STRESS CORROSION CRACKING RESPONSE OF HAND LAY-UP GRY COMPOSITES

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ABSTRACT

Stress corrosion cracking is the consequence of tensile stress actions, from any sources, simultaneous with corrosion on a structural component above certain critical tensile stress levels in specific corrosive media. Hand lay-up glass reinforced plastics (GRP) composites coupon samples (30% fibre volume content) were immersed for twenty-four hours in the following chemicals:0.50M H_2S0_4,0.50M Chromic Acid, 50% Acetic Acid, 0.50M Ethanol, and 0.50M Methanol They were subsequently subjected to tests at Constant tensile stresses using a bending stress rig while the corrosive fluid dripped on a filter paper wrapped on the stressed specimen. The location of the maximum tensile stresses due to bending was identified very close to the supporting clamp. A constant load was applied for a duration of 100 seconds at 50%, 60%, 70%, 75% *and 80% of the dry laboratory temperature average tensile strength of the GRP composites (about* 128 *MPa). In each corrosive medium except Methanol there was no observable indication of stress corrosion cracking. Only those coupon samples immersed in 0.50M methanol exhibited stress corrosion cracking with brittle fracture below 90MPa (about 70% of the tensile strength) of the GRP composites.*

Keywords*: Crack Initiation, Crack Propagation, Stress Corrosion Cracking, Repassivation.*

1.0 INTRODUCTION

Stress corrosion cracking is the result of the combined actions of static tensile stresses simultaneous with corrosive damages in a sufficiently aggressive corrosive medium. This occurs only above certain critical tensile stress levels peculiar to the material of the mechanical component and the surrounding corrosive medium [1]*. It is known that compressive stresses do not affect the stress corrosion cracking response of a given material [1,2]. The corrosive medium, which promotes this mode of mechanical failure-stress corrosion cracking is specific to the material. SCC is also sensitive to "Corrosion Potentials" in the particular chemical medium.

Stress corrosion cracking was originally identified among certain metal alloys exposed to specific corrosive media. However many metal alloys are now known to be susceptible to this mode of failure [3]. Examples include carbon steel in nitrate solutions and austenitic stainless steel in chloride solutions [4, 5]. At the same time a number of other mechanical engineering materials are susceptible to stress corrosion cracking under certain promoting conditions [6, 7]. Some thermoplastics, as Polyethylene [PE] and Polypropylene [PP] are susceptible to stress corrosion cracking in chromic acid due to residual stresses [8]. Polymath 1-methacrylates [PMMA] are susceptible to stress corrosion cracking as a consequence of pre-stressing before exposure in ethanol. Plastics components designated as "stable" may, under a tensile stress in contact with a corrosive medium, experience the formation

of stress cracks much like SCC in metals. The performance of glass-reinforced plastics components in corrosive media is affected only by certain chemicals, the extent of which is still under investigation for some chemicals [6, 9], so also are other chemical and physical effects. Production related defects common with hand lay-up moulding technique (as interlaminar delaminations) can promote the penetration of certain destructive chemicals into the resin matrix so as to promote stress corrosion cracking.

The effect of heat or light on plastics for long periods is known as "ageing". A combined effect of immersion for several hours or days and months together with tensile tests frequently provides adequate data on stress corrosion cracking response of plastics in general. Various interactions occur between the chemical medium and the plastics molecules, which may result in irreversible changes. These may include changes in chemical composition of the chain molecules, cross-linking, or oxidation [8]. These changes strongly influence the mechanical and physical properties of the resin matrix [7, 10]. Frequently the micro mechanics of the responses of the resin matrix interacting with the reinforcing fibres play a dominant role in the overall performance of the GRP composites especially in pure tension [7, 11]. However in practice plastics components reinforced or not are typically under stress either from residual stresses associated with manufacturing processes or from externally applied loads.

Stress corrosion cracking occurs in two stages, namely: "Crack Initiation" and "Crack Propagation". During crack initiation stress is locally intensified around a stress raiser even before any crack becomes visible. The occurrence of crack is associated with a crack tip, which has a very small radius with high stress concentration. This tends to promote the second stage the crack propagation which involves the growth of the crack. Crack growth may result in fracture of the mechanical component or in repassivation, which stops the process of stress corrosion cracking. In fibre reinforced plastics (FRP) composites with resin matrices repassivation frequently occurs as a crack within the resin matrix approaches a reinforcing fibre. This stops' the attempt at stress corrosion cracking at the particular tensile stress level. These processes are typically localized in the resin matrix in GRP composites. Damaging effects on the reinforcing fibres are reduced by special production processes applied during the manufacture of the reinforcing glass fibres together with the introduction of special chemicals and additives, including the catalysts and accelerators used in GRP moulding, At the same time special gel coat resins are applied at the surfaces and at those other locations most likely to get in contact with hostile media so as to minimize the effects of these damaging chemicals. However, when GRP composites are completely immersed in a hostile medium the combined effects of tensile stresses and the corrosive chemical may result in stress corrosion cracking. This study investigated the stress corrosion Reponses of hand lay-up GRP composites in contact with some corrosive media, namely sulpuric acid, chromic acid, acetic acid, ethanol and methanol, in combined action with tensile stresses at 50% and above of the dry laboratory temperature tensile strength of the GRP composites. These tests were performed at constant tensile stresses while the test samples were soaked in the particular corrosive medium using the constant load rig [8] in Fig. 1.

2.0 INVESTIGATION PROCEDURE

2.1 Test Specimens and the Corrosive Media

E - Glass fibres in catalysed and accelerated

polyester resins were moulded at 30% fibre volume content into flat sheets using hand lay-up contact moulding method, to a thickness of 5.0mm. One ply continuous strands mats, two plies of chopped strands mats and two plies of woven rovings (or as necessary for the required thickness) were used for the production of these flat sheets. Fibre directions were randomly aligned for all sheets. Hand rollers and other moulding details were employed to prevent possible interlaminar delaminations within the resin matrix so as to prevent migration of hostile chemicals during test. The moulded sheets were then allowed to set in the dry laboratory temperature for a few days. They were subsequently demoulded, cleaned and cut to the coupon sample test size of 230mm long by 20mm wide and 5.0mm thick for the stress corrosion cracking investigations. Several coupon samples were prepared.

The following corrosive chemicals were then prepared for the stress corrosion cracking media:

a) 0.50M H_2S0_4
b) 0.50M Chromic Acid
c) 50M%AceticAcid
d) 0.50M Ethanol
e) 0.50M Methanol

These chemicals were prepared by the Department of Pure and Industrial Chemistry of this University. Two coupon samples were to be tested in each chemical medium at any given constant tensile stress level. Four coupon samples would be tested in any corrosive chemical that tended to promote stress corrosion cracking.

2.2 Experimental Procedure

The test rig in Fig. 1 was used to establish the average tensile strength in bending of the GRP test coupons at dry laboratory temperature of about 30°C, using four coupon test samples without the corrosive fluid wetting arrangement. The tensile strength in Pascals (N/m^2) due to bending, at the supporting clamp A, upper fibres is given by:

$$\sigma_{max} = \frac{Mc}{1} \quad (1)$$

Where

M = FL is the bending moment at A, due to the bending force F at B

L = 200mm = 0.20m

F = is the value of the bending force F in Newtons

c = 2.50mm = 0.0025m

1 = $bt^3/12$ is the area moment of inertia about the neutral axis of bending

b = 20mm = 0.02m is the width of the loaded specimen

t = 5mm = 0.005m is the thickness of the coupon specimen.

Four coupon test samples were soaked for 24 hours in each of the corrosive chemicals for test at each constant tensile stress level (equal to 50%, 60%, 70%, 75%, and 80% of the average dry laboratory temperature strength of the GRP composites). These coupon samples were loaded so as to subject the upper parts of the loaded coupons close to the clamp at A, in the test rig (Fig. 1) to these constant tensile stresses starting at 50% of the strength of the GRP composites. The constant stress was held for a maximum duration of 100 seconds or until fracture. If there was no fracture the force F was increased to produce a tensile stress at A equal to 60% of the strength of the GRP composites. Again the constant tensile stress at A was held for a maximum duration of 100 seconds or until fracture. This was repeated at 70%, 75% and 80% of the tensile strength of the GRP. Two coupon sample specimens were tested in each corrosive medium at each constant load if no stress corrosion cracking was indicated in that medium.

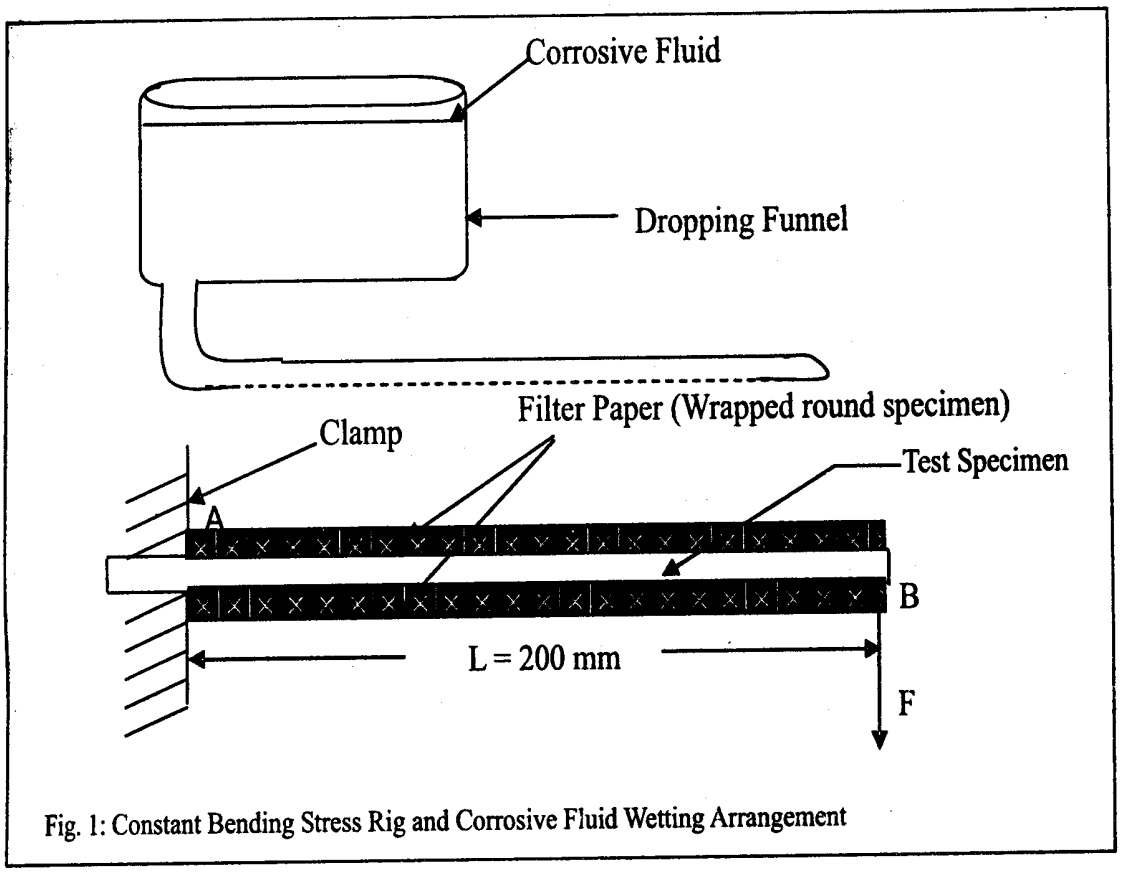

Fig. 1: Constant Bending Stress Rig and Corrosive Fluid Wetting Arrangement

3.0 RESULTS AND DISCUSSION

The average tensile strength of the GRP composites in bending at dry laboratory temperature (about 30°C) was established as 128MPa. Four coupon samples were tested to establish this average strength. The related responses of the GRP coupon sample specimens corresponding to the percentages of the strength of the GRP are summarized in Table 1.

3.1 Stress Corrosion Cracking Response in 0.50M H_2SO_4

At a constant tensile stress (close to the upper clamp at A) due to bending equal to 50% (64MPa) of the strength of the GRP there was no indication of crack initiation at any moment for the 100 seconds duration of the application of the constant tensile stress. The H_2SO_4 (0.50M) fluid was made to drip continuously soaking the filter paper which was wrapped round the loaded GRP coupon specimen. This was repeated at 60% (77MPa), 70% (90MPa), 75% (96MPa), and 80% (102MPa) of the strength of the GRP. Finally at about 105MPa the test specimen fractured as the load was gradually increased above 80% of the strength of the composites.

3.2 Stress Corrosion Cracking Responses in 0.50M Chromic Acid, 50% Acetic Acid, and 0.50M Ethanol

The investigation was repeated in each of the above corrosive chemical media. In both chromic acid and acetic acid fracture occurred again at about 105MPa, above 80% of the strength of the composites. In ethanol the specimens fractured at a much higher tensile stress of 118MPa, about 10 seconds into the attainment of that constant load.

Table 1: Summary of the Responses of GRP Coupons in Corrosive Chemical Media at Constant Tensile Stresses

Corrosive Chemical Medium	Const. Bending Tensile Stress at Clamp	Response of GRP Coupon Specimen
0.5M H_2S0_4 0.50M Chromic acid 50% Acetic acid 0.50M Ethanol 0.50M Methanol	64 MPa = 50% of Dry Lab. Temp.Tensile strength of GRP composites	No indication of crack initiation throughout 100 seconds duration of constant load
0.5M H_2S0_4 0.50M Chromic acid 50% Acetic acid 0.50M Ethanol 0.50M Methanol	77MPa = 60% of strength of GRP composites	No indication of crack initiation for the 100 seconds duration of constant load
0.5M H_2S0_4 0.50M Chromic acid 50% Acetic acid 0.50M Ethanol	90MPa = 70% of strength of GRP composites	No indication of crack initiation for the 100 seconds duration of constant load
0.50M Methanol	88MPa 94MPa somewhere from below 70% to 73% of strength of GRP composites	One sample fractured at 88MPa, one at 90 MPa, and two at 94MPa. These seemed to be due to stress corrosion Cracking.
0.5M H_2S0_4 0.50M Chromic acid 50% Acetic acid 0.50M Ethanol	96Mpa, = 75% of strength of GRP composites	No indication of crack initiation for the 100 seconds duration of constant load
$0.5M_2$ H_2SO_4 0.50M Chromic acid 50% Acetic acid	105MPa slightly above 80%of strength of GRP composites	Fracture of GRP Coupon samples 5 to 12 seconds into the application of load
0.50M Ethanol	11.8MPa = 92% of average strength of the GRP composites	Fracture of coupon samples about 10 seconds into the load application

3.3 Stress Corrosion Cracking Response in 0.50M Methanol

During the investigation in 0.50M methanol both coupon samples fractured at about 94 MPa two seconds after the attainment of this stress which was about 73% of the dry laboratory temperature tensile strength of the GRP. Consequently two additional coupon samples were tested. One fractured at 88Mpa, below 70% of the tensile strength, while the other one fractured 14 seconds into the application of 90 MPa constant tensile stress

4.0 CONCLUSION AND RECOMMENDATIONS

Hand lay-up GRP composites coupon specimens soaked for twenty-four hours were tested for responses to stress corrosion cracking in H_2S0_4, Acetic acid, Chromic acid, Ethanol and Methanol all of which normally promote corrosion. Each chemical had a concentration of 0.50M except Acetic Acid with 50% concentration. Constant tensile stresses were applied, by means of a constant bending force, on the upper fibres of the clamped coupon specimens. Only those samples soaked in methanol consistently exhibited what could be considered stress corrosion cracking at constant tensile stresses between 88MPa and 94MPa representing 70% to 73% of the average dry laboratory temperature tensile strength of the hand lay- up GRP composites. In the other corrosive chemicals it was observed that any tendency to fracture within the resin matrix below 80% of the strength of the GRP was countered by

repassivation promoted by the reinforcing fibres, which stopped any attempted at crack propagation at that tensile stress level. The normal tendency for strength reduction of GRP [12] in corrosive media, combined with the relatively high concentration of the chemicals to cause the fracture of the coupon samples at those higher stress levels shown in Table 1. However although all the fractured samples exhibited brittle fracture, only those soaked in 0.50M Methanol were considered to have failed by stress corrosion cracking. In conclusion, stress corrosion cracking in GRP composites should be expected at tensile stresses above 90MPa in Methanol at concentrations of 0.50M and higher. It is observed that the average laboratory tensile strength of these GRP samples were higher than other GRP specimens produced earlier [12] by hand lay-up methods because special care was applied in the production of these recent samples to reduce or prevent interlaminar delaminations. These could have reduced the strength of the GRP samples. It is recommended that necessary precaution be taken in the moulding or hand lay-up GRP composites to eliminate production defects especially interlaminar delaminations, and some others that cause strength reductions in GRP composites [12].

ACKNOWLEDGMENT

I am grateful to Dr. L.E.S. Akpanisi, the Head of the Department of Pure and Industrial Chemistry, and Mr. A.E. Umo and other staff of the same department of this University for provision and preparation of the corrosive chemicals in their appropriate concentrations, for the above investigations. I am also grateful to Mr. P.A.N Eme of the Department of Civil Engineering Workshop and Laboratories of this University for assistance in the conduction of the constant load tests presented in this report. Thank you all.

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