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Effect of hygrothermal environment on the tension–tension fatigue performance and reliable fatigue life of T700/MTM46 composite laminates

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Introduction

Hygrothermal Environment

The hygrothermal environment has a great influence on the performance of the CFRP composites commonly used in aircraft, and is increasingly of concern to aircraft designers.

Research Status

Existing research has mainly focused on the effect of hygrothermal aging on the static strength of composites. However, there is less research on the effect of the hygrothermal environment on the reliable fatigue life.

FRP Composites

The high specific strength and specific stiffness of composite materials, especially fiber reinforced polymer composites (FRP), make them suitable for use in the aerospace industry

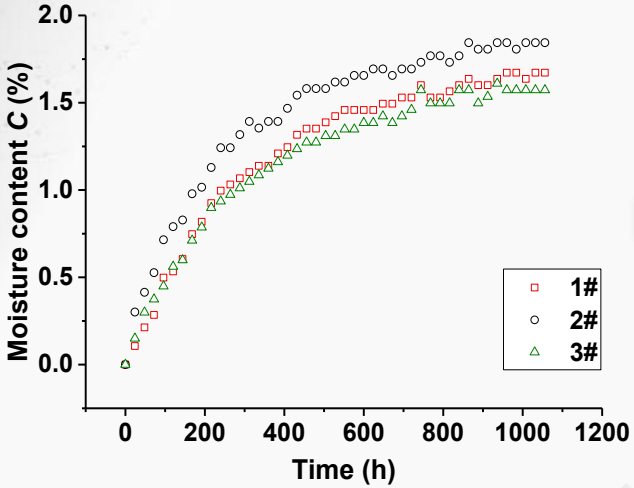
Fatigue Performance

Fatigue performance has a great influence on the safety and reliability of composites, and the hygrothermal environment has itself a great influence on it.

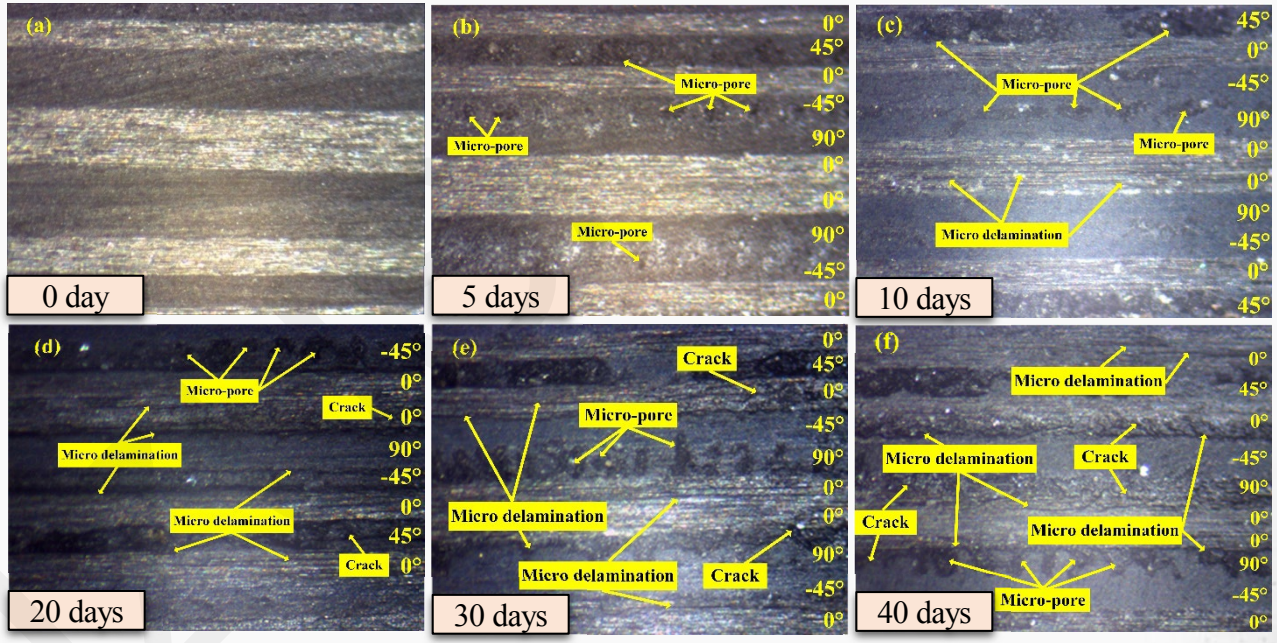
Our work

It is necessary, therefore, to study further the effects of hygrothermal aging on the fatigue performance of composite materials.

Moisture absorption behavior



Moisture absorption curve of the moisture absorption specimens



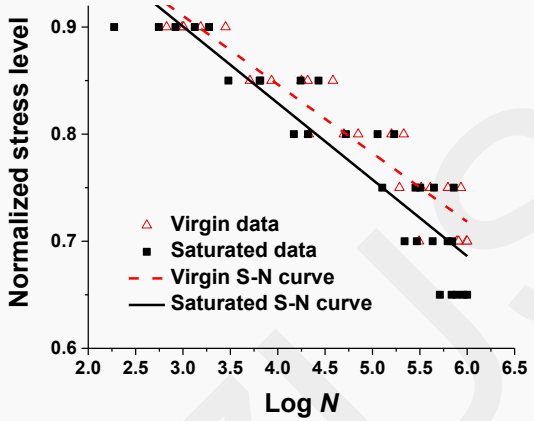
Damage evolution of fatigue specimen during moisture absorption

- The average moisture content of T700/MTM46 composite laminates was about 1.69 % when effective moisture equilibrium was achieved.
- In the process of moisture absorption, damage such as micropores and micro-delamination appeared, but these were much less than that those generated during the fatigue process.

Tension–tension fatigue life

S-N equation:

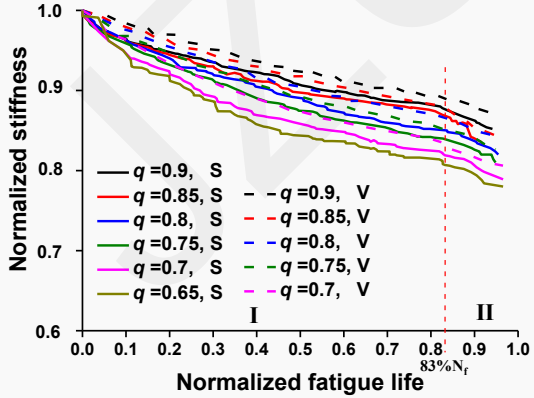
$$S = \lg C / m \lg e + 1 / m \lg e \lg N$$



- The *S-N* curve of the moisture-saturated specimens is entirely below that of the virgin specimens, which means that the fatigue life of the saturated specimens is lower than that of the virgin specimens at the same stress level.

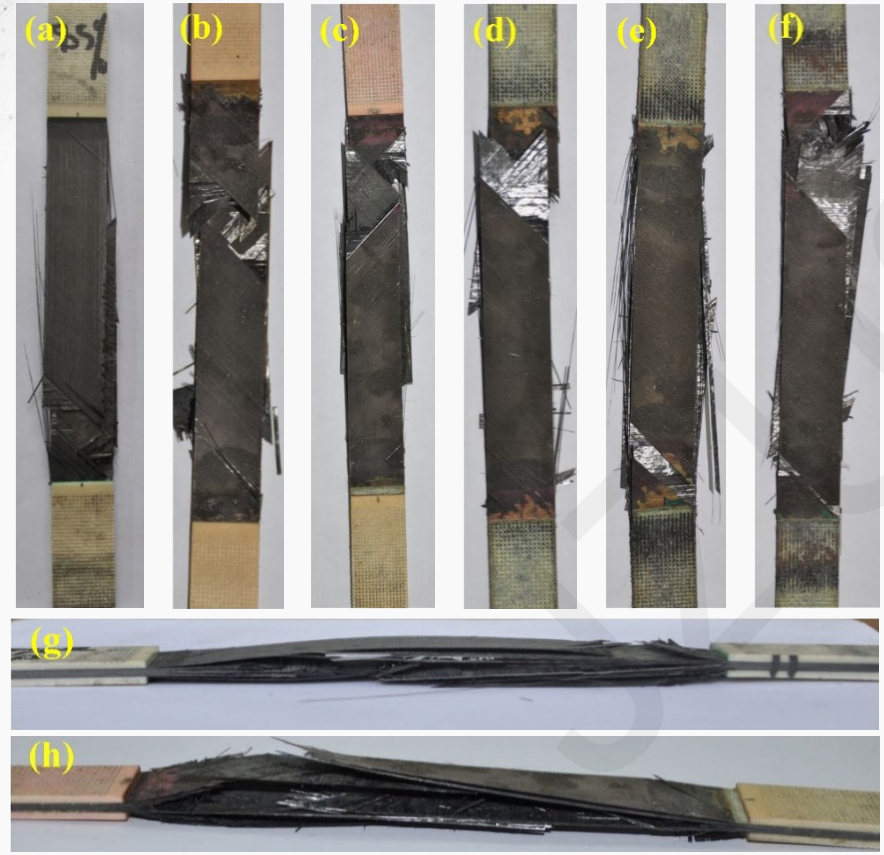
Stiffness degradation:

$$\frac{E_N}{E_1} = \left[\frac{\left(\frac{\Delta p}{\Delta d}\right) - \left(\frac{\Delta p}{\Delta d}\right)_{N_i}}{\left(\frac{\Delta p}{\Delta d}\right)_{N=1}} \right]$$



- After hygrothermal aging, the stiffness at the moment before the fatigue failure of specimens was reduced by 23.5 %, 22.1 %, 18.2 %, 17.3 %, 16.9 % and 14.6 % at the stress levels of q=0.65, 0.7, 0.75, 0.8, 0.85 and 0.9, respectively.

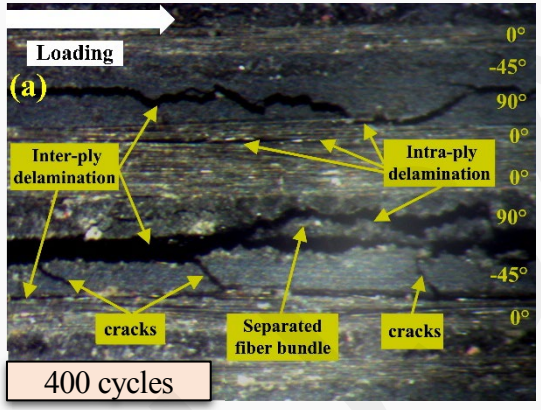
Fatigue damage modes

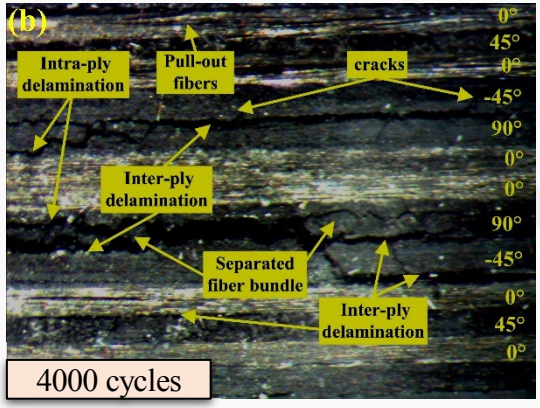


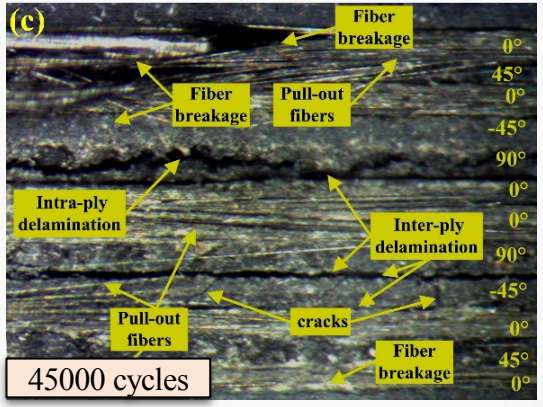
- The damage modes of the moisture-saturated specimens during fatigue were similar to those of the virgin specimens, and the most obvious mode remains severe delamination throughout the whole gauge length.

Fatigue failure modes of (a): virgin specimen (q=0.85) (b): q=0.9 (c): q=0.85 (d): q=0.8 (e): q=0.75 (f): q=0.7, Top view. (g): virgin specimen (q=0.85) (h): q=0.85, Edge view.

Fatigue damage evolution







Edge view of moisture saturated fatigue specimen under q=0.8 stress level

Statistical analysis of fatigue life data

Log-normal:

$$F(\lg x;\mu,\sigma)=\int_{-\infty}^{\lg x}\frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{(\lg x-\mu)^2}{2\sigma^2}\right]\mathrm{d}(\lg x)$$

3P Weibull:

$$F(x;\alpha,\beta,b)=1-\exp\left[-\left(\frac{x-\alpha}{\beta-\alpha}\right)^b\right],\quad x\geq 0$$

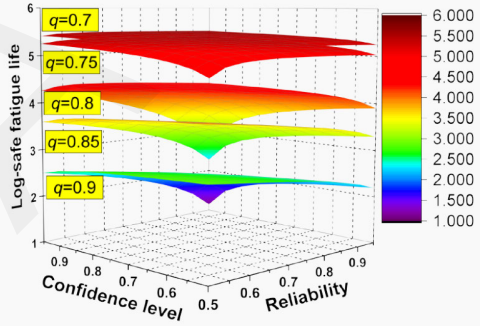
Fatigue life data: parameters and correlation coefficient for two statistical distributions

distribution	parameters	Stress level					
		0.9	0.85	0.8	0.75	0.7	0.65
Log-normal	μ	2.8682	3.9559	4.6988	5.5137	5.6160	5.8795
	σ	0.3880	0.3796	0.4561	0.2778	0.2127	0.1137
	r	0.9738	0.9717	0.9819	0.9780	0.9823	0.9806
3P Weibull	α	0	2124.7	10694	34782	56181	192440
	β	1178	13740	82342	426050	534470	815730
	b	1.0778	0.6544	0.5516	1.6462	1.4655	2.1059
	r	0.9897	0.939	0.9764	0.9717	0.9752	0.9789

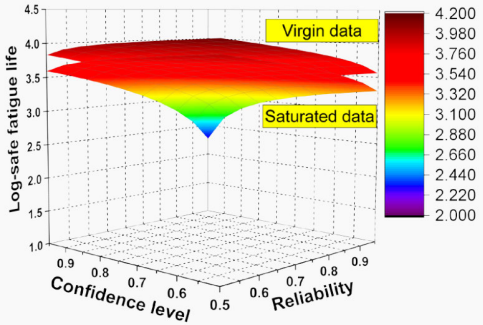
- According to the value of correlation coefficient *r*, the fatigue data can be described better under most stress levels as a log-normal distribution.

Reliability analysis for fatigue life

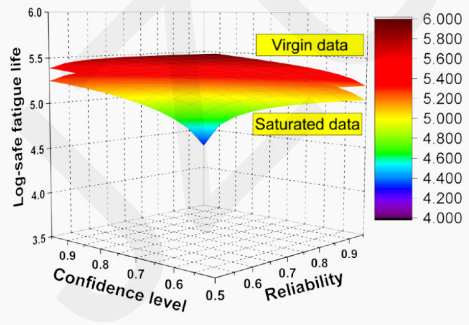
- The p- γ -S-N surfaces were established to predict the reliable fatigue life of the T700/MTM46 laminates.



***p*- γ -*S*-*N* surface of T700/MTM46 laminates after hygrothermal aging**



q=0.85 stress level



q=0.75 stress level

***p*- γ -*S*-*N* surface of saturated and virgin T700/MTM46 laminates**

- The p- γ -S-N surfaces of the moisture-saturated specimens were located under those of the virgin specimens.

Highlights

Fatigue performance is important for acknowledge the safety of aircraft, and hygrothermal environment also has a great influence on the degradation of composite properties. The article’ s highlights are listed as below.

- The damage evolution of T700/MTM46 composite laminates during moisture absorption was affirmed.
- Tension-tension fatigue tests of laminate after hygrothermal aging were performed.
- Reliability fatigue life of laminate after hygrothermal aging were calculated, and p-γ-S-N surfaces were established.
- Fatigue performance of moisture-saturated laminates was compared with that of virgin laminates, and hygrothermal treatment greatly reduced fatigue performances of T700/MTM46 composite laminates.