed in the formation of the free surfaces. The JT$_J$ concept enables a quantification of these energy dissipative processes which will be shown in the paper.

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EXPERIMENTAL

Method and Materials. TPU/ABS blends with 0%, 20% and 50% TPU (thermoplastic polyurethane) and PC/ABS blends with 45%, 60% and 70% PC were chosen for this study. The specimens were produced by injection moulding. The dimensions of the single edge notched three point bend specimen were: length L = 80 mm, width W = 10 mm and thickness B = 4mm. The specimen had sharp notches made with a razor blade. The notch depth was a = 4.5 mm and the notch tip radius was 0.2 μm. For the measurements a Charpy impact tester with 4J work capacity was used and impact load (F)- deflection (f)- diagramms were recorded. The experimental conditions were: pendulum hammer speed v_H = 1,5 ms^{-1} and support span s = 40 mm, i.e. s/W = 4. An improved test procedure of the stop block technique was used in this study (1). In general the multiple specimen R curve method was used. The stable crack growth Δa is quantified on the fracture surface by light microscopy. The fracture surfaces are produced by breaking the specimen at liquid nitrogene temperature and high pendulum hammer speed. The value of J for each specimen was determined from the area under its F- f- curve following eqn. 1 (2):

$$J = \eta_e \frac{A_e}{B(W-a)} + \eta_p \frac{A_p}{B(W-a)} \{ 1 - \frac{(0,75\eta_e-1)\Delta a}{(W-a)} \} \qquad (1)$$

This equation includes a crack length correction, so all that demands about a limitation of Δa, which are made in the standards and drafts (3), are unnecessary.

JT_J concept. On the basis of works by Saka et al (4), Michel and Will worked out a model to quantify energy dissipative processes occuring during stable crack growth (3,5,6). This concept is based on the following assumption: Stable crack growth occurs, if the energy dissipated in a material specific way compensates for the surplus of available energy caused by crack propagation. Consequently the stable crack growth is controlled by the product JT_J. Michel and Will showed in (3,5,6) that JT_J controlled stable crack growth occurs if the J-Δa values follow eqn. 2 and 3:

$$J = \sqrt{A + B\Delta a} \qquad (2)$$

$$\frac{W-a}{J} \frac{dJ}{d(\Delta a)} > 1 \qquad (3)$$

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RESULTS

There are two ASTM standards, E 813 and E 1152, for conducting J-tests on metals (7,8) and an EGF procedure for ductile materials (2). While generally similar, there are differences between the standards. A comparison of these has been undertaken in (9). For conducting J-crack growth resistance curve tests on plastics a testing protocol of the ESIS TC 4 group exist (10). This is the one testing instruction for polymer materials.

The construction of valid crack growth resistance curves of polymers is very difficult, because of   many reasons, for example
- small amounts of crack growth are difficult to measure and they are subject to error and
- crack tip blunting processes are not clarified.

Therefore small Δa values ($\Delta a < 0,05mm$) and crack tip blunting processes are not considered. $J_{0.2}$, which measures the fracture resistance at 0.2 mm of total crack growth is used to give an estimate of J close to the point of crack initiation.

TPU/ABS blends. Fig.1 shows the J_R curves of the TPU/ABS blends investigated. These J_R curves are evaluated using the proposal of the ESIS TC 4 testing protocol (10). It becomes clear, that the crack initiation value $J_{0.2}$ increases with increasing TPU-content.

The J versus Δa curves describe not only crack tip blunting and crack initiation but also the materials resistance against stable crack growth. The materials resistance against stable crack growth is characterized by the tearing modulus, T_J (11). This value depends on the slope of the fit curve. If this fit curve is a power law, like the testing protocol (10) requires, the value of T_J depends on the amount of stable crack growth. In this case T_J can not be a material characteristic parameter.

Michel and Will (3,5,6) pointed out, that stable crack growth can be JT_J controlled. Fig. 2 shows the same J-Δa values as Fig. 1, but these are fitted by a square root function (eqn. 2). Now it is possible to determine the crack initiation values $J_{0.2}$ and the JT_J values of the materials. Both values are geometry independent fracture mechanics values, if the validity criteria are fulfilled. Thus, they can be used for the toughness characterization of the materials. The meaning of the JT_J value is the following:

- The JT_J values can be used for the quantification of energy dissipative processes in the materials. This is for polymers of a special importance (12) and no other quantity exists for purpose.
- The product JT_J is a very sensitive indicator for changes in morphology (1,12).
- JT_J can be used for a direct comparison of crack resistance curves, which is especially important in the field of materials development.
- The JT_J values increasing with increasing TPU- content and the $J_{0,2}$ values are nearly the same as in Fig. 1. It becomes clear, that the JT_J concept can be used to get the "conventional" informations about crack resistance behaviour , like the standards and drafts are doing, and additionally to get informations about energy dissipation which can be related with morphology parameters. Such morphology toughness relations are discussed in (1,12).

PC/ABS blends. For these materials the influence of temperature on toughness behaviour was of a special interest. Fig. 3 shows J_R curves of PC/ABS blends with 45% and 70% PC at room temperature and at T = -30°C. From these R-curves it can be quoted:
- The crack initiation values of T45 MN (45 % PC) are the same at both temperatures. That means, the aim to get high toughness properties at low temperatures is fulfilled.
- The temperature influences only the material resistance against crack growth, energy dissipative processes are increasing and so the value of JT_J.
- The crack initiation values of T85 MN (70 % PC) are increasing with increasing temperature, because of the high PC content. Also the JT_J values are increasing. This product has at low temperatures a very good energy capacity. The morphological reasons for this material behaviour are also discussed in (12).

SYMBOLS USED

$A_{e;p}$	elastic; plastic shares of total deformation energy (Nmm)
E_d	Young's modulus (MPa), determined on the unnotched specimen, impact velocity 1 ms^{-1} (MPa)
$J_{0,2}$	critical J integral value (N/mm) at Δa = 0,2 mm
Δa	stable crack growth (mm)
$\eta_{e;p}$	elastic; plastic work factors
v	Poissons ratio

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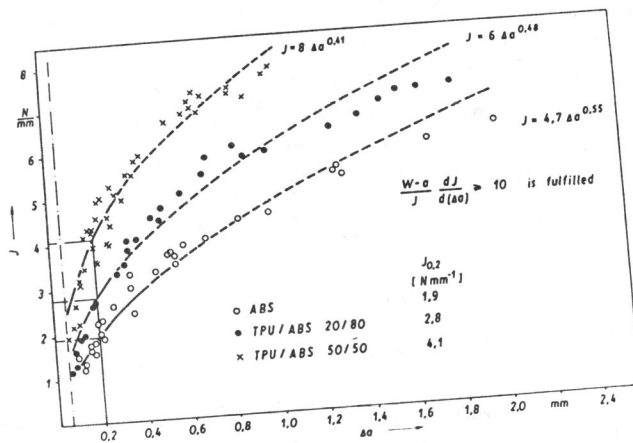(12) Grellmann, W., Seidler, S., J. Mat. Sci., in preparation

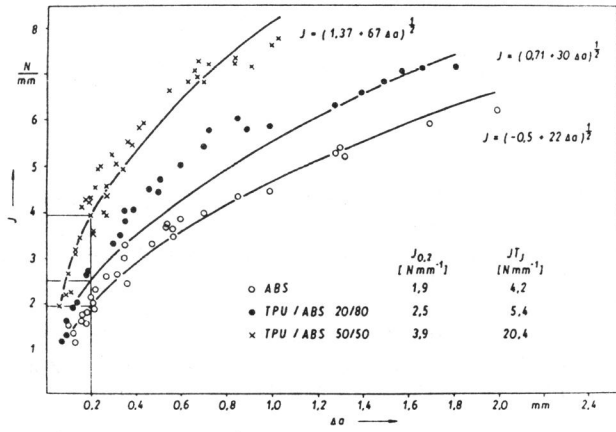Fig. 1: J versus Δa curves of TPU/ABS blends, interpretation follows (10)

Fig. 2: J_R curves of TPU/ABS, interpretation follows JT_J-concept
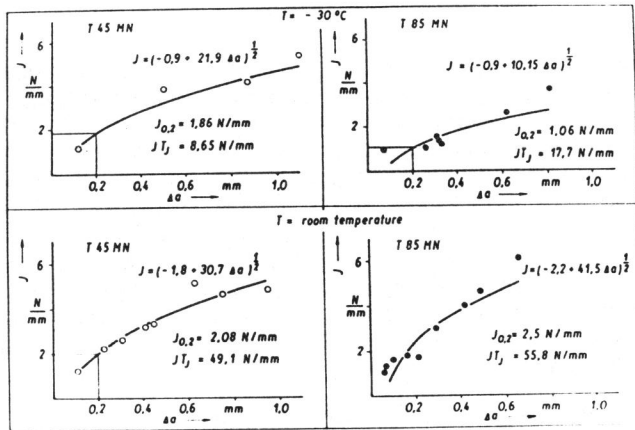

Fig. 3: Dynamic R curves of PC/ABS blends, T = room temperature and T = - 30 °C

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