Effect of thermal-mechanical cycling on damping capacity of B/Al composite

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B/Al composites possess high strength and stiffness with a low density, having an application as high performance structural materials in aircraft and spacecraft components [1, 2]. In many cases, the components in such applications are subjected to externally applied loads under conditions of varying temperature. The property degradation caused by "thermal-mechanical cycling (TMC)" can sometimes limit the service reliability of the composites [3–5]. Furthermore, fiber-reinforced metal matrix composites (FMMCs) exhibit a lower damping capacity compared with other metal matrix composites, hence limiting their applications and performance in dynamic structures. The damping capacity of FMMCs is closely associated with the interfacial internal-friction [6]. The interface slip contributes strongly to the damping capacity. The weaker the interface bonding, the higher the damping capacity, including the logarithmic decrement δ and the inverse quality factor Q^{-1} . The damping capacity of the B/Al composites could be optimized by tailoring the interfacial strength, while maintaining the high-modulus and high-strength property of the composites.

The material used in this study was an aluminum alloy 5A06 (AA5A06) matrix composite unidirectionally reinforced by boron fibers with a diameter of 140 μm, which was fabricated by the vacuum hot-isostatic press/diffusion bonding technique. A stack of 9 foil-fiber plies with an average of 56 fibers/cm for each ply was pressed to 1.4 mm thick B/Al sheet. The nominal fiber volume fraction was 50 vol%.

The size of the specimens for the TMC tests was $125 \times 10 \times 1.4$ mm^3. The longitudinal direction of the specimens was parallel to the fiber direction. After polishing and cleaning, the specimens were mounted on a pure copper clamp plate, one end of which was fixed to the rigid frame and the opposite end was loaded with an external stress of 110 MPa. The applied stress was parallel to the longitudinal direction of the specimens. The TMC with 2000 cycles was carried out in temperature intervals from 20 to 270 °C with the heating rate of 1.25 °C/s and the cooling rate of 2.5 °C/s. The hold-time at both the lower and upper temperatures was 60 s.

Specimens for the damping and the modulus measurements were taken after every 500 TMC cycles. The damping measurements were carried out using a cantilever beam configuration under free vibration at a frequency of 1 kHz and were characterized by the logarithmic decrement δ and the inverse quality factor Q^{-1}. The logarithmic decrement δ is given by [7]

$$\delta = \frac{1}{n} \ln \left(\frac{A_{\mathrm{i}}}{A_{\mathrm{i+n}}} \right) \tag{1}$$

where A_{i} and $A_{\mathrm{i+n}}$ are the amplitudes of the ith cycle and $(i + n)$th cycle, at times t_1 and t_2, respectively, separated by n periods of oscillation, as shown in Fig. 1. The inverse quality factor Q^{-1} is given by [8]

$$Q^{-1} = \frac{F_2 - F_1}{F_{\mathrm{n}}} \tag{2}$$

where F_1 and F_2 refer to half-power bandwidth frequencies and F_{n} the resonant frequency in the spectrum of square amplitude vs. frequency, as shown in Fig. 2. The resonant frequency f_1 can also be measured. As a cantilever beam, the gauge length of a specimen was always the same for every measurement. After the damping measurements, the longitudinal Young's modulus of the specimens were accurately examined using an Instron machine with the crosshead speed of 0.1 mm/min and the limited maximum loads of 110 MPa.

Figs 3 and 4 show that the logarithmic decrement δ and the inverse quality factor Q^{-1} increase with the TMC cycles, respectively. It seems that the damping capacity increases more strongly at lower TMC cycles.

To study the effect of the degradation in the interfacial strength during TMC on the damping capacity of the composites, the Young's modulus of the composites was measured after different TMC cycles, as shown in Fig. 5. It can be found that the Young's modulus decreases with the TMC cycles. The striking feature of Fig. 5 is that the value of the Young's modulus decreases more steeply in the early TMC cycles. Because the Young's modulus of the composites is mainly determined by the load-transfer from the matrix to fibers, only the degradation of the interfacial strength can decrease the Young's modulus of the composites. Therefore, the decrease of the Young's modulus of the composites suggests that the interfaces are degraded during the TMC test.

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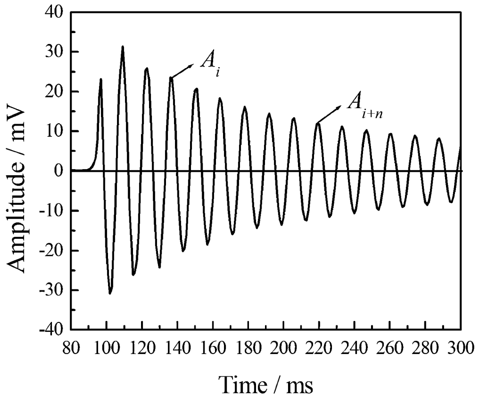

Figure 1 Typical amplitude decay of B/Al composite under free vibration.

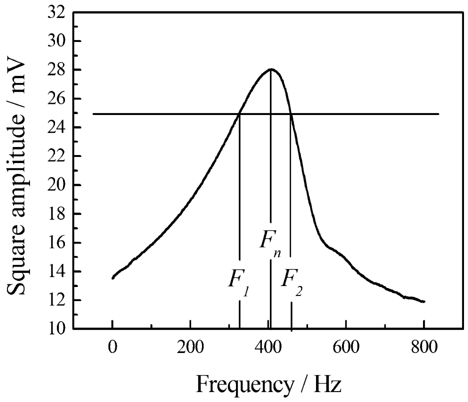

Figure 2 Square amplitude as a function of frequency.

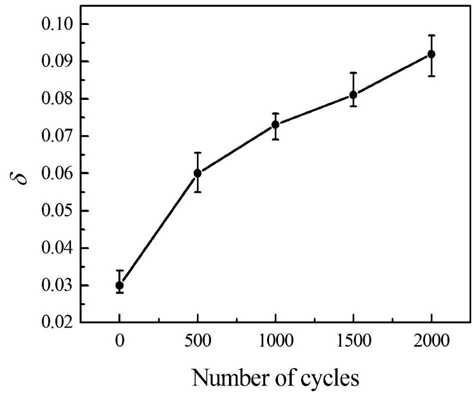

Figure 3 The effect of TMC cycles on the logarithmic decrement δ of B/Al composites.

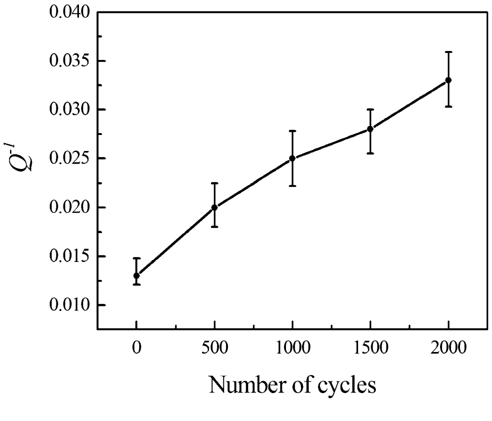

Figure 4 The effect of TMC cycles on the inverse quality factor Q^{-1} of B/Al composites.

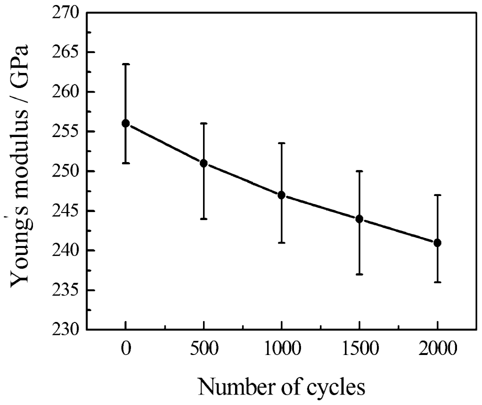

Figure 5 The effect of TMC cycles on the Young's modulus E of B/Al composites.

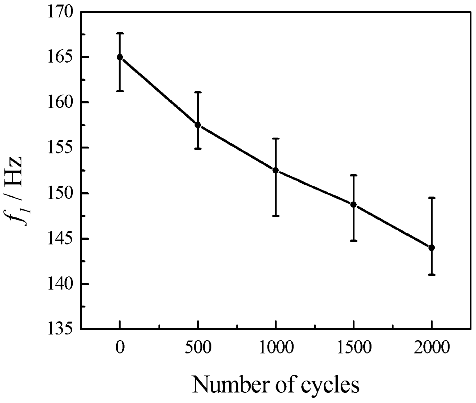

Figure 6 The effect of TMC cycles on the resonant frequency f_1 of B/Al composites.

The change of the resonant frequency f_1 during TMC is shown in Fig. 6. It can be seen that the resonant frequency f_1 decreases with the TMC cycles. As it is well known, the resonant frequency f_1 is directly proportional to the square root of Young's modulus. Therefore, the decreasing of the resonant frequency f_1 further suggests that the Young's modulus decreases, indicating that the degradation of the interfacial strength occurs during the TMC test.

It is thought that the effect of TMC on the damping behavior of B/Al composites is primarily attributed to the dislocation and the interface damping. During thermal cycling, thermal mismatch stresses could be induced due to the great difference of the coefficients of thermal expansion between the matrix and the fibers and may be sufficient to produce dislocations in the composite materials. Consequently, the dislocations generated during TMC become a possible source for the high internal friction to increase the damping capacity of the composites. However, there is little relationship between the decreasing of the Young's modulus and the dislocation damping of the composites.

Being surface defects, interfaces may significantly affect the damping behavior of FMMCs [9]. In the B/Al composites, there are generally well-bonded interfaces between the unidirectional boron fibers and the AA5A06 matrix, in addition to some weakly-bonded interface [10]. At temperatures above 100 °C, the internal friction at the well-bonded interfaces likely occurs and becomes a source for interface damping [6]. Another primary source for interface damping is the interfacial slip that occurs at the local weakly bonded interfaces. With increasing TMC cycles, the interfacial bonding of B/Al composites may become weaker, which would contribute to the internal friction and the interfacial slip that results in the increase of the damping capacity.

According to the above study, the main conclusions are given as follows. With increasing TMC cycles, the Young's modulus decreases gradually, which corresponds to the interfacial degradation in the B/Al composite. The increase in damping capacity with the TMC cycles is primarily associated with the degradation of the interfacial strength, particularly with the interfacial slip occurring at the local weakly bonded interfaces. Therefore, TMC can be a probe to determine the interface degradation in FMMCs.

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