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# Effects of Thermal and Cryogenic Conditionings on Mechanical Behavior of Thermally Shocked Glass Fiber/Epoxy Composites

**B.C.Ray**
Department of Metallurgical and Materials Engineering, National Institute of Technology, Rourkela – 769008 India
**bcray@nitrkl.ac.in**

## ABSTRACT

A very large thermal expansion mismatch may result in weakening at the fiber/matrix interface and/or a possible matrix cracking due to thermal shock stress. The short beam shear specimens of glass/epoxy composite were treated at 40°C temperature for a certain time and then exposed to –40°C temperature for different conditioning times. The treatment was performed in the opposite direction of thermal cycle. The three-point bend test was carried out at room temperature with different crosshead speeds. The debonding effect of different natures of thermal shock (up- and down-cycles) and strengthening phenomena of thermal conditionings (above and subzero temperature conditionings) were assessed in the present study for the different durations of conditioning and different states of thermal conditionings(thermal and cryogenic). The state of the interactions between fiber and polymer matrix by the treatment was reflected in the shear values of the composites.

**KEY WORDS:** composites, polymer, thermal shock, adhesion, temperature, mechanical behavior

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# INTRODUCTION

Stresses are set up in a composite as a consequence of differences between the thermal expansion coefficients of the constituents. These thermal stresses may initiate yielding or debonding [1]. Although thousands of polymer matrix composite components are currently in service in many applications as well as civil infrastructure repair and rehabilitation, barrier are still there to further implementation in more structurally critical and complex temperature applications [2,3]. The most critical factor that greatly influences the mechanical behavior of composite materials is the fiber/matrix interfacial bond. The interfacial bond transfer loads and thereby ensures the integrity of composite materials [4]. It is therefore necessary to examine what really happens at the interface by thermal shock treatment. Polymers are known to have a strain rate dependent deformation response that is nonlinear above about one or two percent strain [5]. Viscoelastic models are used to capture this behavior from a phenomenological point of view [6]. Polymer deformation has been observed to be due to the motion of molecular chain and the resistance to this flow [7]. Environmental exposure most often lead to matrix degradation, fiber/matrix debonding and delamination in polymer composites. The level of adhesion between matrix and fiber affects the mechanical behavior in the off-axis and also parallel to the fiber [8]. The shear failure mode is dominated by fiber/matrix interfacial failure more in composites having lower adhesive strength anf less in composites with greater fiber/matrix adhesion [9]. Epoxy resin and E-glass fiber are found to be loading rate sensitive. But a direct correlation between the rate dependency of the composite and those of the constituent phase may be difficult or rather complicated phenomena [10-13]. The fiber and matrix interactions are likely to be greater in woven fabric composites as compared to composite made up of unidirectional fibers. Localized starins in the matrix may increase as the fibers straighten under tensile loading or buckle under compression [14]. The ductility or failure strain of a matrix resin may become a limiting factor for the composite strength [15]. Differential thermal expansion in a composite is a prime cause of thermal shock. Thermal expansion coeffients in polymers are considerably greater, thus failure of the bond between fiber and resin may occur under extreme of temperature [17]. The use of composite in safety critical applications leads to uneasiness since the mechanical response is not well understood in active and complex environmental conditions.

## EXPERIMENTAL

E-glass fiber woven roving and epoxy adhesive were used to fabricate composite laminates. The short beam shear (SBS) specimens of glass/epoxy laminates were first exposed to 40°C temperature for 5 minutes. Then the samples were immediately treated at a –40°C temperature. Here at this temperature, specimens were conditioned for 5, 10, 15, 20 and 30 minutes. Another lot of samples was first cryogenically treated at a –40°C temperature for 5 minutes. Then the specimens were immediately exposed to 40°C temperature. Here the conditioning time was varied like that of the previous treatment. The 3-point bend tests were carried out at room temperature for each stage of conditioning time in the finishing temperature of thermal shock cycle. The tests were performed at a 2 mm/min and 10 mm/min crosshead speeds. Ten identical specimens were tested at each point of the SBS test. The tests were conducted within reasonable time after the treatment to avoid any reversible recovery to occur. The interlaminar shear strength (ILSS) value was calculated as follows,

$$ILSS = 0.75p/bt$$

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

## RESULTS AND DISCUSSION

Figure 1 shows the effect of cryogenic conditioning time on ILSS value of thermally shocked (down-thermal shock i.e. 40°C temperature to –40°C temperature exposure) glass/epoxy composites for 2mm/min and 10mm/min crosshead speeds. There is a slight improvement in shear strength for the less conditioning times. A degradative effect is observed in ILSS value for both the crosshead speeds for longer conditioning time. The debonding effect is counteracted by the compressive stresses of the following concurrent cryogenic conditioning. The conditioning at a –40°C temperature may result in development of mechanical locking at the fiber/matrix interface. The mechanical keying factor might be dominating over the weakening effect of thermal shock for the short conditioning time. The cryogenic conditioning causes differential contraction and may increase the resistance to debonding by better adhesion at the interface [18]. The mechanical keying factor could be contributing to the increased value of shear strength for the shorter conditioning time. The longer conditioning at –40°C temperature may result in large misfit strain at the interface. The differences in the thermal expansion coefficients of the fiber and matrix result in the development of misfit strain at the fiber/resin interface [4, 19]. The longer conditioning time may eventually leads to matrix and interfacial crackings. These crackings are shown in the scanning electron micrograph (Figure 2) of the thermally shocked and thermally conditioned at −40°C temperature for 30 minutes conditioning.

Figure 2 is drawn to show the effect of thermal conditioning time at 40°C temperature on ILSS value of thermally shocked (up-thermal shock cycle i.e. −40°C temperature to 40°C temperature exposure). Here there is no noticeable change observed in ILSS value for both the crosshead speeds. The weakening effect of thermal shock is being nullified by the strengthening effect of post-curing phenomena at 40°C temperature conditioning. The misfit strain may not be dominating over the further polymerization phenomena for conditioning at a 40°C temperature. The lower value of ILSS at lower crosshead speed may be due to higher failure strain of the epoxy matrix [20].

The SBS test is performed to assess the interfacial bond strength. The fiber/matrix interfacial debonding may be reflected in the test if only the bonding level is a variable [21, 22]. One of the disadvantages of glass fiber is poor adhesion to matrix polymer. Glass fibers exhibit rate dependence behavior. The increasing strain rate leads to the increase of failure strength. It is possibly accompanied by a reduction in matrix ductility [23]. The nature and order of degradation by complex and active environments need to be critically investigated to expand the acceptability of polymeric composites. The concentration of thermal stresses around manufacturing and other defects most often results in catastrophic failure [24].

## CONCLUSIONS

Thus, in conclusion the debonding effect of thermal shock and strengthening phenomena of concurrently following thermal and cryogenic conditioning in glass/epoxy composite are shown here. It is noticed that the cryogenic treatment following thermal shock is not so effective in counteracting the debonding phenomena of thermal shock. Differential coefficients of thermal contraction may modify the local stress thresshold required for interfacial debonding. This eventually leads to nucleation of delamination. The thermal treatment yields better interfacial strength to the thermally shocked glass/epoxy composites. Thermal conditioning may result in much better interfacial adhesion at the interface not by weak mechanical interlocking factor, but by surface chemistry principles at the fiber/epoxy interface.

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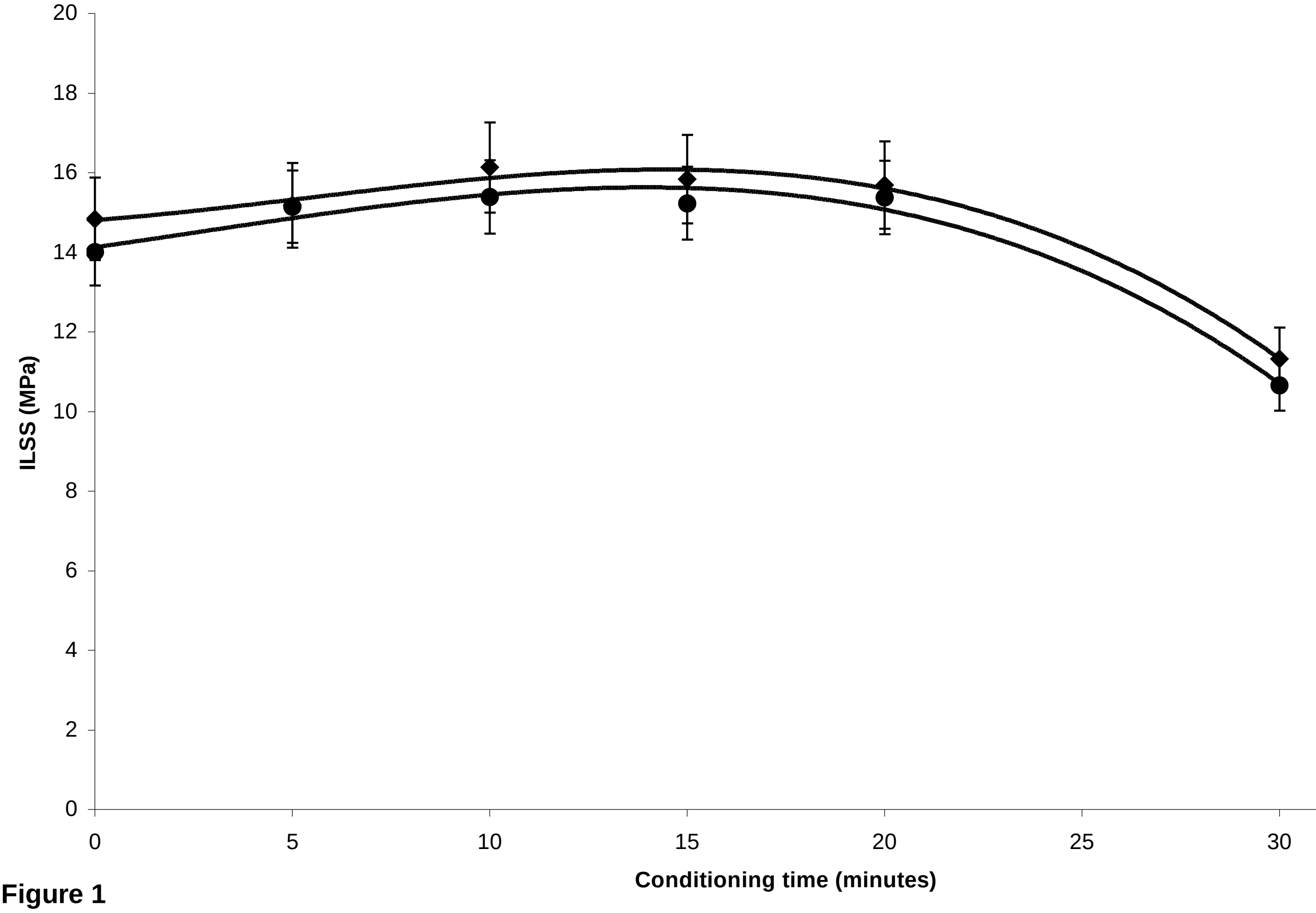
## FIGURE CAPTIONS

Figure 1. Effect of cryogenic conditioning on ILSS of thermally shocked glass/epoxy composites at 2 mm/min (•) and 10 mm/min (♦) crosshead speeds.

Figure 2. Scanning electron micrograph shows matrix and interfacial crackings in thermally shocked and thermally conditioned glass/epoxy composites at a 750 magnification.

Figure 3. Effect of thermal conditioning on ILSS of thermally shocked glass/epoxy composites at 2 mm/min (•) and 10 mm/min (♦) crosshead speeds.



20
18
16
14
12
10
8
6
4
2
0
ILSS (MPa)
0
5
10
15
20
25
30
Conditioning time (minutes)

Figure 1

Figure 2

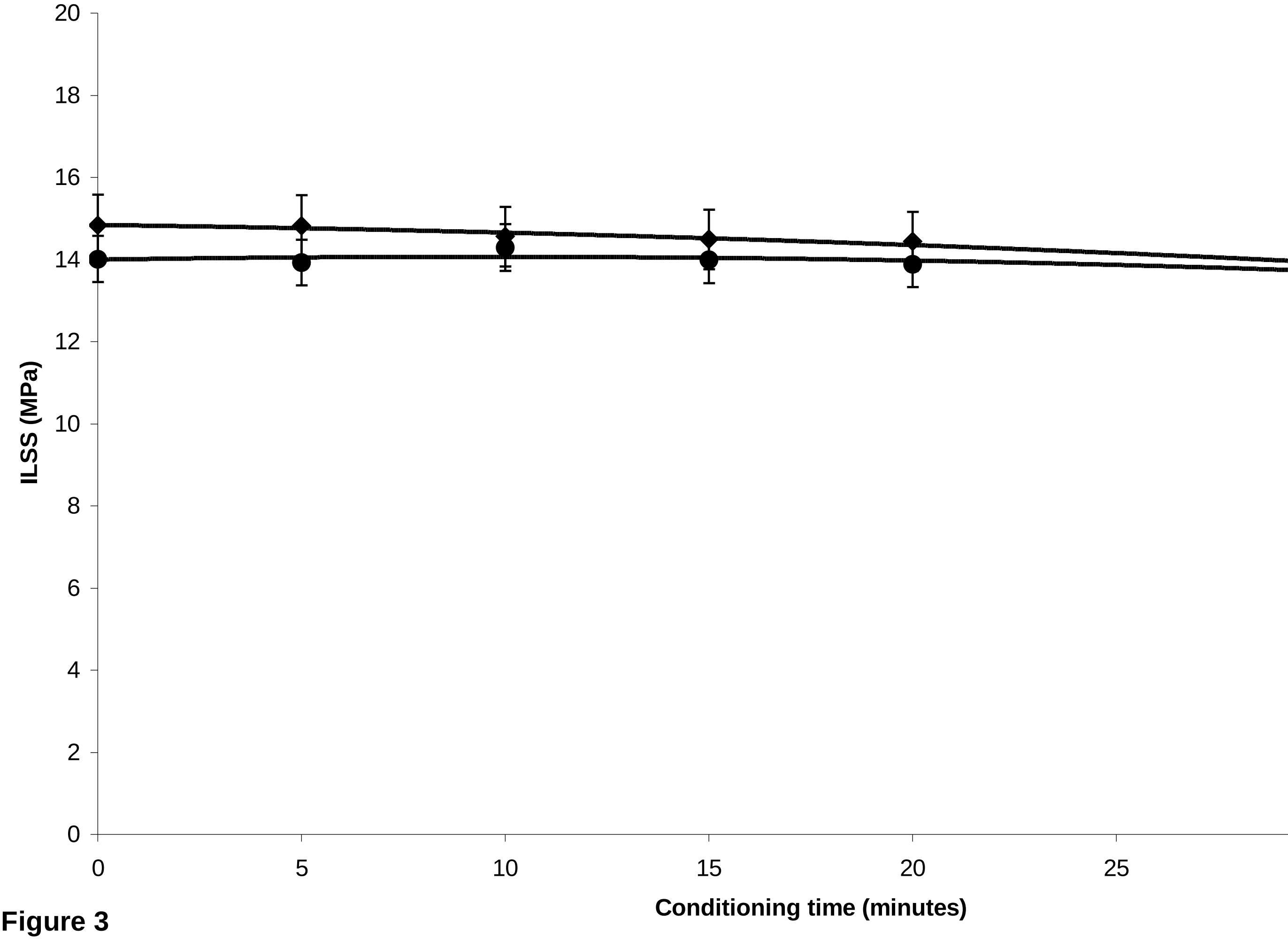

20
18
16
14
12
10
8
6
4
2
0
ILSS (MPa)
0
5
10
15
20
25
Conditioning time (minutes)

Figure 3