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SANDWICH CONSTRUCTIONS AND CORE MATERIALS; GENERAL TEST METHODS

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DEPARTMENT OF DEFENSE
Washington, D. C. 20301

Sandwich Constructions and Core Materials; General Test Methods

MIL-STD-401B

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

2. Recommended corrections, additions, or deletions should be addressed to the Commander, Naval Air Systems Command, (Code 52021), Washington, D. C. 20360.

CONTENTS

FIGURES

1. SCOPE

1.1 Scope. This standard covers the general requirements and methods for testing sandwich core materials and for testing sandwich construction of the types used primarily in aircraft structures. This standard does not include test methods applicable only to a specific product; such test methods are included in the detailed specifications for the product.

* 2. REFERENCED DOCUMENTS 1/

2.1 The issues of the following documents in effect on the date of invitations for bids form a part of this standard to the extent specified herein.

Military Standards

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes.

(Copies of standards required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. 1/ The following documents form a part of this standard to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

American Society for Testing and Materials

ASTM C 177	Method of Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate.
ASTM C 236	Method of Test for Thermal Conductance and Transmittance of Built-up Sections by Means of the Guarded Hot Box.
ASTM C 271	Method of Test for Density of Core Materials for Structural Sandwich Constructions.
ASTM C 272	Method of Test for Water Absorption of Core Materials for Structural Sandwich Constructions.

1/ Designations of comparable test methods of the American Society for Testing and Materials (ASTM) are given, where they exist, for reference information. The methods specified herein are similar in techniques and procedures to the ASTM methods but are frequently more restricted in scope to include tests specifically applicable to sandwich constructions for aircraft.

American Society for Testing and Materials (Continued)

ASTM C 273	Method of Shear Test in Flatwise Plane of Flat Sandwich Constructions or Sandwich Cores.
ASTM C 297	Methods for Tension Test of Flat Sandwich Constructions in Flatwise Plane.
ASTM C 363	Method of Test for Delamination Strength of Honeycomb Type Core Material.
ASTM C 364	Method of Test for Edgewise Compressive Strength of Flat Sandwich Constructions.
ASTM C 365	Method of Test for Flatwise Compressive Strength of Sandwich Cores.
ASTM C 393	Method of Flexure Test of Flat Sandwich Constructions.
ASTM C 394	Method of Test for Shear Fatigue of Sandwich Core Materials.
ASTM D 1781	Method for Climbing Drum Peel Test for Adhesives.

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

3. DEFINITIONS

3.1 General. The following terms are used throughout this standard and their interpretation shall be construed in accordance with the following definitions.

3.1.1 Sandwich. A laminar construction, consisting of thin facings bonded to a relatively thick lightweight core, resulting in a rigid and lightweight panel. In this standard, bonded means "joined by welding, brazing or adhesive."

3.1.2 Core. A lightweight natural, synthetic, or fabricated material bonded between the facings of sandwich construction in order to separate the facings and to support them against buckling under stress.

3.1.3 Facing. One of the two outer layers which have been bonded to the core of a sandwich.

3.1.4 Flatwise. Describes the application of forces in a direction normal to the plane of sandwich. Thus flatwise compression and flatwise tension designate forces applied to compress the sandwich core and to pull the facings from the core, respectively. Flatwise flexure designates bending so as to produce curvature of the plane of a sheet of sandwich.

3.1.5 Edgewise. Describes the application of forces in directions parallel and actually in the plane of a sheet of sandwich.

3.1.6 Isotropic. Describes material, either facings or cores, having the same properties in all directions.

3.1.7 Orthotropic. Describes material, either facings or cores, having different strength and elastic properties in different directions.

3.1.7.1 Orthotropic facing directions are usually described in terms appropriate to the facing composition such as warp and fill direction in cloth, for example.

3.1.7.2 Orthotropic core directions for the identification of the different axes for strength determinations are designated as "T," "L," and "W," which are specified for the following cores;

Core	"T" direction	"L" direction	"W" direction
Wood (End grain to facing)	Parallel to grain	Tangential to annual growth rings	Radial to annual growth rings
Honeycomb	Parallel to core flutes	Parallel to core ribbons	Perpendicular to core ribbons
Cellular Plastic	Parallel to slab or core thickness	Parallel to direction of foaming	Perpendicular to direction of foaming

These directions are further defined by the sketches of Figure 1.

4. GENERAL REQUIREMENTS

4.1 Selection of test samples. The number of samples to be chosen and the method of their selection depend on the purpose of the particular tests under consideration.

* 4.1.1 Design data. If tests are to be made to determine design values for cores, consideration must be given to the number of samples to be tested, and the number of specimens to be tested from each sample. It is suggested that at least

12 samples be tested to furnish average values and standard deviation to indicate variability and reliability of the data for selecting appropriate design values. The average values, number of tests, and standard deviation shall be reported.

4.1.2 Quality assurance provisions.

* 4.1.2.1 Sampling for the various inspections, examinations and tests. Where the inspection lot consists of a number of supposedly identical items, the provisions of MIL-STD-105 apply and should be referenced. The inspection level and Acceptable Quality Level (AQL) to be used will depend upon the expense and importance of the tests involved.

If the inspection lot is of such a nature that MIL-STD-105 should not be used, then not less than five (5) specimens of a given type shall be tested for lot acceptance, with a clear statement of what shall constitute acceptance or rejection of the lot.

When appropriate, variables sampling plans may be used instead of attribute plans.

4.2 Test conditions. The conditions of test depend on the purpose of the particular tests under consideration and should be stipulated in the procurement specification for the material. Normal or room temperature tests shall be conducted at 73 ±2° F (23 ±1° C) and 50 ±4 percent relative humidity. If the physical properties of the materials being tested are affected by moisture, the test specimens shall be brought to constant weight before testing, preferably in a conditioning chamber with temperature and humidity control. The tests shall preferably be made in a room under the same conditions. This would provide specimens having a uniform moisture content, and changes in moisture content would not occur during test.

Care shall be taken in processing specimens which may have been exposed to high humidity and conditions other than normal. Specimens to which loading fittings are bonded should be conditioned prior to bonding the fittings otherwise conditioning may not penetrate to the entire specimen. The fittings should then be bonded to the specimens under the exposure conditions so as to avoid changing the state of the specimen as would be done by bonding a wet specimen in a hot press, for example.

In conducting tests at high or low temperatures the specimen should be maintained at the desired temperature until thermocouple readings taken within the specimen show constant temperature throughout the specimen. A check on one or two specimens will usually indicate how much time is needed for attaining equilibrium conditions.

* 4.3 Test apparatus. Apparatus for performing specific tests is described in the detailed test method and special apparatus for certain materials is described in procurement specifications for the material. General requirements presented here shall be met by apparatus for any tests. Measuring equipment for determining specimen dimensions and weights shall not be in error by more than ±1/2 percent. The testing machine

shall measure loads within ±1 percent of the true load applied. Mass inertia effects of machine fixtures and specimens shall be properly accounted for in calibration of repeated loading test machines so that loading is correct in the load range and machine speeds being used. The speed of the testing machine shall not deviate by more than 25 percent from the specified rate. Strain gages shall measure strains within ±1 percent of their readings. Specific test methods may specify smaller allowable errors but the errors specified here shall not be exceeded in any test. Apparatus for tests, at elevated temperature, should be free of oils and grease and other surface contaminants that might solidify and interfere with free motion of movable parts, such as knife edges and bearings. Apparatus should be made of materials that can withstand long exposure to the elevated temperature without serious deterioration. Stainless steel has been found satisfactory for temperatures up to 1600° F (870° C). Heating can be done in an oven at the milder temperatures, but it will be found advantageous to use radiant heat sources, such as quartz lamps, at higher temperatures.

4.4 Report of test results. The report of each test shall include a complete description of the material tested. Cores shall be described in detail as to the type of material configuration, orientation, and density. Descriptions of sandwich constructions shall include the type, size, and orientation of the facings, the procedure and materials used to bond the facings to the core, and detailed description of the core and its orientation.

The report shall give information on the previous conditioning of test specimens and the conditions during testing.

The report shall include a description of the testing machine and testing apparatus used to measure deformations or deflections.

The report shall include a brief description of testing procedures and shall give detailed descriptions and discussions of procedures which differ from those prescribed in this Standard.

Test results shall be presented in concise form including tables of data, diagrams and graphs, where necessary, and descriptions of test failures, including photographs, if necessary.

* 4.5 Designation of units of measurement. Dimensions, weights, forces, and temperatures are given in U.S. Customary Units and in International Units SI. Values given in the Standard might not be converted literally, but are rounded for convenience and to correspond to accuracy of available measuring instruments.

5. DETAIL TEST METHODS

5.1 Core test methods.

5.1.1 Core Density and Specific Gravity.
(ASTM C 271)

5.1.1.1 Scope. The method describes a test procedure for determining the apparent density and specific gravity of cores of sandwich construction.

5.1.1.2 Test specimens. The test specimens may be any convenient size or shape of core material that can be accurately measured. The number of test specimens shall be determined in accordance with 4.1. The test conditions shall conform to 4.2.

5.1.1.3 Test procedure. The test specimens shall be weighed to an accuracy of ±0.5 percent and the dimensions measured within an accuracy of ±0.5 percent.

5.1.1.4 Calculations. The following formulas shall be used to calculate the core density in pounds per cubic foot:

$$\text{Density } (\text{lb/ft}^3) = \frac{\text{wt (lb)}}{\text{vol (ft}^3)} = 1728\,\frac{\text{wt (lb)}}{\text{vol (in.}^3)} = 3.81\,\frac{\text{wt (gm)}}{\text{vol (in.}^3)} = 62.4\,\frac{\text{wt (gm)}}{\text{vol (cm}^3)}$$

Specific gravity shall be calculated as follows:

$$\text{Apparent Specific Gravity} = \frac{\text{Density lb/ft}^3}{62.4}$$

5.1.1.5 Report. In addition to the general report requirements of 4.4, the test report shall give the individual and average core density in pounds per cubic foot.

5.1.2 Core Moisture Sorption.
(ASTM C 272)

5.1.2.1 Scope. This method describes a test procedure for determining the sorption of water by core materials when immersed.

5.1.2.2 Test specimen. The test specimen shall be 3 inches square and 1/2 inch thick (75 mm by 75 mm by 12 mm). The thickness of the specimen shall be in the same direction as the core thickness when used in sandwich construction. The test specimens shall be machined, sawed, or sheared from the core samples so as to have smooth surfaces which are free from cracks. The number of test specimens shall be determined in accordance with 4.1. Specimens shall be conditioned in accordance with 4.2.

5.1.2.3 Test procedure. The conditioned specimens shall be weighed to an accuracy of ±0.5 percent, and then completely immersed to a depth of 1 to 2 inches (25 to 50 mm) in distilled water, maintained at a temperature of 73 ±2° F (23 ±1° C). Specimens which float shall be held under water by a loose net or screen, weighted just enough to submerge the specimens. The specimens shall be removed from the water and weighed after increasing periods of immersion so as to determine the moisture sorption - time curve for 60 days. Upon removal of specimens from the water, one at a time, all surface water shall be wiped off with a dry cloth and the specimen weighed immediately. For cores that tend to trap water in surface pores or core cells, the specimen should be dipped in absolute alcohol, dried quickly in a gentle current of warm air, and weighed immediately. If a core material is known or suspected to contain any appreciable amounts of water-soluble ingredients, the specimens of this core shall be reconditioned at 50 ±4 percent relative humidity at 73 ±2° F (23 ±1° C) to obtain the amount of dissolved material, as determined by difference in weight of originally conditioned and reconditioned specimens.

5.1.2.4 Report. In addition to the general report requirements of 4.4, the test report shall include:

(a) Moisture sorption data presented as a graph of percent water sorption versus time in days.

(b) Amount of water soluble material, if any, expressed as percent of original conditioned sample.

* 5.1.3 Core Thermal Conductivity.
(ASTM C 177)

Note: The referenced method describes procedures and apparatus suitable for determining thermal conductivity in the range -100° F to 500° F and 200° F to +1,300° F (-73° C to +705° C).

5.1.4 Core Compression.
(ASTM C 365)

5.1.4.1 Scope. This method of test describes a procedure for determining compressive properties of sandwich cores and sandwich constructions. Deformation data can be obtained; and, from a complete load-deformation curve, it is possible to compute the compressive stress at proportional limit load, ultimate compressive strength, and modulus of elasticity of the core.

Core properties are usually required, for design purposes, in a direction normal to the plane of facings as the core would be placed in a sandwich construction, and the test procedure pertains to compression in this direction in particular, but also can be applied to determining compression properties in other directions.

5.1.4.2 Test specimens. Flatwise compression specimens shall be of core or of sandwich and shall have a minimum 2- by 2-inch (5- by 5-cm) cross section. The height of the specimens shall be not greater than 8 inches (20 cm) nor less than 1/2 inch (12 mm). Edgewise compression specimens of core (not sandwich) shall be at least 2 inches by 3/8 inch (5- by 1-cm) in cross section and shall be not greater in height than 4 times the smallest cross-sectional dimension. The dimensions of the specimens shall be measured to an accuracy of at least 0.5 percent. The number of specimens shall be determined in accordance with 4.1. The specimens shall be conditioned in accordance with requirements of 4.2.

* 5.1.4.3 Specimen preparation. Care shall be taken to prepare the test specimens so that the loaded ends will be parallel to each other and perpendicular to the sides of the specimen. In order to avoid local crushing at the ends of some cores in flatwise compression, particularly honeycomb and gridded cores, it is desirable to reinforce the ends with a suitable material. The ends may be cast in a molding material, such as plaster of Paris or cast resin, or they may be dipped in a thin layer of resin (epoxy resin has been found to be satisfactory) and cured at room temperature or slightly elevated temperature. The resin-dipping procedure results in leaving openings at the ends of the cells of the specimen, thus allowing circulation of exposure media if such exposures are to be made. It has been found that a resin dip, as shallow as 1/16 inch (2 mm), will provide adequate support for many types of cores so as to prevent localized end failures.

* 5.1.4.4 Test procedure. The load shall be applied to the specimen through a spherical loading block, preferably of the suspended, self-aligning type. Care shall be taken so that the block shall apply load as uniformly as possible over the entire loading surface of the specimen. The load shall be applied at a constant rate of movement of the movable head of the testing machine (Note 1) and at such a rate that the maximum load (Note 2) will occur between 3 and 6 minutes.

Note 1: A suggested rate of head movement is 0.3 percent of core height, per minute.

Note 2: For cores that continue to compress and have no definite maximum load, the maximum load shall be the load at 2 percent strain, or if head movement is measured, the maximum load shall be the load at 10 percent total compression.

Data for stress-strain curves may be taken. For determining strains, deformations shall be measured to at least the nearest 0.0001 inch (0.002 mm) by means of a compressometer, having a gage length not exceeding 2/3 of the height of the specimen. The compressometer shall measure average deformations (measurements can be taken on two opposite sides of the specimen and averaged) over the central portion of the height of the specimen. The compressometer shall be light in weight, require a minimum force to operate, and shall be attached in such a way that it will not damage or stiffen the specimen, thus producing incorrect results. Increments in load should be chosen so that at least 12 readings of deformation are taken to proportional limit.

A Marten's mirror-type of strain gage, a Tuckerman strain gage, or a microformer type, with autographic recorder, have been found to work satisfactorily for most cores. For honeycomb cores having cells smaller than 1/2 inch (12 mm), it has been found that properties of specimens 1/2 inch (12 mm) in height are no different than for specimens 4 or 8 inches (10 or 20 cm) long; thus, a long specimen can be tested using a long gage length and, in general, a more practical, simpler test will result than if short 1/2-inch (12-mm) specimens are tested. For extremely soft cores, it has been found necessary to measure strains with Filar microscopes, focused on points of fine needles inserted in the core. Bonded electric resistance strain gages are usually not considered satisfactory for soft cores because of the stiffness of the gage. The reinforcing effect of bonding these gages to some cores leads to large errors in actual strain measurement.

Note: The use of dial gages for measuring head movement to obtain strains is not as accurate as, nor exactly comparable to, the use of strain gages mounted on the specimen. Such measurements of total compression, interpreted as strains, lead to value of moduli of elasticity having considerable variation, and to values perhaps only 1/10 of the values as correctly obtained by measuring directly on the specimen. Also, proportional limit loads will be greater if head movement is interpreted as strain, thus leading to unconservative proportional limit stresses.

5.1.4.5 Report. In addition to the general report requirements of 4.4, the test report shall include:

(a) Description of specimen ends including details of procedures used to obtain these end conditions.

(b) Stress-strain or load-deformation diagrams, if deformations were measured; and these data should be analyzed to give the core modulus of elasticity and stress at proportional limit.

(c) Compressive strength values, individual and averages.

5.1.5 Core Shear.
(ASTM C 273)

5.1.5.1 Scope. This method of test describes a procedure for determining shear properties of sandwich cores or of composite sandwich construction. The core or sandwich specimen is bonded between thick steel plates which are displaced, relative to each other, during testing, thus placing the bonded specimen in shear. Deformation data can be obtained and, from a complete load-deformation curve, it is possible to compute the shear stress at proportional limit load, shear strength, and shear modulus.

Shear properties, usually required for design purposes, are those associated with shear distortion of planes parallel to the edge plane of a sandwich. This test is designed to apply, in particular, to core thus oriented, and then the test determines shear strength parallel to the plane of the sandwich and shear modulus associated with distortion in a plane normal to sandwich facings. The method may be used to determine shear properties in other directions.

Example: For honeycomb cores, the shear properties are determined by bonding the heavy steel plates on the core cell ends; and, load is applied so as to shear the TL (strong) or TW (weak) core plane (see Figure 1).

* 5.1.5.2 Test specimens. Shear specimens shall be of core or of sandwich and shall preferably be 2 inches by 1/2 inch by 6 inches (50 by 12 by 150 mm) in size. If a different size is to be tested, the width shall be not less than twice the thickness, and the length shall be not less than 12 times the thickness. The dimensions of the specimens shall be measured to an accuracy of at least 0.5 percent. The number of specimens shall be determined in accordance with 4.1. The test specimens shall be conditioned as described in 4.2.

* 5.1.5.3 Specimen preparation. Figure 2 shows apparatus for applying tensile loads or compressive loads to produce shear in the specimen. Care should be taken to prepare the test specimen so that the surfaces to be bonded will be plane and parallel to each other. The loading plates shall be bonded to the specimen with a fairly rigid adhesive (epoxide resin adhesive or phenol-vinyl-polymers have been found to be suitable for bonding the loading plates). Care shall be taken not to crush the core when the plates are being bonded to it. The plates shall be properly positioned on the core so that the line of action of the testing force shall pass as closely as possible through diagonally opposite corners of the specimen. The thickness of the loading plates may be varied with the strength of the specimen. It has been found that loading plates having a stiffness not less than 600,000 pound-inches^2 per inch of width per inch of core thickness (2.67 MN-cm^2 per cm of width per cm of core thickness) have performed satisfactorily.

* 5.1.5.4 Test procedure. The load shall be applied to the ends of the loading plates in tension or compression, through a universal joint or a spherical bearing block, so as to distribute the load uniformly across the width of the specimen and along a line extending from diagonally opposite corners of the specimen. The load shall be applied through continuous motion of the movable head of the testing machine, at a rate such that failure will occur in not less than 3 and not more than 6 minutes.

Note: A suggested head travel of 0.5 percent of specimen length, per minute, may be used as a guide in obtaining the proper testing machine speed.

Data for stress-strain curves may be taken. For determining strains, deformations shall be measured to at least the nearest 0.0001 inch by means of apparatus such as a dial gage attached to measure motion of loading plates relative to each other. Increments in load should be chosen so that at least 12 readings of deformation are taken to proportional limit.

5.1.5.5 Calculations. Shear stresses shall be computed from the formula:

$$f_s = \frac{P}{ab}$$

where f_s = shear stress
P = applied load
a = specimen length
b = specimen width

Specimen shear modulus shall be computed from the formula:

$$G = W \frac{t}{ab}$$

where $W = \frac{P}{r}$ Slope of initial linear portion of load deformation $(P-r)$ curve

r = movement of one load plate with respect to the other

t = specimen thickness.

Note. If the specimen is of core alone, the modulus is obtained for the core. However, if the specimen is of sandwich, G is a composite modulus and the core modulus may be computed from the formula shown below. In this formula, to obtain the core modulus by running the test on the sandwich construction, the value of G_f may be unavailable or difficult to determine. It is therefore suggested that, if the value of G_c is desired when only the sandwich construction is available for testing, the sandwich construction specimen may be positioned in the shear jig so that the line of action of the testing force will pass through the diagonally opposite corners of the core material in the sandwich construction.

$$G_c = \frac{t_c G}{d\left[1 - \frac{G}{G_f}\left(1 - \frac{t_c}{d}\right)\right]}$$

where G_c = core shear modulus
G = composite specimen shear modulus
G_f = facing shear modulus
t_c = core thickness
d = sandwich total thickness.

5.1.5.6 Report. In addition to the general report requirements of 4.4, the test report shall include:

(a) Description of bonding process used to attach the loading plates.

(b) Stress-strain or load-deformation diagrams, if deformations were measured and these data should be analyzed to give the core shear modulus and stress at proportional limit.

(c) Shear strength, individual values, and averages.

5.1.6 Core Tension.

5.1.6.1 Scope. This test method is the same as for Sandwich Tension (see 5.2.3). Tension tests are usually made on sandwich and the load is applied in a direction normal to the facings of the sandwich, to test the facing-to-core bond as well as the core. If core specimens are to be tested, it is permissible to bond the loading cubes directly to the core, and thus determine strength of the bond or the tensile strength of the core, whichever is the weaker.

* 5.1.7 Core Water Migration.

5.1.7.1 Scope. This test shall determine the rate of water migration into the core of a sandwich with a punctured facing. The specimen shall be a sandwich at least 5 by 5 inches (12 by 12 cm) in cross section. The facings shall be of impervious material and shall be bonded to the core with a water-resistant adhesive.

Note: It has been found helpful to have facings of transparent glass or plastic to permit visual observation into the core cells by illumination.

The adhesive shall be applied so that fairly heavy fillets form between the core cell wall ends and the facings, thus assuring a water-tight joint between the facings and core. A hole, opposite one centrally located core cell, shall be drilled through the upper facing. The hole shall lead directly into only one cell. A suitable connection shall be provided, such as a bored rubber stopper glued over the hole, for the application of hydrostatic pressure. The primary cell shall be filled with distilled water, measuring the amount of water required or the increase in weight of the sandwich specimen. The primary cell shall then be connected to a distilled water source under a constant head of 3 feet (1 m). The amount of water, transfused during a 24-hour period, shall be determined by weighing the specimen or by measuring the amount transfused.

Note: If transparent facings are used, the water can be colored by fluorescein or eosin dyestuffs to aid visual observation.

The atmospheric conditions under which the tests are conducted shall be reported. It is recommended that the tests be conducted at 73 ±2° F (23 ±1° C), 50 ±4 percent relative humidity, and specimens be conditioned to constant weight under those conditions before testing. The water migration shall be computed as being the cells filled in the 24-hour period. This can be obtained by dividing the amount of transfused water by the amount necessary to fill one cell.

5.1.8 Node Delamination of Honeycomb Core. (ASTM C 363)

* 5.1.8.1 Scope. This method of test describes a procedure for determining the delamination strength (node-to-node bond strength) of honeycomb core.

5.1.8.2 Test apparatus.

(a) Tension testing device, capable of slow, uniform head motion, that will indicate load at failure to within 1 percent accuracy.

(b) Grips, of multiple-pin type or clamping type, multi-pin type is preferred (see Figure 8)

* 5.1.8.3 Test specimens. The specimen of honeycomb core shall be 5 ±1/16 by 10 ±1/2 inches (12 by 25 cm) long, with a test section, outside the grips, of 8 ±0.5 inches, and with the width parallel to the node-to-node bond area. The thickness of the core slice, if possible, shall be 0.500 ±0.005 or 0.625 ±0.005 inch. Specimens shall be conditioned in accordance with 4.2.

In the event that a clamping type of grip is to be used instead of a multiple pin type, the specimen ends can be reinforced against crushing by filling with plaster or reinforcing with a dip coating of resin.

5.1.8.4 Test procedure. Apply tensile load so as to produce a constant rate of grip separation, and reach maximum load in 3 to 6 minutes. Failure in the grips shall not be considered a satisfactory test.

5.1.8.5 Calculation. The delamination strength (node-to-node bond strength) shall be calculated by the formula:

$$F = \frac{P}{LT}$$

where: F = the delamination strength,
P = the ultimate tensile force,
L = width of specimen, and
T = thickness of specimen.

5.1.8.6 Report. In addition to the delamination strength the test shall include the general report requirements of 4.4.

5.2 Sandwich test methods.

5.2.1 Sandwich Compression.

(a) Flatwise compression of sandwich (load applied normal to facings) is performed in accordance with 5.1.4, as for compression of cores.

(b) Edgewise compression sandwich is performed as described below (ASTM C 364)

* 5.2.1.1 Scope. The Edgewise Compression Sandwich test covers a procedure for determining compressive properties of sandwich constructions in a direction parallel to the plane of a sheet of sandwich. The edgewise compressive strength of short specimens of sandwich provides a basis for judging the load-carrying capacity of the sandwich in terms of developed facing stresses as compared to the yield stress of the facings. The sandwich column, no matter how short, is usually subject to a buckling type of failure. This failure manifests itself by wrinkling of the facing, shear crimping, dimpling of facings or general buckling, in which case, the core deforms to the wavy shape of the facings; by dimpling of the facings into the cell of honeycomb-like cores; or by bending of the sandwich resulting in crimping near the ends, due to core shear failure or perhaps failure of the core-to-facing bond (see Figure 7).

* 5.2.1.2 Test specimens. Edgewise compression specimens of sandwich construction shall be at least 2 inches wide (5 cm), but not less than twice the sandwich thickness, nor less than the width of two complete core cells. The unsupported specimen length (dimension parallel to direction of applied load) shall be not greater than eight times the sandwich thickness.

Care shall be taken in preparing the test specimens to insure smooth end surfaces, free of burrs. The ends shall be parallel to each other (WARNING-good, flat ends are essential for preventing localized end failures at low loads) and at right angles to the length of the specimens. The dimensions of the specimens shall be measured to at least the nearest 0.5 percent.

The number of specimens shall be determined in accordance with 4.1.

The specimens shall be conditioned as described in 4.2.

* 5.2.1.3 Test procedure. The facings of the sandwich shall be supported against lateral buckling at the specimen ends. This can be done by fitting the specimen snugly in round steel bars slotted axially to their diameter. These bars shall have a diameter not less than the thickness of the sandwich plus 3/8 inch (1 cm). Alternate methods of supporting the specimen ends can be accomplished by clamps of rectangular steel bars, fastened together so as to clamp the specimen lightly between them. The cross-sectional dimensions of each of these bars shall preferably be not less than the sandwich thickness; shall be not less than four times the facing thickness; nor less than 1/4 inch (6 mm) in any case. End support may also be obtained by casting the ends of the specimens in a resin, in plaster of Paris, or other suitable molding material.

The load shall be applied to the specimen through apparatus, properly centered on the specimen to distribute the load equally into each facing. Suitable apparatus is shown in Figure 3. The load may be considered to be distributed properly if strains, measured on each facing, are within 10 percent of each other in the early stages of loading. It is essential that strains be measured to avoid widely varying results, due to different effective eccentricities, which occur if strains are not properly balanced. A strain gage, measuring to at least 0.0001 inch (0.002 mm), and having a gage length not greater than 2/3 the unsupported specimen length, will perform satisfactorily on the facings. If a complete stress-strain diagram is desired, load-deformation data may be taken throughout the test.

The load shall be applied at a constant rate of movement of the movable head of the testing machine, and at such a rate that failure occurs in not less than 3 and not more than 6 minutes. A suggested rate of head movement is 0.3 percent of specimen length per minute, for use as a guide in obtaining the proper testing machine speed.

5.2.1.4 Report. In addition to the general report requirements of 4.4, the test report shall include the facing stresses at proportional limit and maximum load.

5.2.2 Sandwich Shear.

5.2.2.1 Scope. This test method is the same as for Core Shear (5.1.5). The core shear testing procedure includes suggestions and computations relative to determining shear properties of sandwich as well as core.

5.2.3 Sandwich Tension.
(ASTM C 297)

5.2.3.1 Scope. This test method covers the procedure for determining the strength in tension flatwise (load applied normal to sandwich facings) of the core, or of the facing-to-core bond of assembly sandwich. The test is performed on specimens, bonded between heavy metal loading blocks, which are pulled apart in a testing machine.

* 5.2.3.2 Test specimens. Flatwise tensile specimens shall be the thickness of the sandwich and not less than 1 square inch (25 by 25 mm) in cross section; for open-celled cores, having cells larger than 3/8 inch (1 cm), the area shall be a minimum of 4 square inches. The dimensions of the test specimens shall be measured to at least 0.5 percent accuracy. The number of test specimens shall be as required in 4.1. The specimens shall be conditioned in accordance with 4.2.

* 5.2.3.3 Specimen preparation. Loading blocks shall be bonded to the facings of the test specimen by a method which shall not appreciably affect the existing bond between facings and core. The bonding pressure shall be less than the original pressure used to bond the facings to the core, and the assembly temperature shall be room temperature, or it shall be at least 50° F (28° C) lower than the temperature at which the sandwich was originally bonded. (Epoxide resin adhesives have been found useful for bonding the loading blocks at room temperature or at slightly elevated temperature.)

* 5.2.3.4 Test procedure. The specimen, with bonded loading blocks, shall be placed in a self-aligning loading fixture which shall not apply eccentric loads. A satisfactory type of apparatus is shown in Figure 4. The load shall be applied at a constant rate of movement of the movable head of the testing machine, and at such a rate that the maximum load will occur in not less than 3 or not more than 6 minutes. A head movement of 6 percent of specimen thickness per minute is suggested as a guide in obtaining the proper testing machine speed.

5.2.3.5 Report. In addition to the general requirements of 4.4, the test report shall include:

(a) Description of bonding process used to attach the leading blocks.

(b) Tensile strength values; individual and averages.

5.2.4 Sandwich Flexure.
(ASTM C 393)

5.2.4.1 Scope. This test method pertains to the bending of sandwich so that the applied moments produce curvature of the plane of a sheet of sandwich construction. The usual procedure applies shear, as well as bending moment, on the sandwich. The test can produce failure in the sandwich by shearing the core, by shearing the bond between the core and facings, by direct compression or tension failure of the facings, or by localized wrinkling of thin facings at load points or reactions. Thus the test specimen must be carefully designed so that the property sought is actually the one obtained. Long spans produce high facing stresses so that core failures or bond failures would not be expected. Short spans tend to produce core shear or bond failures, provided the facings are thick enough to carry the stresses produced by bending moments and also the local stresses at the load points. Stress concentrations at load points can be reduced by using 2-point loading rather than a single central load point. If deflection readings are taken on a short specimen, it is possible to obtain an approximate value of the core shear modulus. If bending stiffness of the sandwich is not known or cannot be computed, it is possible to obtain bending stiffness by testing a long flexure specimen. The following testing procedures can be used to obtain approximate values of core shear modulus and strength, but the test method of 5.2.2 is more accurate. Approximate value of facing properties can also be obtained; however, test methods for determining properties of the facing material will give more accurate results.

5.2.4.2 Test specimen. The test specimen shall be rectangular in cross section. The facings shall be of the same thickness and the same material. The depth of the specimen shall be equal to the thickness of the sandwich construction, and the width shall be not less than twice the total thickness, not less than 3 times the dimensions of a core cell, nor greater than 1/2 the span length. The specimen length shall be equal to the span length plus 2 inches (5 cm) or plus 1/2 the sandwich thickness, whichever is the greater. The dimensions of the test specimens shall be measured to at least 0.5 percent accuracy. The number of test specimens shall be as required in 4.1. The specimens shall be conditioned in accordance with 4.2.

5.2.4.2.1 Specimen construction. The test specimen shall be constructed so as to determine the properties to be measured.

(a) Shear properties. For determining core shear or bond strength and core shear modulus, the load shall be applied at 2 quarter-span points. The span length (a_s) and facing thickness (t) shall be proportioned so that the ratio of span length to facing thickness (a_s/t ratio) shall not exceed four times the ratio of facing proportional limit stress (F_{PL}) to estimated core shear strength (S); ($a_s/t < 4F_{PL}/S$).

(b) Bending properties. For determining facing strength and pure bending sandwich stiffness, the load shall be applied at two quarter-span points. The span length (a_B) and the facing thickness (t) shall be proportioned so that the ratio of span length to facing thickness (a_B/t ratio) shall be not less than the ratio of estimated strength of facing (F) to core shear strength (S); ($a_B/t > F/S$). If the core shear strength (S) is not available, it may be obtained by conducting a core shear test as outlined in 5.1.5).

* 5.2.4.3 Test procedure. Loads shall be applied to the specimen at two quarter-span points through round steel bars or steel pipes, having a diameter not less than one-half and not more than one and one-half times the sandwich thickness (see apparatus in Figure 5). The bars or pipes shall be circular in cross section to within one percent of their diameter; they shall be straight to within 0.5 percent of their length. If, after a trial test, it is found that local failures occur under load points, it will be

permissible to place thin narrow plates at these points to prevent such failure. The load shall be applied, preferably, through a constant rate of movement of the movable head of the testing machine, and at such a rate that the maximum load will occur in not less than 3 and not more than 6 minutes.

Data for load-deflection curves may be taken to determine core or facing proportional limit stresses, or to determine approximate core shear modulus or sandwich bending stiffness. Increments in load shall be chosen so that not less than 12 readings are taken to proportional limit. Deflections shall be measured to the nearest 0.001 inch (0.01 mm) by apparatus, supported on pins, located at the neutral axis of the sandwich at each reaction point. The apparatus, shown in Figure 5, has been found satisfactory.

5.2.4.4 Calculations. The following formulas are given for determining properties of specimens constructed in accordance with the discussion of 5.2.4.2, and tested in accordance with 5.2.4.3. The core shear stress is given approximately by the formula:

$$S = \frac{P_s}{(d + t_c)b}$$

where S = core shear stress
P_s = total force, applied at 2 points located a distance of $a_s/4$ from each reaction
a_s = span length
d = total sandwich thickness
t_c = core thickness
b = sandwich width

The average facing stresses are given by the formula (for thick facings the stress will be slightly greater at the surface than the average stress):

$$F = \frac{P_B \, a_B}{4t(d + t_c)b}$$

where F = facing stress
P_B = total force, applied at 2 points located a distance of $a_B/4$ from each reaction
a_B = span length
t = facing thickness
d = total sandwich thickness
t_c = core thickness
b = sandwich width

The core shear modulus is given by the formula:

$$G = \frac{P_s \, a_s \, t_c}{2w_s \, (d + t_c)^2 \, b \left(1 - \dfrac{11 P_s a_s^3}{768 w_s D b}\right)}$$

where G = core shear modulus

P_s = total force, applied at 2 points located a distance $a_s/4$ from each reaction

w_s = mid span deflection of sandwich (P_s/w_s is slope of initial portion of force-deflection curve)

a_s = span length

t_c = core thickness

d = total sandwich thickness

b = sandwich width

D = flexural stiffness of sandwich

$$\left(D = \frac{E(d^3 - t_c^3)}{12L}\right)$$

E = modulus of elasticity of facings

L = 0.91 for isotropic facings and 1.00 for most orthotropic facings.

If D is unknown and cannot be computed as above, the sandwich can be tested for deflections on a long span, a_s, and on a short span, a_s, (see 5.2.4.2 for determining spans), and then G and D determined from the following:

$$G = \frac{P_B\, a_B\, t_c \left[\left(\frac{a_B}{a_s}\right)^2 - 1\right]}{2(d + t_c)^2\, b\, w_B \left[\frac{P_B\, w_s}{P_s\, w_B}\left(\frac{a_B}{a_s}\right)^3 - 1\right]} \qquad D = \frac{11 P_B\, a_B\, a_s^2 \left[\left(\frac{a_B}{a_s}\right)^2 - 1\right]}{768\, b\, w_B \left[1 - \frac{P_B\, w_s\, a_B}{P_s\, w_B\, a_s}\right]}$$

Note: Although one-third span two point loading and single point loading are used by Industry they are not recommended for Quality Assurance testing since their resultant values diverge from the norm established by quarter-span two point loading.

5.2.4.5 Report. In addition to the general report requirements of 4.4, the test report shall include maximum facing and core shear stresses, load-deflection diagrams, core shear modulus, and sandwich stiffness as obtained from the particular tests performed.

5.2.5 Sandwich Thermal Conductivity.
(ASTM C 236)

Note: Experiments to evaluate typical aircraft sandwich have not been found in the literature, but it is expected that the referenced test method would give satisfactory results.

5.2.6 Sandwich Peel.
(ASTM D 1781)

5.2.6.1 Scope. This method of test is intended for determining the comparative peel resistance of adhesive bonds between facings and cores of sandwich constructions, when tested under specified test conditons. The method is most applicable when the facings being peeled are relatively thin. The peeling torque calculated from this test includes both the forces required to peel the adhesive bond, and to bend the facing.

* 5.2.6.2 Test apparatus. The peel test apparatus shall consist of a flanged drum, flexible loading straps or cables, and suitable clamps for holding the test specimen. The apparatus shown in Figure 6 has been found to be satisfactory. The outside radius of the drum shall be 2.000 ±0.005 inches (50.80 ±0.05 mm). The radius of the flange, including one half of the thickness of the loading straps or cables, shall be 0.500 ±0.005 inch (12.70 ±0.05 mm) larger than the radius of the drum. This 0.500 ±0.005 inch (12.70 ±0.05 mm) distance is the effective torque arm of the apparatus. A suitable top clamp (Clamp A), for use in loading the specimen, and a drum clamp (Clamp B) shall be used to initially hold the facings tangent to the face of the drum, similar to those shown in Figure 6. The drum shall be balanced about its axis by the use of a weight placed diametrically opposite Clamp B, to compensate for the weight of this clamp. The drum and flange with Clamp B and its compensating weight shall not weigh more than 8 pounds (3.63 kg), a lighter weight being preferable to facilitate handling of the apparatus.

Note: Other dimensions of the drum and flange may be used upon agreement between the supplier and purchaser of the adhesive. For comparative purposes these dimensions should be constant.

* 5.2.6.3 Test specimen. For evaluation of adhesives in sandwich constructions the test specimen shall conform to the general form and dimensions of the specimen shown in Figure 6. The length of the specimen shall be at least 10 inches (25 cm). Thickness of core is not important, except in the sense that the sandwich specimen shall not bend while the facing is being peeled. For comparative evaluation of adhesives in bonding metal-faced sandwich constructions, a facing of 2024-T3 clad aluminum alloy 0.020 inch (0.5 mm) thick, and a core 1/2 inch (12.7 mm) thick has been found to be suitable. These specimens may be cut from larger bonded panels if desired. At least 6 specimens, two or more from each of 3 bonded panels, shall be tested for each adhesive sample.

Note: Direct comparisons of test results can be made only when specimen design is identical.

5.2.6.4 Calibration of test apparatus. The load to overcome resisting torque of each particular drum, Clamp B, and the counter weight shall be determined. This may be done by inserting a strip of thin fabric having negligible stiffness in place in the sandwich specimen, and applying a load sufficient to roll the drum upward around the fabric. This load, with the radius of flange 0.5 inch (12.70 mm) larger than the radius of the drum, will be about four times the total weight of the drum, Clamp B, and the compensating weight.

5.2.6.5 Test procedure. The test specimen shall be clamped securely to the drum by Clamp B as shown in Figure 6, and the other end of the specimen clamped by Clamp A or another suitable test grip. The specimen and apparatus shall then be suspended from the top head of the testing machine by a pin through the hole in Clamp A, or by use of the test grip. The weighing apparatus shall be balanced to zero. The loading bar is then pinned to the fixed fittings in the lower head of the testing machine.

An initial force, equal to that obtained in calibration of the apparatus for load to overcome the resisting torque of the drum, shall be applied by loading the apparatus in tension. The specimen is then ready for testing.

The peel of at least 6 inches (15 cm) of the facing of the sandwich panel, shall then be made by the loading of the apparatus in tension, at a testing machine head speed of 1.00 ±0.01 inch (2.5 ±0.025 cm) per minute. It is preferred that an autograph recording of the force versus head movement, or force versus distance peeled, be made during the peel test. If autographic equipment is not available, average forces can be obtained by recording those at fixed increments of time after the start of the test. The load may be recorded 15 seconds after the start of the test and at each 5-second interval. This will permit calculating an average load over 5 inches (13 cm) of peeling, as described in 5.2.6.6.

* 5.2.6.6 Computation. The average peeling force required to peel the facing shall be taken from the autographic curve for the peeling of the sandwich specimens between 1 and 6 inches (2.5 and 15 cm), or as the average of load readings taken at the fixed time increments during this part of the test. The average peeling torque per unit specimen width for peeling the strip of facing shall be calculated as follows:

$$T = \frac{\text{Torque arm}}{\text{Width of specimen}} \text{(Average peeling force minus force to overcome resisting torque of drum)}$$

The maximum peeling force obtained during the test shall also be recorded, and the maximum peeling torque shall be calculated in accordance with the above formula.

Note: The peeling torque calculated by the method described includes that torque required to bend the facing as well as to peel the facing from the core. Therefore, for comparative evaluation of adhesives, facings of the same material and thickness shall be used. Approximate correction for torque required to bend the facing can be obtained by testing a piece of unbonded facing in the peel apparatus. Thus an approximation of the actual torque necessary to peel the adhesive can be obtained by subtracting the torque necessary to bend the unbonded facing from the average torque needed to peel the sandwich. If this procedure is followed, the report shall give the torque necessary to bend the unbonded facing and also the torque necessary to peel the sandwich.

5.2.6.7 Report. In addition to the general report requirements of 4.4, the test report shall include the following:

(a) Number of specimens tested.

(b) Number of test panels represented.

(c) Force required to overcome the resisting torque of the particular peeling drum used.

(d) Average and maximum peeling torque values per unit specimen width for each specimen, and average values for each group of specimens.

(e) Type of failure, that is, cohesive failure within the adhesive, adhesive to the facing, adhesion to the core, or combinations thereof for each individual specimen.

(f) Approximate radius of the facing for each specimen after peeling.

5.3 Fatique tests. Tests can be conducted under repeated stressing (fatigue) with only slight modifications to adapt apparatus to repeated load (fatigue) testing machines. A minimum of five specimens are required for static control tests, and a similar number for each stress level to be tested to establish a curve of stress versus number of cycles to failure (S-N curve). Usually five stress levels are sufficient for establishing a curve, however, more tests may be needed to firmly determine endurance limits. The average of the static control tests shall correspond with the 100% level for the repeated load tests. The stress level under repeated loading is defined as the maximum repeated stress to which the specimen is subjected. The stress shall be cycled between the maximum and a minimum stress of one-tenth the maximum. A mean load of 50% of the difference between maximum and minimum load shall be applied through the preloading mechanism of the testing machine and a dynamic load (the remaining 50%) through the dynamic loading mechanism. The loading shall be checked frequently unless the testing machine is equipped with automatic load maintainers. The test shall be continued until failure has occurred or a specified number of cycles has been reached without failure. Data reported shall include maximum repeated stress levels, speed of repeated stressing, and number of cycles to cause failure.

5.4 Creep characteristics. Tests can be conducted under long-time loading to determine creep characteristics or rupture at various sustained stress levels. Constant load shall be applied by means of weights, weights and a lever system, or other mechanical or hydraulic apparatus. Deformations or deflections shall be measured initially and also periodically throughout the test time.

Data reported shall include creep rate beyond the initial deformation or deflection as obtained by dividing the creep by the time period between deformation or deflection readings in hours or days; load sustained and expressed as a percent of static control strength; and time to failure, if failure occurred.

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

Preparing activity:
Navy - AS

Review:
Army - MR, EL
Navy - AS
Air Force - 11, 84

User:
Army - MI, ME, AV
Navy - SH

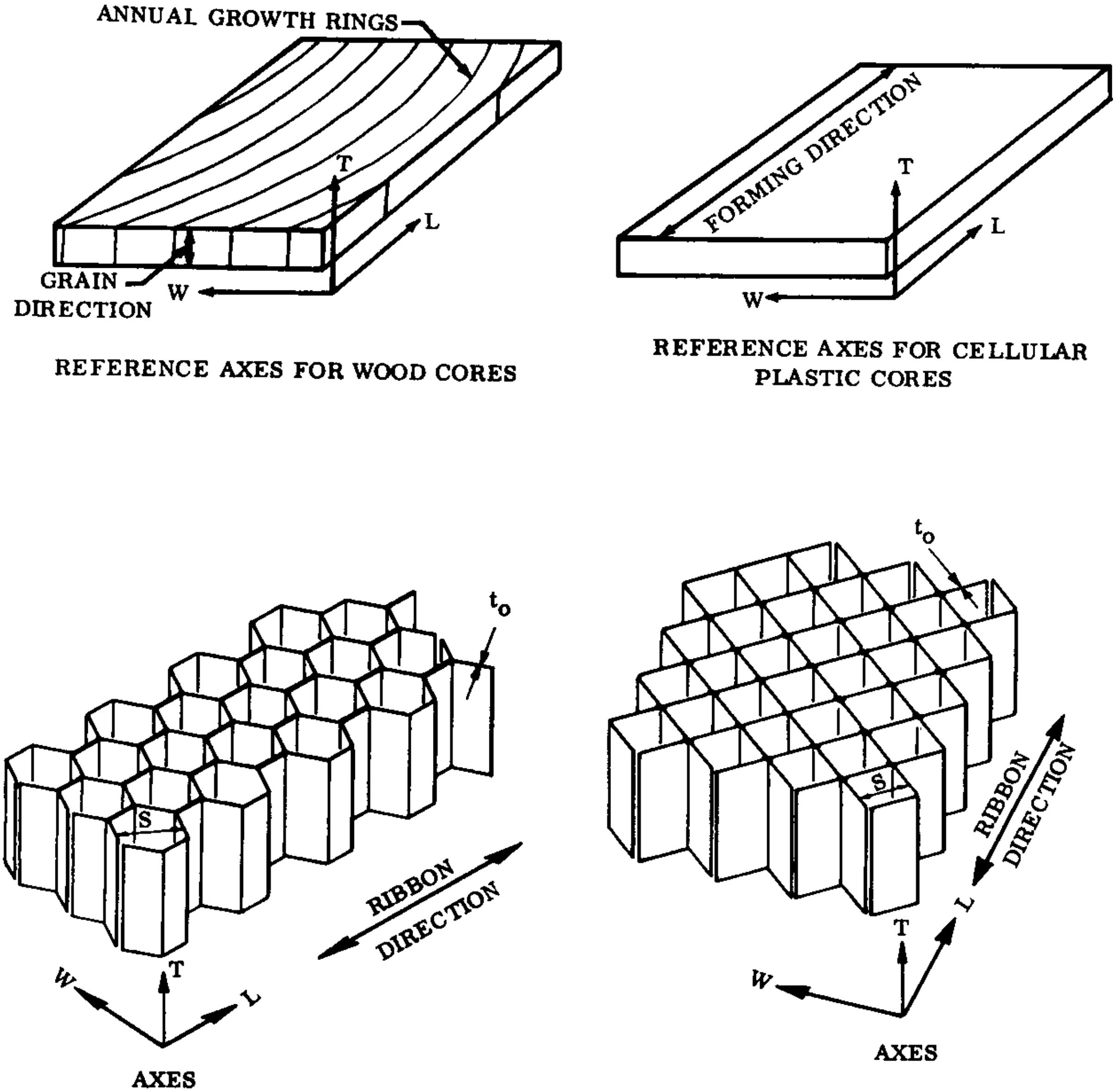

Figure 1. Axes notation for sandwich cores.

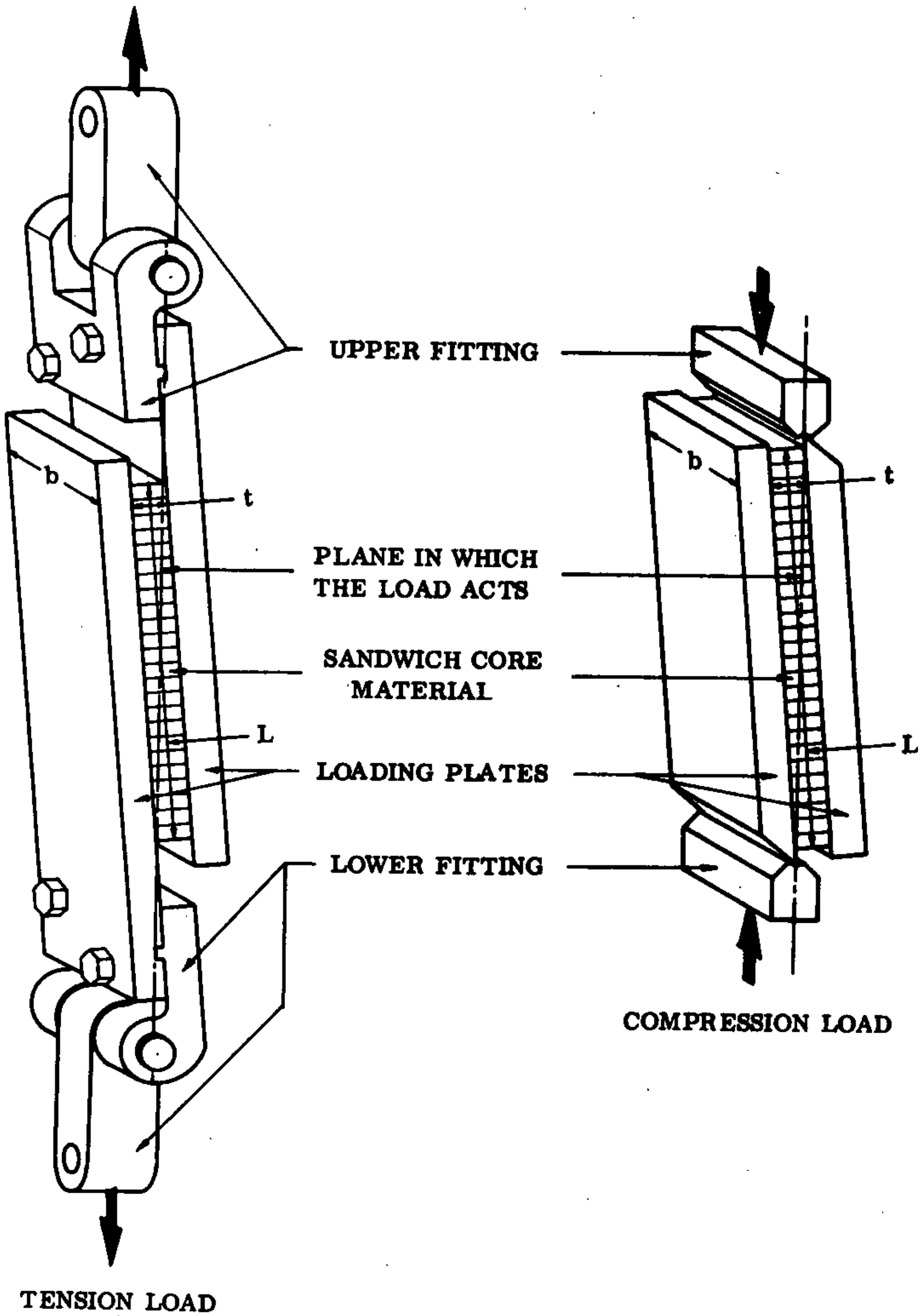

Figure 2. Sketch showing shear specimens attached to loading plates and plane of action of applied loads.

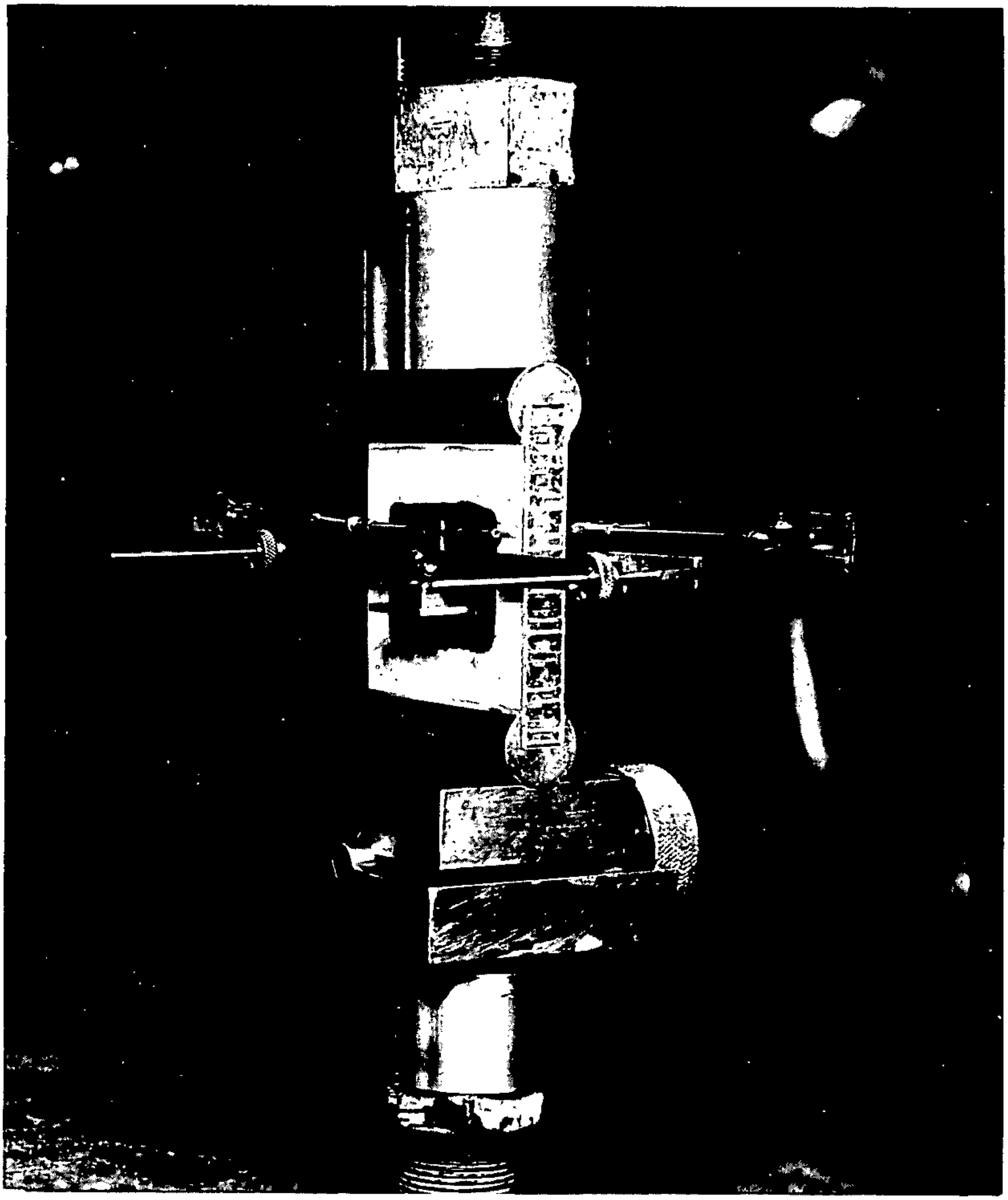

Figure 3. Compression test apparatus showing an adjustable supporting base and slotted round bars in position on the specimen ends. Deformations are being measured with Marten's mirror compressometers.

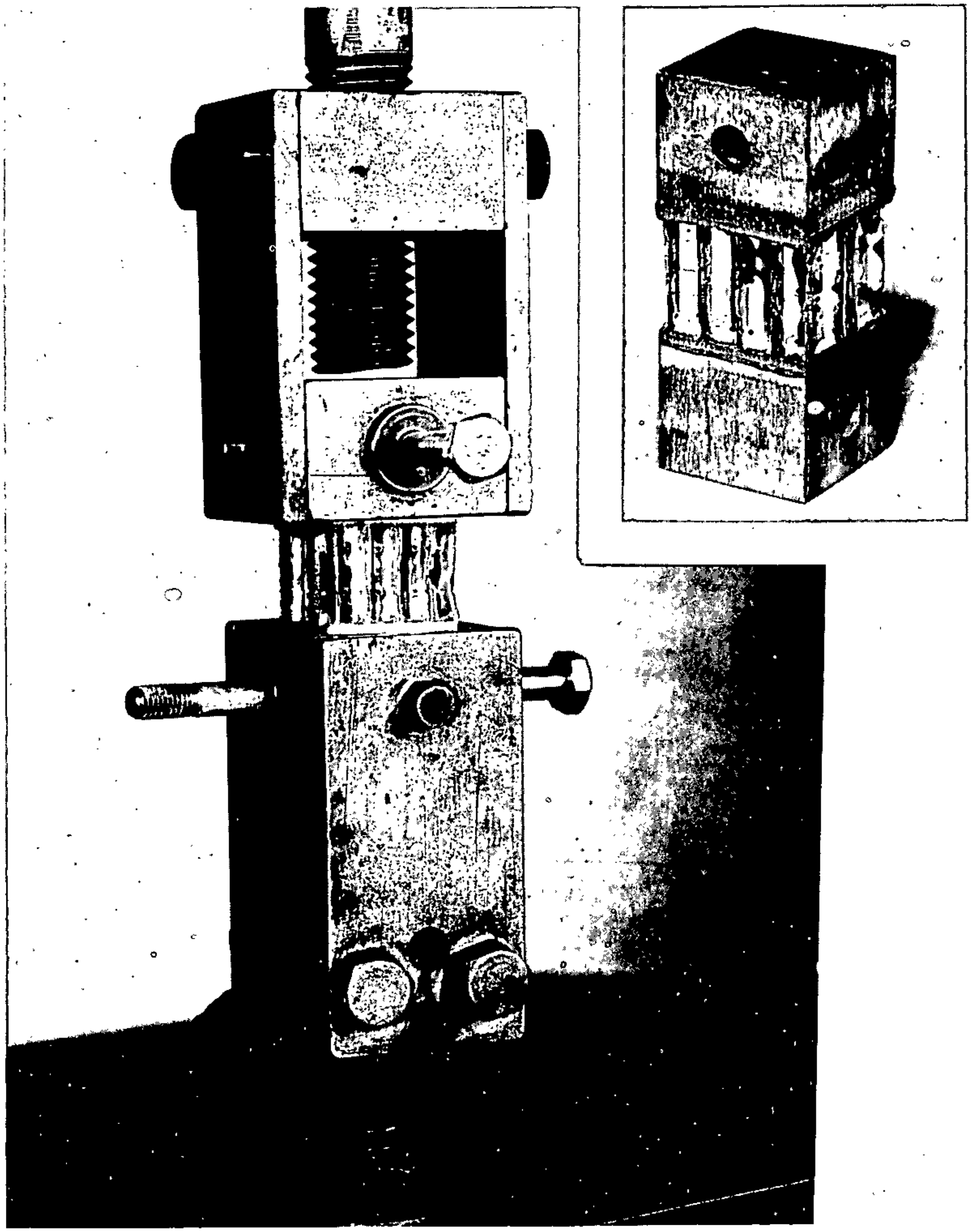

Figure 4. Test apparatus for tension flatwise test of core material for sandwich-type constructions showing specimens and fitting for applying load.

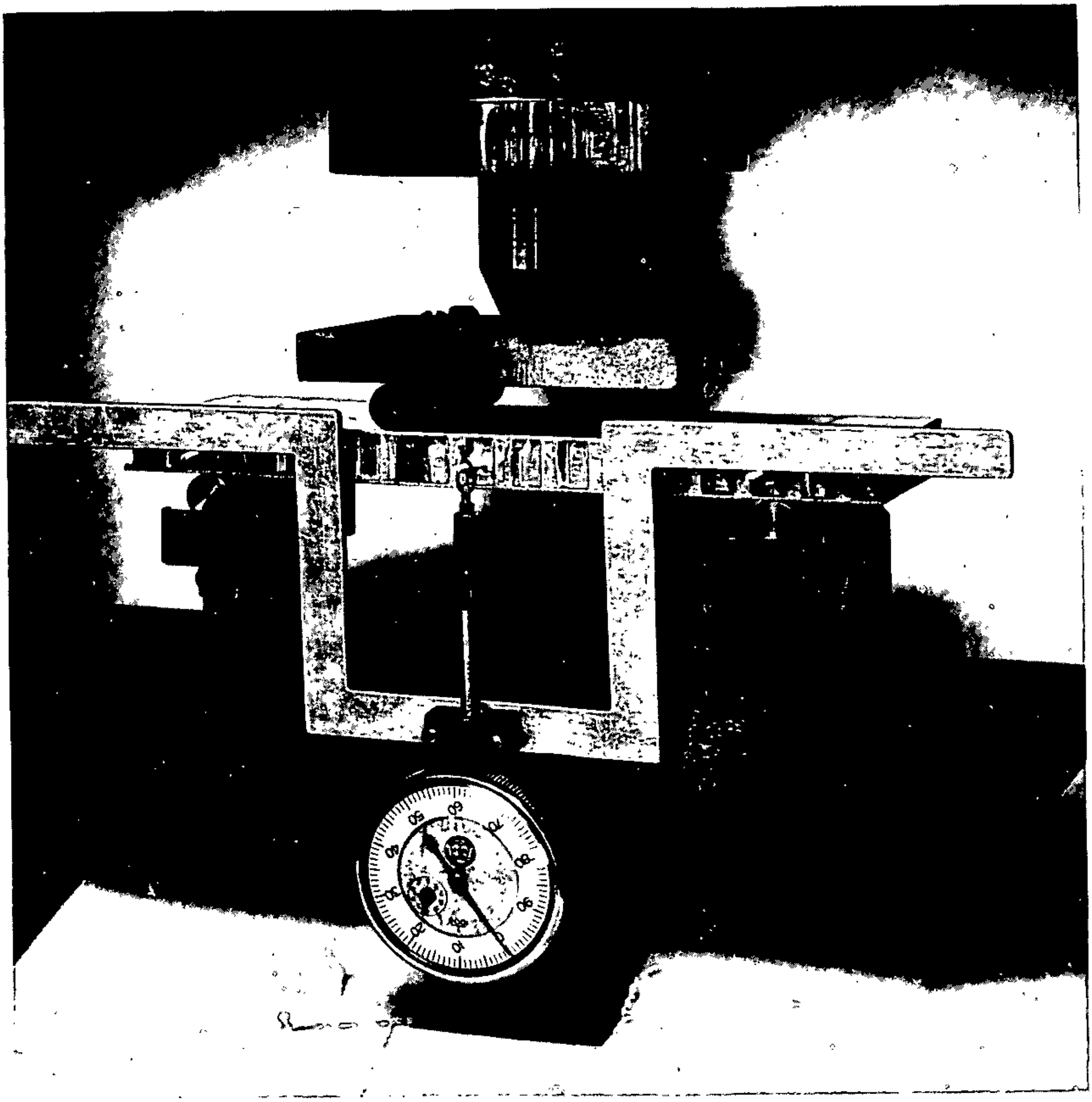

Figure 5. Apparatus for conducting flexure test of sandwich construction.

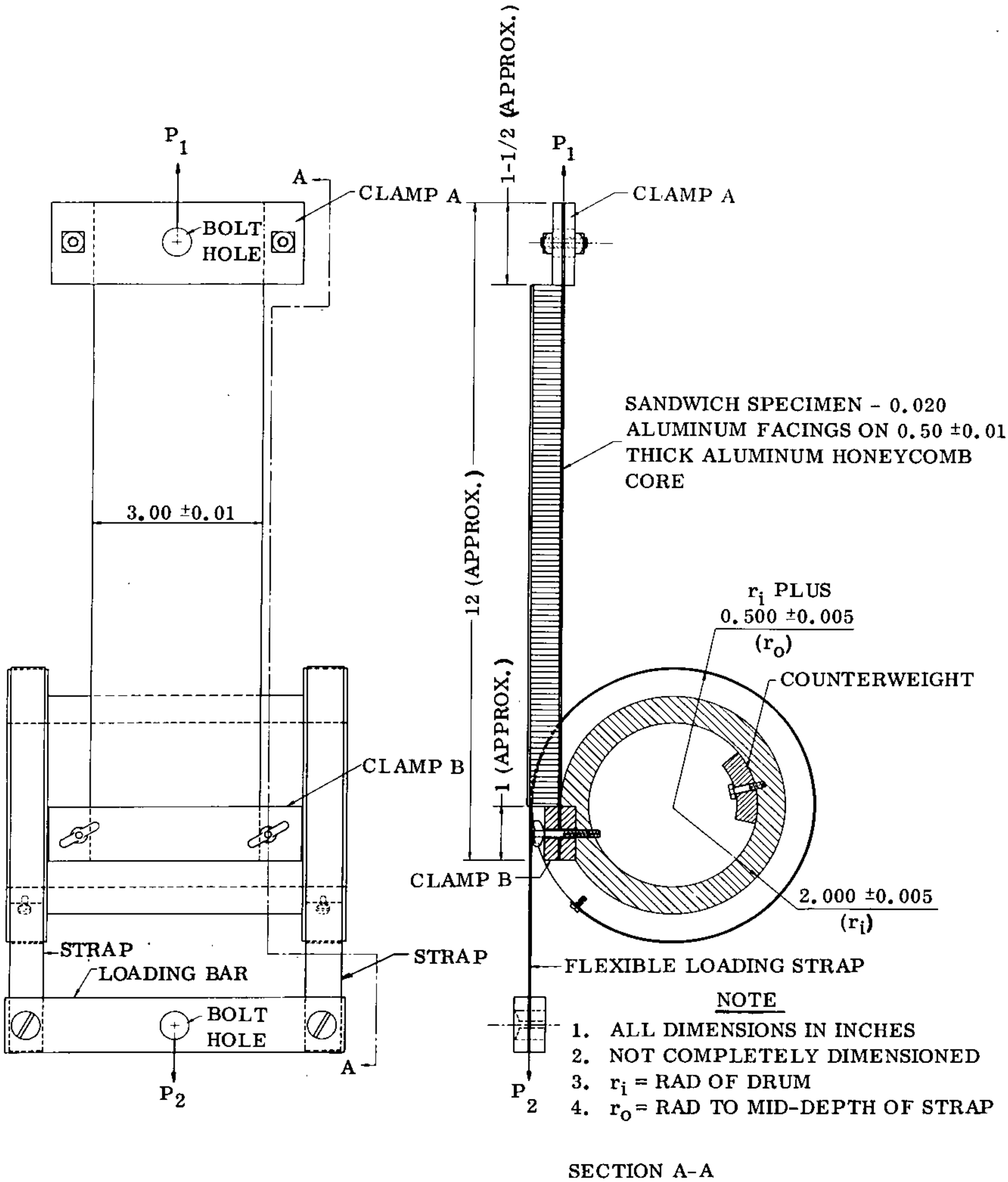

Figure 6. Type of apparatus suitable for making sandwich peel test.

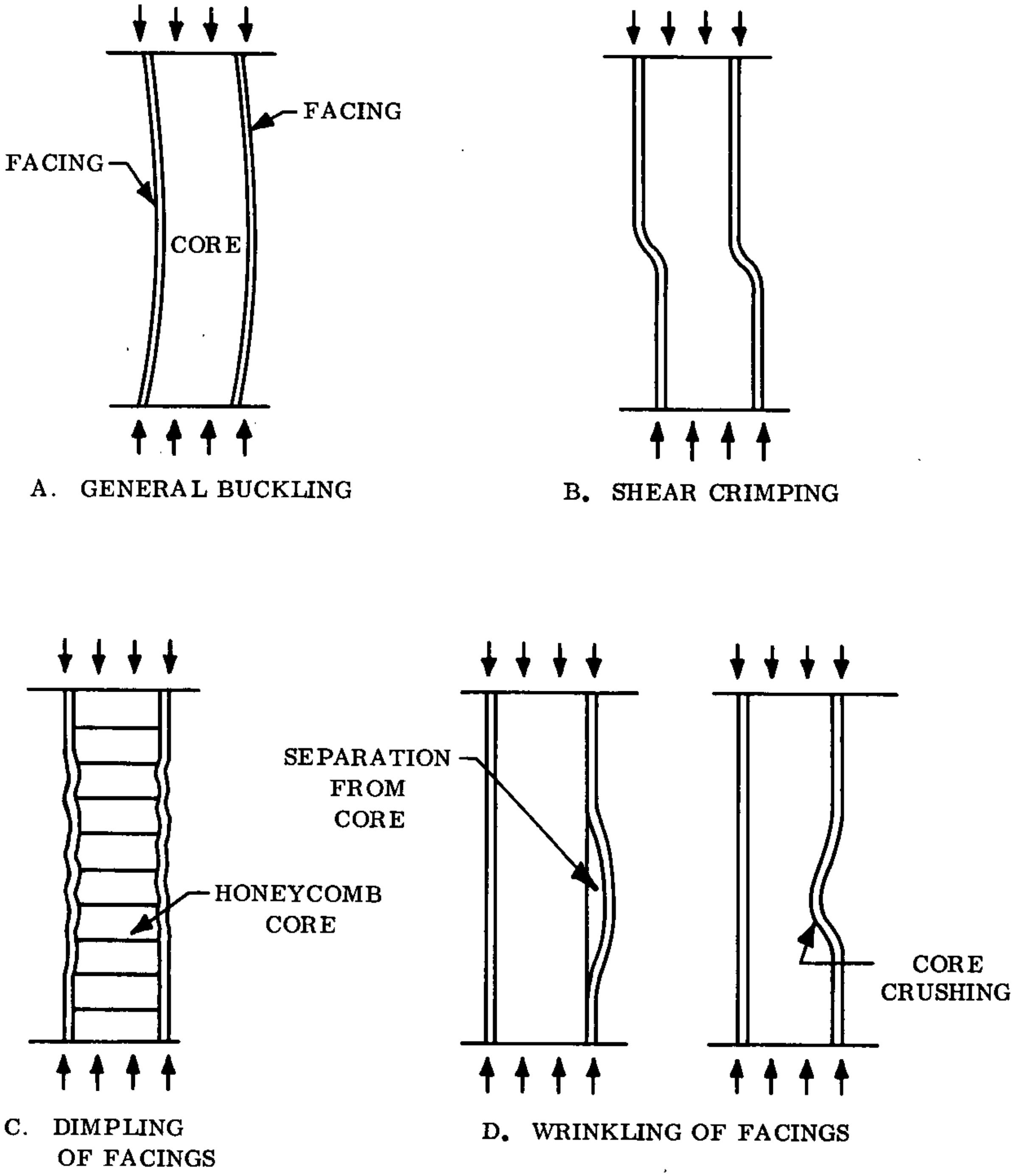

Figure 7. Possible modes of failure of sandwich composite under edgewise loads: General buckling, shear crimping, dimpling of facings, and wrinkling of facings either away from or into the core.

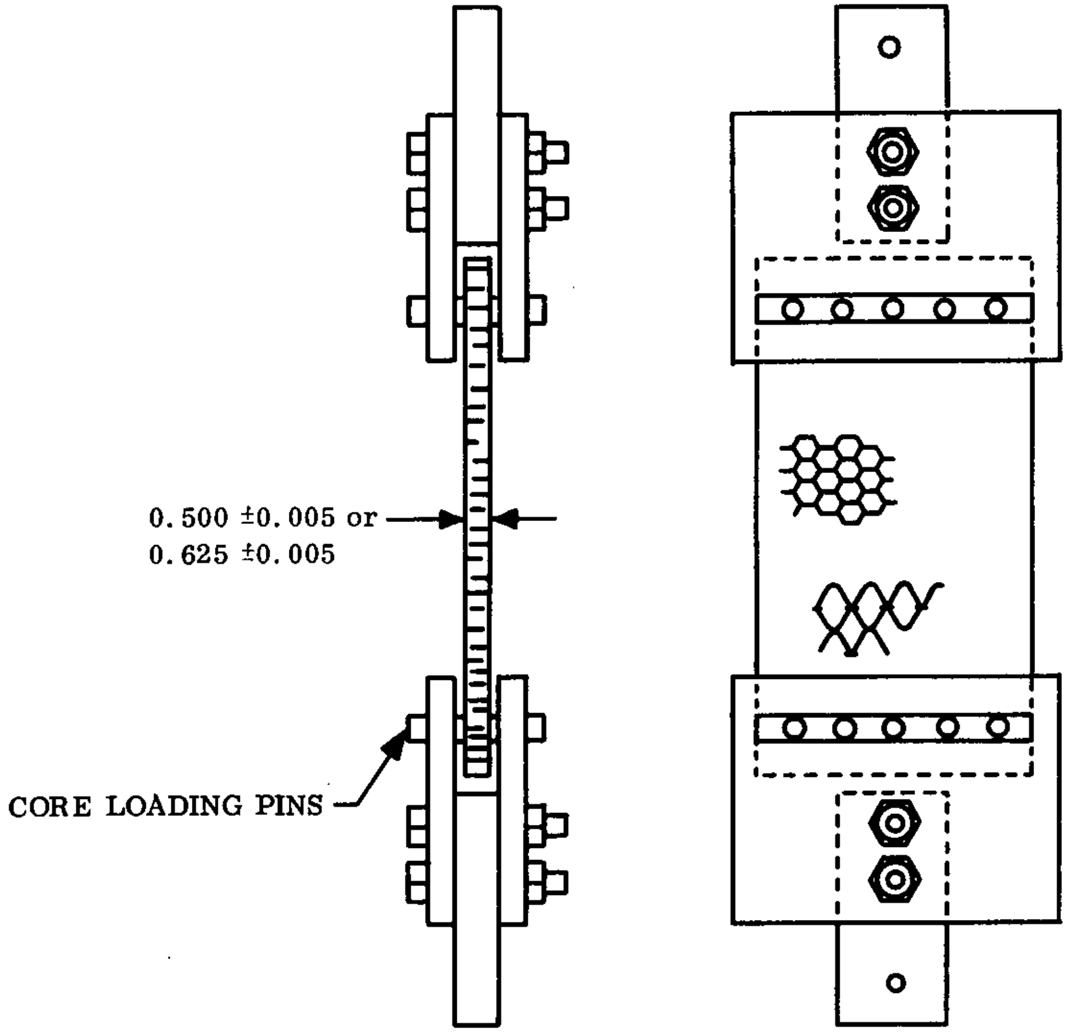

Figure 8. Apparatus for node strength tests.

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SPECIFICATION ANALYSIS SHEET

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SPECIFICATION

SANDWICH CONSTRUCTIONS AND CORE MATERIALS; GENERAL TEST METHODS

ORGANIZATION *(Of submitter)*

CITY AND STATE

CONTRACT NO.

QUANTITY OF ITEMS PROCURED

DOLLAR AMOUNT
$

MATERIAL PROCURED UNDER A

☐ DIRECT GOVERNMENT CONTRACT ☐ SUBCONTRACT

1. HAS ANY PART OF THE SPECIFICATION CREATED PROBLEMS OR REQUIRED INTERPRETATION IN PROCUREMENT USE?

A. GIVE PARAGRAPH NUMBER AND WORDING.

B. RECOMMENDATIONS FOR CORRECTING THE DEFICIENCIES.

2. COMMENTS ON ANY SPECIFICATION REQUIREMENT CONSIDERED TOO RIGID

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