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INTERNATIONAL ASSOCIATION OF PLUMBING AND MECHANICAL OFFICIALS
UNIFORM EVALUATION SERVICES

EVALUATION CRITERIA FOR FIBER-REINFORCED CONNECTORS

EC 028-2017
(Adopted November 2017)

1.0 Introduction

1.1 Purpose: The purpose of this evaluation criteria is to establish the requirements for fiber-reinforced connectors to be recognized in an evaluation report independently reviewed and issued by a certification body under the International Building Code® (IBC) and the International Residential Code® (IRC).

This Evaluation Criteria provides requirements for the evaluation of fiber-reinforced connectors to supplement the requirements provided in the IBC, IRC, or other associated standards for these products.

1.2 Scope: This scope of this criteria is fiber-reinforced connectors used in concrete sandwich panel construction. This criteria is applicable to fiber-reinforced connectors that are either pre-assembled in a factory or assembled in the field. This evaluation criteria focuses on structural requirements determining the strength of fiber-reinforced connectors as an alternative to the requirements of Section 1901 of the IBC. Other product characteristics shall comply with the governing code provisions or certification body's evaluation criteria, as applicable.

The certification body issuing the evaluation report shall be accredited as complying with ISO/IEC Standard 17065 by an accreditation body conforming to ISO/IEC 17011 that is a signatory to the International Accreditation Forum (IAF) Multilateral Recognition Agreement (MLA).

2.0 Referenced Standards

2.1 General: Standards referenced in this criteria shall be applied consistent with the specific edition of the code(s) for which the Evaluation Report is prepared unless otherwise approved by the certification body.

- **2.1.1** International Building Code®, 2015, International Code Council
- **2.1.2** International Residential Code®, 2015, International Code Council
- **2.1.3** ACI 318-14, Building Code Requirements for Structural Concrete, American Concrete Institute
- **2.1.4** ASTM C31-12, Standard Practice for Making and Curing Concrete Test Specimens in the Field, ASTM International
- **2.1.5** ASTM C39-14a, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, ASTM International

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2.1.6 ASTM C42-13, Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete, ASTM International

2.1.7 ASTM C581-15, Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service, ASTM International

2.1.8 ASTM D2247-15, Standard Practice for Testing Water Resistance of Coatings in 100 % Relative Humidity, ASTM International

2.1.9 ASTM D3039-14, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, ASTM International

2.1.10 ASTM D3418-15, Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry, ASTM International

2.1.11 ASTM D7205-06(2016), Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars, ASTM International

2.1.12 D7705/D7705M-12, Standard Test Method for Alkali Resistance of Fiber Reinforced Polymer (FRP) Matrix Composite Bars used in Concrete Construction, ASTM International

2.1.13 ASTM E84-13a, Standard Test Method for Surface Burning Characteristics of Building Materials, ASTM International

2.1.14 ASTM E119-12a, Standard Test Methods for Fire Tests of Building Construction and Materials, 2012, ASTM International

2.1.15 ASTM E488-10, Standard Test Methods for Strength of Anchors in Concrete Elements, 2010, ASTM International

2.1.16 ASTM E1356-08(2014), Standard Test Method for Assignment of the Glass Transition Temperatures by Differential Scanning Calorimetry, ASTM International

2.1.17 NFPA 259, Standard Test Method for Potential Heat of Building Materials, 2013, National Fire Protection Association

2.1.18 NFPA 268, Standard Test Method for Determining Ignitability of Exterior Wall Assemblies Using a Radiant Heat Energy Source, 2012, National Fire Protection Association

2.1.19 NFPA 285, Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-Load-Bearing Wall Assemblies Containing Combustible Components, 2012, National Fire Protection Association

2.1.20 UL 263, Standard for Fire Tests of Building Construction and Materials, Edition 14, dated June 21, 2011, Underwriters Laboratories

2.1.21 UL 723, Standard for Test for Surface Burning Characteristics of Building Materials, Edition 10, dated September 10, 2008, Underwriters Laboratories

2.1.22 ISO/IEC 17011:2004 – Conformity Assessment – General Requirements for Accreditation Bodies Accrediting Conformity Assessment Bodies, International Organization for Standardization

2.1.23 ISO/IEC 17020:2012 – Conformity Assessment – Requirements for the Operation of Various Types of Bodies Performing Inspection, International Organization for Standardization

2.1.24 ISO/IEC 17025:2005 – General Requirements for the Competence of Testing and Calibration Laboratories, International Organization for Standardization

2.1.25 ISO/IEC 17065:2012 -- Conformity assessment -- Requirements for Bodies Certifying Products, Processes and Services, International Organization for Standardization

3.0 Definitions

3.1 Fiber-Reinforced Connector: A two-dimensional, truss-configured component, produced from continuously wound alkali resistant glass fibers embedded in a polymer matrix. The connectors are embedded into concrete slabs to form a sandwich panel and may be surrounded by insulation material.

3.2 Sandwich Panel: A wall element consisting of two concrete slab elements spaced apart by placement of fiber-reinforced connectors. Rigid or non-rigid insulation may be placed between the slab elements. The slab elements may function as a composite, non-composite, or both.

3.3 Embedment Depth: The distance from the concrete surface into which the connector is inserted to the deepest end of the connector.

3.4 Edge Distance: The distance from the edge of the concrete to the leading edge of the connector.

4.0 Basic Information

4.1 General: The following information shall be submitted.

4.1.1 Product Description

Description of system and components shall include dimensions, designations, constituent materials, surface finishes, coatings, fabrication techniques, and other material specifications.

4.1.2 Installation Instructions

Instructions for fiber reinforced connectors shall include limitations, requirements and methods for field preparation and assembly.

4.1.3 Identification

Packaging labels for fiber reinforced connector systems shall include the manufacturer or a registered trademark, model or name of the product, size, and applicable certification body logo and evaluation report number. In addition, identifying marks may be placed on the connectors.

4.2 Testing Laboratories: Testing laboratories shall be accredited for the applicable testing procedures in accordance with ISO/IEC 17025 by a recognized accreditation body conforming to ISO/IEC 17011 that is a signatory to the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement (MRA). Testing at a non-accredited laboratory may

4.3 be permitted by the certification body, provided the testing is conducted under the supervision of an accredited laboratory and the supervising laboratory issues the test report.

4.4 Test reports: Test reports, submitted to the certification body, shall consist of:

4.4.1 A description of the test procedures, test results, observations, tested assemblies, load measurements, and photographs of specimens and typical failures.

4.4.2 A description of the test specimens.

4.4.3 Information as set forth in the referenced test standard.

4.5 Product Sampling and Preparation of Test Specimens: The testing laboratory shall perform random sampling of the components at the manufacturing site. As an alternative, random sampling may be taken from the manufacturer's production inventory, provided the testing laboratory verifies the samples comply with product specifications. Tests shall be prepared in accordance with Section 5.0 of this criteria. The testing laboratory shall witness or perform the preparation and assembly of the test specimens that reflects the field preparation and assembly procedures.

5.0 Testing and Performance Requirements

5.1 General: Reports of all applicable tests shall be submitted and comply with Section 4.3 of this criteria.

5.2 Connector Properties:

5.2.1 General: Properties of the Connector material shall be reported in accordance with Table 1 of this criteria. These tests shall serve as a portion of testing performed for quality control. Where necessary to conform to the test method, test coupons for testing connector material properties may be prepared by testing laboratory cutting sections from the randomly sampled connectors. Alternatively, test coupons may be fabricated under observation of the testing laboratory using the same materials as the connectors, according to the process(es) approved in the Quality Manual. Whether the coupons are prepared from connectors, or separately fabricated, the resulting test coupons shall represent the least cross-section of the fiber-reinforced connector in dimension and fiber-content, and if applicable, fiber orientation, and be oriented to the expected direction of maximum stresses.

5.2.2 Durability: Testing shall be conducted in accordance with ASTM D2247. Exposure conditions are 100 percent humidity at 100 ± 4°F (38 ± 2°C) for 1,000 and 3,000 hours. Specimen preparation and quantity shall be in accordance with Section 5.2.1 of this criteria. Tensile strength shall be determined after exposure and compared to values determined for control specimens. Minimum strength retention shall be 90 percent for 1,000 hours and 85 percent for 3,000 hours.

5.2.3 Chemical Resistance: Testing shall be conducted in accordance with ASTM C581. Exposure shall be to an alkali solution with a pH of 13 at 140 ± 3°F (60 ± 1.6°C) for 90 days. Specimen preparation and quantity shall be in accordance with Section 5.2.1 of this criteria. Tensile strength shall be determined after exposure and compared to values determined for control specimens. Minimum strength retention shall be 80 percent.

5.2.4 Glass Transition Temperature: The Glass Transition temperature (T_g) of the connector shall be determined by Differential Scanning Calorimetry (DSC) analysis in accordance with ASTM D3418 or ASTM E1356 on five or more samples. The minimum T_g shall be 212°F (100°C).

5.3 Tension Capacity: Tensile capacity of fiber-reinforced connectors embedded in concrete shall be determined in accordance with Section 6.2 of this criteria. Testing shall occur in uncracked concrete.

5.4 Shear Capacity:

5.4.1 Normal Direction: Shear capacity of fiber-reinforced connectors embedded in concrete stressed in the normal direction shall be determined in accordance with Section 6.3 of this criteria. Testing shall occur in uncracked concrete.

5.4.2 Transverse Direction: Shear capacity of fiber-reinforced connectors embedded in concrete stressed in the transverse direction shall be determined in accordance with Section 6.3 of this criteria. Testing shall occur in uncracked concrete.

5.5 Sensitivity to Sustained (Creep) Load: The sensitivity of fiber-reinforced connectors to embedded in concrete to sustained loading shall be determined in accordance with Section 6.4 of this criteria. Testing shall occur in uncracked concrete.

5.6 Structural Design Strengths:

5.6.1 Characteristic Strength: The characteristic strength shall be determined in accordance with Eq.-1:

$$F_{ch} = F_{tsi,}(1 - K \cdot v_{test}) \qquad \text{(Eq.-1)}$$

where

K = tolerance factor corresponding to a 5 percent probability of non-exceedance with a confidence of 90 percent derived from a non-central t distribution for which the population standard deviation is unknown

F_{ch} = characteristic value (5 percent fractile), lb (N)

$F_{ts,i}$ = average of test results for test series i, lb (N); and

$v_{ts,i}$ = coefficient of variation of the population sample corresponding to test series i, percent

Load-displacement relationships shall be derived from the test results.

5.7 Fire Resistance Rating: Fire resistance ratings are optional. Unless data in accordance with this section is submitted, the sandwich panels shall be limited to nonfire-resistance-rated construction. Acceptable performance shall be determined by one of the following methods:

5.7.1 In accordance with IBC Section 703.2 based on tests in accordance with Section 6.4 of this criteria.

5.7.2 In accordance with IBC Section 722.2.1.2 for wall panels with two or more wythes of concrete.

5.8 Exterior walls of Types I, II, III, or IV Construction: Unless data in accordance with this section is submitted, the sandwich panels shall be limited to Type V construction. Wall assemblies intended for Types I, II, III, or IV Construction shall comply with IBC Section 2603.5 based on tests in accordance with Section 6.5 of this criteria.

6.0 Test Methods

6.1 Test Specimen Preparation

6.1.1 Concrete: Concrete shall comply as normal weight. Optionally, testing in lightweight concrete may be conducted.

6.1.1.1 Composition: Coarse and fine aggregates in normal-weight or lightweight concrete shall comply with ACI 318 Section 26.4.1.2.1. The aggregate description shall include rock and mineral components, shape, hardness, and maximum size and grading specification. The cement shall be portland cement conforming to ASTM C150 and both cement replacements and chemical admixtures shall be prohibited. Water shall comply with ACI 318 Section 26.4.1.3.1.

6.1.1.2 Proportions: Mixing and proportioning shall comply with ACI 318 Section 26.4. The concrete mixture components and proportions shall be described.

Compressive Strength Testing: Compressive strength cylinders shall be prepared in accordance with ASTM C31. Cylinders may either be cured under standard laboratory conditions or to the same environment as the test specimen. For the latter, cylinder molds shall be removed concurrently with removal of forms from the test specimen. Concrete compressive strength at the time of connector testing shall consist of compression tests complying with ASTM C39 conducted on concrete cylinders or cores taken from the test specimen in accordance with ASTM C42. Cylinder and core strengths shall not be combined. Determine mean strength test values from: (a) linear interpolation of a test series using the beginning and ending tests as endpoints; or (b) strength-age relationships developed using compression tests of concrete test specimen at various test ages.

6.1.2 Test Specimen Construction: Test specimens shall be designed as either a three-layer construction with outer concrete layers of equal thickness, a single layer of insulation, and a single connector, or a five-layer construction with outer concrete layers of equal thickness, a center layer of concrete, two layers of insulation of equal thickness and a total of two connectors, one attaching each of the outer layers of concrete to the inner layer of concrete. Test specimen

6.1.3 construction shall be symmetric about the connector. Manufacturer's recommendations and installation instructions shall be followed in the construction of test specimens. Additional requirements for test specimens as set forth in Section 6.0 of ASTM E488 shall be observed.

6.1.4 Test Specimen Dimensions:

6.1.4.1 Each insulation layer shall be at least 2 inches (51 mm) thick and be recognized by a current Evaluation Report issued by an accredited certification body as complying with the IBC or IRC.

6.1.4.2 Outer concrete layers shall be at least 1.5 times as thick as the embedment depth of the connector, the central layer of concrete shall be at least 2.5 times as thick as the embedment depth of the connector.

6.1.4.3 Concrete cover shall comply with requirements in Section 20.6.1.3 of ACI 318.

6.1.4.4 The edge distance shall be at least two times the embedment depth of the connector.

6.1.5 Connector orientation: connectors that are designed to be used in more than one orientation shall be tested in all orientations for which recognition is sought.

6.1.6 Connection points for loading in tension: For attachment to the testing machine, the specimen shall contain embedded anchors that do not interfere with the connector, have a combined capacity of at least double the expected connector capacity, and are arranged symmetrically about the connector to allow force to be applied perpendicular to the concrete layers.

6.1.7 Connection points for loading in shear: For attachment to the testing machine, the specimen shall contain embedded anchors that do not interfere with the connector, have a combined capacity of at least double the expected connector capacity, and are arranged symmetrically about the connector to allow force to be applied parallel to the concrete layers, in the plane of the connector.

6.1.8 Reinforcement: Any reinforcement used in the concrete portion of the test specimen shall not interfere with the connector failure region.

6.2 Tension Testing:

6.2.1 Static testing shall be conducted in accordance with ASTM E488, except the configuration in Figure 1 of this criteria shall be used.

6.2.2 Five or more test specimens shall be tested.

6.2.3 Tensile load to failure. Where failure modes are not observed, the peak load recorded shall be used to determine design strengths in Section 5.5 of this criteria.

6.3 Shear Testing:

6.3.1 The static testing shall be conducted in accordance with ASTM E488. The applied load shall be measured using a load cell in line with the actuator. The

6.3.2 displacement shall be measured directly on the specimen using a linear variable displacement transducer (LVDT).

6.3.3 Normal Direction: For loading in the direction of the connector axis, the configuration shown in either Figure 2 or 3 of this criteria shall be used

6.3.4 Transverse Direction: For loading transverse to the connector axis, the configuration shown in Figure 4 of this criteria shall be used.

6.3.5 Five or more test specimens shall be tested.

6.3.6 Shear load to failure. Where failure modes are not observed, the peak load recorded shall be used to determine design strengths in Section 5.5 of this criteria.

6.4 Sensitivity to Sustained (Creep) Loading:

6.4.1 Testing shall be conducted in accordance with ASTM E488 Section 11.6, except the configuration in Figure 5 or 6 of this criteria shall be used.

6.4.2 Two or more test specimens shall be tested. At least one test specimen is required for minimum and maximum insulation thicknesses tested in tension or shear in accordance with Section 6.2 of this criteria. Additional insulation thicknesses may be tested as an option.

6.4.3 Testing shall be conducted at an elevated temperature of 150°F (66°C) or greater.

6.4.4 The sustained tension or shear load, F_{sust} applied shall be determined in accordance with Eq.-2:

$$F_{sust} = XF_{t,i}\left(\frac{f_{c,test}}{f_{c,t}}\right)^{n}, lb\ (N) \qquad \text{(Eq.-2)}$$

Where:

X = a reduction factor for the sustained load under the test. The minimum value shall be 0.55 except where a design decrease factor for sustained load is determined from Section 6.4.7 of this criteria.

$F_{t,i}$ = Either 1) mean tension capacity as determined from static tension tests described in Section 6.2 of this criteria; or 2) mean shear capacity as determined from static shear tests described in Section 6.3 of this criteria; in the lowest strength concrete, where results that are less than 85 percent of the mean value shall be excluded from the determination of the mean: the mean shall be recalculated with the remaining results, lb. (N).

$f_{c,test}$ = concrete compressive strength as measured at the time of testing, psi (pa)

$f_{c,t}$ = concrete compressive strength corresponding to the tests used to establish $F_{t,i}$, psi (pa)

n = 0.5 for concrete failure
= 0 for connector damage.

6.4.5 The Findley Power Law shall be used to project total displacement for the prescribed duration. Findley Power Law is in the form of Eq.-3.

$$\Delta(t) = \Delta_o + mt^n \text{ , in. (mm)} \qquad \text{(Eq.-3)}$$

Where:
$\Delta(t)$ = Projected total displacement of the connector over the lifetime, t, in. (mm)
Δ_o = initial displacement at the commencement of the sustained loading, in. (mm)
t = intended duration under sustained load, hours

The recorded displacements from sustained load tests are plotted versus time on a log-log scale. The value of the power n is determined by measuring the slope of the resulting line. The value of coefficient m is determined as the y-intercept of the line at t = 1 hour. The material constant n was determined to be independent of load while m is load dependent.

6.4.6 The mean displacement $\Delta(t)$, described in Section 6.4.5 of this criteria, shall be less than the mean displacement at peak load determined from Section 5.6.1 of this criteria.

6.4.7 If the requirements in Section 6.4.6 result in failure, the sustained load may be reduced, where the constant 0.55 in Eq-2 is reduced and the tests repeated. The minimum permitted reduction constant of the sustained load is 0.40. A sustained load adjustment factor shall be applied to design for sustained loading according to Eq.-4:

$$\Psi_{red} = \frac{F_{sust,f}}{F_{sust,i}} \leq 1.0 \qquad \text{Eq.-4}$$

Where:
Ψ_{red} = reduction factor for design of connectors subjected to sustained loading
$F_{sust,f}$ = Sustained load from Eq.-2 where 0.4 ≤X< 0.55
$F_{sust,i}$ = Sustained load from Eq.-2 where X≥ 0.55

6.5 Fire-Resistance Testing (Optional): Tests for fire-resistance of sandwich panels shall be conducted as load-bearing or non-load-bearing walls in accordance with ASTM E119 or UL263 for the intended duration, which shall be no less than one hour. For load-bearing walls, loading methods shall represent field-use conditions with either one or both wythes loaded in conformance with ASTM E119 Section 7.4.1.1 and Note 7 for double walls. The actual load applied shall be reported. Analyses establishing the applied load is no less than the full design load for the panel tested may be considered.

6.6 Exterior Walls of Types I, II, III, or IV Construction (Optional): For use on non-load-bearing walls of Types I, II, III, or IV Construction, the following information is needed in accordance with IBC Section 2603.5.

6.6.1 NFPA 285: This test pertains to a non-load-bearing wall assembly.

6.6.2 ASTM E84 or UL 723: This test pertains to foam plastic insulation and any material deemed to be combustible. Details shall conform to IBC Section 2603.5.4.

6.6.3 ASTM E119 or UL263: This test required to comply with IBC Chapter 6 and is optional where walls are used in Type II-B construction only.

6.6.4 Thermal Barrier: Foam plastic insulation shall be covered by minimum one inch (25.4 mm) thick concrete on each face.

6.6.5 NFPA 259: This test pertains to foam plastic insulation. Details shall conform to IBC Section 2603.5.3.

6.6.6 NFPA 268: Details shall conform to IBC Section 2603.5.7. This test is optional if the exterior face is minimum one inch (25.4 mm) thick bare concrete.

7.0 Quality Control

7.1 Inspections of manufacturing facilities are required for this product by the certification body or an accredited inspection agency. Inspections by inspection agencies accredited for metal products in accordance with ISO/IEC 17020 by an accreditation body recognized as conforming to ISO/IEC 17011 are permitted.

7.2 Quality documentation complying with IAPMO-UES Minimum Requirements for Listee's Quality Assurance System (IAPMO ES-010) or equivalent shall be submitted. The quality documentation, as it relates to manufacturing of steel components of the connectors, shall include the items in Section 4.1.1 of this criteria, tolerances for physical and chemical properties, acceptance test standards, and other aspects of the controls on the production.

7.3 Inspections for installation of the connectors into concrete shall comply with applicable requirements in IBC Chapter 17. Where connector installation is conducted at fabrication shops, provisions in IBC Section 1704.5 shall apply. Where connector installation occurs at the jobsite, periodic special inspection in accordance with IBC Sections 1704 and 1705 shall be provided.

8.0 Evaluation Report Recognition

8.1 Evaluation reports shall include:

8.1.1 The manufacturer's name, product name of proprietary components, and the basic information set forth in Section 4.1 of this criteria for all assembly components.

8.1.2 Design load and displacement values, and corresponding installation parameters.

8.1.3 For sustained loading, the lifetime t and as applicable, load reduction factor Ψ_{red}.

8.2 The evaluation report shall also include the following or equivalent statements:

8.2.1 Design of concrete panels and other elements attached to the fiber-reinforced connectors is beyond the scope of this report and shall comply with governing code provisions. The design is subject to approval of the code official.

8.2.2 Connectors shall be located in a region of the concrete member where analysis indicates no cracking (uncracked) at service loads or deformations. The analysis for the determination of crack formation shall include the effects of restrained shrinkage, as applicable, in accordance with 24.4.2 of ACI 318.

8.2.3 Use of the connectors to resist seismic loads in Seismic Design Categories C, D, E, or F is beyond the scope of this report.

8.2.4 Use of the connectors to resist fatigue or shock loading is beyond the scope of this report.

8.2.5 Fire resistance ratings, as applicable. If fire resistance is not documented, the evaluation report shall state that sandwich panels shall be limited to use where non-fire resistance rated construction is permitted.

8.2.6 Types I, II, III or IV construction, as applicable. If data in Section 6.6 of this criteria is not available, the evaluation report shall state that sandwich panels shall be limited to type V construction.

8.2.7 Inspection requirements as set forth in Section 7.3 of this criteria.

Table 1

Property	Test Standard	No. of Specimens
Tensile Strength	ASTM D3039 or D7205	20
Tensile Modulus	ASTM D3039 or D7205	20
Flexural Strength	ASTM D790	20
Flexural Modulus	ASTM D790	20
Durability	ASTM D2247	20
Chemical Resistance	ASTM C581 or D7705	20

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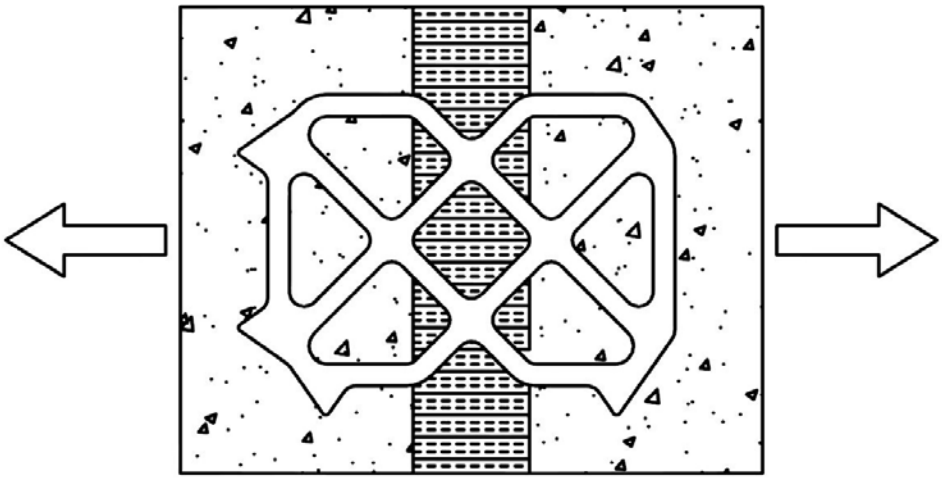

Figure 1 – Three Layer Construction (Tension Test)

Note to the Figures: These figures are suggested and may need to be modified by the testing laboratory. Test assemblies shall represent field use conditions and comply with Section 6.1.3 of this criteria.

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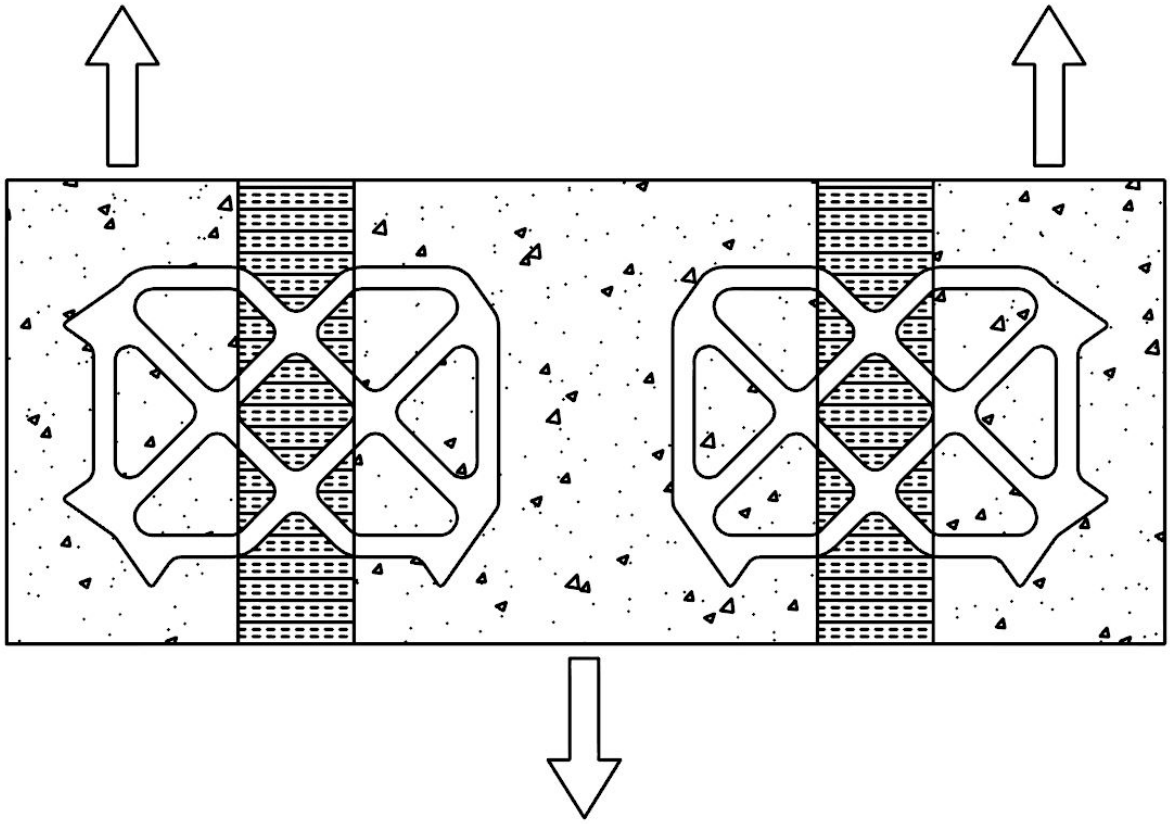

Figure 2 – Five Layer Construction (Shear Test – Normal Direction)

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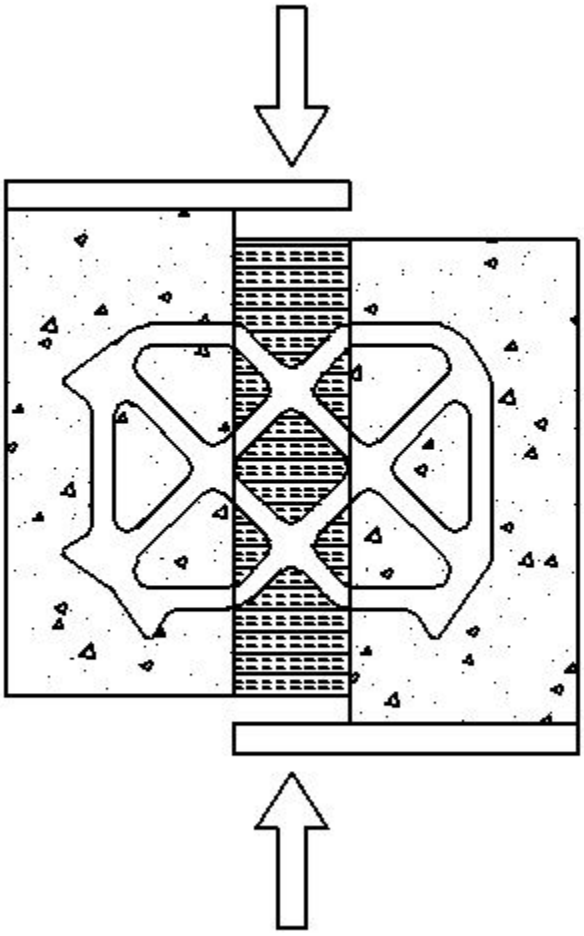

Figure 3 – Three Layer Construction (Shear Test – Normal Direction)

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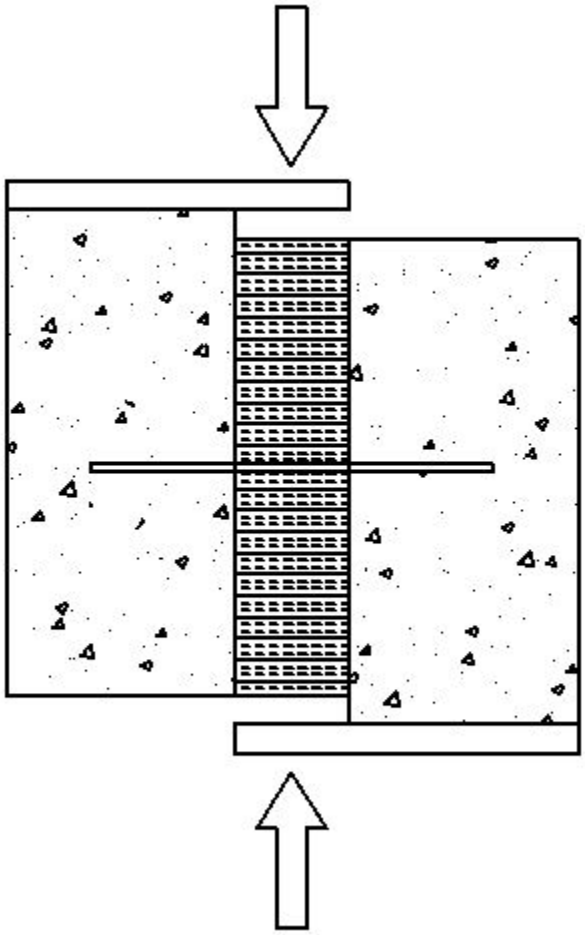

Figure 4 – Three Layer Construction (Shear Test – Transverse Direction)

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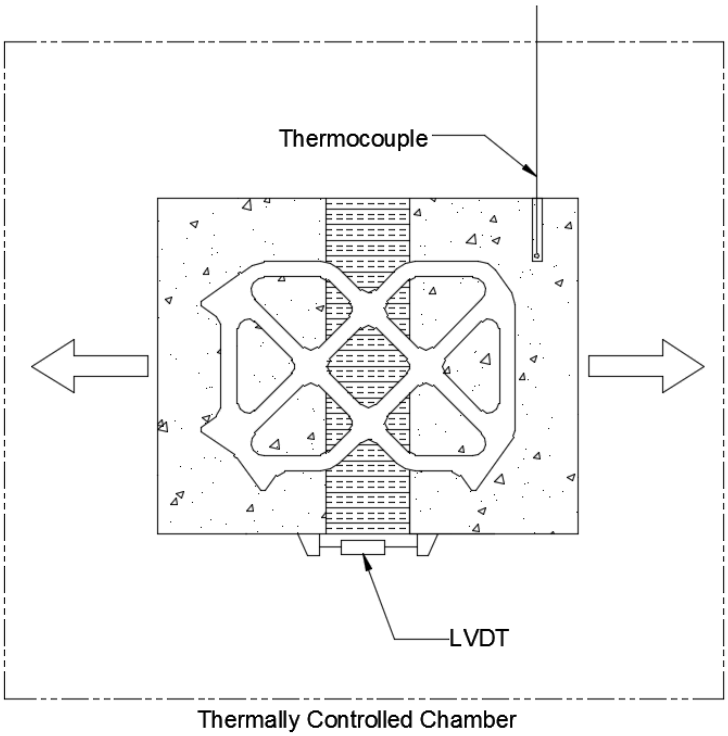

Figure 5 – Sustained Load (Creep) Construction in Tension

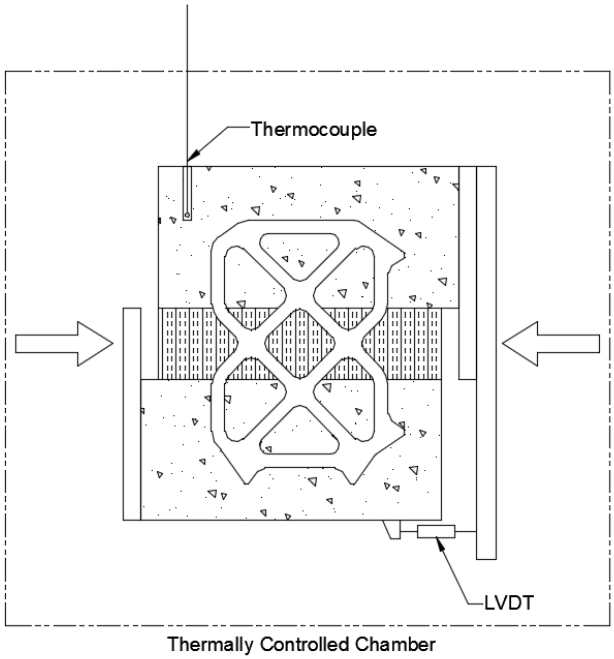

Figure 6 – Sustained Load (Creep) Construction in Shear