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An Assessment on Failure Behaviour of Environmentally Conditioned FRP Composites: An Emphasis on Micromechanics Understanding

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Abstract: Glass, Carbon and Kevlar fibers based polymeric composites were exposed to a set of different environmental situations (change in temperature,humidity,sudden flutation of temperature and humidity, sub- and cryo-environments, thermal shock, thermal spike, thermal fatigue, environmental fatigue with and/or without prior thermal conditioning including sometimes by micro-wave-assisted polymerization). The environmentally conditioned specimen were tested with 3-point bend fixture and then interlaminar shear strength(ILSS) values were calculated. These values are plotted against different parameters to index the impact and implications of various environmental parameters on the fluations of delamination strength and stiffness. The extensive Scanning Electron Microscope(SEM) study are adopted to assess and evaluate the impact of environmentally inducted defects and damages in changing or controlling the threshold value of crack initiation and propagations. One of the basic objectives is to reveal the prevailing and dominant failure behavior and modes under various environmental in-service realistic conditions.

1.Introduction:

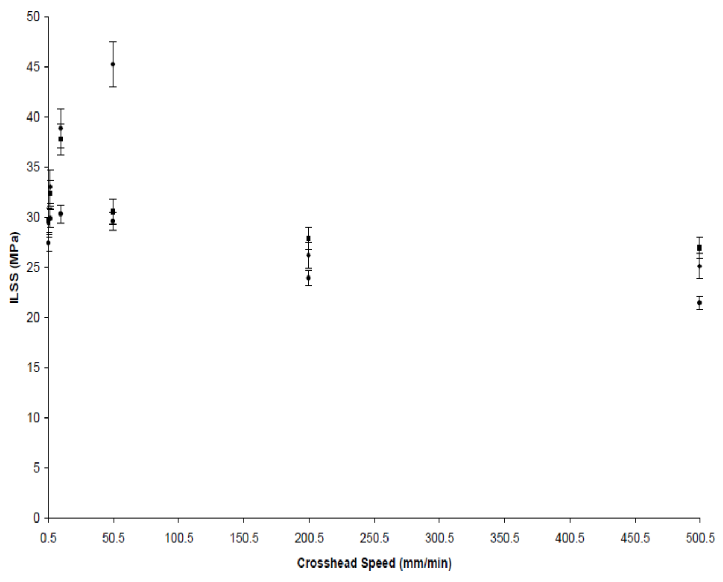
Upon their introduction to high-performance engineering applications, polymer fibrous composites were touted as the universal panacea for all structural engineering application. The degree of environmental degradation that occurs in a fiber reinforced polymer composites structure is linked directly with the amount of moisture that is absorbed. But the moisture absorption kinetics of epoxy resin differ widely and also change with physical ageing. The state of fiber/matrix interface is believed to influence the nature of diffusion modes. A significant weakening often appears at the interface during the hygrothermal ageing.

2. Experimental case studies

Micromechanics of damage growth and failure

The key to the understanding of micromechanisms and a development of physically based failure criteria is a fractographic examination, which is defined as the interpretation of fracture morphology to glean information about the FRPs' failure.

2.1 Loading rate sensitivity at ambient and sub-ambient temp.



- ➢ILSS(↓) at higher loading rate
- ➢Crack blunting ⟶ at higher rates of loading.

Room temp.(●)
After thawing at ambient temp.(■)
Cryogenic temp.(◆)

Fig 1: Variation of ILSS values of GFRP composite

2.2 Temperature effect on humid ageing

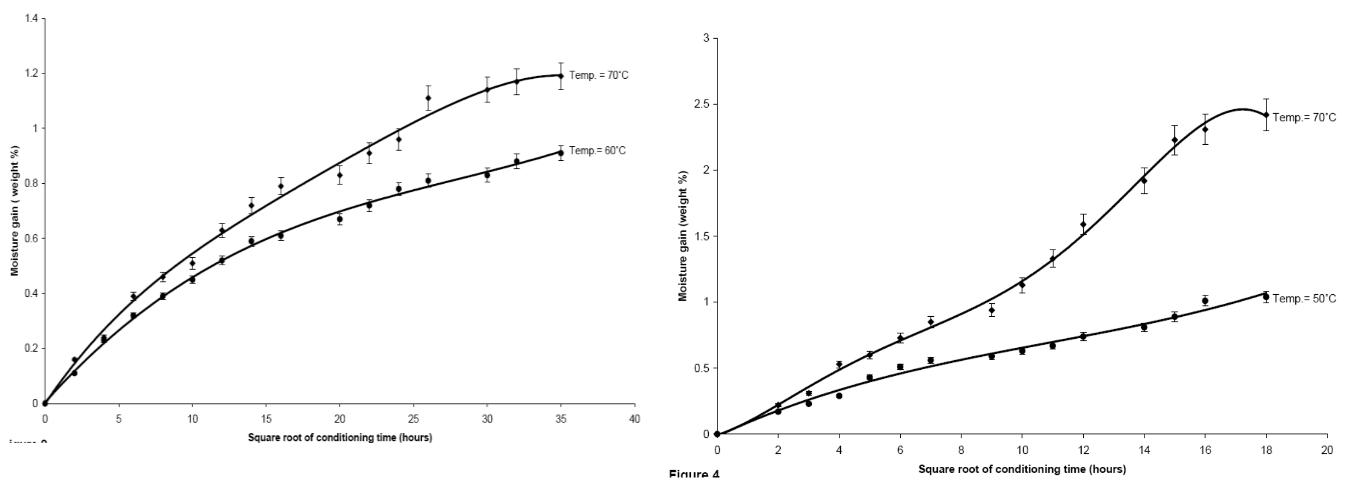


Fig 2: (A) Moisture absorption kinetics at 60ºC at 95%RH ,70ºC at 95%RH
(B) Moisture absorption kinetics at 50ºC at 95%RH, 70ºC at 95%RH

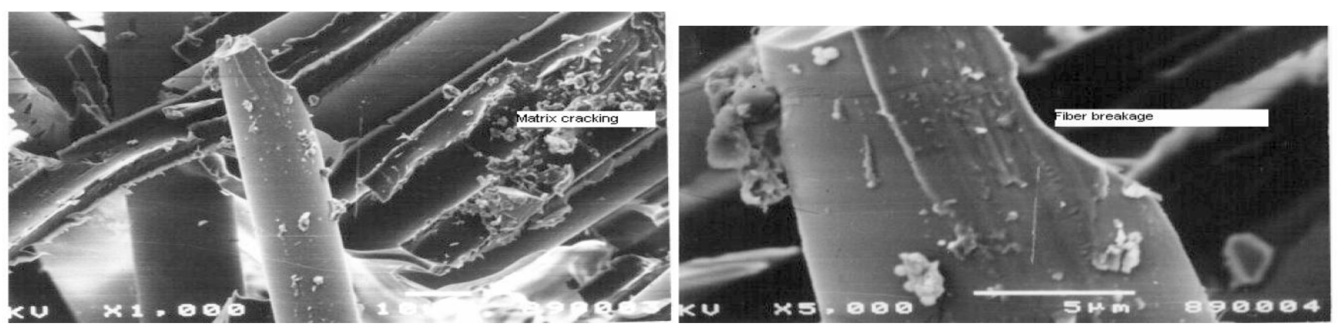


Fig 3: SEM shows matrix cracking and fiber damage in CFRP composite

➢Higher temperature ⟶ moisture uptake
↓
delamination nucleation

2.3 Matrix cracking

Matrix cracking(ply splitting)
↓
Low strength transverse to the fiber

➢Loading rate increases then number of splits increases but spacing between splits reduced.

Matrix cracking

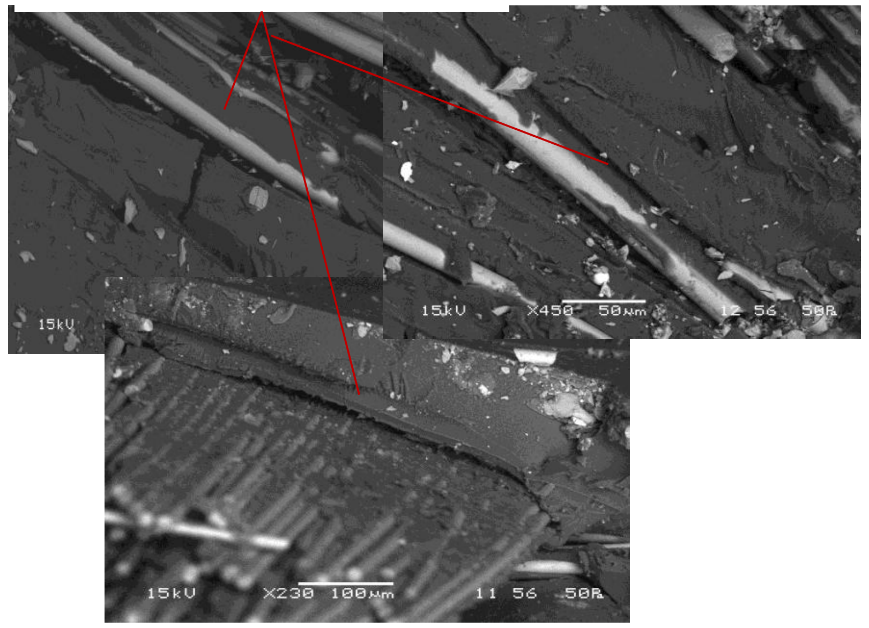


Fig 4: Matrix Cracking in GFRP composites

2.4 Thermal shock on interfacial adhesion of thermally conditioned

➢Debonding effect of thermal shock is evident for lesser time

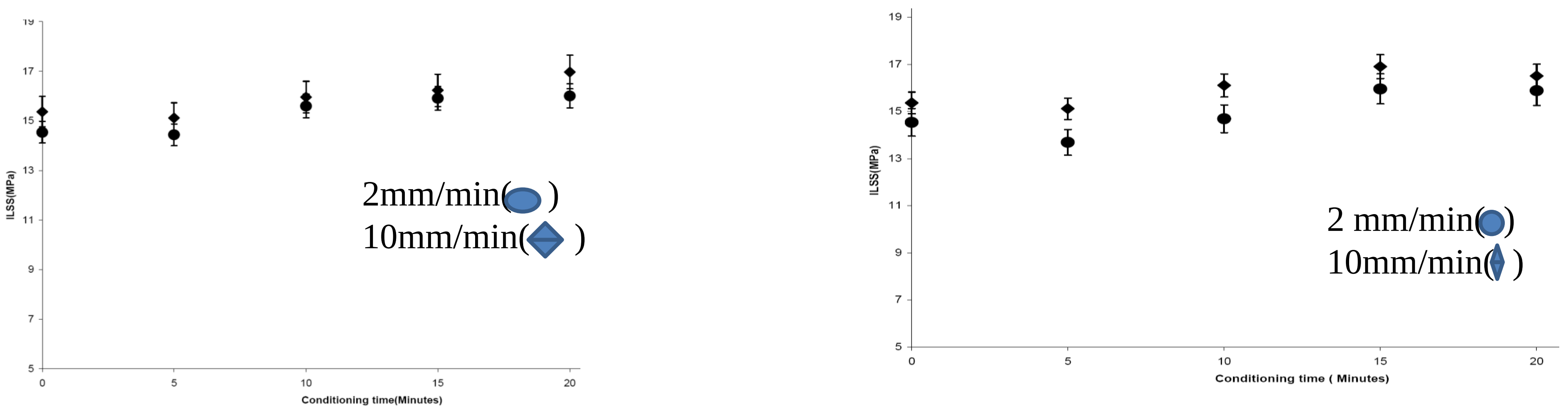


Fig 5:Downthermal and upthermal cycle on ILSS value of GFRP at 2mm/min and 10mm/min crosshead speed

At high temperature ⟶ resin exhibit high plasticity ⟶ Cusps formed

2.5 Cups

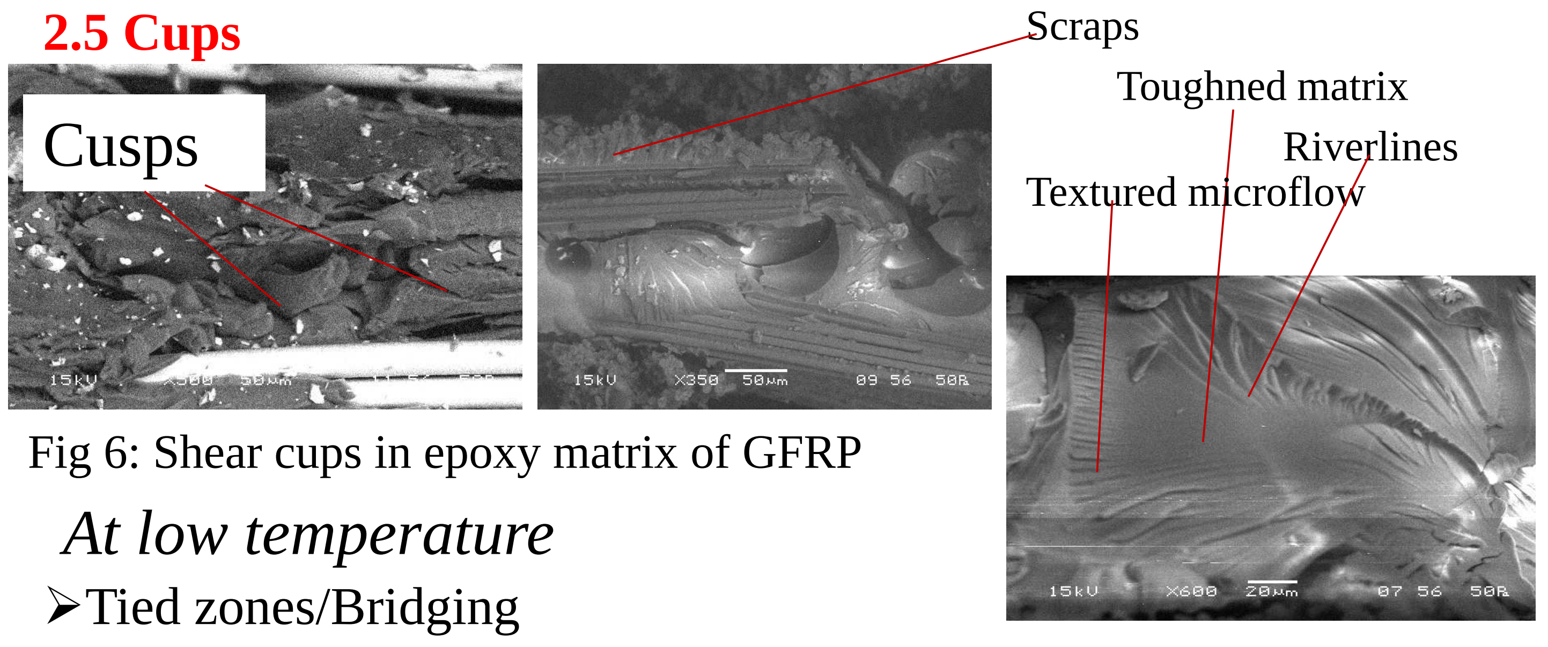


Fig 6: Shear cups in epoxy matrix of GFRP

- ✓Cups is attributed to the formation of inclined cracks by a local mode I stress.
- ✓When loading increases the angle cracks extend along the 45 lines. These angle cracks converge to produce the S-shaped cusps.

At low temperature

➢Tied zones/Bridging

Mode I fracture ⟶ Fiber bridging(tied zones) ⟶ Crack length increases
↓
Corrugated cross-section developed

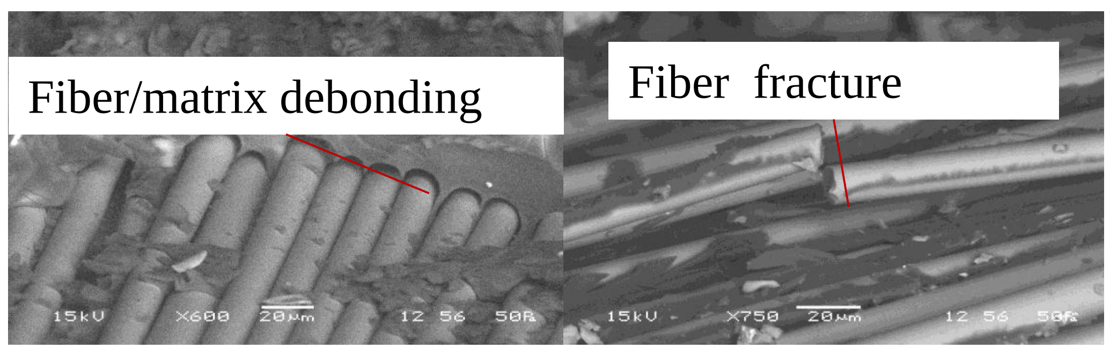


Fig 7: Fiber/matrix debonding and fiber fracture in GFRP

Fiber /matrix debonding in process zone
↓
Fiber bridging
Nesting of fibers

➢2.6 Riverlines mark

⟶ Chevrons point ⟶ Global carck growth

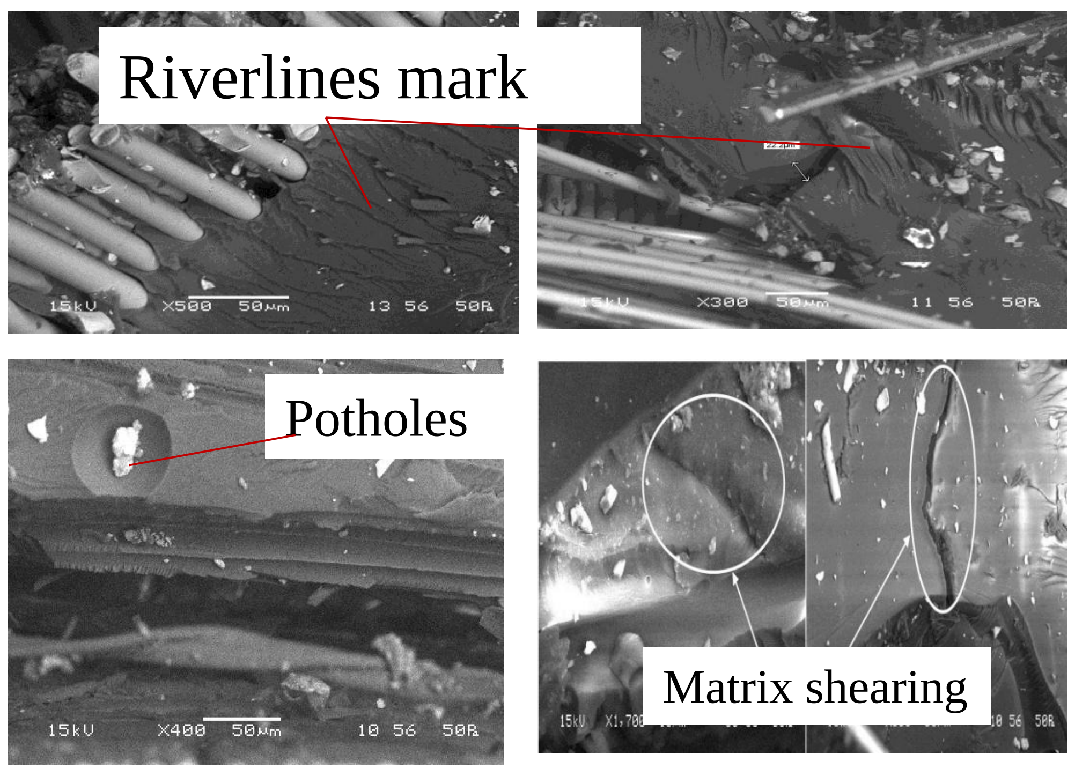


Fig 8: Examples of microscopic failure modes

- ✓"Riverlines" are a natural development of scraps and convergence of crack planes.
- ✓The convergence of pairs of planes from the tributaries of the rivers, ultimately converging into one crack.
- ✓Direction of crack growth is the direction in which the riverlines converge.
- ✓In low temperature, due to shrinkage of matrix, a loss of patch bonding tends to occur over time, particularly if freeze-thaw cycling occurs which is assisted by potholes in the matrix region.

➢In general, at low loading rates mechanisms such as craze(crack blunting) dominates, where as at high loading rate fracture is more brittle, fracture surface is smooth.

3.Remarks

The present experimental exploration testing on FRP composites have revealed the presence of a possible and more prevailing mode of failure in each environmentally conditioned specimen. The progressive and perpetual changes in microstructural integrity in FRPs under the influences of environmental parameters are a critical concern in evolving the deformation behavior, and subsequently assessing the environmental damages in terms of micromechanics which is more precisely controlled by changes of crack density, presence of voids, swollen fibre ends, fibre split, fiber breakage and dynamic nature of interfaces because of moisture ingression and thermal fluctuations..

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