CHARACTERISATION OF TEMPERATURE-DEPENDENT BEHAVIOUR OF CHOPPED STRAND MAT GRP DURING LOW CYCLIC FATIGUE

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Introduction

A wide range of structures or components are commonly being manufactured using fibre-reinforced polymer composites. Despite its widespread application, mechanical properties of CSM-GRP at elevated temperature has not been thoroughly studied although mechanical properties of composite materials are strongly dependent on temperature, with strength and modulus rapidly decreasing once the temperature exceeds the glass transition temperature.
The lack of experimental data on the post-fire or due to the elevated temperature for the fatigue life prediction of CSM laminates has caused the necessity for further research. The investigation presented here is in developing a model capable of predicting the stiffness degradation of CSM and to validate the model. In this paper, the previously proposed fatigue life prediction models [1, 2] have been extended to include both residual stiffness and strength degradation models together with thermal stresses, so as to come up with more reliable fatigue prediction model under thermal and cyclic loadings. A series of fatigue tests in tension-tension mode at room and elevated temperatures were carried out for life cycle performance at different load levels and the experimental findings are used to evaluate an established the proposed theoretical model.

Analytical Model

In the prediction model suggested by Ye [1] , a stiffness degradation model was proposed, which assumes that the residual stiffness is a monotonically decreasing function of the fatigue cycle and can be written as

$$E_N = \left[1 - \left\{N \cdot C \cdot (n+1)\right\}^{1/(n+1)} \cdot \sigma_{\max}{}^{2n/(n+1)}\right] \cdot E_0 \quad (1)$$

Caprino and D'Amore [2], on the other hand, introduced a residual strength degradation model, accounting for the stress ratio, R. It is assumed that the decrease in material strength as a function of the number of cycles is described as

$$\sigma_{\max} = \frac{\sigma_0 - \sigma_N}{\alpha \cdot (1-R) \cdot \left(N^{\beta} - 1\right)} \quad (2)$$

In order to consider the temperature effects into the analytical model, it is assumed that the temperature is only variable of the residual strength [3]. In addition, a polynomial expression of 2nd order will be introduced to fit the experimental data to model the temperature function, f_T. As a result, the following polynomial expression is obtained:

$$\sigma_n = f_T(T) = a_0 + a_1 T + a_2 T^2 \quad (3)$$

where the polynomial coefficient a with subscripts 0, 1 and 2 can be obtained through experiments.
Consequently substituting both eq. (2) and (3) into eq. (1) yields the proposed stiffness degradation model as:

$$E_N = \left\{1 - \left[N \cdot C \cdot (n+1)\right]^{1/(n+1)} \cdot \left[\frac{\sigma_0 - a_0 - a_1 T - a_2 T^2}{\alpha \cdot (1-R) \cdot \left(N^{\beta} - 1\right)}\right]^{2n/(n+1)}\right\} \cdot E_0 \quad (4)$$

where C, n, α, β, a_0, a_1 and a_2 are the material parameters to be determined from experimental data.

Experimentation

Materials
The glass-reinforced fibre polymer type of composite materials in CSM form are tested for low cycle fatigue under elevated ranges of temperature. ASTM 3039/D 3039M-80 [4], ISO 527-4 [5] and ISO 2818 [6] are used for specimen preparation and experiments. The fabric was perturbed into the isophthalic polyester resin in chopped-strand mat (CSM) form. The test specimens were then cut to size from the large panels in accordance to type 2 in ISO 527-4 [5]. A series of samples (approximately 200) were manufactured to conduct low cyclic fatigue test involving mechanical and thermal loading.

Apparatus
Cyclic loadings were applied using the INSTRON Digital 8805 servo-hydraulic machine, a floor-mounted universal material testing machine. The specimens were pre-heated in the environmental chamber for 10 minutes at the required temperature prior to the static and dynamic tests. A non-contacting video extensometer was also installed to capture the axial and lateral strain values of the specimens during loading.

Procedures
Low cycle fatigue tests on the standard specimens were conducted at 500, 1500 and 2500 cycles. After the specimens were dynamically loaded, tensile tests were eventually made to evaluate the residual strength of the specimens. An environmental chamber was equipped to the tensile machine throughout the tests. Each specimen

was heated on the mechanical grip inside the environmental chamber to the desired temperature. The tests were conducted at three different temperatures such as 25ºC, 50ºC and 75ºC for predicting the behaviour of the specimens under elevated temperatures.

Validation Study and Discussion

Validation of the above model is carried out on the basis of the experimental results. Prior to the validation, analysis of the stiffness and strength degradation model is performed using Lin Ye model [1] and Caprino [2] model to define the parameters for the proposed model. A curve fitting program, named GraphPad Prism 5 [7], with a least squares fit method was used to obtain all the empirical parameters of the proposed model.

The empirical parameters extracted from the previously proposed model [1, 2] and the temperature model are tabulated in Table 1 and Table 2 respectively.

Table 1. Empirical Parameters at 25 ºC with 40% stress

Parameter	C	n	α	β	R
Value	9.57×10^{-13}	1.44	0.078	0.268	0.1097

Table 2. Parameters of temperature model at 40% stress

NOC	a_0	a_1	a_2
0	169.6	-0.5384	-0.00225
500	108.1	1.271	-0.01723
1500	109.4	1.195	-0.01675
2500	107.4	1.212	-0.01639

For the purpose of simplicity only parameters at 25ºC with 40% stress are shown and only results at 40% stress are graphically presented in Fig. 1.

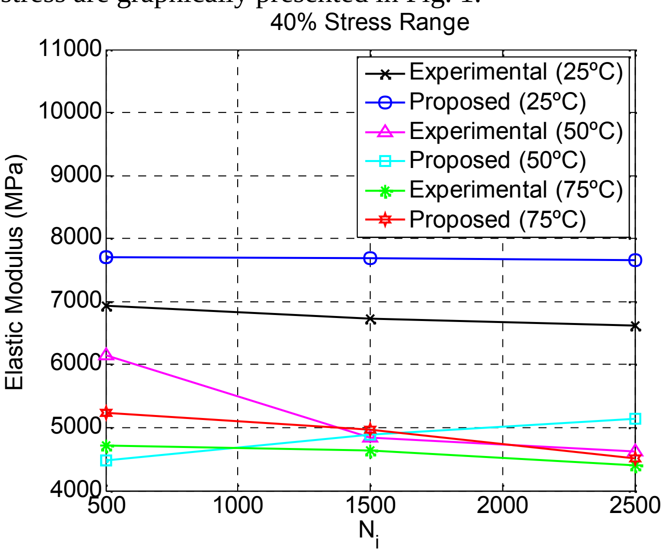

Fig. 1 The comparison of experimental and predicted elastic modulus at 40% stress

The strain-stress in this study showed non-linear trend and the results of both static and cyclic tests showed a wide scatter. It can also be observed that the experimentally obtained Young's modulus showed a huge leap at the beginning of cyclic loading between 0 and 500 and slight degradation thereafter up to 2500 cycles. This trend can be attributed to the fact that the liquid resins of thermosetting polymers are converted into hard brittle solids by chemical cross-linking resulted from thermal stress and external loads [8]. It is believed that stresses at very low cycles microscopically affected interfaces between glass fibres and resin matrix, so that a chemical bonding was reinforced and consequently stiffened the whole specimen.

The phenomenon of a drop in modulus and strength was more dramatic as the specimen was subjected to increasing thermal stress. Hence the observation of the phenomena leads to the conclusion that an increased thermal stress causing a drastic reduction in mechanical properties. The specimens are exceptionally sensitive to heat since the specimens of GRP in CSM form are matrix dominated composite laminates and its mechanical properties more dramatically reduce at 50°C and 75°C than under room temperature.

Conclusion

A fatigue life prediction model based on the residual stiffness degradation has been proposed and validated by conducting low cycle fatigue tests on a series of GRP in CSM form samples. Relatively close agreement of results using the prediction model with the experiments in a deviation range of 10% provides good validation study. The proposed model can be used easily for predicting the fatigue life of a structure which involves several parameters due to the mechanical and elevated temperature cases.

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