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Loading Rate Sensitivity of Fibrous Composite Materials

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ABSTRACT

Different loading conditions are probable in many of the applications where fiber-reinforced polymer (FRP) composites find use as potential and promising materials. Experimental studies have been carried out to study the effects of thermal ageing on mechanical behavior of glass fiber/epoxy composites. The inter-laminar shear strength (ILSS) is found to be affected by this conditioning. A change in loading rate may result in variation of failure modes.

INTRODUCTION

Composite structures undergo different loading condition during their service life. Mechanical response of materials is sensitive to the rate at which they are loaded. For the effective use of FRP composites their response under different loading rates should be clearly understood. The effect of varying loading rate on the mechanical properties of fiber reinforced polymer composites has been investigated and reported a variety of contradictory observations and conclusions.[1]Polymer matrix composite offers several advantages over conventional metals, ceramics and plastics due to its low density, high specific strength and lack of corrosion. The matrix is temperature dependent and change in temperature can cause internal stresses to be setup as a result of differential thermal contraction and expansion between the two constituents in Glass/epoxy and carbon/epoxy composites used for primary aircraft structures are subjected to thermal effects throughout their lives. Carbon and glass fiber reinforced composites used extensively in airframe doors, inner air brakes, tail plane and elevator, fuselage, floor panels. During a cruise cycle the thermal input to an aircraft structure ranges from ambient temperature on ground to a very low temperature during flight. At 30,000 ft height the temperature is 50^{o}C and on the ground an additional temperature increase is obtained during stays in tropical and arid places. E-glass fibers and matrix resins such as epoxy and polyester are known to be highly loading rate sensitive.[3]The mechanical properties of E-glass/epoxy composite are sensitive at low rate of strain rate. Greater the strain rate and the loading velocity, the greater are the stiffness and ultimate strength of the composite material. Failure strength of glass/epoxy composite increases manifold and failure strain reduces sharply at high range of strain rate.[4]

Whereas unidirectional carbon fiber reinforced composites is relatively rate dependent when loaded in the fiber direction.[5] The lack of a significant rate dependency of CFRP reflects the lack of rate dependent of the carbon fiber. Interface plays an important role for transmitting the load from the matrix to the fibers, which contribute the greater portion of the composite strength.[6] According to Tanoglu etal. the fiber/matrix interface mechanical properties are sensitivity to loading rate.[7] The relative contribution of the constituents (fiber, matrix and interface) to the fracture energy depends on the rate of loading.[8] A direct co-relation between the loading rate dependency of composites and those of the constituent phases may be difficult or rather complicated.

The main objective of the present investigation deals with the effect of thermal ageing on glass/epoxy composites at different loading speed. The combined effects of oxygen in the air and heat can lead to thermo-oxidative degradation and subsequent loss in mechanical properties. Various factors, such as the chemical nature of the cross-linking agent in a thermoset polymer, or the presence of glass or carbon fiber reinforcement , can influence long-term ageing behavior. [9]Thermal ageing is done at ,below and above room temperature .There are significant chemical and structural changes in epoxy networks takes place during thermal ageing. In case of polymer molecules a dynamic mechanical relaxation occurs due to heat transfer between the intermolecular mode i.e the strain sensitive mode and the intra molecular mode i.e the strain insensitive mode .As the heat is transferred into the intra-molecular modes with a relaxation time, the physical properties of polymer materials depend decisively on frequencies of molecular excitation through the relaxation time depends on temperature.[10].

EXPERIMENTAL WORK

Araldite LY-556 ,an unmodified epoxy resin based on Bisphenol-A and hardener(Ciba-Geigy,India)HY-951,aliphatic primary amines were used with woven silane treated E-glass fibers to fabricate the composite by hand lay-up method. The fiber weight percentage was 60% in the composite laminate. They were cured for 48hours at room temperature. The laminates were cut into short beam shear test(SBS) specimen by a diamond cutter. The test specimen were exposed to $+50^{o}$C and -50^{o} Cfor two hours. The SBS tests were performed at, below and above 50^{o}c to determine the interlaminar shear strength (ILSS). The SBS test was conducted using INSTRON 1195 as per ASTM standard (D2344) at different cross head speed ranging from 1, 10,100,200,500mm/min.

The ILSS values were calculated as follows:

ILSS= 0.75P/bt

P is the breaking load, b the width of specimen ,t the thickness of specimen.

Thermal conditioning:- Thermal conditioning was done in a baking oven held at 50^{o}Csufficient time was given after the temperature of the oven reached the set temperature so that there is uniform temperature throughout the oven. The specimen were held for 2 hours after which they were wrapped in Al foil and were taken for 3-point bend test.

Cryogenic conditioning:- cryogenic conditioning was done at a temperature of -50^{o}C in a double compressor fitted deep freezer. The specimen were put into the chamber and held for 2hours.The specimen were tested in the 3-point bend test at this temperature.

RESULT AND DISCUSSION

From the investigation it is observed that at 1 to 100 mm/min the ILSS increases with increase of cross head velocity due to increase in stiffness of the composite. Cross head speed above 100 mm/min results decrease in ILSS due to brittle behavior of matrix. Higher cross head speed during testing restricts and /or minimizes the relaxation processes at the crack tip. Thermal stress induced cracks may possibly grow without blunting at a steady rate, that could reduce the ILSS at higher loading rate.

From SEM micrographs it is clear that the failure modes change with changing in loading rate. The microstructure of polymer matrix is influenced by temperature.

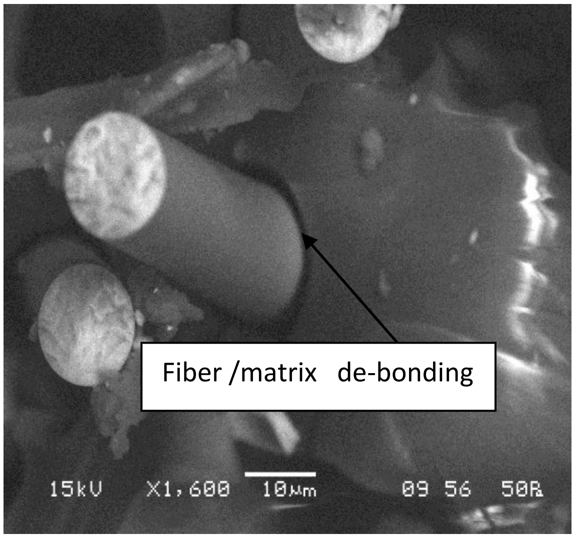

Fig.1 Scanning electron microscopy showing fiber matrix debonding in glass/epoxy composites.

Fig.2 and Fig.3 revealing matrix cracking and fiber breakage under the influence of thermal ageing. The failure mode changes from fiber brittle failure to brittle failure with consider matrix damage ,as the cross head speed increases . A weaker interfacial bond may result in a low flexural strength of the laminate.

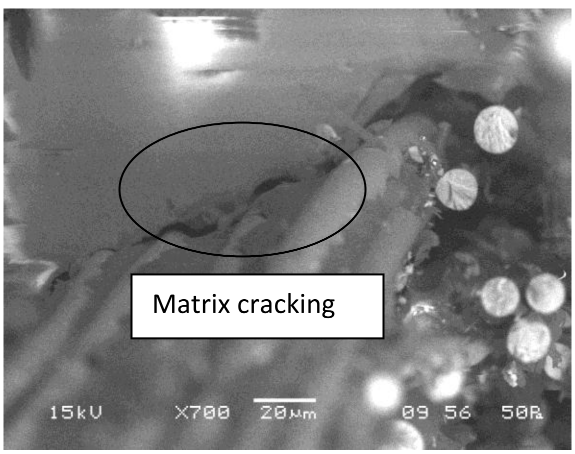

Fig.2 SEM micrograph is showing matrix cracking in glass/epoxy composite.

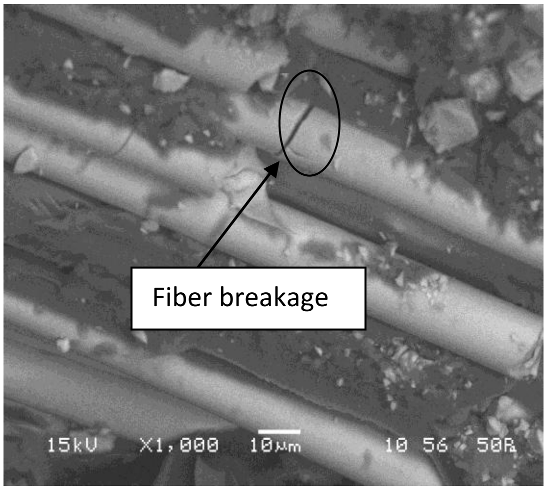

Fig.3 Fiber breakage in glass/epoxy composite.

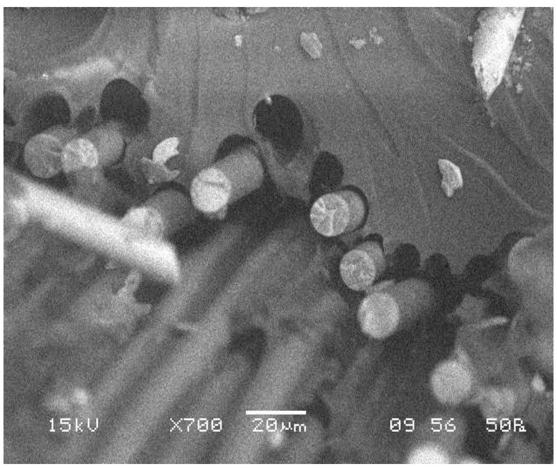

Fig.4 Glass-epoxy laminates with 60% fiber volume fraction showing matrix with signs of fiber pull-out.

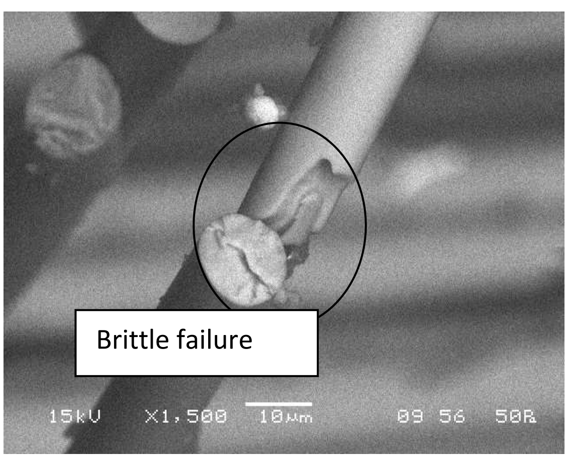

Fig.5 Glass-epoxy composite showing brittle failure with fiber breakage.

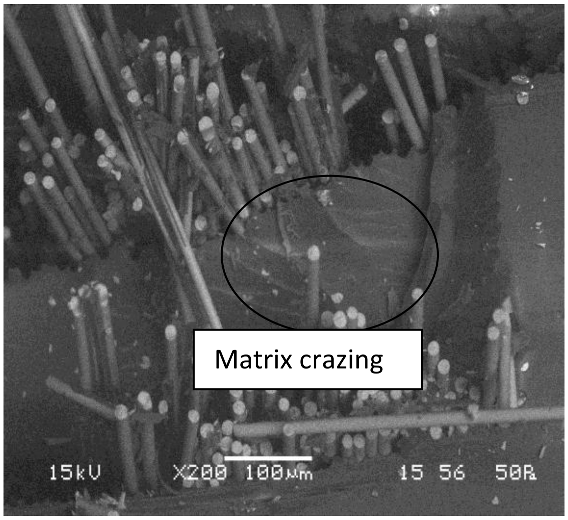

Fig.6 Matrix damage is leading to matrix crazing in glass-epoxy composite.

The composite sensitivity to strain rate is mostly driven by the resin behavior.[11] Failure in a fiber composite may initiates from small defects such as broken fibers ,matrix pores and de-bonded interfaces. A plastic deformation zone ahead a crack tip may be formed by matrix deformation and matrix cracking. Immediately behind the crack tip the broken fibers can pull out of the matrix, fiber pull out is an energy absorbing mechanism. The deteriorated composite integrity can cause low strength at high loading. Intermolecular forces and stress relaxation at the crack tip of an epoxy resin at the cryogenic temperature are found to play an important for higher fracture toughness.[12]

CONCLUSION

The fabrication of samples and subsequent three point bend test at the conditioning temperatures is revealed to ascertain the effects of loading speed on the failure behavior of FRP composites. The effects of thermal ageing of glass/epoxy composite at different rates are experimentally investigated. Loading rate sensitivity is strongly evident at a lower range of cross head speed and the ILSS values are found to increase. Thereafter, the ILSS values could decrease with increasing loading rate. Thermal conditioning imparts better adhesion and thus improved ILSS than cryogenic conditioning might have introduced matrix cracking and or interfacial de-bonding.

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