STIFFNESS DEGRADATION BEHAVIOR OF A POLYMER NANOCOMPOSITE UNDER CONSTANT AMPLITUDE FATIGUE LOADS

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Abstract

A thermosetting epoxy polymer LY556 was modified with 10 wt. % of silica nano particles and infused in to anE-glass fiber cloth to produce quasi-isotropic lay-up GFRP nanocomposite laminate. Standard fatigue test specimens were cut and prepared from the laminate. Constant amplitude fatigue tests at stress ratio, R = 0.1 were conducted with various maximum stress. The stiffness of the specimen was continuously monitored during the fatigue tests. The normalized degradation behavior was similar at all the stress levels.The stiffness of the composite was estimated using a micro-mechanics based model. The predicted stiffness degradation curves were observed to comparereasonably well with experimental results.

Key words: Nano-composite, Stiffness Degradation, Micromechanics, Fatigue life, Degradation model

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INTRODUCTION

Fiber reinforced polymer (FRP) composites are widely used in aerospace structures since they possess high specific strength and stiffness. These composites experience static and fatigue loads in service and hence they need to possess high fracture toughness and fatigue durability. Efforts have been made in the recent past to improve the fatigue properties of FRPs by addition of nano fillers in the epoxy matrix. Addition of various types of nano fillers such as silica nanoparticles, carbon nanotubes and various types of nanoclays have all been shown to improve fatigue properties of FRPs [1,2]. The aim of this investigation was to experimentally determine the stiffness degradation behavior of a GFRP nanocomposite under constant amplitude fatigue loads and compare with predictions based on a micro-mechanics model.

EXPERIMENTAL

The neat LY556 epoxy resin and silica nanoparticle-epoxy resin mix were mixed along with the required amount of curing agent, stirred and degassed. The microscopic observation of the nano-modified epoxy mix showed that thesilica particles of about 20 nm were distributed evenly throughout the epoxy resin (Fig. 1). E-glass fibre cloth pieces were laid up in a quasi-isotropic sequence [(+45/-45/90/0/)$_s$]$_2$ and the nano-modified epoxy resin was infused under vacuum, cured at 100 ^{0}C for 2 hours and post-cured at 150 ^{0}C for 10 hours. The tensile properties of GFRP nanocomposite laminate thus produced [3] were as follows; UTS = 381 MPa, E = 18.77 GPa. Fatigue test specimens of size 150 mm x 25 mm x 2.7 mm were cut from the laminate and end-tabbed. All the fatigue tests were performed in a 25kN computer-controlled servo-hydraulic test machine. The fatigue parameters employed were as follows: stress ratio, R = 0.1, sinusoidal waveform, frequency= 2 Hz. The load versus displacement data was obtained at regular intervals during the fatigue tests and the stiffness was determined from this data.

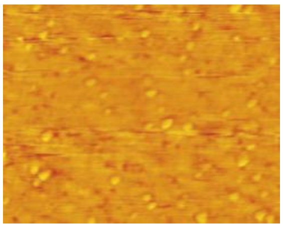


Fig. 1. Atomic force microscopic phase image of the bulk epoxy nanocomposite [3]

RESULTS AND DISCUSSION

The fatigue test results in terms of S-N curve determined at stress ration R = 0.1 for GFRP nanocomposite is shown in Fig. 2. The normalised stiffness degradation behavior determined at various stress levels is shown in Fig. 3. As observed generally in FRP composites [4] , the stiffness of the nanocmposite decreased wth fatigue cycles. Three distinctly different stages in the stiffness degradation curve, generally observed in composites[4] were clearly identifiable inthese curves. The normalized degradation behavior was observed to be similar at all the stress levels as shown in Fig. 3. The initiation and growth of fatigue damages such as matrix cracks, disbonds and delamination have been observed to result in such stiffness degradation of composite [4] leading to fatigue failure.

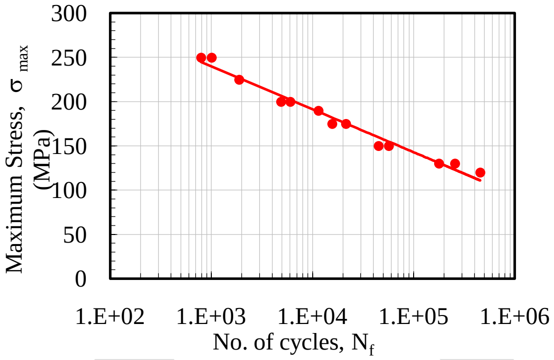


Fig. 2. Stress-life (S-N) curve at R = 0.1 determined for GFRP nanocomposite

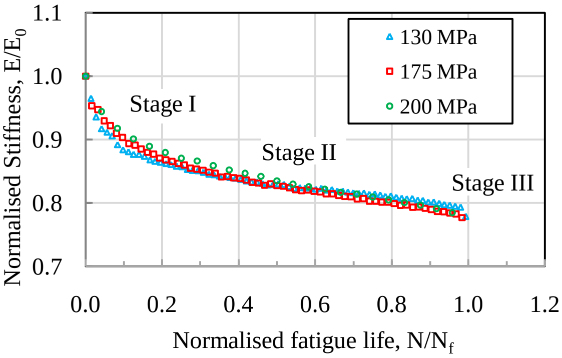


Fig. 3. Experimental stiffness degradation curves determined for GFRP nanocomposite under fatigue

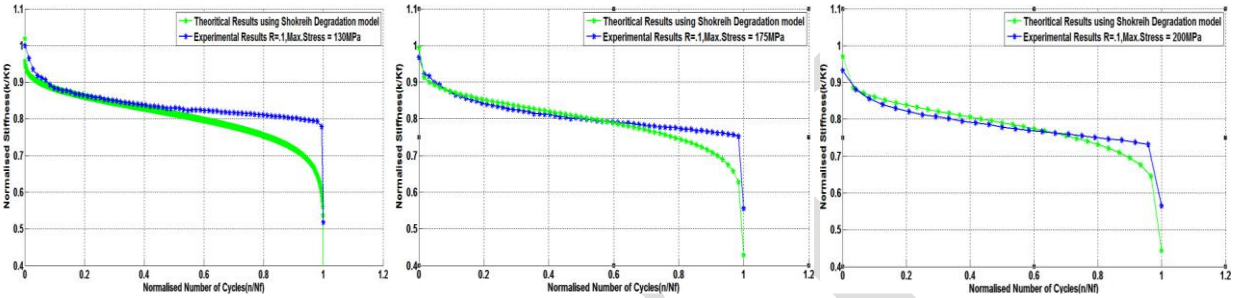
Many different models have been proposed to define the stiffness degradation behavior in FRP composites [5]. The model proposed by Shokreih et al. [6-8] relates stiffness degradation as a function of stress state, number of cycles and fatigue life for the given stress condition and is expressed as:

$$E(R,\sigma,n)=\left[1-\left(\frac{\log(n)-\log(.25)}{\log(N_f)-\log(.25)}\right)^{\lambda}\right]^{\frac{1}{\gamma}}\left(E_s-\frac{\sigma}{\varepsilon_f}\right)+\frac{\sigma}{\varepsilon_f}$$

Where, E (R,σ,n) = Residual Stiffness in the laminate, E_s = Static stiffness(N/mm), σ = Maximum applied stress(MPa), ε_f = Strain to failure(με), n = Number of applied cycles, N_f = Fatigue life at applied stress, γ, λ = experimental and curve fitting parameters. The test results obtained from static and fatigue tests (see Table 1)were used to estimate the curve fitting parameters. Using these results in the above equation, the stiffness degradation was predicted and compared with experimental results as shown in Fig. 4. It can be clearly seen that the predicted stiffness degradation behavior is quite comparable to experimental results at all the stress levels.

Table 1. Values used to determine the constants in eqn. (1)

Property	Value	Max. Stress(MPa)	No. of cycles to fail, (N_f)
Static stiffness, E_s (kN/mm)	12.799	130	177500
Strain to falure, ε_f ($\mu\varepsilon$)	0.06	175	15500
Experimental Parameter, γ	0.30	200	6000
Curve fitting Parameter, λ	14.7	225	1900



a) $\square_{max}$ = 130 MPa (b) $\square_{max}$ = 175 MPa (c) $\square_{max}$ = 200 MPa

Fig. 4. Comparison of experimental and predicted stiffness degradation behavior

CONCLUSIONS

The stiffness of GFRP nanocomposite was observed to degrade with fatigue cycles. The normalised degradation behavior was similar at all the stress levels. The micro-mechanics based model was observed to predict the stiffness behavior and compare quite well with experimental results.

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REFERENCES

[1] Thostenson ET, Li C, Chou TW, *ComposSci Tech* 65 (2005) 491

[2] Hussain F, Hojjati M, Okamoto M, Gorga RE,*J Comp Mater* 40 (2006) 1511

[3] Manjunatha CM, Taylor AC, Kinloch AJ, Sprenger S,*Compos Sci Tech* 70 (2010) 193

[4] Gagel A, Lange D, Schulte K, *Compos Part A: ApplSciManuf* 37 (2006) 222

[5] Lian W, Proceeding of 5th Int. Conf. on Fatigue of Composites ICFC5 Ed. W-X Yao,16-19 Oct 2010, Nanjing, China, p131-146

[6] Shokreih MM, Lessard LB, Behrooz FT, *Compos Struct* 85 (2008) 205
[7] Shokrieh MM, Lessard LB., *J Compos Mater* 34(13) (2000) 1056
[8] Shokrieh MM, Lessard LB. *J Compos Mater*34(13) (2000) 108