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DOCUMENT NO.	REV
1797-RPT-003	NC

RELEASE DATE 12/01/03

DOCUMENT CONTROL NO. 008

LAT TRACKER
SIDE WALL TEST COUPON
TEST PLAN and FINAL REPORT

FOR

Stanford Linear Accelerator Center

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Revision Record

Revision	Date	Approved	Change	CN No.
NC	11/26/03	N. Virabouth	Initial Release	NA

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1.0 SCOPE

This test plan/final report has been prepared in order to document the specimen geometry, test procedures and test results used to determine design allowable properties for the Tracker Tower Sidewall Assembly insert design and loading configurations.

1.1 Introduction

Stanford Linear Acceleration Center has been contracted to design, fabricate, assemble and test the tower assembly for the Gamma Ray Large Area Space Telescope (GLAST) Tracker. The tower assembly consists of multiple trays stacked together to form the tower. Each tray consists of carbon/carbon closeouts connected with titanium corner brackets and M4 inserts.

1.2 Summary

COI was contracted by SLAC to determine mechanical and insert pullout, shearout and tearout strength allowable properties on a K13D2U/CE3 prepreg tape/SF-YS-90A-75/CE3 fabric/1145 aluminum foil hybrid panel. The panel consisted of the following ply orientation:
[0/90*/0/157.5/22.5/45/0/135/135/90/45/22.5/157.5/0/0/90*/1145-H19 aluminum foil]

Six (6) 0- and 90-degree tension and compression specimens were fabricated and tested along with six (6) short beam shear specimens. Six (6) M4 and M2.5 insert pullout, shearout and tearout specimens of various configurations (see LAT-DS-02528) were also fabricated from the panel and tested at ambient temperature.

2.0 APPLICABLE DOCUMENTS

2.1 ATK COI Documents

SP-T-022	Standard Practice Testing Interlaminar Shear
SP-T-023	Standard Practice Testing Tensile Properties of Laminates
SP-T-025	Standard Practice Testing Compression Properties of Laminates

2.2 Customer Documents

LAT-DS-00303	LAT Tracker Tower Assembly Sidewall –X Assembly Sidewall –X
LAT-DS-00304	LAT Tracker Tower Assembly Sidewall +X Assembly Sidewall +X
LAT-DS-00305	LAT Tracker Tower Assembly Sidewall –Y Assembly Sidewall –Y
LAT-DS-02528	LAT Tracker Tower Assembly Sidewall Test Panel Coupon Cut Detail
LAT-DS-00306	LAT Tracker Tower Assembly Sidewall +Y Assembly Sidewall +Y

2.3 Other Documents

None

3.0 TEST MATRIX

The tests planned for determining mechanical and insert strength properties are outlined in Table 3.1. The matrix defines the number of specimens, specimen configuration, properties, and procedures to be employed.

Table 3-1 K13D2U/CE3/SF-YS90A-75/CE3/1145-H19 Aluminum Foil Hybrid Panel Allowable Test Matrix

Test	Direction	Property	Specimen Configuration	Number of Specimens	Test Procedures
Tension	0	Strength Modulus	9.0 by 1.0	6	SP-T-023
	90	Strength Modulus	9.0 by 1.0	6	SP-T-023
Compression	0	Strength Modulus	4.5 by 0.50	6	SP-T-025 Method B
	90	Strength Modulus	4.5 by 0.50	6	SP-T-025 Method B
Interlaminar Shear	TT	Strength	1.25 by 0.25	6	SP-T-022
M2.5 with Insert Thermal Boss Shear Out	0	Strength	LAT-DS-02528-1	6	Section 4.4
M2.5 without Insert Corner Shear Out 2 Holes	0	Strength	LAT-DS-02528-2	6	Section 4.5
M2.5 without Insert Corner Tear Out	0	Strength	LAT-DS-02528-3	6	Section 4.6
M2.5 without Insert Corner Tear Out	90	Strength	LAT-DS-02528-4	6	Section 4.7
M2.5 without Insert Thermal Boss Shear Out	0	Strength	LAT-DS-02528-5	6	Section 4.8
M2.5 with Insert Thermal Boss Tear Out	90	Strength	LAT-DS-02528-6	6	Section 4.9
M2.5 without Insert Thermal Boss Shear Out	90	Strength	LAT-DS-02528-8	6	Section 4.10
M2.5 without Inserts Pullout	TT	Strength	LAT-DS-02528-9	12	Section 4.11
M4 with 2 Insert Thermal Boss Shearout	0	Strength	LAT-DS-02528-10	6	Section 4.12
M4 with Insert Corner Tearout	0	Strength	LAT-DS-02528-11	6	Section 4.13
M4 with Insert Shearout	45	Strength	LAT-DS-02528-12	6	Section 4.14
M4 with Insert Corner Tearout	90	Strength	LAT-DS-02528-13	6	Section 4.15
M4 with Insert Thermal Boss Shearout	0	Strength	LAT-DS-02528-14	6	Section 4.16

4.0 TEST PROCEDURE

4.1 Tensile Properties

Tensile properties were determined as summarized below and per SP-T-023.

4.1.1 Summary

Six (6) 0-degree and six (6) 90-degree tensile specimens were fabricated from the hybrid panel (Figure 4.1). The specimens were tested on the Instron model 4505 Universal Test System at a crosshead rate of 0.05 inch per minute to failure. A MTS model 632-17E-20 1.0 inch gauge length extensometer was used to measure specimen deformation (strain) during loading. All specimens were tested at ambient temperature.

4.1.2 Specimen Geometry

The tensile specimens were 9.0 inches long in the test direction by 1.0 inch wide. G-10 glass doublers were bonded to the ends of the specimen using EA9394 paste adhesive mixed with 2.5% by weight of 0.005 inch diameter glass spheres to control bondline thickness.

4.1.3 Calculations

4.1.3.1 Tension Strength

The tension strength was calculated as follows:

$$F_{tu} = \frac{P_{ult}}{w * t}$$

Where: Ftu = Tension strength (ksi)

Pult = Ultimate load (lb)

w = Width of specimen (in)

t = Thickness of specimen (in)

4.1.3.2 Tension Modulus

The tension modulus was calculated as follows:

$$E_t = \left(\frac{P_2 - P_1}{\varepsilon_2 - \varepsilon_1} \right) \frac{1}{w * t}$$

Where: Et = Tension Modulus (msi)

P2 = Load at 1500 microstrain (lb)

P1 = Load at 100 microstrain (lb)

ε2 = 1500 microstrain (με)

ε1 = 100 microstrain (με)

w = Width of specimen (in)

t = Thickness of specimen (in)

4.1.3.3 Allowable Tensile Strength

The statistically-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The tensile strength allowable was determined assuming a normal distribution statistical model. Note: the tensile strength B-basis value was determined only on this hybrid panel and may not be valid for another hybrid panel.

The allowable ultimate tensile strength value was calculated as follows:

$$F_{tua} = \overline{X}_{tu} - k_B S_{tu}$$

Where: Ftua = Ultimate tensile strength allowable (ksi)

$\overline{X}_{tu}$ = Average value of the tensile strength data (ksi)

Stu = Standard deviation value of the tensile strength data (ksi)

kB = 3.007 is the one-sided B-basis tolerance for a sample size of six

4.2 Compression Properties

Compression properties were determined as summarized below and per SP-T-025 Method B.

4.2.1 Summary

Six (6) 0-degree and six (6) 90-degree compression specimens were fabricated from the hybrid panel (Figure 4.1). G-10/glass doublers were bonded to each end of the specimen. The specimens were instrumented with back-to-back strain gages. The specimens were loaded to failure using a Wyoming modified Celanese Compression Test Fixture. The specimens were loaded on an Instron model 4505 Universal Test System at a crosshead rate of 0.05 inch per minute. Load and strain gage data were recorded in intervals of 2 seconds or less.

4.2.2 Specimen Geometry

The compression specimens were 4.50 inches long in the test direction by 0.50 inch wide. G-10 glass doublers, 2.0 inches long were bonded to the ends of the specimens using EA9394 paste adhesive mixed with 2.5% by weight of 0.005 inch diameter glass spheres to control bondline thickness. The specimen gauge section was 0.50 inch long by 0.50 inch wide.

4.2.3 Instrumentation

Each specimen was instrumented with CEA-06-062UW-350 axial strain gages bonded back-to-back with M-Bond 200 adhesive.

4.2.4 Calculations

4.2.4.1 Compression Strength

The compression strength was calculated as follows:

$$F_{cu} = \frac{P_{ult}}{w*t}$$

Where: Fcu = Compression strength (ksi)

Pult = Ultimate load (lb)

w = Width of specimen (in)

t = Thickness of specimen (in)

4.2.4.2 Compression Modulus

The compression modulus was calculated as follows:

$$E_c = \left(\frac{P_2 - P_1}{\varepsilon_2 - \varepsilon_1} \right) \frac{1}{w*t}$$

Where: Ec = Compression Modulus (msi)

P2 = Load at 500 microstrain (lb)

P1 = Load at 100 microstrain (lb)

ε2 = 1500 microstrain (με)

ε1 = 100 microstrain (με)

w = Width of specimen (in)

t = Thickness of specimen (in)

4.2.4.3 Allowable Compression Strength

The statistically-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The compression strength allowable was determined assuming a normal distribution statistical model. Note: the compression strength B-basis value was determined only on this hybrid panel and may not be valid for another hybrid panel.

The allowable ultimate compression strength value was calculated as follows:

$$F_{cua} = \overline{X}_{cu} - k_B S_{cu}$$

Where: Fcua = Ultimate compression strength allowable (ksi)

$\overline{X}_{cu}$ = Average value of the compression strength data (ksi)

Scu = Standard deviation value of the compression strength data (ksi)

kB = 3.007 is the one-sided B-basis tolerance for a sample size of six.

4.3 Interlaminar (Short Beam) Shear

4.3.1 Summary

Six (6) interlaminar shear (short beam) shear specimens, 1.25 inches long by 0.25 inch wide were machined from the hybrid panel, (Figure 4.1).

The specimens were tested in 3-point bending at a span-to-depth ratio of 4:1. The specimens were placed on a test jig, with 0.125 inch diameter supports and a 0.250 inch diameter load nose, and tested on the Instron model 4505 Universal Test System at a crosshead rate of 0.05 inch per minute to failure.

4.3.2 Specimen Geometry

The short beam shear specimens were 1.25 inches long by 0.25 inch wide.

4.3.3 Calculations

4.3.3.1 Interlaminar (Short Beam) Shear

The interlaminar (short beam) shear strength was calculated as follows:

$$F_{SBS} = \frac{3}{4}\frac{P_{ult}}{w*t}$$

Where: FSBS = Interlaminar (short beam) shear strength (psi)

Pult = Ultimate Load (lb)

w = Specimen width (in)

t = Specimen thickness (in)

4.3.3.2 Allowable Interlaminar Shear Strength

The statistically-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The interlaminar shear strength allowable was determined assuming a normal distribution statistical model. Note: the interlaminar shear strength B-basis value was determined only on this hybrid panel and may not be valid for another hybrid panel.

The allowable ultimate interlaminar shear strength value was calculated as follows:

$$F_{SBS} = \overline{X}_{SBS} - k_B S_{SBS}$$

Where: F_{SBS} = Ultimate interlaminar shear strength allowable (psi)

$\overline{X}_{SBS}$ = Average value of the interlaminar shear strength data (psi)

SSBS = Standard deviation value of the interlaminar shear strength data (psi)

k_B = 3.007 is the one-sided B-basis tolerance for a sample size of six.

4.4 M2.5 Fastener Thermal Boss with Insert Shear-out

The M2.5 fastener thermal boss with insert shear-out tests were conducted as described below.

4.4.1 Specimen Configuration

Six (6) 0-degree thermal boss shear-out blank coupons 6.000 ± 0.050 inch long in the test direction by 1.000 ± 0.050 inch wide were machined from the as-fabricated hybrid panel (Figure 4.1). A 0.246 ± 0.050 inch through-hole was placed at one end of the specimen (Item 1, Figure 4.2) at an edge distance of 0.306 inch (e/D = 1.24) and a width distance of 0.500 inch (w/D = 2.03). A titanium insert (PN 102-TKR-14-2020-1) was bonded in the hole using EA9394 paste adhesive mixed with 0.005 inch diameter glass spheres to control bondline thickness.

4.4.2 Test Procedure

The specimens were tested at ambient temperature on the Instron model 4505 Universal Test Machine at a crosshead rate of 0.05 inch per minute to failure. An aluminum test jig with a threaded insert (Figure 4.3) was attached to the lower crosshead of the Instron test machine using a threaded rod. A universal joint was attached to the load cell located on the upper crosshead of the test machine. A 1.0 inch wide mechanical wedge grip was pinned in the universal joint. The specimen was fastened to the insert of the test jig using a M2.5 countersink A286 fastener torqued at 7 in-lb (0.8N-m). The specimen was placed in the mechanical grip and loaded to failure at a crosshead rate of 0.05 inch per minute. Failure was defined as a 10% or greater drop in maximum load. Figure 4.4 is a photograph of the test setup.

4.4.3 Calculations

4.4.3.1 Ultimate Load

The fasteners for this set of specimens failed prior to specimen failure. Therefore, only the ultimate load shall be recorded.

4.4.3.2 Ultimate Load Allowable

The statistical-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The ultimate load allowable was determined assuming a normal distribution statistical model. Note: the ultimate load B-basis value was determined based on the shear failure of the fastener for this specimen configuration.

The allowable shear-out strength value was calculated as follows:

$$P_{ultu} = \overline{X}_{Pulta} - k_B * S_{Pulta}$$

Where: P_{ulta} = Ultimate load allowable (lb)

$\overline{X}_{Pulta}$ = Average ultimate load value (lb)

k_B = 3.007 for the one-sided B-basis tolerance for a sample size of 6

S_{Pulta} = Standard deviation value of the ultimate load data set (lb)

4.5 M2.5 Fastener 2-Hole Corner Shear-Out without Inserts

The 2-hole M2.5 fastener corner shear-out tests were conducted as described below.

4.5.1 Specimen Configuration

Six (6) 0-degree 2-hole corner shear out blank coupons 6.000 ± 0.050 inch long in the test direction by 1.000 ± 0.050 inch wide were machined from the as-fabricated hybrid panel (Figure 4.1). Two (2) 0.118 -0.002/+0.005 inch countersink holes, 0.015 inch deep with a 100-degree pitch were placed in each specimen off centered (0.527 ± 0.050 inch). One (1) hole was located at an edge distance of 0.990 ± 0.050 inch and the other hole at an edge distance of 0.360 ± 0.050 inch, Item 2 Figure 4.2.

4.5.2 Test Procedure

The specimens were tested at ambient temperature on the Instron model 4505 Universal Test Machine at a crosshead rate of 0.05 inch per minute to failure. A steel test jig with two (2) threaded holes (Figure 4.6) was attached to the lower crosshead of the Instron Test Machine using a threaded pullrod. A universal joint was attached to the load cell located on the upper crosshead of the test machine. A one-inch wide mechanical wedge grip was pinned to the universal joint. The specimen was fastened to the test jig using two (2) M2.5 countersink A286 fasteners torqued to 7 in-lb (0.8 Nm). The specimen was placed in the mechanical grip and loaded in tension to failure at a crosshead rate of 0.05 inch per minute. Failure was defined as a 10% or more drop in maximum load. Figure 4.7 is a photograph of the test setup.

4.5.3 Calculations

Failure modes may be classified as follows: 1) fastener failure; shear or yield; 2) bearing; 3) net tensions; and 4) tearout. A schematic of failure modes 2, 3, and 4 are shown in Figure 4.5.

4.5.3.1 Bearing Strength

The failures of these specimens were in bearing. Bearing strength for a double fastener specimen is determined as follows:

$$F_B = \frac{P_{ult}}{2 * t * D}$$

Where: F_B = Bearing strength (ksi)

P_{ult} = Ultimate load (lb)

t = Specimen thickness (in)

D = Nominal specimen diameter (in)

4.5.3.2 Bearing Strength Allowable

The statistical-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The bearing strength allowable was determined assuming a normal distribution statistical model. Note: The bearing strength B-basis value was determined based on the specific specimen configuration, panel layup and torque value and may not represent any other geometries or panel orientations.

The allowable bearing strength value was calculated as follows:

$$F_{Ba} = \overline{X}_{Ba} - k_B * S_{Ba}$$

Where: F_{Ba} = Bearing strength allowable (ksi)

$\overline{X}_{Ba}$ = Average bearing strength of the data set (ksi)

S_{Ba} = Standard deviation of the bearing data set (ksi)

k_B = 3.007 for the one-sided B-basis tolerance for a sample size of 6

4.6 M2.5 Fastener 0-Degree Corner Tearout without Inserts

The M2.5 fastener 0-degree corner tearout without insert tests were conducted as described below.

4.6.1 Specimen Configuration

Six (6) 0-degree corner tearout blank coupons, 6.000 ± 0.050 inches long in the test direction by 1.000 ± 0.050 inch wide at one end radiusing down to 0.747 ± 0.050 inch at the other end were waterjet machined from the as-fabricated hybrid panel (Figure 4.1). One (1) 0.118 -0.002/+0.005 inch diameter countersink hole, 0.015 inch deep, with a 100-degree pitch was placed in each specimen a distance of 0.247 ± 0.050 inch from the radius side and 0.334 ± 0.050 inch from the specimen edge, Item 3, Figure 4.2.

4.6.2 Test Procedure

The specimens were tested at ambient temperature on the Instron model 4505 Universal Test Machine at a crosshead rate of 0.05 inch per minute to failure. An aluminum test jig with a threaded insert (Figure 4.3) was attached to the lower crosshead of the Instron test machine using a threaded rod. A universal joint was attached to the load cell located on the upper crosshead of the test machine. A 1.0 inch wide mechanical wedge grip was pinned in the universal joint. The specimen was fastened to the insert of the test jig using a M2.5 countersink A286 fastener torqued at 7 in-lb (0.8N-m). The specimen was placed in the mechanical grip and loaded in tension to failure at a crosshead rate of 0.05 inch per minute. Failure was defined as a 10% or greater drop in maximum load. Figure 4.8 is a photograph of the test setup.

4.6.3 Calculations

Failure modes may be classified as follows: 1) fastener failure; shear or yield; 2) bearing; 3) net tensions; and 4) tearout. A schematic of failure modes 2, 3, and 4 are shown in Figure 4.5.

4.6.3.1 Bearing Strength

The failure of these specimens were in bearing. Bearing strength for a double fastener specimen is determined as follows:

$$F_B = \frac{P_{ult}}{t * D}$$

Where: F_B = Bearing strength (ksi)

P_{ult} = Ultimate load (lb)

t = Specimen thickness (in)

D = Nominal specimen diameter (in)

4.6.3.2 Bearing Strength Allowable

The statistical-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The bearing strength allowable was determined assuming a normal distribution statistical model. Note: The bearing strength B-basis value was determined based on the specific specimen configuration, panel layup and torque value and may not represent any other geometries or panel orientations.

The allowable bearing strength value was calculated as follows:

$$F_{Ba} = \overline{X}_{Ba} - k_B * S_{Ba}$$

Where: FBa = Bearing strength allowable (ksi)

$\overline{X}_{Ba}$ = Average bearing strength of the data set (ksi)

S_{Ba} = Standard deviation of the bearing data set (ksi)

k_B = 3.007 for the one-sided B-basis tolerance for a sample size of 6

4.7 M2.5 Fastener 90-Degree Corner Tearout without Inserts

The M2.5 fastener 90-degree corner tearout without insert tests were conducted as described below.

4.7.1 Specimen Configuration

Six (6) 90-degree corner tearout blank coupons, 6.00 ± 0.050 inches long by 1.000 ± 0.050 inch wide at one end radiusing down to 0.848 ± 0.050 inch wide at the other end were waterjet machined from the as-fabricated hybrid panel (Figure 4.1). One (1) 0.018 -0.002/+0.005 inch diameter countersink hole, 0.015 inch deep, with a 100-degree pitch was placed in each specimen a distance of 0.348 ± 0.050 inch from the radius side and 0.247 ± 0.050 inch from the specimen edge, Item 4, Figure 4.2.

4.7.2 Test Procedure

The specimens were tested at ambient temperature on the Instron model 4505 Universal Test Machine at a crosshead rate of 0.05 inch per minute to failure. An aluminum test jig with a threaded insert (Figure 4.3) was attached to the lower crosshead of the Instron test machine using a threaded rod. A universal joint was attached to the load cell located on the upper crosshead of the test machine. A 1.0 inch wide mechanical wedge grip was pinned in the universal joint. The specimen was fastened to the insert of the test jig using a M2.5 countersink A286 fastener torqued at 7 in-lb (0.8N-m) The specimen was placed in the mechanical grip and loaded to failure at a crosshead rate of 0.05 inch per minute in tensile. Failure was defined as a 10% or greater drop in maximum load. Figure 4.9 is a photograph of the test setup.

4.7.3 Calculations

Failure modes may be classified as follows: 1) fastener failure; shear or yield; 2) bearing; 3) net tensions; and 4) tearout. A schematic of failure modes 2, 3, and 4 are shown in Figure 4.5.

4.7.3.1 Bearing Strength

The failure of these specimens were in bearing. Bearing strength for a double fastener specimen is determined as follows:

$$F_B = \frac{P_{ult}}{t * D}$$

Where: F_B = Bearing strength (ksi)

P_{ult} = Ultimate load (lb)

t = Specimen thickness (in)

D = Nominal specimen diameter (in)

4.7.3.2 Bearing Strength Allowable

The statistical-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The bearing strength allowable was determined assuming a normal distribution statistical model. Note: The bearing strength B-basis value was determined based on the specific specimen configuration, panel layup and torque value and may not represent any other geometries or panel orientations.

The allowable bearing strength value was calculated as follows:

$$F_{Ba} = \overline{X}_{Ba} - k_B * S_{Ba}$$

Where: F_{Ba} = Bearing strength allowable (ksi)

$\overline{X}_{Ba}$ = Average bearing strength of the data set (ksi)

S_{Ba} = Standard deviation of the bearing data set (ksi)

k_B = 3.007 for the one-sided B-basis tolerance for a sample size of 6

4.8 M2.5 Fastener 0-Degree Thermal Boss Shearout without Insert

The M2.5 fastener 0-degree thermal boss shearout without insert tests were conducted as described below.

4.8.1 Specimen Configuration

Six (6) M2.5 0-degree thermal boss shearout blank coupons, 6.000 ± 0.050 inches long in the test direction by 1.000 ± 0.050 inch wide were waterjet machined from the as-fabricated hybrid panel (Figure 4.1). One (1) 0.118 -0.002/+0.005 inch diameter countersink hole, 0.015 inch deep with a 100-degree pitch was placed in each specimen along the centerline (0.5000 ± 0.050 inch) and 0.247 ± 0.050 inch from the edge, Item 5, Figure 4.2.

4.8.2 Test Procedure

The specimens were tested at ambient temperature on the Instron model 4505 Universal Test Machine at a crosshead rate of 0.05 inch per minute to failure. An aluminum test jig with a threaded insert (Figure 4.3) was attached to the lower crosshead of the Instron test machine using a threaded rod. A universal joint was attached to the load cell located on the upper crosshead of the test machine. A 1.0 inch wide mechanical wedge grip was pinned in the universal joint. The specimen was fastened to the insert of the test jig using a M2.5 countersink A286 fastener torqued at 7 in-lb (0.8N-m) The specimen was placed in the mechanical grip and loaded to failure at a crosshead rate of 0.05 inch per minute in tensile. Failure was defined as a 10% or greater drop in maximum load. Figure 4.10 is a photograph of the test setup.

4.8.3 Calculations

Failure modes may be classified as follows: 1) fastener failure; shear or yield; 2) bearing; 3) net tensions; and 4) tearout. A schematic of failure modes 2, 3, and 4 are shown in Figure 4.5.

4.8.3.1 Bearing Strength

The failure of these specimens were in bearing. Bearing strength for a double fastener specimen is determined as follows:

$$F_B = \frac{P_{ult}}{t * D}$$

Where: F_B = Bearing strength (ksi)

P_{ult} = Ultimate load (lb)

t = Specimen thickness (in)

D = Nominal specimen diameter (in)

4.8.3.2 Bearing Strength Allowable

The statistical-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The bearing strength allowable was determined assuming a normal distribution statistical model. Note: The bearing strength B-basis value was determined based on the specific specimen configuration, panel layup and torque value and may not represent any other geometries or panel orientations.

The allowable bearing strength value was calculated as follows:

$$F_{Ba} = \overline{X}_{Ba} - k_B * S_{Ba}$$

Where: F_{Ba} = Bearing strength allowable (ksi)

$\overline{X}_{Ba}$ = Average bearing strength of the data set (ksi)

S_{Ba} = Standard deviation of the bearing data set (ksi)

k_B = 3.007 for the one-sided B-basis tolerance for a sample size of 6

4.9 M2.5 Fastener 90-Degree Thermal Boss Tearout with Insert

The M2.5 90-degree thermal boss tearout with insert tests were conducted as described below.

4.9.1 Specimen Configuration

Six (6) 90-degree thermal boss tearout blank coupons, 6.000 ± 0.050 inches long in the test direction by 1.000 ± 0.050 inch at one end radiusing down to 0.806 ± 0.050 inch at the other end were waterjet machined from the as-fabricated hybrid panel (Figure 4.1). One (1) 0.246 ± 0.050 inch through-hole was placed at one end of each specimen (Item 6, Figure 4.2) at a distance of 0.306 ± 0.050 inch from the radius side and 0.591 ± 0.050 inch from the specimen edge. A titanium insert (PN102-TKR-14-2020-1) was bonded in the hole using EA9394 paste adhesive mixed with 0.005 inch diameter glass spheres to control bondline thickness.

4.9.2 Test Procedure

The specimens were tested at ambient temperature on the Instron model 4505 Universal Test Machine at a crosshead rate of 0.05 inch per minute to failure. An aluminum test jig with a threaded insert (Figure 4.3) was attached to the lower crosshead of the Instron test machine using a threaded rod. A universal joint was attached to the load cell located on the upper crosshead of the test machine. A 1.0 inch wide mechanical wedge grip was pinned in the universal joint. The specimen was fastened to the insert of the test jig using a M2.5 countersink A286 fastener torqued at 7 in-lb (0.8N-m) The specimen was placed in the mechanical grip and loaded to failure at a crosshead rate of 0.05 inch per minute in tensile. Failure was defined as a 10% or greater drop in maximum load. Figure 4.11 is a photograph of the test setup.

4.9.3 Calculations

Failure modes may be classified as follows: 1) fastener failure; shear or yield; 2) bearing; 3) net tensions; and 4) tearout. A schematic of failure modes 2, 3, and 4 are shown in Figure 4.5.

4.9.3.1 Ultimate Load

The fasteners for this set of specimens failed prior to specimen failure. Therefore, only the ultimate load shall be recorded.

4.9.3.2 Ultimate Load Allowable

The statistical-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The ultimate load allowable was determined assuming a normal distribution statistical model. Note: the ultimate load B-basis value was determined based on the shear failure of the fastener for this specimen configuration.

The allowable shear-out strength value was calculated as follows:

$$P_{ultu} = \overline{X}_{Pulta} - k_B * S_{Pulta}$$

Where: P_{ulta} = Ultimate load allowable (lb)

$\overline{X}_{Pulta}$ = Average ultimate load value (lb)

k_B = 3.007 for the one-sided B-basis tolerance for a sample size of 6

S_{Pulta} = Standard deviation value of the ultimate load data set (lb)

4.10 M2.5 Fastener 90-Degree Thermal Boss Shearout without Insert

The M2.5 fastener 90-degree thermal boss shearout without insert tests were conducted as described below.

4.10.1 Specimen Configuration

Six (6) M2.5 90-degree thermal boss shearout blank coupons, 6.000 ± 0.050 inches long in the test direction by 1.000 ± 0.050 inch wide were waterjet machined from the as-fabricated hybrid panel (Figure 4.1). One (1) 0.118 -0.002/+0.005 inch diameter countersink hole, 0.015 inch deep, with a 100 degree pitch was placed in each specimen along the centerline (0.500 ± 0.050 inch) and 0.334 ± 0.050 inch from the specimen edge, Item 8, Figure 4.2.

4.10.2 Test Procedure

The specimens were tested at ambient temperature on the Instron model 4505 Universal Test Machine at a crosshead rate of 0.05 inch per minute to failure. An aluminum test jig with a threaded insert (Figure 4.3) was attached to the lower crosshead of the Instron test machine using a threaded rod. A universal joint was attached to the load cell located on the upper crosshead of the test machine. A 1.0 inch wide mechanical wedge grip was pinned in the universal joint. The specimen was fastened to the insert of the test jig using a M2.5 countersink A286 fastener torqued at 7 in-lb (0.8N-m) The specimen was placed in the mechanical grip and loaded to failure at a crosshead rate of 0.05 inch per minute in tensile. Failure was defined as a 10% or greater drop in maximum load. Figure 4.12 is a photograph of the test setup.

4.10.3 Calculations

Failure modes may be classified as follows: 1) fastener failure; shear or yield; 2) bearing; 3) net tensions; and 4) tearout. A schematic of failure modes 2, 3, and 4 are shown in Figure 4.5.

4.10.3.1 Bearing Strength

The failure of these specimens were in bearing. Bearing strength for a double fastener specimen is determined as follows:

$$F_B = \frac{P_{ult}}{t * D}$$

Where: F_B = Bearing strength (ksi)

P_{ult} = Ultimate load (lb)

t = Specimen thickness (in)

D = Nominal specimen diameter (in)

4.10.3.2 Bearing Strength Allowable

The statistical-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The bearing strength allowable was determined assuming a normal distribution statistical model. Note: The bearing strength B-basis value was determined based on the specific specimen configuration, panel layup and torque value and may not represent any other geometries or panel orientations.

The allowable bearing strength value was calculated as follows:

$$F_{Ba} = \overline{X}_{Ba} - k_B * S_{Ba}$$

Where: F_{Ba} = Bearing strength allowable (ksi)

$\overline{X}_{Ba}$ = Average bearing strength of the data set (ksi)

S_{Ba} = Standard deviation of the bearing data set (ksi)

k_B = 3.007 for the one-sided B-basis tolerance for a sample size of 6

4.11 M2.5 Fastener Pullout without Inserts

The M2.5 fastener pullout tests were conducted as described below.

4.11.1 Specimen Configuration

Twelve (12) M2.5 fastener pullout blank coupons, 2.00 ± 0.030 by 2.00 ± 0.030 inches were waterjet machined from the as-fabricated hybrid panel (Figure 4.1). One (1) 0.118 -0.002/+0.005 inch diameter countersink hole, 0.015 inch deep with a 100-degree pitch was placed in the center of each specimen, Item 9, Figure 4.2.

4.11.2 Test Procedure

The specimens were tested at ambient temperature on the Instron model 4505 Universal Test Machine at a crosshead rate of 0.05 inch per minute to failure. A 4.0 by 4.0 by 1.0 inch steel plate with a 1.0 inch diameter through hole was used as the test aperture, Figure 4.13. The aperture plate was attached to the lower crosshead of the Instron Universal Test Machine. The M2.5 fastener was bolted to one end of an aluminum insert, Figure 4.13, at a torque value of 7 in-lb (0.8 Nm). A threaded pullrod was attached to the other end of the aluminum insert and to an adapter attached to the load cell. The specimens were loaded to failure at crosshead rate of 0.05 inch per minute to failure. Failure was defined as a 10% or greater drop in maximum load. Figure 4.4 is a photograph of the test setup.

4.11.3 Calculations

4.11.3.1 Ultimate Load

There is no calculation associated with this test procedure. Ultimate load shall be recorded.

4.11.3.2 Ultimate Load Allowable

The statistical-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The ultimate load allowable was determined assuming a normal distribution statistical model. Note: the ultimate load B-basis value was determined based on the shear failure of the fastener for this specimen configuration.

The allowable shear-out strength value was calculated as follows:

$$P_{ultu} = \overline{X}_{Pulta} - k_B * S_{Pulta}$$

Where: P_{ulta} = Ultimate load allowable (lb)

$\overline{X}_{Pulta}$ = Average ultimate load value (lb)

k_B = 2.211 for the one-sided B-basis tolerance for a sample size of 6

S_{Pulta} = Standard deviation value of the ultimate load data set (lb)

4.12 M4 Fastener 0-Degree 2-Hole Thermal Boss Shearout with Inserts

The M4 fastener 2 hole thermal boss 0-degree shearout with inserts tests were conducted as described below.

4.12.1 Specimen Configuration

Six (6) thermal boss 0-degree shearout blank coupons, 6.000 ± 0.050 inches long in the test direction by 1.054 ± 0.050 inch wide were waterjet machined from the as-fabricated hybrid panel (Figure 4.1). Two (2) 0.266 ± 0.002 inch diameter countersink holes, 0.015 inch deep, with a 100-degree pitch were placed on the end of the specimen along the centerline (0.527 ± 0.050 inch) at an edge distance of 1.049 ± 0.050 inch and 0.419 ± 0.050 inch, respectively, Item 10, Figure 4.2. A titanium insert (PN 102-TKR-14-2020-3) was bonded in the hole using EA9394 paste adhesive mixed with 0.005 inch diameter glass spheres to control bondline thickness.

4.12.2 Test Procedure

The specimens were tested at ambient temperature on the Instron model 4505 Universal Test Machine at a crosshead rate of 0.05 inch per minute to failure. A steel test jig with two (2) threaded holes (Figure 4.6) was attached to the lower crosshead of the Instron Test Machine using a threaded pullrod. A universal joint was attached to the load cell located on the upper crosshead of the test machine. A one-inch wide mechanical wedge grip was pinned to the universal joint. The specimen was fastened to the test jig using two (2) M4 countersink A286 fasteners torqued to 31.8 in-lb (3.6 Nm). The specimen was placed in the mechanical grip and loaded to failure at a crosshead rate of 0.05 inch per minute. Failure was defined as a 10% or more drop in maximum load. Figure 4.15 is a photograph of the test setup.

4.12.3 Calculations

Failure modes may be classified as follows: 1) fastener failure; shear or yield; 2) bearing; 3) net tensions; and 4) tearout. A schematic of failure modes 2, 3, and 4 are shown in Figure 4.5.

4.12.3.1 Bearing Strength

The failure of these specimens were in bearing. Bearing strength for a double fastener specimen is determined as follows:

$$F_B = \frac{P_{ult}}{2 * t * D}$$

Where: F_B = Bearing strength (ksi)

P_{ult} = Ultimate load (lb)

t = Specimen thickness (in)

D = Nominal specimen diameter (in)

4.12.3.2 Bearing Strength Allowable

The statistical-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The bearing strength allowable was determined assuming a normal distribution statistical model. Note: The bearing strength B-basis value was determined based on the specific specimen configuration, panel layup and torque value and may not represent any other geometries or panel orientations.

The allowable bearing strength value was calculated as follows:

$$F_{Ba} = \overline{X}_{Ba} - k_B * S_{Ba}$$

Where: F_{Ba} = Bearing strength allowable (ksi)

$\overline{X}_{Ba}$ = Average bearing strength of the data set (ksi)

S_{Ba} = Standard deviation of the bearing data set (ksi)

k_B = 3.007 for the one-sided B-basis tolerance for a sample size of 6

4.13 M4 Fastener 0-Degree Corner Tearout with Insert

The 0-degree corner tearout with insert tests using M4 fastener were conducted as described below.

4.13.1 Specimen Configuration

Six (6) 0-degree corner tearout blank coupons, 6.000 ± 0.050 inch long in the test direction by 1.000 ± 0.050 inch wide at one end radiusing to 0.834 inch wide at the other end were waterjet machined from the as-fabricated hybrid panel, Figure 4.1. One (1) 0.266 ± 0.002 inch diameter countersunk hole, 0.015 inch deep with a 100-degree pitch was placed 0.334 ± 0.050 inch from the radius edge and 0.306 ± 0.050 inch from the end of the specimen, Item 11, Figure 4.2. A titanium insert (PN 102-TKR-14-2020-3) was bonded in the countersink hole using EA9394 paste adhesive mixed with 0.005 inch diameter glass spheres to control bondline thickness.

4.13.2 Test Procedure

The specimens were tested at ambient temperature on the Instron model 4505 Universal Test Machine at a crosshead rate of 0.05 inch per minute to failure. An aluminum test jig with a threaded insert (Figure 4.3) was attached to the lower crosshead of the Instron Universal Test Machine using a threaded rod. A universal joint was attached to the load cell located on the upper crosshead of the test machine. A 1.0 inch wide mechanical wedge grip was pinned in the universal joint. The specimen was fastened to the insert of the test jig using a M4 countersink A286 fastener torqued at 32 in-lb (3.6 N-m) The specimen was placed in the mechanical grip and loaded to failure at a crosshead rate of 0.05 inch per minute in tensile. Failure was defined as a 10% or greater drop in maximum load. Figure 4.16 is a photograph of the test setup.

4.13.3 Calculations

Failure modes may be classified as follows: 1) fastener failure; shear or yield; 2) bearing; 3) net tensions; and 4) tearout. A schematic of failure modes 2, 3, and 4 are shown in Figure 4.5.

4.13.3.1 Ultimate Load

The fasteners for this set of specimens failed prior to specimen failure. Therefore, only the ultimate load shall be recorded.

4.13.3.2 Ultimate Load Allowable

The statistical-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The ultimate load allowable was determined assuming a normal distribution statistical model. Note: the ultimate load B-basis value was determined based on the shear failure of the fastener for this specimen configuration.

The allowable shear-out strength value was calculated as follows:

$$P_{ultu} = \overline{X}_{Pulta} - k_B * S_{Pulta}$$

Where: P_{ulta} = Ultimate load allowable (lb)

$\overline{X}_{Pulta}$ = Average ultimate load value (lb)

k_B = 3.007 for the one-sided B-basis tolerance for a sample size of 6

S_{Pulta} = Standard deviation value of the ultimate load data set (lb)

4.14 M4 Fastener 45-Degree Shearout with Inserts

The M4 fastener 45-degree insert shearout tests were conducted as described below.

4.14.1 Specimen Configuration

Six (6) 45-degree shearout blank coupons, 6.000 ± 0.050 inch long in the test direction by 1.000 inch wide with 2 45-degree angle cuts at one end of the specimen were waterjet machined from the as-fabricated hybrid panel, Figure 4.1. One (1) 0.266 ± 0.050 inch diameter countersunk hole, 0.015 inch deep, with a 100-degree pitch was placed an edge distance of 0.433 ± 0.050 inch, Item 12, Figure 4.2. A titanium insert (PN 102-TKR-14-2020-3) was bonded in the hole using EA9394 paste adhesive mixed with 0.005 inch diameter glass spheres to control bondline thickness.

4.14.2 Test Procedure

The specimens were tested at ambient temperature on the Instron model 4505 Universal Test Machine at a crosshead rate of 0.05 inch per minute to failure. An aluminum test jig with a threaded insert (Figure 4.3) was attached to the lower crosshead of the Instron test machine using a threaded rod. An Universal joint was attached to the load cell located on the upper crosshead of the test machine. A 1.0 inch wide mechanical wedge grip was pinned in the Universal joint. The specimen was fastened to the insert of the test jig using a M4 countersink A286 fastener torqued at 32 in-lb (3.6 N-m) The specimen was placed in the mechanical grip and loaded to failure at a crosshead rate of 0.05 inch per minute in tensile. Failure was defined as a 10% or greater drop in maximum load. Figure 4.17 is a photograph of the test setup.

4.14.3 Calculations

Failure modes may be classified as follows: 1) fastener failure; shear or yield; 2) bearing; 3) net tensions; and 4) tearout. A schematic of failure modes 2, 3, and 4 are shown in Figure 4.5.

4.14.3.1 Ultimate Load

The fasteners for this set of specimens failed prior to specimen failure. Therefore, only the ultimate load shall be recorded.

4.14.3.2 Ultimate Load Allowable

The statistical-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The ultimate load allowable was determined assuming a normal distribution statistical model. Note: the ultimate load B-basis value was determined based on the shear failure of the fastener for this specimen configuration.

The allowable shear-out strength value was calculated as follows:

$$P_{ultu} = \overline{X}_{Pulta} - k_B * S_{Pulta}$$

Where: P_{ulta} = Ultimate load allowable (lb)

$\overline{X}_{Pulta}$ = Average ultimate load value (lb)

k_B = 3.007 for the one-sided B-basis tolerance for a sample size of 6

S_{Pulta} = Standard deviation value of the ultimate load data set (lb)

4.15 M4 Fastener 90-Degree Corner Tearout with Inserts

The M4 fasteners 90-degree corner tearout tests were conducted as described below.

4.15.1 Specimen Configuration

Six (6) 90-degree corner tearout blank coupons, 6.000 ± 0.050 inches long in the test direction by 1.000 ± 0.050 inch wide at one end radiusing down to 0.806 ± 0.050 inch at the other end were waterjet machined from the as-fabricated hybrid panel, Figure 4.1. One (1) 0.266 ± 0.050 inch diameter countersink hole, 0.015 inch deep, with a 100-degree pitch was placed 0.306 ± 0.050 inch from the radius side and 0.334 ± 0.050 inch from the end, Item 13, Figure 4.2. A titanium insert (PN 102-TKR-14-2020-3) was bonded in the countersunk hole using EA9394 paste adhesive mixed with 0.005 inch diameter glass spheres to control bondline thickness.

4.15.2 Test Procedure

The specimens were tested at ambient temperature on the Instron model 4505 Universal Test Machine at a crosshead rate of 0.05 inch per minute to failure. An aluminum test jig with a threaded insert (Figure 4.3) was attached to the lower crosshead of the Instron test machine using a threaded rod. A universal joint was attached to the load cell located on the upper crosshead of the test machine. A 1.0 inch wide mechanical wedge grip was pinned in the universal joint. The specimen was fastened to the insert of the test jig using a M4 countersink A286 fastener torqued at 32 in-lb (3.6 N-m). The specimen was placed in the mechanical grip and loaded to failure at a crosshead rate of 0.05 inch per minute in tensile. Failure was defined as a 10% or greater drop in maximum load. Figure 4.18 is a photograph of the test setup.

4.15.3 Calculations

Failure modes may be classified as follows: 1) fastener failure; shear or yield; 2) bearing; 3) net tensions; and 4) tearout. A schematic of failure modes 2, 3, and 4 are shown in Figure 4.5.

4.15.3.1 Net Tension

All specimen failed by net tension. Net tensile strength was determined as follows:

$$F_{NT} = \frac{P_{ult}}{w * t}$$

Where: F_{NT} = Net tension strength (ksi)

P_{ult} = Ultimate load (lb)

W = Specimen width (in)

t = Specimen thickness (in)

4.15.3.2 Net Tension Allowables

The statistical-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The net tension strength allowable was determined assuming a normal distribution statistical model. Note: The net tension strength B-basis value was determined based on the specific specimen configuration, panel layup and torque value and may not represent any other geometries or panel orientations.

The allowable net tension strength value was calculated as follows:

$$F_{NTa} = \overline{X}_{NTa} - k_B * S_{NTa}$$

Where: F_{NTa} = Net tension strength allowable (ksi)

$\overline{X}_{NTa}$ = Average net tension strength of the data set (ksi)

S_{NTa} = Standard deviation of the net tension data set (ksi)

k_B = 3.007 for the one-sided B-basis tolerance for a sample size of 6

4.16 M4 Fastener 0-Degree Thermal Boss Shearout with Insert

The 0-degree thermal boss shearout tests were conducted as described below.

4.16.1 Specimen Configuration

Six (6) 0-degree thermal boss blank coupons, 6.000 ± 0.050 inches long in the test direction by 1.000 ± 0.050 wide were waterjet machined from the as-fabricated hybrid panel, Figure 4.1. One (1) 0.266 ± 0.002 inch diameter countersunk hole, 0.015 inch deep, with a 100-degree pitch was placed along the centerline (0.500 ± 0.050 inch) and 0.306 ± 0.050 inch from the edge, Item 14, Figure 4.2. A titanium insert (PN 102-TKR-142020-3) was bonded in the countersunk hole using EA9394 paste adhesive mixed with 0.005 inch diameter glass spheres to control bondline thickness.

4.16.2 Test Procedure

The specimens were tested at ambient temperature on the Instron model 4505 Universal Test Machine at a crosshead rate of 0.05 inch per minute to failure. An aluminum test jig with a threaded insert (Figure 4.3) was attached to the lower crosshead of the Instron test machine using a threaded rod. A universal joint was attached to the load cell located on the upper crosshead of the test machine. A 1.0 inch wide mechanical wedge grip was pinned in the universal joint. The specimen was fastened to the insert of the test jig using a M4 countersink A286 fastener torqued at 32 in-lb (3.6 N-m) The specimen was placed in the mechanical grip and loaded to failure at a crosshead rate of 0.05 inch per minute in tensile. Failure was defined as a 10% or greater drop in maximum load. Figure 4.19 is a photograph of the test setup.

4.16.3 Calculations

Failure modes may be classified as follows: 1) fastener failure; shear or yield; 2) bearing; 3) net tensions; and 4) tearout. A schematic of failure modes 2, 3, and 4 are shown in Figure 4.5.

4.16.3.1 Tearout Strength

These specimens failed in tearout. Tearout strength was determined as follows:

$$F_{TO} = \frac{P_{ult}}{2 * ed * t}$$

Where: F_{TO} = Tearout Strength (ksi)

P_{ult} = Ultimate Load (lb)

ed = Nominal edge distance (in)

t = Specimen thickness (in)

4.16.3.2 Tearout Strength Allowable

The statistical-based material strength allowable is a 95% lower confidence bound on the 10th percentile of the material strength. The tearout strength allowable was determined assuming a normal distribution statistical model. Note: The tearout strength B-basis value was determined based on the specific specimen configuration, panel layup and torque value and may not represent any other geometries or panel orientations.

The allowable tearout strength value was calculated as follows:

$$F_{TOa} = \overline{X}_{TOa} - k_B * S_{TOa}$$

Where: F_{TOa} = Tearout strength allowable (ksi)

$\overline{X}_{TOa}$ = Average tearout strength of the data set (ksi)

S_{TOa} = Standard deviation of the tearout data set (ksi)

k_B = 3.007 for the one-sided B-basis tolerance for a sample size of 6

5.0 TEST RESULTS

5.1 Tensile Properties

5.1.1 0-Degree

The individual 0-degree tensile specimen test results are listed in Table 5.1. The stress versus strain curves for the individual 0-degree tensile specimens are plotted in Figures A1 through A6.

Table 5-1 0-Degree Tension Specimen Test Results

Specimen ID	Width (in)	Thickness w/ Al Foil (in)	Thickness w/o Al Foil (in)	Ult Load (lb)	Ult. Strength w/ Al Foil (ksi)	Ult. Strength w/o Al Foil ksi)	Modulus (msi)	Failure Strain (με)	(1) Failure Mode
-1	1.0060	0.0592	0.0572	4977.1	83.57	86.49	30.89	2852	MAT
-2	1.0070	0.0621	0.0601	4966.0	79.41	82.05	28.91	2926	LAB
-3	1.0070	0.0609	0.0589	5138.5	83.79	86.63	29.92	3028	MVV
-4	1.0080	0.0621	0.0601	4981.4	79.58	82.23	29.17	2839	LAT
-5	1.0080	0.0615	0.0595	5002.9	80.70	83.42	29.82	2873	MAT
-6	1.0095	0.0624	0.0604	4769.4	75.71	78.22	29.17	2738	MGV
Average	**1.0076**	**0.0614**	**0.0594**	**4972.6**	**80.46**	**83.17**	**29.64**	**2876**	
Std. Dev	**0.0012**	**0.0012**	**0.0012**	**118.2**	**3.01**	**3.15**	**0.73**	**97**	
COV	**0.12%**	**1.94%**	**2.00%**	**2.38%**	**3.74%**	**3.79%**	**2.45%**	**3.36%**	
B-Basis					**71.42**	**73.69**			

(1) Schematic defining failure modes found in Figure B1

The average 0-degree tensile strength excluding the aluminum foil thickness in the calculations was just over 83 ksi with a corresponding B-basis just under 74 ksi. The average chord modulus, from 100 to 1500 microstrain, was 29.6 msi. The average strain-at-failure was just over 0.28%. The majority of the 0-degree tensile specimens failed by multiple modes near the tabs. Figure B2 is a photograph of the 0-degree failed tensile specimens.

5.1.2 90-Degree

The individual 90-degree tensile specimen test results are listed in Table 5.2. The stress versus strain curves for the individual 90-degree tensile specimens are plotted in Figures A7 through A12.

Table 5-2 90-Degree Tension Specimen Test Results

Specimen ID	Width (in)	Thickness w/ Al Foil (in)	Thickness w/o Al Foil (in)	Ult Load (lb)	Ult. Strength w/ Al Foil (ksi)	Ult. Strength w/o Al Foil (ksi)	Modulus (msi)	Failure Strain (με)	(1) Failure Mode
-1	0.9980	0.0628	0.0608	2723.9	43.46	44.89	17.41	2302	LIT
-2	0.9885	0.0629	0.0609	2517.6	40.49	41.82	17.20	2271	LGM
-3	0.9970	0.0631	0.0611	2767.2	43.99	45.43	17.59	2539	LIT
-4	0.9990	0.0629	0.0609	2543.6	40.48	41.81	17.29	1849	AAB
-5	0.9975	0.0628	0.0608	2557.7	40.83	42.17	17.75	2243	LAT
-6	1.0030	0.0627	0.0607	2366.7	37.63	38.87	17.24	2140	AIT
Average	**0.9972**	**0.0629**	**0.0609**	**2579.5**	**41.15**	**42.50**	**17.41**	**2224**	
Std. Dev	**0.0048**	**0.0001**	**0.0001**	**146.3**	**2.31**	**2.39**	**0.22**	**226**	
COV	**0.48%**	**0.22%**	**0.22%**	**5.67%**	**5.62%**	**5.62%**	**1.25%**	**10.17%**	
B-Basis					**34.19**	**35.32**			

(1) Schematic defining failure modes found in Figure B1

The average 90-degree tensile strength excluding the aluminum foil thickness in the calculations was just under 43 ksi with a corresponding B-basis of 35 ksi. The average 90-degree chord modulus from 100 to 1500 microstrain was 17.4 msi. The average strain-at-failure was just over 0.22%. The 90-degree tensile specimens tended to show lateral or angular failure mode at or near the tabs. Figure B3 is a photograph of the 90-degree failed tensile specimens.

5.2 Compression Properties

5.2.1 0-Degree

The individual 0-degree compression specimen test results are listed in Table 5.3. The stress versus strain curves for the individual 0-degree compression specimen are plotted in Figures A13 through A18.

Table 5-3 0-Degree Compression Specimen Test Results

Specimen ID	Width (in)	Thickness w/ Al Foil (in)	Thickness w/o Al Foil (in)	Ult Load (lb)	Ult. Strength w/ Al Foil (ksi)	Ult. Strength w/o Al Foil (ksi)	Modulus (msi)	(1) Failure Mode
-1	0.4938	0.0626	0.0606	711.2	23.01	23.77	28.72	DGM
-2	0.4920	0.0618	0.0598	713.1	23.45	24.24	27.37	DGM
-3	0.4938	0.0626	0.0606	673.2	21.78	22.50	26.39	DGM
-4	0.4940	0.0622	0.0602	706.8	23.00	23.77	28.22	DGM
-5	0.4960	0.0620	0.0600	718.3	23.36	24.14	23.65	DGM
-6	0.4950	0.0625	0.0605	695.7	22.49	23.23	27.91	DAT
Average	**0.4941**	**0.0623**	**0.0603**	**703.1**	**22.85**	**23.61**	**27.04**	
Std. Dev	**0.0013**	**0.0003**	**0.0003**	**16.5**	**0.62**	**0.65**	**1.84**	
COV	**0.27%**	**0.54%**	**0.56%**	**2.34%**	**2.73%**	**2.75%**	**6.82%**	
B-Basis					**20.97**	**21.66**		

(1) Schematic defining failure modes found in Figure B4

The average 0-degree compression strength excluding the aluminum foil thickness in the calculations was just over 24 ksi with a corresponding B-basis value of 22 ksi. The average chord modulus from 100 microstrain to 500 microstrain was 27 msi. The stress versus strain curves are all non-linear an indication of a buckling failure mode. The majority of the specimens show a delamination failure in the gage section. Figure B5 is a photograph of the failed 0-degree compression specimen.

5.2.2 90-Degree

The individual 90-degree compression specimen test results are listed in Table 5.4. The stress versus strain curves for the individual 90-degree compression specimen are plotted in Figures A19 through A24.

Table 5-4 90-Degree Compression Specimen Test Results

Specimen ID	Width (in)	Thickness w/ Al Foil (in)	Thickness w/o Al Foil (in)	Ult Load (lb)	Ult. Strength w/ Al Foil (ksi)	Ult. Strength w/o Al Foil (ksi)	Modulus (msi)	(1) Failure Mode
-1	0.4940	0.0619	0.0599	452.4	14.80	15.29	15.05	SGM
-2	0.4950	0.0620	0.0600	442.2	14.41	14.89	17.14	SGM
-3	0.4945	0.0618	0.0598	461.6	15.10	15.61	17.50	TGM
-4	0.4949	0.0615	0.0595	459.1	15.08	15.59	16.96	LGM
-5	0.4948	0.0625	0.0605	458.8	14.84	15.33	17.35	HGM
-6	0.4982	0.0616	0.0596	453.2	14.77	15.26	16.64	DGM
Average	**0.4952**	**0.0619**	**0.0599**	**454.6**	**14.83**	**15.33**	**16.77**	
Std. Dev	**0.0015**	**0.0004**	**0.0004**	**7.0**	**0.25**	**0.26**	**0.90**	
COV	**0.27%**	**0.54%**	**0.56%**	**2.34%**	**2.73%**	**2.75%**	**6.82%**	
B-Basis					**14.07**	**14.53**		

(1) Schematic defining failure modes found in Figure B4

The average 90-degree compression strength excluding the aluminum foil thickness in the calculations was just over 15 ksi was a corresponding B-basis value of 14.5 ksi. The stress versus strain curves are all non-linear at failure, indicating buckling failure modes. The 90-degree compression specimen exhibited multiple failure modes. Figure B6 is a photograph of the 90-degree compression specimens.

5.3 Interlaminar (Short Beam) Shear

The interlaminar (short beam) shear specimen were tested in 3-point bending. Two (2) specimens were tested with the aluminum foil up. These specimen failed by plastic deformation. Two (2) specimens were tested with the aluminum side down. These specimens failed in shear. Four (4) more specimens were tested with the aluminum foil down.

Table 5.5 lists the individual short beam shear specimen test results. Figures A25 through A30 are plots of the stress versus crosshead travel for each of the individual short beam shear specimens.

Table 5-5 Interlaminar (Short Beam) Shear Specimen Test Results

Specimen ID	Width (in)	Thickness w/ Al Foil (in)	Thickness w/o Al Foil (in)	Ult Load (lb)	Ult. Strength w/ Al Foil (psi)	Ult. Strength w/o Al Foil (psi)	Failure Mode
-1	0.2525	0.0618	0.0598	88.9	4273	4416	Interlaminar
-2	0.2540	0.0604	0.0584	82.5	4033	4171	Interlaminar
-3	0.2540	0.0596	0.0576	85.2	4221	4368	Interlaminar
-4	0.2535	0.0572	0.0552	80.3	4153	4304	Interlaminar
-5	0.2510	0.0621	0.0601	88.0	4234	4375	Interlaminar
-6	0.2540	0.0582	0.0562	80.5	4084	4229	Interlaminar
Average	**0.2532**	**0.0599**	**0.0579**	**84.2**	**4166**	**4311**	
Std. Dev	**0.0012**	**0.0019**	**0.0019**	**3.7**	**93**	**94**	
COV	**0.48%**	**3.25%**	**3.36%**	**4.42%**	**2.24%**	**2.19%**	
B-Basis					**3886**	**4027**	

The average interlaminar shear strength excluding the aluminum foil thickness in the calculations was 4300 psi with a corresponding B-basis of 4000 psi. All specimens failed by interlaminar shear.

5.4 M2.5 Fastener 0-Degree Thermal Boss with Insert Shearout Test Results

Table 5.6 lists the results of the M2.5 fastener 0-degree thermal boss with insert individual specimen shearout test results. Figure A31 to A36 plot load versus crosshead travel for each of the individual specimens.

Table 5-6 M2.5 Fastener 0-Degree Thermal Boss with Insert Individual Specimen Shearout Test Results

Specimen ID	Maximum Load (lb)	Maximum Cross-Head Travel (in)	Failure Mode
1-1	373.5	0.0582	Fastener Shear
1-2	383.5	0.0595	Fastener Shear
1-3	357.8	0.0635	Fastener Yield
1-4	361.2	0.0518	Fastener Yield
1-5	360.7	0.0609	Fastener Yield
1-6	359.8	0.0502	Fastener Yield
Average	**366.1**	**0.0574**	
Std. Dev.	**10.2**	**0.0052**	
COV	**2.78%**	**9.15%**	
B-Basis	**335.4**		

No visual damage was exhibited by the specimens after loading. The fasteners either sheared or yielded resulting in the 10% drop in load. The average maximum load for all specimens was 366 lb with a maximum individual value of 385 lb and a minimum individual value of 358 lb.

5.5 M2.5 Fastener 2-Hole Corner 0-Degree Shearout Test Results

The individual M2.5 fastener 2-hole 0-degree corner shearout specimen test results are listed in Table 5.7. The individual specimen load versus crosshead travel curves are plotted in Figures A37 to A42.

Table 5-7 M2.5 Fastener 2-Hole Corner without Insert 0-Degree Shearout Test Results

Specimen ID	Width (in)	Thickness (in)	Nominal Hole Diameter (in)	Maximum Load (lb)	Maximum Cross-Head Travel (in)	Nominal Bearing Strength (ksi)	Failure Mode
2-1	0.9965	0.0621	0.1180	493.2	0.0624	33.65	Laminate Bearing Failure
2-2	0.9800	0.0617	0.1180	490.5	0.0551	33.69	Laminate Bearing Failure
2-3	1.0000	0.0612	0.1180	508.1	0.0575	35.18	Laminate Bearing Failure
2-4	0.9995	0.0614	0.1180	502.0	0.0532	34.64	Laminate Bearing Failure
2-5	0.9985	0.0614	0.1180	489.2	0.0542	33.76	Laminate Bearing Failure
2-6	0.9965	0.0617	0.1180	504.4	0.0563	34.64	Laminate Bearing Failure
Average	**0.9952**	**0.0616**		**497.9**	**0.0565**	**34.26**	
Std. Dev.	**0.0076**	**0.0003**		**7.9**	**0.0033**	**0.65**	
COV	**0.76%**	**0.52%**		**1.60%**	**5.82%**	**1.88%**	
B-Basis				**474.0**		**32.32**	

All specimens failed in bearing (Figure B7). The average ultimate load for the data set was 498 lb with a B-basis value of 474 lb. The calculated bearing strength using actual measured specimen thickness and nominal hole diameter was 34 ksi with a corresponding B-basis value of 32 ksi.

5.6 M2.5 Fastener 0-degree Corner Tearout without Insert Test Results

The individual M2.5 fastener 0-degree corner tearout specimen test results are listed in Table 5.8. Te individual specimen load versus crosshead travel curves are plotted in Figures A43 to A48.

Table 5-8 M2.5 Fastener 0-Degree Individual Corner Tearout Specimen

Specimen ID	Width (in)	Thickness (in)	Nominal Hole Diameter (in)	Maximum Load (lb)	Maximum Cross-Head Travel (in)	Nominal Bearing Strength (ksi)	Failure Mode
3-1	0.7435	0.0619	0.1180	273.1	0.0495	37.39	Laminate Bearing Failure
3-2	0.7435	0.0622	0.1180	261.2	0.0511	35.59	Laminate Bearing Failure
3-3	0.7445	0.0613	0.1180	269.2	0.0456	37.22	Laminate Bearing Failure
3-4	0.7440	0.0622	0.1180	273.5	0.0426	37.26	Laminate Bearing Failure
3-5	0.7430	0.0610	0.1180	257.0	0.0419	35.70	Laminate Bearing Failure
3-6	0.7425	0.0612	0.1180	264.5	0.0409	36.63	Laminate Bearing Failure
Average	**0.7435**	**0.0616**		**266.4**	**0.0453**	**36.63**	
Std. Dev.	**0.0007**	**0.0005**		**6.7**	**0.0042**	**0.81**	
COV	**0.10%**	**0.86%**		**2.50%**	**9.35%**	**2.21%**	
B-Basis				**246.4**		**34.20**	

All specimens failed in bearing (Figure B8). The average ultimate load for the data set was 266 lb with a B-basis value of 246 lb. The calculated bearing strength using actual measured specimen thickness and nominal hole diameter was 37 ksi with a corresponding B-basis value of 24 ksi for this specimen configuration.

5.7 M2.5 Fastener 90-Degree Individual Corner Tearout Specimen Test Results

The individual M2.5 fastener 90-degree corner specimen tearout test results are listed in Table 5.9. The individual specimen load versus crosshead travel curves are plotted in Figure A49 to A54.

Table 5-9 M2.5 Fastener 90-Degree Individual Corner Tearout Specimen Test Results

Specimen ID	Width (in)	Thickness (in)	Nominal Hole Diameter (in)	Maximum Load (lb)	Maximum Cross-Head Travel (in)	Nominal Bearing Strength (ksi)	Failure Mode
4-1	0.8455	0.0620	0.1180	267.9	0.0499	36.62	Laminate Bearing Failure
4-2	0.8455	0.0617	0.1180	277.9	0.0453	38.17	Laminate Bearing Failure
4-3	0.8455	0.0607	0.1180	271.0	0.0425	37.84	Laminate Bearing Failure
4-4	0.8475	0.0618	0.1180	262.5	0.0462	36.00	Laminate Bearing Failure
4-5	0.8440	0.0617	0.1180	269.0	0.0472	36.95	Laminate Bearing Failure
4-6	0.8475	0.0610	0.1180	272.4	0.0467	37.84	Laminate Bearing Failure
Average	**0.8459**	**0.0615**		**270.1**	**0.0463**	**37.24**	
Std. Dev.	**0.0014**	**0.0005**		**5.1**	**0.0024**	**0.85**	
COV	**0.16%**	**0.83%**		**1.89%**	**5.24%**	**2.28%**	
B-Basis				**254.7**		**34.68**	

All specimens failed in bearing (Figure B9). The average ultimate load for the data set was 270 lb with a B-basis value of 255 lb. The calculated bearing strength using actual measured specimen thickness and nominal hole diameter was 37 ksi with a corresponding B-basis value of 35 ksi for this specimen configuration.

5.8 M2.5 Fastener Thermal Boss 0-Degree Shearout Test Results

The individual M2.5 fastener thermal boss 0-degree shearout specimen test results are listed in Table 5.10. The plots of the individual specimen load versus crosshead table curves are shown in Figures A55 to A60.

Table 5-10 M2.5 Fastener Individual Thermal Boss Specimen 0-degree Shearout Test Results

Specimen ID	Width (in)	Thickness (in)	Nominal Hole Diameter (in)	Maximum Load (lb)	Maximum Cross-Head Travel (in)	Nominal Bearing Strength (ksi)	Failure Mode
5-1	0.9990	0.0620	0.1180	260.5	0.0507	35.61	Laminate Bearing Failure
5-2	0.9985	0.0623	0.1180	265.4	0.0458	36.10	Laminate Bearing Failure
5-3	0.9970	0.0621	0.1180	270.7	0.0452	36.94	Laminate Bearing Failure
5-4	0.9950	0.0622	0.1180	248.8	0.0432	33.90	Laminate Bearing Failure
5-5	0.9975	0.0600	0.1180	256.5	0.0399	36.23	Laminate Bearing Failure
5-6	0.9965	0.0608	0.1180	247.9	0.0387	34.55	Laminate Bearing Failure
Average	**0.9973**	**0.0616**		**258.3**	**0.0439**	**35.56**	
Std. Dev.	**0.0014**	**0.0009**		**9.1**	**0.0044**	**1.13**	
COV	**0.14%**	**1.53%**		**3.51%**	**9.93%**	**3.19%**	
B-Basis				**231.0**		**32.15**	

All specimens failed in bearing (Figure B10). The average ultimate load for the data set was 258 lb with a corresponding B-basis value of 231 lb. The calculated bearing strength using actual specimen thickness and nominal hole diameter was 36 ksi with a B-basis value of 32 ksi for this specimen configuration.

5.9 M2.5 Fastener Thermal Boss with Insert 90-Degree Tearout Test Results

The individual M2.5 fastener thermal boss 90-degree tearout specimen with insert test results are listed in Table 5.11. The plots of the individual specimen load versus crosshead travel curves are shown in Figures A61 to A66.

Table 5-11 Individual M2.5 Fastener Thermal Boss 90-Degree Tearout Specimen with Insert Test Results

Specimen ID	Maximum Load (lb)	Maximum Cross-Head Travel (in)	Failure Mode
6-1	365.0	0.0499	Fastener Distorted
6-2	360.1	0.0504	Fastener Distorted
6-3	361.8	0.0540	Fastener Distorted
6-4	364.2	0.0541	Fastener Distorted
6-5	379.9	0.0672	Fastener Distorted
6-6	386.9	0.0648	Fastener Distorted
Average	**369.7**	**0.0567**	
Std. Dev.	**11.0**	**0.0074**	
COV	**2.98%**	**13.09%**	

None of the specimens exhibited any visual damage due to loading. The failures occurred by fastener yielding. The average maximum failure load was 370 lb with an individual high value of 387 lb and an individual low value of 360 lbs.

5.10 M2.5 Fastener Thermal Boss 90-Degree Shearout Test Results

The individual M2.5 fastener thermal boss 90-degree shearout specimen test results are listed in Table 5.12. The plots of load versus crosshead travel are found in Figures A67 to A72.

Table 5-12 Individual M2.5 Fastener Thermal Boss 90-Degree Specimen Shearout Test Results

Specimen ID	Width (in)	Thickness (in)	Nominal Hole Diameter (in)	Maximum Load (lb)	Maximum Cross-Head Travel (in)	Nominal Bearing Strength (ksi)	Failure Mode
8-1	1.0000	0.0622	0.1180	275.5	0.0488	37.54	Laminate Bearing Failure
8-2	0.9925	0.0623	0.1180	272.1	0.0452	37.01	Laminate Bearing Failure
8-3	0.9920	0.0620	0.1180	275.7	0.0473	37.68	Laminate Bearing Failure
8-4	0.9980	0.0622	0.1180	279.0	0.0488	38.01	Laminate Bearing Failure
8-5	1.0005	0.0620	0.1180	278.9	0.0497	38.12	Laminate Bearing Failure
8-6	0.9990	0.0622	0.1180	269.4	0.0454	36.70	Laminate Bearing Failure
Average	**0.9970**	**0.0622**		**275.1**	**0.0475**	**37.51**	
Std. Dev.	**0.0038**	**0.0001**		**3.8**	**0.0019**	**0.56**	
COV	**0.38%**	**0.20%**		**1.38%**	**3.99%**	**1.49%**	
B-Basis				**263.7**		**35.84**	

All specimens failed in bearing, Figure B11. The average ultimate failure load for this set of data was 275 lb with a corresponding B-basis value of 264 lb. The calculated bearing strength using actual specimen thickness and nominal hole diameter was 38 ksi with a corresponding B-basis value of 36 ksi for this specimen configuration.

5.11 M2.5 Fastener Pullout Test Results

The individual M2.5 fastener pullout specimen test results are listed in Table 5.13. The plots of load versus crosshead travel for the individual pull through specimens are found in Figures A73 to A84.

Table 5-13 Individual M2.5 Fastener Pullout Specimen Test Results

Specimen ID	Maximum Load (lb)	Maximum Cross-Head Travel (in)	Failure Mode
9-1	83.8	0.0085	Hole Failure
9-2	79.9	0.0103	Hole Failure
9-3	82.3	0.0195	Hole Failure
9-4	78.2	0.0113	Hole Failure
9-5	81.4	0.0131	Hole Failure
9-6	82.2	0.0104	Hole Failure
9-7	84.0	0.0096	Hole Failure
9-8	83.7	0.0095	Hole Failure
9-9	73.4	0.0106	Hole Failure
9-10	80.4	0.0111	Hole Failure
9-11	87.7	0.0114	Hole Failure
9-12	82.6	0.0115	Hole Failure
Average	**81.6**	**0.0114**	
Std. Dev.	**3.5**	**0.0028**	
COV	**4.33%**	**24.63%**	
B-Basis	**73.8**		

All specimens failed by hole pull-through, Figure B12. The average ultimate load for this data set was 82 lb with a maximum individual value of 88 lb and a minimum individual value of 73 lb. The corresponding B-basis value was 74 lb.

5.12 M4 Fastener 2-Hole Thermal Boss 0-Degree Shearout Test Results

The individual M4 fastener with inserts 2-hole thermal boss specimen 0-degree shearout test results are listed in Table 5.14. The load versus crosshead travel curves are plotted in Figures A85 to A90.

Table 5-14 Individual M4 Fastener with Inserts 2-Hole Thermal Boss Specimen 0-degree Shearout Test Results

Specimen ID	Width (in)	Thickness (in)	Nominal Hole Diameter (in)	Maximum Load (lb)	Nominal Bearing Strength (ksi)	Maximum Cross-Head Travel (in)	Failure Mode
10-1	1.0510	0.0618	0.2660	2075.9	63.14	0.1041	Laminate Bearing Failure
10-2	1.0530	0.0602	0.2660	1855.2	57.93	0.0730	Laminate Bearing Failure
10-3	1.0510	0.0615	0.2660	2071.5	63.31	0.0810	Laminate Bearing Failure
10-4	1.0520	0.0608	0.2660	1940.7	60.00	0.0743	Laminate Bearing Failure
10-5	1.0515	0.0611	0.2660	2055.0	63.22	0.0908	Laminate Bearing Failure
10-6	1.0515	0.0618	0.2660	1950.6	59.33	0.0720	Laminate Bearing Failure
Average	**1.0517**	**0.0612**		**1991.5**	**61.15**	**0.0825**	
Std. Dev.	**0.0008**	**0.0006**		**89.9**	**2.36**	**0.0127**	
COV	**0.07%**	**1.03%**		**4.51%**	**3.87%**	**15.38%**	
B-Basis				**1721.2**	**54.04**		

All specimens failed in bearing, Figure B13. The average ultimate failure load for this data was 1992 lb with a maximum individual value of 2076 lb and a minimum value of 1940 lb. The B-basis value was 1721 lb. The calculated bearing strength using actual specimen thickness and nominal hole diameter was 61 ksi with a corresponding B-basis value of 54 ksi for this specimen configuration.

5.13 M4 Fastener Corner Tearout with Inserts 0-Degree Test Results

The individual M4 fastener corner 0-degree tearout specimen test results are listed in Table 5.15. The load versus crosshead travel curves are plotted in Figures A90 to A96.

Table 5-15 Individual M4 Fastener Corner 0-Degree Specimen with Insert Tearout Test Results

Specimen ID	Maximum Load (in)	Maximum Cross-Head Travel (in)	Failure Mode
11-1	956.3	0.0815	Insert Hole Distortion with Fastener Shear
11-2	1059.4	0.1195	Insert Hole Distortion with Fastener Shear
11-3	1007.8	0.1030	Insert Hole Distortion with Laminate Failure
11-4	938.1	0.0787	Insert Hole Distortion with Fastener Shear
11-5	938.3	0.0861	Insert Hole Distortion with Fastener Shear
11-6	1034.7	0.0837	Insert Hole Distortion with Laminate Failure
Average	**989.1**	**0.0921**	
Std. Dev.	**52.2**	**0.0159**	
COV	**5.28%**	**17.29%**	

All the specimens exhibited damage to the titanium insert by bearing yield. Two (2) of the specimens also exhibited secondary failure of the laminate at the insert tearout, Figure B14. The average maximum load for this data set was 909 lb with a maximum individual load value of 1059 lb and a minimum individual load value of 938 lb.

5.14 M4 Fastener 45-Degree Shearout with Insert Test Results

The individual M4 fastener 45-degree shearout with insert specimen test results are listed in Table 5.16. The load versus crosshead curves for the individual specimens are plotted in Figures A97 to A102.

Table 5-16 Individual M4 Fastener 45-Degree Shearout with Insert Specimen Test Results

Specimen ID	Maximum Load (lb)	Maximum Cross-Head Travel (in)	Failure Mode
12-1	679.2 *	0.0665	Insert Hole Distortion with Fastener Shear
12-2	948.2	0.0676	Insert Hole Distortion with Fastener Shear
12-3	964.1	0.0647	Insert Hole Distortion with Insert Tearout
12-4	996.4	0.0673	Insert Hole Distortion with Insert Tearout
12-5	1021.4	0.0785	Insert Hole Distortion with Insert Tearout
12-6	822.7	0.0633	Insert Hole Distortion with Insert Tearout
Average	**950.6**	**0.0680**	
Std. Dev.	**76.9**	**0.0054**	
COV	**8.09%**	**7.95%**	
B-Basis	**688.5**		

* Not included in the statistical analysis

All the specimens exhibited insert hole distortion. Two (2) specimens sheared the fasteners prior to damaging the laminate. Four (4) of the specimens exhibited insert tearout, Figure B15. The fastener shear failure of specimen 12-1 was at a relatively low value of 679 lb. this result was excluded from the statistical analysis. The average ultimate load value for the remaining five (5) specimen was 950 lb with a B-basis value of 689 lb. *Note that the B-basis allowable reported needs to be considered with respect to the failure modes noted.*

5.15 M4 Fastener 90-Degree Corner with Insert Tearout Test Results

The individual M4 fastener corner specimen 90-degree tearout test results are listed in table 5.17. The load versus crosshead travel curves are plotted in Figures A103 to A108.

Table 5-17 Individual M4 Fastener 90-Degree Corner Tearout Specimen Test Results

Specimen ID	Width (in)	Thickness (in)	Nominal Hole Diameter (in)	Maximum Load (lb)	Net Tension (ksi)	Maximum Cross-Head Travel (in)	Failure Mode
13-1	0.8010	0.0624	0.2260	884.7 *	17.70 *	0.0852	Insert Hole Deformation with Fastener Shear
13-2	0.8030	0.0614	0.2260	1036.3	21.02	0.1045	Insert Hole Deformation with Fastener Shear
13-3	0.8050	0.0587	0.2260	1058.5	22.40	0.0734	Insert Hole Deformation with Laminate Net Tension
13-4	0.8025	0.0580	0.2260	1035.8	22.25	0.0707	Insert Hole Deformation with Laminate Net Tension
13-5	0.8025	0.0600	0.2260	1027.3	21.34	0.0677	Insert Hole Deformation with Laminate Net Tension
13-6	0.8025	0.0606	0.2260	973.2	20.01	0.0646	Insert Hole Deformation with Laminate Net Tension
Average	**0.8028**	**0.0602**		**1026.2**	**21.40**	**0.0777**	
Std. Dev.	**0.0013**	**0.0016**		**31.8**	**0.98**	**0.0149**	
COV	**0.16%**	**2.74%**		**3.10%**	**4.56%**	**19.21%**	
B-Basis				**917.8**	**18.08**		

* Not included in the statistical analysis

All specimens exhibited hole deformation of the insert. Four (4) of the specimens also failed by net tension, Figure B16. The other two (2) specimens sheared the fastener. The results of specimen 13-1 were excluded from the statistical analysis due to a low load value and failure mode. Though Specimen 13-2 did not fail by net tension, its value wasn't the next lowest and was included in the statistical analysis. The average failure load for the five (5) specimen data set was 1026 lb with a B-basis of 918 lb. The average net tension strength was 21.4 ksi with a B-basis value of 18 ksi. *Note that the B-basis allowable reported needs to be considered with respect to the failure modes noted.*

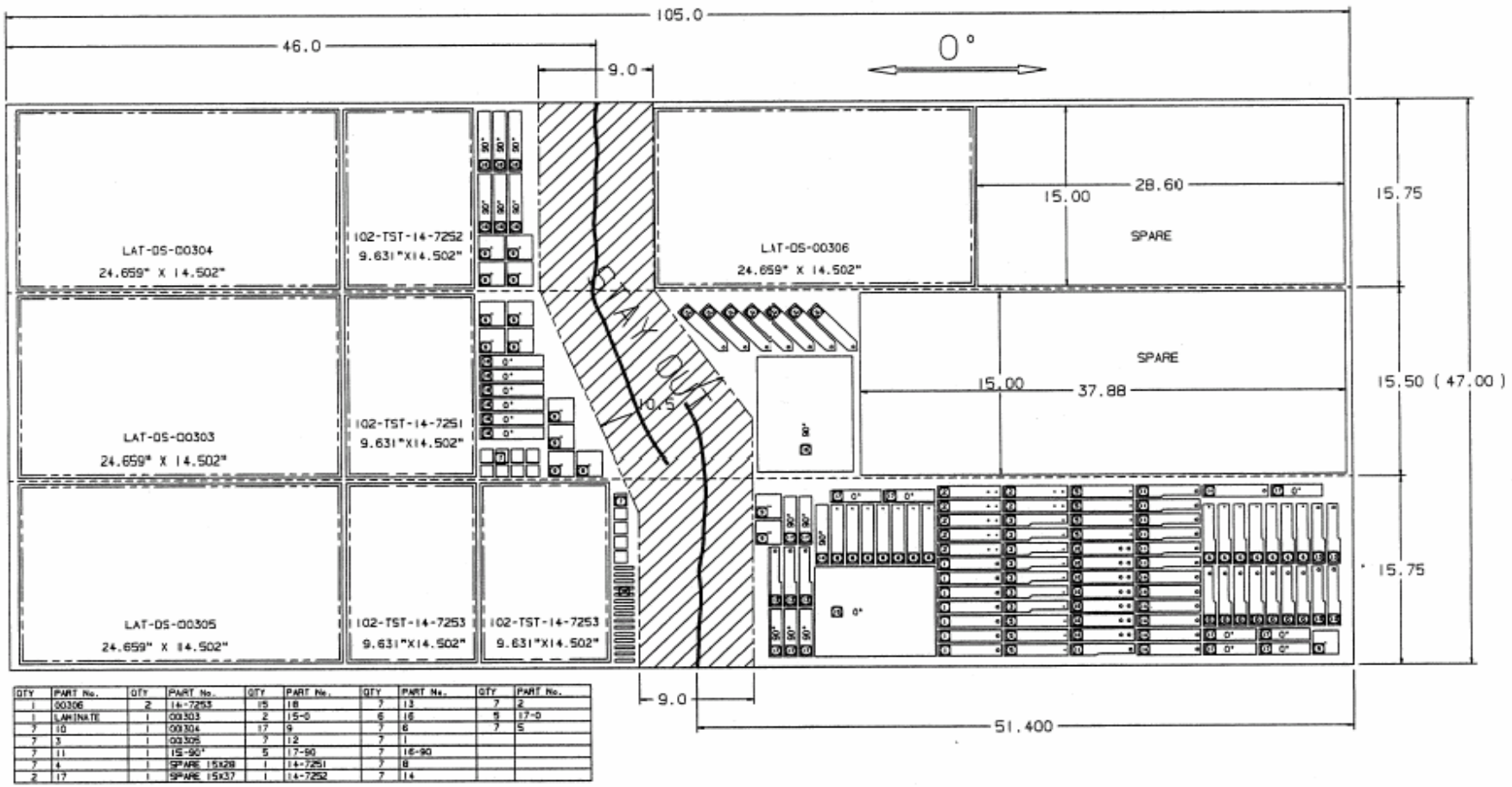
5.16 M4 Fastener Thermal Boss 0-Degree Shearout Test Results

The individual M4 fastener with insert thermal boss specimen 0-degree shearout test results are listed in Table 5.18. The load versus crosshead travel curves are plotted in Figures A109 to A114.

Table 5-18 Individual M4 Fastener Thermal Boss 0-Degree Shearout Specimen Test Results

Specimen ID	Width (in)	Thickness (in)	Nominal Hole Diameter (in)	Maximum Load (lb)	Tearout Strength (ksi)	Maximum Cross-Head Travel (in)	Failure Mode
14-1	0.9945	0.0623	0.2660	1008.4	26.45	0.0755	Insert Hole Distortion with Insert Tearout and Fastener Shear
14-2	0.9970	0.0629	0.2660	1026.4	26.66	0.0749	Insert Hole Distortion with Insert Tearout
14-3	0.9970	0.0607	0.2660	1031.4	27.76	0.0858	Insert Hole Distortion with Insert Tearout
14-4	0.9950	0.0617	0.2660	1032.5	27.34	0.0813	Insert Hole Distortion with Insert Tearout
14-5	0.9970	0.0590	0.2660	938.8	26.00	0.0667	Insert Hole Distortion with Insert Tearout and Fastener Shear
14-6	0.9975	0.0613	0.2660	993.2	26.47	0.0783	Insert Hole Distortion with Insert Tearout and Fastener Shear
Average	**0.9963**	**0.0613**		**1005.1**	**26.78**	**0.0771**	
Std. Dev.	**0.0013**	**0.0014**		**35.9**	**0.65**	**0.0065**	
COV	**0.13%**	**2.23%**		**3.57%**	**2.43%**	**8.41%**	
B-Basis				**882.8**	**24.57**		

All specimens exhibited insert hole deformation. All fasteners also exhibited tearout failure of the inserts (Figure B17) with several also shearing the fastener. The average failure load for the set of six (6) specimens was 1005 lb with a B-basis value of 803 lb. The average calculated tearout strength was 26.8 ksi with a corresponding B-basis value of 24.6 ksi.



QTY	PART No.	QTY	PART No.	QTY	PART No.	QTY	PART No.	QTY	PART No.
1	00306	2	14-7253	15	18	7	13	7	2
1	LAMINATE	1	00303	2	15-0	6	16	5	17-0
7	10	1	00304	17	9	7	6	7	5
7	3	1	00305	7	12	7	1		
7	11	1	15-90°	5	17-90	7	16-90		
7	4	1	SPARE 15x28	1	14-7251	7	8		
2	17	1	SPARE 15x37	1	14-7252	7	14		

Figure 4-1 Specimen Locations on the -Fabricated Hybrid Panel.

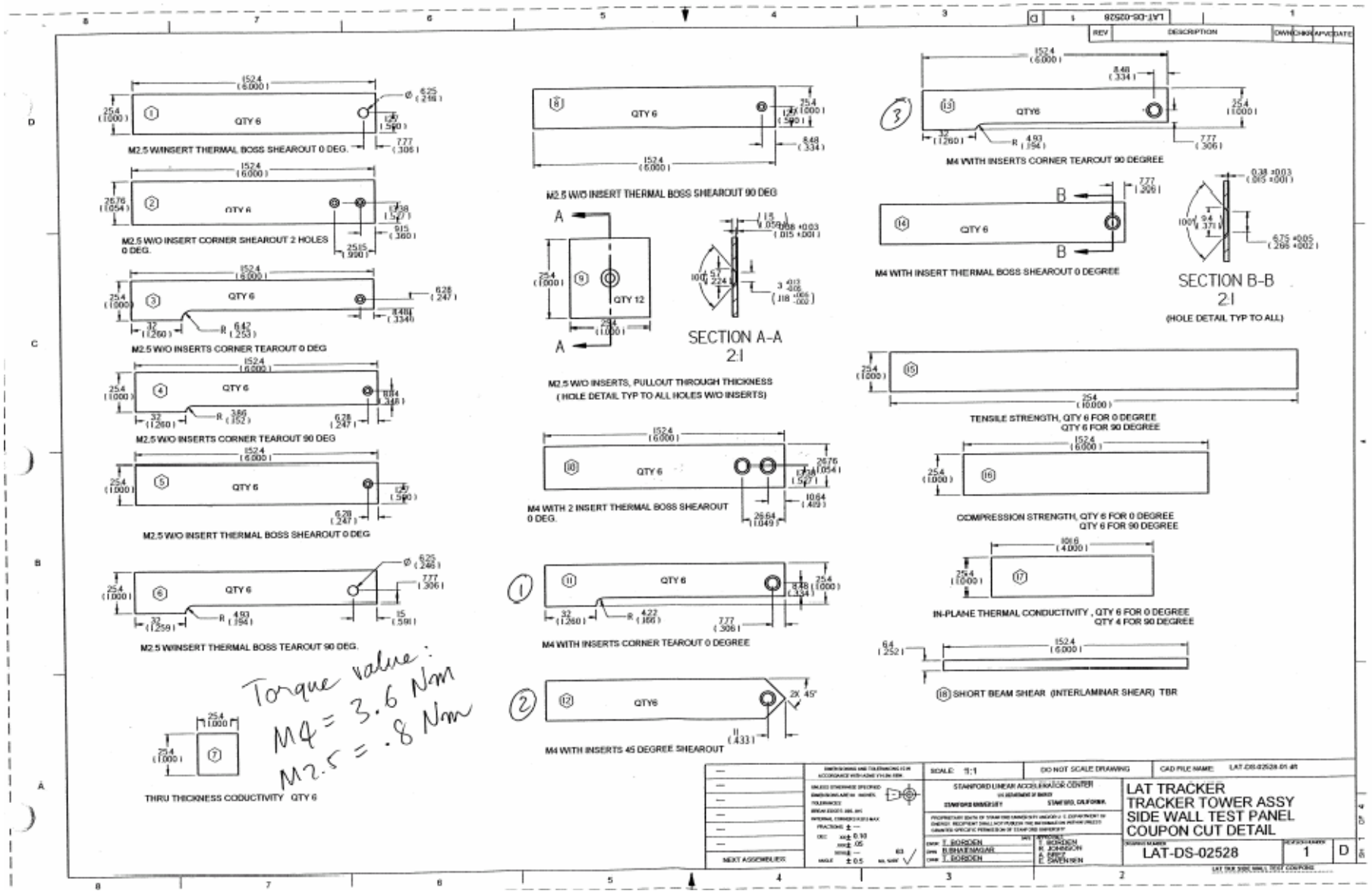


Figure 4.2 Drawing LAT-DS-02528 Side Wall Test Panel Coupon Details.

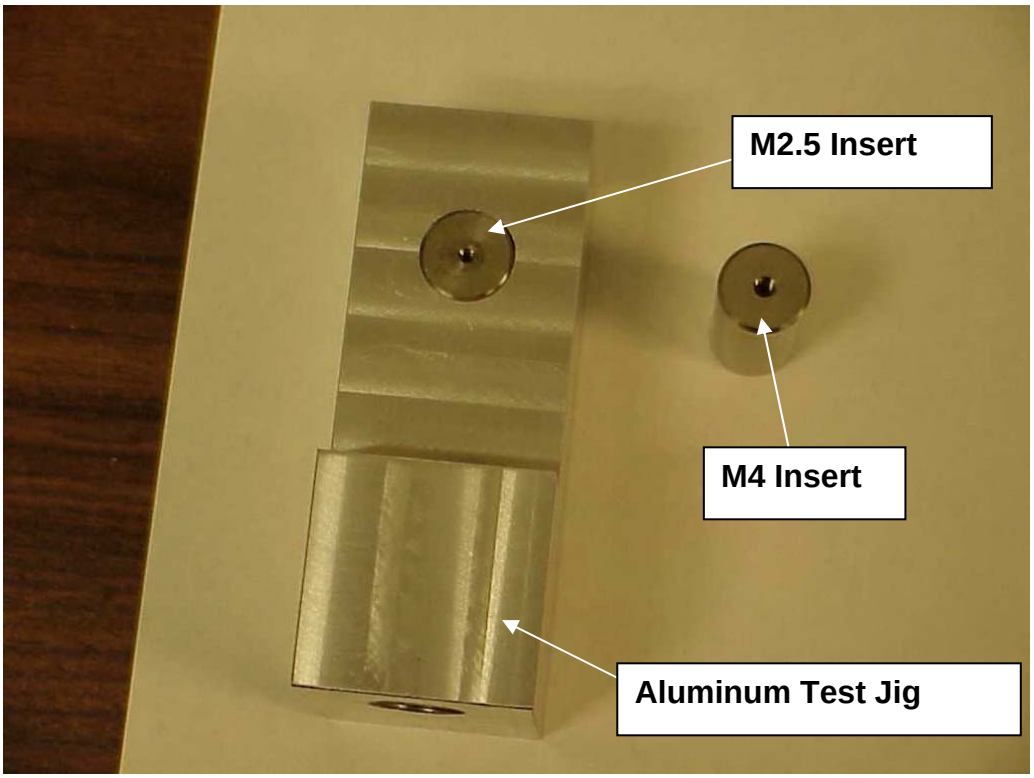
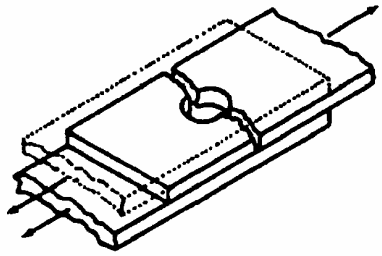


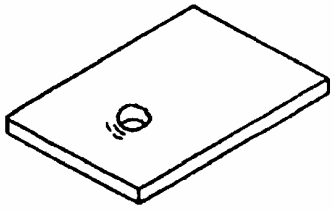
Figure 4.3 Photograph of the single hole aluminum test jig with threaded inserts.

[PHOTOGRAPH UNAVAILABLE]

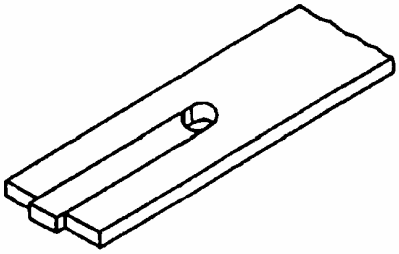
Figure 4.4 Photograph of the M2.5 fastener thermal boss with insert 0-degree shearout test setup.



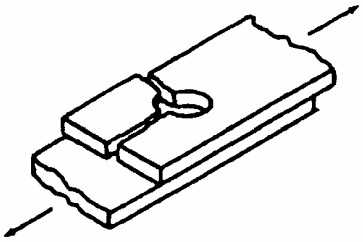
L-NT, L-NC: Laminate Net Section Tension (or Compression) Failure



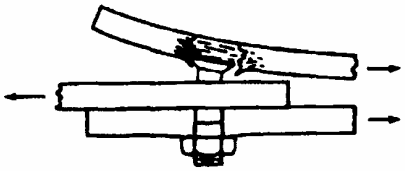
L-BR: Laminate Bearing Failure



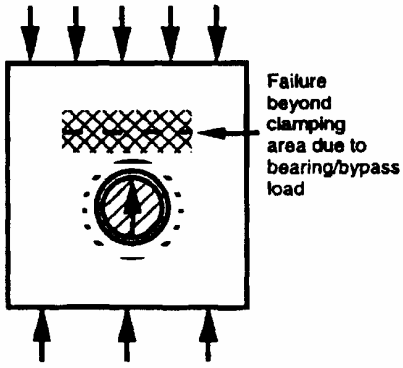
L-SO: Laminate Shear-out Failure



L-MM: Mixed Mode Failure (unsuitable for data generation)



L-PT: Fastener Pull-Through (or Partial Pull-Through) Failure



L-OC: Laminate Off-Set Compression Failure

Failure mode descriptions for mechanically fastened joints.

Figure 4.5 Schematic of the typical fastener bearing, net tension and shearout failure modes.

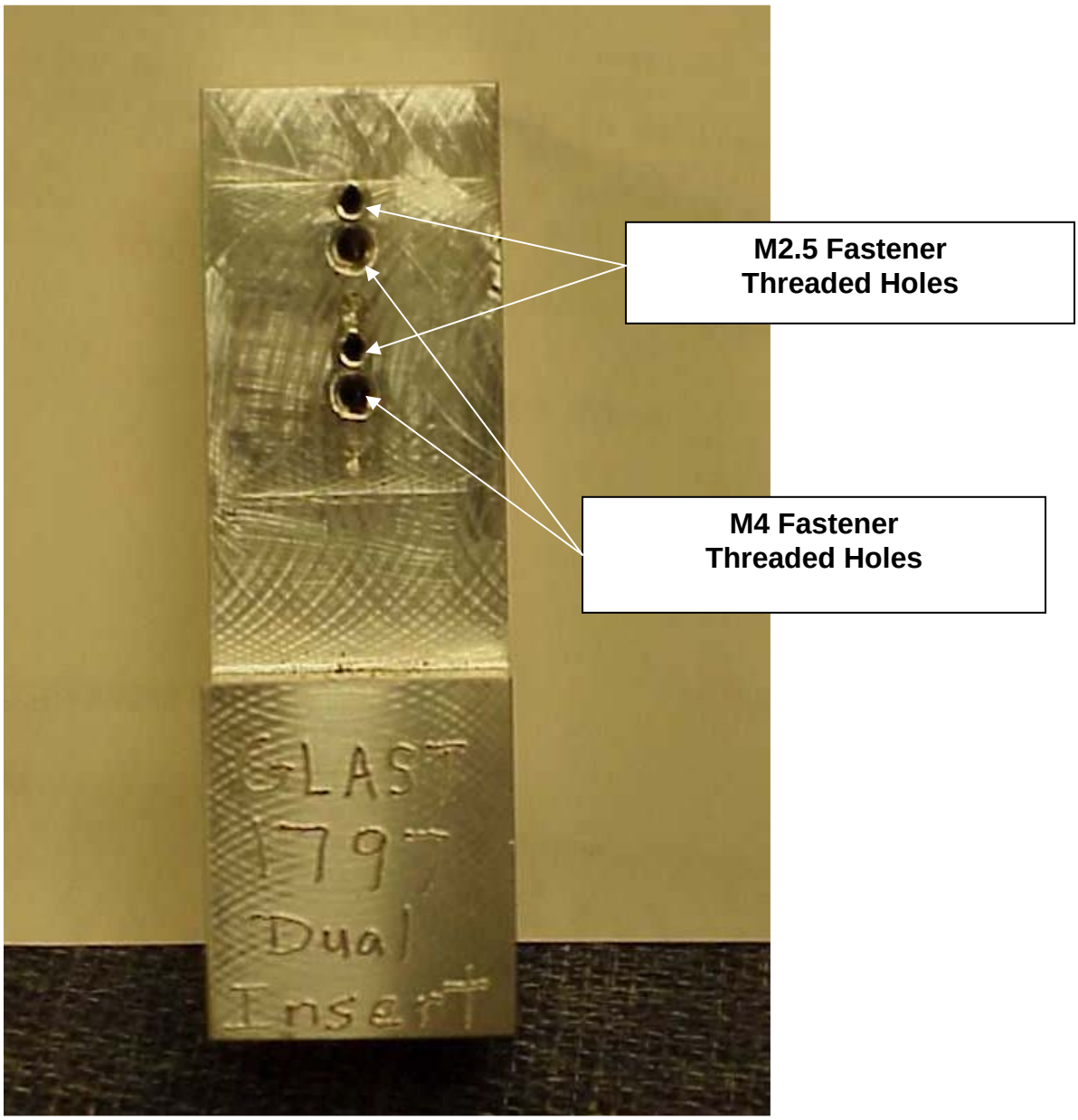


Figure 4.6 Photograph of the M2.5 and M4 fastener two-hole threaded aluminum test jig.

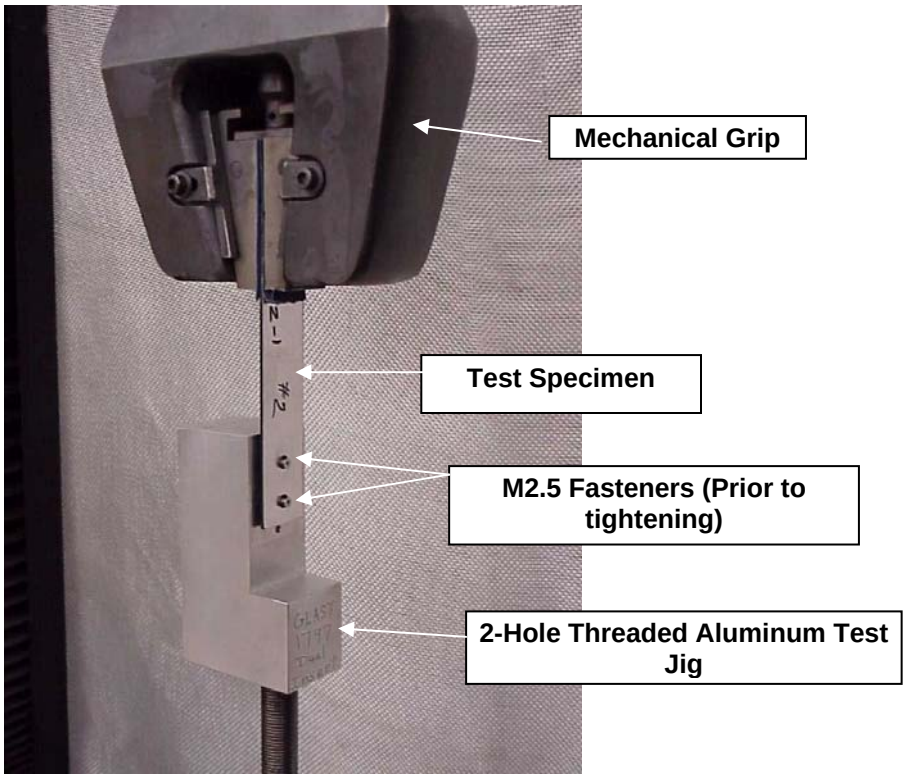


Figure 4.7 Photograph of the M2.5 fastener two-hole corner 0-degree with insert test setup.

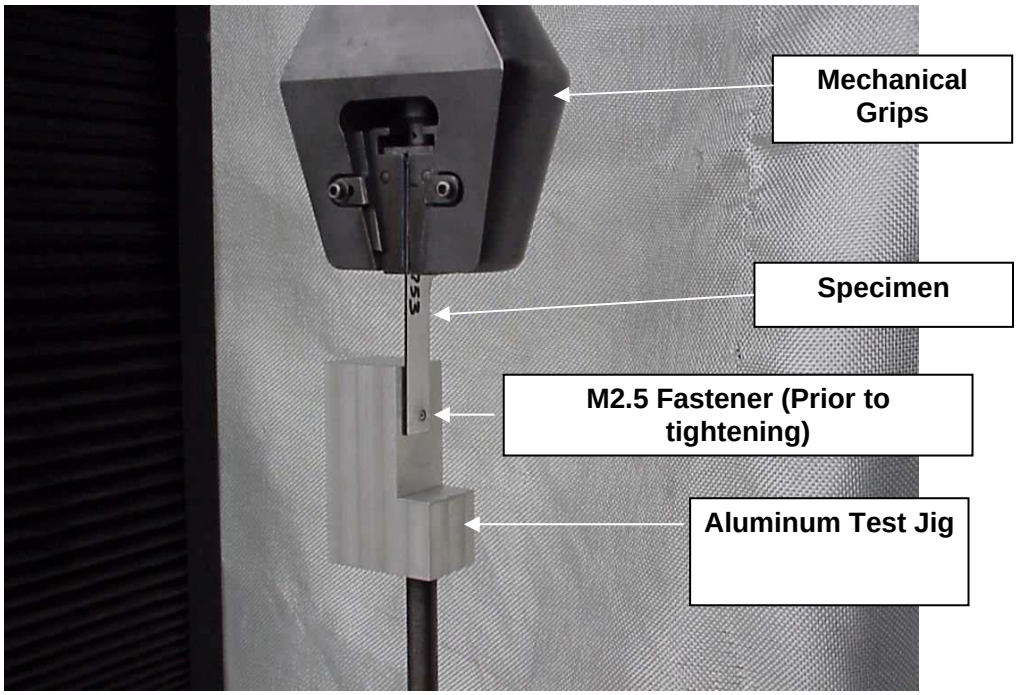


Figure 4.8 Photograph of the M2.5 fastener corner 0-degree tearout without insert test setup.

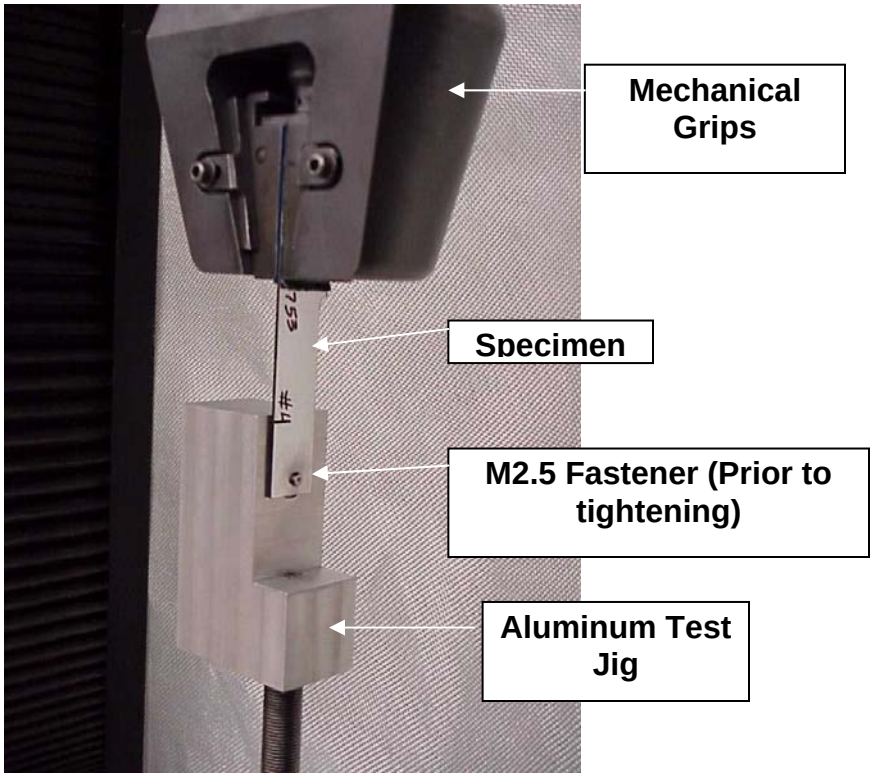


Figure 4.9 **Photograph of the M2.5 fastener corner 90-degree tearout without inserts test setup.**

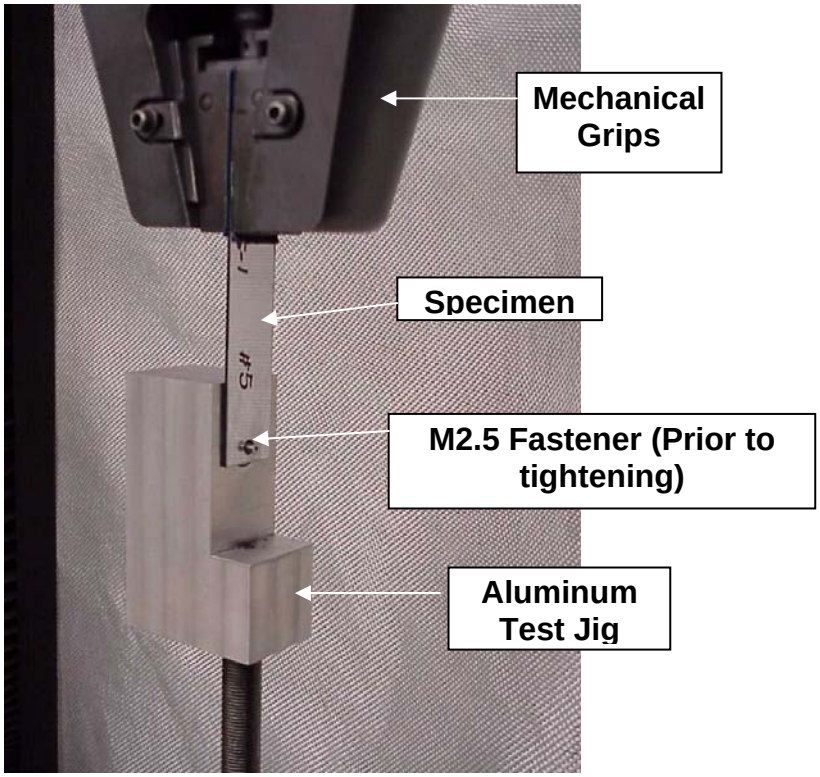


Figure 4.10 **Photograph of the M2.5 fastener thermal boss 0-degree shearout without insert test setup.**

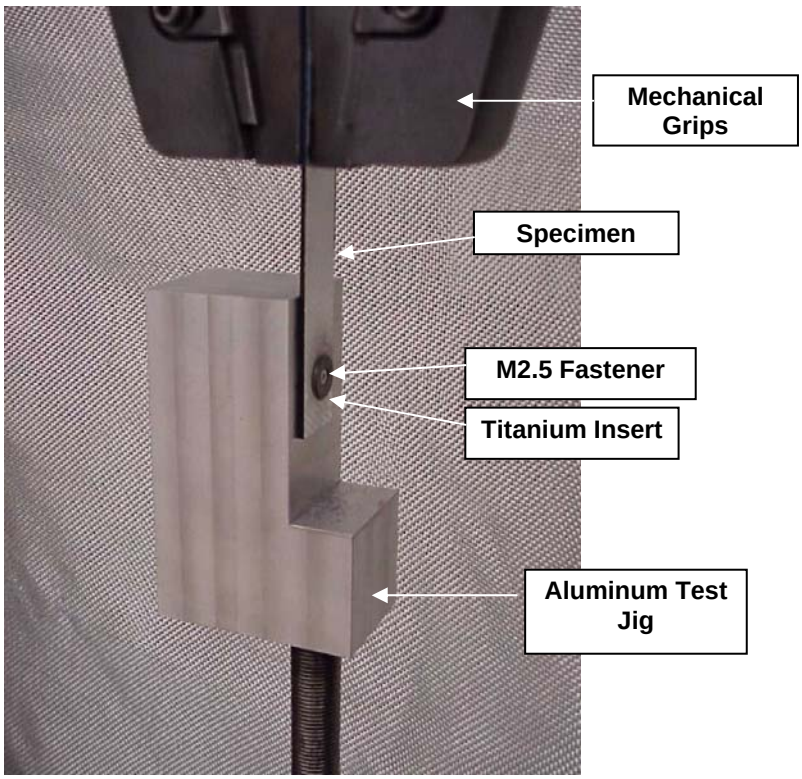


Figure 4.11 Photograph of the M2.5 fastener thermal boss 90-degree tearout with insert test setup.

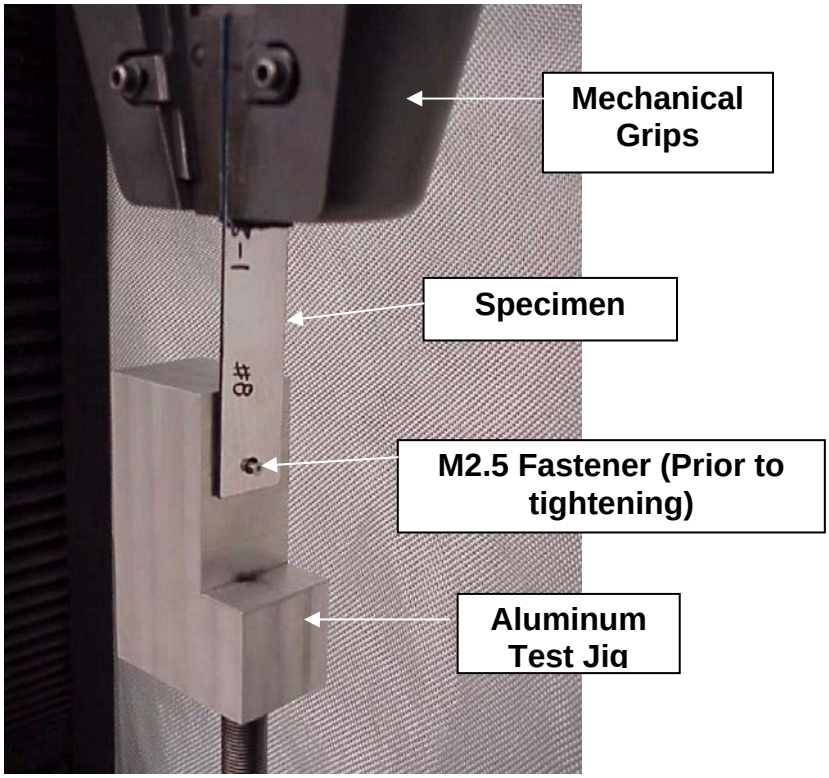


Figure 4.12 Photograph of the M2.5 fastener thermal boss 90-degree shearout without insert test setup

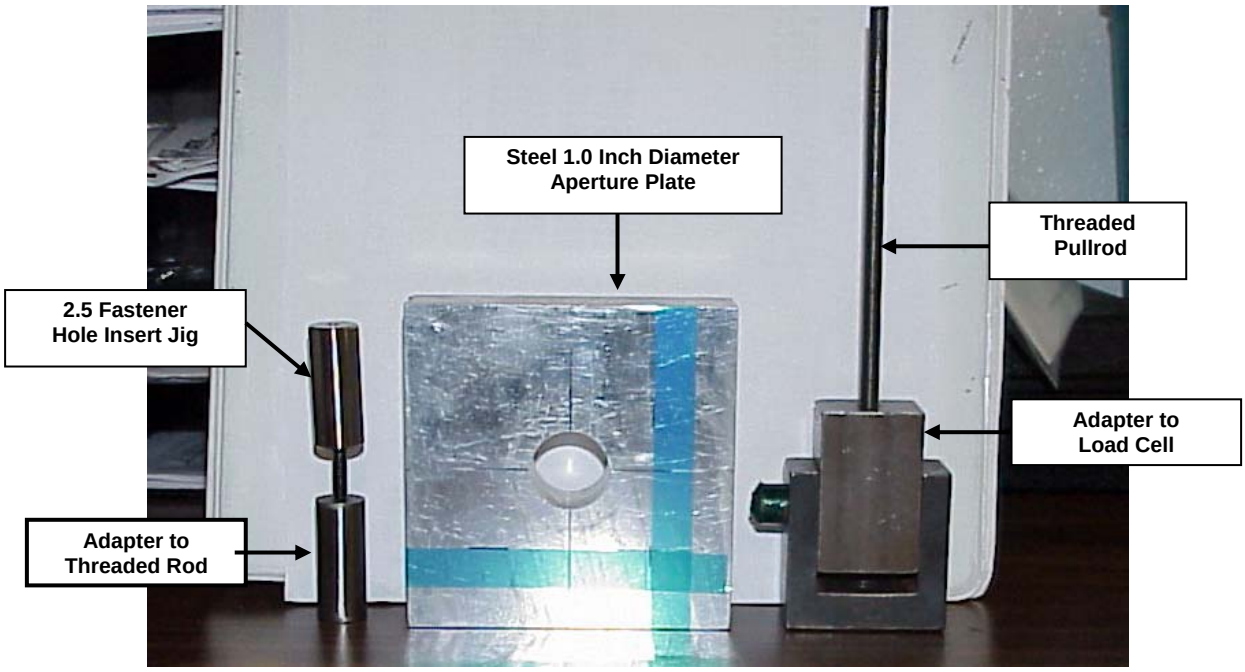


Figure 4.13 Photograph of the aperture plate and threaded insert test jig for the M2.5 fastener pullout tests.

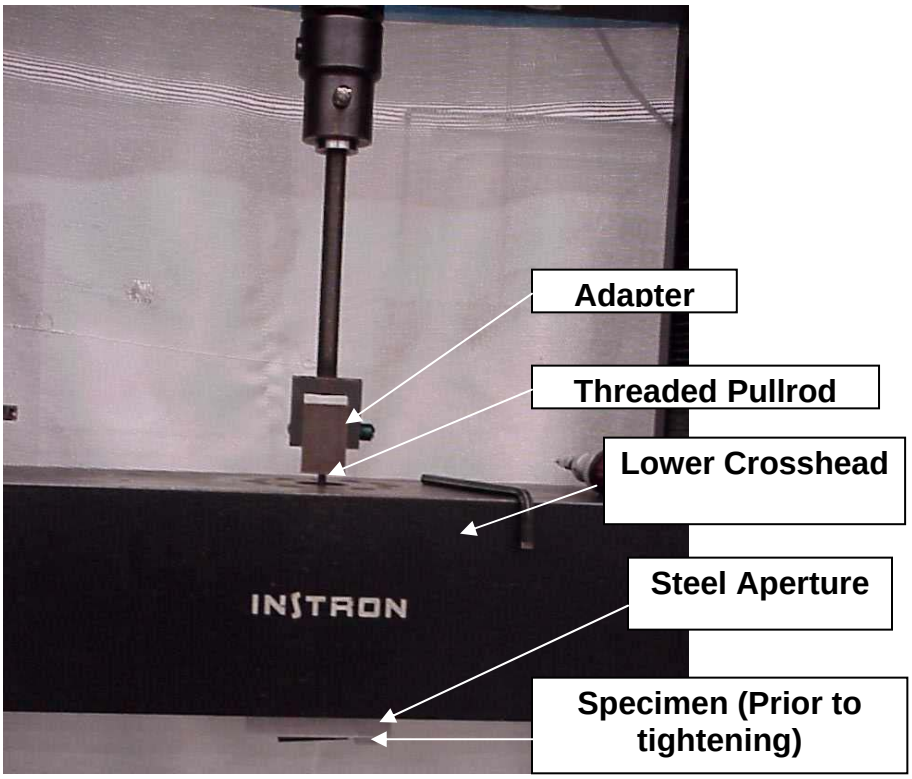


Figure 4.14a Photograph of the M2.5 fastener pullout test setup.

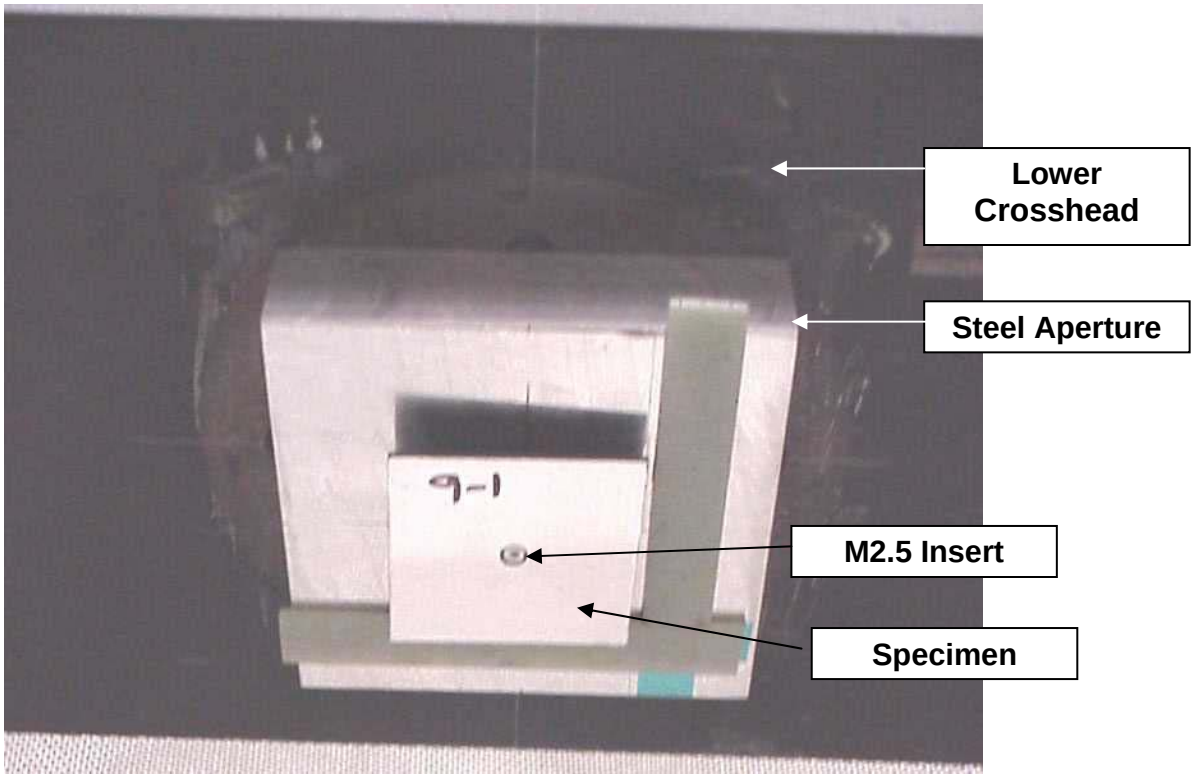


Figure 4.14b Photograph of the M2.5 fastener pullout test setup.

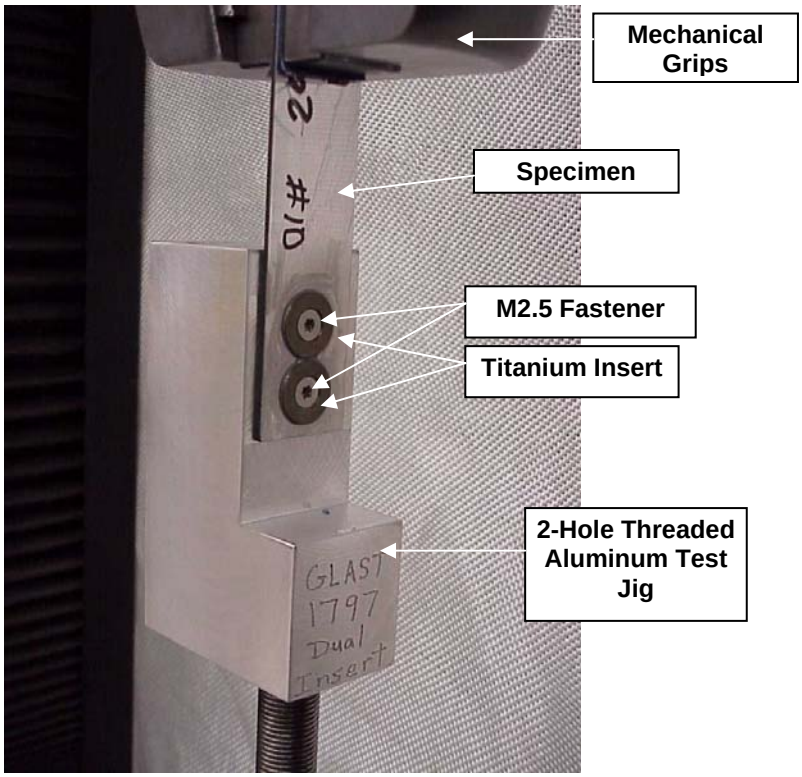


Figure 4.15 Photograph of the M4 fastener 2-hole thermal boss 0-degree shearout with inserts test setup.

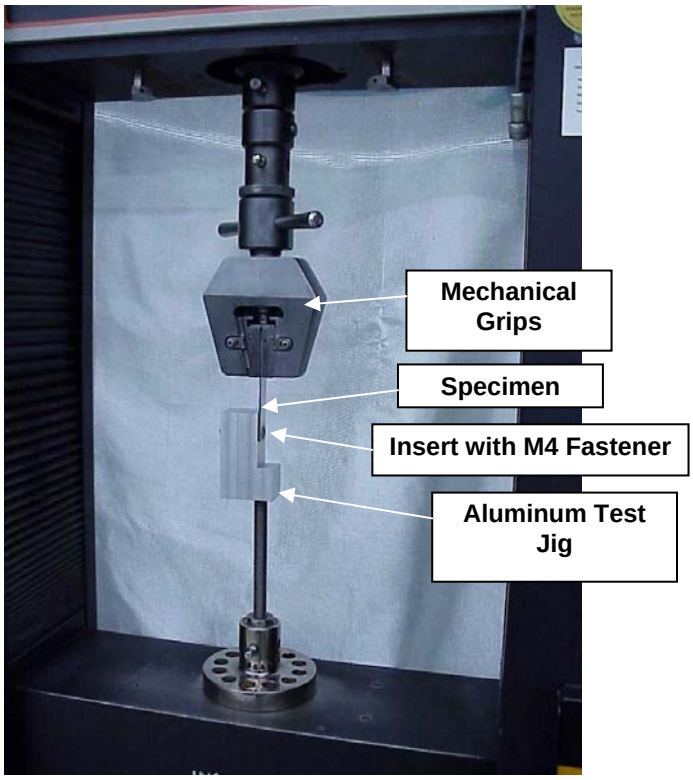


Figure 4.16 Photograph of the M4 fastener corner 0-degree tearout with insert test setup.

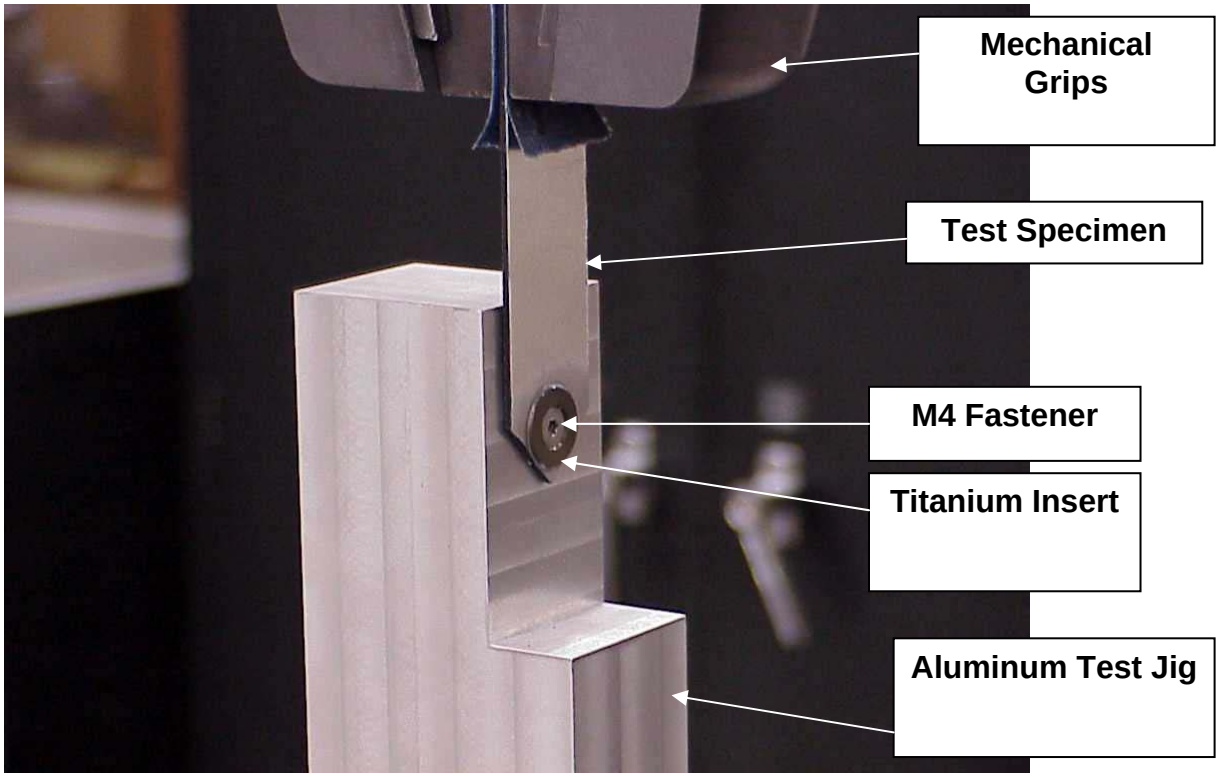


Figure 4.17 Photograph of the M4 fastener 45-degree shearout with insert test setup.

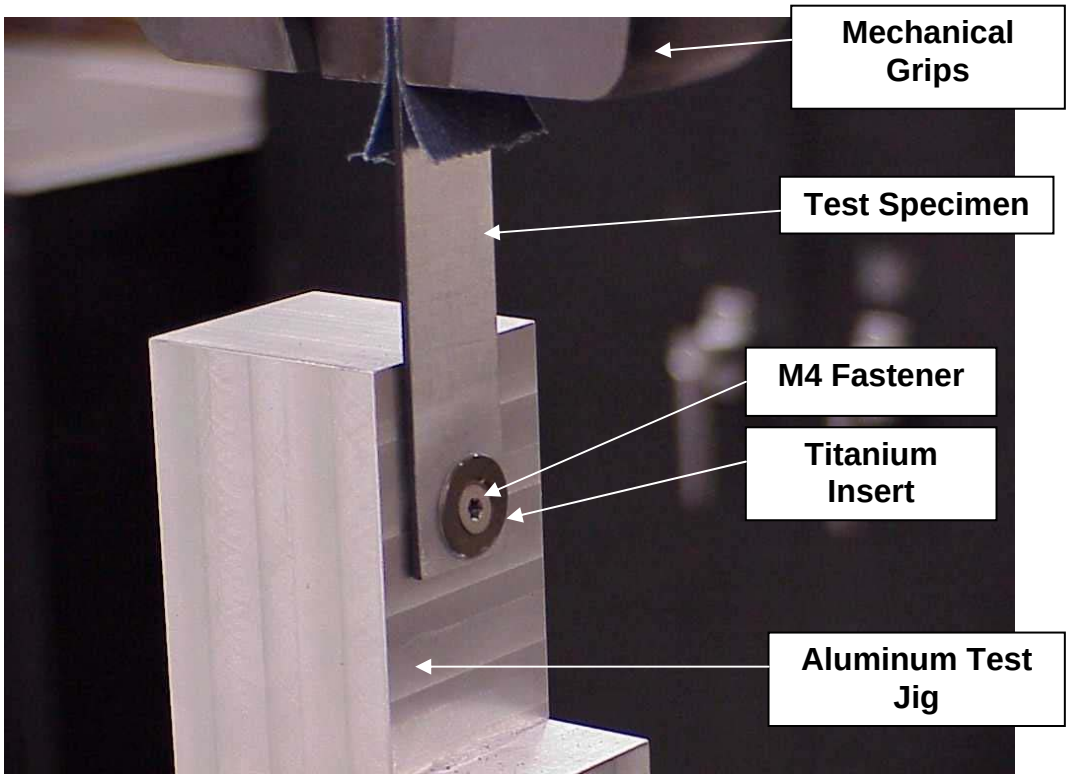


Figure 4.18 Photograph of the M4 fastener corner 90-degree tearout with insert test setup.

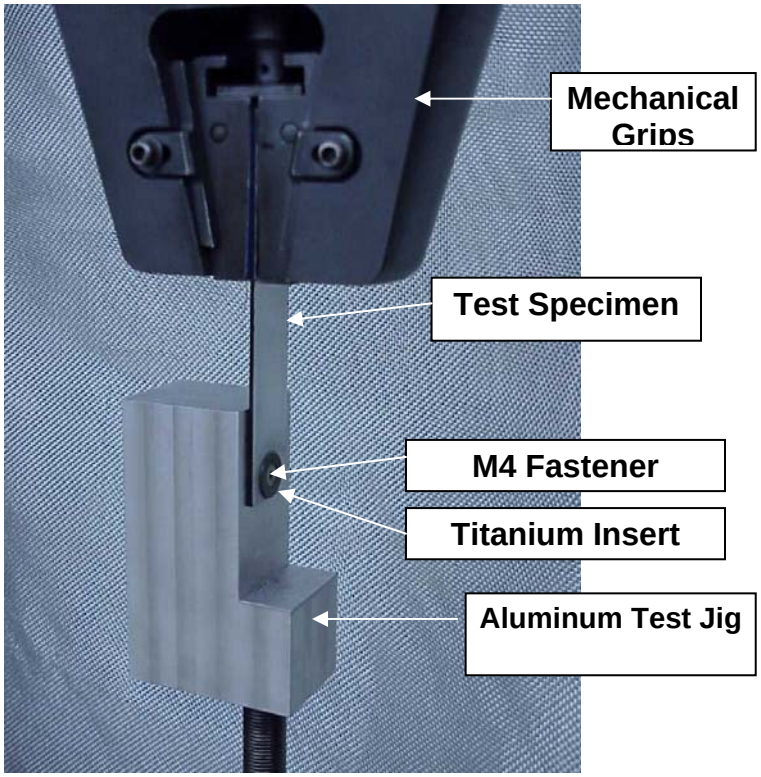


Figure 4.19 Photograph of the M4 fastener thermal boss 0-degree shearout with insert test setup.

Appendix A

[Load Versus Strain or Crosshead Travel Curves]

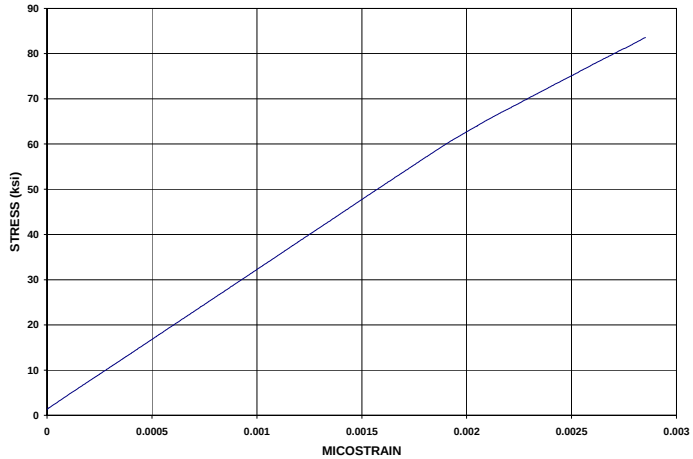


Figure A1 0-Degree Tension Specimen 15-1 Stress Versus Strain Curve

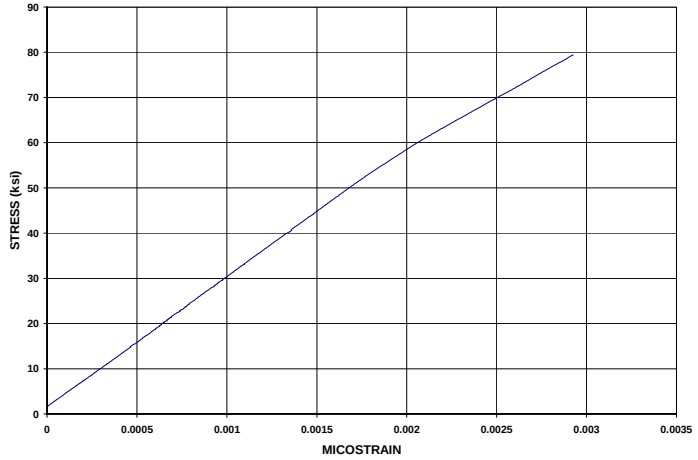


Figure A2 0-Degree Tension Specimen 15-2 Stress Versus Strain Curve

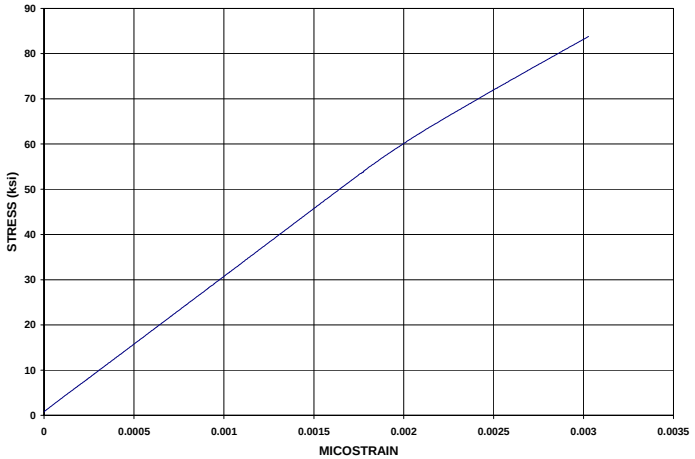


Figure A3 0-Degree Tension Specimen 15-3 Stress Versus Strain Curve

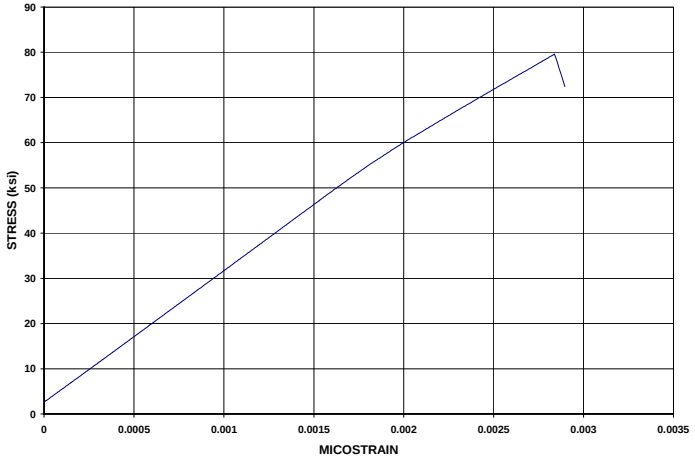


Figure A4 0-Degree Tension Specimen 15-4 Stress Versus Strain Curve

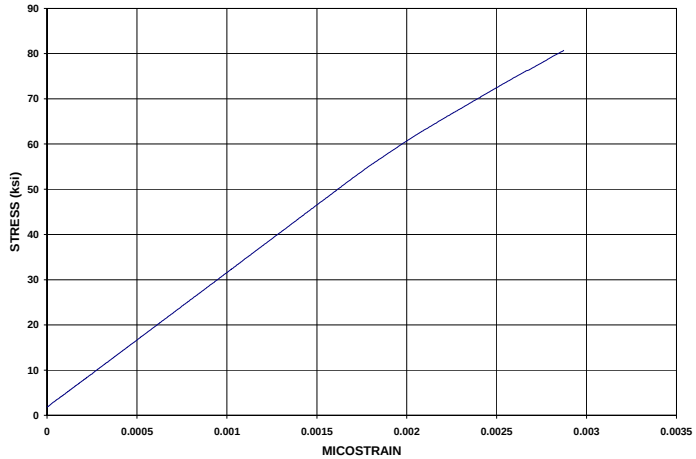


Figure A5 0-Degree Tension Specimen 15-5 Stress Versus Strain Curve

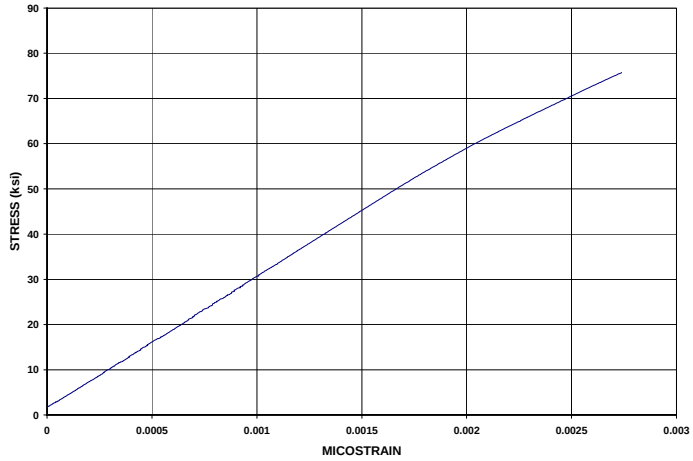


Figure A6 0-Degree Tension Specimen 15-6 Stress Versus Strain Curve

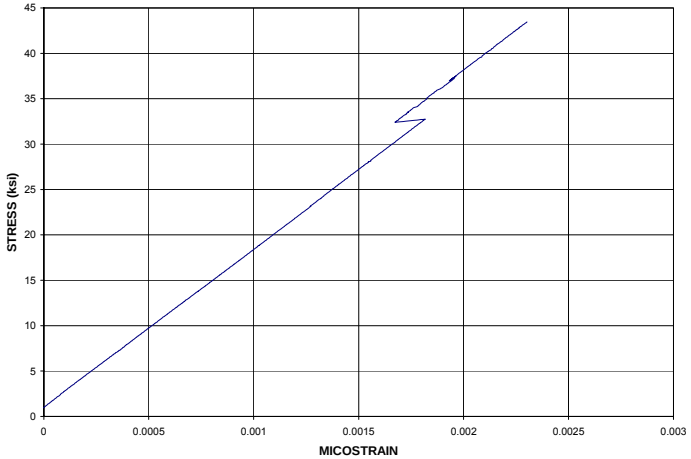


Figure A7 90-Degree Tension Specimen 15-1 Stress Versus Strain Curve

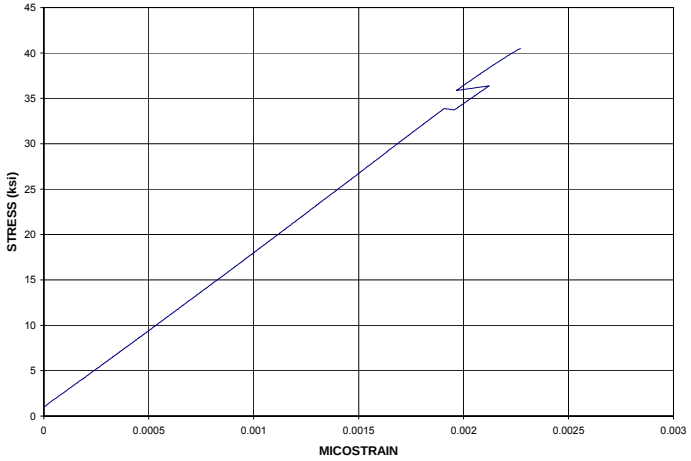


Figure A8 90-Degree Tension Specimen 15-2 Stress Versus Strain Curve

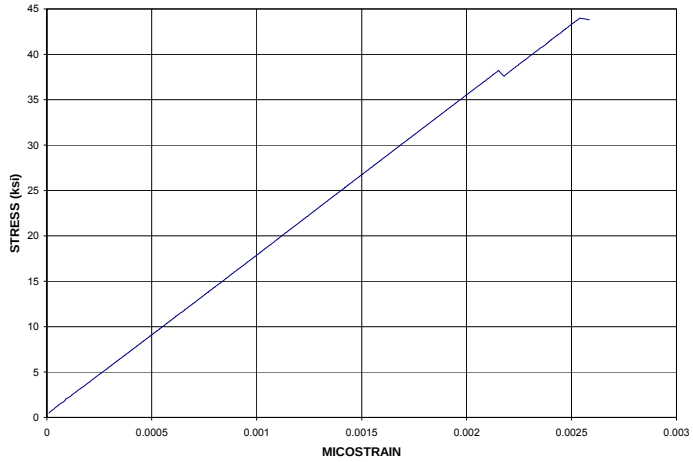


Figure A9 90-Degree Tension Specimen 15-3 Stress Versus Strain Curve

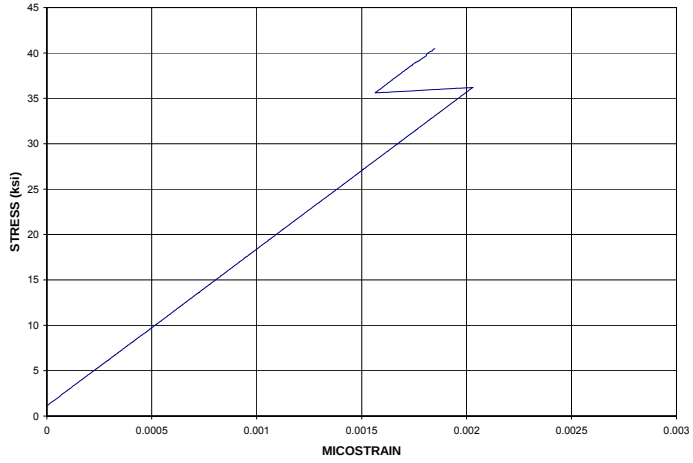


Figure A10 90-Degree Tension Specimen 15-4 Stress Versus Strain Curve

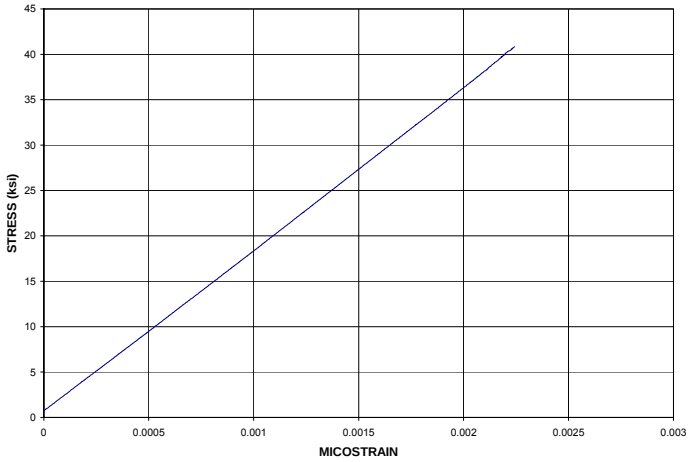


Figure A11 90-Degree Tension Specimen 15-5 Stress Versus Strain Curve

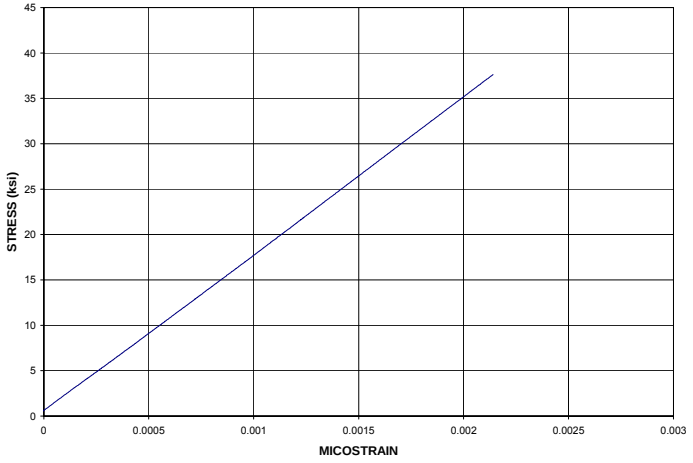


Figure A12 90-Degree Tension Specimen 15-6 Stress Versus Strain Curve

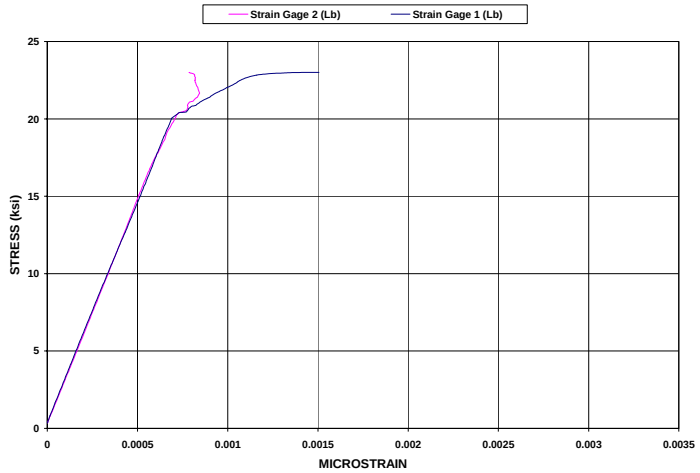


Figure A13 0-Degree Compression Specimen 16-1 Stress Versus Strain Curve

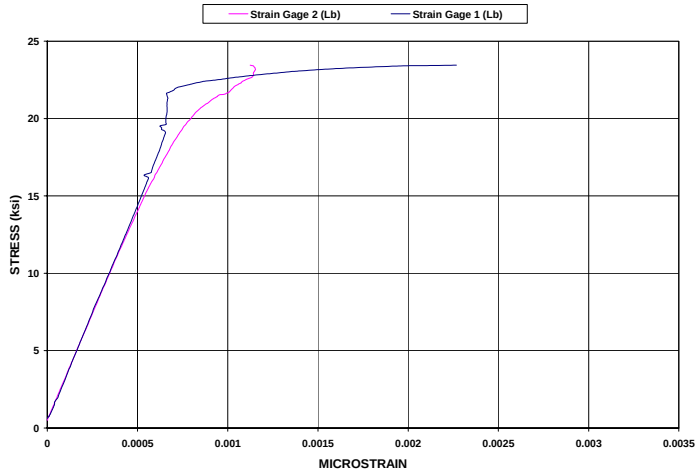


Figure A14 0-Degree Compression Specimen 16-2 Stress Versus Strain Curve

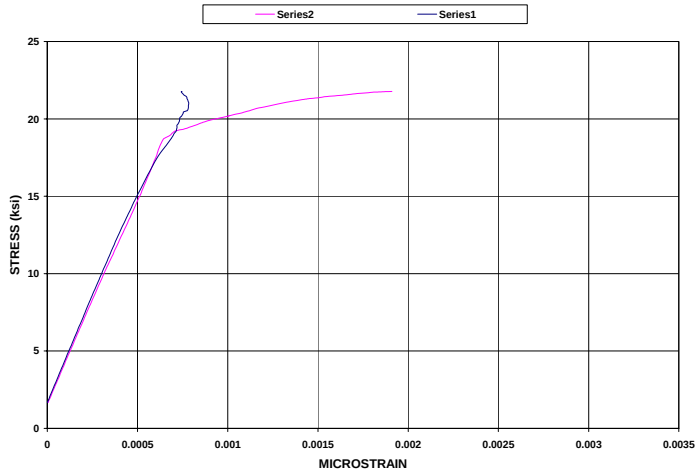


Figure A15 0-Degree Compression Specimen 16-3 Stress Versus Strain Curve

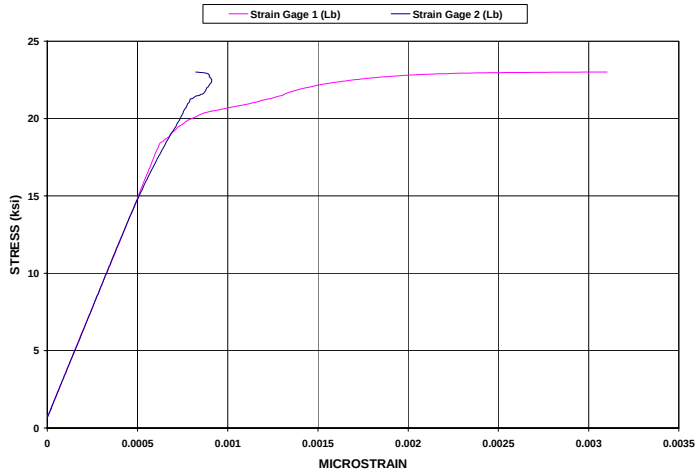


Figure A16 0-Degree Compression Specimen 16-4 Stress Versus Strain Curve

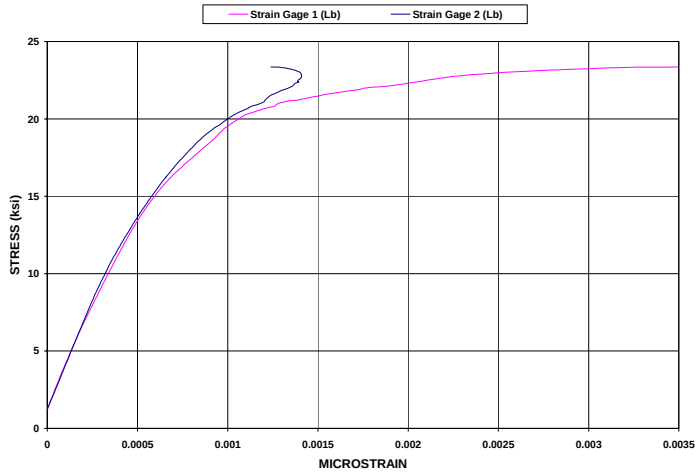


Figure A17 0-Degree Compression Specimen 16-5 Stress Versus Strain Curve

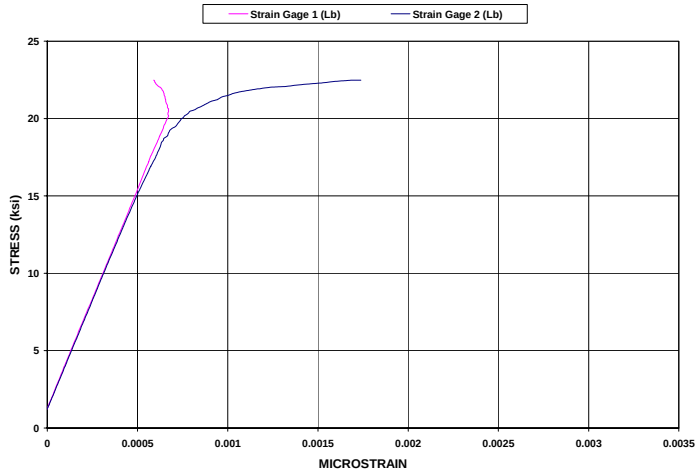


Figure A18 0-Degree Compression Specimen 16-6 Stress Versus Strain Curve

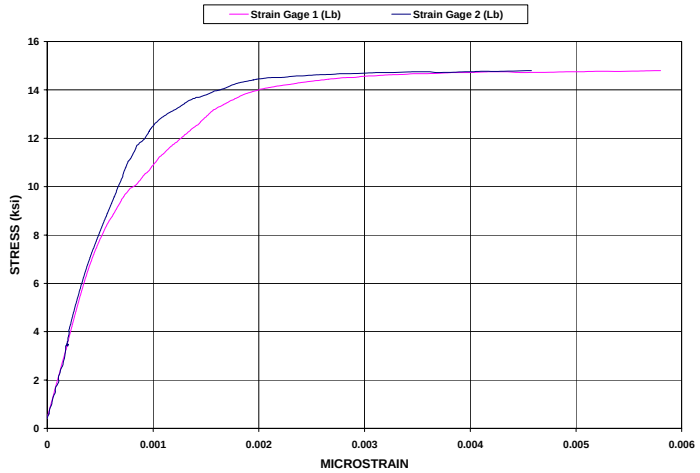


Figure A19 90-Degree Compression Specimen 16-1 Stress Versus Strain Curve

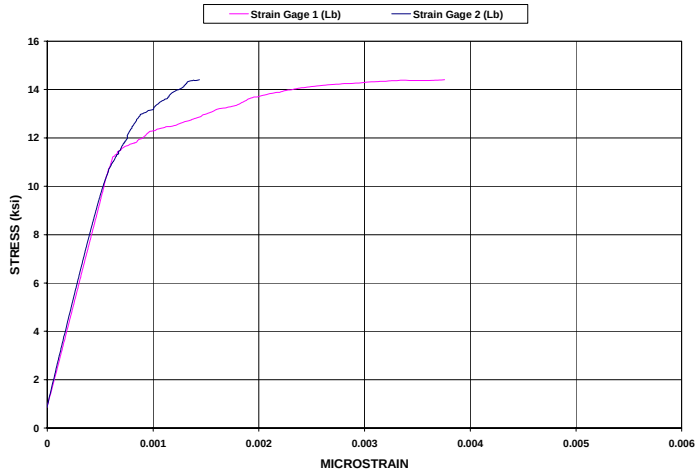


Figure A20 90-Degree Compression Specimen 16-2 Stress Versus Strain Curve

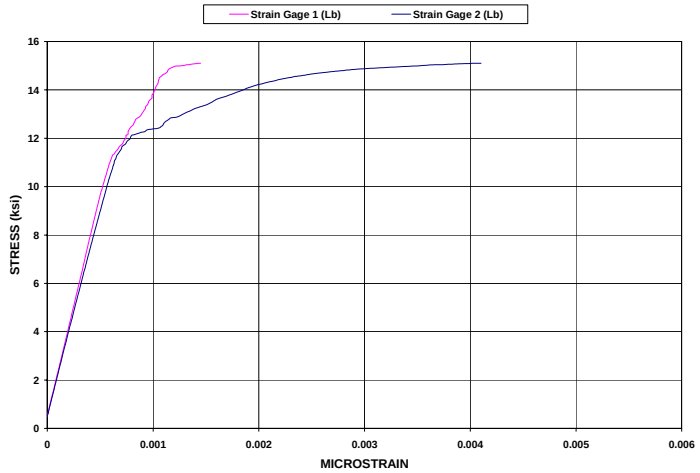


Figure A21 90-Degree Compression Specimen 16-3 Stress Versus Strain Curve

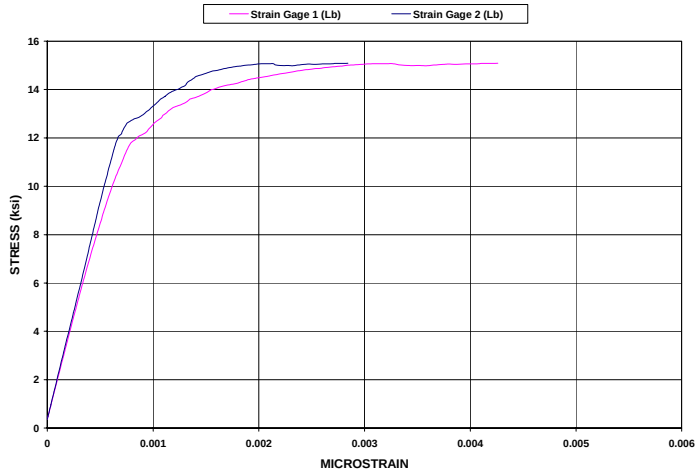


Figure A22 90-Degree Compression Specimen 16-4 Stress Versus Strain Curve

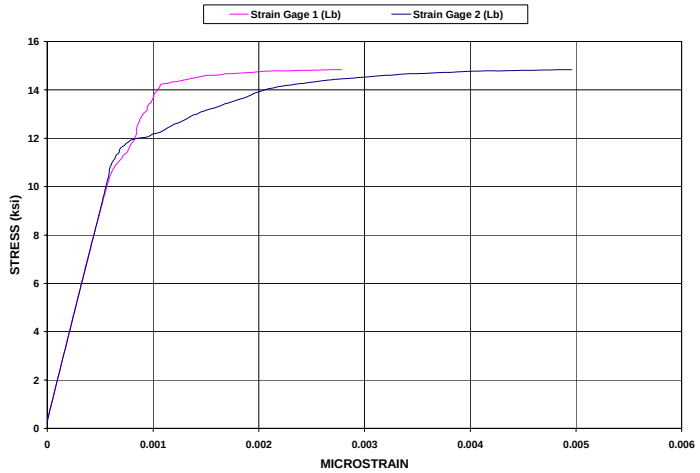


Figure A23 90-Degree Compression Specimen 16-5 Stress Versus Strain Curve

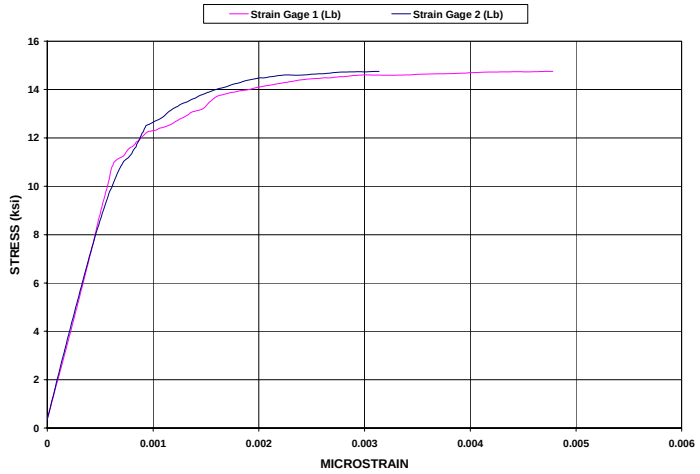


Figure A24 90-Degree Compression Specimen 16-6 Stress Versus Strain Curve

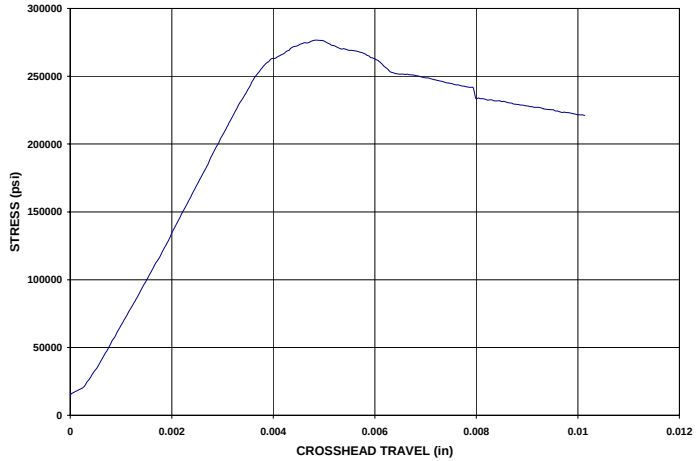


Figure A25 Interlaminar (Short Beam) Shear Specimen 18-1 Stress Versus Crosshead Travel Curve

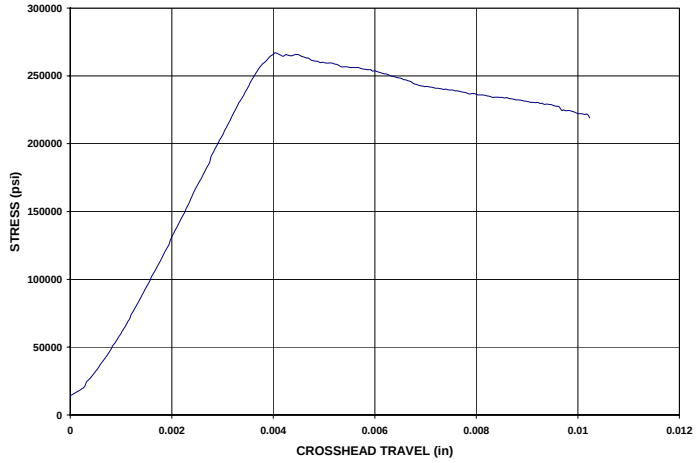


Figure A26 Interlaminar (Short Beam) Shear Specimen 18-2 Stress Versus Crosshead Travel Curve

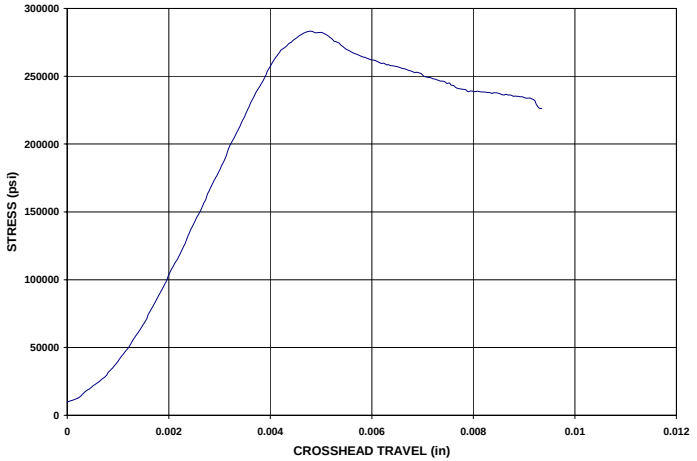


Figure A27 Interlaminar (Short Beam) Shear Specimen 18-3 Stress Versus Crosshead Travel Curve

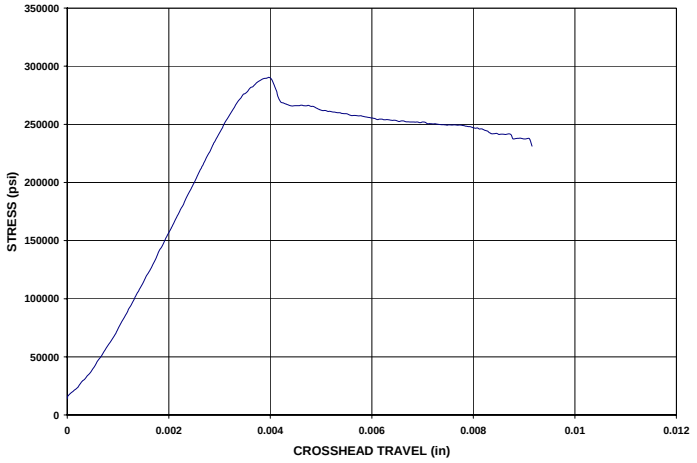


Figure A28 Interlaminar (Short Beam) Shear Specimen 18-4 Stress Versus Crosshead Travel Curve

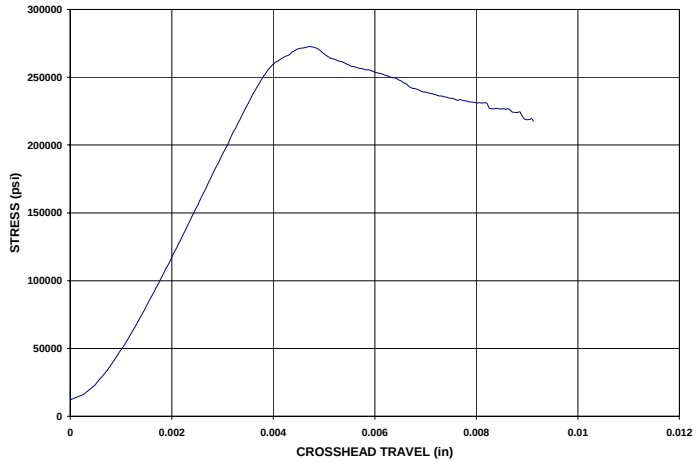


Figure A29 Interlaminar (Short Beam) Shear Specimen 18-5 Stress Versus Crosshead Travel Curve

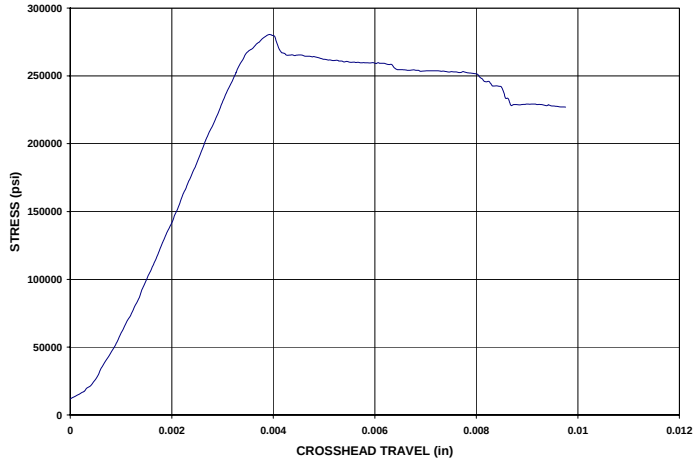


Figure A30 Interlaminar (Short Beam) Shear Specimen 18-6 Stress Versus Crosshead Travel Curve

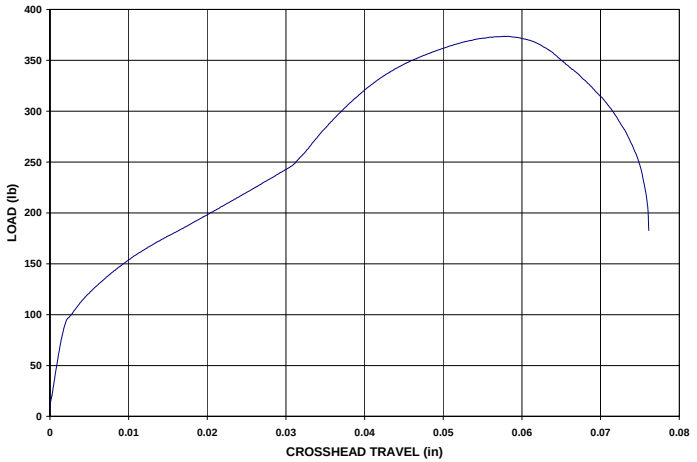


Figure A31 M2.5 Thermal Boss with Insert Specimen 1-1 0-Degree Shear Out Load Versus Crosshead Travel Curve

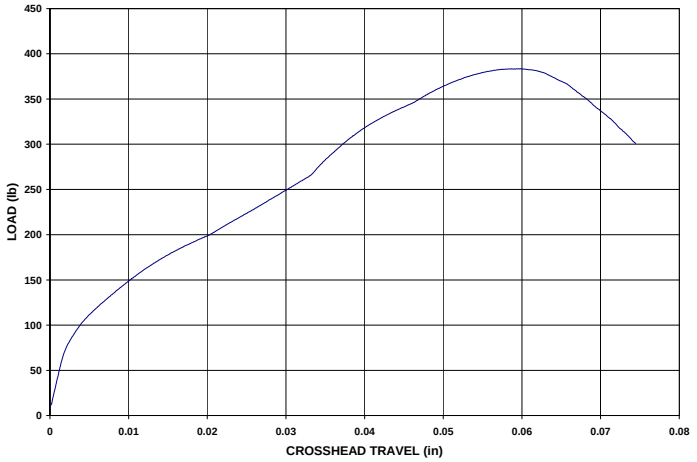


Figure A32 M2.5 Thermal Boss with Insert Specimen 1-2 0-Degree Shear Out Load Versus Crosshead Travel Curve

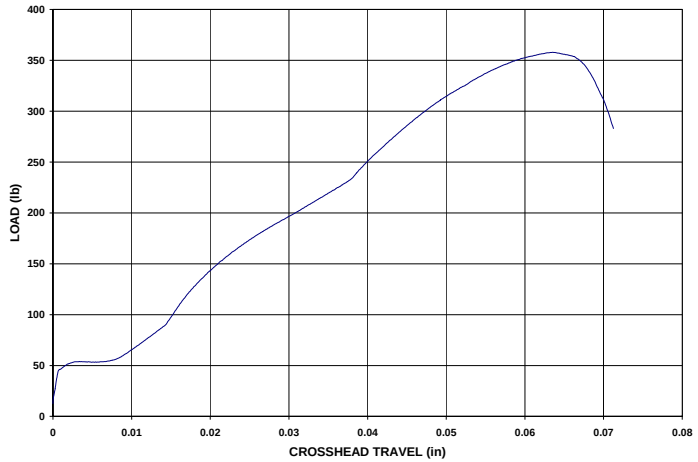


Figure A33 M2.5 Thermal Boss with Insert Specimen 1-3 0-Degree Shear Out Load Versus Crosshead Travel Curve

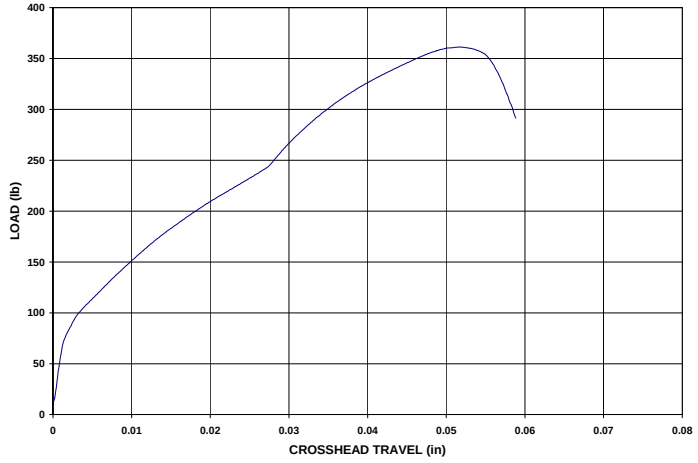


Figure A34 M2.5 Thermal Boss with Insert Specimen 1-4 0-Degree Shear Out Load Versus Crosshead Travel Curve

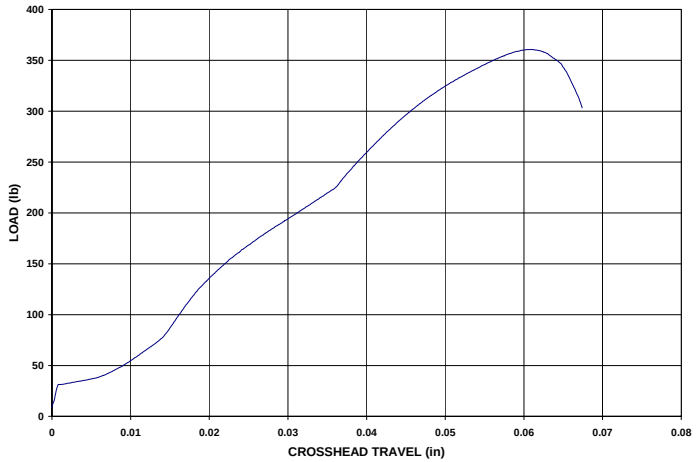


Figure A35 M2.5 Thermal Boss with Insert Specimen 1-5 0-Degree Shear Out Load Versus Crosshead Travel Curve

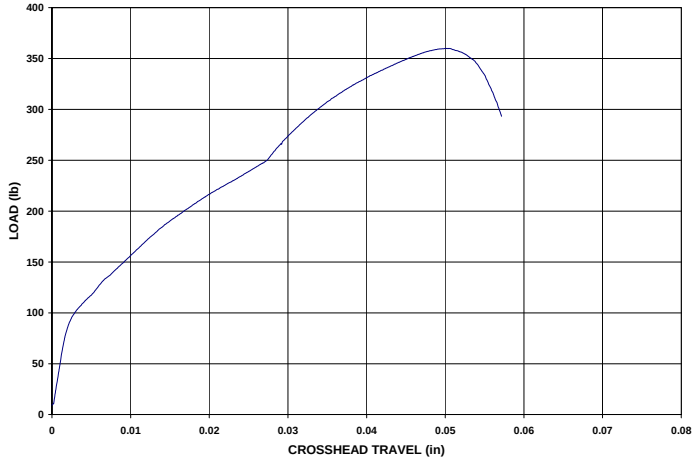


Figure A36 M2.5 Thermal Boss with Insert Specimen 1-6 0-Degree Shear Out Load Versus Crosshead Travel Curve

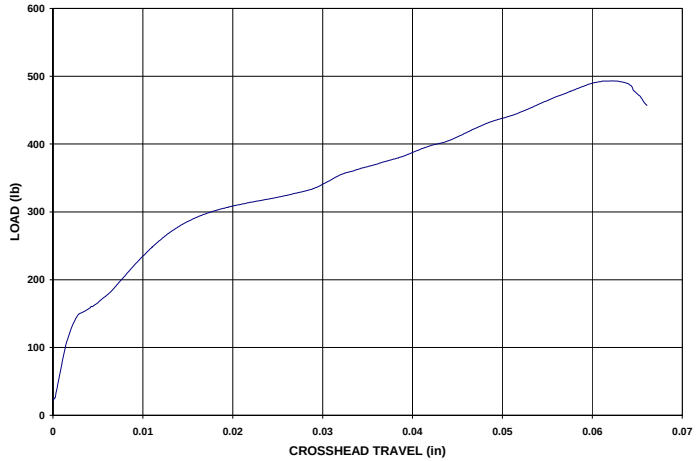


Figure A37 M2.5 Two-Hole Corner without Insert Specimen 2-1 0-Degree Shear Out Load Versus Crosshead Travel Curve

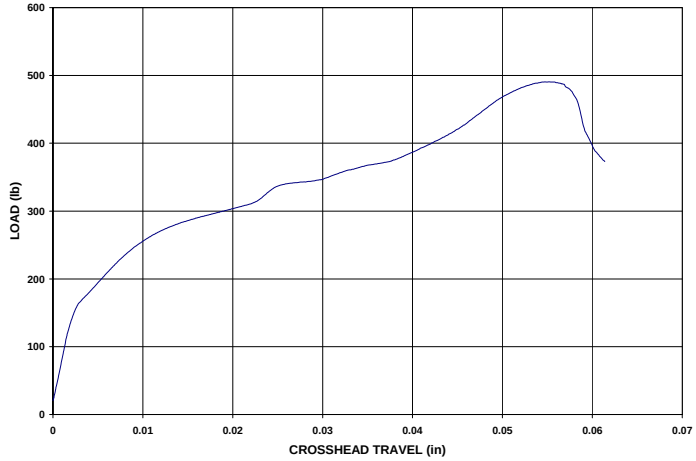


Figure A38 M2.5 Two-Hole Corner without Insert Specimen 2-2 0-Degree Shear Out Load Versus Crosshead Travel Curve

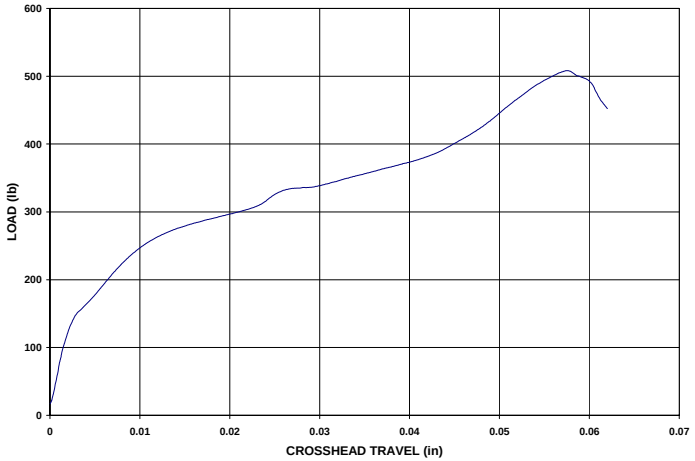


Figure A39 M2.5 Two-Hole Corner without Insert Specimen 2-3 0-Degree Shear Out Load Versus Crosshead Travel Curve

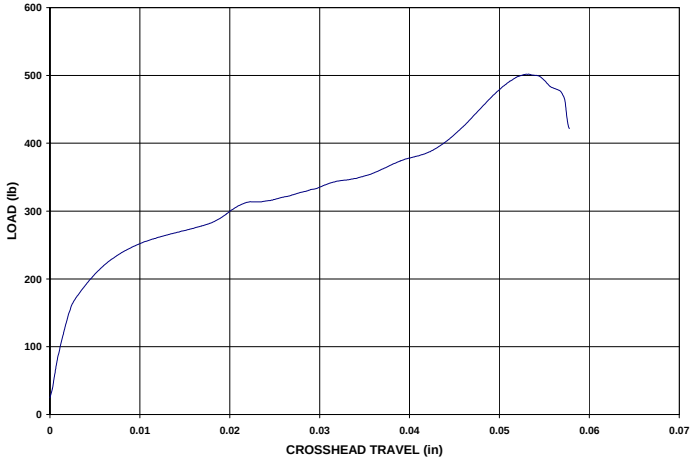


Figure A40 M2.5 Two-Hole Corner without Insert Specimen 2-4 0-Degree Shear Out Load Versus Crosshead Travel Curve

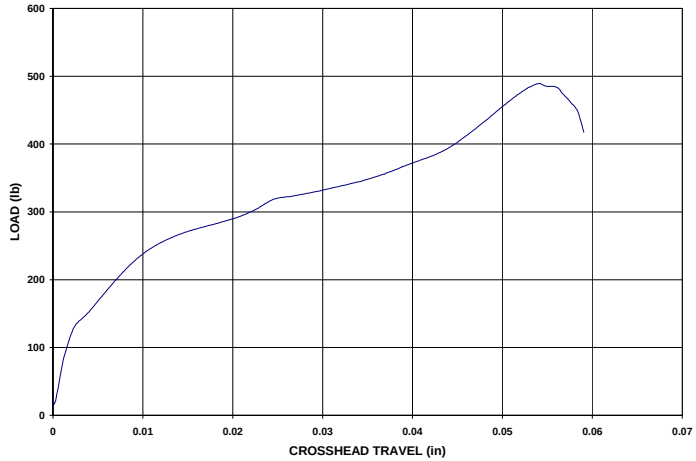


Figure A41 **M2.5 Two-Hole Corner without Insert Specimen 2-5 0-Degree Shear Out Load Versus Crosshead Travel Curve**

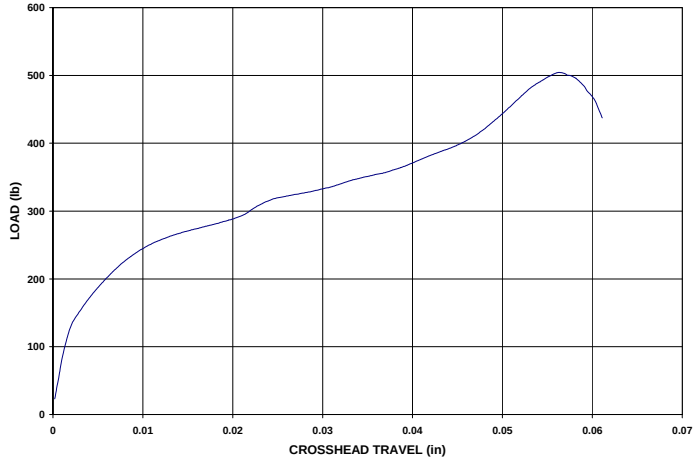


Figure A42 **M2.5 Two-Hole Corner without Insert Specimen 2-6 0-Degree Shear Out Load Versus Crosshead Travel Curve**

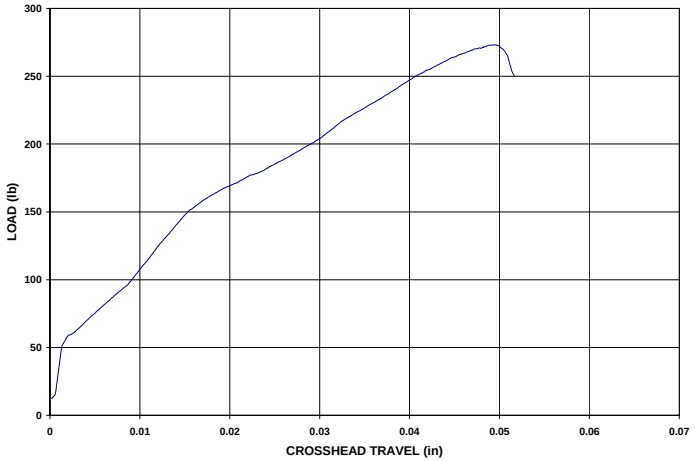


Figure A43 **M2.5 Corner without Insert Specimen 3-1 0-Degree Tear Out Load Versus Crosshead Travel Curve**

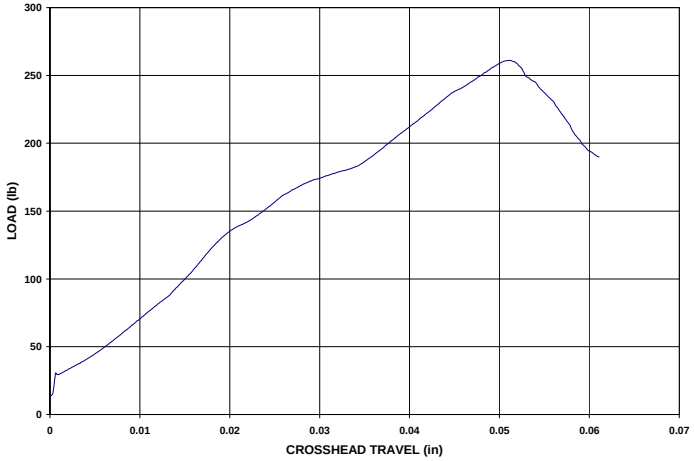


Figure A44 **M2.5 Corner without Insert Specimen 3-2 0-Degree Tear Out Load Versus Crosshead Travel Curve**

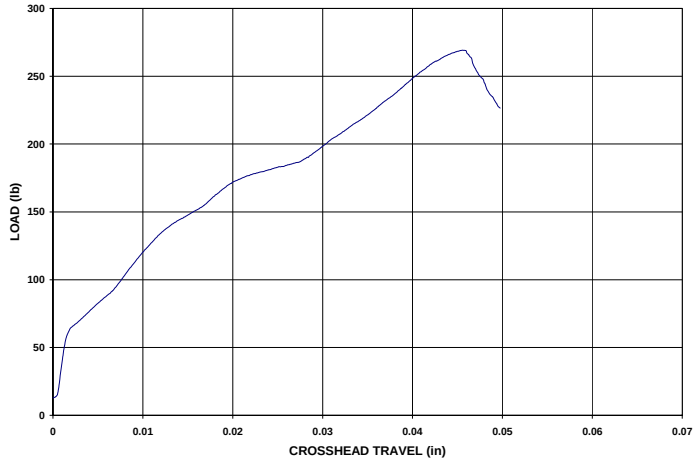


Figure A45 M2.5 Corner without Insert Specimen 3-3 0-Degree Tear Out Load Versus Crosshead Travel Curve

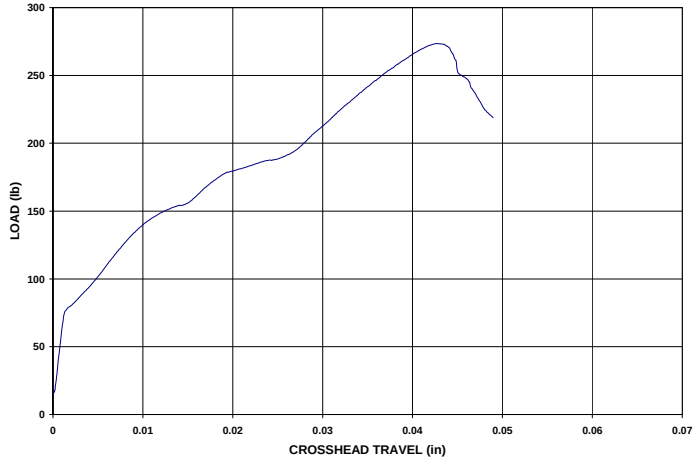


Figure A46 Corner M2.5 without Insert Specimen 3-4 0-Degree Tear Out Load Versus Crosshead Travel Curve

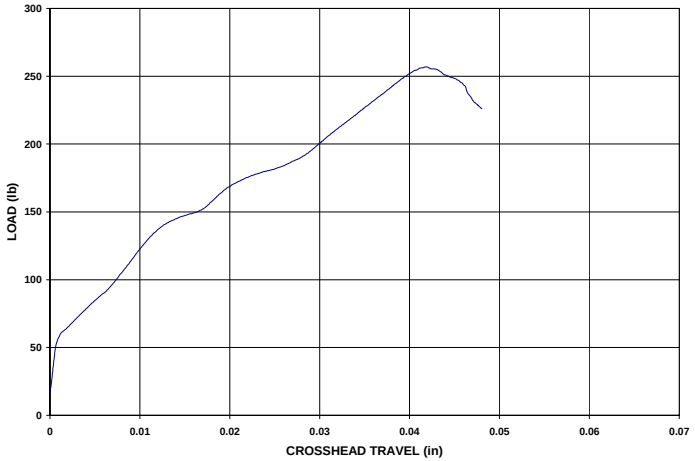


Figure A47 M2.5 Corner without Insert Specimen 3-5 0-Degree Tear Out Load Versus Crosshead Travel Curve

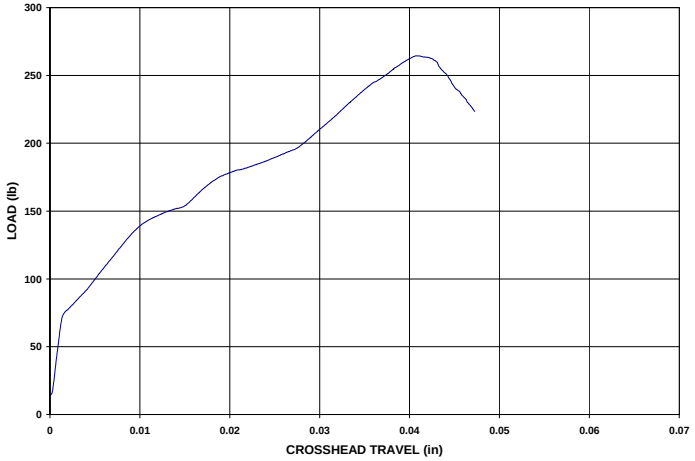


Figure A48 Corner M2.5 without Insert Specimen 3-6 0-Degree Tear Out Load Versus Crosshead Travel Curve

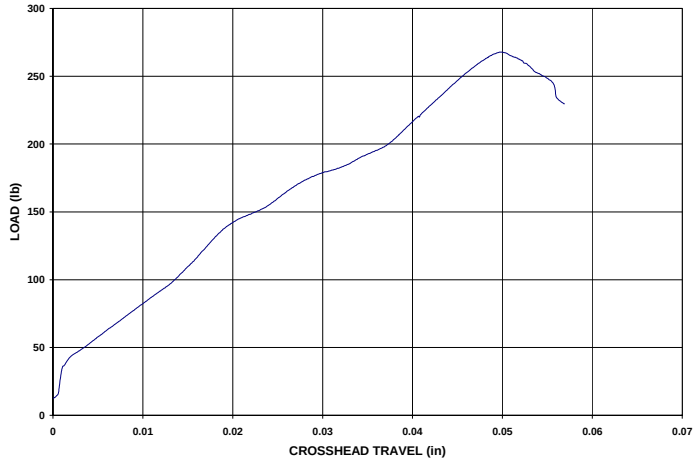


Figure A49 **M2.5 Corner without Insert Specimen 4-1 90-Degree Tear Out Load Versus Crosshead Travel Curve**

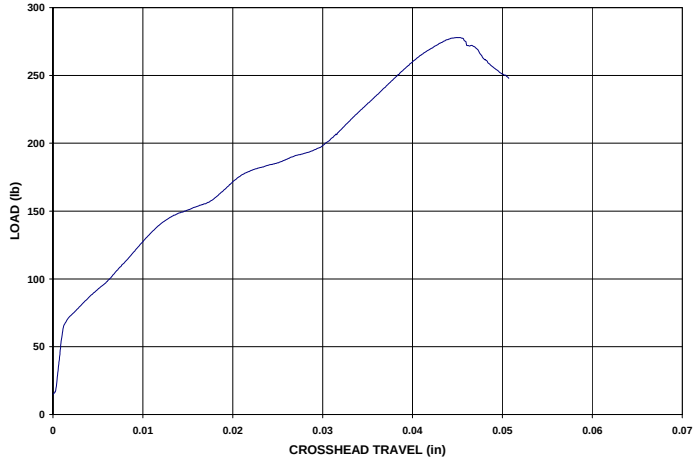


Figure A50 **M2.5 Corner without Insert Specimen 4-2 90-Degree Tear Out Load Versus Crosshead Travel Curve**

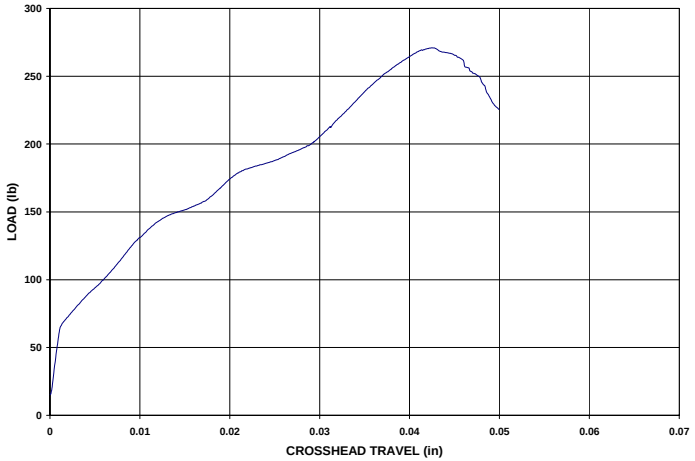


Figure A51 **M2.5 Corner without Insert Specimen 4-3 90-Degree Tear Out Load Versus Crosshead Travel Curve**

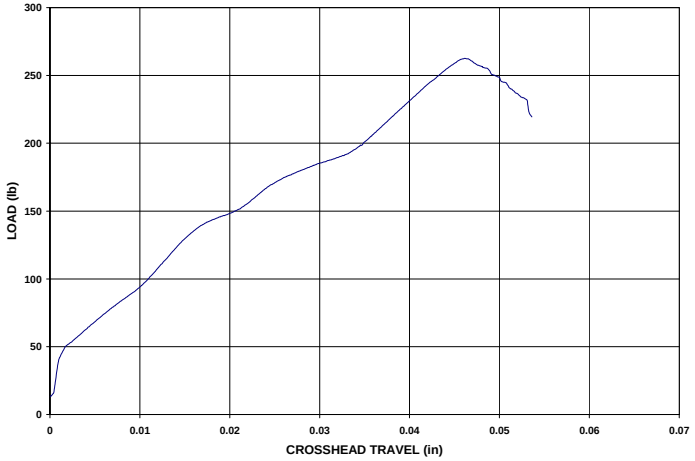


Figure A52 **M2.5 Corner without Insert Specimen 4-4 90-Degree Tear Out Load Versus Crosshead Travel Curve**

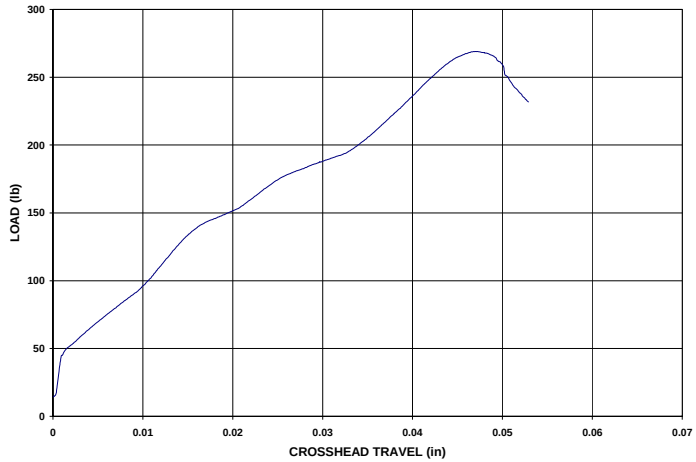


Figure A53 M2.5 Corner without Insert Specimen 4-5 90-Degree Tear Out Load Versus Crosshead Travel Curve

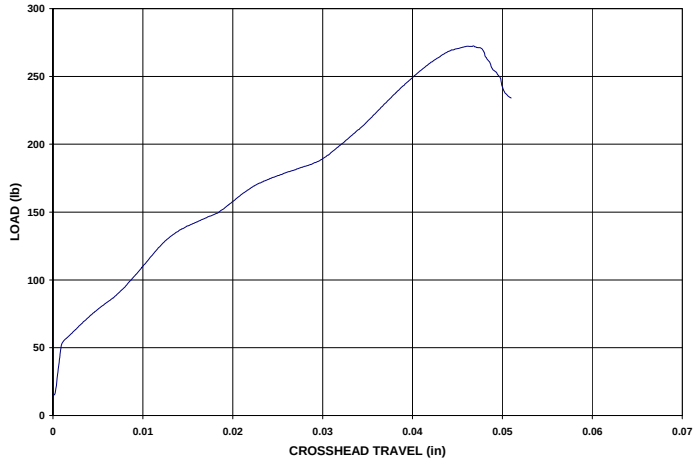


Figure A54 M2.5 Corner without Insert Specimen 4-6 90-Degree Tear Out Load Versus Crosshead Travel Curve

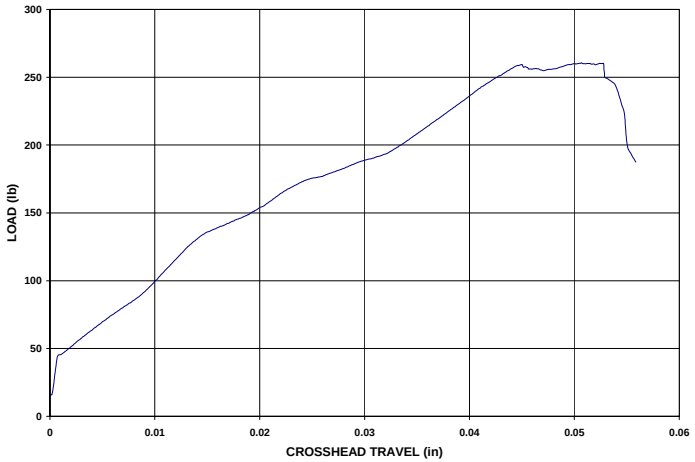


Figure A55 M2.5 Thermal Boss without Insert Specimen 5-1 0-Degree Shear Out Load Versus Crosshead Travel Curve

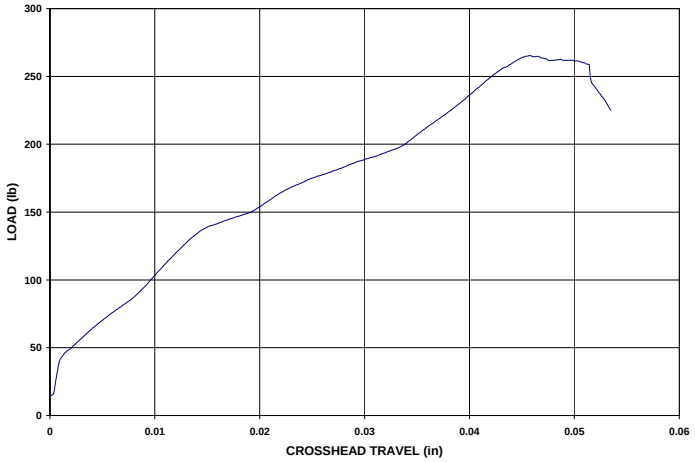


Figure A56 M2.5 Thermal Boss without Insert Specimen 5-2 0-Degree Shear Out Load Versus Crosshead Travel Curve

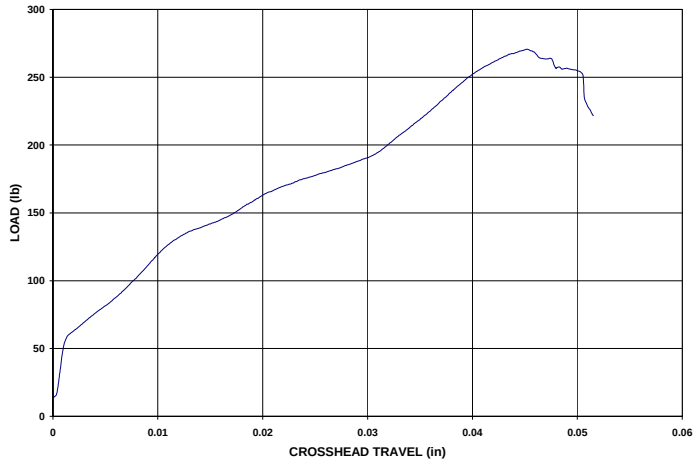


Figure A57 M2.5 Thermal Boss without Insert Specimen 5-3 0-Degree Shear Out Load Versus Crosshead Travel Curve

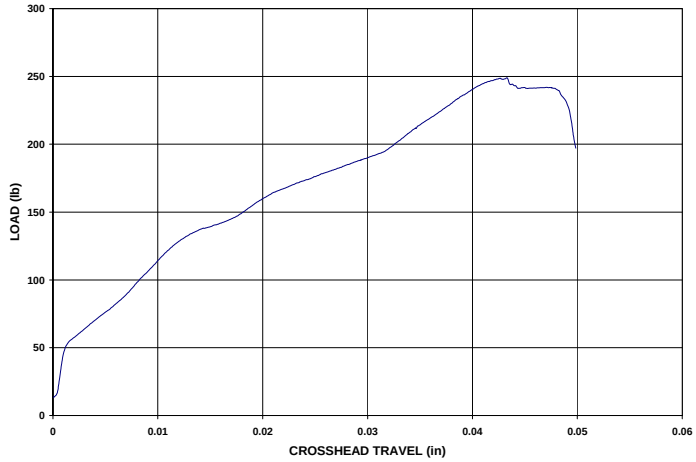


Figure A58 M2.5 Thermal Boss without Insert Specimen 5-4 0-Degree Shear Out Load Versus Crosshead Travel Curve

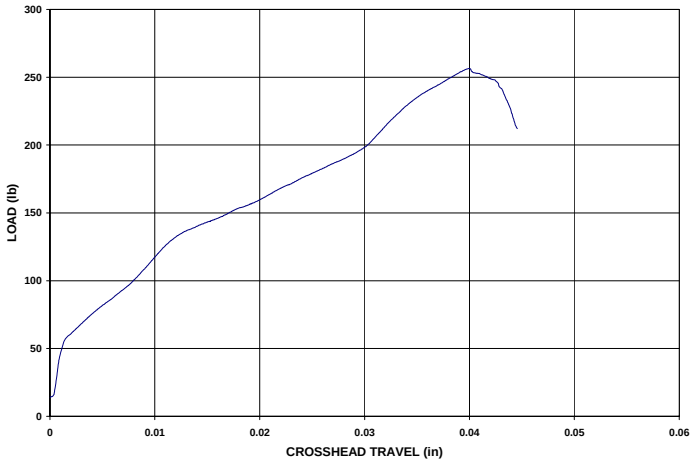


Figure A59 M2.5 Thermal Boss without Insert Specimen 5-5 0-Degree Shear Out Load Versus Crosshead Travel Curve

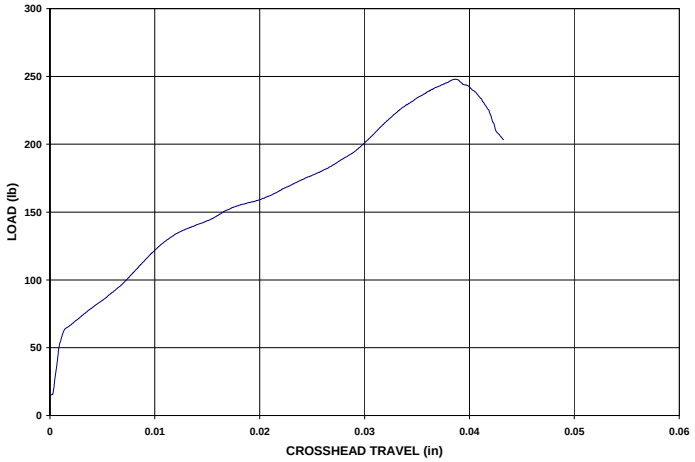


Figure A60 M2.5 Thermal Boss without Insert Specimen 5-6 0-Degree Shear Out Load Versus Crosshead Travel Curve

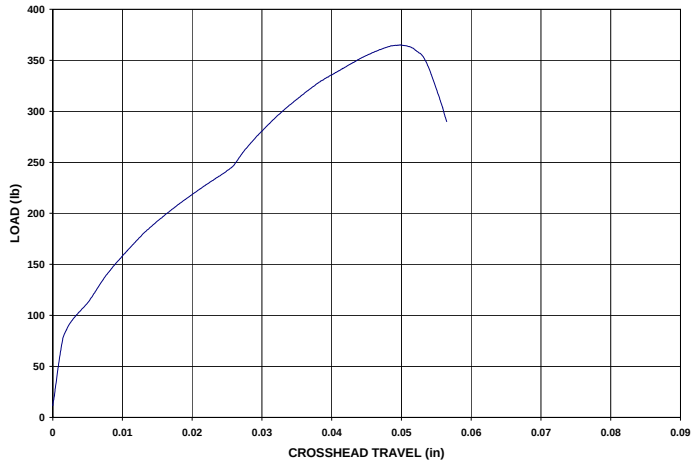


Figure A61 **M2.5 Thermal Boss with Insert Specimen 6-1 90-Degree Tear Out Load Versus Crosshead Travel Curve**

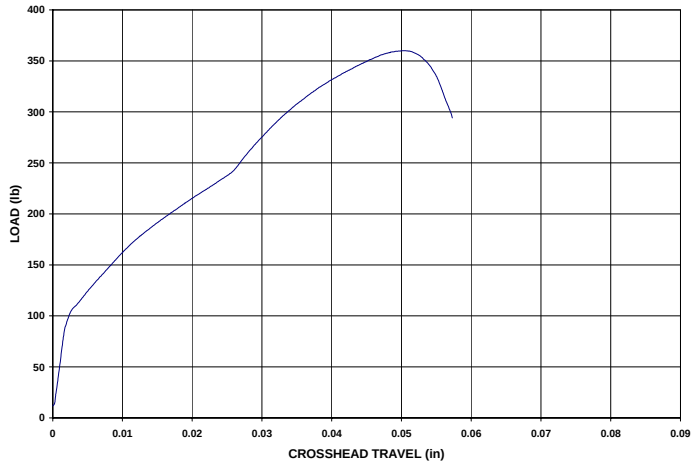


Figure A62 **M2.5 Thermal Boss with Insert Specimen 6-2 90-Degree Tear Out Load Versus Crosshead Travel Curve**

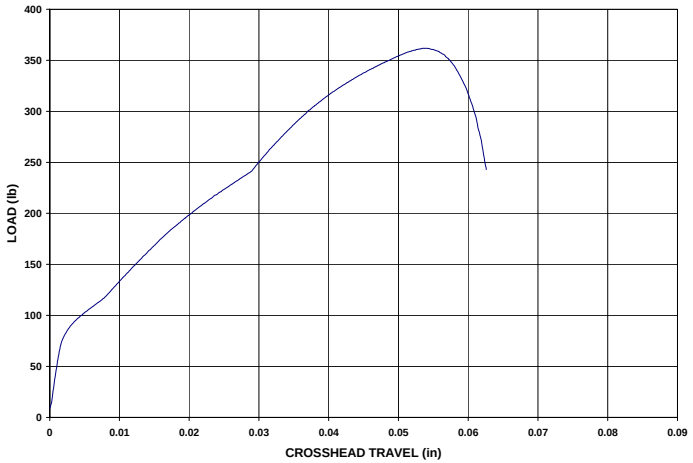


Figure A63 **M2.5 Thermal Boss with Insert Specimen 6-3 90-Degree Tear Out Load Versus Crosshead Travel Curve**

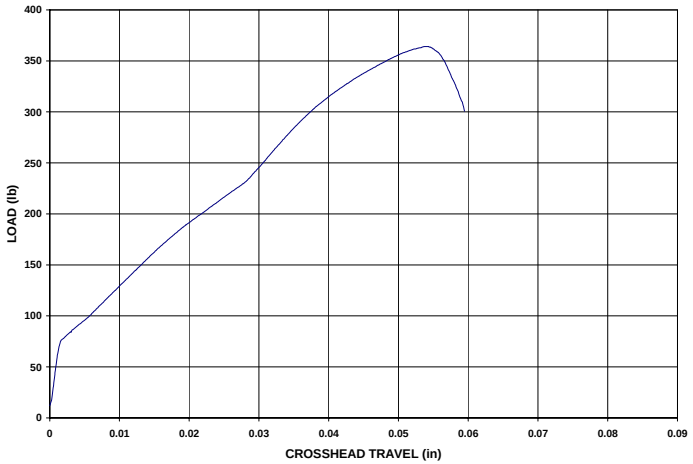


Figure A64 **M2.5 Thermal Boss with Insert Specimen 6-4 90-Degree Tear Out Load Versus Crosshead Travel Curve**

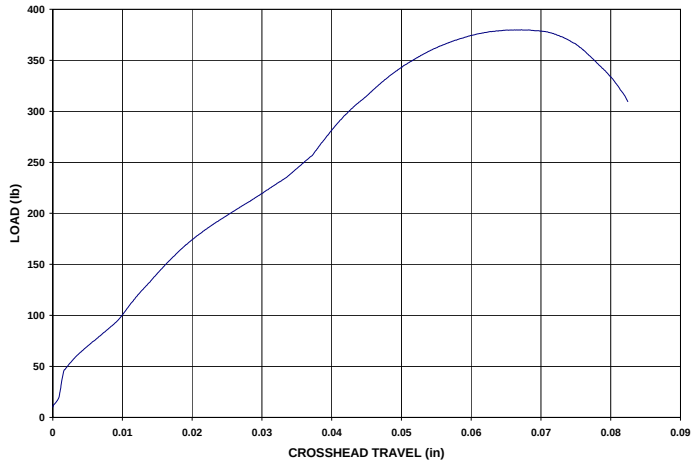


Figure A65 M2.5 Thermal Boss with Insert Specimen 6-5 90-Degree Shear Out Load Versus Crosshead Travel Curve

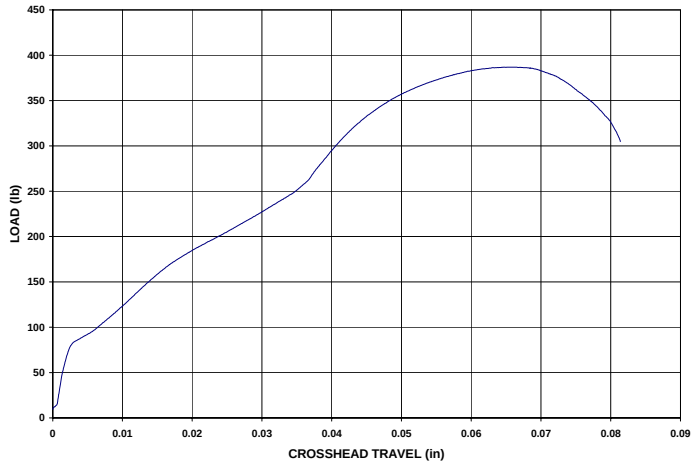


Figure A66 M2.5 Thermal Boss with Insert Specimen 6-6 90-Degree Shear Out Load Versus Crosshead Travel Curve

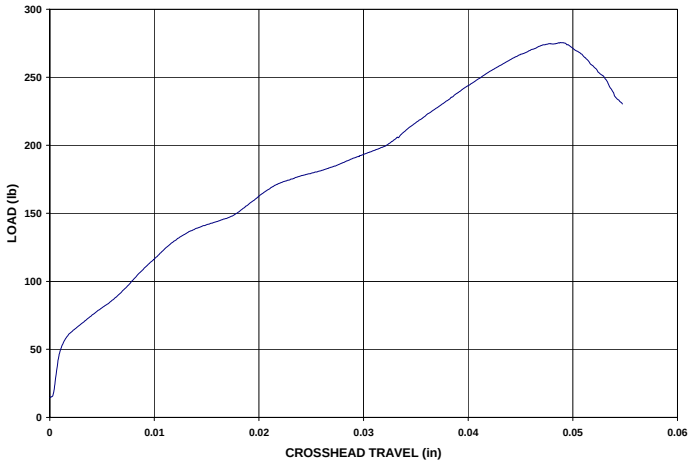


Figure A67 M2.5 Thermal Boss without Insert Specimen 8-1 90-Degree Shear Out Load Versus Crosshead Travel Curve

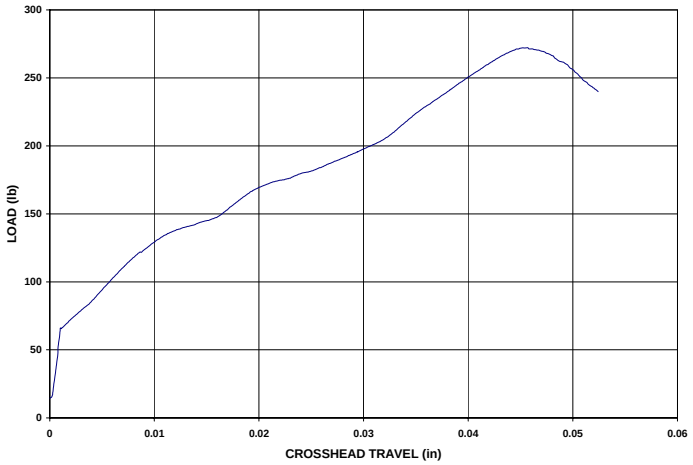


Figure A68 M2.5 Thermal Boss without Insert Specimen 8-2 90-Degree Shear Out Load Versus Crosshead Travel Curve

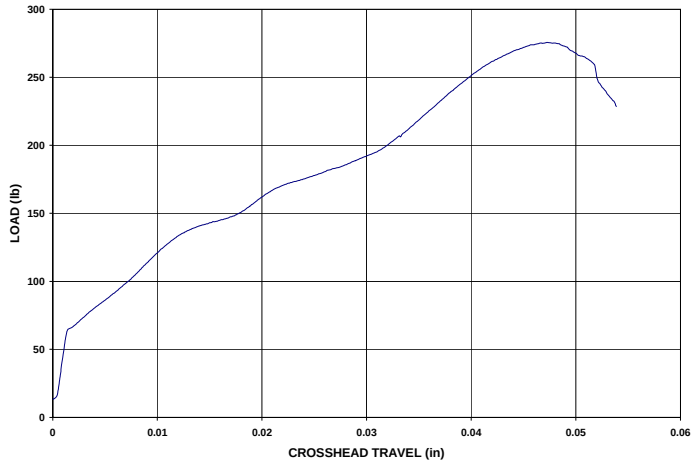


Figure A69 M2.5 Thermal Boss without Insert Specimen 8-3 90-Degree Shear Out Load Versus Crosshead Travel Curve

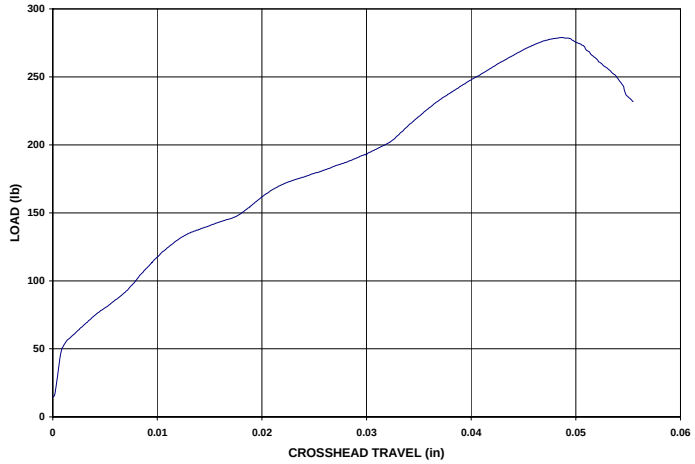


Figure A70 M2.5 Thermal Boss without Insert Specimen 8-4 90-Degree Shear Out Load Versus Crosshead Travel Curve

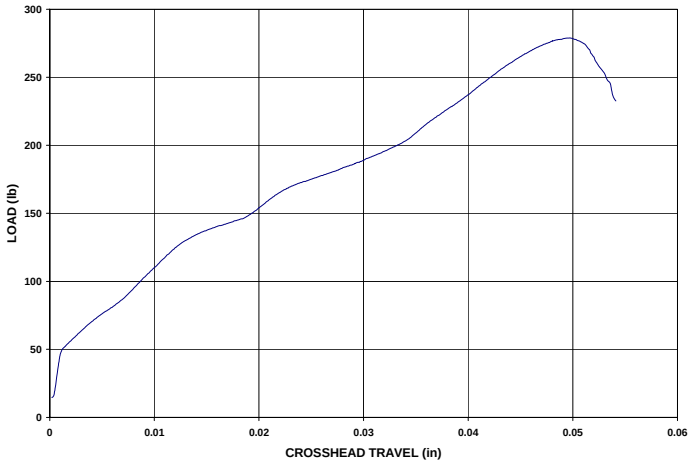


Figure A71 M2.5 Thermal Boss without Insert Specimen 8-5 90-Degree Shear Out Load Versus Crosshead Travel Curve

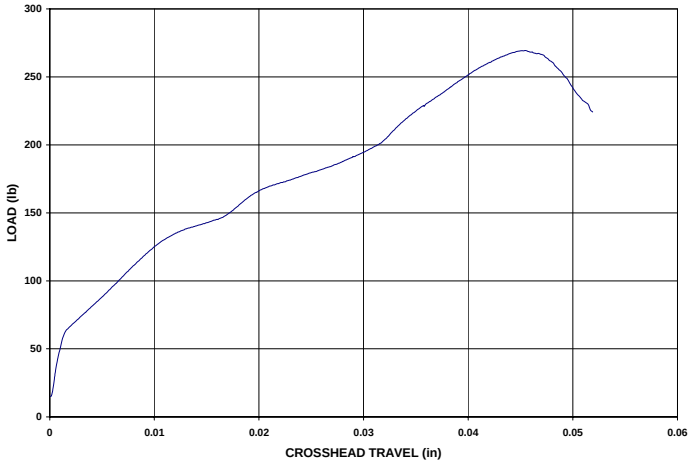


Figure A72 M2.5 Thermal Boss without Insert Specimen 8-6 90-Degree Shear Out Load Versus Crosshead Travel Curve

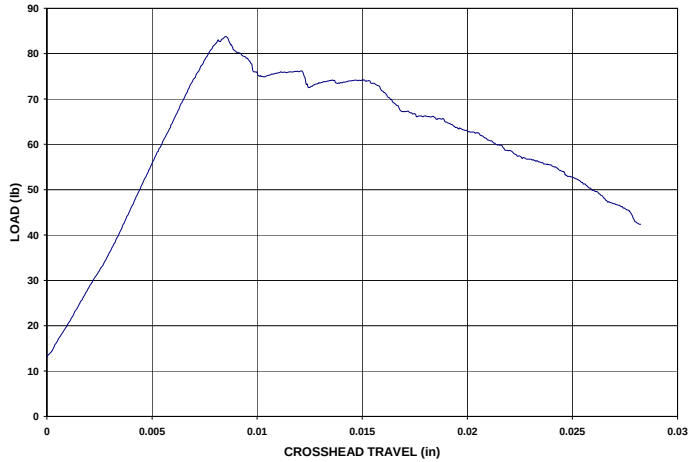


Figure A73 M2.5 without Insert Specimen 9-1 Through Thickness Pull Out Load Versus Crosshead Travel Curve

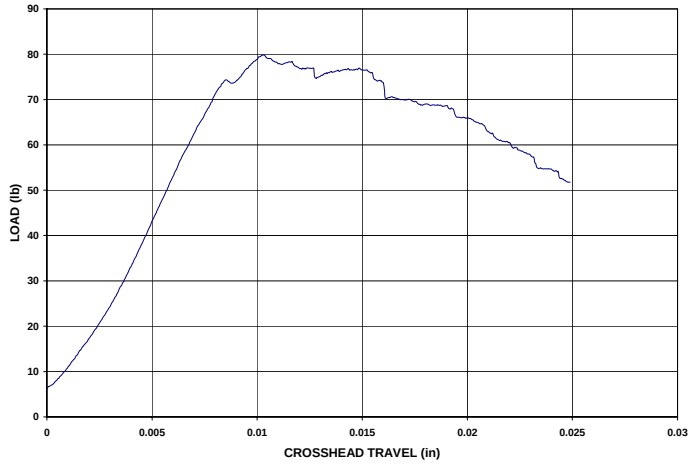


Figure A74 M2.5 without Insert Specimen 9-2 Through Thickness Pull Out Load Versus Crosshead Travel Curve

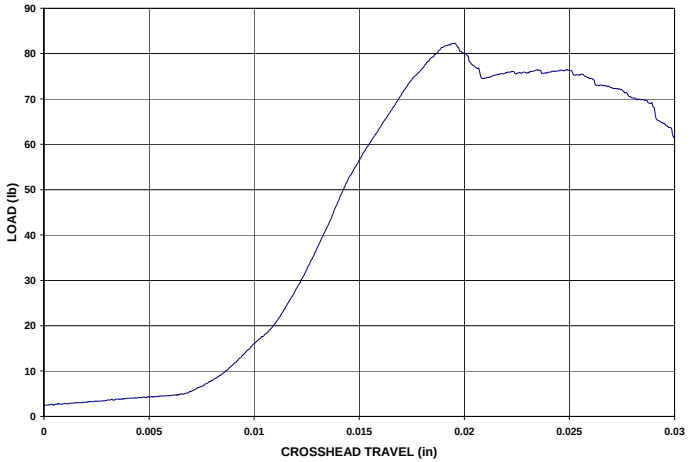


Figure A75 M2.5 without Insert Specimen 9-3 Through Thickness Pull Out Load Versus Crosshead Travel Curve

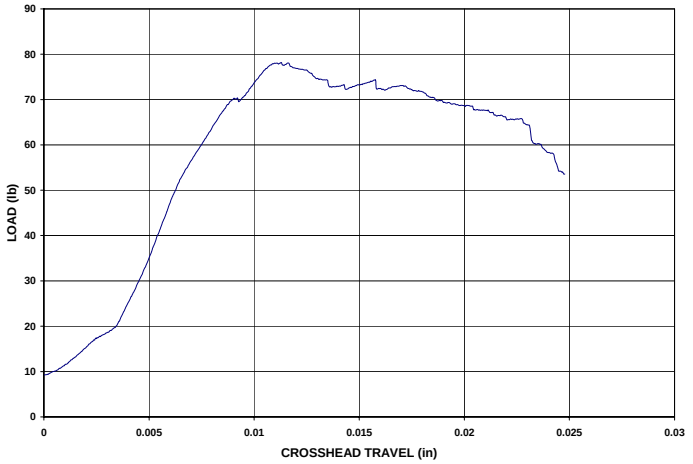


Figure A76 M2.5 without Insert Specimen 9-4 Through Thickness Pull Out Load Versus Crosshead Travel Curve

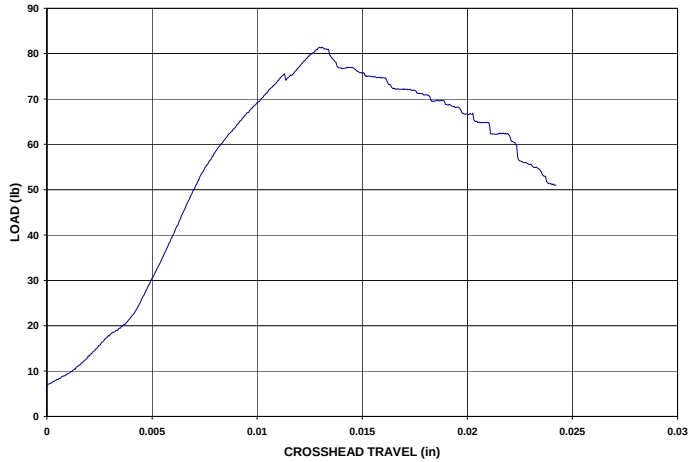


Figure A77 M2.5 without Insert Specimen 9-5 Through Thickness Pull Out Load Versus Crosshead Travel Curve

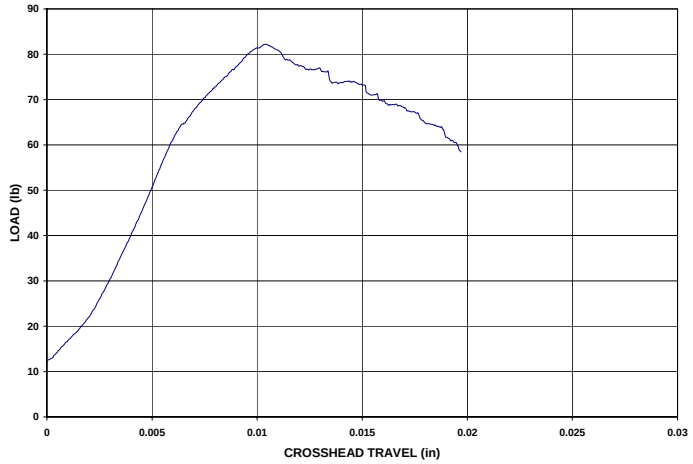


Figure A78 M2.5 without Insert Specimen 9-6 Through Thickness Pull Out Load Versus Crosshead Travel Curve

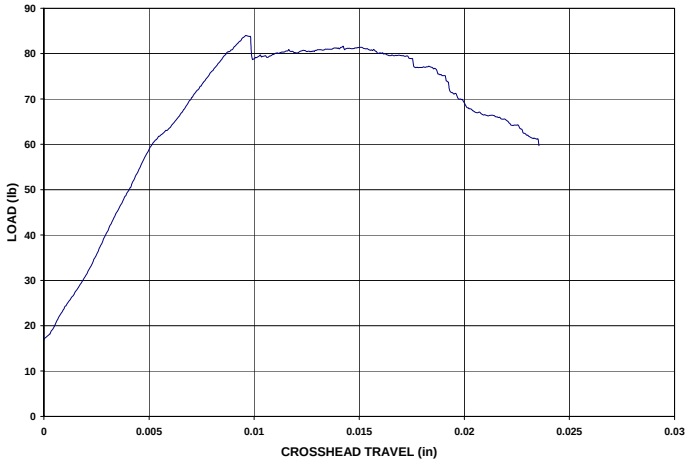


Figure A79 M2.5 without Insert Specimen 9-7 Through Thickness Pull Out Load Versus Crosshead Travel Curve

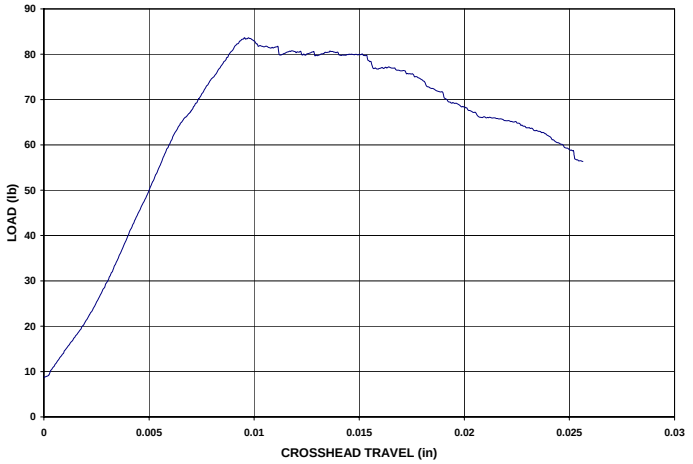


Figure A80 M2.5 without Insert Specimen 9-8 Through Thickness Pull Out Load Versus Crosshead Travel Curve

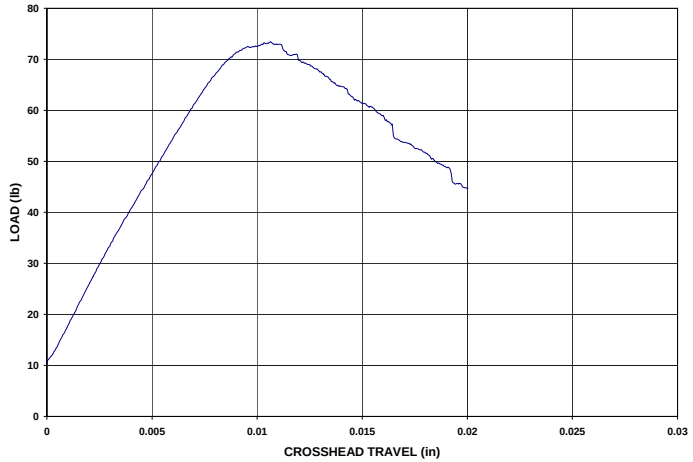


Figure A81 M2.5 without Insert Specimen 9-9 Through Thickness Pull Out Load Versus Crosshead Travel Curve

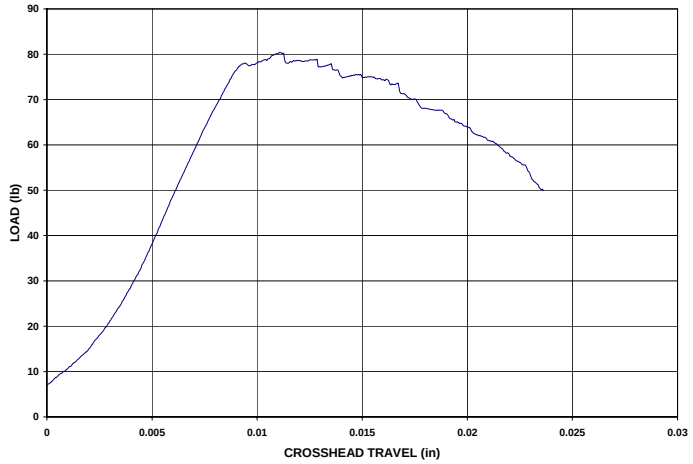


Figure A82 M2.5 without Insert Specimen 9-10 Through Thickness Pull Out Load Versus Crosshead Travel Curve

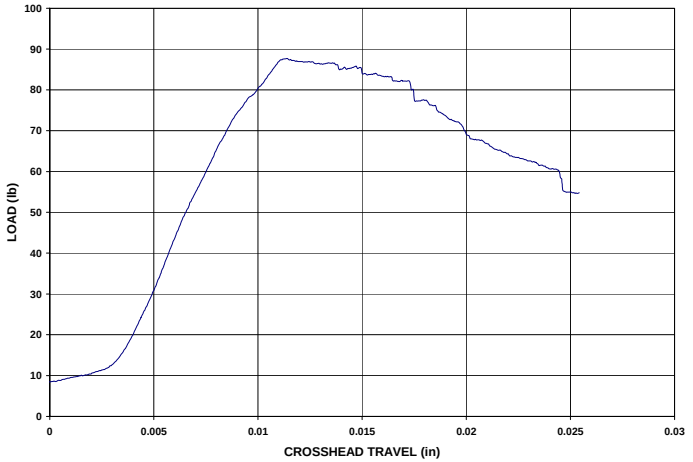


Figure A83 M2.5 without Insert Specimen 9-11Through Thickness Pull Out Load Versus Crosshead Travel Curve

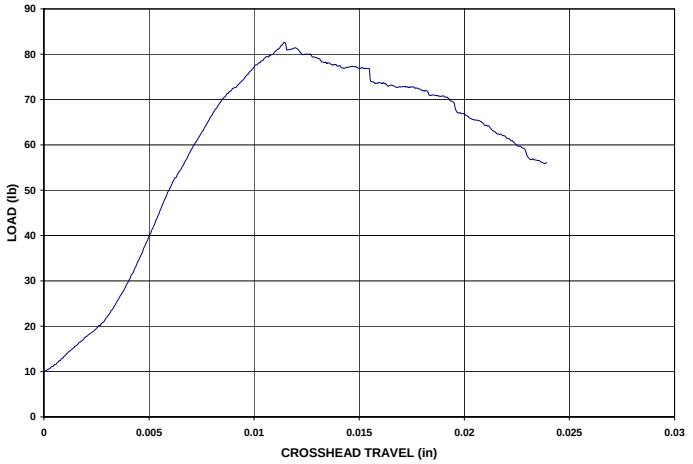


Figure A84 M2.5 without Insert Specimen 9-12 Through Thickness Pull Out Load Versus Crosshead Travel Curve

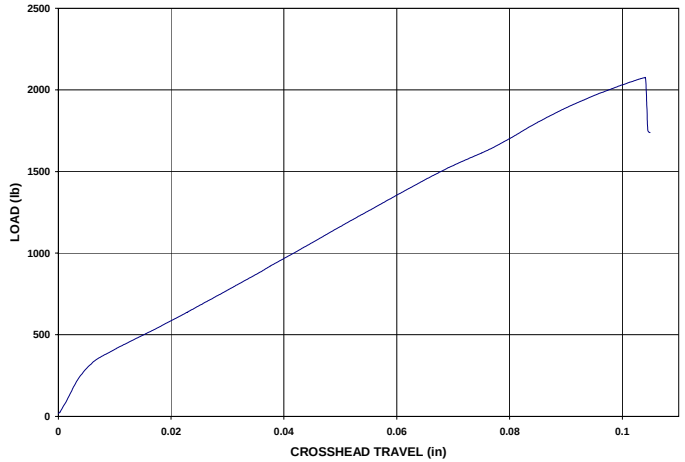


Figure A85 M4 Thermal Boss with 2 Inserts Specimen 10-1 0-Degree Shear Out Load Versus Crosshead Travel Curve

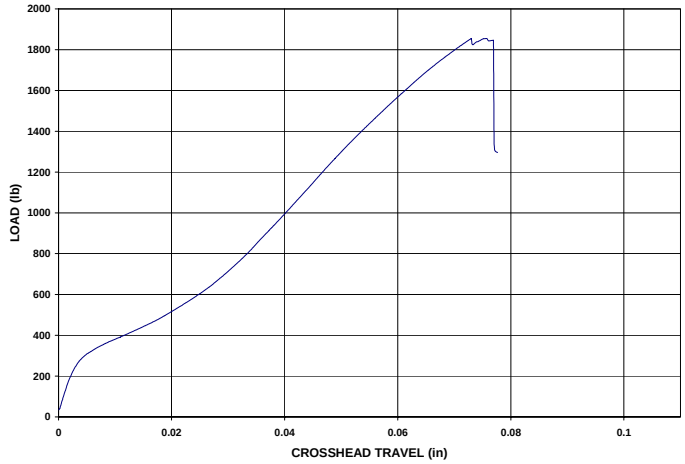


Figure A86 M4 Thermal Boss with 2 Inserts Specimen 10-2 0-Degree Shear Out Load Versus Crosshead Travel Curve

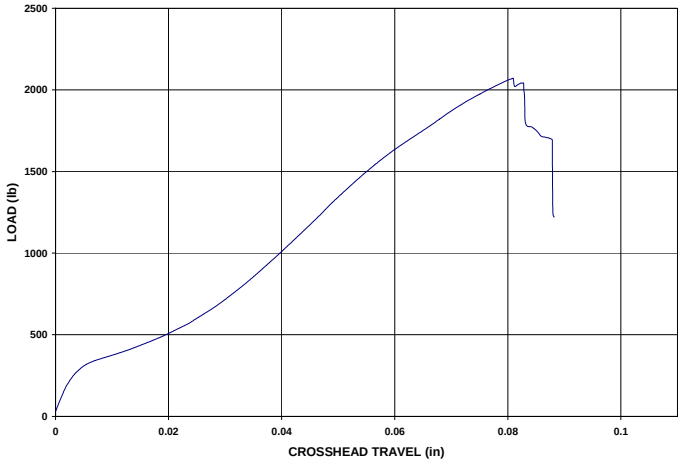


Figure A87 M4 Thermal Boss with 2 Inserts Specimen 10-3 0-Degree Shear Out Load Versus Crosshead Travel Curve

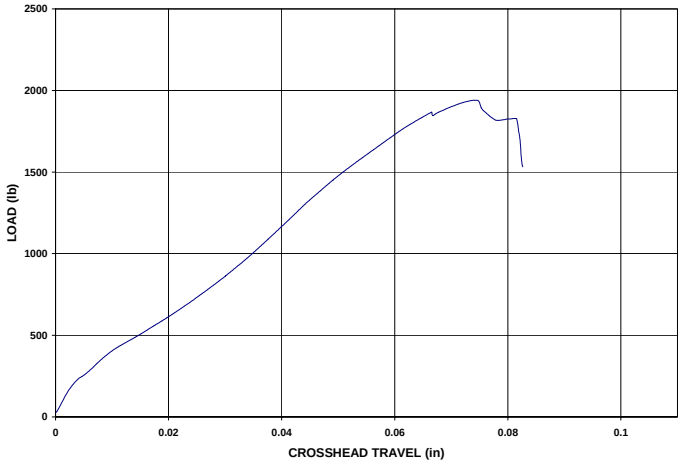


Figure A88 M4 Thermal Boss with 2 Inserts Specimen 10-4 0-Degree Shear Out Load Versus Crosshead Travel Curve

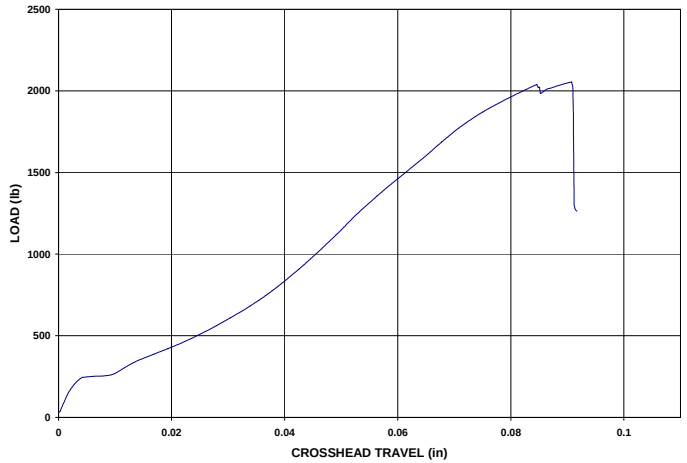


Figure A89 M4 Thermal Boss with 2 Inserts Specimen 10-5 0-Degree Shear Out Load Versus Crosshead Travel Curve

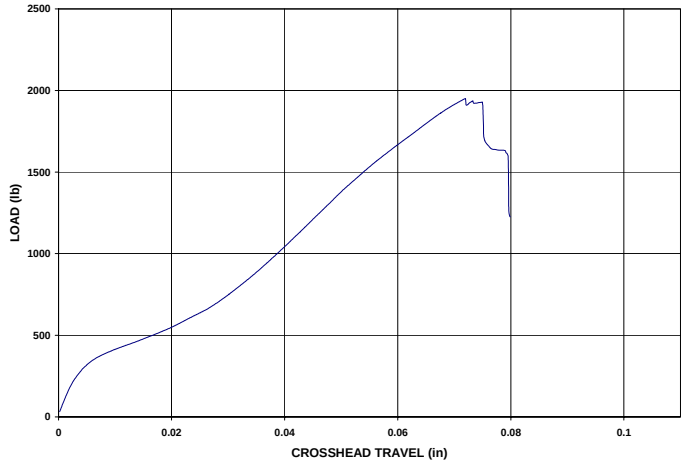


Figure A90 M4 Thermal Boss with 2 Inserts Specimen 10-6 0-Degree Shear Out Load Versus Crosshead Travel Curve

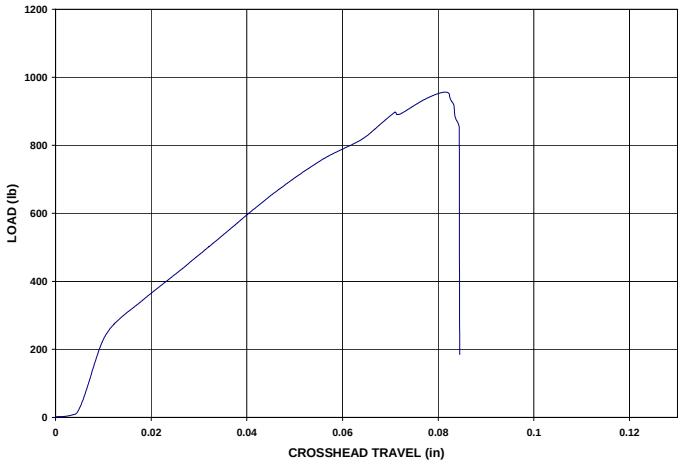


Figure A91 M4 Corner with Insert Specimen 11-1 0-Degree Tear Out Load Versus Crosshead Travel Curve

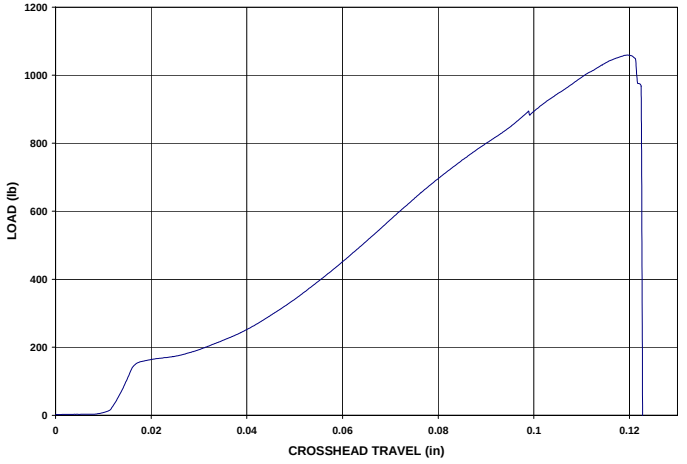


Figure A92 M4 Corner with Insert Specimen 11-2 0-Degree Tear Out Load Versus Crosshead Travel Curve

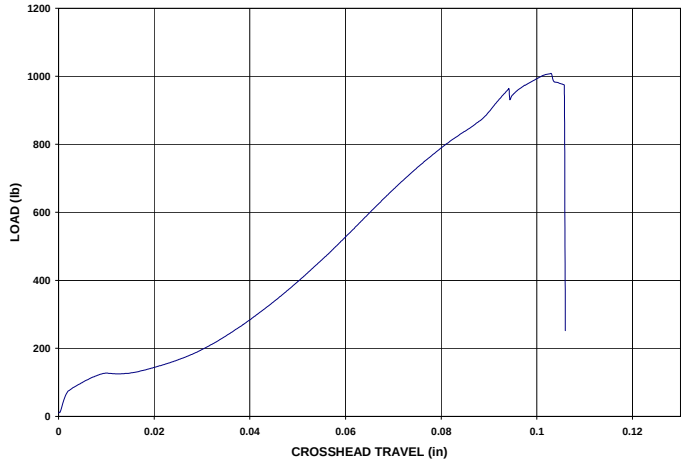


Figure A93 M4 Corner with Insert Specimen 11-3 0-Degree Tear Out Load Versus Crosshead Travel Curve

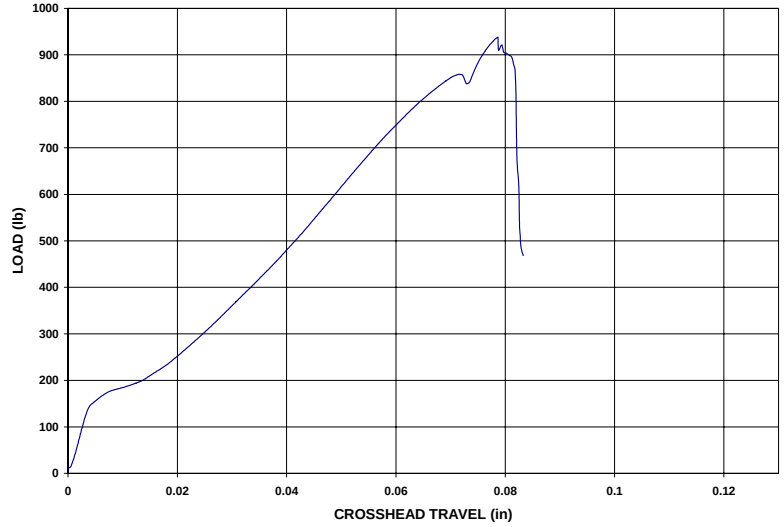


Figure A94 M4 Corner with Insert Specimen 11-4 0-Degree Tear Out Load Versus Crosshead Travel Curve

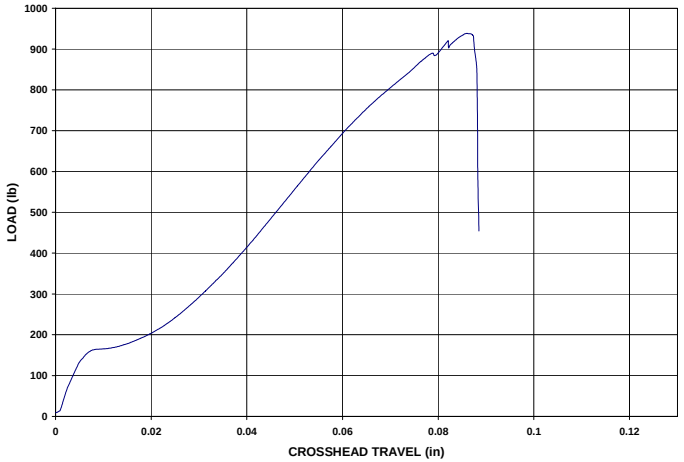


Figure A95 M4 Corner with Insert Specimen 11-5 0-Degree Tear Out Load Versus Crosshead Travel Curve

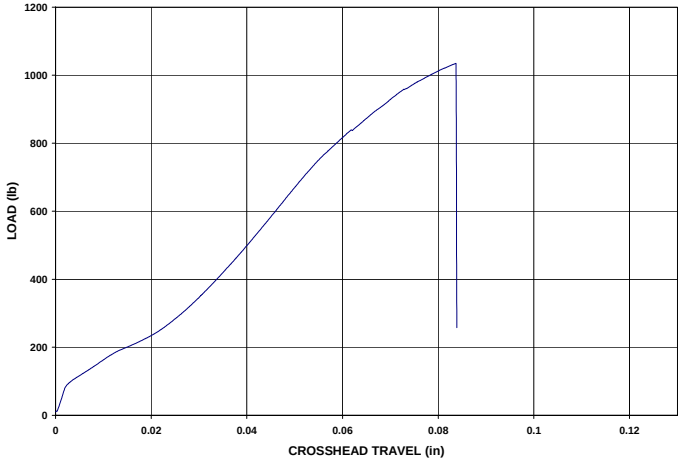


Figure A96 M4 Corner with Insert Specimen 11-6 0-Degree Tear Out Load Versus Crosshead Travel Curve

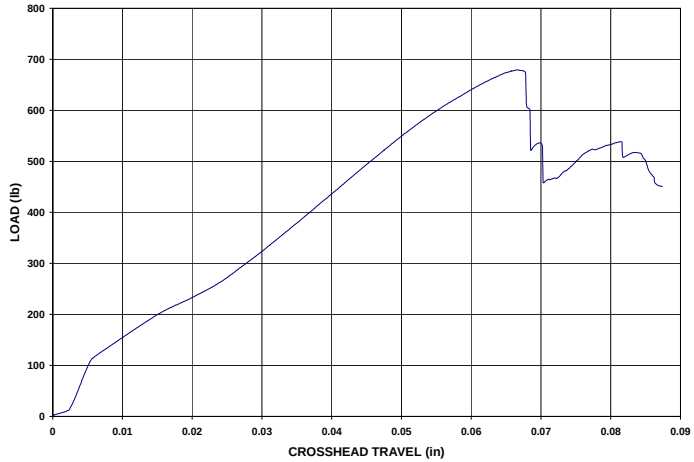


Figure A97 M4 with Insert Specimen 12-1 45-Degree Shear Out Load Versus Crosshead Travel Curve

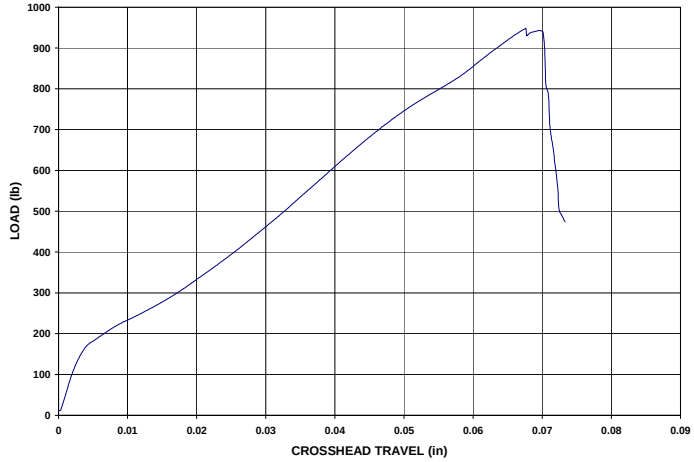


Figure A98 M4 with Insert Specimen 12-2 45-Degree Shear Out Load Versus Crosshead Travel Curve

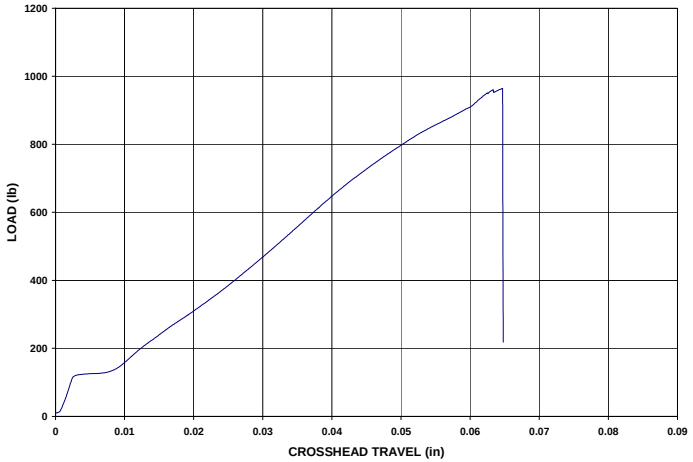


Figure A99 M4 with Insert Specimen 12-3 45-Degree Shear Out Load Versus Crosshead Travel Curve

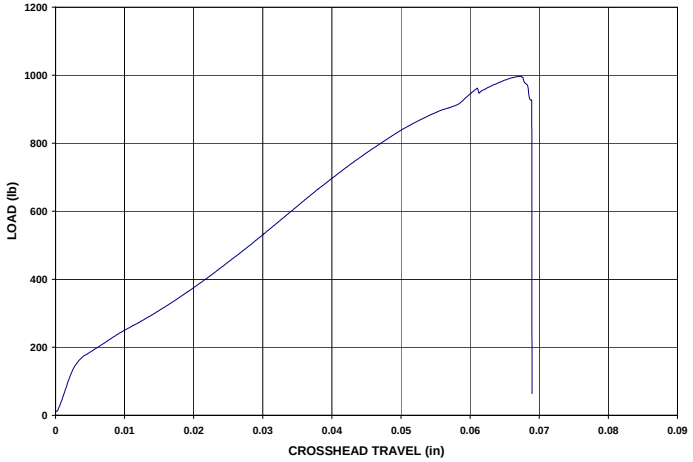


Figure A100 M4 with Insert Specimen 12-4 45-Degree Shear Out Load Versus Crosshead Travel Curve

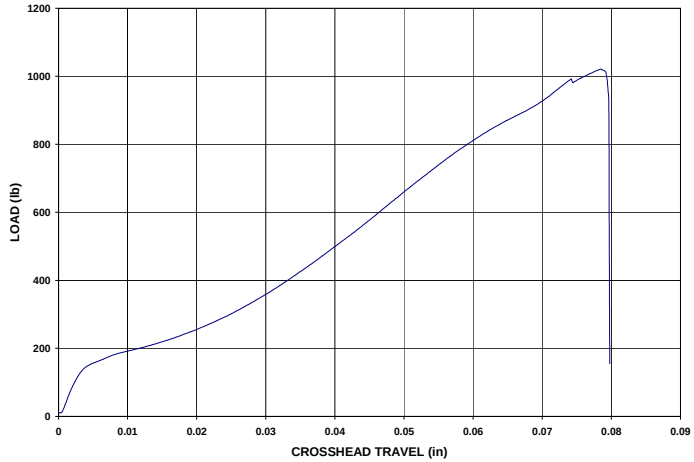


Figure A101 M4 with Insert Specimen 12-5 45-Degree Shear Out Load Versus Crosshead Travel Curve

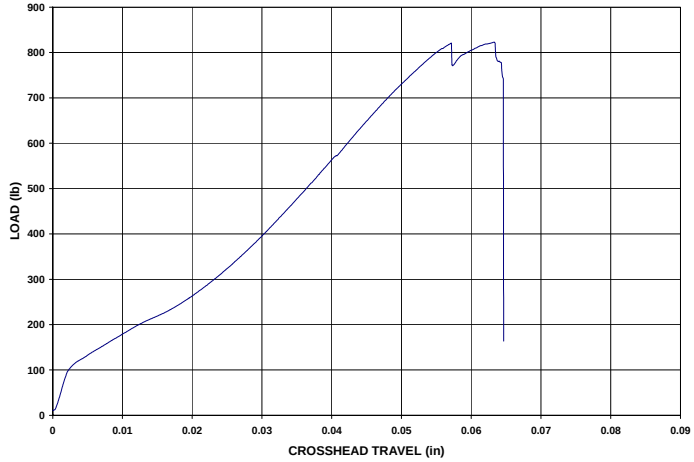


Figure A102 M4 with Insert Specimen 12-6 45-Degree Shear Out Load Versus Crosshead Travel Curve

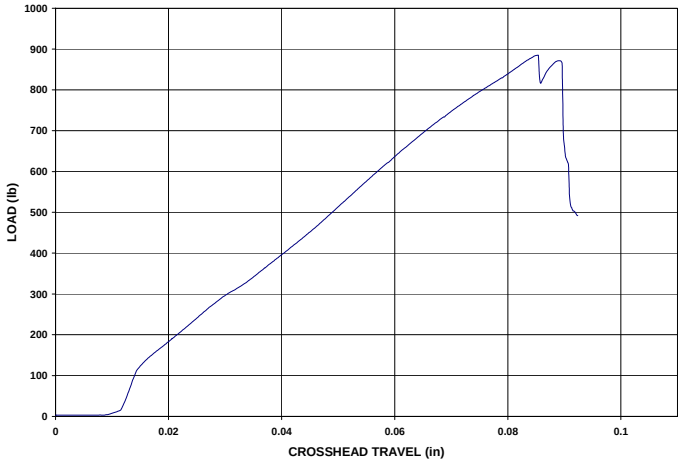


Figure A103 M4 Corner with Insert Specimen 13-1 90-Degree Tear Out Load Versus Crosshead Travel Curve

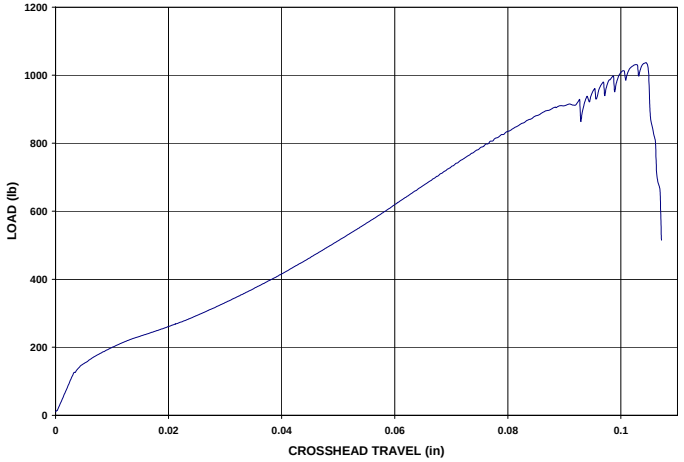


Figure A104 M4 Corner with Insert Specimen 13-2 90-Degree Tear Out Load Versus Crosshead Travel Curve

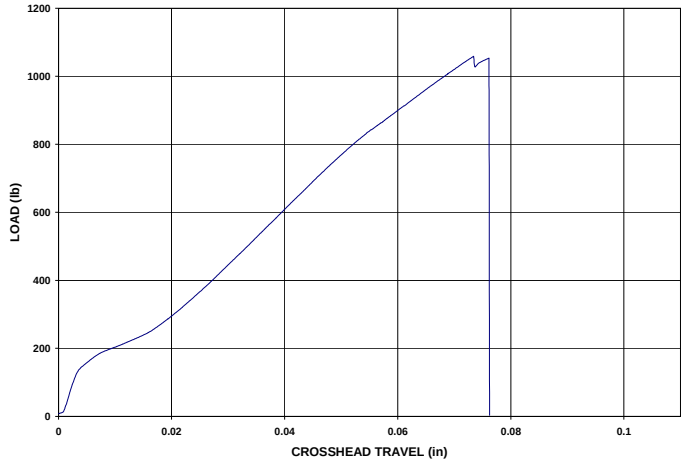


Figure A105 M4 Corner with Insert Specimen 13-3 90-Degree Tear Out Load Versus Crosshead Travel Curve

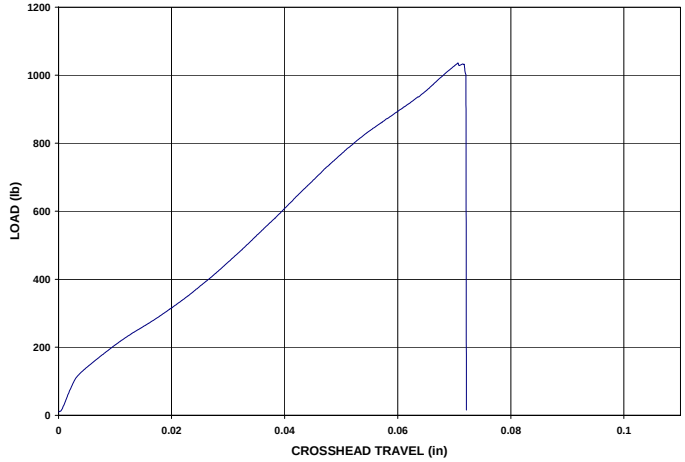


Figure A106 M4 Corner with Insert Specimen 13-4 90-Degree Tear Out Load Versus Crosshead Travel Curve

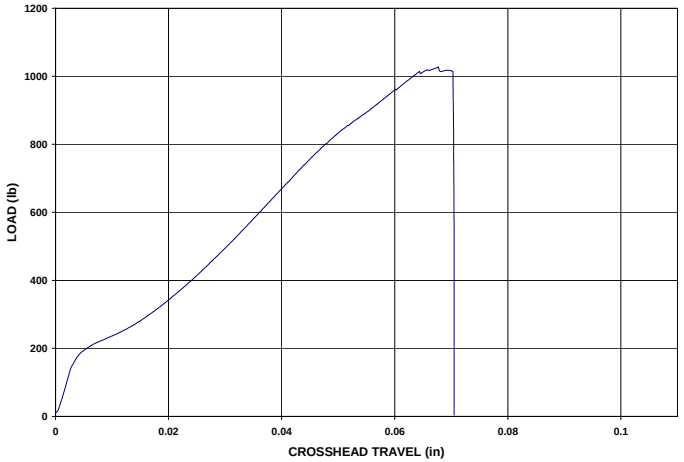


Figure A107 M4 Corner with Insert Specimen 13-5 90-Degree Tear Out Load Versus Crosshead Travel Curve

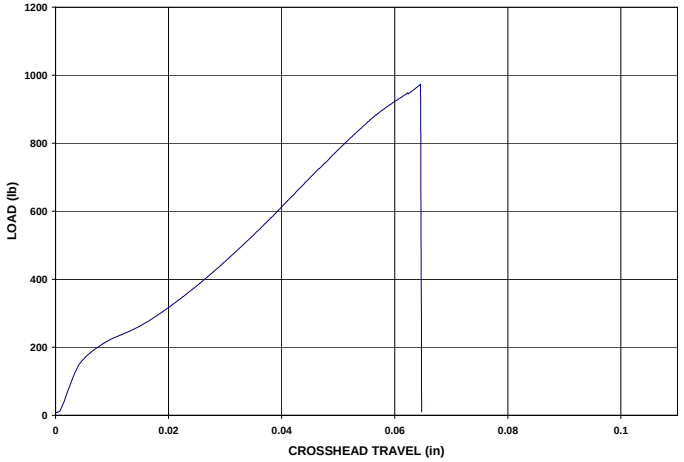


Figure A108 M4 Corner with Insert Specimen 13-6 90-Degree Tear Out Load Versus Crosshead Travel Curve

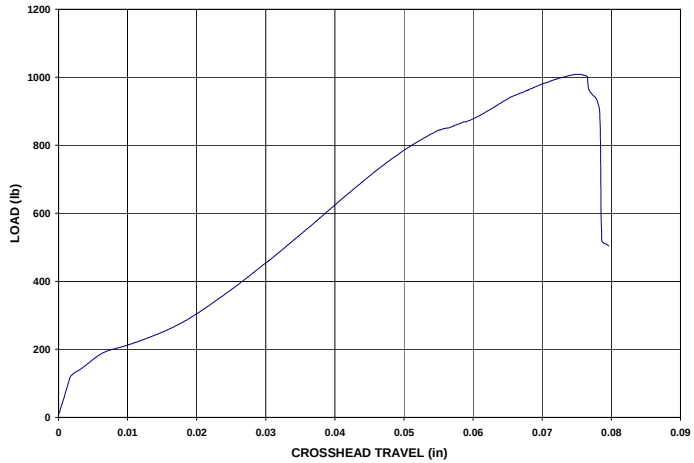


Figure A109 M4 Thermal Boss with Insert Specimen 14-1 0-Degree Shear Out Load Versus Crosshead Travel Curve

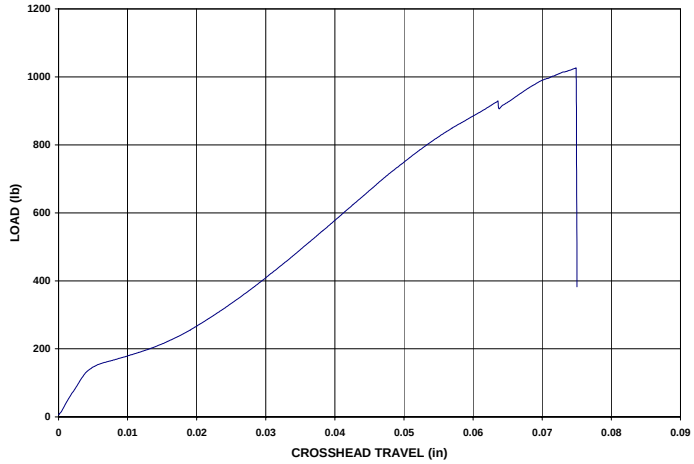


Figure A110 M4 Thermal Boss with Insert Specimen 14-2 0-Degree Shear Out Load Versus Crosshead Travel Curve

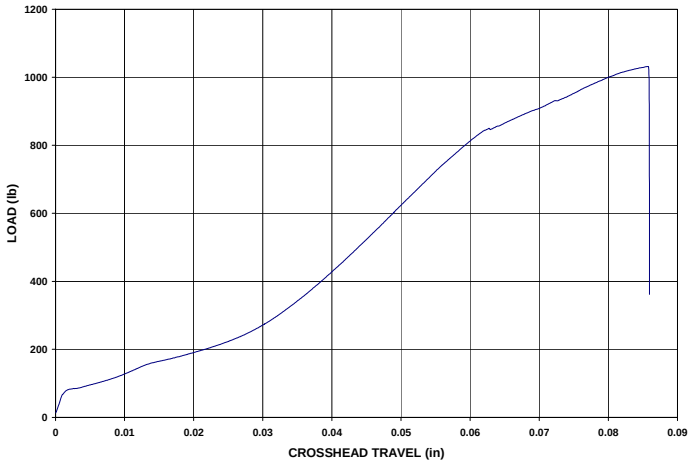


Figure A111 M4 Thermal Boss with Insert Specimen 14-3 0-Degree Shear Out Load Versus Crosshead Travel Curve

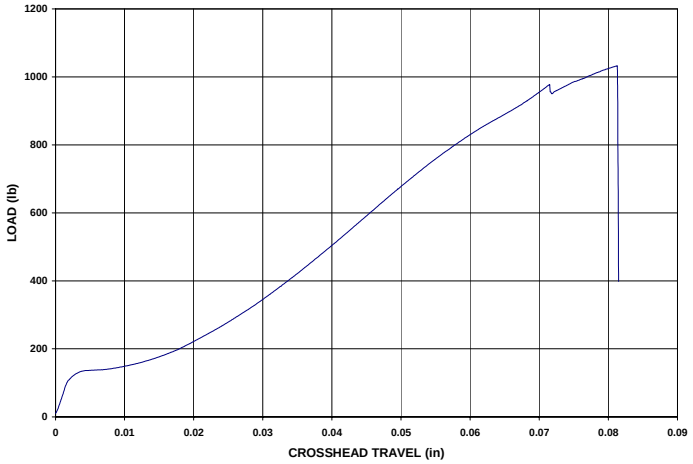


Figure A112 M4 Thermal Boss with Insert Specimen 14-4 0-Degree Shear Out Load Versus Crosshead Travel Curve

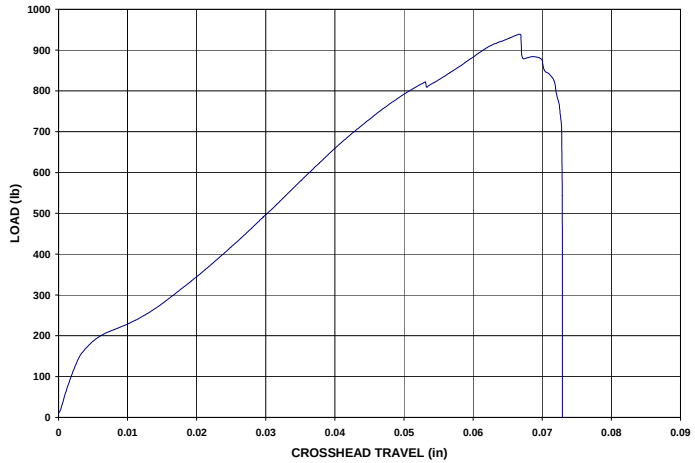


Figure A113 M4 Thermal Boss with Insert Specimen 14-5 0-Degree Shear Out Load Versus Crosshead Travel Curve

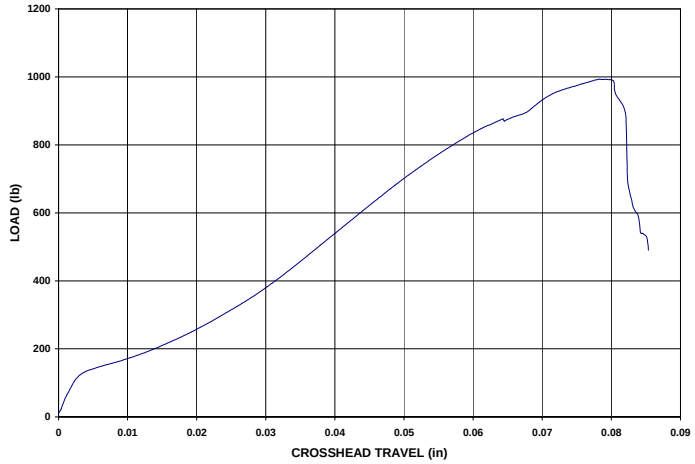
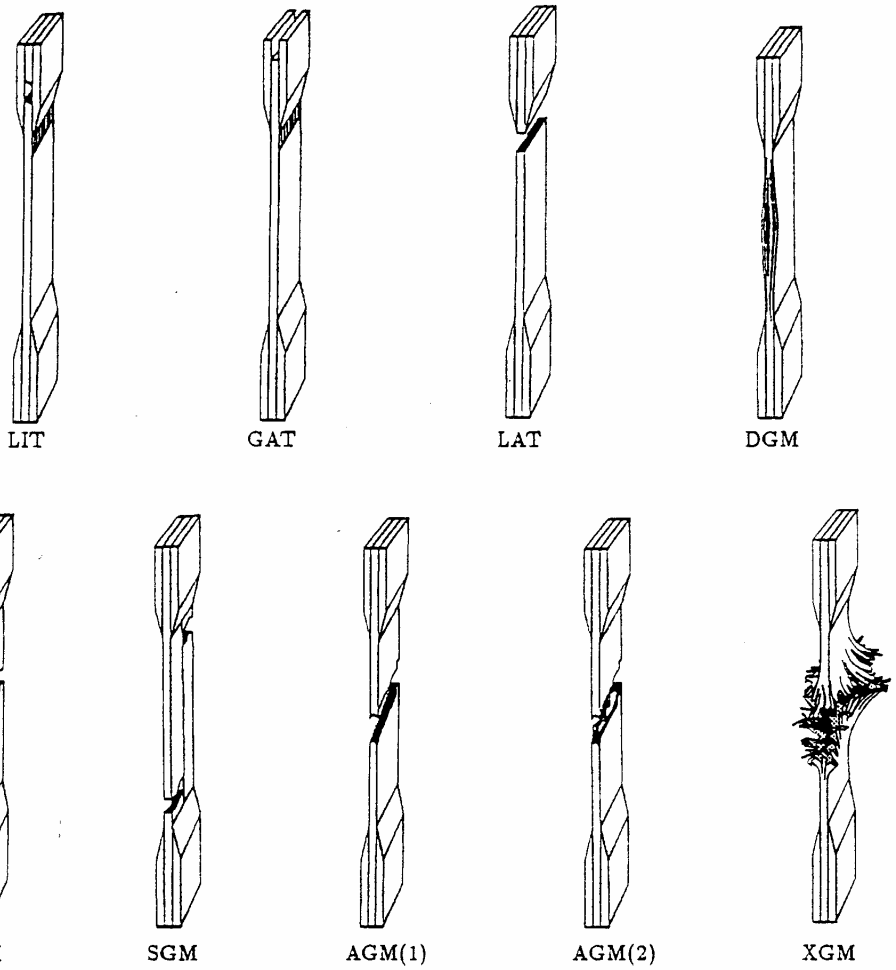


Figure A114 M4 Thermal Boss with Insert Specimen 14-6 0-Degree Shear Out Load Versus Crosshead Travel Curve

Appendix B
Failed Specimen Photographs



First Character

Failure Type	Code
Angled	A
edge Delamination	D
Grip/tab	G
Lateral	L
Multi-mode	M(xyz)
long. Splitting	S
eXplosive	X
Other	O

Second Character

Failure Area	Code
Inside grip/tab	I
At grip/tab	A
<1W from grip/tab	W
Gage	G
Multiple areas	M
Various	V
Unknown	U

Third Character

Failure Location	Code
Bottom	B
Top	T
Left	L
Right	R
Middle	M
Various	V
Unknown	U

Figure B1 Schematic of Typical Tensile Specimen Failure Modes.

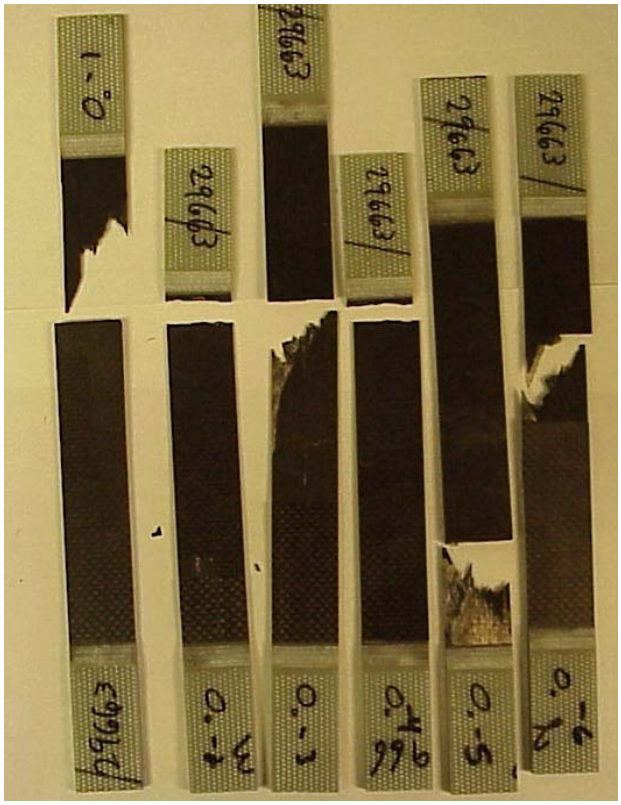


Figure B2 Photograph of the Failed Individual 0-Degree Tensile Specimens.

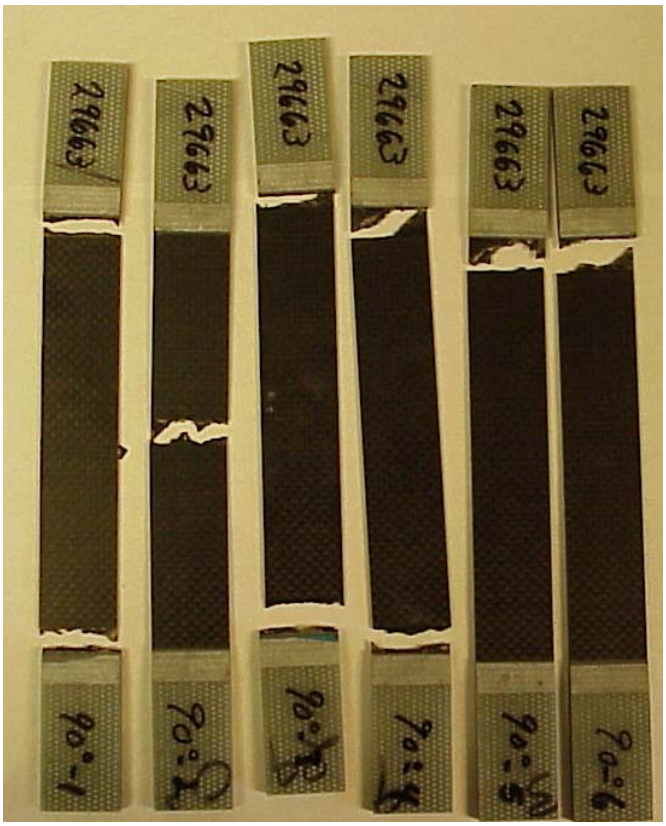
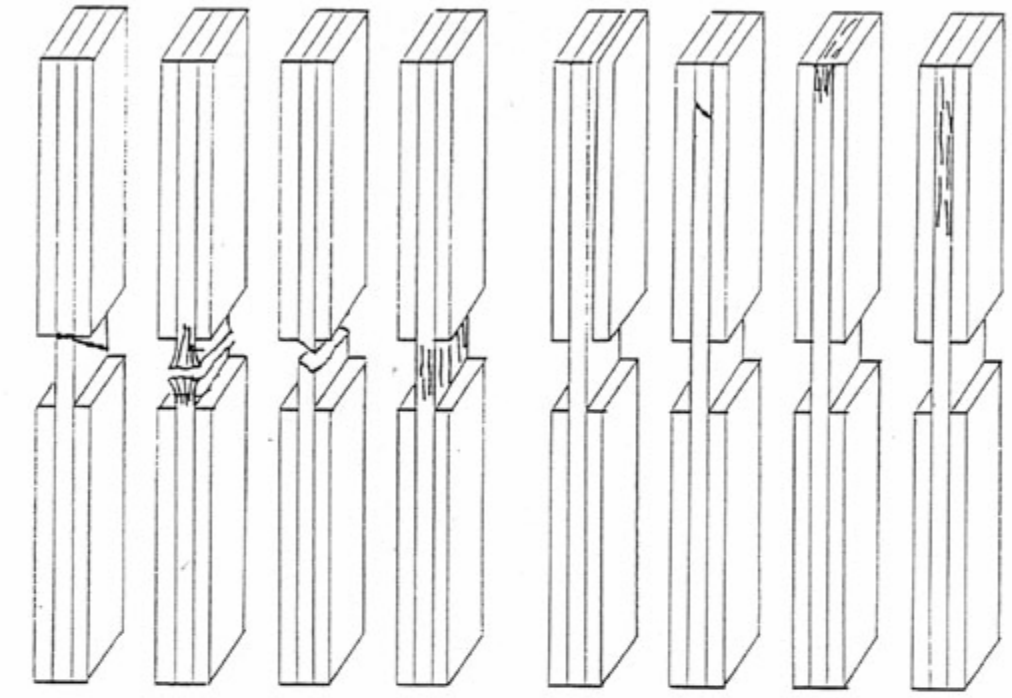


Figure B3 Photograph of the Failed Individual 90-Degree Tensile Specimens.



First Character

Failure Mode	Code
Angled	A
Brooming	B
end-Crushing	C
Delamination	D
Euler Buckling	E
tHfough-thickness	H
Lateral	L
Multi-mode	M(xyz)
long.-Splitting	S
Transverse Shear	T
eXplosive	X
Other	O

Second Character

Failure Area	Code
Inside grip/tab	I
At grip/tab	A
Gage	G
Multiple Areas	M
Tab adhesive	T
Various	V
Unknown	U

Third Character

Failure Location	Code
Bottom	B
Top	T
Left	L
Right	R
Middle	M
Various	V
Unknown	U

Figure B4 Schematic of Typical Compression Specimen Failure Modes.

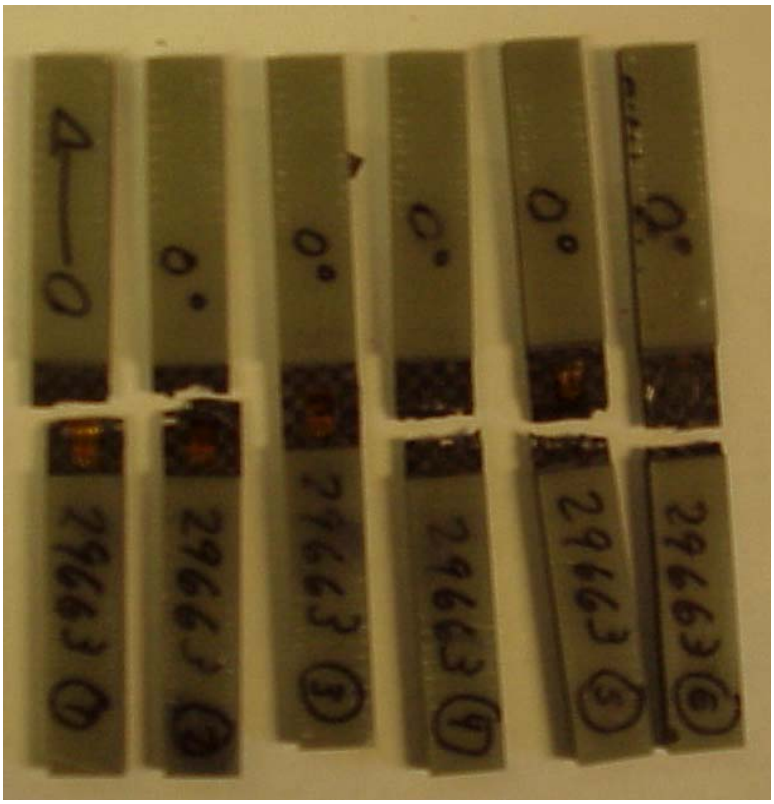


Figure B5 Photograph of the Failed Individual 0-Degree Compression Specimens.

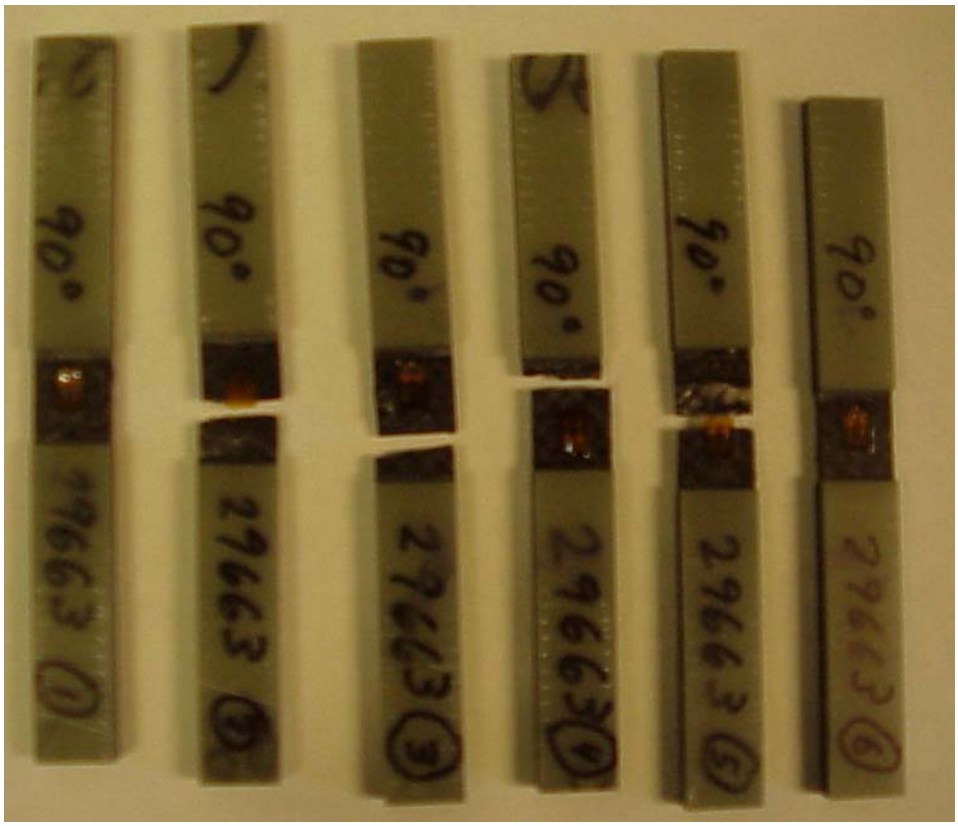


Figure B6 Photograph of the Failed Individual 90-Degree Compression Specimens.

Figure B7 Photograph of the Failed 2-Hole Corner without Insert Shearout Test Specimens.

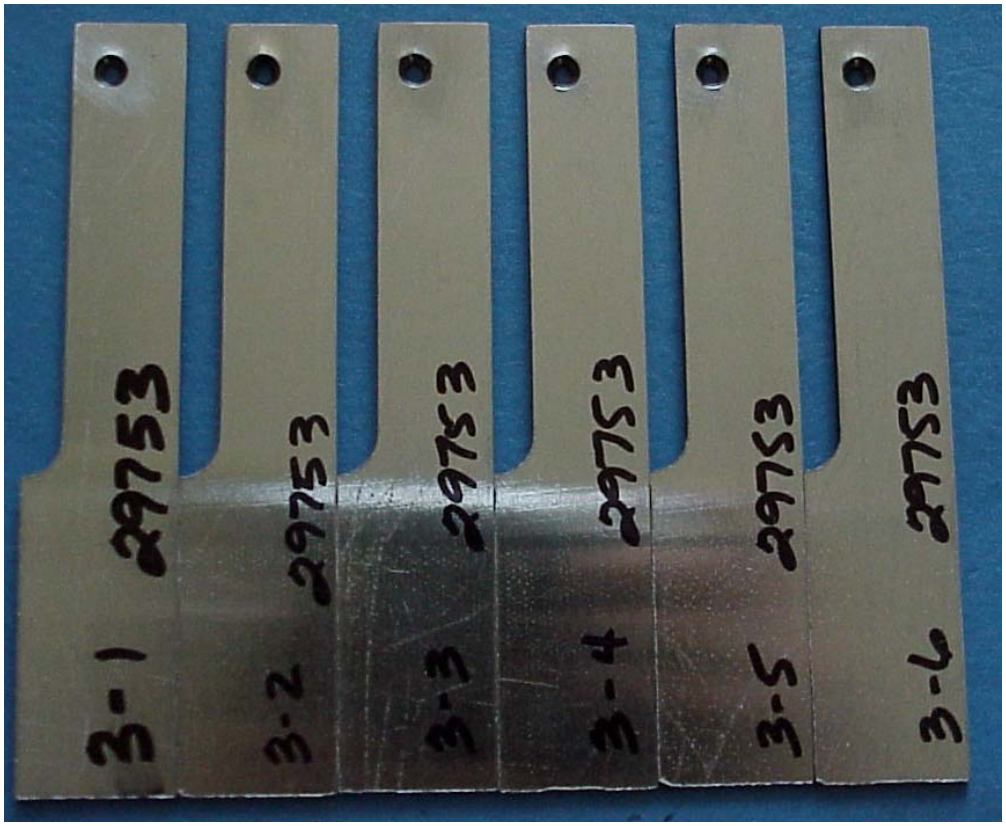


Figure B8 Photograph of the Failed M2.5 Fastener 0-Degree Corner Tearout Specimens.

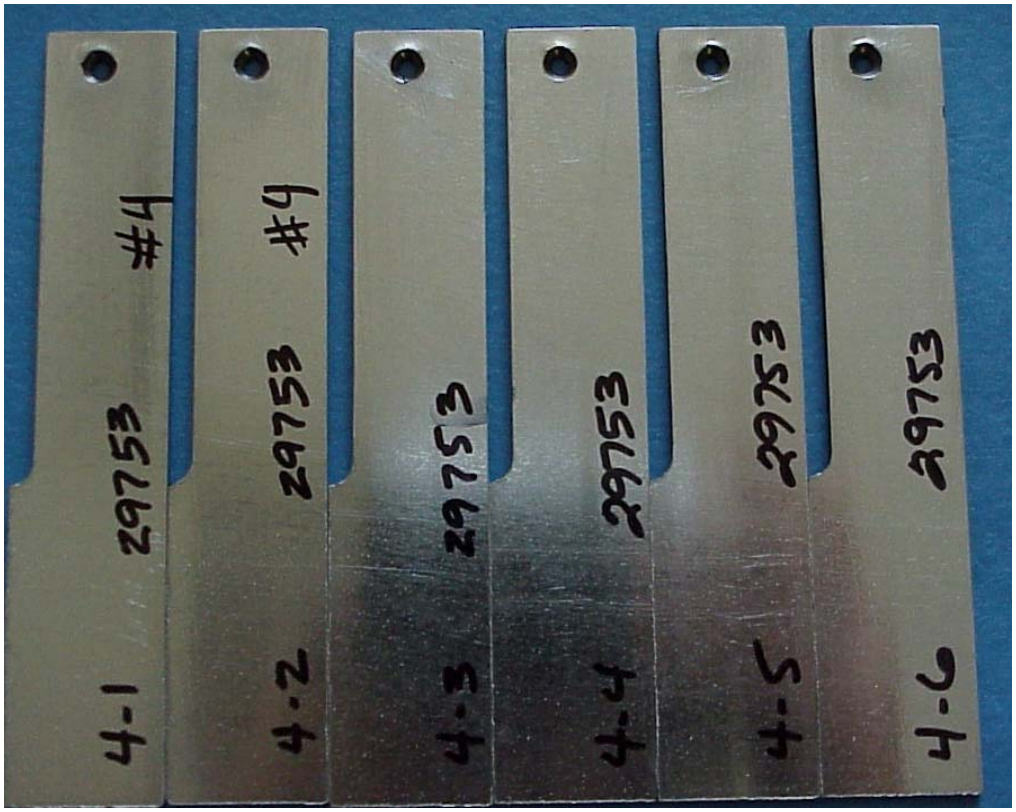


Figure B9 Photograph of the Failed M2.5 Fastener 90-Degree Corner Tearout Specimens.

Figure B10 Photograph of the Failed M2.5 Fastener 0-Degree Thermal Boss Shearout Specimens.

Figure B11 Photograph of the Failed M2.5 Fastener 90-Degree Thermal Boss Shearout Specimens.

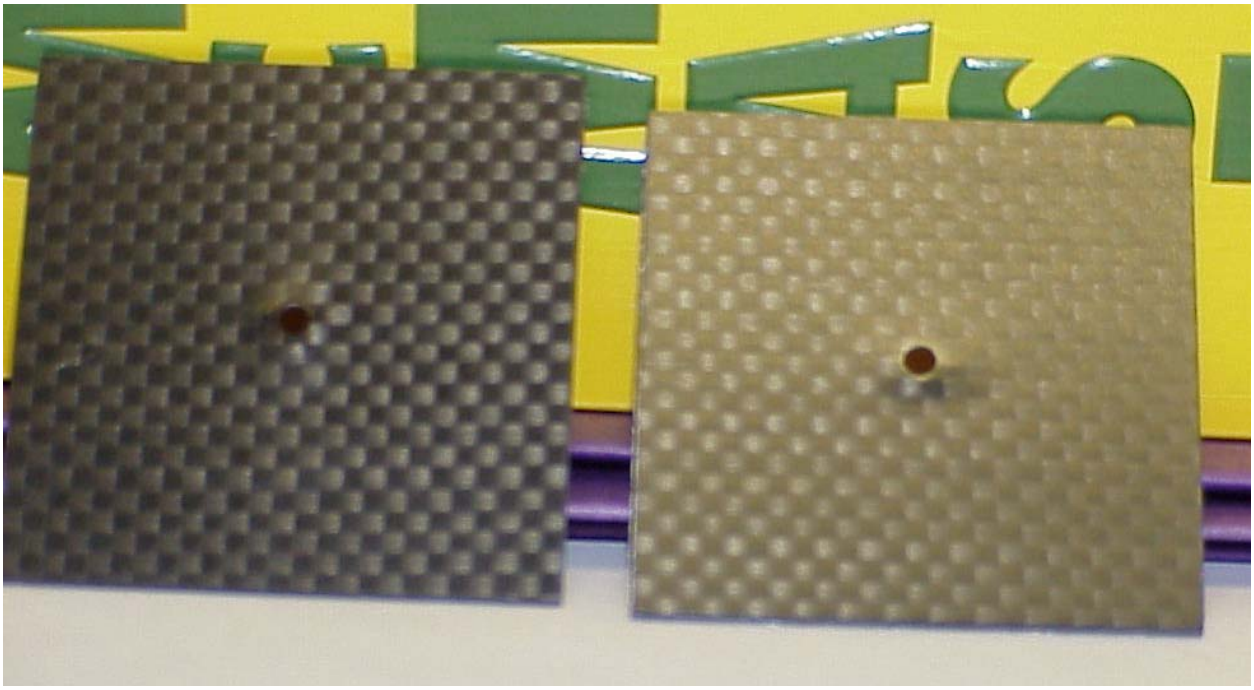


Figure B12 Photograph of the Typical Failed M2.5 Fastener Pullout Specimens (Actual 9-1 and 9-2).

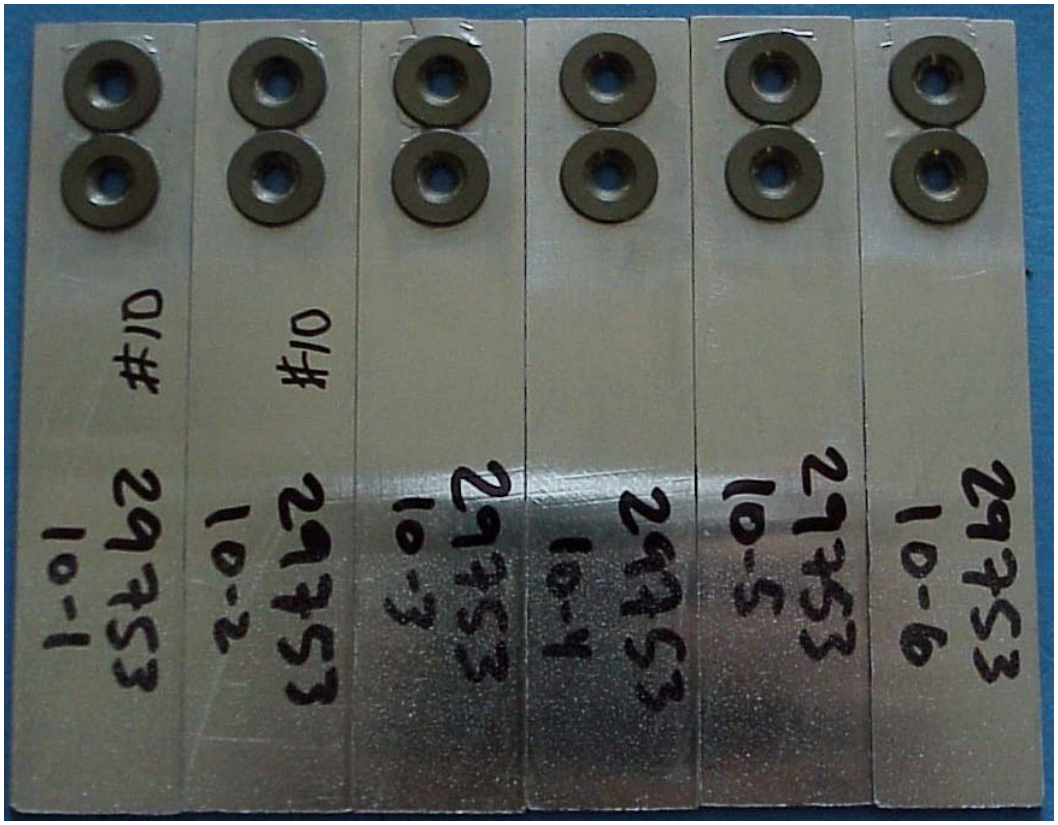


Figure B13 Photograph of the Failed M4 Fastener 2-Hole Thermal Boss Shearout Specimens with Insert.

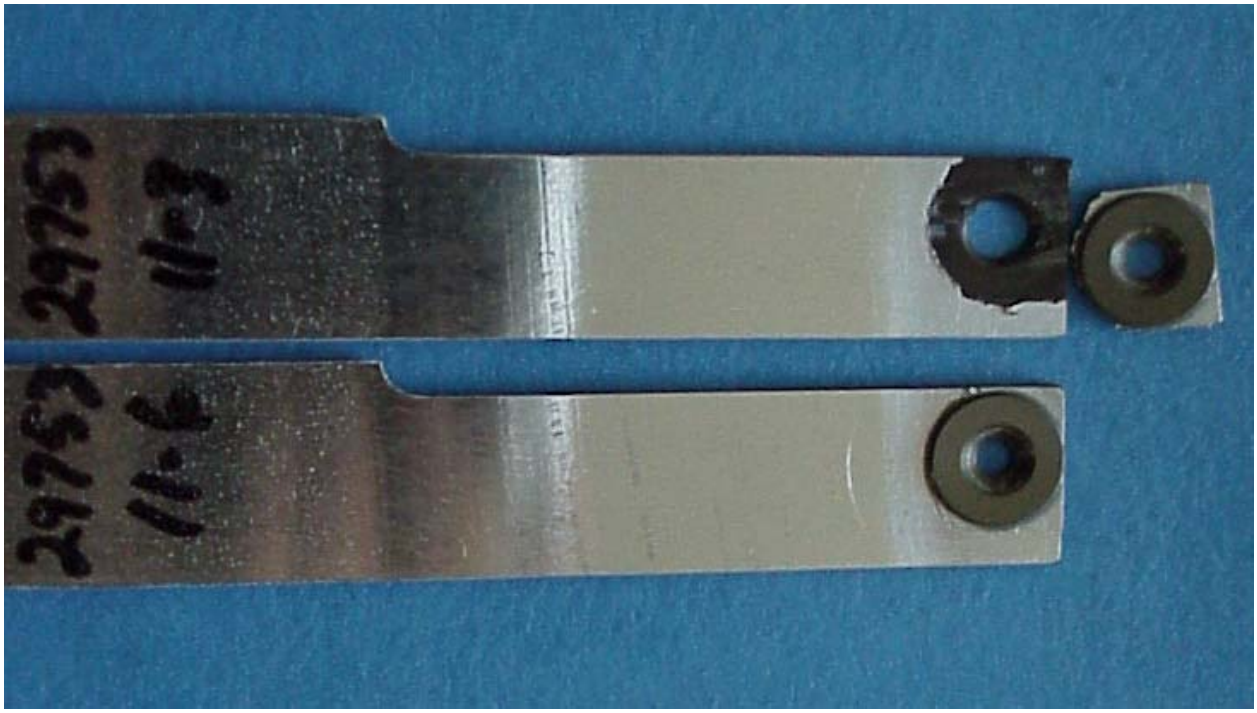


Figure B14 Photograph of the Failed M4 Fastener 0-Degree Corner Tearout Specimens with Insert Specimen 11-3 and 11-6.

Figure B15 Photograph of the Failed M4 Fastener 45-Degree Shearout Specimens with Insert.

Figure B16 Photograph of the Failed M4 Fastener 90-Degree Corner Tearout Specimens with Insert.

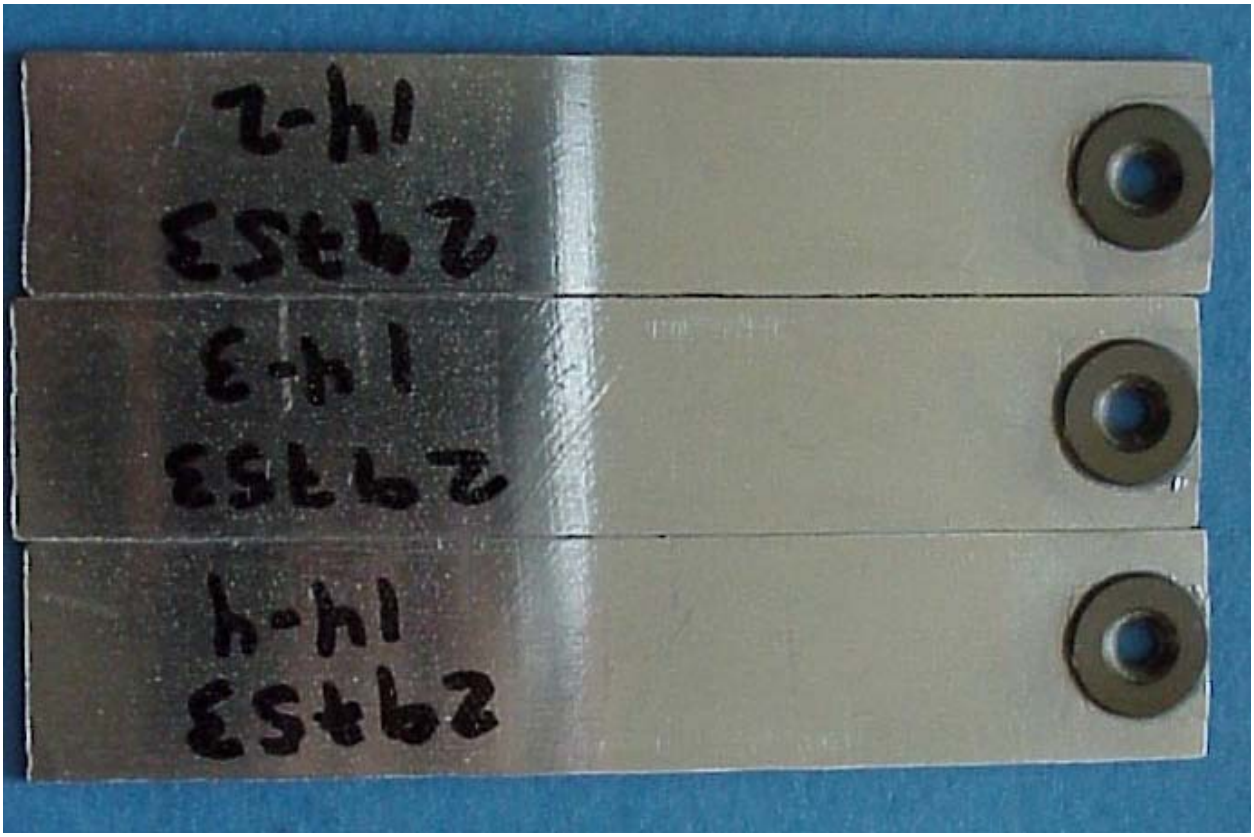


Figure B17 Photograph of the Failed 0-Degree Thermal Boss Shearout Specimens with Insert.