ANISOTROPIC ELASTIC CONSTANTS OF A FIBER-REINFORCED BORON-ALUMINUM COMPOSITE

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Abstract

Elastic constants, both the $C_{ij}$'s and the $S_{ij}$'s, were measured and calculated for a laminated, uniaxially fiber-reinforced boron-aluminum composite. Three theoretical models were considered: square-array, hexagonal-array, and random-distribution. By combining several existing theoretical studies on randomly distributed fibers, a full set of elastic constants can be predicted for this model. The random-distribution model agrees best with observation, especially for off-diagonal elastic constants. Considering all nine elastic constants, observation and theory differ on the average by six percent.

1. Introduction

Fiber-reinforced composites have been studied extensively, both experimentally and theoretically. Recent reviews on this subject include that of experiment by Bert and of theory by Sendeckyj.

Two types of fiber-reinforced composites occur in practice: continuous-fiber and short (chopped)-fiber. The former type has been studied more thoroughly and constitutes the object of this study.
Boron-fiber-reinforced aluminum, a so-called advanced-technology composite, was the particular material that was studied. The principal purpose of the study was to evaluate various models for predicting the composite's macroscopic elastic constants from those of its constituents. The composite's elastic constants were measured two ways: by ultrasonic-velocity measurements, which yield the $C_{ij}$'s, the elastic stiffnesses; and by standing-wave resonance, which yields the $S_{ij}$'s, the elastic compliances. These macroscopic elastic constants define for most cases the mechanical response of the composite to an applied force.

2. Material

The studied composite consisted of 0.14-mm-diameter boron fibers in an aluminum-alloy-6061 matrix. The alloy was in the F-tempered condition, as diffusion bonded. The composite, containing 43 percent fibers by volume, was fabricated as a 10 x 10 x 1.1 cm plate containing about seventy plies. Figure 1 is a photomicrograph showing the distribution of fibers in the transverse plane. Cracks in the boron fibers developed during specimen preparation and do not exist in the bulk material. Mass density, measured hydrostatically, was 2.534 g/cm$^3$.

Throughout this study we adopt the following co-ordinate system: $x_3$ is the fiber direction, $x_1$ is normal to the laminae plane, and $x_2$ is orthogonal to $x_1$ and $x_3$. Thus, $x_1$ and $x_2$ are equivalent directions from the viewpoint of all three theoretical models considered here.

3. Experimental Methods

Our experimental methods were chosen to provide the advantages of small specimens and low inaccuracy.

For brevity, experimental details are omitted here; they were described previously for both the ultrasonic-velocity method by Ledbetter, Frederick, and Austin and the resonance method by Ledbetter.

Briefly, the ultrasonic-velocity method consisted of a pulse-echo technique using gold-plated piezoelectric crystals at frequencies near 10 MHz with specimen thickness varying from 0.2 to 1.0 cm. Except for an improved velocity-measurement system used in this study, it proceeded similarly to that described by Ledbetter and Read.

The resonance method used a three-component (Marx) oscillator. Specimens were rod-shaped, about 0.4 cm in either circular or square cross section, and 4 to 10 cm long. Frequencies ranged from 30 to 50 kHz.