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A MODEL FOR DAMAGE PREDICTION IN POLIMER MATRIX COMPOSITES SUBJECTED TO BENDING FATIGUE LOADING

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The proposed model predicts the damage progress to fatigue failure in cyclic loaded woven composite materials. The relative stiffness is changing per cyclic loading at given stress or strain levels. The correlation between the stiffness degradation rate and the loading parameter is described by a power dependence. The model is validated by experiments performed on ARALDIT/glass tissue and POLIKON/flax tissue composites in fatigue tests; the fatigue damage is recorded by measuring the stiffness changes in the material under this cyclic loading.

Key words: Damage prediction, Fatigue loading, Woven composite materials.

1. INTRODUCTION

Fatigue loading of tissue composite materials develops damage, which causes the degradation of properties such as strength and stiffness. A great majority of structures and components, witch are at risk to fail from fatique failure, are subjected to stresses of variable amplitude and mean levels in service.

During the fatigue lifetime a global degradation or damage of the material appears as microcraks in the matrix material and interfacial craking between tissue and matrix. This failure will accumulate and locally stresses will approach the material strength leading to local fatal failures.

The degradation of the material can be monitored by measuring the change in stiffness. The knowledge of the rate of decrease of the stiffness will enable a forecast of the residual lifetime. In this paper it is shown that this rate depends only on the type of material and on the stress level in the material.

2. EXPERIMENTAL

For fibre reinforced polymer composites the overall S–N curve (load level S versus number of cycles N) can be divided in three regions (stages) (Fig.1).

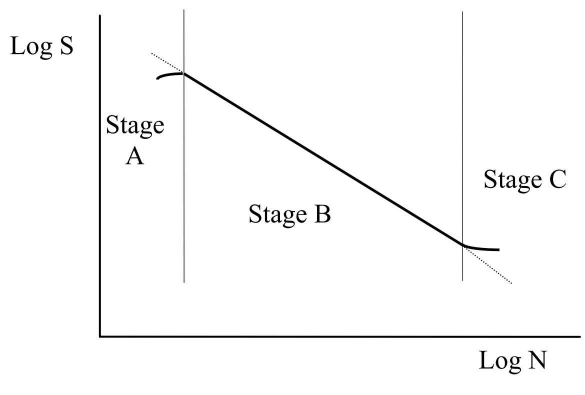

Fig. 1. Schematic S – N curve

Stage A approaches a nearly horiyontal line where the number af cycles to failure depends more on statistical strength distributionthan than on the stress level.

Stage B is a more classical fatigue behaviour where the S-N correlation can be described as a power low function.

Finally the stage C suggest a fatique limit where an infinite lifetime is found below a given stress or strain level – the fatique strength.

In previous publications it was shown how a fatigue lifetime model for fibre reinforced polymers can be derived based on the stiffness degradation [1].

This model was addopted for tissue reinforced polymers and is briefly described below.

The stage B of S–N curve can be empirically described by a power law model expressed as:

$$N_r \cdot T^p = k \tag{1}$$

where k and p are constants, N_r is the number of cycles to failure and T is the parameter which can be presented as a normalized stress, σ/E_0 , where E_0 is the initial stiffness for the material.

The stiffness degradation dE in the material is followed by measuring of the actual cycling stiffness during the fatigue lifetime.

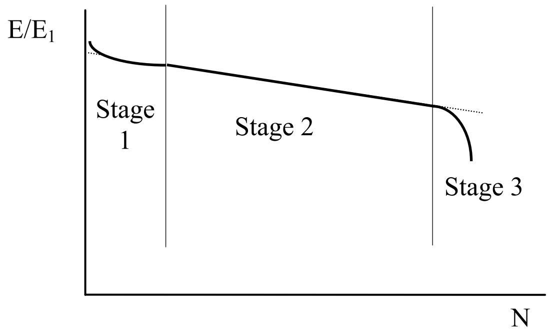

Fig. 2. Progress of stiffness degradation

The normalised stiffness E/E_1 (the stiffness after the first cycle) shows a progress with N, which can be divided into three stages as it is illustrated in Fig.2.

The slope of stage 2, the linear part of the curve is defined to be the stiffness decrease rate. The stage 2 behaviour can be written as:

$$\frac{d\left(\frac{E}{E_1}\right)}{dN} = a \tag{2}$$

where a is the rate of change in stiffness, which is only a function of the stress level .

It is now suggested that:

$$\frac{d\left(\frac{E}{E_1}\right)}{dN} = -m \cdot \left(\frac{\sigma}{E_0}\right)^n \tag{3}$$

Integration gives:

$$\frac{E}{E_1} = 1 - m \cdot \left(\frac{\sigma}{E_0}\right)^n \cdot N \tag{4}$$

From Eq. 4 it is seen that the actual decrease of stiffness depends on the maximum stress level and the number of cycles. The definition of fatigue life of the material can be based on a given decrease in stiffness.

This means that the number of cycles N_c, to a damage level is defined by a stiffness degradation criteria E/E_1 and can be calculated from an expression similar to Eq. 1.

$$N_c \cdot \left(\frac{\sigma}{E_0}\right)^2 = \frac{1 - \frac{E}{E_1}}{m} = k \tag{5}$$

Assuming that n = p, the constant k in the fatigue power law will depend on the charge in stiffness in the material.

Based on Eq. 5 also the stiffness degradation can be predicted at a given loading level for a prescribed number of cycles.

3. RESULTS

Materials. The materials evaluated in this study were: Material 1: ARALDIT – CIBA CY22/ E – 020 glass tissue composite; Material 2: POLIKON – P.210 FA/ flax tissue composite.

The measured tensile static in-plane properties in the longitudinal direction defined as the direction with the highest stiffness are reported in Table 1.

Table 1. Modulus and tensile strength

Sample	E_0[MPa]	σ_t[MPa]
Material 1	33268	425.4
Material 2	2227	131.42

Test specimen. The test specimen is shown in Figure 3, with dimensions given in Table 2.

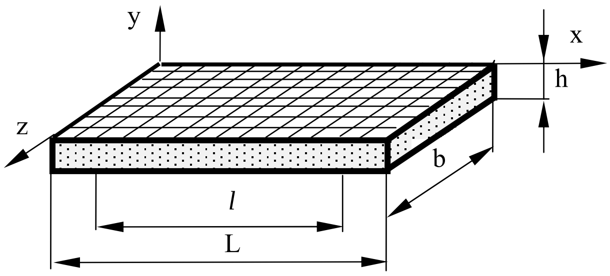

Fig. 3. Test specimen geometry

Table 2. The specimen dimensions

	b[mm]	L[mm]	h[mm]	*l* [mm]
Material 1	20	200	3.3	50
Material 2	18.5	200	3.0	50

Test conditions. All plane bending fatigue tests were performed by symmetrical alternating cycle at the frequency of 23 Hz and the applied maximum stress was 187 MPa ($0.4\sigma_t$) for the Material 1 and 26 MPa ($0.2\sigma_t$) for the Material 2. The tests were carried out using a new model of fatigue testing machine [2], which was designed, built and tested in the Materials Strength Laboratories. The actual cyclic stiffness was evaluated after each 1000 cycles.

4. DISCUSSION

Based on the measured stiffness changes during the tests the values of m, n and k constants were calculated and there are reported in Table 3.

Table 3. The values of m,n, k constants

Sample	m (cicluri)$^{-1}$		k (cicluri)$^{-1}$
Material 1	0.21		4.7
Material 2	0.029		2.07

From Eq. 3, the stiffness decrease rate is for Material 1(Eq. 6) and for Material 2 (Eq. 7):

$$\frac{d\left(\frac{E}{E_1}\right)}{dN} = -0.21 \cdot \left(\frac{\sigma}{E_0}\right)^2 \qquad (6)$$

$$\frac{d\left(\frac{E}{E_1}\right)}{dN} = -0.029 \cdot \left(\frac{\sigma}{E_0}\right)^2 \qquad (7)$$

This model shows good agreement with the experimentally values as illustrated in Fig.4 and 5.

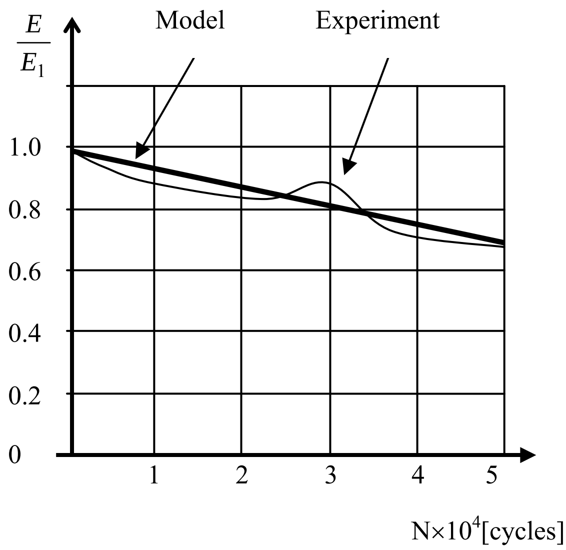

Fig.4. The stiffness decrease rate of ARALDIT/glass tissue

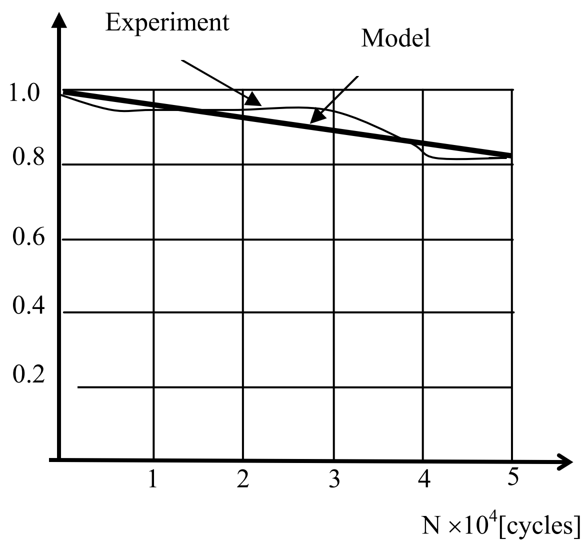

Fig. 5. The stiffness decrease rate of POLIKON/ flax tissue.

From Eq. 5, the number of cycles N_r to break level was calculated and it is reported in Table 4.

Table 4. The number of cycles to break.

Material	$N_{r.mod}$	$N_{r.exp}$	ε [%]
ARALDIT/glass tissue	150510	149587	0.6
POLIKON/flax tissue	66488	65543	1.4

5. CONCLUSIONS

The main aim of the paper was to develop a model, able to explain the damage progress to fatigue in cyclically loaded woven composite materials.

The experimental data show that fatigue lifetime curves can be estimated based on damage measured as stiffness degradation. The correlation between the stiffness degradation rate and the loading parameter follows a power law having the same value for the exponent as the classical empirical power law described the S-N curves.

It was shown how the derived relationship based on constant amplitude fatigue tests can be used for estimating lifetimes for the materials exposed to variable loading sequences.The generated curves may be used as fatigue design curves for components under fatigue loading.

The model has been applied to ARALDIT/ glass tissue and POLIKON/ flax tissue composites.

The results from the modeling studies are in agreement with the rate of stiffness decreasing, experimentally measured. An important loss of stiffness was observed for a low number of cycling loading. This fact can be explained by the accumulation of the matrix cracks.

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