INCH-POUND

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MILITARY STANDARD

TRANSVERSE TENSILE PROPERTIES OF UNIDIRECTIONAL FIBER/RESIN COMPOSITE CYLINDERS

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FOREWORD

1. This Military Handbook is approved for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: U.S. Army Research Laboratory, Materials Directorate, ATTN: AMSRL-MA-S, Watertown, MA 02172-0001 by using the Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

3. This was a joint effort to develop test standardization through the Joint-Army-Navy-NASA-Air Force (JANNAF) Composite Motorcase Subcommittee (CMCS). The purpose was to develop standard tests to determine uniaxial material properties for filament wound structures. Government, industry, and academia contributed in both manpower and funding to complete the process from writing the standards through running the round robin testing.

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Transverse Tensile Properties of Unidirectional Fiber/Resin Composite Cylinders

1. SCOPE

1.1 Scope. This test method covers the determination of the transverse tensile properties of hoop wound resin matrix composites reinforced by high-modulus (greater than 21 GPa or 3 Msi), continuous fibers. It describes testing of hoop wound (90°) cylinders in axial tension for determination of transverse tensile properties.

1.2 Application Guidance. This standard involves hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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.

2. APPLICABLE DOCUMENTS

2.1 Government Documents.

2.1.1 Standards. The following standards form a part of this document to the extent specified herein. Unless otherwise specified, the issue of these documents are those listed in the issue of the Department of Defense Index for Specifications and Standards (DODISS) and supplement thereto, cited in the solicitation (6.2).

MIL-STD-374 Transverse Compressive Properties of Unidirectional Fiber/Resin Composite Cylinders

MIL-STD-375 In-Plane Shear Properties of Unidirectional Fiber/Resin Composite Cylinders

(Unless otherwise indicated, copies of federal and military standards are available from the Naval Publications and Forms Center, (ATTN: NPODS), 5801 Tabor Avenue, Philadelphia, PA 19120-5099.)

2.2 Non-Government Publications: The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted are those listed in the issue of the DODISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DODISS are the issues of the documents cited in the solicitation (see 6.2).

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM D792	Test Method for Specific Gravity and Density of Plastics by Displacement
ASTM D883	Definitions of Terms Relating to Plastics
ASTM D2584	Test Method for Ignition Loss of Cured Reinforced Resins
ASTM D2734	Test Methods for Void Content of Reinforced Plastics
ASTM D3171	Test Method for Fiber Content of Resin-Matrix Composites by Matrix Digestion
ASTM D3878	Terminology of High-Modulus Reinforcing Fibers and Their Composites
ASTM D5229	Test Methods for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
ASTM E4	Practices for Load Verification of Testing Machines
ASTM E6	Terminology Relating to Methods of Mechanical Testing
ASTM E111	Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus
ASTM E122	Practice for Choice of Sample Size to Estimate the Average Quality of a Lot or Process
ASTM E132	Test Method for Poisson's Ratio at Room Temperature
ASTM E177	Practice for Use of Terms Precision and Bias in ASTM Test Methods
ASTM E251	Test Methods for Performance Characteristics of Bonded Resistance Strain Gages
ASTM E456	Terminology Relating to Statistics
ASTM E1012	Practice for Verification of Specimen Alignment Under Tensile Loading
ASTM E1237	Practice for Installation of Bonded Resistance Strain Gages

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187.)

3. DEFINITIONS[1]

3.1 Continuous Fiber. A continuous fiber is a polycrystalline or amorphous body that is continuous within the sample or component and that has ends outside of the stress field under consideration. Minimum diameter is not limited but maximum diameter may not exceed 0.25 mm [0.010 in.].

3.2 Ply. The material laid down in a single winding pass from one end of the mandrel to the other during fabrication.

3.3 Layer. Two consecutive plies wound in opposite directions along the mandrel.

3.4 Winding. An entire part completed by one winding operation and then cured.

3.5 Hoop Wound. A winding of a cylindrical component where the filaments are circumferentially oriented.

3.6 Specimen. A single part cut from a winding. Each winding may yield several specimens.

3.7 Transverse Tensile Elastic Modulus, E_{22}, $[MT^{-2}L^{-1}]$. The tensile elastic modulus of a unidirectional material in the direction perpendicular to the reinforcing fibers.

3.8 Transverse Tensile Strength, σ_{22}^{ut} $[MT^{-2}L^{-1}]$. The strength of a unidirectional material when a tensile load is applied in the direction perpendicular to the reinforcing fibers.

3.9 Transverse Tensile Strain at Failure, ϵ_{22}^{ut} [nd]. The value of strain, perpendicular to the reinforcing fibers in a unidirectional material, at failure when a tensile load is applied in the direction perpendicular to the reinforcing fibers.

[1]If the term represents a physical quantity, its analytical dimensions are stated immediately following the term (or letter symbol) in fundamental dimension form, using the following ASTM standard symbology for fundamental dimensions, shown within square brackets: [M] for mass, [L] for length, [T] for time, [θ] for thermodynamic temperature, and [nd] for non-dimensional quantities. Use of these symbols is restricted to analytical dimensions when used with square brackets, as the symbols may have other definitions when used without the brackets.

4. GENERAL REQUIREMENTS

4.1. Apparatus.

4.1.1 Micrometers. Use suitable ball type micrometers for reading to within 0.025 ± 0.010 mm [0.001 ± 0.0004 in.] of the specimen inner and outer diameters. Flat anvil type micrometer or calipers of similar resolution may be used for the overall specimen length and the gage length (the free length between the fixtures).

4.1.2 Tension Fixture. The tension fixture consists of a steel outer shell, insert, load rod, and spherical washer. An assembly drawing for these components and the test fixture is seen in Figure 1. A tension fixture is required for both ends of the test specimen.

4.1.2.1 Outer Shell. The outer shell (Metric units Figure 2, English units Figure 4) is circular with a concentric circular hollow in one face, a groove along the diameter of the other face, and a center hole through the thickness. Along the diameter perpendicular to the groove, three pairs of small eccentric holes are placed at three radial distances. The two outer pairs of holes are threaded. Four additional threaded holes are placed at the same radial distance as the inner most pair of holes at ninety degree intervals starting forty-five degrees from the diameter that passes through the center groove.

4.1.2.2 Insert. The fixture insert is circular with a center hole through the thickness (Metric Units Figure 3, English Units Figure 5). Two sets of holes are placed along a concentric centerline. These holes align with the inner most set of holes in the outer shell. The set of four holes at ninety degree intervals are counterbored. The insert is fastened inside the hollow of the outer shell to form the concentric groove used to put the specimen in the fixture (Figure 1).

4.1.2.3 Load Rod and Spherical Washers. Two spherical washers for self alignment are placed over a 0.750-UNC-2A x 6.0 inch load rod. The load rod is then slid through the center hole of the outer shell and insert assembly as illustrated in Figure 1.

4.1.2.4 Affiliated Fixtures. The outer shell and insert for the tension fixture are the same outer shell and insert used in MIL-STD-375 (shear testing) and MIL-STD-374 (compression testing).

4.1.3 Testing Machine. The testing machine shall be comprised of the following:

4.1.3.1 Fixed Member. A fixed or essentially stationary member to which one end of the tension specimen/fixture assembly, shown in Figure 6, can be attached.

4.1.3.2 Movable Member. A movable member to which the opposite end of the tension specimen/fixture assembly, shown in Figure 6, can be attached.

4.1.3.3 Drive Mechanism. A drive mechanism shall be used for imparting to the movable member a uniform controlled velocity with respect to the fixed member, this velocity to be regulated as specified in sub paragraph 5.3.6.

4.1.3.4 Load Indicator. A suitable load-indicating mechanism capable of showing the total tensile load carried by the test specimen. This mechanism shall be essentially free of inertia-lag at the specified rate of testing and shall indicate the load within an accuracy of ±1% of the actual value, or better. The accuracy of the testing machine shall be verified in accordance with ASTM Practice E4.

4.1.3.5 Construction Materials. The fixed member, movable member, drive mechanism, and fixtures shall be constructed of such materials and in such proportions that the total longitudinal deformation of the system contributed by these parts is minimized. If the longitudinal deformation between the two ends of the gage section of the test specimen at any time during the test and at any load up to the failure load is less than 99% of the total system deformation, then the true strain rate may be determined by evaluation of the strain rate of the system and application of the corresponding correction.

4.1.4 Strain-Indicating Device. Strain will be determined by means of bonded resistance strain gages. Each strain gage shall be 6.3 mm [0.25 in.] in length (e.g., micro-measurements CAE-09-250UR-350). The specimen shall be instrumented to measure strain in both the axial and circumferential directions to determine Poisson's ratio. Strain gage rosettes (0°/45°/90°) shall be used to correct for gage misalignment. Gage calibration certification shall comply with ASTM Test Method E251. Some guidelines on the use of strain gages on composites are presented below.

4.1.4.1 Surface Preparation. The surface preparation of fiber-reinforced composites discussed in ASTM Practice E1237 can penetrate the matrix material and cause damage to the reinforcing fibers, resulting in improper coupon failures. Reinforcing fibers should not be exposed or damaged during the surface preparation process. The strain gage manufacturer should be consulted regarding surface preparation guidelines and recommended bonding agents for composites, pending the development of a set of standard practices for strain gage installation surface preparation of fiber-reinforced composite materials.

4.1.4.2. Gage Resistance. Consideration should be given to the selection of gages having larger resistance to reduce heating effects on low-conductivity materials. Resistances of 350Ω or higher are preferred. Additional consideration should be given to the use of the minimum possible gage excitation voltage consistent with the desired accuracy (1 to 2 volts is recommended) to further reduce the power consumed by the gage. Heating of the coupon by the gage may affect the performance of the material directly, or it may affect the indicated strain due to a difference between the gage temperature compensation factor and the coefficient of thermal expansion of the coupon material.

4.1.4.3 Temperature Considerations. Consideration of some form of temperature compensation is recommended, even when testing at Standard Laboratory Atmosphere. Temperature compensation is required when testing in non-ambient temperature environments.

4.1.4.4 Transverse Sensitivity. Consideration should be given to the transverse sensitivity of the selected strain gage. The strain gage manufacturer should be consulted for recommendations on transverse sensitivity corrections and effects on composites. This is particularly important for a transversely mounted gage used to determine Poisson's ratio.

4.1.5 Conditioning Chamber. When conditioning materials at non-laboratory environments, a temperature/vapor-level controlled environment conditioning chamber is required which shall be capable of maintaining the required temperature to within ±3°C [±5°F] and the required relative vapor level to within ±3%. Chamber conditions shall be monitored either on an automated continuous basis or on a manual basis at regular intervals.

4.1.6 Environmental Test Chamber. An environmental test chamber is required for test environment other than ambient testing laboratory conditions. This chamber shall be capable of maintaining the gage section of the test specimen at the required test environment during the mechanical test.

4.2. Test Specimen

4.2.1 Geometry. The test specimen shall be as shown in Figure 7. The length of all specimens shall be 140 mm [5.5 in.]. This provides a gage length of 100 mm [4.0 in.]. The inner diameter of all specimens shall be 100 ± 4 mm [4.000 ± 0.015 in.]. Specimens may be fabricated on a tapered mandrel yielding a maximum taper over the specimen length of 0.0005 mm/mm [in./in.] on the diameter. The specimens shall have a nominal wall thickness of 2 mm [0.08 in.], the actual thickness to be specified by the winding parameters and shall be maintained as the test specimen is wound and cured.

4.2.2 Winding. All specimens shall be hoop-wound (approximately 90°) with a single tow and with enough layers to meet the thickness criterion described above.

4.2.3 Number of Test Specimens. At least five specimens per test condition should be tested unless valid results can be gained through the use of fewer specimens, such as in the case of a designed experiment. For statistically significant data, the procedures outlined in ASTM Practice E122 should be consulted. The method of sampling shall be reported.

4.3. Conditioning of Test Specimens. The test specimens shall be conditioned and tested in a room or enclosed space maintained at 23 ± 2°C [75 ± 5°F] and at 50 ± 10% relative humidity for a minimum of 40 hours in accordance with ASTM Method D5229, unless otherwise specified.

5. DETAILED REQUIREMENTS

5.1 Summary of Test Method. A thin walled hoop wound cylinder nominally 100 mm [4 in.] in diameter and 140 mm [5½ in.] in length is bonded into two end fixtures. The specimen/fixture assembly is mounted in the testing machine and monotonically loaded in tension while recording load. The transverse tensile strength can be determined from the maximum load carried prior to failure. If the cylinder strain is monitored with strain gages, then the stress-strain response of the material can be determined. From the stress-strain response the transverse tensile strain at failure, transverse tensile modulus of elasticity, and Poisson's ratio can be derived.

5.2 Significance of Use. This test method is used to produce transverse tensile property data for material specifications, research and development, quality assurance, and structural design and analysis. Factors which influence the transverse tensile response and should, therefore, be reported are: material, methods of material preparation, specimen preparation, specimen conditioning, environment of testing, specimen alignment and gripping, speed of testing, void content, and fiber volume fraction. Properties, in the test direction, which may be obtained from this test method are: Transverse Tensile Strength, σ_{22}^{ut}; Transverse Tensile Strain at Failure, ϵ_{22}^{ut}; Transverse Tensile Modulus of Elasticity, E_{22}; and Poisson's Ratio, v_{21}.

5.3. Procedure.

5.3.1 Parameters to be Specified Prior to Test. The sampling method, specimen geometry, and test parameters used to determine density and reinforcement volume; the tension specimen sampling method; the environmental conditioning test parameters; and, the tensile property and data reporting format desired should be specified prior to test. Specific material property, accuracy, and data reporting requirements should be determined prior to test for proper selection of instrumentation and data recording equipment. Estimates of operating stress and strain levels should also be made to aid in transducer selection, calibration of equipment, and determination of equipment settings.

5.3.2 General Instructions.

5.3.2.1 Test Method Deviations. Any deviation from this test method shall be reported.

5.3.2.2 Specific Gravity and Void Volume Percentage Determination. Unless otherwise directed, determine specific gravity and reinforcement and void volume percentages for each winding. The material used for the determination of these properties should be extracted from the center of the winding if multiple specimens are extracted from one winding or from one of the ends of the winding if only one specimen is extracted from the winding. Determine and report specific gravity and density per ASTM Test Method D792. Determine and report volume percent of the constituents by one of the matrix digestion procedures of ASTM Test Method D3171, or, for certain reinforcement materials such as glass and ceramic, by the matrix burn-off technique of ASTM Test Method D2584. The void content equations of ASTM Test Method D2734 are applicable to both ASTM Test Method D2584 and the matrix digestion procedures.

5.3.2.3 Outer Diameter, Inner Diameter, and Length Measurements. Following any conditioning, but before the tension testing, measure and report the specimens outer diameter, OD, inner diameter, ID, and length. The specimens are measured by first marking two randomly selected locations within the middle two-thirds of the specimen length. At each of the points, average four measurements of the outer diameter on an axis that passes through the point and then repeat the procedure on an axis perpendicular to the initial axis. Repeat the procedure for the inner diameter using the same axes. Subtract the average inner diameter from the average outer diameter and divide the remainder by 2. This value will be used as the composite wall thickness, t_c. Also, obtain four length measurements, made at 90° intervals around the specimen circumference, and compute their average. This value will be used as the specimen length.

5.3.3 Strain Gage Installation. Attach strain gages to the center of the specimens gage section. Three strain gage rosettes (oriented as 0°/45°/90° where 0° is parallel to the specimen axis), mounted 120° around the specimen outer circumference from each other as shown in Figure 7, are recommended in order to ascertain that only tensile loading is being applied. Non-tensile loading may be detected if the strain measured on one of the rosettes is greatly different from the strain on one or both of the other rosettes. For an accurate assessment of Poisson's ratio, strain gages may be optionally attached to the inside of the specimen, directly opposite the gages on the outside, to measure circumferential strain.

5.3.4 Fixture Assembly. Assembly of tension fixture is illustrated in Figure 1. Place two (2) guide pins into the guide pin holes of the insert such that approximately half of the pins length are protruding from the insert. Place the insert inside the concentric circular hollow of the outer shell such that the protruding guide pins enter the outer shell guide pin holes. Secure the insert to the outer shell using four (4) assembly bolts. Place spherical washers over load rod and insert load rod through the center hole of the outer shell and insert assembly.

5.3.5 Securing Specimen. Secure the test specimen within two fixtures, as shown in Figure 6, by filling the fixture cavities with potting material and inserting the specimen ends firmly to the bottom of the cavities while allowing the potting material to form a bead. Cure according to manufacturer's specifications, but the cure temperature should not jeopardize the specimen. Obtain four measurements of the free length between the fixtures, made at 90° intervals around the specimen/fixture circumference, and compute their average. This value will be used as the gage length.

5.3.5.1 Potting Material. The potting material should be selected so that it can be cured at a temperature, T_c, no greater than 28°C [50°F] lower than the glass transition temperature T_g of the specimen, $T_c < T_g - 28°C$ [$T_c < T_g - 50°F$]. It is helpful if the potting material can be removed without a great deal of difficulty upon completion of the test. A potting material should be selected to have properties sufficient to avoid failure of the potting material and failure of the specimen near the potting material during the test.

5.3.6 Speed of Testing. Speed of testing should be set to effect a nearly constant strain rate in the gage section. If strain control is not available on the testing machine, this may be approximated by repeated monitoring and adjusting of the rate of load application to maintain a nearly constant strain rate, as measured by strain transducer response versus time. The strain rate should be selected so as to produce failure within 1 to 10 minutes. If the ultimate strain of the material cannot be reasonably estimated, initial trials should be conducted using standard speeds until the ultimate strain of the material and the compliance of the system are known, and the strain rate can be adjusted. The suggested standard speeds are:

5.3.6.1 Strain Control Machines. A standard strain rate of 0.0125 min^{-1}.

5.3.6.2 Constant Crosshead Speed Machine. A standard crosshead displacement of 1.3mm [0.05 inches] per minute. Use of a fixed crosshead speed in testing machine systems with a high compliance will result in a strain rate which is much lower than required.

5.3.7 Test Environment. The specimen shall be conditioned to the desired moisture profile and tested under the same conditioning fluid exposure level. However, cases such as elevated temperature testing of a moist specimen place unrealistic requirements on the capabilities of common testing machine environmental chambers. In such cases, the mechanical test environment may need to be modified, for example, by testing at elevated temperature with no fluid exposure control, but with a specified limit on time to failure from withdrawal from the conditioning chamber. Modifications to the test environment shall be recorded.

5.3.7.1 Conditioning Environment. If the testing area environment is different than the specimen conditioning environment, then the specimen shall be stored in the conditioned environment until test time.

5.3.8 Data Recording Instrumentation. Attach the data recording instrumentation to the strain gages on the specimen and to the load cell.

5.3.9 Loading. Apply the load to the specimen at the specified rate until failure, while recording data.

5.3.10 Data Recording. Record load versus strain (or displacement) continuously, or at frequent regular intervals. If the specimen is to be failed, record the maximum load, the failure load, and the strain (or displacement) at, or as near as possible to where the load drops off significantly. A 10% load drop off is typically considered significant.

5.3.11 Failure Mode. Record the mode and location of failure of the specimen. Choose, if possible, a standard description from the sketches of common test failure modes which are shown in Figure 8. Failure in a specimen occurring within one specimen width of the bond between the specimen and the test fixture is considered a grip (GR) failure. A grip failure is typically precipitated by an anomalous condition; therefore, the grip failure mode is considered inappropriate.

5.3.12 Specimen/Fixture Bond. A significant fraction of failures in a sample population occurring within one specimen width of the bond between the specimen and test fixture shall be cause to re-examine the means of load introduction into the material. Factors considered should include the alignment of the specimen in the fixture, alignment of the fixtures in the grips, and material used to bond the specimen to the fixture.

5.3.13 Fixture Disassembly. This is only an advised procedure for disassembling the test fixture. Cut each end of the specimen at the base of the fixture. Remove the load rod and spherical washers from the outer shell and insert assembly. Remove the four (4) assembly bolts from the insert. Place the outer shell and insert assembly into an oven at a temperature that will degrade the potting compound. After a sufficient period of time, remove the fixtures from the oven and allow them to cool. Insert two (2) break down bolts into outer shell (see Figure 1). Turn break down bolts to force insert out of the concentric circular hollow of the outer shell. Remove guide pins from insert and outer shell. Wire brush insert and outer shell to remove specimen debris.

5.4 Calculation

5.4.1 Transverse Sensitivity Correction. Correct the strain gage readings for transverse sensitivity separately for each rosette

$$\epsilon_1^i = \frac{\hat{\epsilon}_1^i \left(1 - \nu_o K_{t_1}\right) - K_{t_1} \hat{\epsilon}_3^i \left(1 - \nu_o K_{t_3}\right)}{1 - K_{t_1} K_{t_3}}$$

$$\epsilon_2^i = \frac{\hat{\epsilon}_2^i \left(1 - \nu_o K_{t_2}\right)}{1 - K_{t_2}} - \frac{K_{t_2}\left[\hat{\epsilon}_1^i \left(1 - \nu_o K_{t_1}\right)\left(1 - K_{t_3}\right) + \hat{\epsilon}_3^i \left(1 - \nu_o K_{t_3}\right)\left(1 - K_{t_1}\right)\right]}{\left(1 - K_{t_1} K_{t_3}\right)\left(1 - K_{t_2}\right)}$$

$$\epsilon_3^i = \frac{\hat{\epsilon}_3^i \left(1 - \nu_o K_{t_3}\right) - K_{t_3} \hat{\epsilon}_1^i \left(1 - \nu_o K_{t_1}\right)}{1 - K_{t_1} K_{t_3}}$$

where

ν_o	-	Poisson's ratio for the material used in calibration by the strain gage manufacturer (usually 0.285)
$K_{t_1}, K_{t_2}, K_{t_3}$	-	Transverse sensitivity coefficients for gages (1), (2), and (3) (these values are typically reported by the manufacturers in percentages and must be converted for use in the above equations, e.g., $K_t = 0.7\% = 0.007$),
$\hat{\epsilon}_1^i, \hat{\epsilon}_2^i, \hat{\epsilon}_3^i$	-	The indicated (uncorrected) strains from gages (1), (2), and (3) for the i^{th} rosette
$\epsilon_1^i, \epsilon_2^i, \epsilon_3^i$	-	The corrected strains for gages (1), (2), and (3) for the i^{th} rosette

5.4.2 Principal Strain Calculation. Calculate separately for each rosette the principal strains in the material that results from the applied load using the corrected strain gage readings,

$$\epsilon_{11}^i = \frac{\epsilon_1^i + \epsilon_3^i}{2} - \frac{1}{2}\left(\left(\epsilon_1^i - \epsilon_3^i\right)^2 + \left(2\epsilon_2^i - \epsilon_1^i - \epsilon_3^i\right)^2\right)^{1/2}$$

$$\epsilon_{22}^i = \frac{\epsilon_1^i + \epsilon_3^i}{2} + \frac{1}{2}\left(\left(\epsilon_1^i - \epsilon_3^i\right)^2 + \left(2\epsilon_2^i - \epsilon_1^i - \epsilon_3^i\right)^2\right)^{1/2}$$

where

ϵ_{11}^{i} - Strain in the direction of the fiber (circumferential) for the i^{th} rosette

ϵ_{22}^{i} - Strain in the direction perpendicular to the fiber (axial) for the i^{th} rosette

If ϵ_{11}^{i} or ϵ_{22}^{i} varies by more than 5% with location of rosette around the cylinder, within the strain range used to calculate the transverse elastic modulus (section 5.4.7.1), the strain field is not uniform and the test is invalid.

5.4.3 Calculation of Angle of Rotation from Principal Plane. Calculate separately for each rosette the angle of rotation of the rosette from the principal plane using the corrected strain gage readings.

$$\theta^{i} = \frac{1}{2} \tan^{-1} \left[\frac{2\epsilon_2 - \epsilon_1 - \epsilon_3}{\epsilon_1 + \epsilon_3} \right]$$

where

θ^{i} - The angle of rotation of the i^{th} rosette from the principal plane

If θ_i for any of the rosettes around the cylinder is greater than 10°, the calculation of the principal strains (axial and circumferential strains for the cylindrical specimens) are not considered reliable and the test is invalid.

5.4.4 Limitations of Principal Strain and Angle of Rotation Calculations. The preceding equations used to calculate the principal strain and angle of rotation from the principal plane are developed specifically for gages configured as illustrated in Figure 7.

5.4.5 Average Principal Strain. Calculate the average principal strains in the material

$$\overline{\epsilon}_{11} = \sum_{i=1}^{n} \epsilon_{11}^{i}/n$$

$$\overline{\epsilon}_{22} = \sum_{i=1}^{n} \epsilon_{22}^{i}/n$$

where

$\bar{\epsilon}_{11}$ - average ϵ_{11} for the rosettes,

$\bar{\epsilon}_{22}$ - average ϵ_{22} for the rosettes, and

n - number of rosettes on the test specimen (usually 3).

Record the average strain in the axial ($\bar{\epsilon}_{22}^{ut}$) and circumferential directions at failure.

5.4.6 Tensile Strength. Calculate the transverse tensile strength, σ_{22}^{ut}, using

$$\sigma_{22}^{ut} = P_{max}/A$$

where A is the cross-sectional area,

$$A = \frac{\pi}{4}\left(OD^2 - ID^2\right),$$

and ID and OD are the average inner and outer diameters, respectively.

5.4.7 Tensile Modulus of Elasticity. Select the appropriate chord modulus strain range from Table 1. Calculate the tensile modulus of elasticity using

$$E_{22} = \Delta\sigma_{22}/\Delta\bar{\epsilon}_{22}$$

where:

E_{22} = transverse elastic modulus, MPa [psi],

$\Delta\sigma_{22}$ = difference in applied tensile stress between the two strain points of Table 1, MPa [psi], and

$\Delta\bar{\epsilon}_{22}$ = difference between the two strain points of Table 1 (nominally either 0.001, 0.002, or 0.005)

If data is not available at the exact strain range end points (as often occurs with digital data), use the closest available data point. Report the tensile modulus of elasticity to three significant figures. Also report the strain range used in the calculation.

5.4.7.1 Tabulated Strain Ranges. The tabulated strain ranges should only be used for materials which do not exhibit a transition region (a significant change in the slope of the stress-strain curve) within the given strain range. If a transition region occurs within the recommended strain range, then a more suitable strain range shall be used and reported.

Table 1. Specimen Elastic Modulus Calculation Strain Ranges

Ultimate Tensile Strain Capability of Material $\mu\epsilon$[A]	**Tensile Elastic Modulus Calculations** Axial Strain Range	
	Start Point $\mu\epsilon$	End Point $\mu\epsilon$
< 6000	500	1500
≥ 6000 but < 12,000	1000	3000
≥ 12,000	1000	6000

[A] 1000 $\mu\epsilon$ = 0.001 absolute strain

5.4.7.2 Tensile Modulus of Elasticity (other definitions). Other definitions of elastic modulus may be evaluated and reported at the user's discretion. If such data is generated and reported, report also the definition used, the strain range used, and the results to three significant figures. ASTM Test Method E111 provides additional guidance in the determination of Modulus of Elasticity.

5.4.8 Poisson's Ratio. Select the appropriate elastic modulus strain range from Table 1. Determine the average circumferential strain, $\bar{\epsilon}_{11}$, at each of the two average axial strain, $\bar{\epsilon}_{22}$, strain range end points. Calculate Poisson's ratio using

$$\nu_{21} = -\Delta\bar{\epsilon}_{11}/\Delta\bar{\epsilon}_{22}$$

where

ν_{21} = Poisson's ratio.

$\Delta\bar{\epsilon}_{11}$ = Difference in average circumferential strain between the two strain points of Table 1, and

$\Delta\bar{\epsilon}_{22}$ = Difference between the two axial strain points in Table 1 (nominally either 0.001, 0.002, or 0.005).

If data is not available at the exact strain range end points (as often occurs with digital data), use the closest available data point. Report the tensile modulus of elasticity to three significant figures. Also report the strain range used in the calculation.

5.4.8.1 Tensile Poisson's Ratio (other definitions). Other definitions of Poisson's ratio may be evaluated and reported at the user's discretion. If such data is generated and reported, report also the definition used, the strain range used, and the results to three significant figures. ASTM Test Method E132 provides additional guidance in the determination of Poisson's ratio.

5.4.9 Statistical Requirements. For each series of valid tests calculate the average value ($\bar{x}$), standard deviation (s), and coefficient of variation (cv) for each strength, strain at failure, modulus, and Poisson's ratio.

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

$$s = \left[\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1} \right]^{1/2}$$

$$cv = s/\bar{x}$$

where:

x_i = test value, and
n = number of samples.

6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1. Intended Use. This tension test is used to produce transverse tensile property data for material specifications, research and development, and design and analysis. Specific specimen properties determined from this test are (1) transverse elastic modulus, E_{22}, (2) transverse tensile strength, σ_{22}^{u}, (3) axial strain at failure, ϵ_{22}^{u}, and (4) Poisson's ratio, ν_{21}, in tension. Factors influencing tensile properties which should be reported are material and specimen preparation, specimen conditioning, specimen alignment and gripping, test environment, void content, and fiber volume fraction. This test method is limited to a specimen with a nominal thickness of 2.0 mm [0.08 in.]. Fabrication of test specimens is not limited to filament winding.

6.2 Issue of DODISS. When this standard is used in acquisition, the applicable issue of the DODISS must be cited in the solicitation (see 2.1.1 and 2.2).

6.3 Consideration of Data Requirements. The following data are recommended upon submission of test results.

6.3.1 Material Identification. Complete identification of the material tested, including type, source, manufacturer's code number, form, fiber volume fraction, void content, filament count, ply sequence and wind angle, fiber and resin lot number, and any previous history.

6.3.2 Methods Description. Complete description of the method of fabricating the specimens, including processing details.

6.3.3 Winding Description. Density, fiber volume fraction, and void content for each winding.

6.3.4 Equipment Description. Complete description of the testing equipment used including the test machine, load cell, strain gages, data acquisition system, and estimates of error for each parameter measured. Identification of potting material, radius of bead, and cure temperature.

6.3.5 Conditioning Description. Conditioning procedures used if other than specified in test method.

6.3.6 Environmental Conditions. Relative humidity and temperature conditions in the test room.

6.3.7 Test Methods Summary. Test method used, including type and rate of loading.

6.3.8 Test Procedures Summary. Number of specimens tested and identification number for each specimen.

6.3.9 Test Specimen Dimensions. The outer diameter, inner diameter, wall thickness t_c, total length, and gage length for each specimen, average values, standard deviations, and coefficients of variation.

6.3.10 Strength Summary. Tensile strength for each specimen, average value, standard deviation, and coefficient of variation for valid tests.

6.3.11 Strain Summary. Strain at failure for each specimen (axial and circumferential), average values, standard deviations, and coefficients of variation for valid tests.

6.3.12 Modulus Summary. Transverse elastic modulus for each specimen, average value, standard deviation, and coefficient of variation for valid tests. Include how the modulus was determined and at what point or between what points on the load versus strain or stress versus strain curve.

6.3.13 Poisson's Ratio Summary. Poisson's ratio for each specimen, average value, standard deviation, and coefficient of variation for valid tests.

6.3.14 Load Versus Strain Data. Full load versus strain or stress versus strain curves for the averages in the axial and circumferential directions. If average curves cannot be calculated, the individual load versus strain or stress versus strain curves corresponding to each strain gage should be reported.

6.3.15 Mode of Failure. Mode of failure and failure location in specimen. Use Figure 8 to describe the gage section failure modes. Multiple failure modes can occur in a specimen. Any failure that involves the portion of the specimen bonded to the grips is considered a grip failure (GR).

6.3.16 Date of Test. Specify the date and time each specimen was tested.

6.3.17 Quality Assessment. Quality assessment of the test data (e.g., acceptable, questionable), deviations from this test method, and any explanation.

6.4 Key Words.

Elastic modulus, transverse
Fiber reinforced plastic
Poisson's Ratio
Strength, transverse

Custodians:
Army - MR
Navy - AS
Air Force - 11

Review Activities:
Army - AR, AV, ME, MI
Navy - CH, NW, SH
Air Force - 12, 19, 79, 80
OASD - SO

Civil Agencies:
MSF, LRC, ACO, FAA

Preparing Activity:
Army - MR

Civil Agency Coordinating Activities:
NASA - NA

Project CMPS-0103

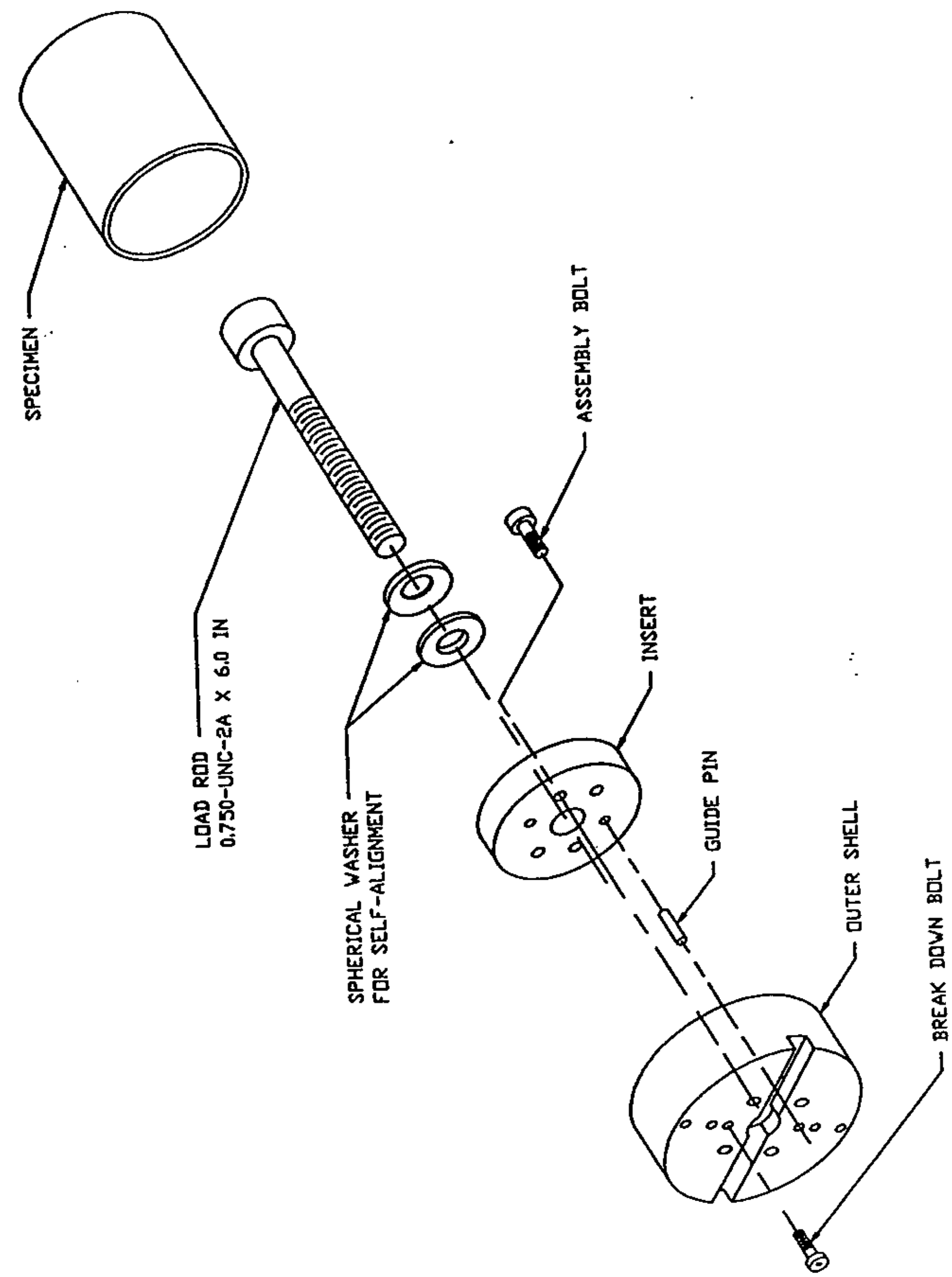


Figure 1. Assembly Drawing for Tension Fixture and Specimen

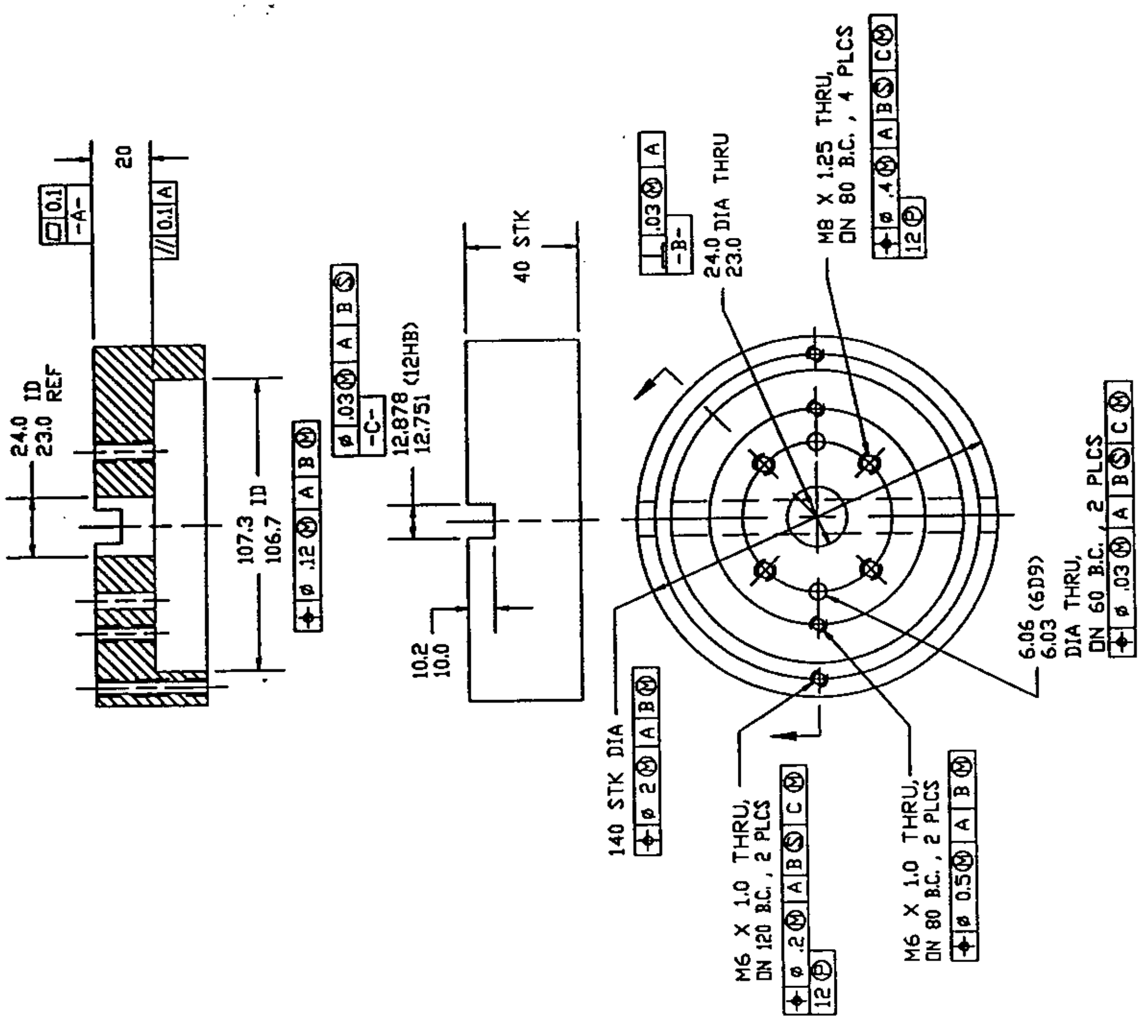


Figure 2. The Outer Shell of the Tension Fixture in Metric Units

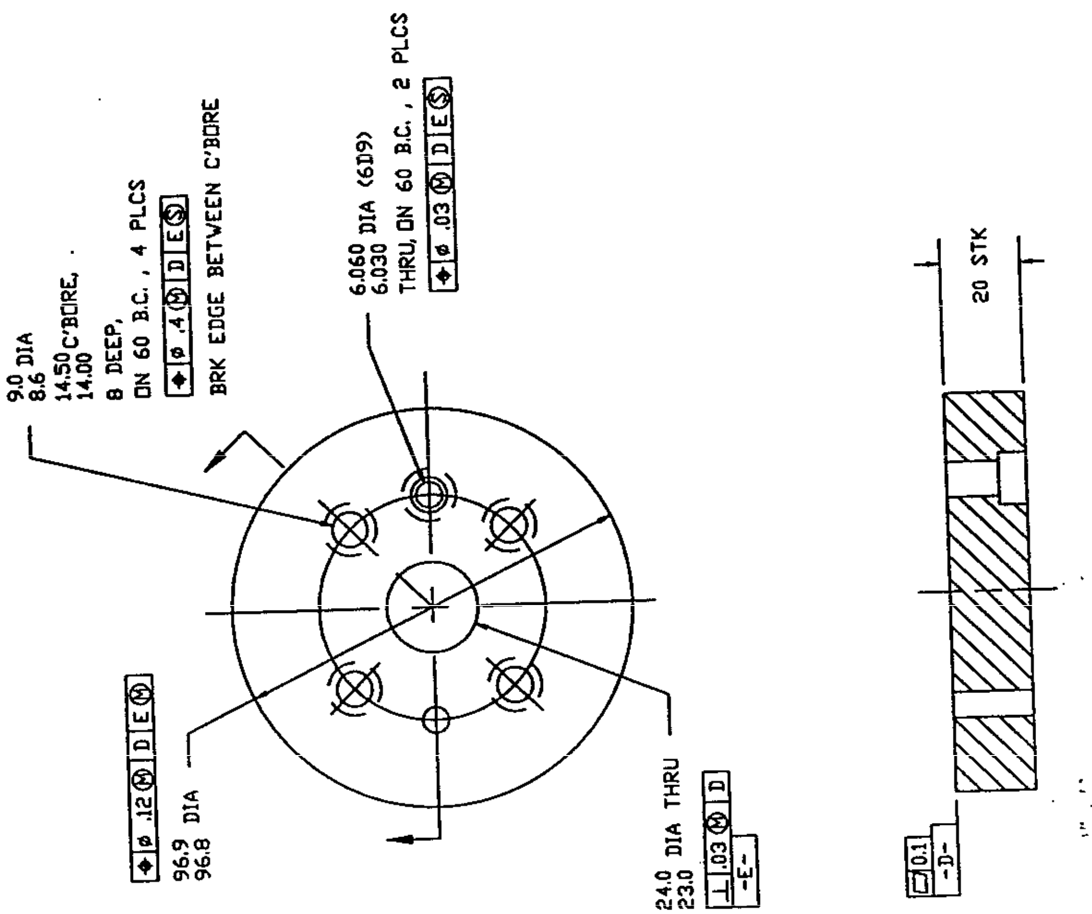


Figure 3. The Insert of the Tensile Fixture in Metric Units

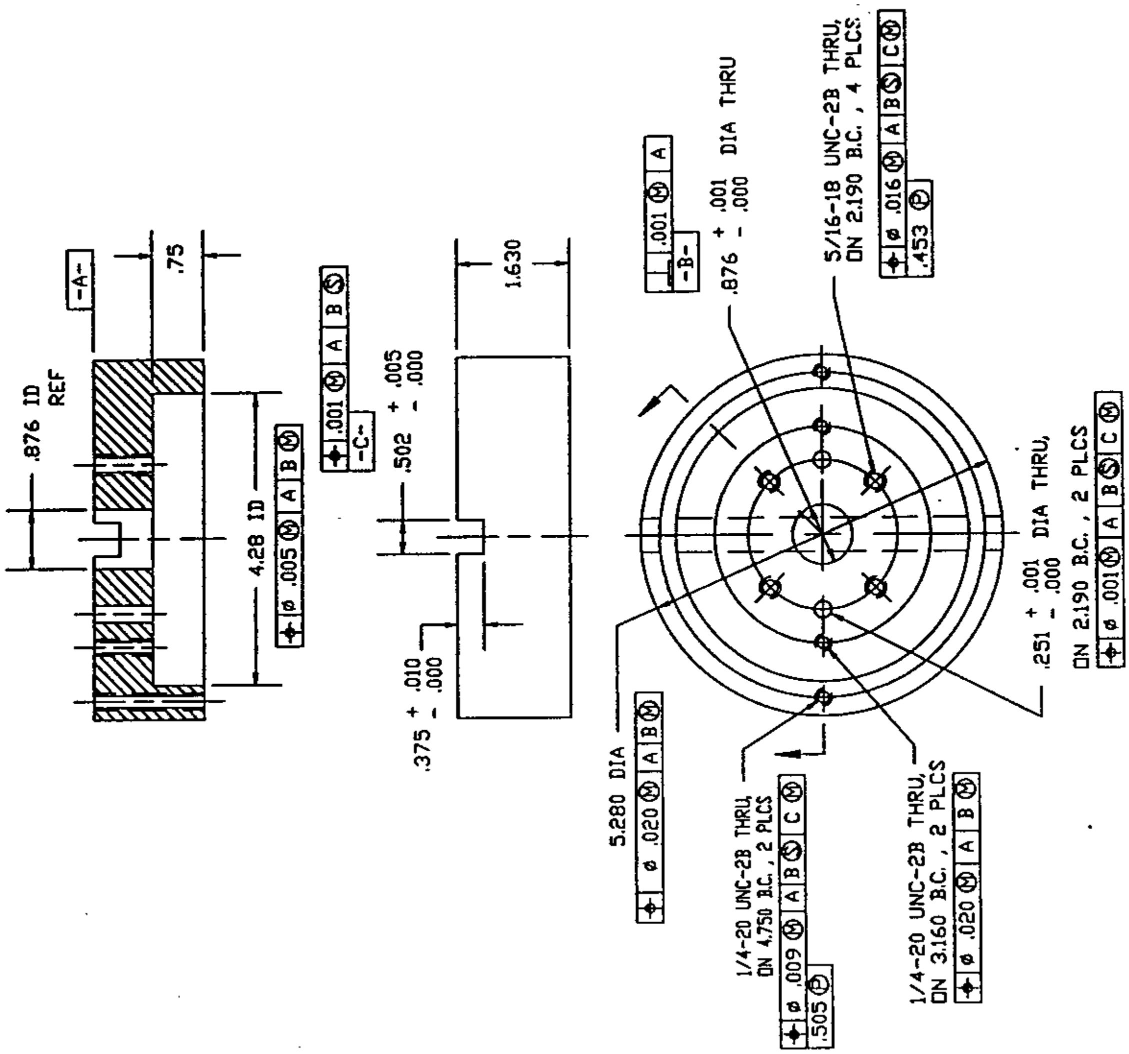


Figure 4. The Outer Shell of the Tension Fixture in English Units

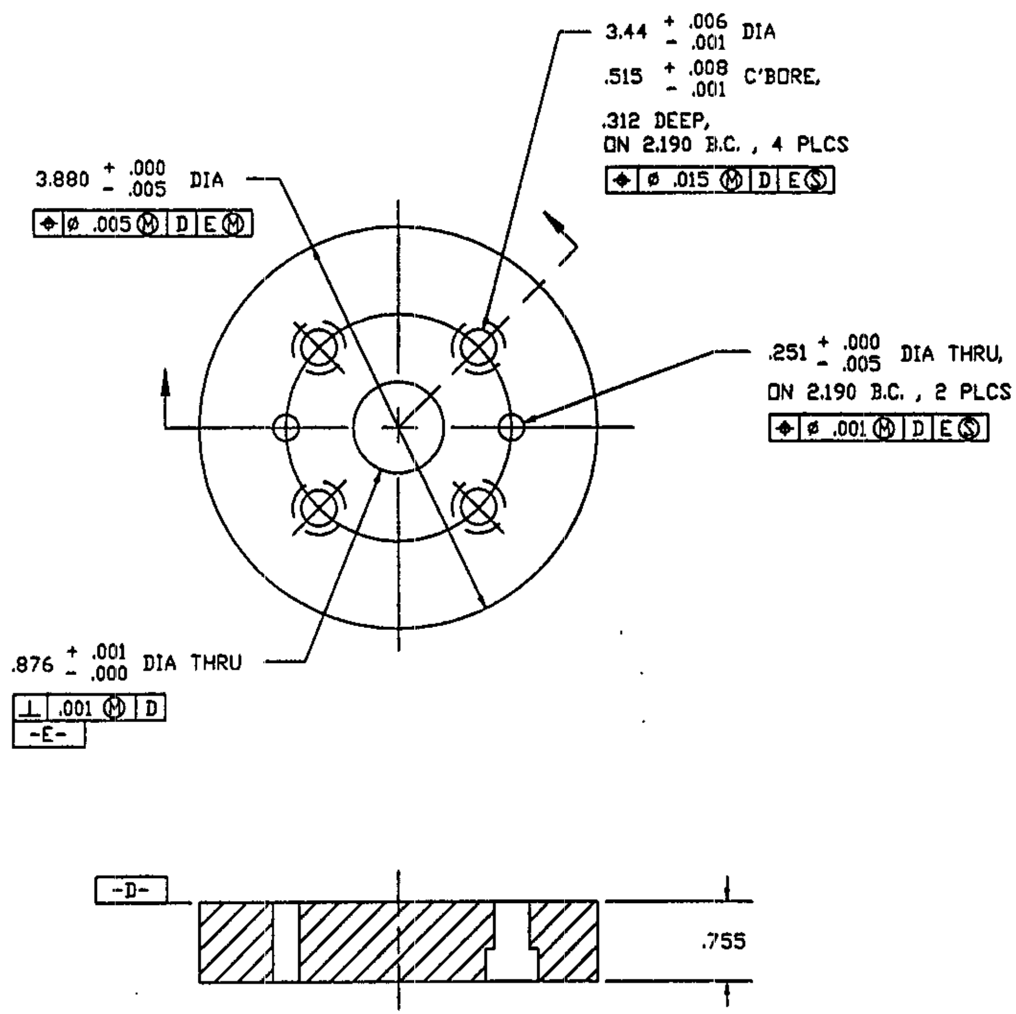


Figure 5. The Insert of the Tensile Fixture in English Units

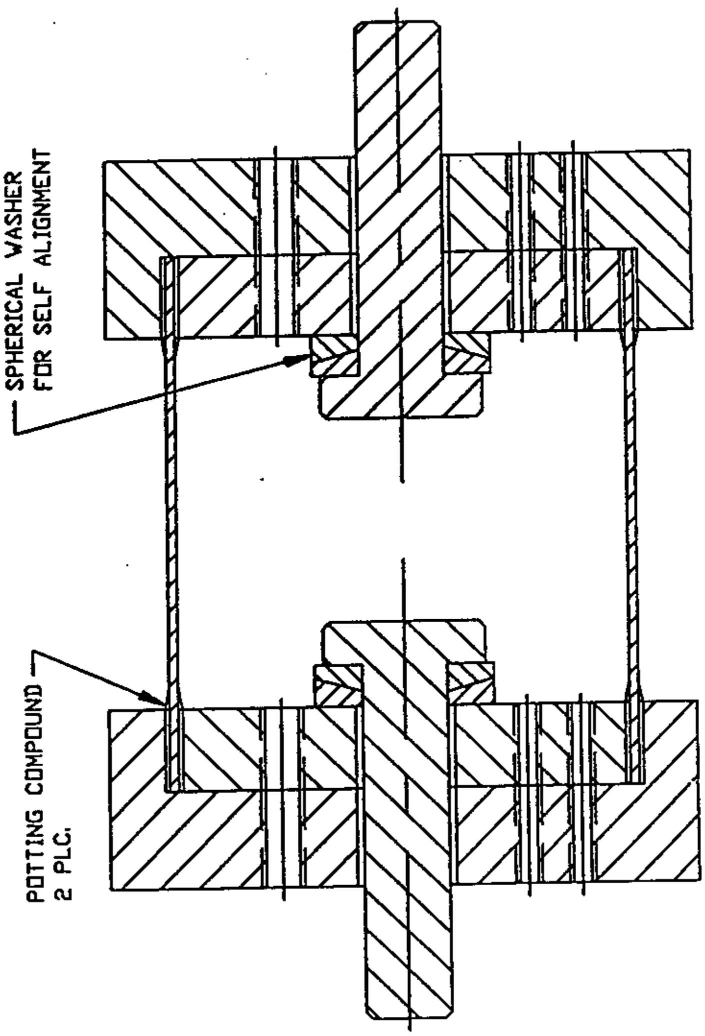
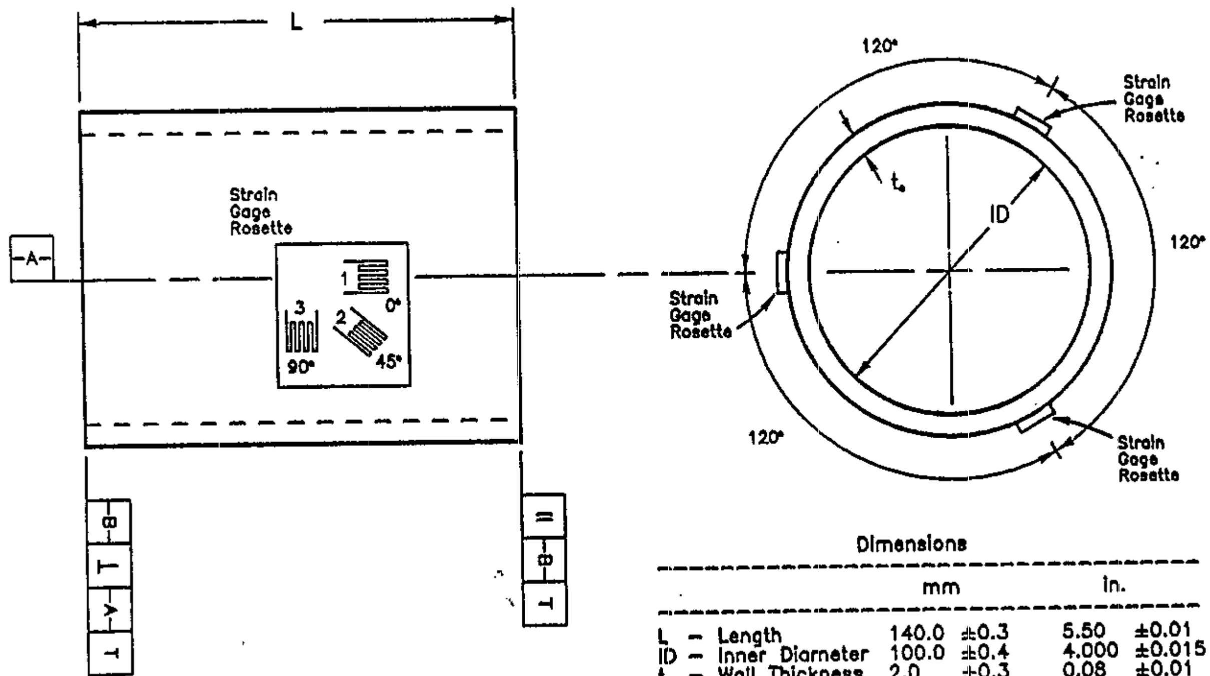


Figure 6. Illustration of Assembled Tension Fixture and Specimen



Dimensions

	mm		in.	
L – Length	140.0	±0.3	5.50	±0.01
ID – Inner Diameter	100.0	±0.4	4.000	±0.015
t_o – Wall Thickness	2.0	±0.3	0.08	±0.01
T – Tolerance	0.08		0.003	

Notes:
1. Tube may be fabricated on a tapered mandrel with maximum taper of 0.0005 in/in (0.0005 mm/mm) on the diameter.
2. Actual measure of inner diameter will depend on specimen placement along tapered mandrel during fabrication.

Figure 7. Test Specimen Shown with Strain Gage Configuration

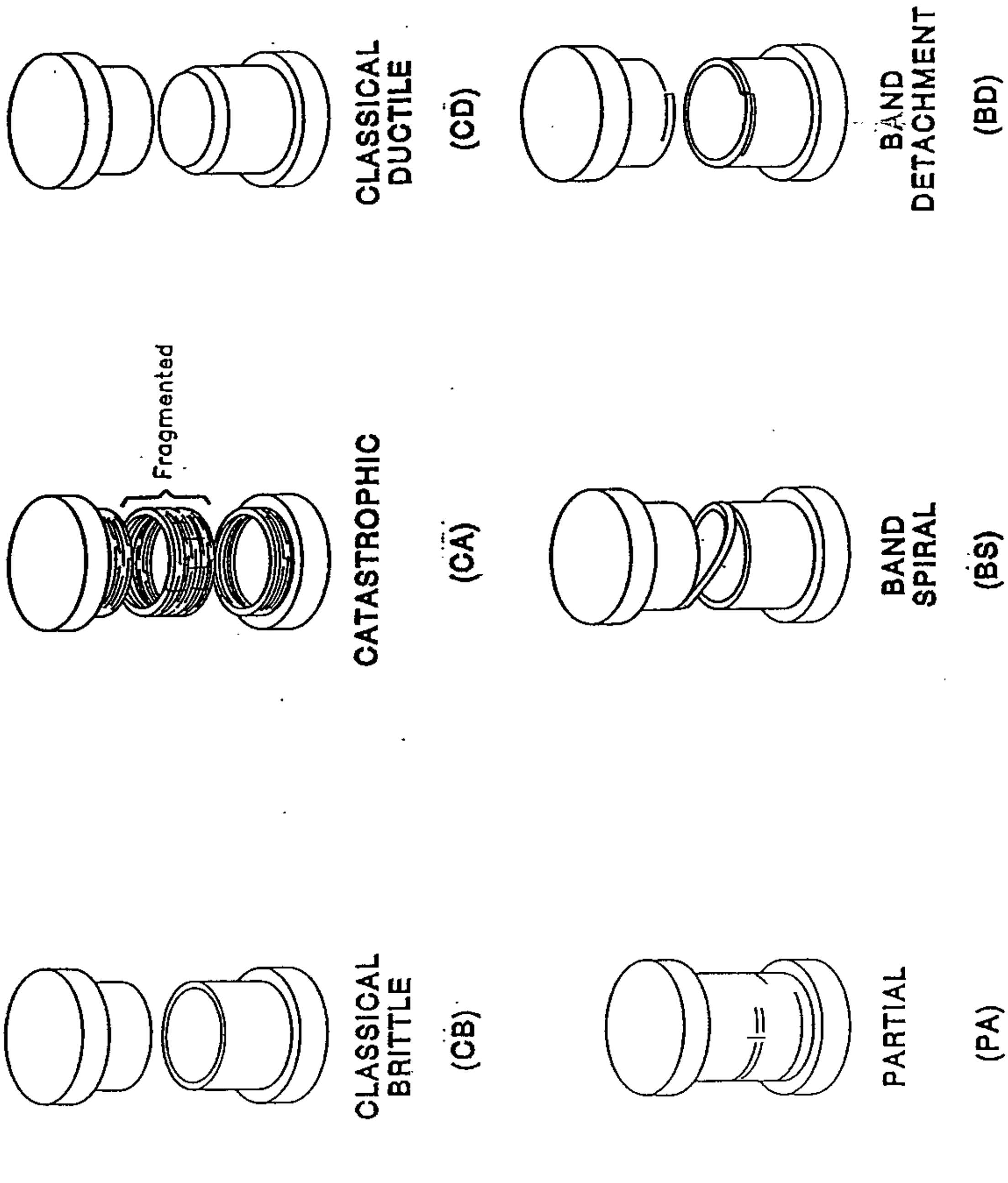


Figure 8. Failure Modes for Hoop Wound Tubes in Tension

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

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1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.
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3. DOCUMENT TITLE
TRANSVERSE TENSILE PROPERTIES OF UNIDIRECTIONAL FIBER/RESIN COMPOSITE CYLINDERS

4. NATURE OF CHANGE *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

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US Army Materials Technology Laboratory
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