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Mechanical properties of TiNi fiber impregnated CFRP composites

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Abstract

TiNi fiber impregnated CFRP composites have been fabricated by hot-pressing at a temperature of 180 °C. The host material (CFRP) layers were stacked with the carbon fibers at angles of 0°, 30°, 60° or 90° relative to the tensile direction. The tensile strengths and Young's moduli of the composites are found to depend strongly on the stacking angle of the carbon fibers. Their values decrease as the stacking angle increases from 30° to 90°. Pores and/or voids are found to congregate near the embedded TiNi fibers and their amounts increase proportionally with the stacking angle of the carbon fibers. The effect of strengthening by stacking angle of carbon fibers was studied by an AE technique during tensile testing.

Keywords: TiNi; CFRP; Tensile strength; Young's modulus; Mechanical properties; Acoustic emission

1. Introduction

Shape memory alloys (SMAs) are one of the best types of functional material to add to composites because they exhibit multiple types of useful behavior, including actuation, superelastic response and self-recovery. In particular, TiNi SMAs have received a great deal of attention because of their large shape memory effect, high damping capacity and high stiffness in the austenite state. Various kinds of composites with new functional properties have been prepared by incorporating SMAs of various shape, such as fibers, ribbons, particles and thin films [1,2].

TiNi fiber impregnated composites show good damping and actuation behavior because of the shape recovery that takes place at and above the austenitic–martensitic transformation temperature of TiNi [3–6]. For the development of TiNi fibers impregnated composites with good actuation behavior, the fundamental evaluation of the mechanical properties of their composites is very important. Furthermore, AE (acoustic emission) technique can provide useful information to investigate the fracture behavior of structural materials, such as fiber reinforced composites, ceramics, composite and concrete structures [7–12]. The AE signals for fiber reinforced composites are generated by microfracture events such as fiber breakage, debonding, and matrix cracking under tensile loading.

However, very little research has been done regarding processing effects, such as stacking angle of carbon fibers on mechanical properties of TiNi fibers impregnated CFRP (carbon fiber reinforced plastics) composites.

Not surprisingly, few investigations into the strengthening properties of these composites using the AE technique have been reported.

To clarify these problems, the present work describes that the effect of stacking angle of carbon fibers on mechanical properties for TiNi fibers impregnated composites.

The strengthening and fracture properties have also been investigated due to AE analysis using tensile specimens attaching AE sensor.

2. Experimental procedure

2.1. Fabrication of tensile specimens

CFRP prepregs (Hexcel Co.) of 0.2 mm in thickness were used as the matrix material. Each CFRP prepreg was cut to a size of 200 × 105 mm^2. TiNi fibers (Daido Steel Co.) of 0.4 mm in diameter were used. Each TiNi/CFRP composite was prepared by sandwiching the TiNi fibers between layers of CFRP prepregs. The prepregs were stacked with carbon fibers

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aligned at angles of either 0°, 30°, 60° or 90° relative to the direction of tensile testing in order to establish the optimal design of TiNi/CFRP composites.

During the lamination procedure, the TiNi fibers were carefully embedded at 1 mm intervals at the center of 8 sheets of CFRP parallel (i.e., at 0°) to the tensile direction using a special steel jig. Anti-heat vinyl sheets were used to prevent the flow of epoxy resin from the CFRP prepregs during heating. Stacked layers of the CFRP prepregs and TiNi fibers were laid up in the steel mold. The TiNi/CFRP composites were formed by curing in a hot press. Curing was accomplished at 180 °C for 2 h at a pressure of 0.3 MPa. These hot-pressed TiNi/CFRP composites were then cut with a diamond blade and prepared as notched tensile test specimens of 200 mm (length) × 12 mm (width) × 1.2 mm (thickness).

2.2. Tensile testing

Tensile testing was performed in conjunction with the AE technique to investigate the mechanical properties of TiNi/CFRP composites. One channel monitoring system consisting of an AE analyzer (DCM140, JTT) and one AE (piezoelectric) sensor (Fuji Ceramics, M304A) were used in the manner illustrated in Fig. 1. One AE sensor was attached at center of specimens. A threshold of 50 μV and a dead time of 1 ms were selected. Strains in each specimen were measured using an extensometer. Tensile tests were performed using a tensile test machine (Shimadzu Co. model AG-IS) with a constant crosshead speed of 0.1 mm/min.

The AE signals generated during tensile testing were detected with an AE sensor and recorded in digital wave form. This was then analyzed by a computer to obtain the cumulative AE events. The microstructural properties of the TiNi/CFRP composites were investigated by SEM observation.

3. Results and discussion

3.1. Microstructure

Fig. 2 shows an SEM micrograph of polished surfaces of hot-pressed TiNi/CFRP composites for different carbon fiber stacking

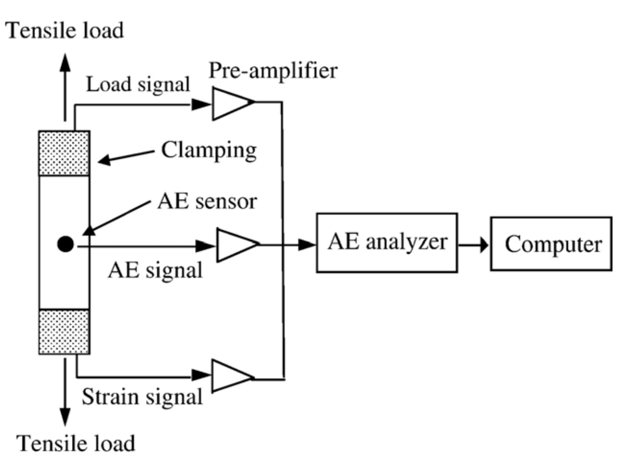

Fig. 1. Schematic drawing of setup for tensile testing of tensile specimens using AE sensor.

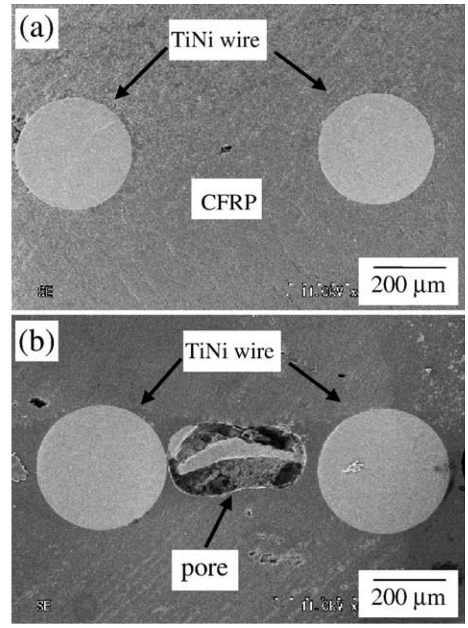

Fig. 2. SEM micrographs of TiNi/CFRP composites with different carbon fiber stacking angles: (a) 0° stacking angle and (b) 30° stacking angle.

angles. The large bright circles visible in the materials are embedded TiNi fibers and the surrounding material is the CFRP matrix. Few pores and/or voids are visible in composites with the carbon fibers arranged at 0° to the tensile direction, whereas large voids exist around TiNi fibers in composites with carbon fibers stacked at 30° to the tensile direction. Combining the data from all cross-sections, the average void size for the 0° stacked specimen was found to be less than 10 μm, whereas that for the 30° specimen was found to be up to 400 μm.

For 60° and 90° stacked specimens, larger voids exist at the interfaces between TiNi fibers and the matrix. One possible explanation for this is that the mass transport of epoxy resin in composites with higher stacking angles may be inhomogeneous during curing, resulting in larger residual defects. These results indicate that a more uniform microstructure is obtained for composites with all fibers stacked at 0° to the tensile direction.

3.2. Tensile strength and Young's modulus

Stress–strain (S–S) curves obtained during tensile testing of specimens are plotted in Fig. 3. All stress–strain curves were linear

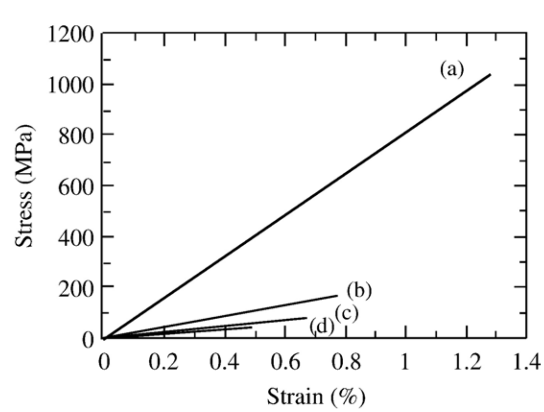

Fig. 3. Stress–strain curves from tensile tests of TiNi/CFRP composites with different carbon fiber stacking angles: (a) 0°, (b) 30°, (c) 60° and (d) 90°.