FRACTURE CHARACTERIZATION OF COMPOSITES IN MIXED MODE LOADING

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The fracture behaviour of a polyester isophtalic resin is presented. Fracture toughness tests were conducted on single edge notched tensile specimens, cut from casted plates. Cure and post cure conditions were varied and their effect on K_c was measured. The problem of the inclined crack, namely the direction of initial crack extension and the critical load, was then studied testing cracked plates under tensile loading. The angle defined by the crack and the load direction was varied from 0^o to 90^o. All the plates were subjected to the same cure conditions. The applicability of the maximum tangencial stress criterium was studied.

INTRODUCTION

A great number of structures are made of glass fibre reinforced plastic (GFRP). These structures may be found in a vast number of industries, from civil and chemical engineering to the construction of boat hulls and vehicle bodies.

Although an interest is now developing in the use of thermoplastic materials for the fabrication of composite structures, the resins generally used in GFRP are of the thermosetting type. The characterization of GFRP fracture behaviour is obviously necessary, if reliable and safe structures are to be made. This characterization is, however, a difficult task, since the behaviour of the composite is not easily related to the behaviour of the components.

The authors are approaching the problem by conducting a research programme that looks, firstly, to the characterization of the resin, and then to the composite. It is expected that this approach

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will make it possible to develop a rigorous assessment of the relationship composite-components.

The present paper will describe the details of the work concerning the behaviour of a resin commonly used in GFRP.

EXPERIMENTAL

Material and specimens

The material tested is the CRYSTIC 272 resin, supplied by Quimigal (Portugal). The 272 resin is a polyester isophtalic resin. The cure system used was a MEKP catalyst (Butanox M50) and a cobalt accelerator (TP 395 VZ). The catalyst and the accelerator were used in a weight fraction of 2% and 0,1%, respectively.

Plates of 4 mm nominal thickness were cast in special purpose built rigs, assuring a constant thickness and a good surface finish. The plates were of 300×400 mm^2 surface area. Single edge notch tensile (SENT) specimens of $120\times30\times4$ mm^3 overall dimensions were saw cut and then machined, Figure 1. A saw cut notch was then produced with a 0.3 mm saw, using a specially designed rig that seeks to guide the saw. It was thus possible to obtain a regular notch, with a front perpendicular to the specimen surface. A natural crack tip was then obtained using a razor blade placed in the notch tip, and subjected to a light impact. The natural crack was typically 2 mm long. Crack length is the total depth of the saw cut notch plus the natural crack length. The ratio crack length/specimen width (a/W) was kept in the .45 to .55 range, and the K_I calibration used is that given in [1],

$$K_I = \frac{P\sqrt{a}}{BW}\left[1.99-0.41(a/W)+18.70(a/W)^2-38.48(a/W)^3+53.85(a/W)^4\right] \quad (1)$$

where P is the applied load, a is the crack length, B is the thickness and W is the width. Centre cracked plates were also used. The plates are of nominal dimensions $340\times160\times4$ mm^3, Figure 2. The centre crack was obtained drilling a 2 mm hole in the centre of the plate; a notch was then cut with a 0.30 mm thick saw. The nominal length of this central notch was 12 mm. Since it was desired to study the direction of initial crack extension and the critical load for the inclined cracks, plates were prepared with notches presenting different inclinations to the load direction. The inclinations were nominally $\beta = 0^o, 15^o, 30^o, 45^o, 60^o, 75^o$ and 90^o.

Similarly to the SENT specimens, the tensile plates were provided with natural cracks at each tip of the saw cut notch. These natural cracks, typically 2 mm long, were obtained through the impact of a razor blade.

SENT tests. Results.

The SENT specimens were tested at 2 mm/min displacement rate in an Hounsfield Tensometer, provided with a 300 N capacity instrumented load cell. In order to assess the shape of the load versus crack mouth displacement curve, an RDP inductive type LVDT transducer was applied to the specimens. The LVDT measured the crack mouth displacement, the gage distance being typically 10 mm. An attempt was made to use conventional clip gauges, but it was found that these produced unacceptable high opening loads when applied to the specimens. Load and displacement signals were, after conditioning, fed to a Bryans xy recorder.

Tests were conducted on specimens with and without post cure, after a given period of cure. The post cure took place in a furnace at 80°C during 3 hours.

The K_c values were then obtained using the expression (1), with P being the critical load.

An essentialy constant toughness was obtained, irrespectively of cure time, Figure 3, when the post cure was applied. However, a decrease in fracture toughness with cure time was observed, Figure 4, for specimens without post cure.

Centre cracked plates results.

Post cured plates of resin subjected to a 24 hours period of cure were tensile tested, at 2 mm/min displacement rate. The angle β at each tip of the centre crack being different, each plate gave two values for β and θ_0, where θ_0 defines the direction of initial crack extension from the pre-existing crack tip. Since it was not always possible to obtain at one tip the same values of β and θ_0 on both faces of the plate, the values used are mean values of both faces readings. All measurements were carried out in a Mitutoyo precision measuring microscope with 30× amplification.

A set of grips and an assembly rig were designed ensuring that no bending effects were introduced during testing. The bolts in the grips were equally tightened with a torque wrench, and the torque was selected ensuring that the load was transmitted through the friction in the grips.

Tests were carried out in the Hounsfield Tensometer already mentioned, except in the case of the $\beta = 0^o$ situations (ie, crack parallel to the load direction) where a 30 ton Tinius Olsen universal testing machine was used. The load at fracture was recorded. Figure 5 shows the θ_0 versus β values obtained, θ_0 being negative because the crack extends downwards.

Figure 6 presents experimental results of the relation σ_{Ic}/σ_c versus β, where σ_{Ic} is the remote critical stress for $\beta=90^o$ and σ_c is the remote critical stress for other β values.

DISCUSSION

Post cure is applied in order to obtain higher values of tensile properties (Young modulus and tensile strength). The present work reveals that the toughness of CRYSTIC 272 resin is essentialy constant to ± 13%, irrespective of cure time, when a post cure is applied. On the other hand, toughness decreases with cure time when no post cure is applied; furthermore, the toughness tends to the value corresponding to post cured material (Figures 3 and 4). The mentioned trends of the tensile strength, Young's modulus and hardness were described in an earlier report, [2], where some preliminary toughness values were already mentioned.

Turning to the inclined crack problem, the maximum tangential stress criterium was used, taking into account a recent discussion on the relative merits of several criteria [3,4,5].

In order to predict the direction of the initial crack extension, theoretical curves corresponding to the maximum tangential stress criterion were obtained using an expression which takes into account Finnie and Saith's correction [6] to the earlier work of Williams and Ewing [7]:

$$\tan^2\beta - [(1-3\cos\theta_0)/\sin\theta_0]\tan\beta - [16\alpha\sin(\theta_0/2)/3\tan\theta_0] \times \times(1-\tan^2\beta) = 0 \qquad (2)$$

where $\alpha = \left(\frac{2r_c}{a}\right)^{1/2}$ and r_c is the critical distance from the crack tip.

A comparison of the remote stress for $\beta=90^o$ and the inclined crack situation was carried out. The theoretical equation, taking into account [6], is expressed as:

$$\frac{\sigma_{Ic}}{\sigma_c} = \cos(\theta_0/2)\,[\sin^2\beta\cos^2(\theta_0/2) - 3/2\sin\beta\cos\beta\sin\theta_0] + + \alpha\,(\cos^2\beta - \sin^2\beta)\sin^2\theta_0 \qquad (3)$$

In both figures 5 and 6 theoretical curves are plotted for α = 0, 0.1 and 0.2.

It should be mentioned that since each plate gives two values of β, two values of σ_{Ic}/σ_c are also obtained for each plate. It was observed that in general the lower β gave results closer to the theoretical prediction.

It should also to be noted that experimental results are closer to the region defined by the α = 0.1 to 0.2 curves, showing that, even for this brittle material, critical conditions do not take place exactly at the crack tip, but at a small distance from the tip.

CONCLUSIONS

- Fracture toughness of CRYSTIC 272 resin decreases with cure time when no post cure is applied, whereas it is practically constant whenever the post cure is used, regardless of cure time.

- Fracture toughness of CRYSTIC 272 resin tends to the value of the post cured resin after a period of two weeks, when post cure is not applied.

- Experimental results for the inclined crack problem were obtained using post cured resin. The maximum tangential stress criterion was found to describe well the results. Theoretical values for α = 0.1 and 0.2 were closer to the present experimental results, suggesting that critical conditions are not reached at the crack tip, but at a small distance from the tip.

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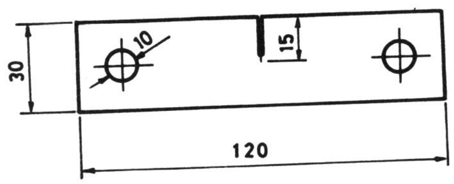

Figure 1 Single edge notch specimens

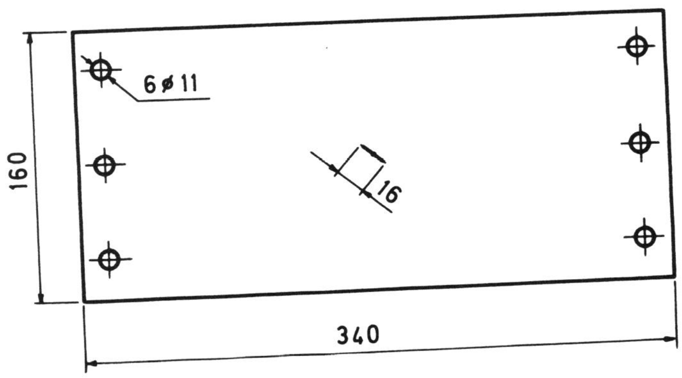

Figure 2 Centre cracked plates

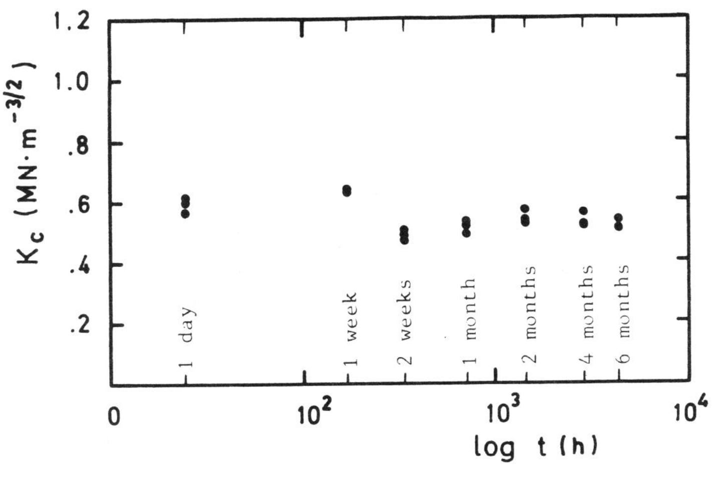

Figure 3 Toughness K_c versus cure time t, for post cured CRYSTIC 272 resin

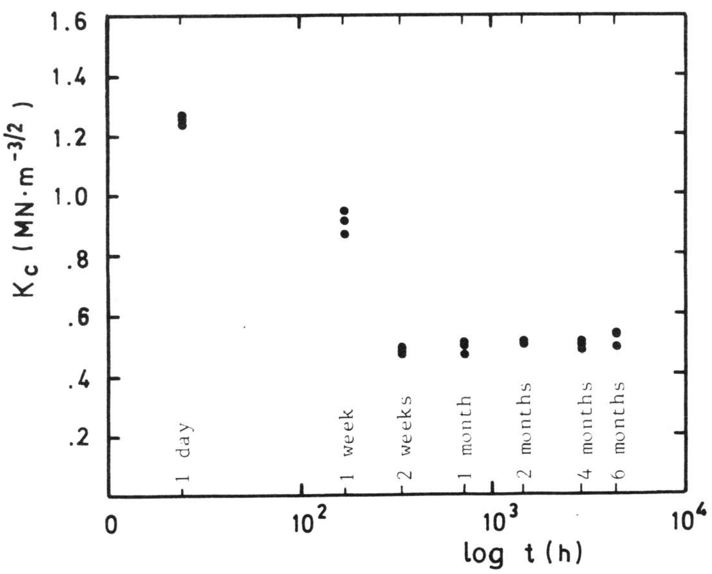

Figure 4 Toughness K_c versus cure time t, for CRYSTIC 272 resin without post cure

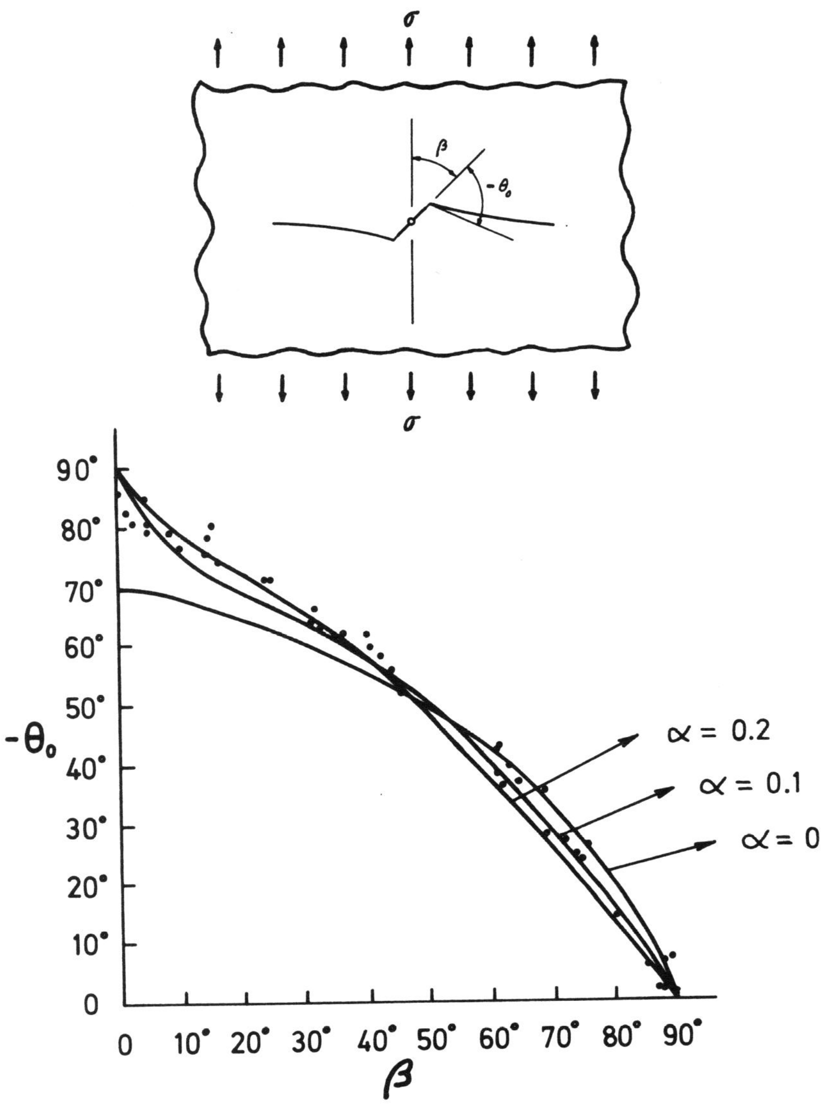

Figure 5 Direction of initial crack extension; experimental results and theoretical curves

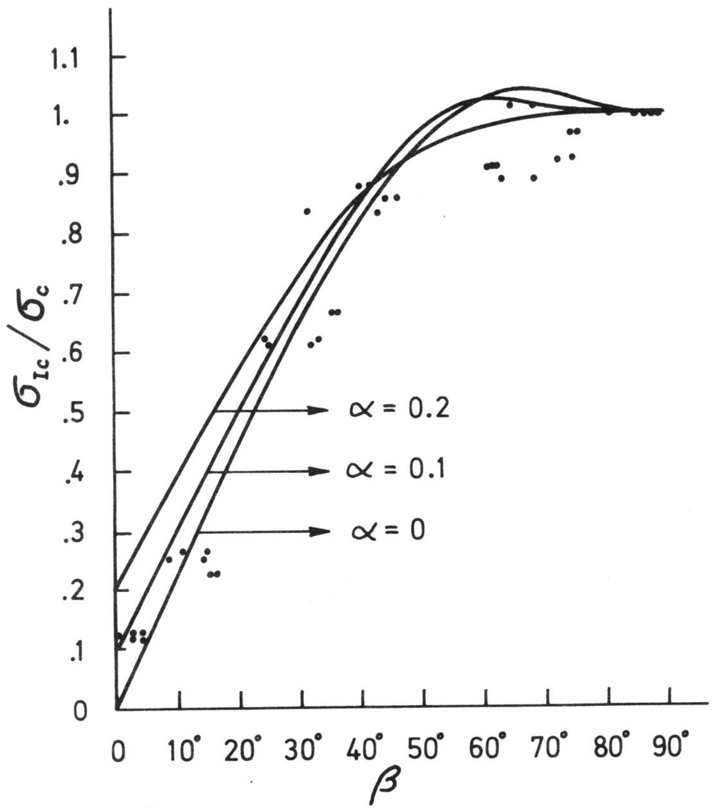

Figure 6 Ratio critical remote stress ($\beta=90^0$)/critical remote stress, as a function of β; experimental results and theoretical curves