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Adhesive strength between TiNi fibers embedded in CFRP composites

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Abstract

The effect of treating the surface of TiNi fiber by acid etching on the interfacial adhesive strength between the TiNi fiber and the CFRP matrix is investigated. For acid etching of the TiNi fiber, acid solutions of 36% HCl, 15% HNO_3, 97% H_2SO_4, and 3% HF+15% HNO_3 were used. The composites were fabricated by curing at 180 °C for 2 h using hot-pressing. The interfacial adhesive strength between the embedded TiNi fiber and the CFRP matrix was evaluated by a pullout test. It was found that surface treatment of the TiNi fiber by acid etching improved interfacial adhesive strength.

Keywords: TiNi; CFRP; Acid etching; Pullout test; Adhesive strength

1. Introduction

Much work has been done to develop composites by incorporating various functional materials such as shape memory alloy (SMA) into structural materials [1–3].

In particular, SMA exhibits various properties, such as martensite phase transformation, superelastic response, and shape memory effect. Therefore, various kinds of polymer matrix composites with new functional properties such as actuation, damping, and damage recovery have been studied by the combination of SMA material and polymer matrix [4–6]. These composites typically use a carbon fiber-reinforced polymer (CFRP) as the matrix because of its high tensile strength and a TiNi SMA wire as the actuator because of its good actuation behavior resulting from the large compressive forces that occur during the austenitic–martensitic transformation.

For useful application, most SMA actuator composites require the strain to be transferred from the SMA to the matrix. To obtain good actuation behavior in these applications [7–9], strong adhesion between TiNi and the CFRP is therefore very important. However, there is a strong possibility that the interfacial adhesion between the fiber and the matrix is poor due to lack of chemical bonding between TiNi and matrix in their composites. The relatively weak interfacial adhesive results in degrading of the material, premature failure, and insufficient actuation response in SMA-embedded composites.

Much work of adhesive strength between fibers and polymer matrix has been reported by surface treatment of ceramic fibers in the fiber-embedded polymer composites [10–12]. It was proved that the surface treatment of carbon fibers has a strong influence on the adhesion to the matrix [13,14]. A study on characterization of the interface between physical surface-treated SMA fibers and resin matrix by the pullout test has been reported [15].

To date, however, very little research has been done regarding the interfacial adhesion of SMA fiber-embedded CFRP composites. In this work, we report experimentally measured interfacial adhesive strengths by pullout testing of a single TiNi fiber embedded in CFRP composites and examine the effect of acid etching of the fiber on the results obtained.

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2. Experimental procedure

0.2 mm thick CFRP prepregs (Hexcel Co.) and 0.4 mm diameter TiNi SMA fiber (Daido Steel Co.) were used to fabricate TiNi fiber-embedded CFRP composites by hot-pressing. The relevant properties of the SMA fiber and CFRP matrix are listed in Table 1. To investigate the effect of surface treatment of the TiNi fiber, the surfaces of TiNi fibers were chemically etched using acid solution. Commercial acid solutions of 36% HCl, 15% HNO_3, 97% H_2SO_4, and 3% HF+15% HNO_3 were used. Before acid etching, the TiNi fibers were cleaned in an ultrasonic bath. The fibers were immersed in one of the acid solutions for 10 min. After finishing surface treatment, the fibers were rinsed thoroughly in acetone and cleaned using filtrated water to remove any impurities on the TiNi surface.

Each composite was prepared by sandwiching a single TiNi fiber between layers of the CFRP prepregs. Each CFRP prepreg was cut to a size of 100 mm×50 mm. During the lamination procedure, the TiNi fiber was carefully placed between 30 sheets (15 sheets above and 15 sheets below) of CFRP prepregs and aligned parallel to the carbon fibers. A special steel jig was used to maintain the shape of the composite system. Anti-heat vinyl sheets were used to prevent the flow of epoxy resin from the CFRP prepreg during heating. Stacks of the CFRP prepreg and TiNi fiber were placed in a steel mold. The composites were fabricated by curing during hot-pressing. The curing was accomplished at 180°C for 2 h at a pressure 0.3 MPa. After curing, the hot-pressed specimens were allowed to cool to room temperature. The hot-pressed composites were cut using a diamond blade and prepared in the form of pullout test specimens as shown in Fig. 1.

The microstructures of TiNi fiber-embedded CFRP composites were investigated by SEM. The surface roughness of the TiNi fiber was measured using a surface roughness analyzer (Ryouka System Co.; model Micromap 123). The pullout testing [16] was used to evaluate the adhesive strength between the TiNi fiber and the CFRP matrix in samples. Ten samples of each composites were tested for evaluation of adhesive strength. The pullout tests were performed with a tensile test machine (Shimadzu Co.; model AG-IS) using a cross-head speed of 0.1 mm/s. The value of adhesive strength (τ) was calculated by applying the following relationship [17]:

$$\tau = \frac{F_{max}}{\pi DL} \quad (1)$$

where F_{max} is the maximum tensile load at the debonding point, D is the diameter of the TiNi fiber, and L is the embedded TiNi fiber length. In order to inspect the failure, scanning electron microscopy was carried out on already tensile specimens.

Table 1
Properties of the TiNi fiber and CFRP prepreg

	TiNi	CFRP prepreg
Density (g/cm^3)	6.5	1.33
Tensile strength (MPa)	11.75	75
Tensile modulus (GPa)	14–57	3.7
Elongation (%)	60	2.4

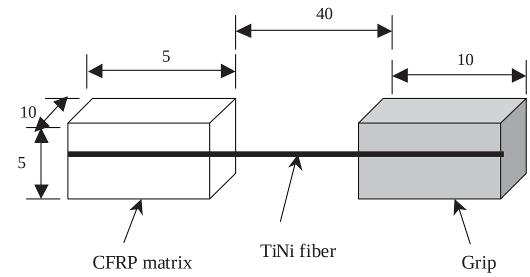

Fig. 1. Shape and dimensions of a TiNi fiber-embedded CFRP specimen for pullout testing.

3. Results and discussion

A SEM micrograph of the polished surfaces of a hot-pressed TiNi fiber-embedded CFRP composite is shown in Fig. 2. The bright, circular area at the center of the micrograph is the embedded TiNi fiber and the surrounding region is the CFRP matrix. The interface between the epoxy resin and TiNi fiber remained well bonded, indicating that there is sufficient mass transport of the epoxy resin to ensure good bonding even during cooling after curing. A few pores were observed in the CFRP matrix. Such pores may have resulted from residual air trapped during the stacking of the CFRP prepregs.

A typical tensile stress–strain curve for TiNi fiber-embedded CFRP sample is shown in Fig. 3 during the pullout test. The tensile load drops rapidly from maximum load. The maximum tensile load is referred to as the pullout load due to debonding.

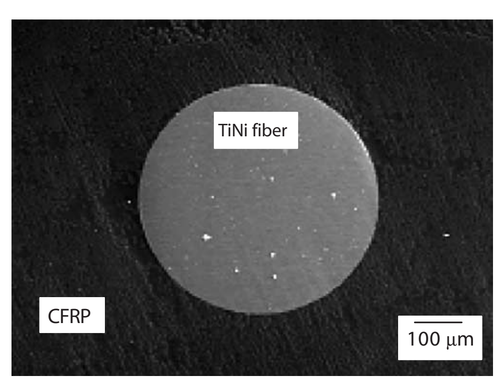

Fig. 2. SEM micrograph of a TiNi fiber-embedded CFRP specimen produced by hot-pressing.