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VIBROSCOPIC DENIER DETERMINATION FOR HIGH MODULUS FIBERS

WALTER H. GLOOR

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AIR FORCE MATERIALS LABORATORY
AIR FORCE SYSTEMS COMMAND
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VIBROSCOPIC DENIER DETERMINATION FOR HIGH MODULUS FIBERS

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Nonmetallic Materials Division

FOREWORD

This report was prepared by the Fibrous Materials Branch, Nonmetallic Materials Division, Air Force Materials Laboratory. It was initiated under Project 7320, "Fibrous Materials for Decelerators and Structures", Task 732001, "Organic and Inorganic Fibers", with Walter H. Gloor as Project Scientist.

This report was released by the author in April 1970

This technical report has been reviewed and is approved.

JACK H. ROSS
Chief, Fibrous Materials Branch
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Air Force Materials Laboratory

ABSTRACT

Determination of fiber linear density by vibroscopic (vibrating string) techniques requires a correction for specimen stiffness when applied to fine diameter, high modulus fibers. The magnitude of this correction is discussed, together with the factors from which it arises and methods of calculation.

I. INTRODUCTION

Tensile characterization of filamentary materials necessitates determination of some measure of fiber size. Commonly employed size measures are diameter, cross-sectional area, and denier, and these are normally determined through relatively straight-forward microscopic, planimetric, or analytical balance techniques. Filament denier for very small fibers (less than 1 mil diameter) is difficult to determine by direct weighing because of the small weights and/or long lengths involved. An approximation can be obtained for those fibers which are part of a multifilament yarn by dividing yarn denier by filament count. Fiber-to-fiber nonuniformity, however, introduces uncertainities. Microscopic diameter measurements are applicable only to circular or near-circular fibers. Planimetry using photomicrographs obtained from mounted cross-sections has the inherent undesirable feature of averaging fiber areas which may be different from those later selected for tensile testing.

II. DISCUSSION

Based on the above considerations, the vibroscopic technique for single fiber denier measurement is attractive in many instances*. In it, an oscillatory force is applied to a filament under tension and the frequency varied until resonance is achieved. Fiber linear density (denier) can then be calculated from the observed values of frequency, tension, fiber length, and other parameters, if certain assumptions are made. The major assumptions are:

a) Uniform linear density along the fiber.
b) The moment of inertia of the fiber about its neutral axis approximates that of a right circular cylinder of equal cross-sectional area.
c) The fiber oscillates as a perfectly flexible string.

Assumptions (a) and (b) normally present no problem; errors introduced because of these for the majority of fibers of interest are relatively minor. Errors arising from the fiber's nonconformance with assumption (c), however, are not necessarily negligible.

Fiber linear density (density x cross-sectional area) is calculated from vibroscope test conditions and results from the following equation:

$$\rho A = \frac{T}{4l^2 f^2} \quad (1)$$

in which ρ, A, T, l and f represent density, area, tensioning force, fiber length, and resonant frequency, respectively, in consistent units. The reasonant frequency used normally is the fundamental for the system in question. Equation (1) is for the ideal case in which the three assumptions listed above are valid. Corrections for nonconformance with assumption (c) are a function of both fiber area and Young's modulus. It is not intended to derive the pertinent basic relationships here; the reader is referred to the above mentioned journal article and any complete mechanics text. For organic textile fibers of conventional diameters, the calculated "stiffness correction factors" normally do not exceed 3% and often are much lower.

Recently, considerable attention has been paid to the mechanical characterization of graphite fibers of very high Young's modulus and in extremely fine diameters. Deviation from assumption (c) was therefore re-examined since the vibroscopic technique is used by some investigators for measurement of graphite fiber denier.

*The Vibroscopic Method for Determination of Fiber Cross-sectional Area", D. J. Montgomery and W. T. Milloway, Textile Research Journal, Vol. XXII, No. 11, November 1952, p. 729.

Applying a correction factor for specimen stiffness results in Equation (1) taking the form:

$$\rho A = (1 + \Delta)\left(\frac{T}{4\ell^2 f^2}\right) \qquad (2)$$

in which

$$\Delta = 2\alpha + 5.47\alpha^2 \qquad (3)$$

and

$$\alpha = \frac{4EI}{\ell^2 T} \qquad (4)$$

where ℓ and T are a previously defined, E is Young's modulus and I is the moment of inertia of the fiber about its neutral axis.

Typical conditions for graphite fiber vibroscopy involve a 2 cm. gage length and tensioning force supplied by a 20 mgm. weight. Equation (4) then reduces to

$$\alpha = 0.0848E^{1/2}d^2 \qquad (5)$$

in which E is in psi x 10^{-6} and d (fiber diameter) is in mils.

Combining Equations (2), (3) and (5), and introducing the necessary proportionality constants, results in

$$\text{Denier} = (1 + 0.1696E^{1/2}d^2 + .0393Ed^4)\frac{1.103}{f^2} \qquad (6)$$

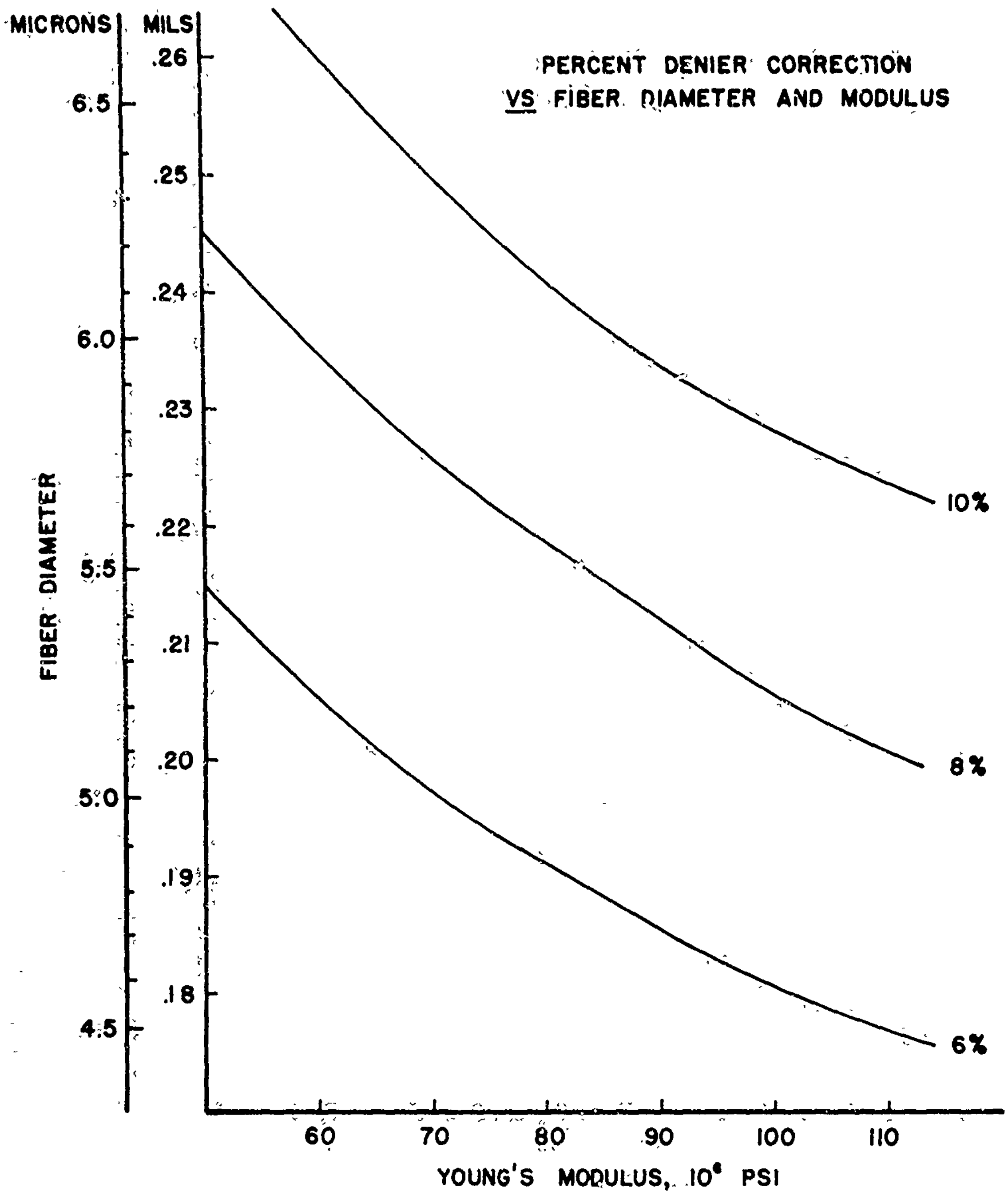
where f is the fundamental reasonant frequency in Kc /Sec, using a 2 cm. fiber and 20 mgm. tensioning weight.

Equation (6) is not directly solvable for denier, however, since diameter and denier are related through density, and the calculation of E from tensile test data is dependent on denier. Iterative procedures can be employed. Also, in many instances, sufficiently close approximations for E and d are known prior to testing to allow calculation of an accurate correction factor (parenthetical expression in Equation (6)).

Figure I shows graphically the relationship between correction factor, fiber diameter, and fiber modulus. As an example, for a 6-micron fiber of 75 million psi modulus, the denier correction factor is approximately 9%. That is, the parenthetical expression in Equation (6) is 1.09.

III. SUMMARY

Denier determinations on the high-modulus graphite fibers of current interest will be low by approximately 5 to 15% unless corrected for stiffness. A correction factor based on fiber diameter and modulus can be determined and applied in a relatively straightforward manner.


MICRONS
MILS
PERCENT DENIER CORRECTION
VS FIBER DIAMETER AND MODULUS
6.5
6.0
5.5
5.0
4.5
.26
.25
.24
.23
.22
.21
.20
.19
.18
FIBER DIAMETER
10%
8%
6%
60
70
80
90
100
110
YOUNG'S MODULUS, 10⁶ PSI

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Diameter						
Modulus						
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