INFLUENCE OF AQUEOUS SOLUTIONS ON MECHANICAL BEHAVIOUR OF GFRP COMPOSITES AT ROOM TEMPERATURE AND AT HIGH TEMPERATURE

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ABSTRACT

Both short-term and long-term properties of a composite depend critically on the conditions of the interface and/or interphase. The interphase may be a chemical reaction zone. Polymer matrix absorbs water and it may dissolve water-soluble matters of polymer. An investigation was carried out here with glass fibre/epoxy composite to find the variation of interlaminar shear strength (ILSS) values by immersing the laminates in NaCl and H_2SO_4 aqueous solutions for about 40 days at ambient condition. The shear values were determined by the short beam shear (SBS) test. The present experiment also focussed to study the effects of high temperature on hydrolysis behaviour of glass fibre/epoxy laminate in saline and water. It was observed that the hydrolysis process greatly accelerated with increased temperature. The study also aimed on absorption kinetic of the laminate in hot water for up to about 325 hours. The effects of such conditionings on the interfacial damage of glass fibre/epoxy were characterized by 3-point SBS test. It may be concluded that the adhesion chemistry at the interface/interphase is markedly deteriorated by acidic solution compared to that of by saline. This is reflected in absorption characteristics as well as in SBS test data. The slightly more reduction in ILSS values in saline water could be due to more amount of absorbed solution for same immersion time.The comparison study reveals that the saline with lower chemical potential than pure water may create a very limited number of osmotic pressure-filled interfacial cracks.

1. INTRODUCTION

The weak link in a fibre reinforced plastic (FRP) composite structure is the transfer of load by the polymer matrix from fibre to fibre and from ply to ply. The stress transfer process most often leads to much higher stresses than those accounted for in analyses such as finite element, laminated plate theory or micromechanical approaches [1]. The presence of interphase between the fibre and matrix is considered to be the weakest structural link and forms an important design criterion. Both short-term and long-term properties of a composite depend critically on the conditions of the interface and/or interphase. The interphase may be a chemical reaction zone [2]. Polymer matrix absorbs water and it may dissolve water soluble matters of polymer. Thereby the absorbed water is creating pockets of osmotic pressure-filled interfacial cracks in aqueous solutions [3].The phenomena lead to loss of mechanical strength of the composite. The cracks and/or interfacial debonding of the fibres accelerate the diffusion rate of the solutions in different aggresive media [4]. An investigation has been carried out here with glass fibre/epoxy composite to find the variation of interlaminar shear strength (ILSS) values by immersing the laminates in NaCl and H_2SO_4 aqueous solutions for about 40 days at ambient condition. The shear values were determined by the short beam shear (SBS) test. The test results could reflect the failure of specimen by microbuckling or interlaminar shear cracking or a combination of fracture modes [5].The existence of better bond between glass fibre and epoxy matrix has recently opened up opportunities for large structural applications especially in the chemical and marine industries. The resistance of the material to such active environments has to be maintained over periods of as long as 20 to 30 years. The thermosetting resins do not dissolve completely in solvents due to their cross-linked structure. They swell to an extent dependent on the chemical affinity of the solvent for the matrix polymer. This swelling causes changes in the internal stress field within the composits [6]. The swelling stress may result in significant loss of adhesion at the fibre/matrix interface.

Glass fibres are also favoured for low load applications such as pipe and small-scale storage in corrosive environments. They have also opened up opportunities for large structural applications especially in the chemical and marine industries. Unfortunately, they are attacked and weakened in aqueous solutions, particularly acidic and alkaline ones. The mechanism of chemical attack of polymers is usually scission of the molecular bonds. The degradation phenomenon in polymer composites such as fibre/resin debonding generally involves physical and also chemical mechanisms [6]. The present experiment aims to study the effects of high temperature on hydrolysis behaviour of glass fibre/epoxy laminate in saline and water. It is observed that the hydrolysis process greatly accelerated with increased temperature. The study also focuses on absorption kinetic of the laminate in hot water for up to about 325 hours. The effects of such conditionings on the interfacial damage of glass fibre/epoxy are characterised by 3-point short beam shear (SBS) test. Tensile and fatigue strengths are considerably decreased after hot water immersion because of the degradation of glass fibres [8]. FRP composite is a very successful material in the marine industry, where water resistance needs to be good over periods of as long as 30 years. Polymers absorb water and it may seek out and dissolve water-soluble inclusions of polymer matrix. This may create pockets of concentrated solutions. The mechanism of degradation range from static fatigue of fibre, to creation of osmotic pressure-filled interfacial cracks [3]. Temperature may further put limitation in the major end use for FRP composites.

2. RESULTS & DISCUSSION

Figure 1 shows the weight gain kinetics of glass fibre/epoxy composite in H_2SO_4 (10 Vol%) and NaCI (10 wt%) aqueous solutions at ambient temperature. It is evident that the gain kinetic of specimen in acidic solution is much faster compared to that of saline water immersed laminate. The probable reason could be due to more generation of osmotic cracks and also due to greater amount of leaching of uncross-linked matter of epoxy resin in acidic medium. The higher degree of interfacial damage may promote higher diffusion rate of solution through capillary path in such environment. The saline will generate smaller osmotic pressure because of lower chemical potential than pure water [3].The lesser interfacial damage in saline is also reflected in the following SBS test results.

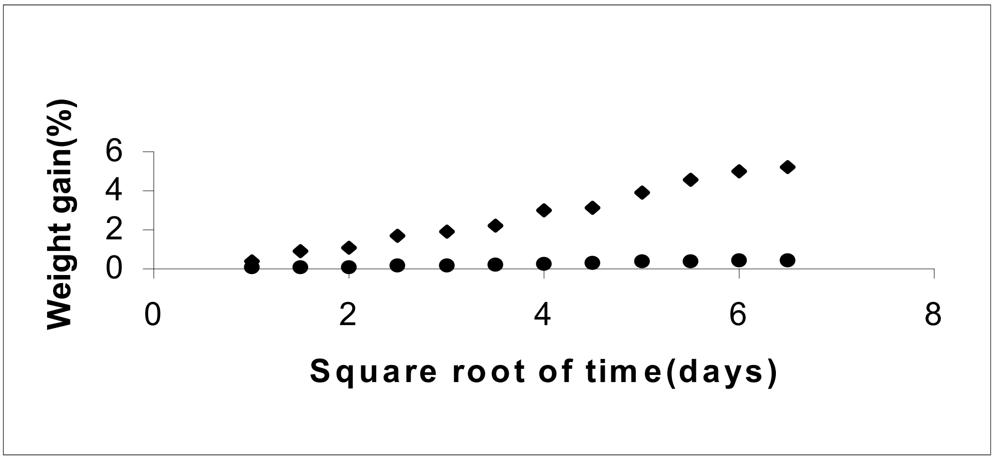

Figure 1. Weight gain (%) kinetics of glass fibre/epoxy composites in saline(•) and acidic(♦) aqueous solutions.

The variation of ILSS values of the laminate in saline with the number of conditioning days is plotted in Figure 2. It is clear from the figure that there is a continuous drop in shear values with immersion time. There is an exception at the initial period of conditioning. The initial exception could be due to the strain-free state of the composite as the swelling stress can release the residual strain that was induced by differential thermal contraction during the cooling of the laminate from its curing temperature [7]. The reduction in ILSS value after the initial stage may be related to fibre/resin debonding. This degradation behaviour involves both physical and chemical mechanisms. It is reasonably be concluded that the cause of interface/interphase damage could be by hydrolysis of saline.

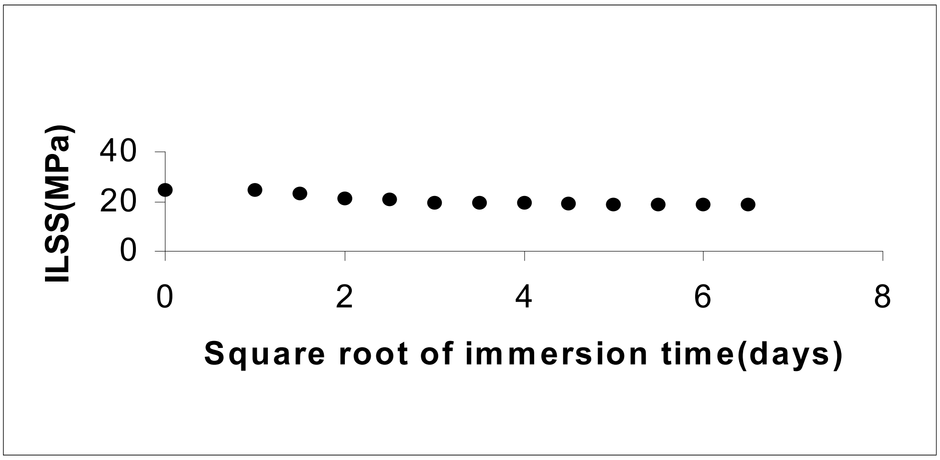

Figure 2. Variation of ILSS values of glass fibre/epoxy composites with immersion time in NaCl aqueous solution.

Figure 3 shows the effect of acidic solution on shear value with the immersion time (days) for glass fibre/epoxy composites. Here it is observed that there is a continuous reduction in ILSS values with the number of immersion days.The nature of curve may indicate the significant loss of adhesion at the fibre/matrix interface. Here more absorbed liquids causes greater swelling. Cross-linked epoxy polymer often contains a small quantity of uncross-linked substance which may be leached out by acidic solution. The dissolution of soluble matters can set up osmotic pressure cells in the laminate [6].This would step-down the local stress threshold required for interfacial debonding, a potential precursor[5] to delamination failure of the laminate.

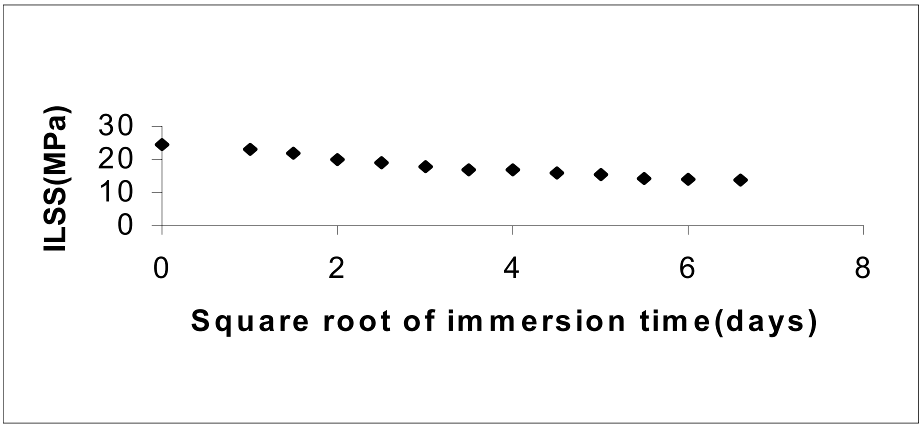

Figure 3. Variation of ILSS values of glass fibre/epoxy laminates with immersion times in acidic solution.

Figure 4 is drawn to investigate the weight gain characteristic of glass/ epoxy composite in water at 96^0C temperature. It is clear that the gain kinetics is very rapidly changing with the immersion time. The water uptake rate increases with conditioning time and absorbed water can cause a certain amount of fibre/resin debonding. The phenomenal rise in gain kinetic after about 200 hours of conditioning could be related to the creation of more porous path due to prolonged hydrolysis. The inter-laminar shear strength (ILSS) of the conditioned specimens is plotted against immersion time in Figure 5. The remarkable fall in shear strength is noticed here, except at initial conditioning time. Cure shrinkage during fabrication can induce residual stress. The polymer matrix absorbs liquid causing swelling. This absorption can also lead to significant residual stresses. These two stresses are opposite in nature.The initial exception could be related to near strain-free state within the composite [4,7]. Differential coefficients of thermal expansion between fibre and epoxy matrix may also lead to residual stresses at the interface. The reduction in shear values for prolonged immersion time may be due to the greater amount of hydroscopic swelling stress. The resulting residual stresses would modify

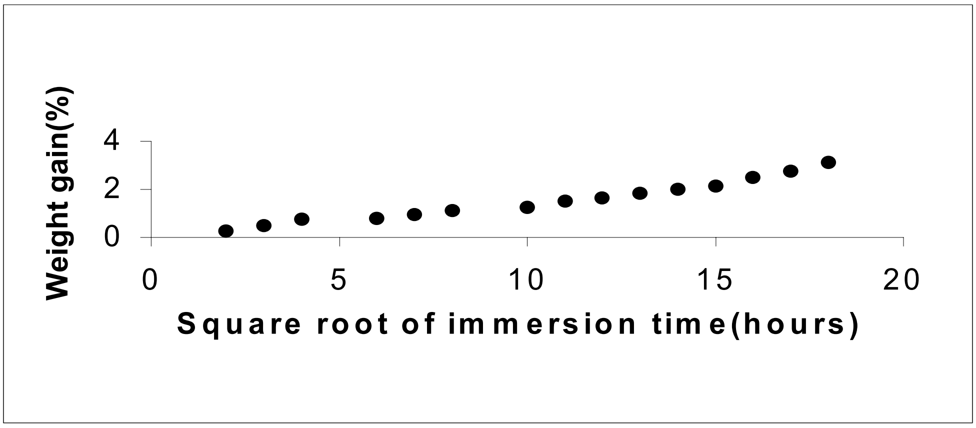

Figure 4. Weight gain (%) characteristic of glass fibre/epoxy composites in hot water.

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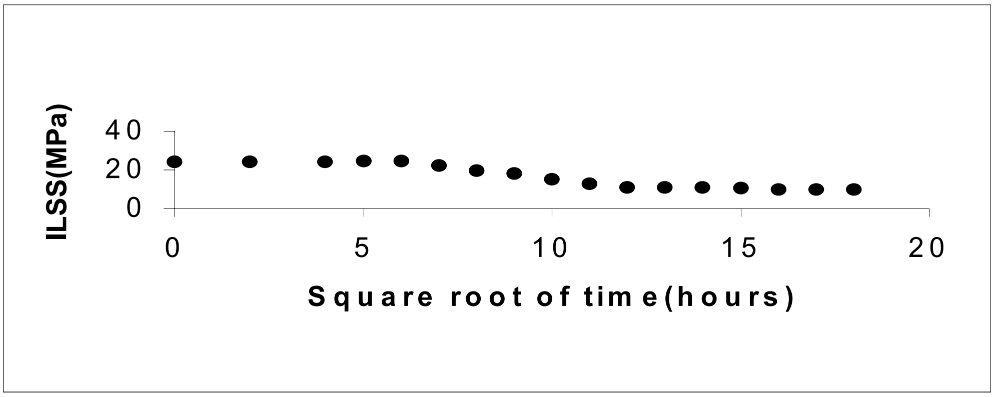

Figure 5. Variation of shear values of immersed glass/epoxy composites in hot Water.

The weight gain kinetic of glass/epoxy laminate is plotted against square root of immersion time in 10% NaCl acquous solution at 96^{0}C temperature in Figure 6. Here the rate of absorption is much higher compared to hot water condition. The aqueous solution may leach out uncross-linked matter of cross-linked epoxy resin. The water-soluble substances in resin can set up osmotic pressure cells [6]. This eventually introduces numerous small cracks. The high fluid uptake characteristic could be related to osmotic cracks and leached out phenomena.

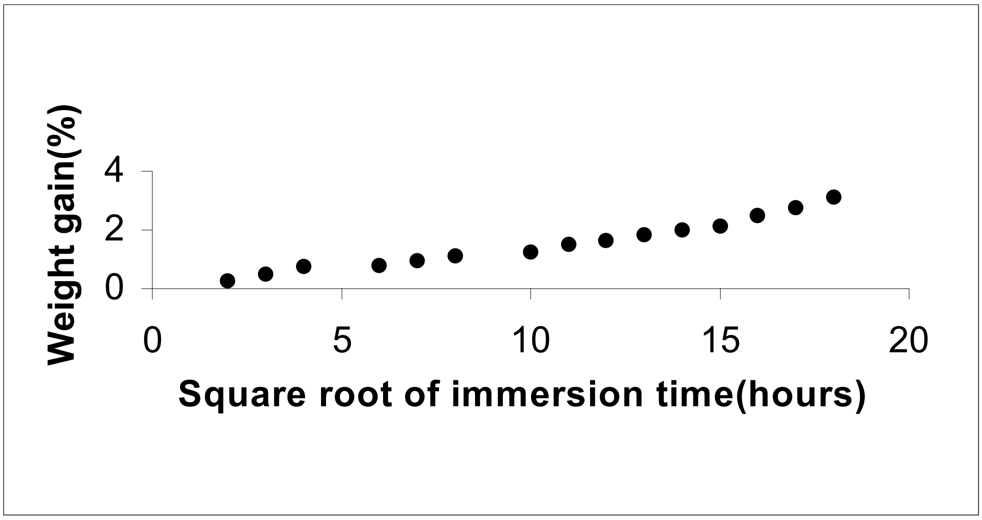

Figure 6. Weight gain (%) kinetic of glass/epoxy laminates in hot saline.

Figure 7 shows the variation of ILSS of the conditioned laminates with the square root of immersion time. Here also it is observed the similarity of behaviour with the hydrothermal conditioning at the initial stage. Thereafter, the continuous reduction in ILSS values is reflected in the figure. Such environment may induce corrosion of the composite. The influence can be complicated by consideration of residual stresses and temperature. The mechanisms and kinetics of degradation of glass fibre composite by hot water and saline have not yet been concluded in the published research studies.

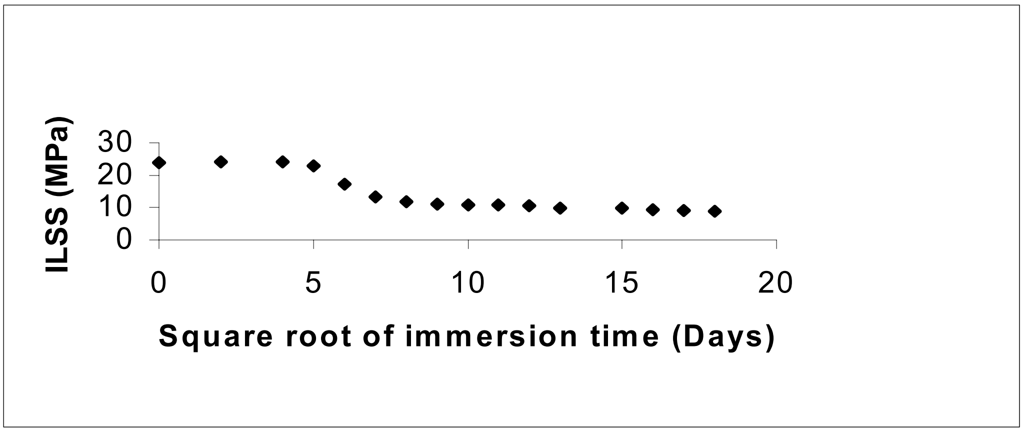

Figure 7. Effect of immersion times in hot saline on ILSS values of glass/epoxy composites.

2. CONCLUSIONS

It may be concluded that the adhesion chemistry at the interface/interphase is markedly deteriorated by acidic solution compared to that of by saline. This is reflected in absorption characteristics as well as in SBS test data. It may also be concluded that the weight gain kinetic of glass/epoxy composite in hot saline water is much higher compared to that in pure hot water conditioning. But no remarkable variations in ILSS value are observed in both the environments. The slightly more reduction in ILSS values in saline water could be due to more amount of absorbed solution for same immersion time. The comparison study reveals that the saline with lower chemical potential than pure water may create a very limited number of osmotic pressure-filled interfacial cracks.

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