ANALYSIS OF FRACTURE BEHAVIOUR OF FIBRE REINFORCED POLYPROPYLENE

W.Grellmann, S.Seidler,[1] B.Michel, P.Will[2]

Experimental results for investigation of dynamical crack resistance curves in the instrumented Charpy impact test on PP/glass fibre composites are presented. For this purpose the multiple specimen R-curve method, stop block technique is used. With the aid of J-Δa curves the influence of a special coupler system on crack toughness is discussed. It is shown that it is possible to quantify energy dissipative processes with the new fracture mechanical value JT_J . The problems of determining physical crack initiation values for short fibre composites are discussed.

INTRODUCTION

The determination of fracture mechanic values as resistance against stable crack growth for fibre reinforced polymers has opened up new ways for optimizing the properties of composites, because the energy dissipative processes occuring during stable crack growth can be quantified. So values can be determined which enable material properties to be fully utilized.

EXPERIMENTAL

Polypropylene/glass fibre composites were chosen for this study. The fibre volume fraction was $f_v = 0.13$. A special coupling agent was used. The specimens were produced by injection moulding. The dimensions of the single edge notched three point bend specimen were:

1)Department of Materials Science, Technical University Carl Schorlemmer, Leuna Merseburg, DDR-4200, G.D.R.
2)Institute of Mechanics of the Academy of Science of the G.D.R., Karl- Marx-Stadt, DDR-9010, G.D.R.

length l= 80mm, width W= 10mm, thickness B= 4mm. The notch depth was a=2mm. The notches had sharp tips made with a razor blade. For the measurements a Charpy impact tester PSW 0,4 of 4 J work capacity was used and impact load (F)-deflection (f)-diagrams were recorded. The experimental parameters were: pendulum hammer speed v_H = 1 m/s and support span s= 40 mm, i.e. s/W= 4. An improved test procedure of the stop-block technique (1) was used in this study. In general the multiple specimen R-curve method was used. The stable crack growth Δa is quantified on the fracture surface by light microscope. 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 load-deflection curve (2). The J-Δa-curve consists of a crack tip blunting region and a crack growth region. These regions were often approximated by straight lines. The blunting line characterizes the region in which crack tip blunting occurs and a stretch zone forms (3). Michel and Will (4) suggested, on the basis of works by Saka et al (5), a practicable model for estimating stable crack growth. This model follows from an energy balance on the crack. According to this model, stable crack growth occurs if the energy dissipated in the plastic zone 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 . The Tearing modulus T_J is proposed by Paris et al (6).

RESULTS AND DISCUSSION

The structure of the composites is characterized by different orientation of regions of fibres with different length. The extension of these regions depends on fibre volume, specimen thickness and processing conditions. The structure in the centre of the specimen is especially critical for determining dynamic R-curves on three point bend specimens. In this zone it is not possible to realize crack stop in the instrumented Charpy impact test under the experimental conditions chosen. Fig. 1 shows the J-Δa-curves determined for the PP/glass fibre composites. For these composites it is very difficult to achieve reproducible stable crack growth. As a result, the measured values were fitted by straight lines (7). An interpretation of these J-Δa-curves using (2,3,8) is not recommendable. Stable crack growth lower than 0,6 mm cannot be quantified because the fracture surface is very rugged. The critical crack initiation value, J_{id}, is determined from the point of

intersection of blunting line and R-curve. By contrast, the blunting lines of the composites studied in this paper are not plotted because they are nearly identical and their slope is so high that the value of J_{id} is hardly influenced. Therefore, crack initiation values are determined from the point of intersection of J-axis and R-curve. The J_{id} - values obtained increase with increasing coupling agent contents. The highest values are achieved for the optimized product PP4. Another value for evaluating J-Δa-curves is the Tearing modulus. The Tearing modulus, T_J, decreases with increasing coupling agent contents, with the exception of PP4. Investigations of fracture behaviour of other composites and polymer blends (9) showed, that independently of the specific behaviour of J_{id} and T_J only the product JT_J quantifies the energy dissipative processes occuring during the fracture process. The values of JT_J are identical for the composites PP2 and PP3. This result agrees with the knowledge about energy dissipation in these materials, which has been obtained in investigations of fracture toughness values as resistance against unstable crack growth. So it can be shown, that JT_J quantifies the energy dissipative processes during fracture. Hence the stable crack growth is controlled by JT_J. So far, this dicussion has referred to the investigation of technical crack initiation value. However, the real physical crack initiation starts if the crack tip blunting, i.e. formation of the stretch zone, is finished. This makes it possible to determine the physical crack initiation value from the point of intersection of stretch zone width and R-curve (2). In accordance with Carling et al (10) it can be shown that stretch zone formation is increasingly hampered if fibre volume increases. SEM observations show a nearly compact stretch zone of matrix material PP. Whereas at low fibre volume fractions large regions are found which are connected with one another, their amount decreases with increasing fibre volume, the stretch zone assumes the form of protuding tips and cannot be proved throughout the complete specimen thickness B. Whereas the stretch zone height of PP/glass fibre composites can be quantified up to fibre volumes $f_v \leq 0,2$, it is almost impossible to quantify the stretch zone width of the PP/composite which are used in this study with a fibre volume of 0,13. So we must say that it is not possible to determine a physical crack initiation value for the composites studied in this paper using J-Δa-curves.
Short glass fibres often cause a brittleness of composites in comparison with matrix material. Therefore the investigation of δ-Δa-curves in addition to the J-Δa-curves is of a special interest for application. For

polymer materials with large plastic deformation on crack tip only processes on crack tip should be considered in the calculation of the critical crack opening displacement, because the differences between the actual COD and that calculated from maximum deflection will increase with increasing plastic deformation. This critical value is denoted δ_{dk} . The determination of δ_{dk} is given in (11). Fig 2 shows the comparison between the δ_{dk} and the δ_d-Δa-curves for PP3 and PP4. The crack initiation values, δ_{ik} , from the δ_k-Δa-curves prove to be a conservative estimation criterion. The δ_{ik}-values have a good correlation with J-values which are determined from the stretch zone height. The good accordance of δ_{ik} and δ_{szH} demonstrates, that only δ_{ik} quantifies the real deformations on the crack tip. So material physical background is pointed out for the use of the proposed enlarged "plastic-hinge" model for evaluating the deformation behaviour of composite materials.

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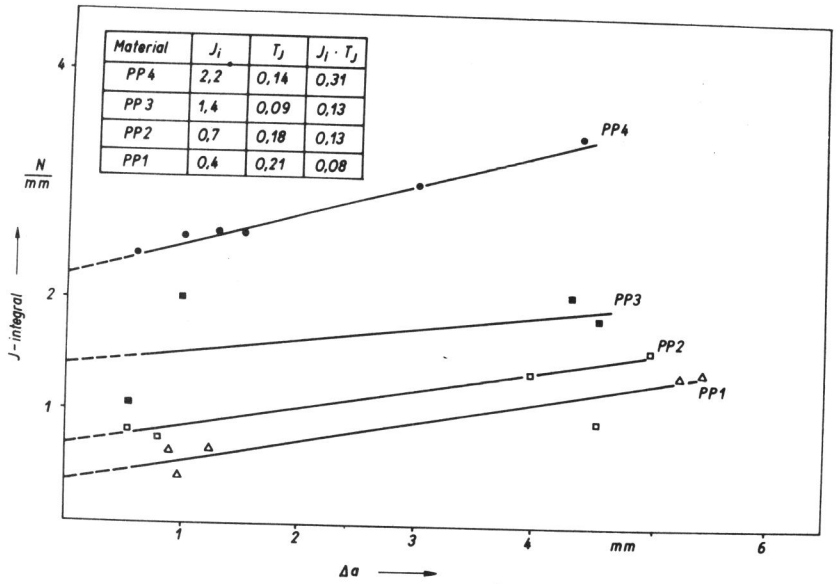

Fig. 1: J - Δa- curves of PP/glass fibre composites

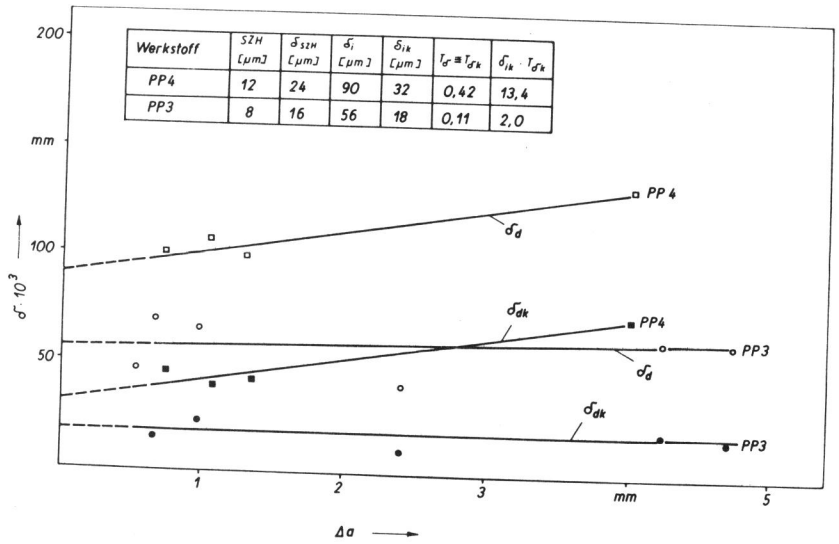

Fig. 2: δ_d -Δa-curves and δ_{dk}-Δa-curves of the composites