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Standard Guide for Testing In-plane Shear Properties of Composite Laminates[1]

This standard is issued under the fixed designation D 4255/D 4255M; 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.

ϵ^1 NOTE—Section 12 was added and other editorial changes were made in December 1994.

1. Scope

1.1 The in-plane shear properties are determined by imposing edgewise shear loads on the specimen using Method A, a fixture consisting of two pairs of rails tensile loaded; or Method B, a fixture consisting of three pairs of rails in tension or compression loading.

1.2 Two methods are presented as follows:

1.2.1 *Method A*—Test of in-plane shear shall be made on specimens clamped between two pairs of steel loading rails. See Fig. 1. This fixture, when loaded in tension, introduces shear forces in the specimen that produce failures across the panel. With most composite sheet materials, failure is due to a combination of diagonal tension and compression forces.

1.2.2 *Method B*—Test of in-plane shear shall be made on specimens clamped securely on opposite edges and a load applied to a third pair of steel rails in the center. See Fig. 2. The center load of either tension or compression will produce a shear load in each section of the specimen. With most composite sheet materials, failure is due to a combination of diagonal tension and compression forces.

NOTE 1—Strain gages at ±45° have shown significantly different shear strains on the same specimen. This may be due to differences in shear behavior with a tensile force at one 45° angle and compression force at the opposite 45° angle.

1.3 *In-plane Shear*—The shear associated with shear forces applied to the edges of the laminate so that the resulting shear deformations occur in the plane of the laminate rather than through the thickness.

1.4 In-plane shear specimens normally fail by buckling out of plane. The measured values of ultimate shear strength and shear modulus may be affected by sample dimensions or physical constraints, or both, that cause the sample to resist this out-of-plane buckling. Because of the above, this method is a standard guide instead of a standard method. Data obtained should be judged on this basis. For similar materials of the same sample dimensions in the same test system, consistent results are possible.

1.5 These methods cover the determination of the in-plane shear properties of resin-matrix composites reinforced by continuous or discontinuous high-modulus, 20 GPa [3 × 10−6 psi] or greater, fibers. This includes the following:

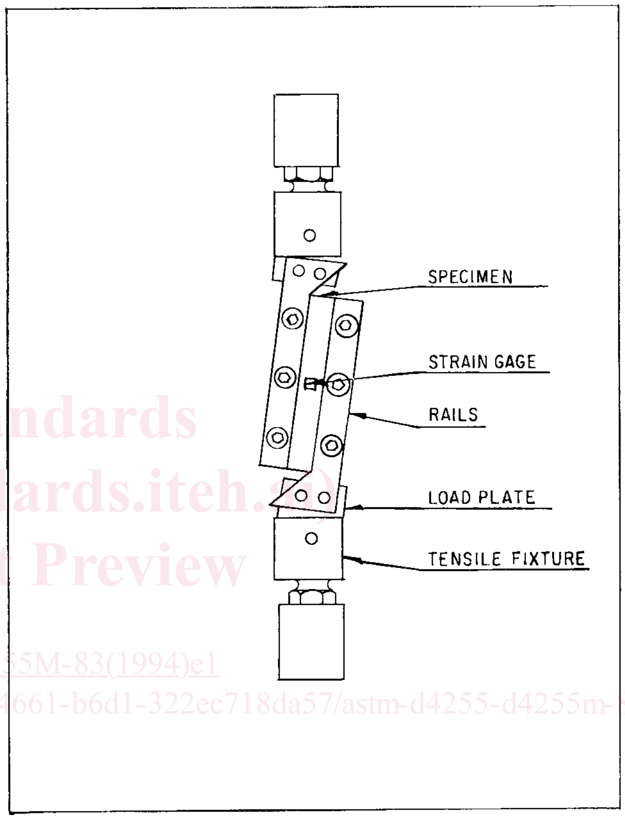

FIG. 1 Method A Assembly Rail Shear Apparatus

1.5.1 *Unidirectional*—Continuous or discontinuous reinforcing fibers, 0° and 90° properties.

1.5.2 *Laminates of Symmetric, Orthotropic Construction (*Note 2*)*—Continuous or discontinuous reinforcing fibers.

NOTE 2—Difficulties may arise when using this method in conjunction with ± 45° angle-ply laminates. In particular, detailed stress analysis has shown that a uniform state of shear is not attained for this orientation. Test Method D 3518/D 3518M is recommended as an alternative.

1.5.3 Random-oriented fibrous laminates.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the*

[1] This guide is under the jurisdiction of ASTM Committee D-30 on High Modulus Fibers and Their Composites and is the direct responsibility of Subcommittee D 30.04 on High-Performance Fibers and Composites.

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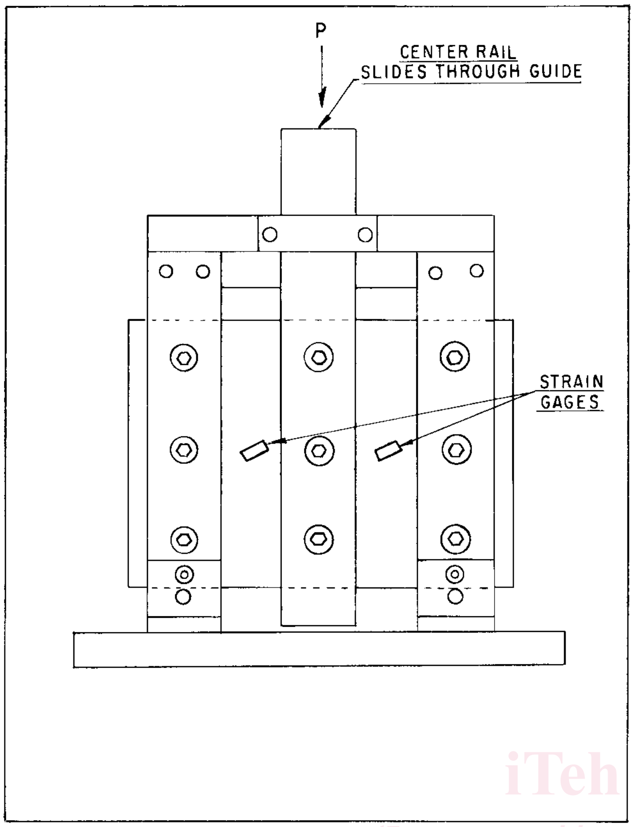


FIG. 2 Method B Assembly Rail Shear Fixture

responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1.7 The values stated in either SI or inch-pound units are to be regarded separately as standard. Within the text the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

D 618 Practice for Conditioning Plastics and Electrical Insulating Materials for Testing[2]

D 3518/D 3518M Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a ±45° Laminate[3]

E 4 Practices for Force Verification of Testing Machines[4]

E 83 Practice for Verification and Classification of Extensometers[4]

3. Summary of Methods

3.1 A flat rectangular plate is tested in a rail shear fixture as follows:

3.1.1 *Method A*—The test fixture consists of two pairs of rails which can be fastened to the test specimen usually by bolts. A tensile force is applied to the rails which induces an in-plane shear load on the specimen. If shear modulus is required, a strain gage is mounted in the center of the specimen at 45° to the specimen's longitudinal axis. The load is applied to failure. The failure strength, elastic shear strain, and failure mode should be recorded. A typical two rail shear fixture is shown in Figs. 1 and 3 with details in Figs. 4-6.

3.1.2 *Method B*—The test fixture consists of three pairs of rails that are fastened to the test specimen usually by bolts. The two outside pairs of rails are attached to a base plate which rests on the test machine. A third pair of rails (middle rails) are guided through a slot in the top of the base fixture. The unit shown is loaded in compression. It would also be permissible to tensile load the middle rails but this will require fastening the base fixture to the test machine. If modulus values are desired, the strain gage should be mounted in the center of both test sections at 45° to the specimen's longitudinal axis. The load is applied to failure. The failure strength, elastic shear strain, and failure mode should be recorded. A typical three rail shear fixture is shown in Fig. 2, Fig. 7, and Fig. 8. Details are shown in Figs. 9-11.

4. Significance and Use

4.1 These shear tests are designed to produce in-plane shear-property data for material specifications, research and development, and design. Factors that influence the shear properties and should therefore be reported are: material, fiber orientation, fiber form (continuous or chopped), stacking sequence, methods of material and specimen preparation, specimen conditioning, environment of testing, void content, volume percent reinforcement, specimen dimensions, and test method chosen.

5. Apparatus

5.1 *Gages*, suitable for reading to within 1 % of the sample length and thickness.

5.2 *Testing Machine*, comprised of the following:

5.2.1 *Fixed Member*—A fixed or essentially stationary member supporting the load fixture.

5.2.2 *Movable Member*, capable of applying a compressive or tensile load to the test fixture.

5.2.3 *Drive Mechanism*—A drive for imparting to the movable member a controlled velocity with respect to the stationary member.

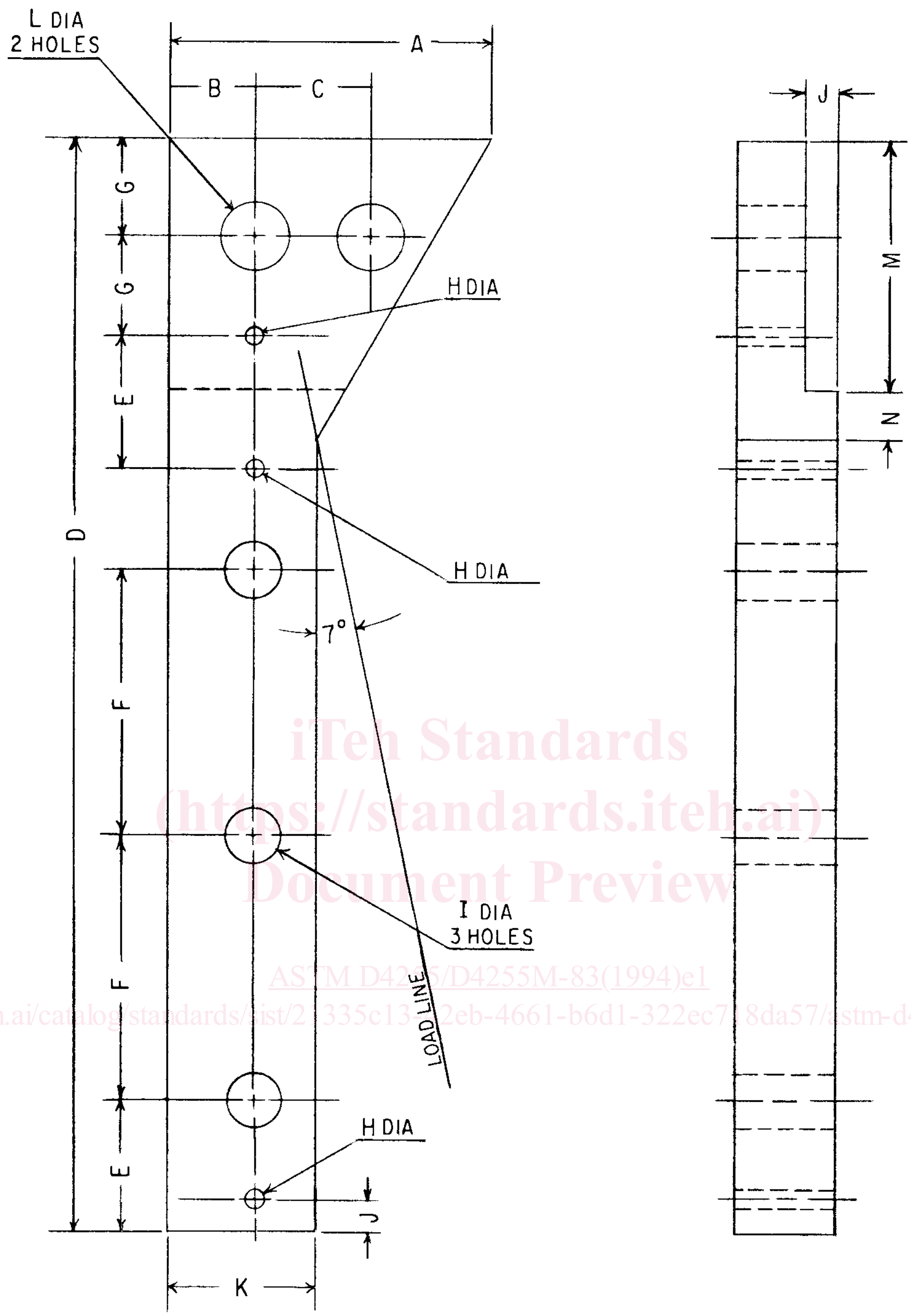
5.2.4 *Load Indicator*—A suitable load-indicating mechanism shall be provided that is capable of showing the total compressive or tensile load carried by the test fixture. This mechanism should indicate the load with an accuracy of 1 % or better of the true value. The accuracy of the testing machine shall be verified in accordance with Practices E 4.

5.2.5 *Strain Recording*—A suitable strain-recording system is required for modulus determinations.

5.3 *Rails*—Rails are shown in Fig. 4, Fig. 9, Fig. 10, and Fig. 11 for clamping the test specimen. Drilled holes should be oversized to prevent stress risers when the bolts are tightened. Hole tolerances will depend on the material tested and gripping methods.

5.3.1 The following modifications have been used to grip the specimens:

[2] *Annual Book of ASTM Standards*, Vol 08.01.
[3] *Annual Book of ASTM Standards*, Vol 15.03.
[4] *Annual Book of ASTM Standards*, Vol 03.01.

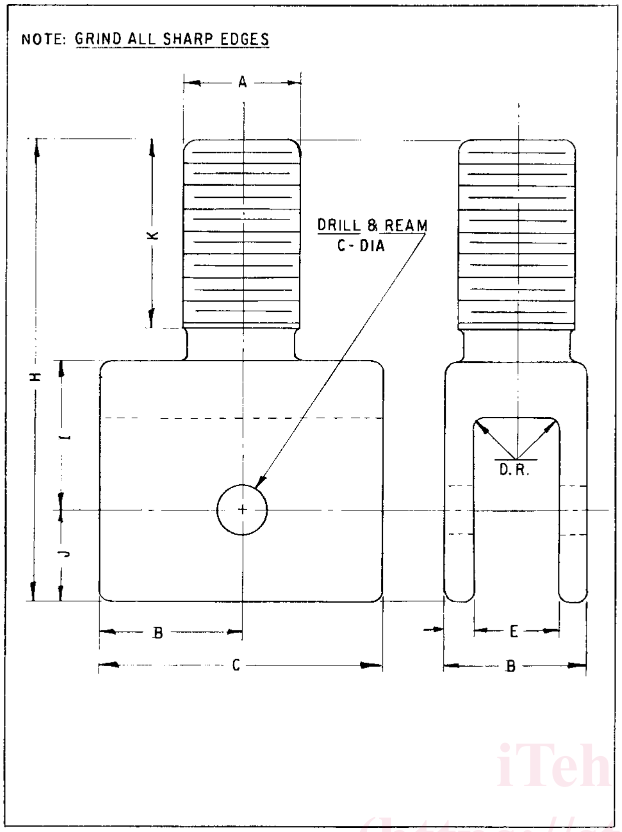


* Surface finish to specification

Dimension	mm	in.	Dimension	mm	in.
A	60.1	2.38	H	3.2	0.125
B	15.9	0.625	I	9.5	0.375
C	22.2	0.875	J	6.5	0.25
D	209.6	8.25	K	28.6	1.125
E	25.0	1.0	L	12.7	0.50
F	51.0	2.0	M	47.6	1.875
G	19.0	0.75	N	9.7	0.38

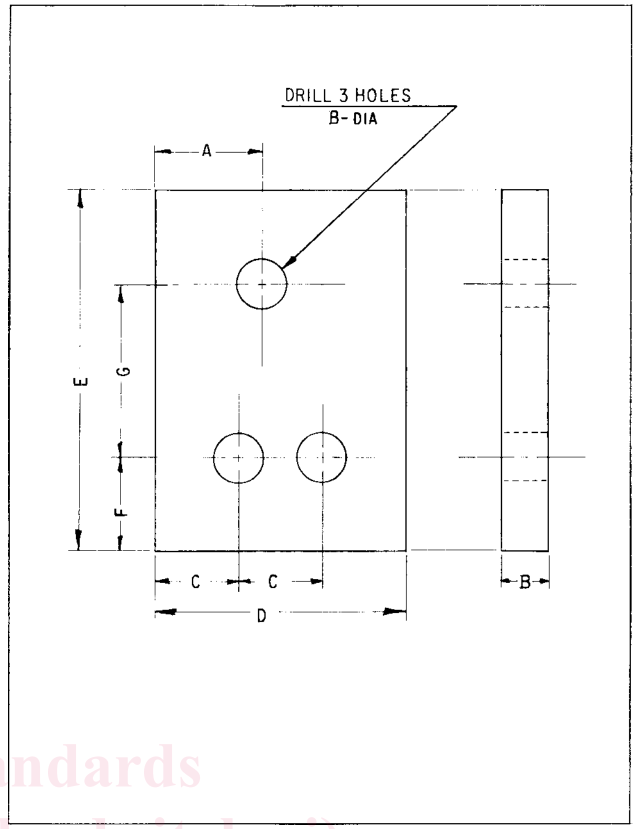
FIG. 4 Rails for Method A

Detail Two Rail Shear Rails
Four Required Two This Way
Two Reversed
Not to Scale



Dimension	mm	in.
A	33.0 to 3.5	1¼ to 12
B	38.0	1½
C	13.0	½
D	6.0	¼
E	24.0	15/16
F	7.0	9/32
G	76.0	3
H	128.5	5 1/16
I	41.3	1⅝
J	25.0	1
K	51.0	2

FIG. 5 Tensile Head for Method A Two Required—Cold-Rolled Steel



Dimension	mm	in.
A	25	1⅛
B	12	½
C	22	⅞
D	67	2⅝
E	98	3⅞
F	25	1
G	48	1⅞

FIG. 6 Load Plate for Method A Two Required—Cold-Rolled Steel

5.3.1.1 Abrasive paper or cloth adhered to the rails,

5.3.1.2 Machining V grooves in the rails,

5.3.1.3 Center punching rails in random order,

5.3.1.4 Changing number of bolt holes from three up to eight per rail associated with smaller holes,

5.3.1.5 Soft metal shims, and

5.3.1.6 Tabbing specimens in rail areas.

5.3.2 The above list is not inclusive but was typical of methods used by various laboratories to meet the requirements of specific materials. Items that work for one material may be unacceptable for another. If these modifications are to be used as part of a specification, it is important that the rail grip system be completely specified and these modifications noted in the test report.

5.4 *Test Fixtures*:

5.4.1 *Method A*—A typical two-rail shear fixture is shown in Fig. 1 and Fig. 3 with details in Figs. 4-6. The test fixture consists of two pairs of rails which can be fastened to the test specimen usually by bolts. The rails are then attached to the test machine through pins, a plate that acts as an aligning fixture, and a clevis that connects directly to the test machine. This equipment is typical but not the only configuration usable. Note that earlier tests have been run where the two rail shear fixtures were compression loaded. Also see 5.3.1 for rail modifications.

5.4.2 *Method B*—A typical three-rail shear fixture is shown in Fig. 2, Fig. 7, and Fig. 8. Details are shown in Figs. 9-11. The test fixture consists of three pairs of rails that are fastened to the test specimen usually by bolts. The two outside pairs of rails are attached to a base plate that rests on the test machine. The third pair of rails (middle rails) are guided through a slot in the top of the base fixture. The unit shown is loaded in compression. It would also be permissible to tensile load the middle rails, but this will require fastening the base fixture to the test machine. This equipment is typical but not the only configuration that is usable. Also see 5.3.1 for rail modifications.

5.5 *Strain*—Where load-strain data are desired, the specimen may be instrumented with strain gages.

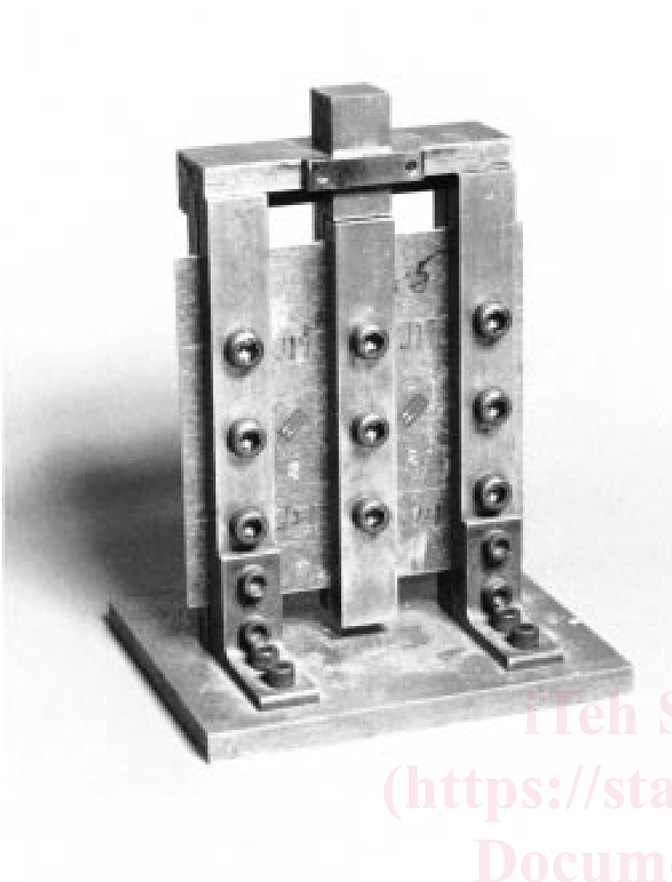


FIG. 7 Method B Assembled Typical Test Fixture

5.5.1 *Location*—The strain gages should be located at the center of the specimen at a 45° angle to the rails as illustrated in Fig. 1 and Fig. 6. The gages, surface preparation, and bonding agents should be chosen to provide for adequate performance on the subject material, and suitable automatic-strain recording equipment shall be employed. Some laboratories have found it necessary to reduce the rail size in the strain-gage area to have sufficient space for the strain gages and wire leads.

5.5.2 For initial trials of the equipment, modification of equipment, or a new material, it is recommended that strain rosettes of 0 and ±45° be used. Using this method, it is possible to see if the major shear strains are at ±45° and if they are equal. If the major shear strains are not at ±45°, it is possible to rotate the strains with use of the 0° data. Equations to rotate strains are available from several references, including most strain-gage manufacturers literature.

NOTE 3—Test data have been recorded where the strain values in one 45° direction are twice that in the other 45° direction, while the 0° strain indicated less than a ±2° correction factor. This may influence the choice of a rosette strain gage instead of a single 45° gage.

6. Test Specimen

6.1 *Geometry*:

6.1.1 *Method A*—The recommended test specimen shall conform to the dimensions shown in Fig. 12 (Note 4) and shall be supported by rails dimensioned in Fig. 4. Note that while the sample outer dimensions are uniform, many variations of hole patterns and tabbed edges have been used. See 5.3.1.

NOTE 4—It is recommended that laminates be 1.27 to 3.17 mm [0.050 to 0.125 in.] thick. Thin laminates tend to exhibit buckling at low loads while thicker laminates can have shear strengths in excess of the rail-clamping capacity.

6.1.2 *Method B*—The test specimen shall conform to the dimensions shown in Fig. 13 (Note 4) and shall be supported by rails dimensioned in Figs. 9-11.

6.2 The straight edges of the specimen may have coarse tool marks from the machining operation; however, the holes should be drilled and reamed if minor delamination occurs. The holes shown are oversize to the bolts, although press fit bolts have been used with success, particularly with tabbed specimens.

6.3 *Number of Specimens*—At least five specimens shall be tested for each sample.

6.4 *Health and Safety*—When fabricating composite specimens by machining operations, a fine dust consisting of particles of fibers or the matrix material, or both, may be formed. These fine dusts can be a serious health or safety, or both, hazard. Adequate protection should be afforded operating personnel and equipment. This may require adequate ventilation or dust collecting, or both, facilities at a minimum.

7. Conditioning

7.1 *Standard Conditioning Procedure*—The test specimen shall be conditioned and tested in a room or enclosed space maintained at 23 ± 2°C [73.4 ± 3.6°F] and 50 ± 5 % relative humidity in accordance with Procedure A of Practice D 618.

8. Procedure

8.1 *Method A*:

8.1.1 *Speed of Testing*, shall be determined by the specifications for the material being tested or by agreement between those concerned. However, when the speed of testing is not specified, a speed of 1 to 1.5 mm/min [0.04 to 0.06 in./min] should be used.

8.1.2 Measure the least length between the rails to the nearest 0.25 mm [0.01 in.] and several thicknesses along the length of the specimen to the nearest 0.025 mm [0.001 in.]. Record the minimum cross-sectional area.

8.1.3 Place the specimen between the pairs of rails. Align the rails with the specimen. Place a 12.5-mm [½-in.] spacer between opposite pairs of rails. Ensure that there is no bearing contact, in the direction of loading, between the 9.5-mm [⅜-in.] diameter bolts and the 12.5-mm [½-in.] diameter holes. Orient the rail guides and apply a torque of 7 to 70 N·m [5 to 50 lbf·ft] to each bolt. Remove the spacer and torque each bolt to 100 N·m [70 lbf·ft]. Use of a fixture to position the rails and sample is helpful.

NOTE 5—Tightening the bolts is very important, however, actual torque values may vary with materials or rail guides, or both. The most important factor is to tighten the rails uniformly. Over tightening must also be guarded against. It is recommended that a fixed pattern of tightening be established and that the bolts be torqued in three stages; finger tighten, then a second level at ¼ to ¾ the final level, then retighten to the final level. An additional check of each bolt is advisable to see that all the bolts

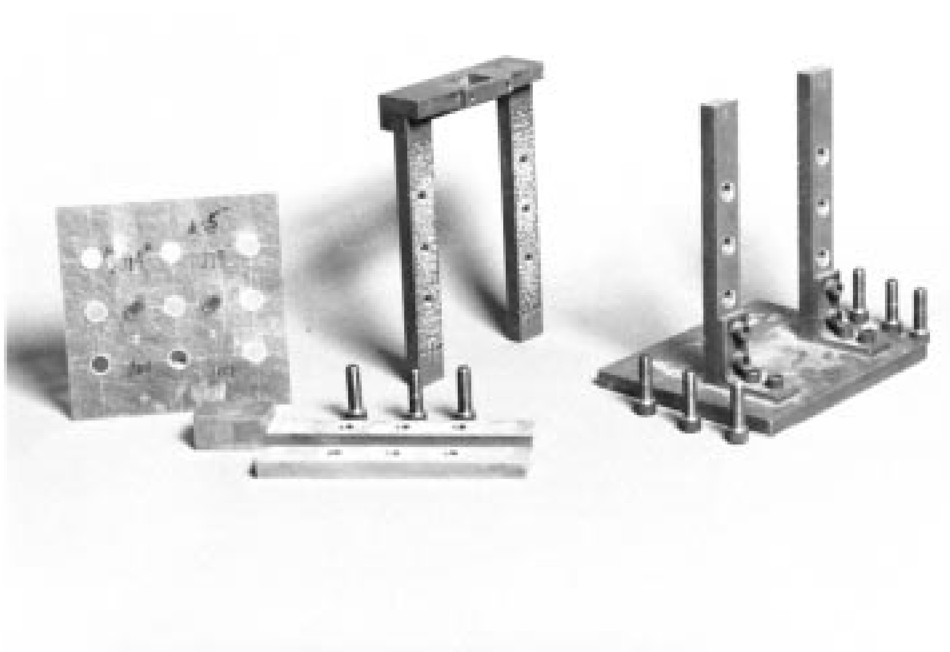


FIG. 8 Method B Disassembled Typical Test Fixture

are at the established torque. A fixture to hold the rails during mounting the sample and tightening the bolts is very helpful.

8.1.4 Place the clamped specimen between the loading heads and check for alignment of the text fixture in a vertical plane through the axis of load application.

8.1.5 If strain is to be determined, attach the strain recording equipment.

8.1.6 Apply a small preload (less than 5 % of failure load) and release to align the heads and rails and zero the strain gages.

8.1.7 Set the speed of testing as recommended.

8.1.8 Record load and strain continuously, if possible.

8.1.9 Record the maximum load carried by the specimen during the test.

8.1.10 Record the strain at or as near as possible to the time of rupture of the specimen.

8.1.11 Record the mode of failure. This is usually from buckling out of plane.

8.2 *Method B*:

8.2.1 See 8.1.1.

8.2.2 See 8.1.2.

8.2.3 Place the specimen in the rails of the test fixture following the procedure outlined in 8.1.3.

8.2.4 Place the test fixture in the testing machine taking care to align the center rail with the movable member of the machine.

NOTE 6—Alignment can be improved by using a spherical seat between the load head and center rail if compression loading is used.

8.2.5 See 8.1.6.

8.2.6 See 8.1.7.

8.2.7 See 8.1.8.

8.2.8 See 8.1.9.

8.2.9 See 8.1.10.

8.2.10 See 8.1.11.

9. Calculations

9.1 *Method A*—This is an apparent shear strength if failure takes place with out-of-plane buckling or from stress associated with rail bolts.

9.1.1 *Shear Strength*—Calculate the shear strength using the following equation, and report the results to three significant figures.

$$S = P/bh$$

S = ultimate shear strength, MPa [psi],
P = maximum load on rails, N [lbf],
b = total length, mm [in.], and
h = thickness, mm [in.].

9.1.2 *Shear Modulus*—Calculate the modulus of elasticity using the following equation, and report the results to three significant figures.

$$G = (\Delta P/\Delta e)/2bh \quad \text{(for + 45° or − 45° strain gage)}$$

G = shear modulus, MPa [psi],
$\Delta P/\Delta e$ = slope of the plot of load as a function of deformation within the linear portion of the curve, MPa/(mm/mm) [psi/(in/in)],
b = total length, mm [in.], and
h = thickness, mm [in.].

9.2 *Method B*—This is an apparent shear strength if failure takes place with out-of-plane buckling or from stress with rail bolts.

9.2.1 *Shear Strength*—Calculate the shear strength using the