FRACTURE MECHANICS OF GLASS REINFORCED PLASTICS UNDER CORROSIVE ENVIRONMENT

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The failure processes in glass reinforced plastics subjected to long-term loading and corrosive environment conditions were investigated. To monitor early stages of composite damage the acoustic emission was used. The effect of stress state on stress corrosion has been studied. The result from GRP are referred to the results from glass fibres. To simulate service conditions some tests were made which included periodic unloading and long-term immersion in acid.

INTRODUCTION

Under the combined influence of stress and corrosive environment glass fibre reinforced plastic (GRP) rupture at much lover stresses than in the absence of the environment as was fund by Hogg and Hull (1). This phenomenon is attributed to ion exchange process in which the metal ions in the glass are replaced by hydrogen ions from the acid. The subsequent shrinkage of the fibre leads to local stress concentrations and cracking

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in the presence of applied stress. The stress corrosion cracking is a very important factor in pressure vessels and especially in pipelines. An effort has been made to evaluate the life-on time of GRP under combined influence of stress and environment, however the mechanisms of corrosion cracking of GRP have not been studied extensively and many unresolved questions remain. This is mainly because of the lack of proper methods to follow the early stage of fracture. Recently Gołaski and Figiel (2) have shown that acoustic emission (AE) can be applied to detect the beginning of stress corrosion cracking as well as to supply on-time data concerning fracture processes in composites. This paper is concerned with the fracture mechanisms of fibre composites under long-term loading and environment conditions. Comprehensive tests have been made including corrosive cracking of glass fibres and corrosive cracking of laminates under uniaxial and biaxial stress conditions. Some of the tests relate to the conditions found in pipe-lines and pressure vessels. To simulate these service conditions more fully some tests were made which included periodic unloading and long-term acid immersion without loading. Effort was made to protect the composite against corrosion by periodic washing with the help of destilled water. To detect the beginning and the intensity of stress corrosion cracking acoustic emission (AE) was used. All the tests were extended to weepage except the fibre samples where the final fracture of all the fibres in the bunch was observed. The results obtained under stress corrosion conditions were compared with the tests using water environment. To compare the results from different tests the results have been expressed in terms of fibre strain $\varepsilon_{\parallel}$.

MATERIAL AND LOADING CONDITIONS

The tests were made on filament wound pipes and bunches of fibres. The pipe diameter was 50 mm and the wall thickness 1.5 mm. The pipes were fabricated from Fibreglass Ltd. Superwind 20/70E glass fibres, 2400 Text roving, and a terephtalic polyster resin Impol T 400. The glass had been treated with a resin compatible layer containing a silane coupling agent. Full details of the method of fabrication and materials used are given elsewhere by Hull et al (3). Two types of pipes were used: hoop wound pipes with winding angle 89° and angle-ply pipes with a winding angle $\phi = \pm 54^{\circ}44'$. These pipes were made up of four complete layers. The volume fraction of fibres using ASTM method D2584 varied between 0.50 and 0.56. The void content was measured using ASTM method D 2734 and was zero for all pipes.

Sections of helically wound pipes were loaded in diametrical parallel plate compression under constant load conditions. The angle-ply pipes were internally pressurised. Two internal pressure tests were used which are designated Mode II and Mode III, respectively. Mode II is a closed-end condition so that the hoop stress σ_H is twice the axial stress σ_A, while in Mode III both ends of the pipe are free to slide on seals so that the axial stress is zero. All the pipes were tested in the presence of 1n HCl.

The AE from tested material was indicated by the number of counts. A signal processor Model 201, Acoustic Emission Technology Corporation was used together with a sensor with the nominal resonanse frequency of 175 kHz. To receive the AE from fibres the bunch of fibres was introduced into wavequide and immersed in acid.

RESULTS

There are two stages in the failure of GRP under strain corrosion conditions: firstly, resin cracking and fibre debonding which allows the corrosive environment to penetrate into the laminate and secondly, fracture of the exposed glass fibres in the presence of the environment. It has been shown by Gołaski et al (4) that in filament wound laminated structures the failure mode depends strongly on loading conditions and material parameters. Therefore the tests have been made on different samples. In hoope wound pipes under diametrical compression the cracks normal to the fibre direction can be seen. For angle-ply pipes under internal pressure condition the failure started due to cracking at the matrix fibre interface. Cohesive crack can be seen for pipes tested in MII and adhesive for pipes tested in MIII. Thus the wetting process differs if the fibres occur in different conditions. The begining of corrosion cracking was monitored by a sharp increase in AE activity. At this same time no sign of weaking of the sample was observed. This can be seen in Fig.1 where summe of AE counts and fibre strain of hoop wound pipe vs time are given for acid and water environment. A small crack through the pipe (1 mm long) took place after 50 min of the test and weepage could be seen. There is no knee on strain diagram when stress corrosion gives rise to fibre failure as well as leakage begins. The AE test was stopped after 60 min when intensive leakage took placed. The environment showed no influence on the fibre strain in the pipe up to 200 min of the test when large corrosion cracking and delamination took place.

Similar results were obtained in angle-ply pipes under internal pressure and environment condition. The results for pipes tested in MII can be seen in Fig. 2. The rapid increase in AE activity is due to corrosion cracking of fibres. The slope of the number of AE counts vs time curve is independent on the environment condition. This suggests that the damage rate for tested pipes is environment independent up to the stress corrosion onset. In these tests no changes in the axial strain of pipes vs time relationship can be seen when failure of fibres starts or veepage occurs. A delay time between the start of loading and the start of corrosive cracking of fibre can be seen in all the samples used. This delay time can be seen in bunch of fibres tested under combined long-term loading and corrosion conditions. This is shown in Fig. 3.

The time up to beginning of corrosion fracture of GRP for different loading mode and strain of fibre is given in Fig. 4. These results are more distinct in Fig 5 where logarithmic coordinates are used. The relationship between the time of corrosive cracking (the difference between the time to total fracture or weepage and the beginning of corrosive cracking) and the $\varepsilon_{\parallel}$ can be seen in Fig 6.

To detect the influence of only acid environment the unloaded hoop wound pipes were immersed in acid during the period of one year. Next the pipes were loaded in diametrical compression and AE was taken. As can be seen in Fig 7 (curve C) the environment did not influence the strength on unloading composites. In this diagram the influence of periodical unloading and washing with the help of destilled water is given. The curve B shows the results for pipe which was periodically unloaded after each 20 min of service and washed carefully with water. After 5 cycles it was loaded again and the results are presented as curve B. Thus a pronounced prolongation of service life was obtained. A small prolongation can be seen when the sample is unloaded after 50% of time of service life and, after washing, loaded again (Fig 7, curve D). As can be seen in Fig 7, curve E, the washing has no influence when it is made after intensive failure cracking has occured.

DISCUSSION AND CONCLUSIONS

For pipes tested in MII and MIII no corrosion cracking was observed at hoop stresses below $\sigma_H = 40$ MPa for pipes tested in MII and $\sigma_H = 100$ MPa for pipes tested in MIII. Below these stresses no damage in matrix was seen after initial loading. The lack of difference between AE count summation rate for pipes in water and acid environment indicates that the corrosion cracking starts after a time from the beginning of loading. This is confirned by the test, where the pipes were unloaded and washed periodically.

The time to the beginning of corrosive fracture and the time to fracture depend strongly on the loading mode. The cracking mode which makes the laminate easier to penetrate occelerates the corrosion fracture processes.

The main conclusions are:

- the onset of stress corrosion failure of GRP and glass fibres gives a rapid rise in AE activity
- there is a linear relationship log $\varepsilon_{\parallel}$ - log t for all types of applied loading modes
- delay time in corrosive failure is observed - this time depends on the loading mode and thus on the type of matrix damage
- the stress corrosion fracture of GRP takes place when cracks in the matrix allow the acid to penetrate into the laminate

- periodical washing of laminate may elongate the service life of samples.

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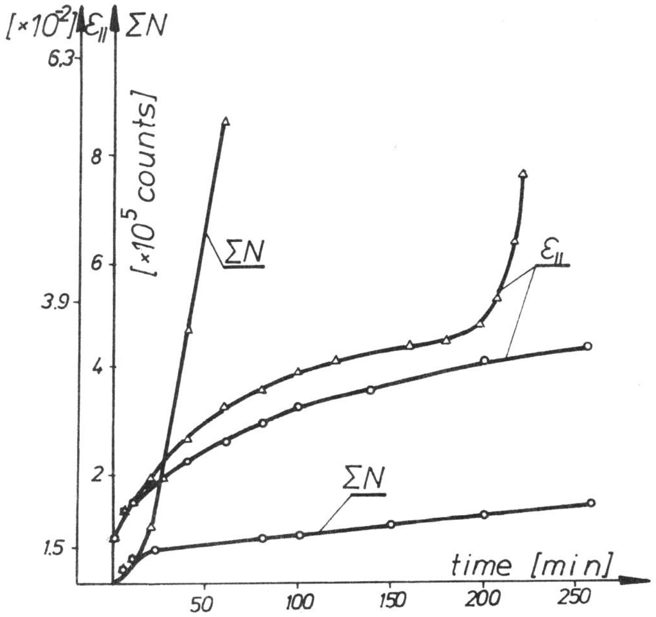

Figure 1 The strain and the AE activity for helically wound pipes under diametrical compression vs. time

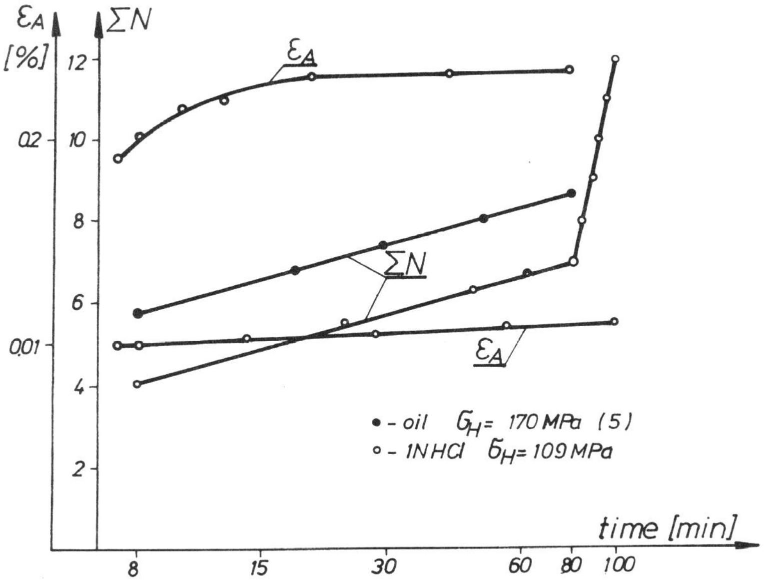

Figure 2 The AE activity and strain vs. log of time for pipes tested in MII

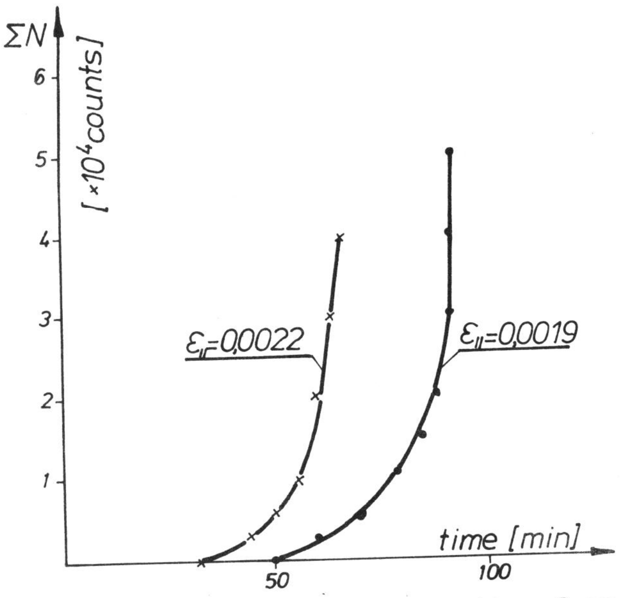

Figure 3 The AE activity vs. time from bunch of fibres in acid environment

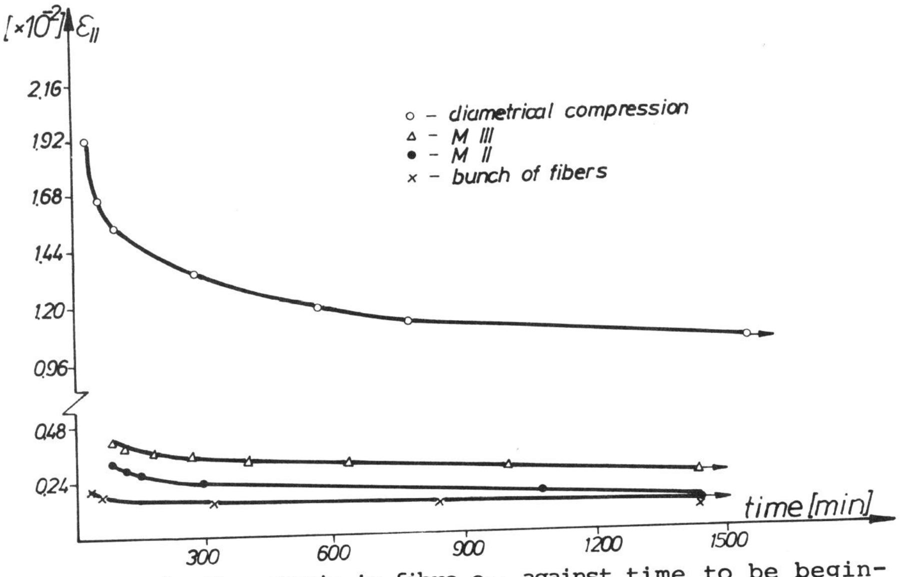

Figure 4 The strain in fibre ε_{11} against time to be beginning of corrosion fracture for different loading modes

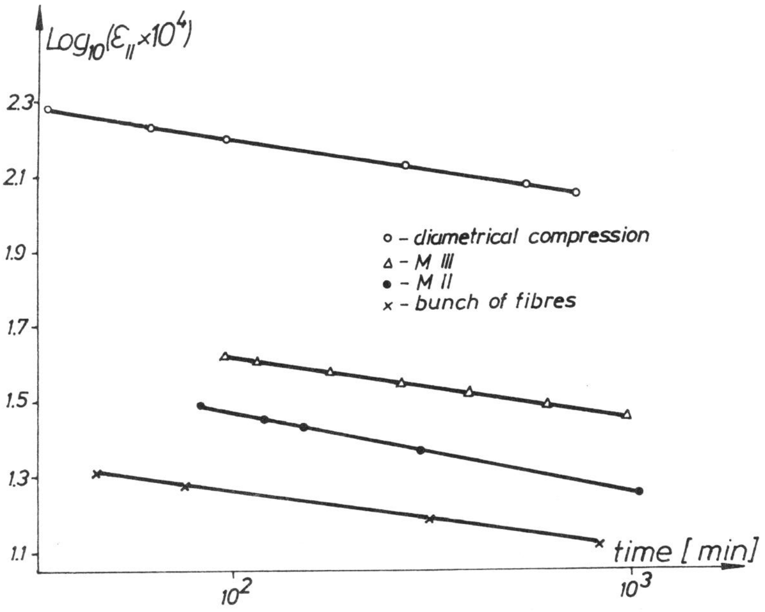

Figure 5 The strain in fibres against time to the beginning of corrosion fracture for different loading modes

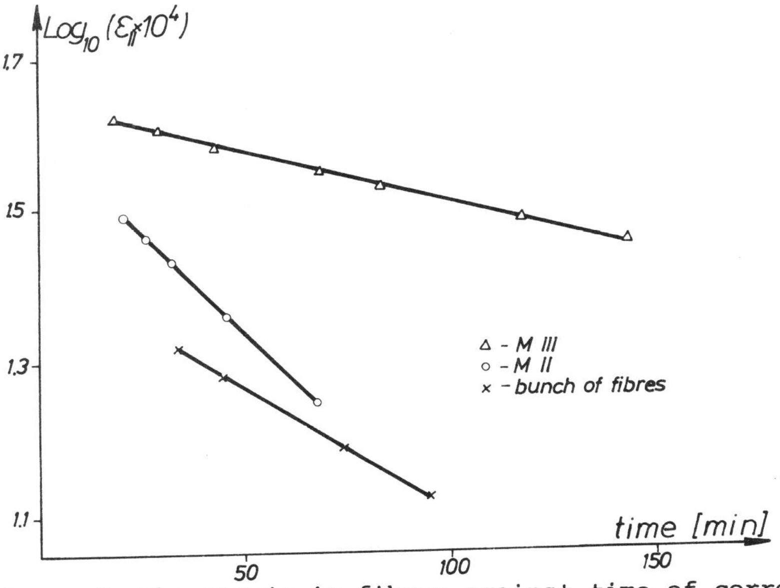

Figure 6 The strain in fibres against time of corrosive fracture for different loading modes

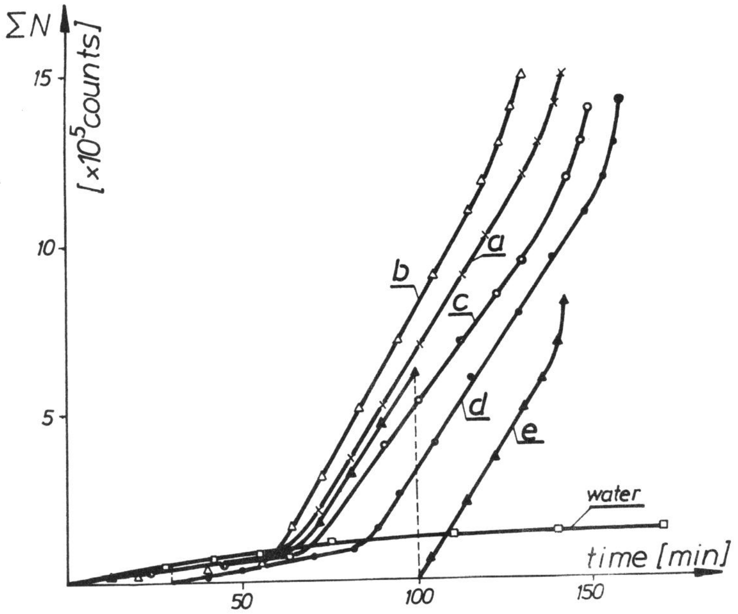

Figure 7 The AE activity vs. time for pipes tested in diametrical compression ($\varepsilon_{11} = 1.68 \times 10^{-2}$)