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Thermal shock on interfacial adhesion of thermally conditioned glass fiber/epoxy composites

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Abstract

The fiber/matrix adhesion is most likely to control the overall mechanical behavior of fiber-reinforced composites. An interfacial reaction may result in various morphological modifications to polymer matrix microstructure in proximity to the fiber surface. The interactions between fiber and polymer matrix during thermal conditioning and thermal shock are important phenomena. Thermal stresses were built-up in glass fiber reinforced epoxy composites by up-thermal shock cycles (negative to positive temperature exposure) for different durations and also by down-thermal shock cycles (positive to negative temperature exposure). The concentration of thermal stresses often results in weaker fiber/matrix interface. A degradative effect was observed in both modes for short shock cycles and thereafter, an improvement in shear strength was measured. The effects were shown in two different crosshead speeds during short-beam shear test.

Keywords: Adhesion; Composite materials; Polymers; Mechanical properties

1. Introduction

Differential thermal expansion is a prime cause of thermal shock in composite materials. Thermal expansion differences between fiber and matrix can contribute to stresses at the interface [1-5]. A very large thermal expansion mismatch may result in debonding at the fiber/matrix interface and/or a possible matrix cracking due to thermal stress [6-8]. The fiber/matrix interface is likely to affect the overall mechanical behavior of fiber-reinforced composites. The performance of fiber reinforced composite is often controlled by the adhesion chemistry at the fiber/matrix interface. Thermal expansion coefficients of polymers are substantially greater compared to metals or ceramics. That is why failure of the bond between fiber and resin occurs under the influence of temperature gradient. The common reinforcement for polymer matrix is glass fiber. One of the disadvantages of glass fiber is poor adhesion to matrix resin. The short beam shear (SBS) test results may reflect the tendency of the bond strength where only the bonding level is a variable [9]. A large number of techniques have been reported for measuring interfacial adhesion in fiber reinforced polymer composites [10-16]. A need probably exists for an assessment of mechanical performance of such composite under the influence of thermal shock. Thermal stresses caused by temperature gradient should be given special attention in many application areas. A better understanding of interfacial properties and characterization of interfacial adhesion strength can help in evaluating the mechanical behavior of fiber reinforced composite materials.

2. Experimental procedure

Glass fiber woven roving and epoxy adhesive (Ciba-Geigy; India, LY-556 Araldite, HY-951 hardener) were used to fabricate composite laminates. The layered structure after room temperature curing was cut into the required size for 3-point bend (SBS) test by diamond cutter. One batch of specimens were kept at 50° C temperature for 5,10, 15 and 20 minutes and then immediately exposed to –20° C temperature again for 5, 10, 15 and 20 minutes duration. Another batch of samples were first kept at –20° C temperature for the same time periods and then exposed to the 50° C temperature for the corresponding same durations. The SBS tests of the conditioned specimens were carried out at room temperature with an Instron tensile testing machine. The tests were performed at a crosshead speed of 2 mm/min and 10 mm/min for each stage of thermal conditioning temperature and time. The interlaminar shear strength (ILSS) was measured as follows,

$$\mathrm{ILSS} = 0.75p/bt$$

where p is the breaking load, b the width, and t the thickness of the specimen.

3. Results and discussion

The effect of down-thermal cycle (from positive to negative temperature exposure) conditioning on ILSS values is shown in Fig.1 for 2 mm/min (●) and 10 mm/min (♦) crosshead speeds. There is a sign of improvement in ILSS value observed for both crosshead speeds except for the 5 minutes conditioning time. There are various sources of residual stresses during such type of complex and active environmental exposure. The thermal conditioning results in post-curing strengthening effect. Residual stresses are also built up because of thermal expansion mismatch between the fiber and epoxy matrix. These misfit strains can result in debonding effects at the fiber/matrix interface. Another source of residual stress is the differential thermal contraction during sudden cooling from 50° C temperature to –20° C temperature. The cryogenic conditioning causes differential contraction and increases the resistance to debonding by mechanical keying factor. The characteristic of the interfacial adhesion is strongly influenced by the presence of residual stresses. However, some of the stresses developed by differential expansion/contraction are relaxed by viscoelastic flow or creep in the polymer matrix [17]. The nature of the stress field (expansion is anisotropic for glass fiber, differing along the fiber axis and in the radial direction) for a long glass fiber surrounded by polyester resin after cooling though 100°C temperature has been shown in the model [18]. The rise in ILSS value may be attributed to the improved adhesion by cryogenic conditioning and also by the post-curing strengthening phenomena. The slight fall in the value at 5 minutes conditioning could be related to the lower degree of cryogenic compressive stress and reduced post-curing time. The strain rate sensitivity is possibly due to additional interfacial cracking. These cracking are shown in the scanning electron micrograph (Fig. 2) for thermally shocked glass/epoxy laminate.

The variation of ILSS values of glass/epoxy laminates with the up-thermal cycle (from negative to positive temperature variation) times at a crosshead speed of 2 mm/min (●) and 10 mm/min (♦) is shown in Fig.3. Here also an improvement is evident with the exception of the 5 minutes cycle. The decrease for the 5 minutes cycle may be related to the debonding effect of thermal shock. Here the weakening effect of thermal shock is dominant because of less conditioning time. Thereafter, the rise in ILSS values with more conditioning time is probably due to greater post-curing effects of thermal conditioning. The continuous rise in ILSS value is not so reflected at the 20 minutes cycle. This could be related to the quite large residual stresses due to the greater thermal expansion coefficient of the epoxy matrix. Higher thermal stresses might start dominating over the cryogenic compressive stresses for a longer thermal cycle time.

The existence of a boundary layer in glass/epoxy could be interpreted by the migration of curing agent to this interface. This layer is found to have a significantly lower molecular mobility compared to bulk resin [19-21].

4. Conclusion

An interfacial reaction may impart various morphological modifications to the matrix microstructure in proximity to the fiber surface. The interactions between fiber and polymer matrix during thermal cycling are important phenomena. It may be reasonable to conclude that both modes of thermal cycling results in improvement of shear strength for the longer times duration. The debonding effect of thermal shock is evident for the lesser time. The strain rate sensitivity is also evident in both conditionings.

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Figure Captions

Figure 1 Effect of down-thermal cycle on ILSS value of glass fiber/epoxy composites at 2 mm/min (•) and 10 mm/min (♦) crosshead speeds.

Figure 2 Scanning electron micrograph shows interfacial cracking in the thermally conditioned glass fiber/epoxy laminates.

Figure 3 Effect of up-thermal cycle on ILSS value of glass fiber/epoxy composites at 2 mm/min (•) and 10 mm/min (♦) crosshead speeds.

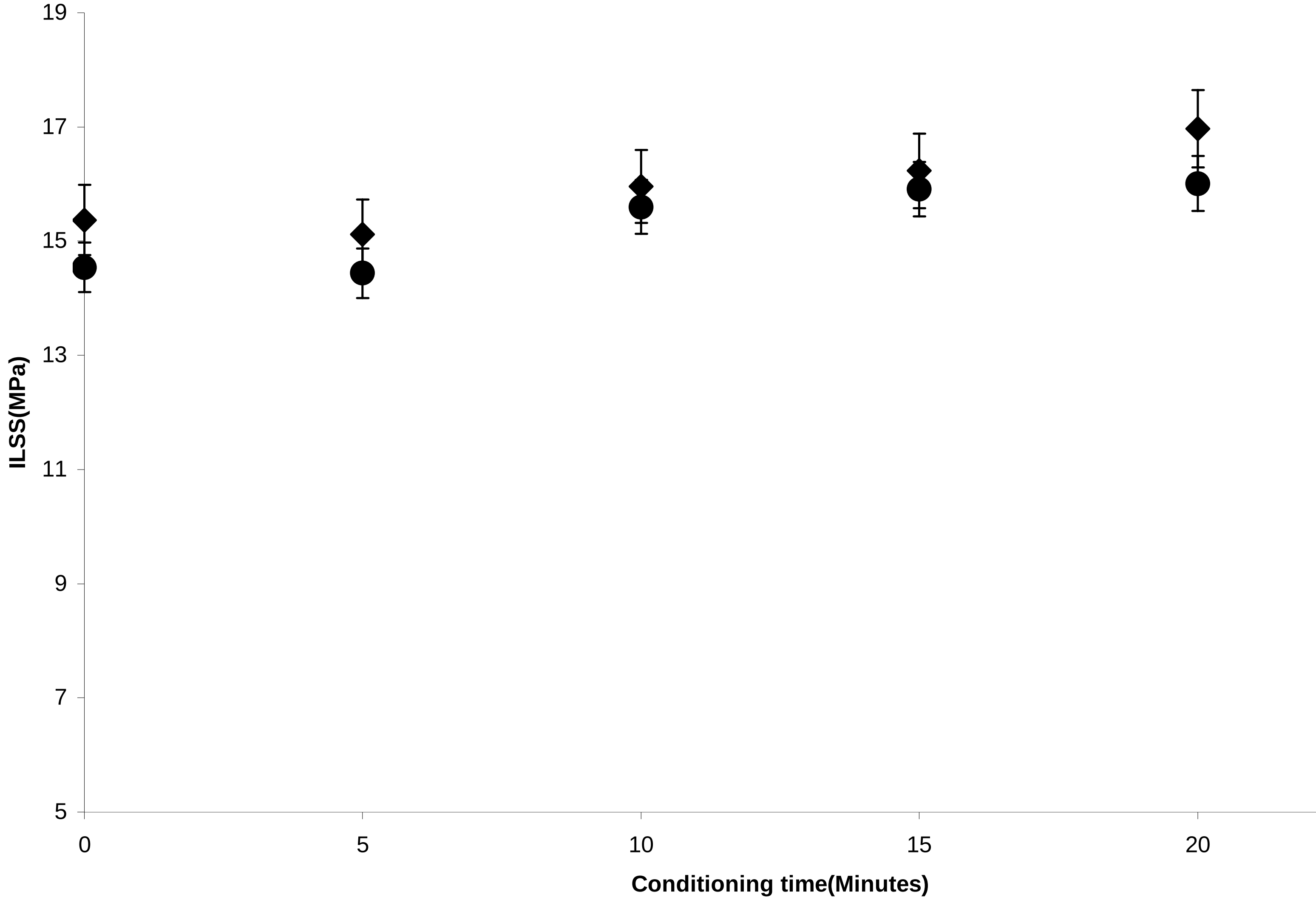
ILSS(MPa)
19
17
15
13
11
9
7
5
0
5
10
15
20
Conditioning time(Minutes)

Figure 1

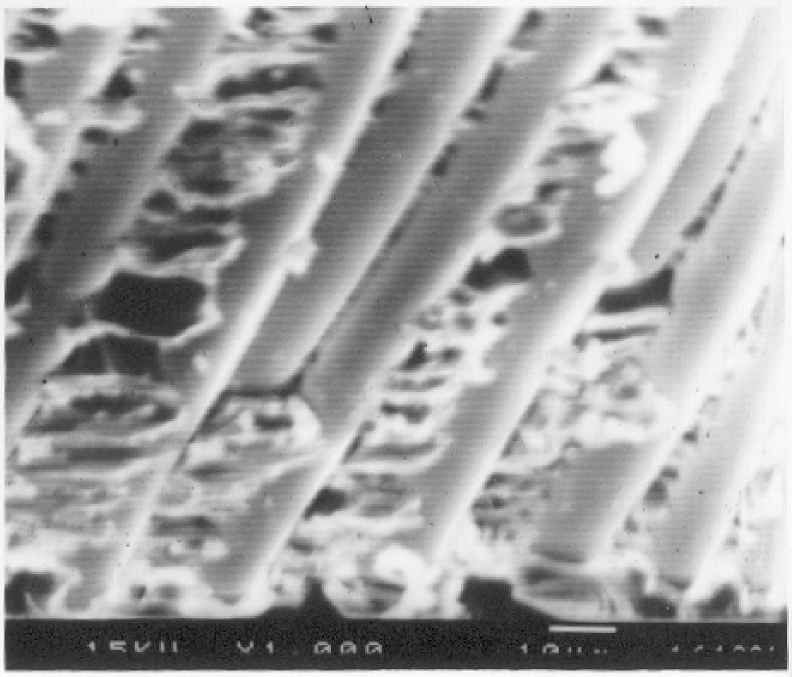

Figure 2

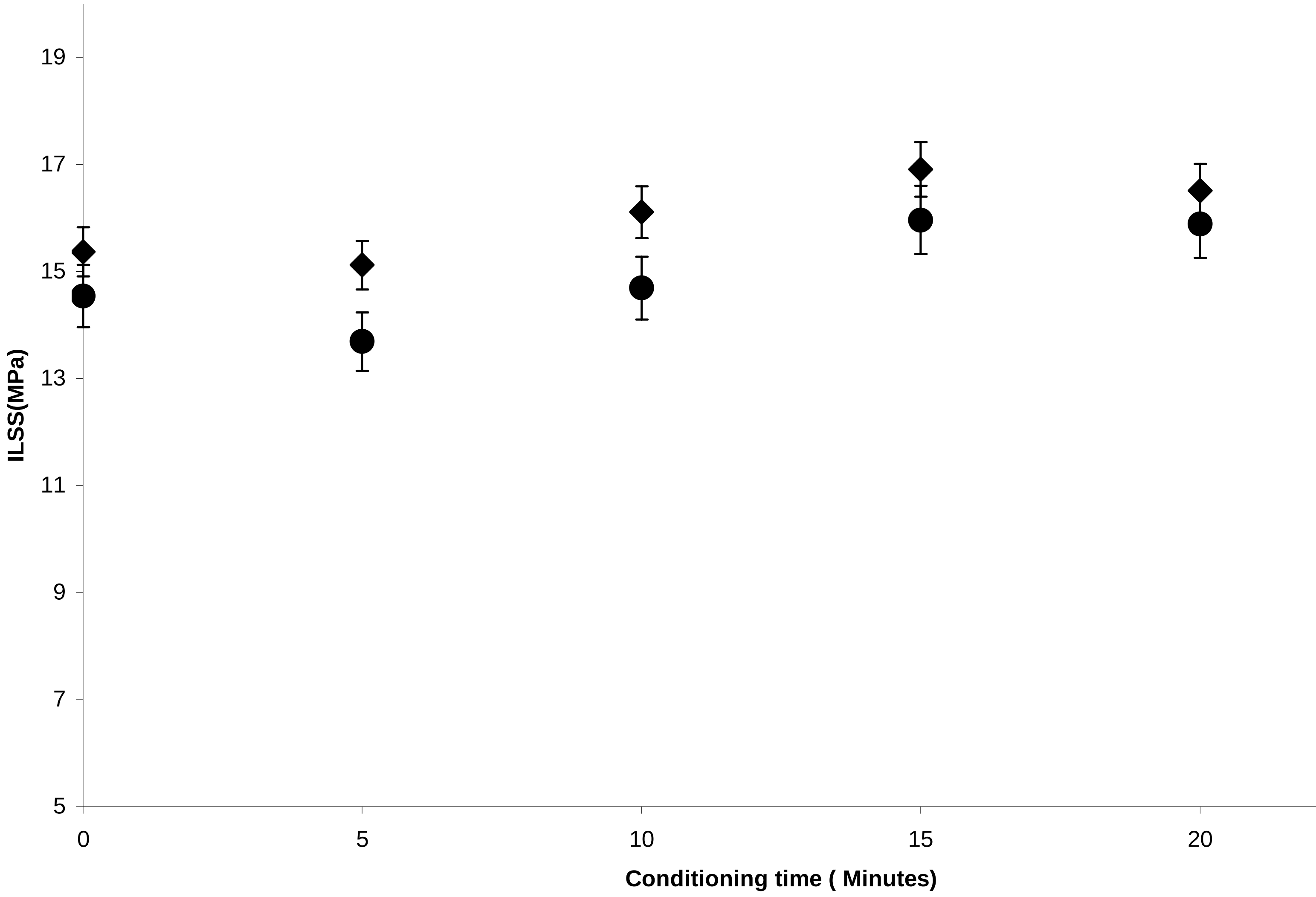
19
17
15
13
11
9
7
5
ILSS(MPa)
0
5
10
15
20
Conditioning time (Minutes)

Figure 3