Temperature rise during fatigue of fibre-reinforced ceramics

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The present work reports on the observation of internal heat generation during fatigue of fibre-reinforced ceramics. Results are presented for a C-fibre/SiC-matrix composite formed by chemical vapour infiltration of 0°/90° fibre cloths (fibre content of the composite: ~40 to 45 vol %). The specimen geometry used in the investigation is given in Fig. 1a. Fatigue testing was conducted under tension–tension loading (the load was varied in a sinusoidal fashion). Platinum-10% rhodium thermocouples were used to measure the temperature rise of the specimen during fatigue. The thermocouple junction was disc-shaped (0.3 mm thick × 1.0 mm radius) to increase the surface contact area and improve response time. Thermocouples were bonded to the specimen (see Fig. 1b) using a cyanoacrylate adhesive (tests using identically prepared thermocouples applied to an aluminium specimen showed no inherent heating of the adhesive during fatigue at frequencies from 1 to 85 Hz). The temperature of the specimen grips was maintained at 295 ± 0.5 K by water cooling. In the vicinity of the test setup, the temperature was 296 ± 1 K. A data acquisition system with an isothermal reference junction was used to continuously store thermocouple data.

Three different experiments were conducted to determine the effect of frequency and maximum fatigue stress on frictional heating. These were: (i) variable frequency, constant stress; (ii) constant frequency, variable stress; and (iii) effect of long term fatigue on specimen temperature.

In the first series of experiments (variable frequency, constant stress), fatigue testing was conducted at sinusoidal frequencies of 1, 10, 25, 50, 75 and 85 Hz (where 85 Hz was the maximum frequency which could be reliably attained on the test system). The stress limits were held constant for all frequencies (σ_{max} = 250 and σ_{min} = 10 MPa). The specimen was fatigued for 10 min at each frequency, after which the load was reduced to zero and the specimen allowed to cool to its initial temperature (295 K) prior to reloading at a higher frequency.

The results of these experiments (Fig. 2) show that significant internal heat generation occurs during fatigue of fibre-reinforced ceramics. At a frequency of 85 Hz the temperature rise measured at the specimen surface approached 32 K (for all frequencies, a steady state temperature rise was typically obtained after 3 to 5 min of testing). The initial test data indicate that an approximately linear relationship exists between steady-state temperature rise and frequency: ΔT (K) ≈ 0.37 × freq. (Hz). Additional testing is required to determine if the linear relationship continues to hold at even higher test frequencies. The

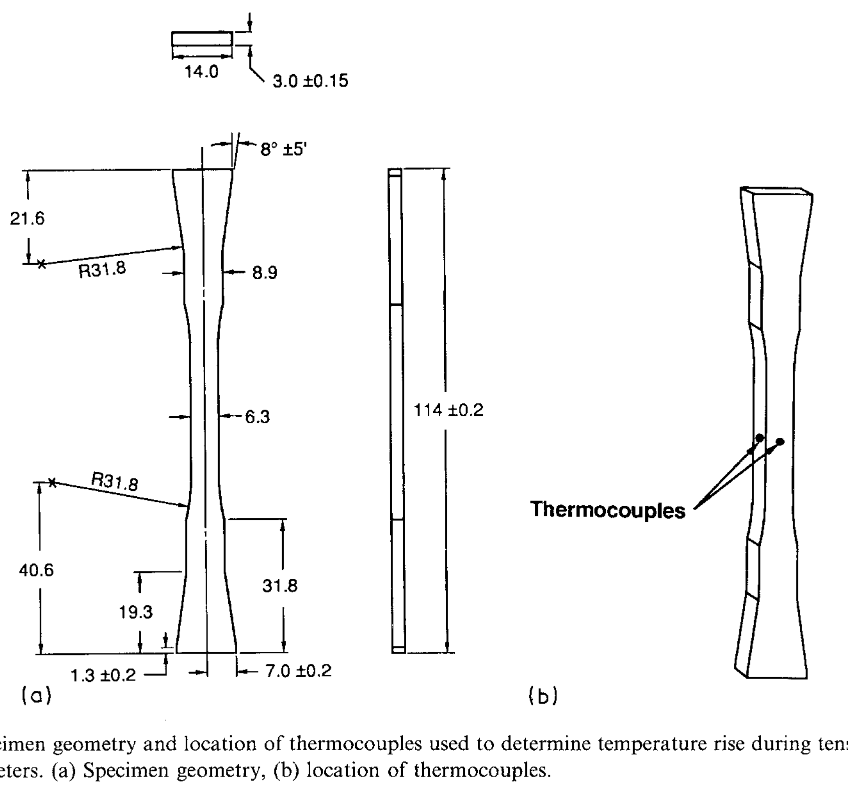

Figure 1 Specimen geometry and location of thermocouples used to determine temperature rise during tensile fatigue loading. Dimensions are in millimeters. (a) Specimen geometry, (b) location of thermocouples.

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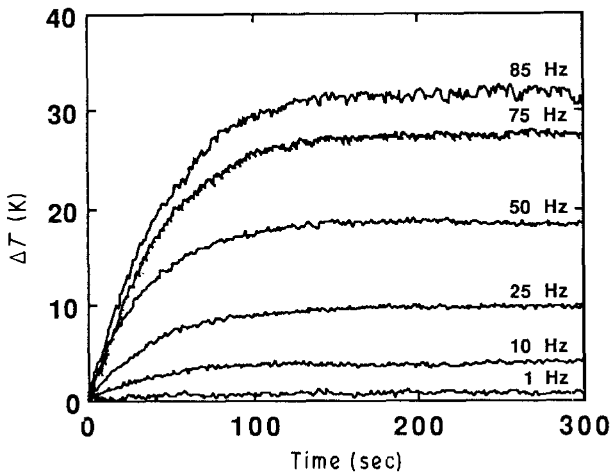

Figure 2 Influence of test frequency on temperature rise. Initial temperature of the composite: 295 K, σ_{max}: 250 MPa, σ_{min}: 10 MPa.

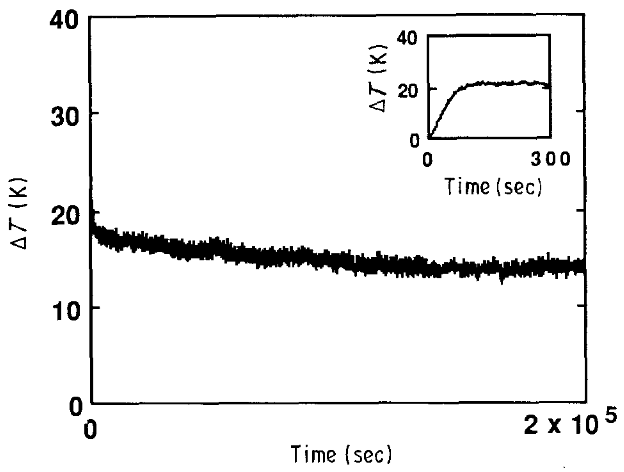

Figure 4 Effect of long duration fatigue cycling on temperature rise. Testing was discontinued at 2×10^5 sec (10^7 fatigue cycles). Initial temperature of composite: 295 K, frequency: 50 Hz, σ_{max}: 250 MPa, σ_{min}: 10 MPa.

temperature rise observed during fatigue is thought to be the result of internal heat generation produced by frictional sliding along fibre–fibre and fibre–matrix interfaces. Frictional sliding has been proposed [1–3] as a possible mechanism for the hysteresis in stress-strain response observed during cyclic loading of fibre-reinforced ceramics [4–6]; the heat generation observed in the present investigation offers further support for this mechanism. It should be noted that a temperature rise is also found during fatigue of fibre-reinforced plastics [7]. However, the predominant mechanism responsible for heating in fibre-reinforced plastics is internal damping, rather than frictional sliding along internal interfaces.

In the second series of experiments (constant frequency, variable stress) the frequency was maintained at 75 Hz and the maximum fatigue stress increased from 50 to 250 MPa in 50 MPa increments (for all stress levels, the minimum fatigue stress was held at 10 MPa). At each stress level, the fatigue load was maintained for 10 min after which the load was reduced to zero and the specimen allowed to cool back to its initial temperature before reloading at a higher stress level. The goal of this series of experiments was to determine if an increase in stress amplitude (and hence, strain amplitude) would result in additional heat generation within the composite. As shown in Fig. 3, the temperature of the composite increased dramatically as the peak fatigue stress was increased (from approximately 0.8 K at 50 MPa to 28 K at 250 MPa).

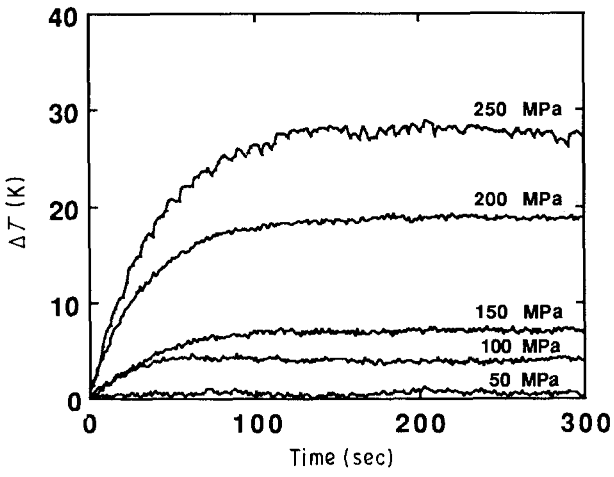

Figure 3 Influence of maximum fatigue stress on temperature rise. Minimum stress of all tests: 10 MPa. Initial temperature of composite: 295 K, frequency: 75 Hz.

In the third experiment (effect of long term fatigue loading on specimen temperature) both the frequency and fatigue stress limits were held constant (frequency = 50 Hz, σ_{max} = 250 and σ_{min} = 10 MPa). Specimens were fatigued for 10^7 cycles to determine if heat generation within the composite would decrease with continued cycling. After an initial temperature rise of 18 to 22 K (based upon three test results), the temperature rise slowly decreased to 14 to 16 K after 10^7 cycles (see Fig. 4). The decrease in specimen temperature with continued cycling may be due to a decrease in frictional heat generation caused by progressive wear along fibre–fibre and fibre–matrix interfaces. Further work is currently being conducted to determine if a decrease in specimen temperature can be used as a measure of damage accumulation during fatigue loading of fibre-reinforced ceramics.

References

1. E. MINFORD and K. M. PREWO, in "Tailoring Multiphase and Composite Ceramics" (Plenum, New York, 1986) p. 561.
2. K. M. PREWO, *J. Mater. Sci.* **22** (1987) 2695.
3. J. W. HOLMES, T. KOTIL and W. FOULDS, in "Symposium on High Temperature Composites, American Society for Composites" (Technomic Publishing, Lancaster PA, 1989) p. 176.
4. D. B. MARSHALL and A. G. EVANS, *J. Amer. Ceram. Soc.* **68** (1985) 225.
5. D. B. MARSHALL and W. C. OLIVER, *ibid.* **70** (1987) 542.
6. T. KOTIL, J. W. HOLMES and M. COMNINOU, *ibid.*, submitted.
7. J. W. DALLY and L. J. BROUTMAN, *J. Composite Mater.* **1** (1967) 424.

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