STRESS CORROSION CRACKING IN PULTRUDED E-GLASS FIBRE REINFORCED VINYL-ESTER COMPOSITE RODS

P.S. Hill, J.C. Curwen, J.E. King, and J.A. Little*

Stress corrosion cracking of notched glass-fibre-reinforced pultruded polymer composite rods has been investigated in 0.6M hydrochloric acid at loads between 10 and 60% of the ultimate tensile strength in air. Crack propagation from the root of the notch was observed, the velocity of which was measured and used to provide data from which the life-time of components in this environment could be predicted.

INTRODUCTION

The accelerated failure of E-glass reinforced composites exposed to acidic environments whilst under stress has been the focus of considerable attention in the past ten years. Catastrophic failures have been observed at loads as little as 10% of the ultimate tensile stress (UTS) in air. Failure occurs because a crack propagation mechanism operates under these conditions, which would not normally be observed in air, Price [1], to a large extent localising failure to a single plane perpendicular to the maximum tensile stress. The work described in this paper examines this type of stress corrosion cracking in pultruded glass fibre reinforced rods, and shows how the growth rate data obtained can be used to predict specimen lives.

EXPERIMENTAL DETAILS

5mm diameter E-glass fibre reinforced vinyl-ester pultruded rods were used for the investigation. The fibres in the rods are necessarily axially aligned by the method of manufacture, and the rods contain a fibre volume fraction of approximately 0.63, determined by image analysis. The distribution of the fibres in the rod was good, but not ideal, with inter-tow resin rich areas observed.

* University of Cambridge, Department of Materials Science and Metallurgy, Pembroke Street, Cambridge, CB2 3QZ, England.

The rods were cut into 30cm lengths and the ends over-wrapped with glass fibre tape and a poly-ester resin to prevent crushing of the rods during testing. The end preparations were machined so that they were parallel to the shaft of the rod.

The specimens were notched symmetrically about the circumference on a lathe using a tool with a cutting tip angle of 50°. The depth of the notch was simply controlled using the scale on the lathe, and was subsequently checked by measuring under a microscope.

The specimens were tested in a Monsanto bench tensometer. A hole comparable to the size of the rod diameter was drilled in a small plastic bottle, and the rod sealed in using silicone rubber. This simple container allowed the localisation of test solution around the notch. Specimens were loaded to different fractions of the UTS before the acid, 0.6M Hydrochloric acid (Price [2]), was added. Time to failure was monitored. Tests were conducted over the range 10 to 60% of the UTS, with a nominal initial notch depth of 0.5mm. Control tests on un-notched specimens in acid, and notched rods in distiled water were carried out in tandem.

RESULTS AND DISCUSSION

As has been reported [1], the failure morphology changed from the characteristic brush-like appearance with extensive longitudinal debonding and cracking seen in air to a surface with three distinct regions, see figure 1. The first region corresponds to the machined notch, the second to a planar area where crack propagation has occurred and in the centre the third portion was analogous to overload failure in air. As the applied test load was decreased, the area of planar surface increased because stress corrosion crack growth occurred over a greater distance before final overload failure, see figure 2. The area of crack growth was determined by optical microscopy combined with image analysis. The crack was not quite symmetrical around the rod due to a small eccentricity in the notch depth, and an average value was determined by analysing the area as if it were perfectly circular.

The diameter of rod expected to support the applied load can be calculated from the UTS, and this corresponded closely with the measured area of overload failure, that is, crack growth occurred until the stress on the uncracked portion of the rod exceeded the UTS.

The crack length was combined with the time to failure to give an average crack velocity. Price [2] reports that the rate controlling steps involved in the cracking mechanism are:
1) time for the acid to reach the fibres, and
2) time for the acid to initiate cracks in the fibres.
In the calculation of the crack velocities here, no allowance has been made for an initiation period because the machining exposed glass fibres to the environment directly at the notch root.

Crack velocity is plotted against the initial stress intensity (K_I) at the notch root, in figure 3. The value of the initial stress intensity was used because the testing system resulted in a small reduction in load as the crack propagated and specimen stiffness decreased. The load drops observed were small compared to the total applied load.

Data published by Price [2] and Noble [3] are also shown in figure 3, and correlation between them can be seen. Both the toughness and the diffusion properties of the matrix are reported to effect the stress corrosion mechanism [1] and [4]. Price used a poly-ester (Crystic 272) containing a volume fraction of E-glass fibres between 0.54 and 0.57 in 0.6M HCl and Noble et al an epoxy (type MY740/HY917/K61B) reinforced with a volume fraction of approximately 0.63 in 5M HCl. The epoxy resin matrix appears to show the smallest crack velocities, i.e. is most resistant to these conditions. The vinyl and poly-esters behaved similarly, even though the lower fibre content of the material used by Price implies that the crack velocities will be decreased because, on average, there will be a greater amount of resin between the fibres across which acid must diffuse if this web does not fail immediately before the next glass fibre is attacked. More detailed tests over a range of acid concentrations are required on materials of varying volume fraction before any further conclusions can be drawn about the behaviour of the vinyl-ester resin.

From crack velocities, failure life times can be predicted. If the failure stress is known then the crack length at which overload failure should occur can be calculated for different applied loads, assuming that there is no notch effect on the UTS. These predicted values are plotted along with those measured in figure 2. Agreement is reasonably good. Life prediction could therefore be carried out using crack velocity data integrated between an initial defect size and the final crack length at failure determined from measurement of the failure strength in air.

CONCLUSIONS

1. A stress corrosion crack mechanism has been shown to operate in these pultruded glass reinforced vinyl-ester rods in 0.6M hydrochloric acid.

2. Observed growth rates are in good agreement with data in the literature for polyester and epoxy systems.

3. Final failure is governed by simple overload considerations without the need to consider a notch effect.

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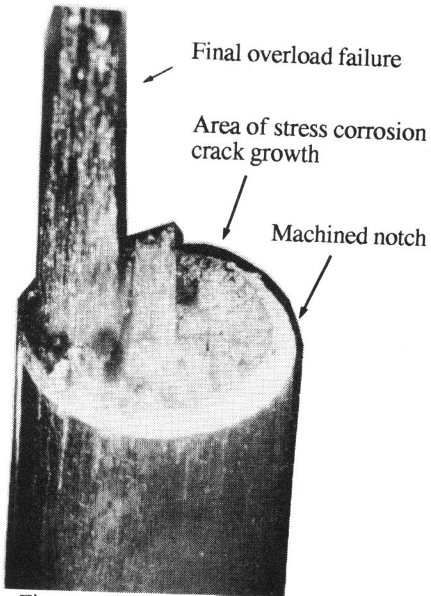

Figure 1. Photograph showing the three distinct areas of the failure surface.

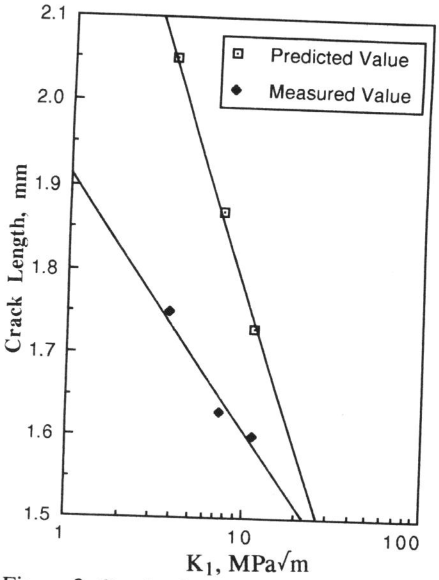

Figure 2. Graph of crack length at failure plotted against initial stress intensity.

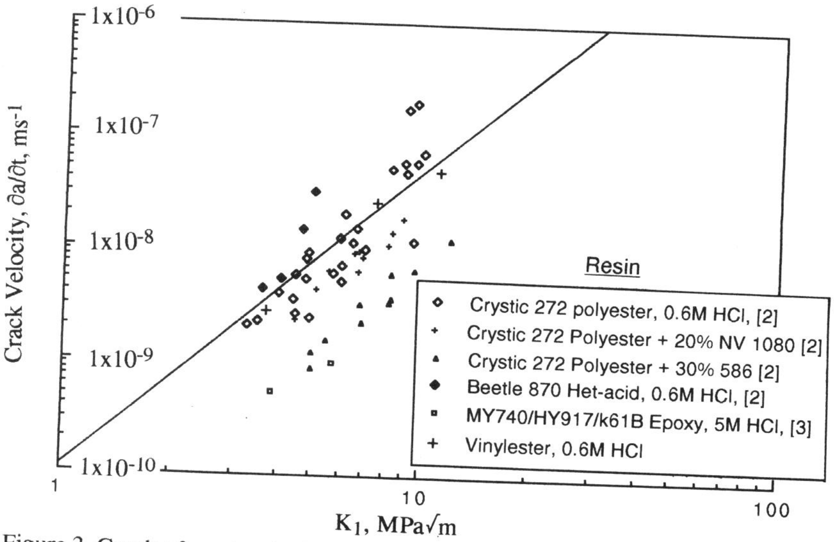

Figure 3. Graph of crack velocity plotted against initial stress intensity