ACID STRESS CORROSION OF E AND C GLASS HYBRID COMPOSITES

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SUMMARY: Acid stress corrosion of GFRP is related to the corrosion of reinforcement. In this study, two types of glass fiber were used; one was E glass corroded in acid and another was C glass. E glass, C glass, and hybrid of E and C glass laminates were tested in acid environments. AE was monitored during creep test. Each specimens showed difference in the AE response. AE activity of E glass and hybrid specimen increased, however AE activity of C glass specimen did not change. Furthermore, C glass and hybrid specimens had longer lifetime than E glass specimen. It was cleared that types of glass fiber greatly affected the lifetime of GFRP laminates. From SEM observation, the fracture surfaces divided into two patterns, one was typical fracture surface of acid stress corrosion and another was the surface which suggested that only interface damaged.

KEYWORDS: GFRP Laminates, Acoustic emission, Environmental Creep, E glass C glass

INTRODUCTION

Glass fiber reinforced plastics (GFRP) are widely used as an anti-corrosive material in the chemical process industry for application such as pipe work, reaction vessel, storage tanks, pumps, fans, scrubbers, etc. However, serious accident occasionally happens when it is used under loads for long period[1] and few cases has been reported. For example, L.S. Norwood and P.J. Hogg[2] reported a case study of GFRP tanks damaged by acid. Furthermore, A.Trevett[3] reported some cases caused by acid stress corrosion even in much lower level than the standard. To prevent from such severe accidents, it is determined to design tanks less than 10% of the tensile strength. The acid stress corrosion of GFRP is related to the corrosion of the glass fiber as a reinforcement. It has been considered that matrix resin works as resistance in composites, so that the glass fiber in it was not attacked by acid. However, once the acid reaches to the glass fiber, for example through cracks, it could be damaged. E glass normally used in GFRP is easily damaged by acid, and it is well-known that C glass resists in acid condition. In nitric acid, cracks occurred for 8hr for E glass, on the other hand, no change was observed until 480hr for C glass as shown Fig. 1and 2. It is suggested that types of glass fiber greatly related to durability of GFRP laminates. However, no data of GFRP using C glass was reported. In this paper, the fracture behaviors of E, C glass and hybrid of E and C glass composites were studied under tensile creep tests in acid environments. Acoustic emission during environmental creep test was monitored to

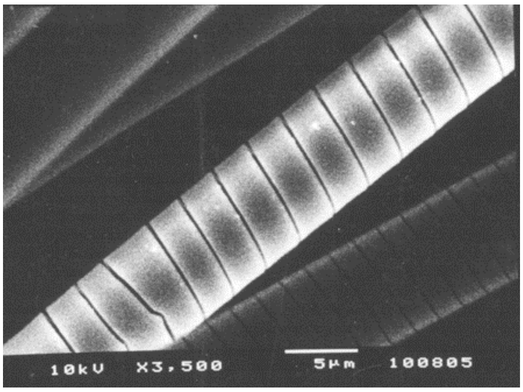


Fig. 1 E glass fiber after immersion for 8 hours in nitoric acid

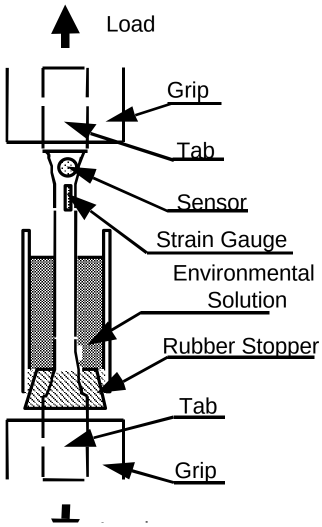
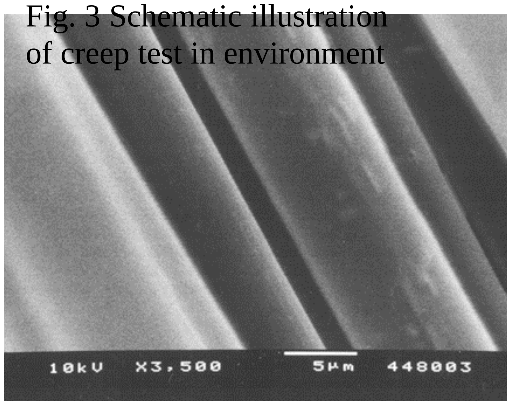


Fig. 2 C glass fiber after immersion for 480 hours in nitoric acid

understand the fracture behavior.

Fig. 3 Schematic illustration of creep test in environment



MATERIALS AND EXPERIMENTALS

Glass fiber reinforced vinyl ester laminates used in this study were fabricated by a hand lay-up method. Vinyl ester resin (R806; Showa high polymer Co. Ltd.) were used as matrix and E glass (YEM 2103-N7; Mie Textile Co.) and C glass(WF230C100BS6; Nittobo Co.) woven cloth were used as reinforcement. The laminates were made of 12 plies, 3mm in thickness. Hybrid specimens were made of both types of glass cloth with ($E_3/C_3/E_3/C_3$). All laminates were post cured at 100 for 1 hour. Dumbbell shaped specimens were prepared according to the ASTM D638. Polyvinylchloride (PVC) end tabs were glued to the specimen ends using an epoxy adhesive to reduce the noise of AE. The static mechanical property of each specimen is shown in Table 1.

The details of the creep test specimen are shown schematically in Fig. 1. The load on the specimen was varied by changing the dead weight. A glass tube with a rubber stopper was used to hold environmental solution. 5wt% nitric acid was used as an environmental solution. The strain gauge was mounted non-immersed position on the specimen for measuring longitudinal tensile strain. Each specimen was initially tested in air for 2hrs until the acoustic emission activity reached a steady state and then tested in environment until the specimen ruptured. Several specimens were tested at different creep stress levels. AE signals were detected using a piezoelectric transducer with a resonant frequency of 150KHz. The threshold level, that AE signals were not detected for one hour without load, was 56mv. The sensor was mounted on the specimen as shown in Fig. 2. Only the ring down counts were measured and recorded using a X-T recorder. All laminates were tested at room temperature. The fracture surfaces were observed by scanning electron microscopy (SEM).

Table. 1 Static mechanical property of composites

	Elastic Modulus, GPa	Tensile Strength, MPa
E glass	16.80	270.50
C glass	16.20	207.93
Hybrid	17.75	219.16

RESULTS

Fig. 4-1 and 4-2 show the results of creep testing at 70MPa. AE rate clearly increased E glass and hybrid specimen after environmental creep test started. AE rate of E glass specimen was increased and failed at 18hr. On the other hand, for C glass specimen, AE rate was not changed and it was not affected by environment, and for hybrid specimen, it was increased just after the environmental solution was added but it became almost constant after 10hr.

Fig. 5 shows the lifetime of each specimen. C glass specimen had longer lifetime than E glass and hybrid specimen. The lifetime of hybrid specimen was longer than E glass specimen under 80 MPa.

Fig. 6,7 and 8 show the SEM photographs of fracture surfaces. The fiber pull-out fracture surfaces are observed in C glass specimen. Whereas, in E glass specimen, flat fracture surface were observed. In hybrid specimen, two patterns of fracture surface were observed in one specimen; E glass area showed flat surface, and C glass area showed fiber pull-out surface.

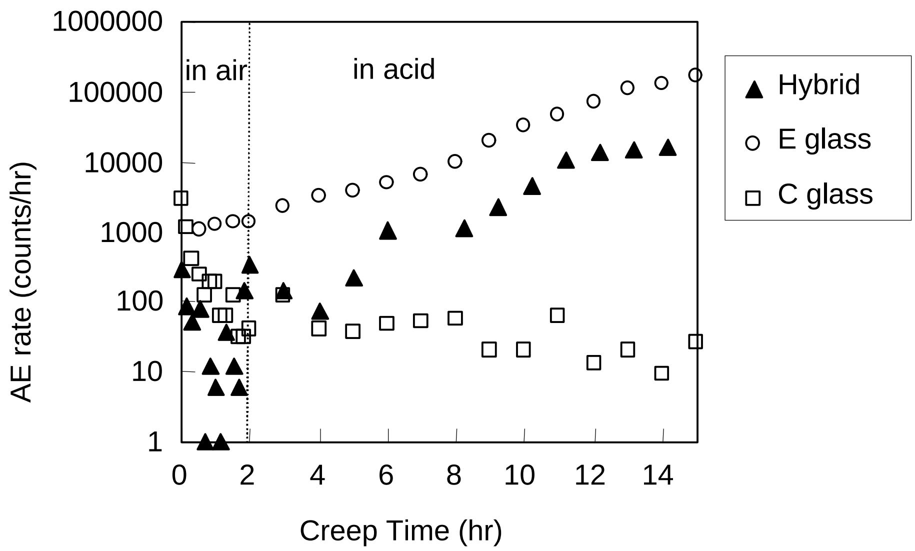


Fig. 4-1 AE Activities at 70MPa until 15hr

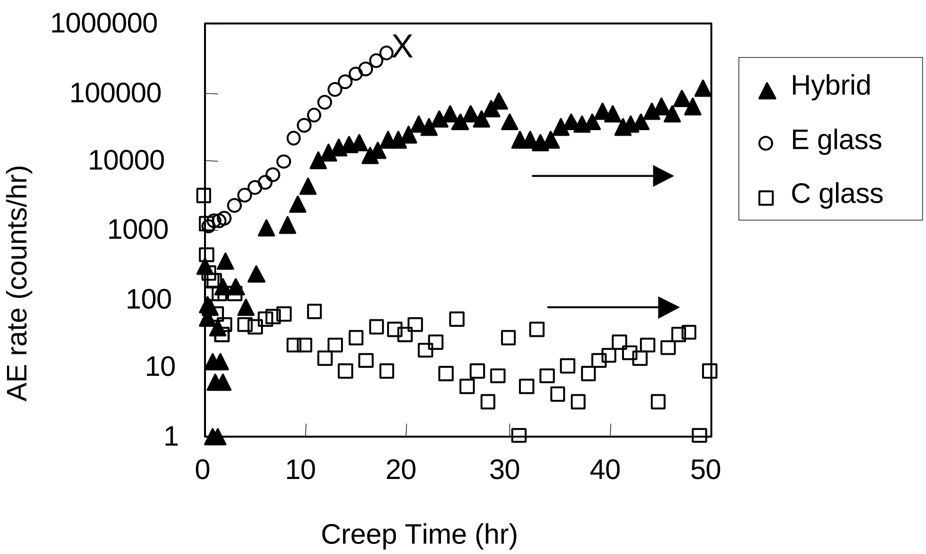


Fig. 4-2 AE activities at 70MPa until 50hr

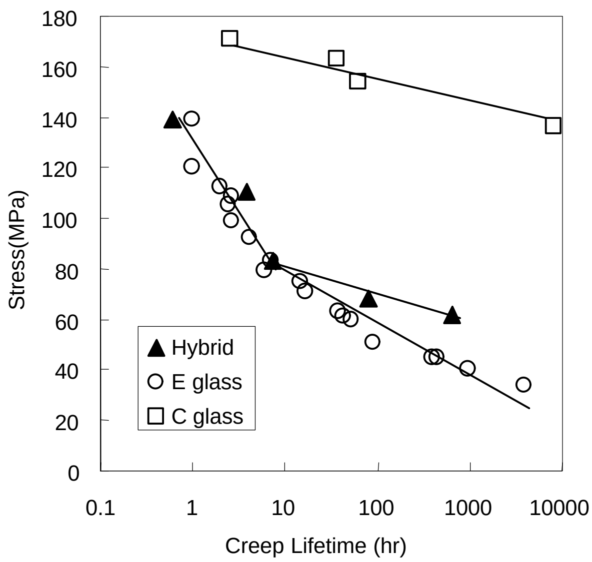


Fig. 5 Relationship between creep lifetime and stress

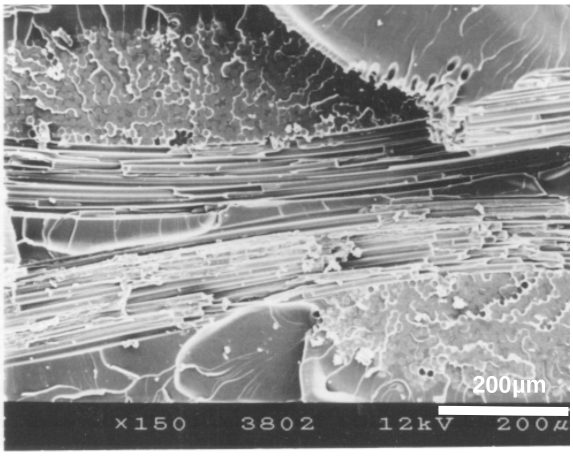


Fig.6 Fracture surface of E glass specimen
(Stress level; 34.0MPa, Lifetime; 3852hr)

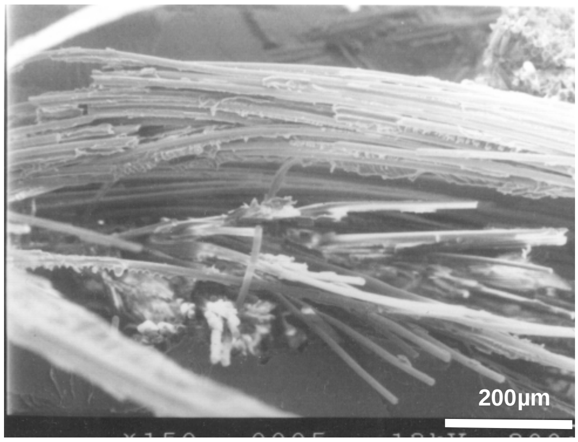


Fig. 7 Fracture surface of C glass specimen
(Stress level, 137.0MPa, Lifetime 8072hr)

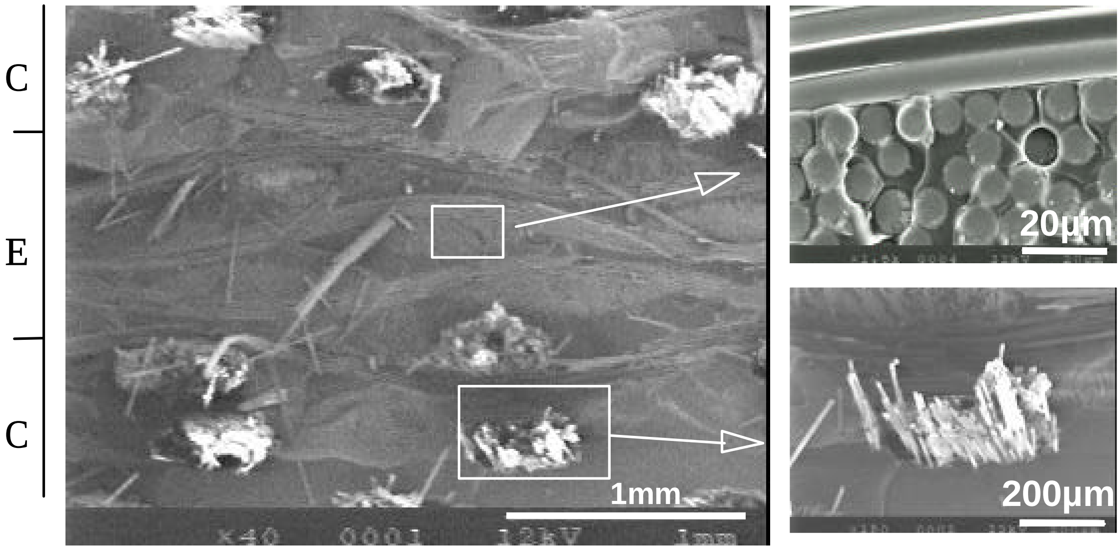


Fig. 8 Fracture surface of hybrid specimen
(Stress level, 70.0MPa, Lifetime 79hr)

DISCUSSION

AE rate of E glass and hybrid specimen drastically increased by adding environmental solution in Fig. 4-1and 4-2. On the other hand, the AE rate of C glass specimen did not change and the effect of environmental solution was not detected. It was because the environmental solution attacked only E glass which is corroded in acid solution. C glass resist in acid, so that the AE rate did not change. It was cleared that AE rate sensitively detected the environmental effect to glass fiber. E glass specimen was affected by acid immediately and failed in short period. On the other hand, C glass specimen was not affected by acid and only stress caused the failure. E glass area of hybrid specimen was also affected by acid, so that the AE rate increased for earlier stage. After all the E glass area of hybrid specimen damaged by acid, only C glass area still worked as a reinforcement. It should be the reason the AE rate became constant later. However, the AE occurred higher rate in later period. It supposed that the C glass area stressed severely. AE rate also detected the effect by stress. AE monitoring would be an useful technique to understand the propagation of damage in composites, but the detail of AE response is still unknown. AE response included various damages such as the damage of glass fiber by acid and the damage of interface by stress.

C glass specimen had a longer lifetime than the others as shown Fig. 5. Hybrid specimen behaved similarly as E glass specimen at higher stress level than 80MPa. There should be two patterns of fracture behavior. Over 80MPa, mainly stress caused failure and C glass area damaged by stress. On the other hand, at lower stress level than 80MPa, C glass area which was not attacked by acid was able to hold the stress. In E glass specimen, all the reinforcement was damaged. The difference of lifetime between E glass specimen and hybrid specimen at lower stress level reflected the advantage of C glass.

The effect of environmental solution to the specimens was clearly shown in Fig. 6,7 and 8. The fracture surface of E glass specimen exhibited the flat surface which is one of evidence of acid stress corrosion. E glass area even located in the middle part of hybrid specimen exhibited the flat surface. The fracture surface of C glass specimen and C glass area of hybrid specimen were completely different from E glass. It exhibited the fiber pull-out fracture which was caused by the damage of interface. The interface of C glass specimen and C glass area of hybrid specimen was damaged by stress before the glass fiber were damaged by acid.

CONCLUSION

Types of glass fiber greatly related to the lifetime of laminates in environmental creep test. C glass specimen had a much longer lifetime than E glass specimen and hybrid specimen. The lifetime of hybrid specimens containing C glass area was longer than E glass specimens at low stress level. Two fracture mechanisms of GFRP were observed. One was a fracture mainly caused by the damage of glass fiber, another was a fracture stress dominated. This study also indicated that AE monitor was an useful technique to detect damage propagation in environmental creep test.

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