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Fatigue strength evaluation for CFRP Based on thermoelastic stress analysis

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Abstract

Carbon fiber reinforced plastic (CFRP) are receiving attentions because of their excellent moldability and productivity, however they show complicated behaviors in fatigue fracture due to the random fibers orientation. In this study, thermoelastic stress analysis (TSA) using an infrared thermography was applied to the evaluation of fatigue damage in short carbon fiber composites. As a result of measuring the temperature waveform with respect to the loading frequency, the temperature waveform at the maximum stress showed nonlinear behavior. It has been shown that fatigue damage and waveform non-linearity are related, so it can be applied to damage detection of CFRP.

1. Introduction

Nondestructive evaluation (NDE) techniques based on thermoelastic stress analysis (TSA) [1, 2] using infrared thermography has been effectively employed for the detection of delamination defects in fiber reinforced plastics. In this study, the authors focused on the nonlinearity of thermoelastic temperature change to detect the progress of fatigue damage in short carbon fiber composites. The load frequency and thermoelastic temperature fluctuation at several different stages of stress during the step test were observed, and the relationship with damage was discussed.

2. TSA of thermoelastic temperature change using infrared thermography

Dynamic stress change cause a very small temperature change under adiabatic conditions in a solid. This phenomenon is known as the thermoelastic effect and is described by Lord Kelvin's equation.

$$\Delta \boldsymbol{T_E} = -\frac{\alpha}{\rho C_p}\boldsymbol{T}\Delta\boldsymbol{\sigma} = -\boldsymbol{kT}\Delta\boldsymbol{\sigma} \quad (1)$$

Here, α is the coefficient of thermal expansion, ρ is the mass density, C_p is the specific heat at constant pressure and T is the absolute temperature. The coefficient k is called thermoelastic constant. The sum of the changes in the principal stresses ($\Delta\sigma$) is obtained by measuring the temperature change (ΔT_E) using infrared thermography.

3. Experimental study

3.1 Specimen and experimental setup

Configurations of the CFRP specimen employed in this study are shown in Fig. 1. The mass content (wt %) of resin and fiber was 67 and 33, respectively. Cyclic-axis sinusoidal waveform loading with a frequency f of 7 Hz and a stress ratio R = 0.1 was applied to the specimen by an electrohydraulic fatigue testing machine. Microscopic visible images on the specimen surface and side surface were taken by optical microscope. The temperature change on the specimen surface was measured by infrared thermography with an MCT array detector (FLIR Systems Inc., SC7500).

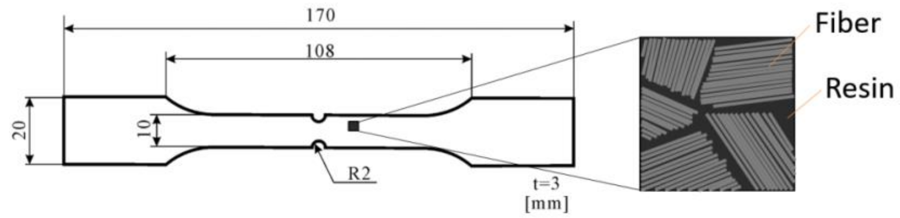


Fig. 1: *Configurations of employed CFRP specimen.*

3.2 Experimental results and discussion

Tests were conducted to increase and decrease stress stepwise in a room temperature atmosphere on short fiber CFRP specimens. The relationship between the number of cycles and stress is shown in Fig.2. The relationship between the number of cycles and the temperature waveform at four points (a) to (d) in Fig. 2 is shown in Fig. 3. From Fig. 3, no disturbance is seen in the waveform at Ntotal = 10,200 cycles (Fig. 3 (a)), but at the maximum tensile load at Ntotal =

12,200 cycles, the waveform is disturbed and nonlinear behavior is observed (Fig. 3 (b)). It can be seen that, as the maximum stress is reduced, this non-linear behavior disappears (Fig. 3 (c)), but when the maximum stress is increased again, the waveform has been disturbed before it reaches σ_{max} *=140MPa* (Fig. 3 (d)).

When stress is applied to a general solid material containing a resin, the temperature fluctuation appears as the opposite phase, but in the case of carbon fiber, it becomes the same phase. Therefore, in the case of compounding, the obtained temperature waveform tends to be different depending on which temperature fluctuation becomes dominant. As a result of the damage, the resin cannot withstand the applied stress at the maximum tension and cannot follow, and it is considered that the waveform is disturbed by the temperature variation of the fiber being dominant only at the maximum tension. From the above results, it is considered that the relationship between fatigue damage and non-linearity of waveform is found, so that it can be applied to damage detection of short fiber CFRP.

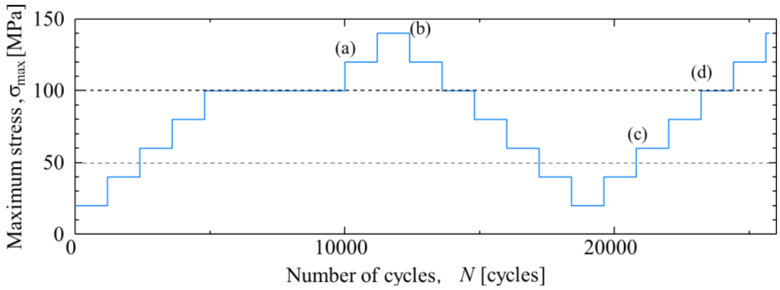
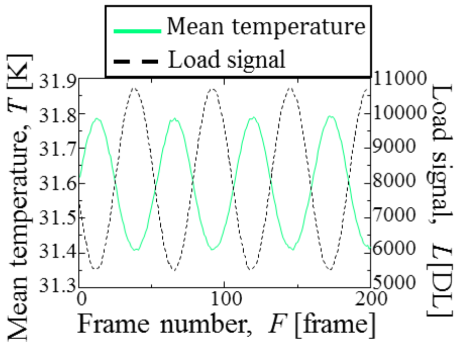
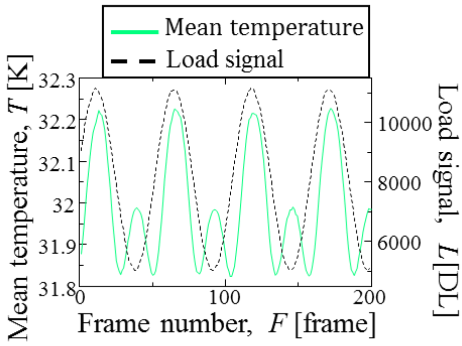


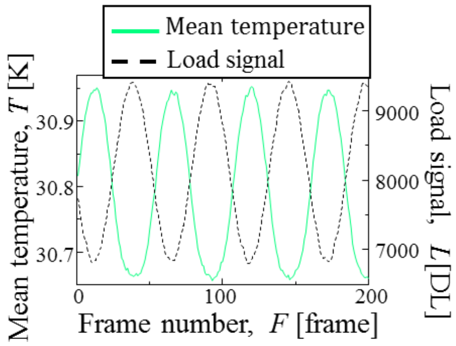
Fig. 2: *Schematic illustration of stair-like stress level test.*



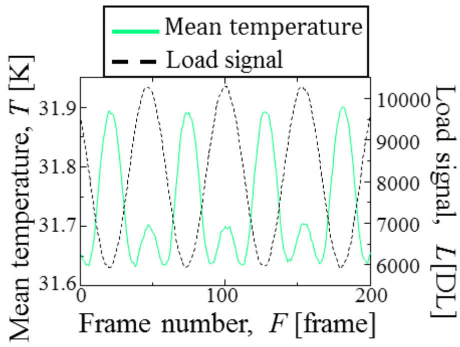
(a) σ_{max} *=120MPa*
N_{total} *=10,200cycle*



(b) σ_{max} *=140MPa*
N_{total} *=12,220cycle*



(c) σ_{max} *=60MPa*
N_{total} *=21,000cycle*



(d) σ_{max} *=100MPa*
N_{total} *=23,400cycle*

Fig. 3: *Change in mean temperature and load signal.*

References

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[2] Dulieu-Barton, J.M., "Introduction to thermoelastic stress analysis," Strain, 35, pp. 35–39, 1999.