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Microstructural model and identification of damage parameters

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OPTIMAT BLADES

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Change record

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draft		Na	na

1 Stiffness degradation model

Stiffness degradation in composite laminates is expressed by empirical expression given by (Philippidis, 2000, Andersen S.I., 1996)

$$\frac{E_N}{E_1} = 1 - K\left(\frac{\sigma_a}{E_0}\right)^c N, \tag{0.1}$$

where E_1 is measured stiffness in first cycle of fatigue test, E_0 is measured stiffness in static test, σ_a is applied stress level, and N is number of cycles at which the corresponding stiffness E_N is measured. The material constants, K and c are determined by curve fit using least squares method. In order to make the curve fit easy, (0.1) is rewritten in form

$$\frac{1-\frac{E_N}{E_1}}{N} = K\left(\frac{\sigma_a}{E_0}\right)^c. \tag{0.2}$$

It is easy to se that (0.2) will produce straight line of form $y = a + bx$ in log-log domain

$$\lg_{10}\left(\frac{1-\frac{E_N}{E_1}}{N}\right) = \lg_{10} K + c\lg_{10}\left(\frac{\sigma_a}{E_0}\right). \tag{0.3}$$

As the material constants are determined, they can be used back into (0.2) to calculate S-N fatigue diagram for any desired stiffness degradation level. In order to do (0.2) is rearranged in following form

$$\sigma_a = E_0\left(\frac{1-\frac{E_N}{E_1}}{KN}\right)^{\frac{1}{c}}, \tag{0.4}$$

or in form of $S = K^* N^{-1/c}$

$$\sigma_a = E_0\left(\frac{1-\frac{E_N}{E_1}}{K}\right)^{\frac{1}{c}} N^{-\frac{1}{c}}, \tag{0.5}$$

where

$$K^* = E_0 \left(\frac{1 - \frac{E_N}{E_1}}{K} \right)^{\frac{1}{c}} . \tag{0.6}$$

2 Experimental considerations on stiffness measurements

2.1 Static tests

An example of step-vise loading unloading curve for glass-fiber epoxy laminate is given in Figure 1. The initial Young's modulus (undamaged) is measured at applied strain within range $0.05\% \le \varepsilon_x \le 0.25\%$, also standard loading rate

$$\frac{\Delta L_2}{\partial t} = 1\left(\frac{mm}{\min}\right), \tag{0.7}$$

given for grip distance $L_2 = 150mm$ must be used. In case different geometries are used for the specimens and consequently the grip distance is changed, the loading rate must be recalculated accordingly so that the strain rate remains the same as given by standard.

$$\frac{\partial \varepsilon}{\partial t} = \frac{1}{L_2}\frac{\Delta L_2}{\partial t} = \frac{1}{150}1 = 0.0066\left(\min^{-1}\right). \tag{0.8}$$

Consequently any loading rate, $\frac{\Delta L_2}{\partial t}$ can be calculated for any used grip distance L_2 and calculated standard strain rate, $\frac{\partial \varepsilon}{\partial t}$ as

$$\frac{\Delta L_2}{\partial t} = \frac{\partial \varepsilon}{\partial t} L_2 . \tag{0.9}$$

At least two loading cycles would be necessary within this range of applied strain to measure initial Young's modulus. It is expected that loading and unloading parts of the strain-stress curve will lay close to each other, that allows to assume that there is no damage produced and influence of viscoelasticity is negligible small. Further the step-vise loading-unloading is carried out until the final failure of the specimen. The loading-unloading steps are to be considered in a way that there are 5-7 steps where the final step (step that leads to final failure) and the step where the initial modulus is measured are not included. As the data are going to be approximated with polynomial, it is not necessary that all test are carried out using the same steps. It would be even better for the objectivity of measurements that different steps are used. Only that 5-7 points would be needed in order to make reasonable nonlinear approximation.

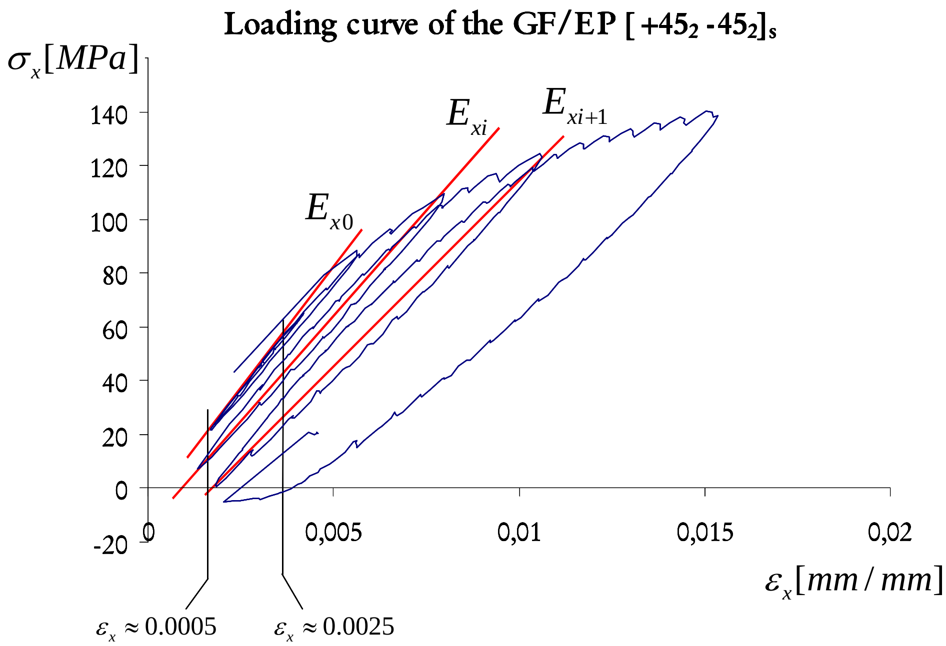

Figure 1.

Damage-wise it is expected that the unloading part of the curves would be straight line since there are no additional damage produced during unloading. However, we could expect a viscoelastic behavior that could forma a hysteresis loops. The easy way to deal with this problem would be to take the whole loop for measuring modulus for each loading-unloading cycle, as it is illustrated in Figure 1. It could be done the same way for measuring modulus for each loading cycle in fatigue test, so that both tests methods are consistent with each other.

If different UD laminates are used, modulus id different directions should be measured, E_1, E_2, and $E_1(\varepsilon_1)$, $E_2(\varepsilon_2)$.

If the appropriate laminate is used, the shear modulus, G_{12}, and $G_{12}(\gamma_{12})$ should be measured in the same manner. The example of step-vise loading-unloading strain-stress curve for glass-fiber epoxy laminate with lay-up [+/-45n]s is given in Figure 2.

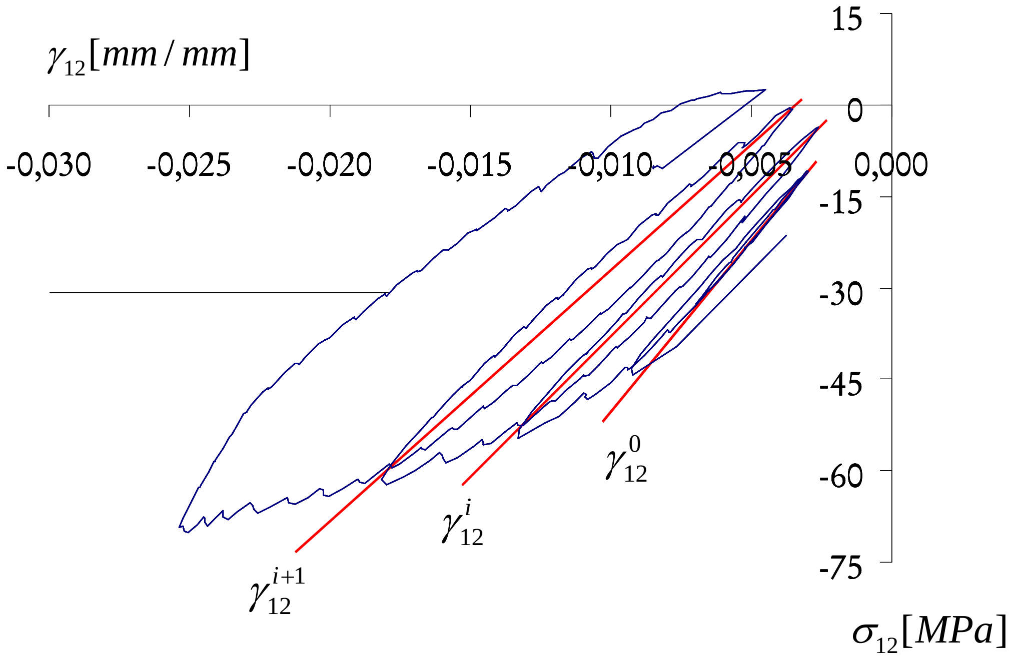

Figure 2.

The same procedures can be used for both, tensile and compression tests.

2.2 Fatigue tests

The fatigue tests is somewhat similar to static loading-unloading tests discussed before, with a difference that there are lot more cycles going to be, and the hysteresis loop is expected not to be so pronounced as for static tests. The schematic illustration of what could be expected is shown in Figure 3.

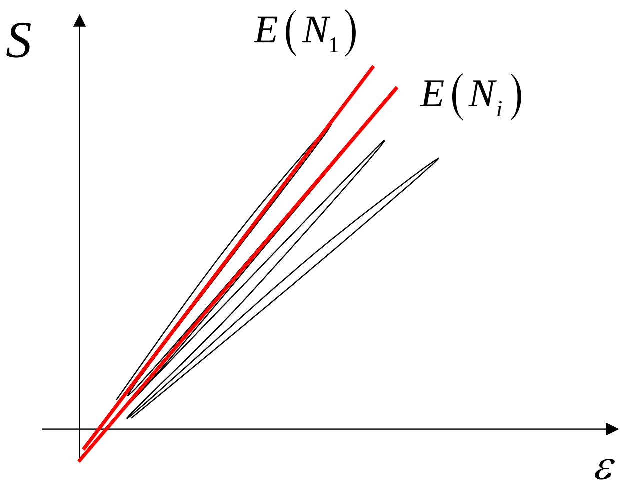

Figure 3.

In order to measure stiffness degradation as function of number of cycles, strain-stress curves must be recorded during the fatigue test. In order to minimize amount of data and do a reasonable approximation, 5 to 7 cycles, evenly spread out over the whole lifetime, would be needed to record and analyze. Each cycle is treated the same way as it is already shown in case of static tests, namely both, loading and unloading parts of data for each loop are used to measure stiffness for corresponding number of cycles. That way we make stiffness measurements in fatigue tests consistent with measurements of stiffness in static tests, and the results can be compared.