Outline

- **ASTM D3379**
- **ASTM C1557**
- **Data Analysis**
- **Fractography**
- **Summary**

Background

ASTM D3379 used to be the accepted standard for the determination of fiber tensile strength.

Designation: D 3379 – 75 (Reapproved 1989)$^{\epsilon 1}$

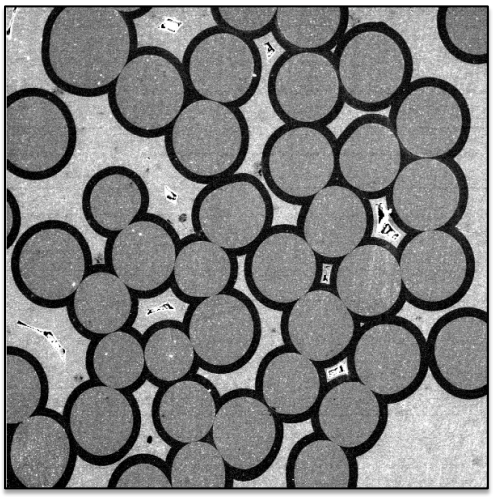
Standard Test Method for Tensile Strength and Young's Modulus for High-Modulus Single-Filament Materials[1]

This standard is issued under the fixed designation D 3379; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This test method has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

$^{\epsilon 1}$ NOTE—Editorial changes were made throughout in May 1989.

Background



Typically, most ceramic fibers have circular cross-sections, and their diameters are typically distributed according to a normal distribution.

Background

According to ASTM D3379 each fiber strength is calculated using the average of the fiber cross-sectional areas.

9.2.8 Determine the true compliance, C, by subtracting the system compliance, C_s, from the indicated compliance, C_a.

9.3 *Area*—Calculate the area as follows:

area →

$$A = \frac{\Sigma a_f \times 10^{-6}}{N(M_f)^2} \quad (1)$$

where:

A = average filament area, m^2 (or $in.^2$),
a_f = area of one filament, mm^2 (or $in.^2$),
N = number of filaments measured, and
M_f = photomicrograph magnification factor.

NOTE 3—Equation 1 is applicable only to SI units. A suitable conversion factor must be used for inch-pound units.

9.4 *Tensile Strength*—Calculate the tensile strength as follows:

strength →

$$T = F/A \quad (2)$$

where:

T = tensile strength, Pa (or psi),
F = force to failure, N (or lbf), and

Background

What is the effect of calculating each fiber strength using the average fiber cross-sectional area, on the parameters of the distribution of fiber strengths?

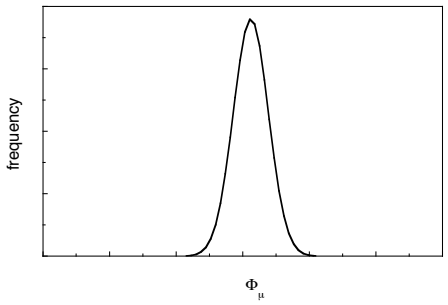
Analysis

- Consider a collection of N fibers.
- Strengths are distributed according to a 2-parameter Weibull distribution.

$$P_f = 1 - exp\left(-\frac{V}{V_o}\left(-\frac{\sigma}{\sigma_o}\right)^m\right)$$

Analysis (cont.)

Assume the fibers have a circular cross-section, and their diameters are distributed according to a normal distribution.



$$f(\phi) = \frac{1}{\Phi_{sd}\sqrt{2\pi}} exp(-(\phi - \Phi_\mu)^2 / 2\Phi_{sd}^2)$$

Analysis (cont.)

Assume the parameters of the distributions of fiber diameters and strengths are known.

- m, σ_o
- Φ_μ, Φ_{SD}

Analysis (cont.)

Define the "modified fiber strength" as the ratio of the breaking load divided by the average of the fiber cross-sectional areas, i.e., this is the value of strength that would be calculated if we followed ASTM D3379

$$\sigma_i^* = \frac{L_i}{A_\mu}$$

σ^*: "modified fiber strength"
L_i: breaking load for i-th fiber
A_μ: average of cross-sectional areas

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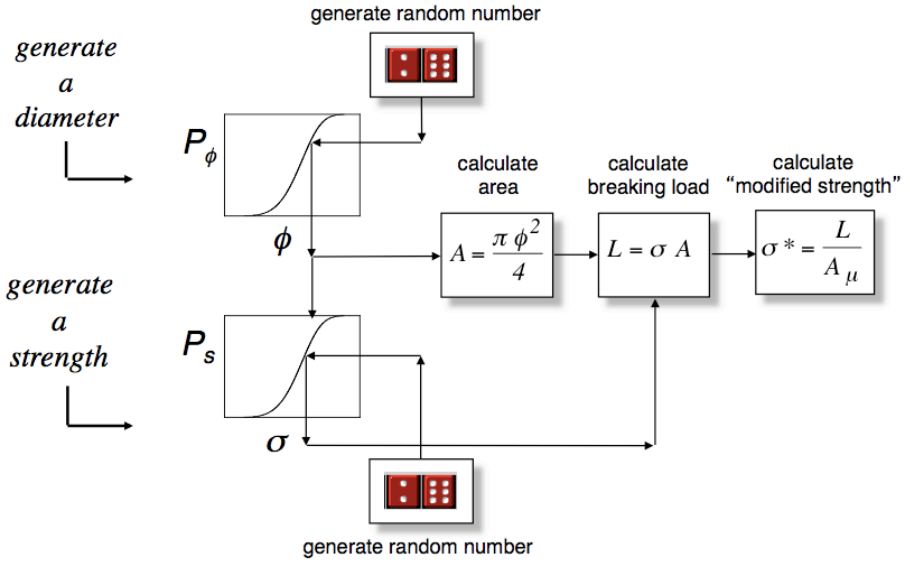
Analysis (cont.)



Analysis (cont.)

We estimate the parameters of the distribution of "modified fiber strengths" first by ranking the "modified fiber strengths" in ascending order and then by assigning probabilities of failure according to the following estimator:

$$P_i^* = \frac{i - 0.5}{N_f}$$

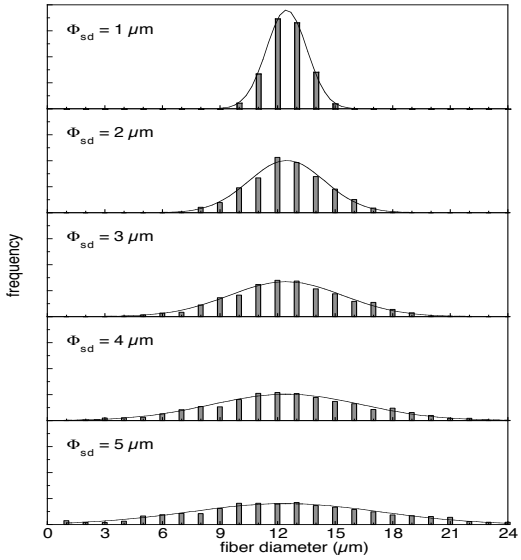
Analysis (cont.)

Let us consider the following cases:

- σ_o = 3 GPa
- Φ_μ = 12 µm
- n = 1000

Φ_{SD}/m	3	5	10	15
1 μm	10 rep	10 rep	10 rep	10 rep
2 μm	10 rep	10 rep	10 rep	10 rep
3 μm	10 rep	10 rep	10 rep	10 rep
4 μm	10 rep	10 rep	10 rep	10 rep
5 μm	10 rep	10 rep	10 rep	10 rep

Analysis (cont.)



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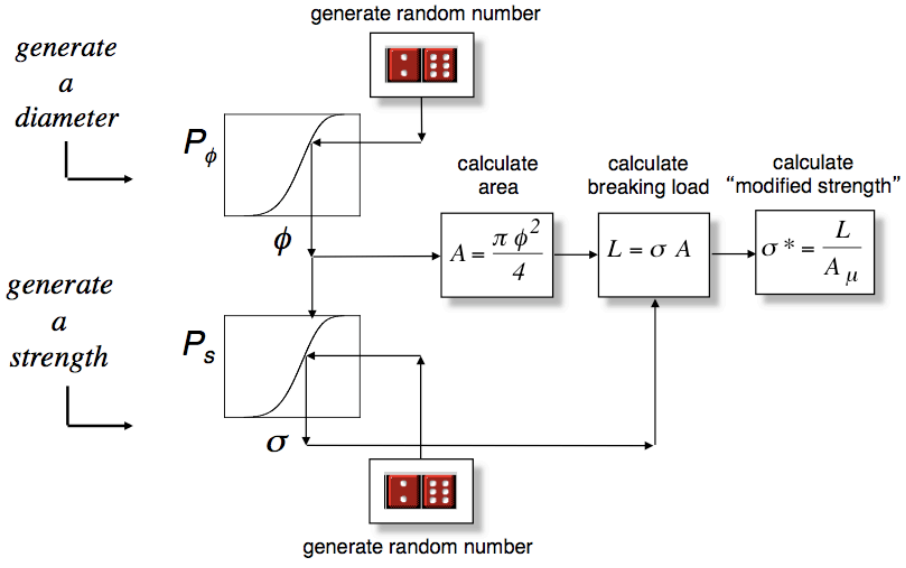
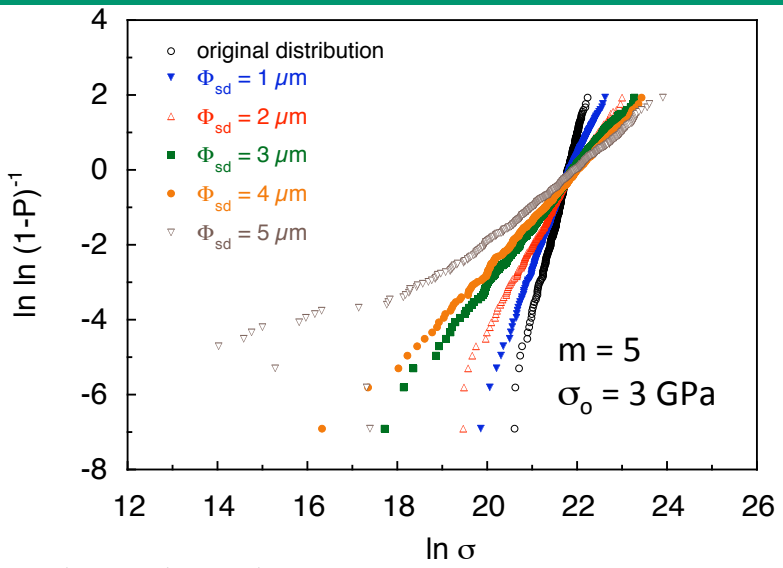
Analysis (cont.)



Distributions of "modified fiber strengths"



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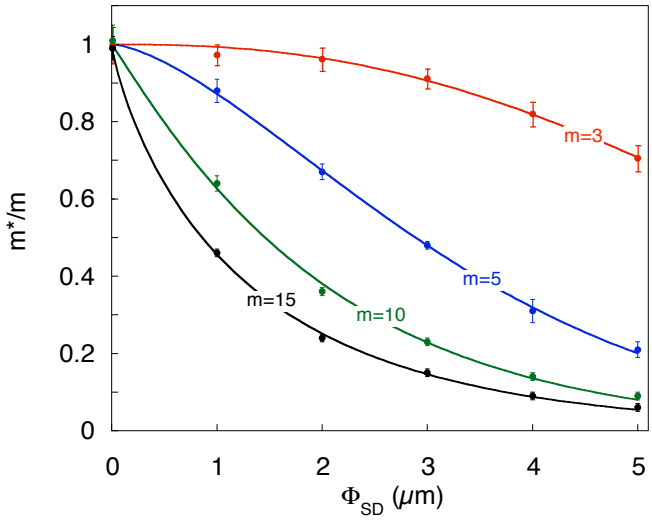
Parameters of Distribution of "Modified Fiber Strengths"



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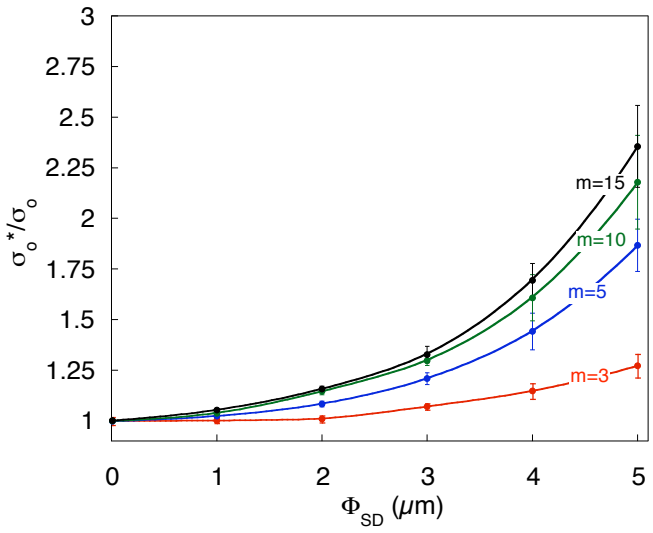

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Summary

When obtaining each fiber strength using the average fiber cross-sectional area, the distribution of "modified fiber strengths" exhibits more dispersion than the original distribution of fiber strengths.

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Summary (cont.)

This can be rationalized by considering that on average the one-to-one relationship between

- large diameter fibers - large breaking loads
- small diameter fibers - small breaking loads

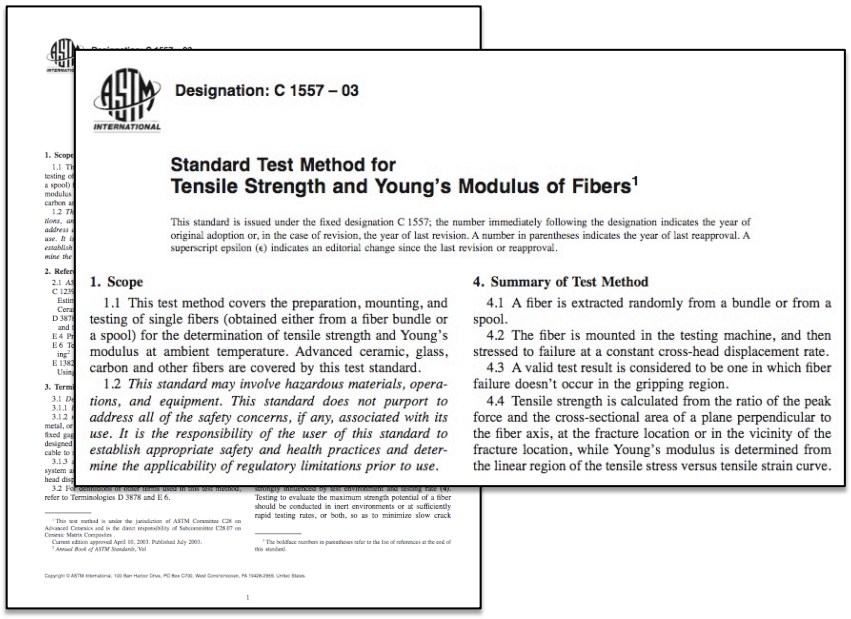
is lost when dividing all the breaking loads by the same number (average cross-sectional area).

Summary (cont.)

Therefore,

It is not appropriate to calculate individual fiber strengths (and in turn, the parameters of the distribution of fiber strengths) using the average of the fiber cross-sectional areas!

For accurate strength measurements it is necessary to determine the cross-sectional area of **each** fiber at the fracture plane



Designation: C 1557 – 03

Standard Test Method for Tensile Strength and Young's Modulus of Fibers[1]

This standard is issued under the fixed designation C 1557; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the preparation, mounting, and testing of single fibers (obtained either from a fiber bundle or a spool) for the determination of tensile strength and Young's modulus at ambient temperature. Advanced ceramic, glass, carbon and other fibers are covered by this test standard.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

4. Summary of Test Method

4.1 A fiber is extracted randomly from a bundle or from a spool.

4.2 The fiber is mounted in the testing machine, and then stressed to failure at a constant cross-head displacement rate.

4.3 A valid test result is considered to be one in which fiber failure doesn't occur in the gripping region.

4.4 Tensile strength is calculated from the ratio of the peak force and the cross-sectional area of a plane perpendicular to the fiber axis, at the fracture location or in the vicinity of the fracture location, while Young's modulus is determined from the linear region of the tensile stress versus tensile strain curve.

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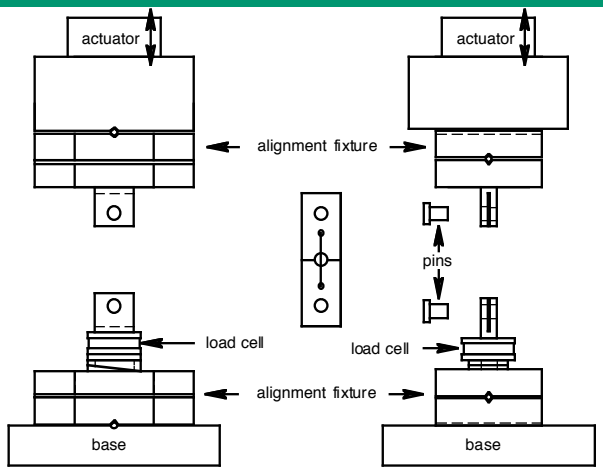

Front View Side View

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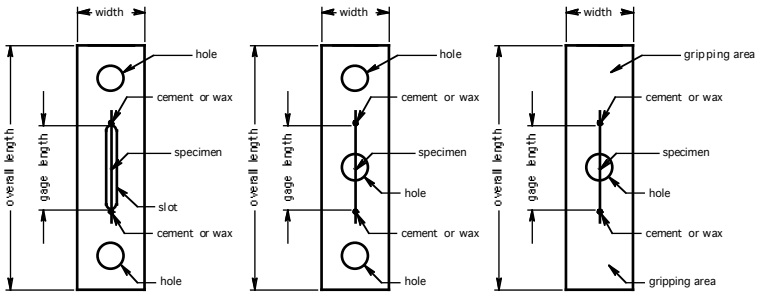

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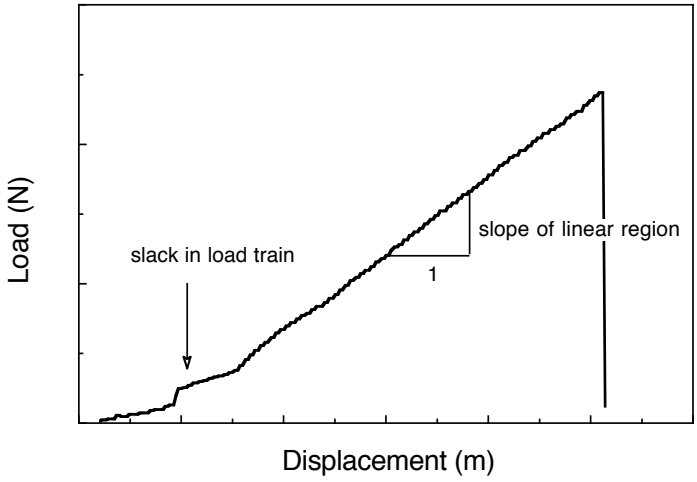

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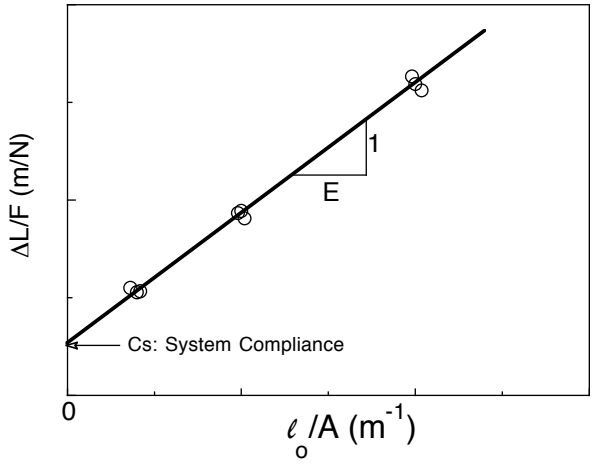

Summary

- ASTM has standardized a test method to determine the tensile properties of ceramic fibers (C1557)
- The test method requires direct measurements of the cross-sectional of the fiber at the fracture plane to determine the tensile strength
- FRACTOGRAPHY
- Data analysis and probability distribution functions