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In situ strength distribution of carbon fibers in unidirectional metal-matrix composites-wires

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Abstract

Based on an etching method and the fiber-bundle tensile testing technique, a new method has been developed for the testing and characterization of the strength distributions of in situ fibers in unidirectional aluminum-matrix-composite wires. According to this method, a systematic study on in situ properties of T300 fiber and M40J fibers in MMCs wires have been performed at strain rates ranging from 0.001 to 1300 1/s. Experimental results show that both T300 fiber and M40J fibers are strain-rate insensitive materials. Results also show that the modulus, ultimate strength and unstable strain of two fibers have been degraded to some degree by high-temperature processing. Micrographs indicate that there are obvious crack distributions on the surfaces of in situ fibers and this is the main reason for the decreasing fiber strength. On the basis of the fiber-bundles model and the statistical theory of fiber strengths, the distribution parameters for in situ fiber strength have been obtained. The evaluated stress/strain curves from the theoretical model are in good agreement with the test data. Statistical analysis results show that the high-temperature manufacturing processing only affects the Weibull scale parameter, σ_0, of T300 fibers and does not affect the shape parameter, β whereas for M40J fibers, both the shape and scale parameters have been changed by high-temperature manufacturing processing. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: A. Metal-matrix composites; In-situ strength; Statistical model; High strain rate

1. Introduction

It has been found that the strength of a metal-matrix composite (MMC) reinforced by unidirectional fibers does not reach that predicted by the rule of mixtures (ROM) [1–3]. Although these results can be influenced by the method of calculation, the most common explanation has been that the strength of the fiber has been degraded by high-temperature processing [4,5]. For fiber-reinforced composite materials, the fibers are the main load-bearing elements and it is therefore important to be able to measure and characterize the in situ strength properties of fiber in MMCs reliably.

Some authors have reported that the strength distributions of in situ fibers can be obtained by etching and single-fiber tests [4,5], but there are shortcomings in such method. First, it is rather tedious to extract individual fibers from a bundle and to perform numerous tests on fibers with very small diameters. Second, the extraction of fibers from a bundle inevitably has selected the stronger ones since the weaker fibers are prone to damage and fracture in the process. Third, it is very difficult to determine the exact cross-sectional area of a single fiber. Chi et al. [6] proposed a procedure for determining the monotonic properties of single fibers by measuring the strengths of fiber bundles. Xia et al. [7] extended the method to the dynamic state and first successfully performed tensile impact tests on fiber bundles and their testing strain rate was up to 1100 1/s. Wang et al. [8] established a single Weibull distribution and a bimodal Weibull distribution model for strain-rate and temperature-dependent fiber strength. On the basis of these models, the strain rate and temperature dependence of E-glass fiber and Kevlar fiber have been studied systematically [8,9].

Based on etching method and fiber bundles test, the strength distribution of in situ fiber in MMCs has been tested and characterized.

2. Experimental procedure and experimental results

The MMCs in the present paper are T300/Al wires and m40J/Al wires, which are produced by the ultrasonic liquid infiltration method [10]. The matrix is an

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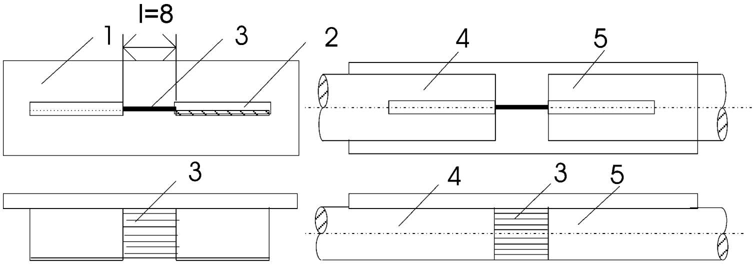

Fig. 1. Specimen and its connection: 1, supplement plate; 2, lining block; 3, composite wires; 4, input bar; 5, outputbar.

industrial pure aluminum (>99.6 wt.% purity). The diameter of the composite wire is about 0.5 mm, and the volume fraction of the fiber in composite is about 50%. The specimen and its connection are shown in Fig. 1. First, the lining blocks (2) were glued on the supplement plate (1) perpendicularly, 10 composite wires (3) were put into the slot of the lining blocks parallel, then wires were glued with blocks by a high shear strength adhesive (SA103) and covered with a thick metal plate by SA103. To extract the fibers from the composites, the aluminum matrix was dissolved in a 5% by weight solution of NaOH which does not degrade the fibers [11]. Then the 10 composite wires have been change into 10 bundles of in situ fibers. Finally, the blocks with the slots in the ends of input bar (4) and output bar (5) were connected using high shear strength adhesive. The supplement plate was taken off before testing.

The tensile tests for in situ fiber bundles were performed on self-designed tensile impact apparatus [12] and MTS810. The strain rate ranges from 0.001 to 1300 1/s. In addition, in order to compare the difference between in situ fiber and original fiber, the tensile tests for original fiber bundles also have been performed at the same strain rate. Figs. 2–5 show the stress/strain curves of in situ T300 fiber bundles, original T300 fiber bundles, in situ M40J fiber bundles and original fiber bundles at different strain rates. The average experimental values and their maximum deviations at different loading conditions are listed in Tables 1 and 2.

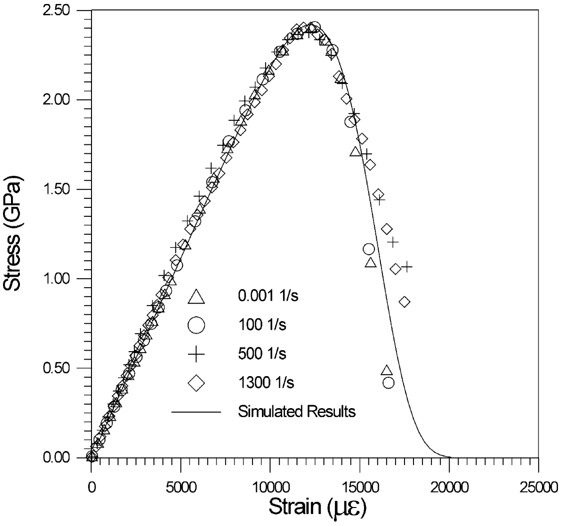

Fig. 3. Stress/strain curves of original T300 fiber bundles at different strain rates.

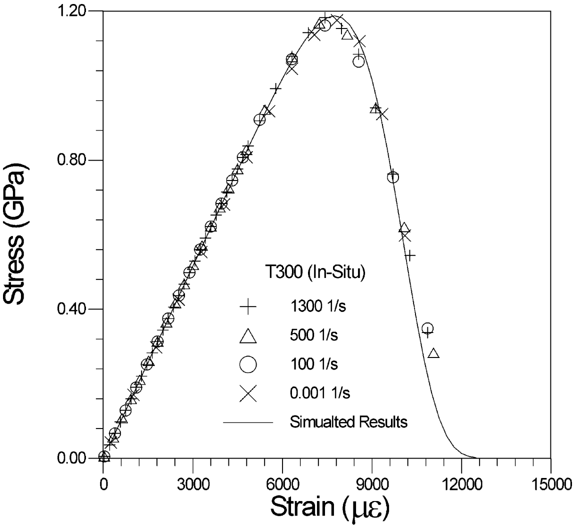

Fig. 2. Stress/strain curves of in situ T300 fiber bundles at different strain rates.

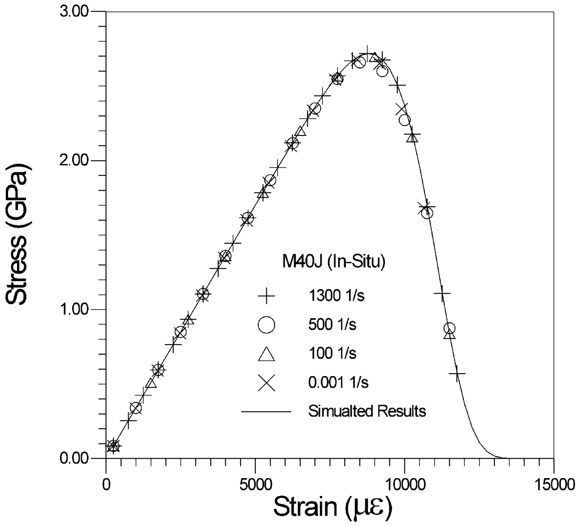

Fig. 4. Stress/strain curves of in situ M40J fiber bundles at different strain rates.