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Experimental Results of Single Screw Mechanical Tests: a follow-up to SAND2005-6036

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ABSTRACT

The work reported here was conducted to address issues raised regarding mechanical testing of attachment screws described in SAND2005-6036, as well as to increase the understanding of screw behavior through additional testing. Efforts were made to evaluate fixture modifications and address issues of interest, including: fabrication of 45° test fixtures, measurement of the frictional load from the angled fixture guide, employment of electromechanical displacement transducers, development of a single-shear test, and study the affect of thread start orientation on single-shear behavior. A286 and 302HQ, #10-32 socket-head cap screws were tested having orientations with respect to the primary loading axis of 0°, 45°, 60°, 75° and 90° at stroke speeds 0.001 and 10 in/sec. The frictional load resulting from the angled screw fixture guide was insignificant. Load-displacement curves of A286 screws did not show a minimum value in displacement to failure (DTF) for 60° shear tests. Tests of 302HQ screws did not produce a consistent trend in DTF with load angle. The effect of displacement rate on DTF became larger as shear angle increased for both A286 and 302HQ screws.

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1. Background

The work detailed in this report is a follow-up to the series of experiments presented in SAND2005-6036 "Deformation and Failure Behavior of Attachment Screws for the W80 WES Housing" [1]. Those experiments were conducted as part of the ASC VV-4.1 FY04 abnormal mechanical milestones predictions and analysis to quantify the failure mechanics of select machine screws used in the W80-3[2]. Screws were tested in loading orientations from straight tension (0°) to shear (90°), including 30°, 45°, and 60° orientations. The work reported here was conducted to address issues raised regarding the milestone experiments, as well as to increase the understanding of screw behavior through additional testing.

Experiments were performed that addressed some of the recommendations for further work which were outlined in [1]. Those experiments included:

- Fabrication and testing of new 45° test fixtures
- Development of a single-shear test
- Testing of #10 screws at 60° and 75° shear

Additional experiments were performed to evaluate fixture modifications and address issues of interest to the present investigators;

- Measure frictional load resulting from the angled screw fixture guide
- Compare electromechanical displacement transducers to optical sensors used in previous work
- Develop a single-shear test to compliment the angled shear geometries
- Investigate the affect of thread start orientation on single-shear behavior

Because significant effort had been expended during previous work, this work focused on investigating the areas listed above using two screw materials and two test displacement rates. The screws were A286 and 302HQ, #10-32 socket-head cap, manufactured by B&B Specialties. Background on screws manufactured by B&B Specialties is contained in Appendix A of SAND2005-6036 [1]. Displacement rates were 0.001 in/s and 10 in/s. Screws were tested having orientations with respect to the primary loading axis of 0° (tension), 45°, 60°, 75° and 90° (single shear).

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2. Experimental Apparatus and Procedures

2.1. Test Frames

Tension and angled screw tests conducted under a constant displacement rate of .001 in/s were performed on an MTS 880 servo-hydraulic test frame. Force was measured using a 20 kip load cell, model 380.25, which is integral to the cross head of the frame.

Tests conducted at a displacement rate of 10 in/s were performed on a high-rate MTS servo-hydraulic test frame having a static load capacity of 20 kip ($20x10^3$ pounds). Force was measured using a Kistler quartz load washer, model 9061, calibrated for a 4000 lbf range.

A 100 kip capacity MTS servo-hydraulic load frame was used for single shear tests under constant displacement rate of .001 in/s. Force was measured using a MTS load cell, model 662.10A-09, with a calibrated range of 10 kip. These tests could have been performed on the MTS 880, but scheduling made use of the 100 kip frame the logical choice.

Fixture displacements were measured with several devices. The optical sensors used in the milestone work, MTI-2000 Fotonic made by MTI Instruments, were compared to differential reluctance transducers (DVRT's), made by Microstrain Inc. The DVRT's were used for all subsequent tests from 0° to 75° orientations. A laser extensometer, EIR model LE-01, and the DVRT were used for the single-shear tests at .001 in/s and 10 in/s displacement rate, respectively.

The measurement precision of this work was established by load and displacement transducers calibrated in accordance with industry standards using measurement values traceable to the National Institute of Standards and Technology (NIST). Load measurements for tests run at displacement rates of .001 in/s were taken directly from MTS load cells calibrated in accordance with ASTM E4-03. Typical error recorded at the time of calibration is less than 0.25% of reading, with an uncertainty of ±0.25% for a confidence level of 95%. The force washer used for tests run at displacement rates of 10 in/s was calibrated at the time of use in accordance with ASTM E4-03 by comparing the force washer and charge amplifier system output to a calibrated MTS 20 kip load cell. The DVRT displacement sensors were calibrated at time of use by comparing the DVRT and signal conditioner system output to a displacement standard calibrated by Lockheed Martin Calibration Services in accordance with ANSI/NCSL Z540-1-1994. The EIR laser extensometer was calibrated at time of use by comparing the unit output to a LVDT integral to the load frame and calibrated in accordance with MTS Procedure FS-CA 2104 Rev. E. Calibration constants were determined from time of use calibration data by curve fitting. Standard deviation of the difference between the recorded data and the calibration curve fit varied with the individual sensor system and order of fit, but in all cases was less than 1% of full scale.

2.2. Tension Fixture

Tension test fixtures are shown in Figure 2.1. These are the same fixtures as used in the milestone work, and drawings can be found in [1]. The gage length for a tension test is defined by the distance between the bottom of the screw head and the first thread engaged in the thread mount. For this work, the gage length was .200 in, which was maintained by placing a spacer between the head mount and the thread mount. The .200 in gage length was determined by the angled shear fixture development that occurred during the milestone work [1].

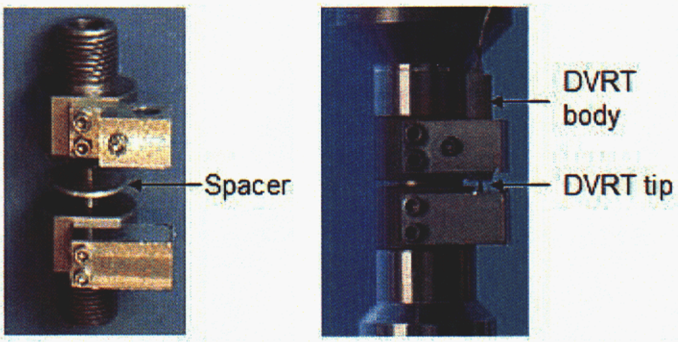


Figure 2.1 Tension (0°) test fixtures with spacer to set gage length at .200 in.

2.3. Angled shear fixtures

The angled shear fixtures used for this work were developed during the milestone effort. An angled shear fixture is shown in Figure 2.2, and drawings can be found in [1]. The only significant difference between the 45°, 60°, and 75° fixtures was the orientation of the screw and mating face of the two halves. The gage length was maintained at .200 in for all angles. One of the questions raised concerning this fixture design regarded how much friction force was generated between the guide and the moving half of the fixture. To measure the force due to friction, the guide design was modified to carry three load sensors distributed around the circumference of the guide.

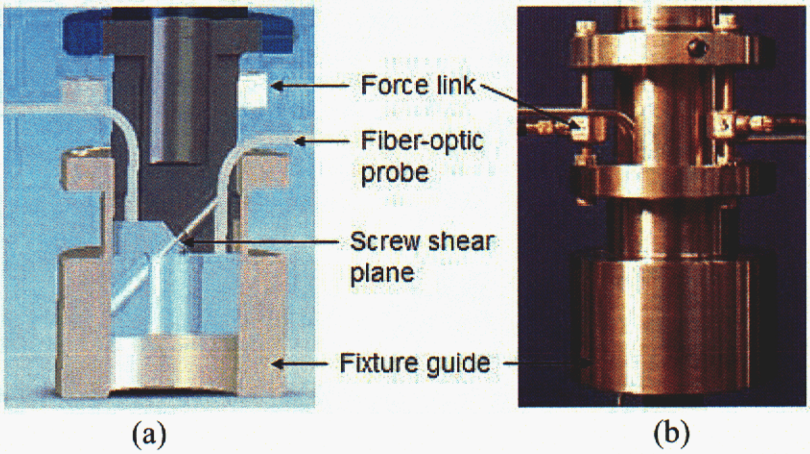
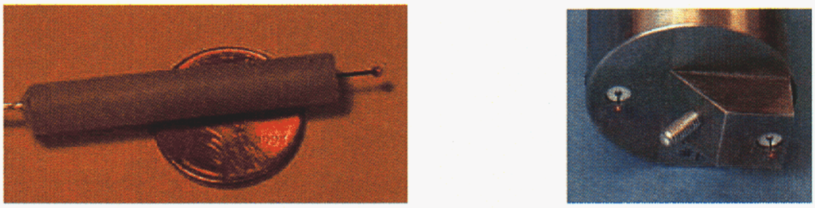


Figure 2.2 Angled shear fixture. (a) Solid model and (b) assembled with force links to measure frictional force from guide.

Linear DVRT's were used to check the displacement measurements obtained from the optical displacement sensors previously employed. Some of the data from the optical sensors suggested that the two halves of the fixture could rotate slightly during the test. The rotation was not considered to be a problem in terms of screw behavior, but the displacement measurement could have been affected since the sensor response can change if the angle between the probe and reflecting surface varies from the angle used at the time of calibration. The DVRT's are much less sensitive to changes in angle between the fixture halves because they have a very small diameter spherical tip that contacts the moving half of the fixture. The DVRT's were placed in the same bores designed for the optical sensors, as shown in Figure 2.3.



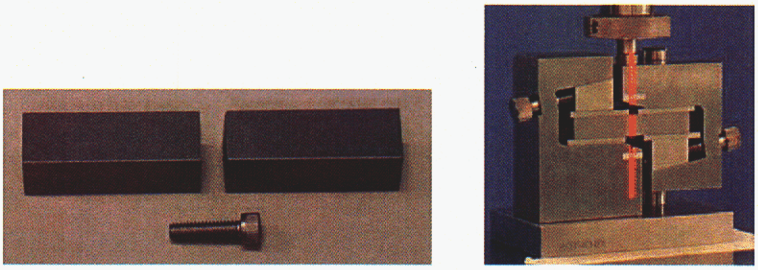
(a) (b)

Figure 2.3 Placement of DVRT's in an angled shear fixture. (a) DVRT, (b) spherical tips extending from bore in the fixture.

2.4. Single shear fixture

The double-shear tests used in the milestone work had several features that were inconsistent with the angled shear tests. The gage length was defined between two shear planes, and was not maintained at .200 in. The screw was not threaded into a mating half of the fixture, which in some cases allowed more bending to take place than would have if the restraint of a threaded section were present. The lack of threads in the double-shear fixture also meant that the rotational orientation of the screw was not constant relative to the loading axis. Some of the double-shear test data contained scatter which suggested that the rotational orientation could affect the result. A single-shear test was developed to address these points.

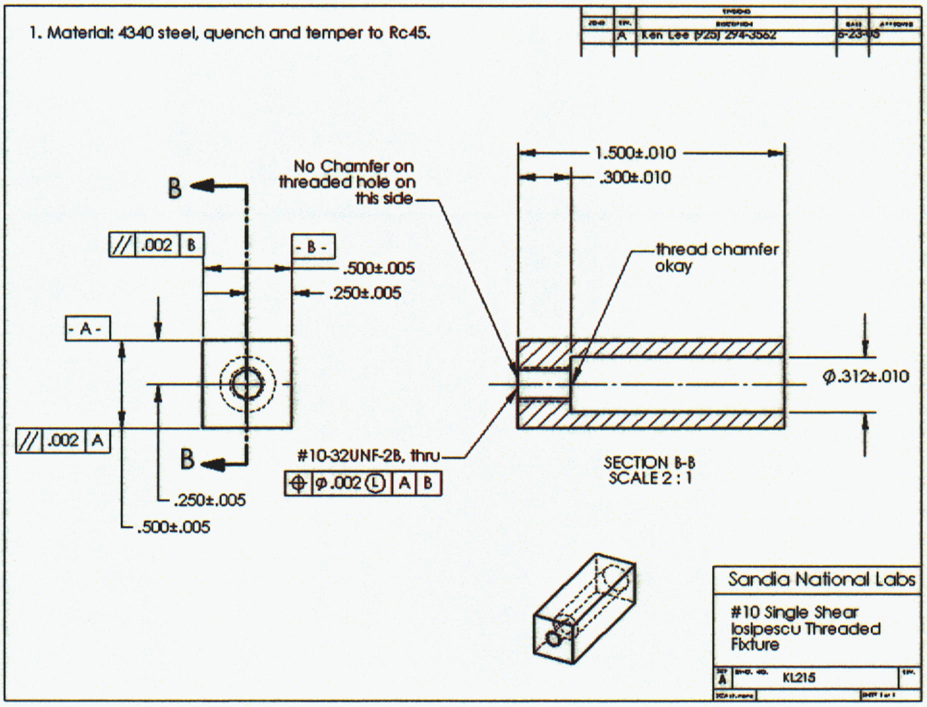
Fixtures for the single shear test are shown in Figure 2.4. A commercial fixture, the Modified Wyoming shear fixture [3, 4] which is a variation of that developed by Iosipescu [5], was used to grip two blocks joined by a test screw. One of the blocks contained a threaded hole and the other was drilled with a counter bore to provide a .200 in gage section, as shown in Figure 2.5. Displacement between the right- and left-hand sides of the fixture introduced shear in the screw joining the two blocks. Displacement was measured with a laser extensometer at the .001 in/s rate, and with a DVRT at the 10 in/s rate.



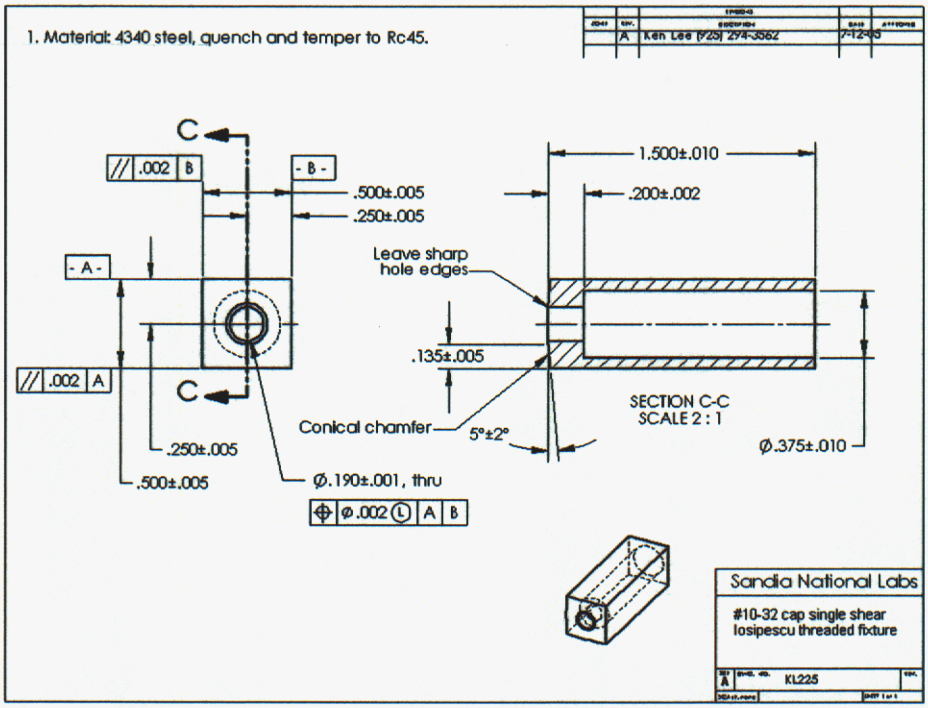
(a) (b)

Figure 2.4 Single shear screw fixture. The test screw joins two blocks (a) which are gripped in a shear fixture (b). The red line in (b) is from the laser extensometer used to measure displacement between the two halves of the fixture.

Rotation of the threaded block about the screw axis allowed the affect of thread start orientation on single-shear behavior to be measured. Because screw failure is localized near the surface of threaded holes, it is reasonable to expect that the local geometry plays a role, particularly when a strong shear component is present. In the context of a metal cutting operation, the threaded block acts like the knife of a metal shear, while the drilled block provides the reaction force. Rotation of the block results in a different knife geometry and, consequently, the contact geometry of the screw is different. This type of study was not possible with the angled shear fixtures because the thread start orientation was fixed (at random) by the tap used to thread the hole.



(a)



(b)

Figure 2.5 Drawing of single-shear blocks showing the threaded half (a) and counter bore half (b).

2.5. Screws from different manufacturing lots

All screws used in this study were manufactured by B&B Specialties. The A286 and 302HQ screws tested at 0.001 in/s stroke speed were from lot 76403 and 74409, respectively. The A286 and 302HQ screws tested at 10 in/s were from lot 78681 and 7044, respectively. Testing showed little variation in behavior between the lots. Results of the lot-to-lot comparisons are shown in Appendix A. Certification for screws used in this study can be found in Appendix B.

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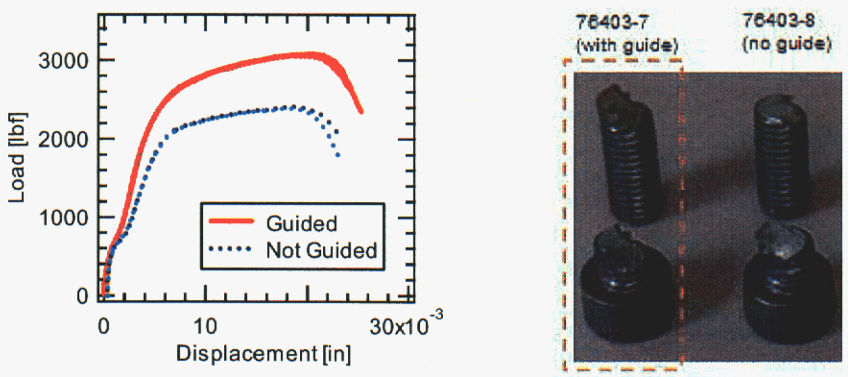
3. Results

3.1. Angled shear fixtures: friction force

The two halves of the angled shear fixtures were guided by a sleeve in order to maintain the intended screw orientation and provide defined boundary conditions for modeling the tests. Effects of the guide on measured load, displacement, and fracture surface morphology are shown in Figure 3.1. Clearly, the guide had a strong effect on the test results. The question, then, regards the origin of those effects. Friction between the guide and the fixture may have accounted for the increased force. Consequently, the frictional force was measured for 60° and 75° angled shear tests of 302HQ by joining the guide to the upper half of the fixture with three small load cells (Figure 2.2). As shown in Figure 3.2, the frictional force was insignificant. The difference in fracture surface orientation between screws tested with the guide and those tested without the guide indicates that different failure modes operate with and without the guide. This agrees with arguments presented in the milestone report [1].



(a) (b)

Figure 3.1 (a) Load displacement data for #10-32 A286 screws tested at 45° with (red) and without (blue) the fixture guide. Stroke speed was 0.0001 in/s and the screws were preloaded up to 40 in-lb (b). The failure mode of the screws tested at 45° changes from slanted fracture surfaces with the guide, to nearly flat fracture surfaces without the guide.

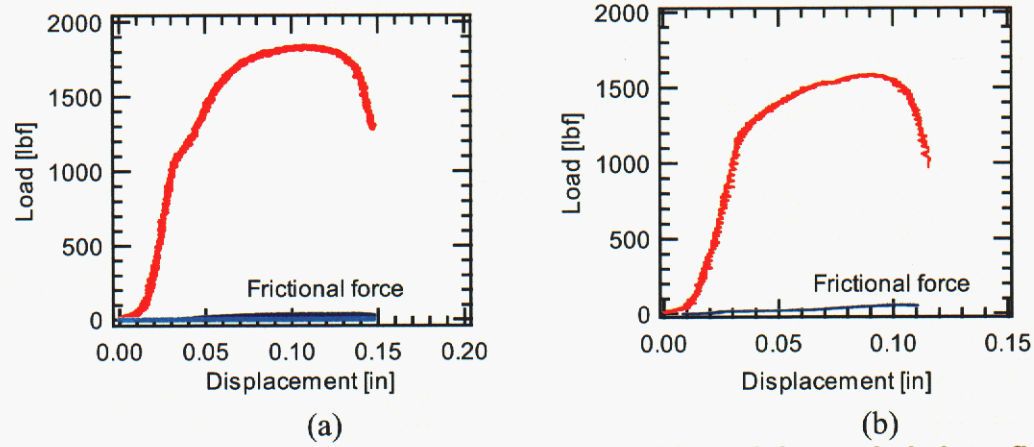


Figure 3.2 **Force due to friction between the guide and the angled shear fixtures was measured using the force links shown in Figure 2.2. (a) 60o shear, (b) 75o shear.**

3.2. Angled shear fixtures: displacement measurement

Comparison between displacement measurements using optical sensors and DVRT's are shown in Figure 3.3. Although the difference was insignificant, the DVRT's were used for the remainder of this work. The displacement data shown in Figure 3.3 are the average values of the two displacement sensors, which are located opposite each other, 1.00 in from the fixture center. A look at the individual signals, shown in Figure 3.4, indicates some rotation between the two halves of the fixture can occur during a test, since the two displacement traces are not the same. However, using the difference in measured displacement and the 1.00 in offset from center, the angle of rotation was calculated to be less than 0.5° at 75° shear.

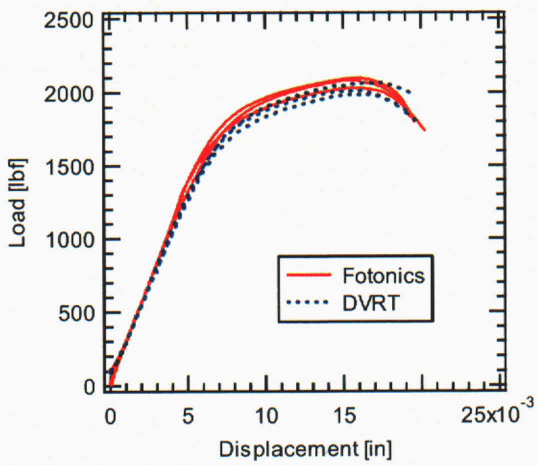


Figure 3.3 **Load and displacement data of 75o shear test collected using optical displacement sensors and DVRT's. The displacement is the average of the two sensor measurements. No significant differences between the averaged measurements were observed based on the type of displacement sensor.**

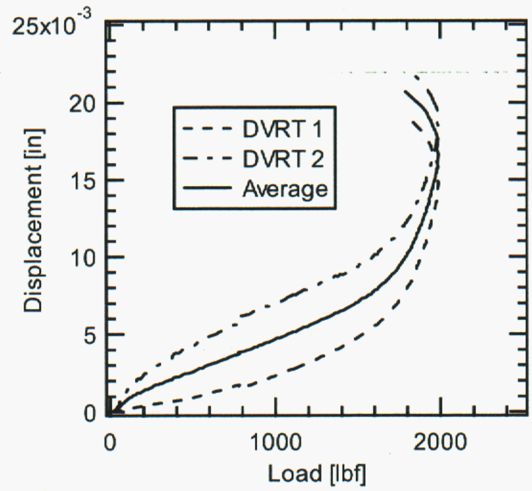


Figure 3.4 Differences in displacement measurements made by the individual DVRT's (see Figure 2.3). Similar differences were measured with the optical sensors. The screw was from lot 76403 and tested at 75o shear.

3.3. Single shear: thread start orientation

Test results showing the effect of rotating the threaded block of the single-shear fixture are shown in Figure 3.5. Each 90° rotation of the block resulted in a different contact geometry between the screw and the first thread in the block as shown in Figure 3.7, and a different load-displacement response. Thread start was defined as the location at the surface of a tapped hole where the thread crown of the screw intersects the surface. The A286 screws were less sensitive to thread start orientation than the 302HQ screws.

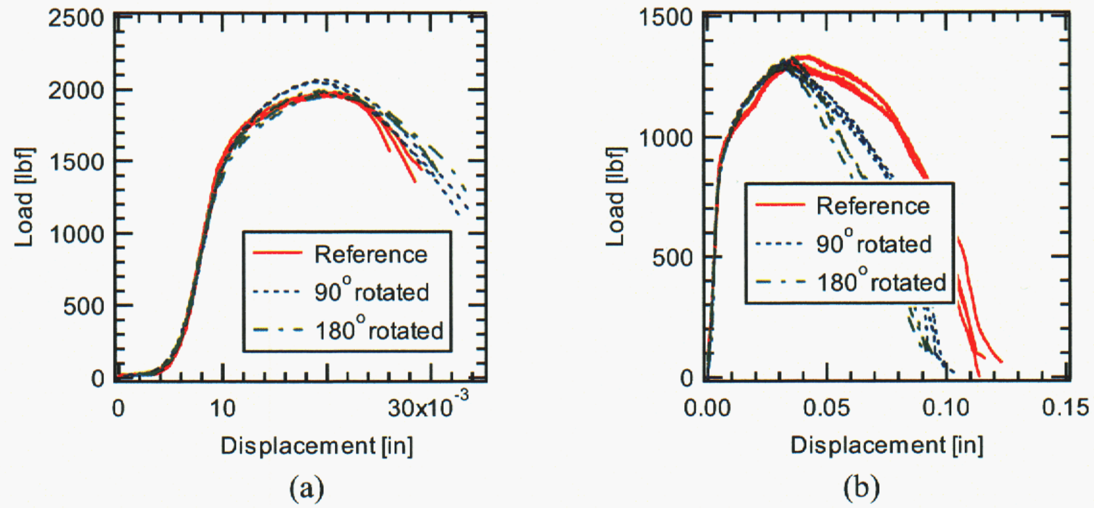


Figure 3.5 Force-displacement curves from single shear tests of (a) A286 (size 10, lot 78681) and (b) 302HQ screws (size 10, lot #7044). Assembly of screw and adapter was rotated to change shear plane.

The thread start location of angled and single shear fixtures is shown in Figure 3.6. Because the reference orientation of the single shear fixture has similar location of thread initiation, results from the reference orientation are compared with angle shear test results. Figure 3.7 depicts shear failure planes of 302HQ size #10 screws at different orientations. Tests were stopped before complete failure of the screws and the threaded adapter was removed before taking photos. It is shown in Figure 3.7 that failure initiation positions vary from thread root to thread crown under different orientation.

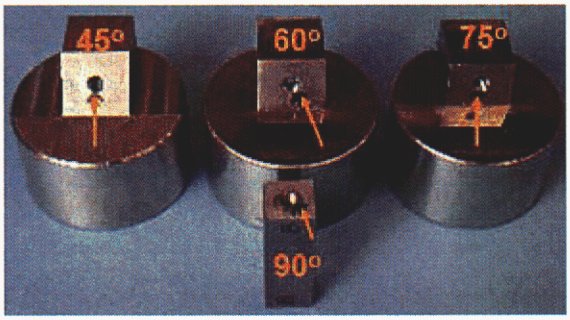


Figure 3.6 The thread start location of angled and single shear fixture for size #10 screws.

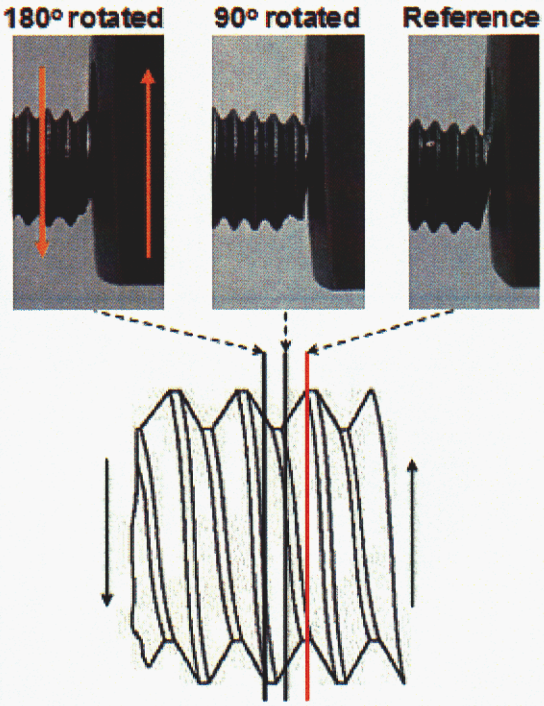


Figure 3.7 Change of shear failure planes by rotation of threaded block. The screws are 302HQ size #10 from lot 7044. Images are representative of replicate tests.

3.4. A286 screws under various loading conditions

Force-displacement curves of A286 screws (size #10, lot #76403) tested at .001 in/s under various loading angles are compared in Figure 3.8. Note that the displacement to failure (DTF), measured either as maximum load or maximum displacement, was larger for the 60° shear tests than for both the 75° shear and 90° shear tests. The milestone work [1] reported a minimum in DTF values for 60° shear. However, the milestone work employed a double shear geometry, and did not test screws at 75°.

Force-displacement curves of A286 screws (size #10, lot #78681) tested at 10 in/s rate under various loading angles are shown in Figure 3.9. There is no minimum in DTF at the 60° shear angle. All DTF values at 10 in/s are smaller than the DTF values for corresponding angles tested at 0.001 in/s. Figure 3.10 shows the rate effect on force-displacement data for each load angle.

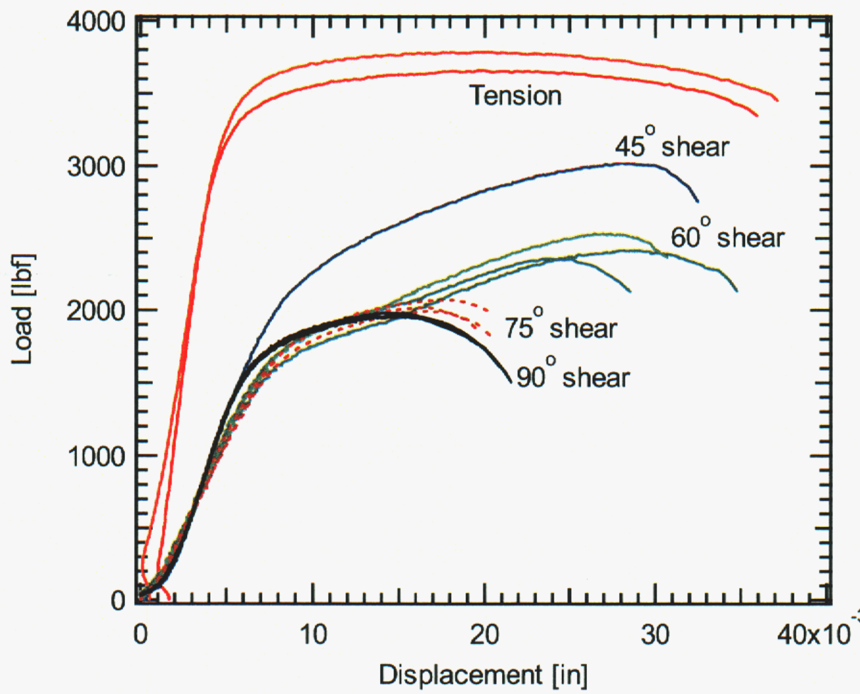


Figure 3.8 Comparison of force-displacement curves from various loading conditions for A286 (#10-32, lot #76403) screws. Stroke speed 0.001 in/sec.

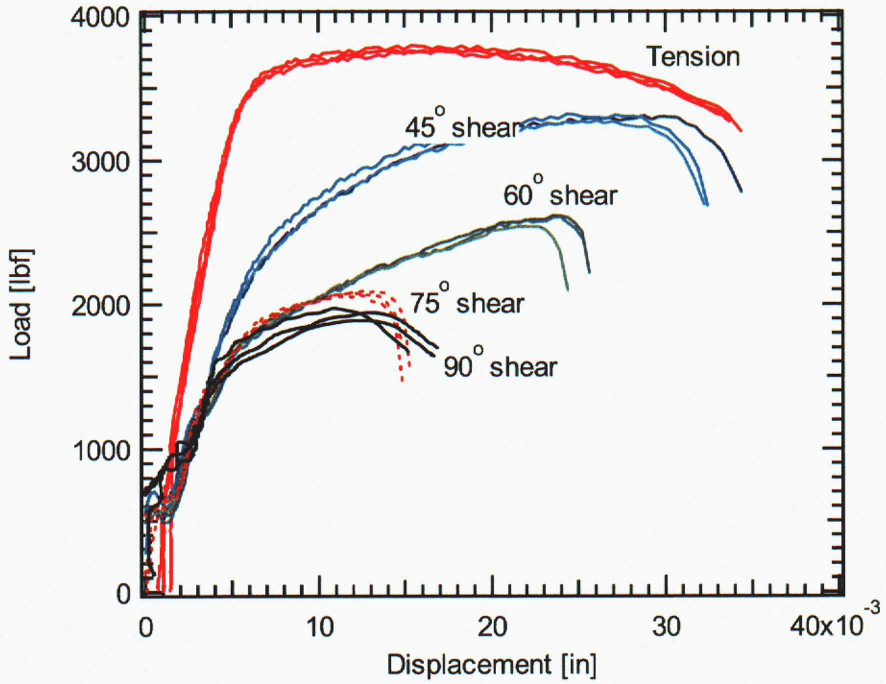
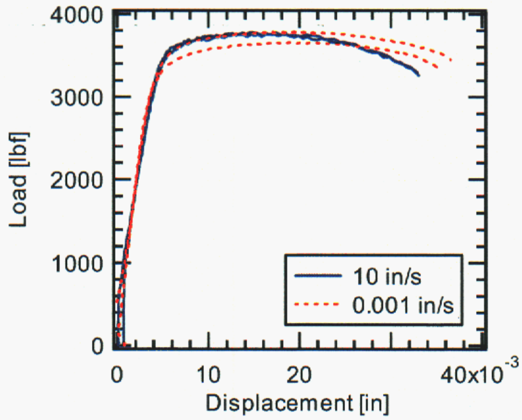
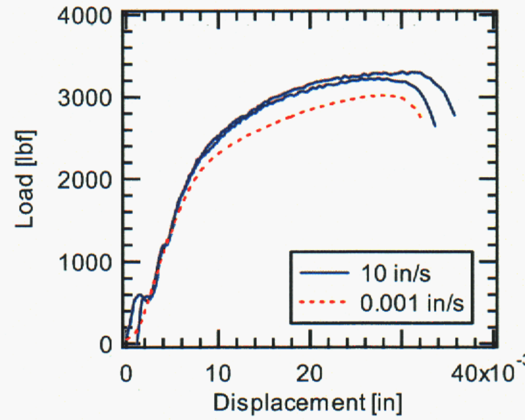


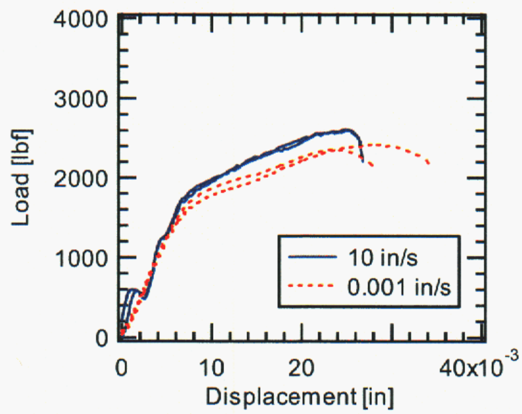
Figure 3.9 Comparison of force-displacement curves from various loading conditions for A286 (#10-32, lot #78681) screws. Stroke speed 10 in/sec.



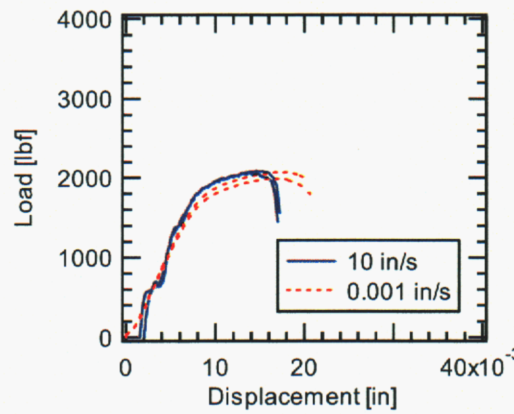
(a) Tension



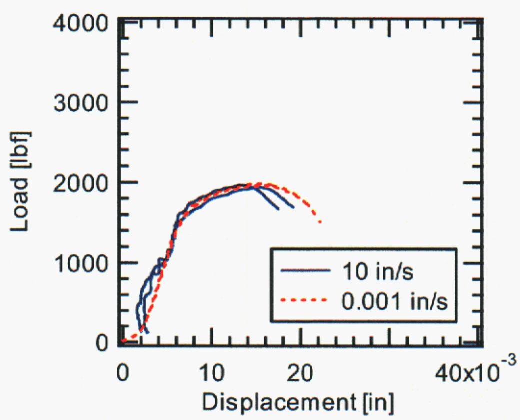
(b) 45° shear



(c) 60° shear



(d) 75° shear



(e) 90° shear

Figure 3.10 Comparison of force-displacement curves at different stroke speeds 0.001 and 10 in/sec for A286, #10-32 screws. Plots for 0.001 and 10 in/sec are from Figures 3.8 and 3.9, respectively.

3.5. 302HQ screws under various loading conditions

Force-displacement curves for 302HQ (size #10, lot #74409) screws tested at .001 in/s under various loading angles are shown in Figure 3.11. In contrast to the A286 tests in Figure 3.8, there is no monotonic trend in DTF with load angle.

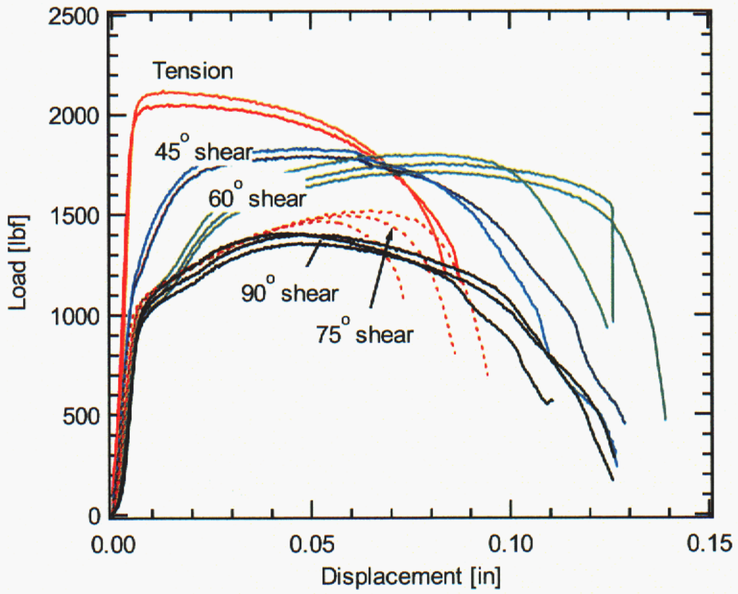


Figure 3.11 Comparison of force-displacement curves from various loading conditions for 302HQ (#10-32, lot #74409) screws. Stroke speed 0.001 in/sec.

Force-displacement curves of 302HQ screws (size #10, lot #7044) tested at 10 in/s rate are under various loading angles are compared in Figure 3.12. All DTF values at 10 in/s are smaller than the DTF values for corresponding angles tested at 0.001 in/s. Figure 3.13 shows the rate effect on force-displacement data for each load angle.

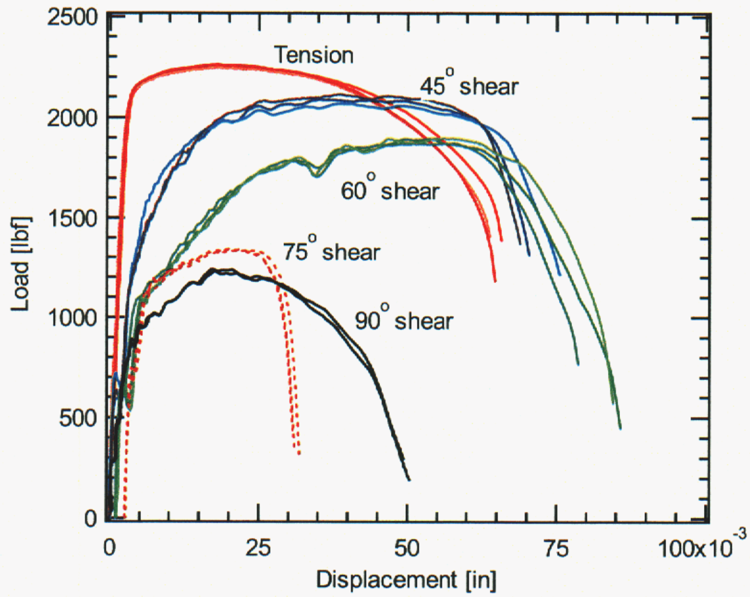


Figure 3.12 Comparison of force-displacement curves from various loading conditions for 302HQ (#10-32, lot #7044) screws. Stroke speed 10 in/sec.

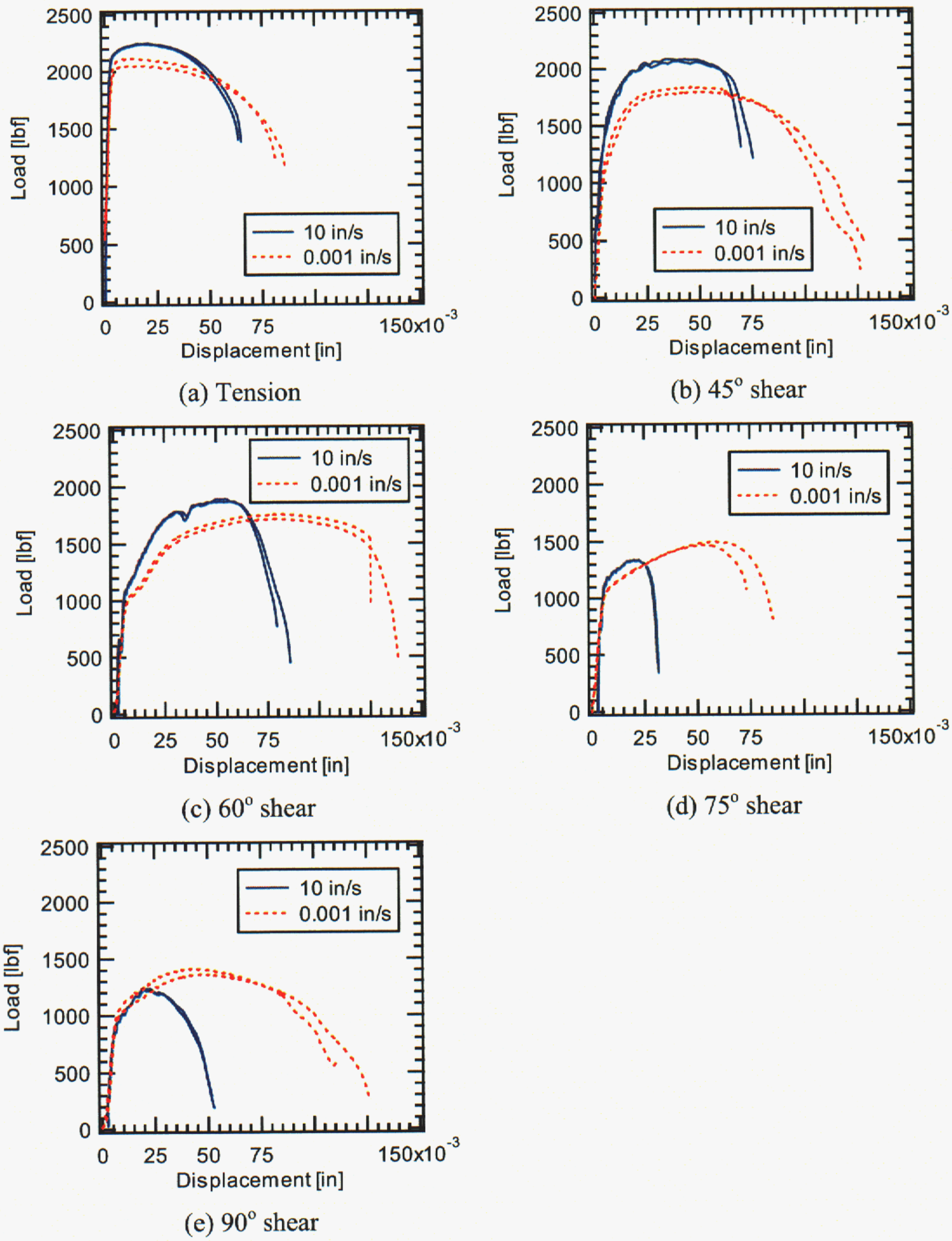


Figure 3.13 Comparison of force-displacement curves at different stroke speeds 0.001 and 10 in/sec for 302HQ, #10-32 screws. Plots for 0.001 and 10 in/sec are from Figures 3.11 and 3.12, respectively.

4. Summary and Conclusions

- Tests of A286 and 302HQ #10-32 socket-head cap screws were completed at 0° (tension), 45°, 60°, 75°, and 90° (single shear).
- Friction force between the guide and moving half of the 60° and 75° angle shear fixtures was measured with three small load cells. The frictional force was insignificant compared with total force.
- A single shear test was developed that was consistent with the angled shear tests.
- The affect of thread start orientation on single-shear behavior was measured by rotating the threaded block about the screw axis. The A286 screws were less sensitive to thread start orientation than were the 302HQ screws. The single shear thread start orientation that was most similar to the orientation of the other fixtures was used for comparison to the angled shear data.
- The minimum in displacement to failure (DTF) reported in the milestone work for A286 #8-32 screws at 60° was not observed with A286 #10-32 screws using the new angled shear and single shear fixtures. The DTF values for 75° shear and for 90° single shear tests were less than the DTF for 60°.
- The effect of displacement rate on DTF became larger as shear angle increased for both A286 and 302HQ screws.
- Displacement rate effects were larger for 302HQ screws than for A286 screws.

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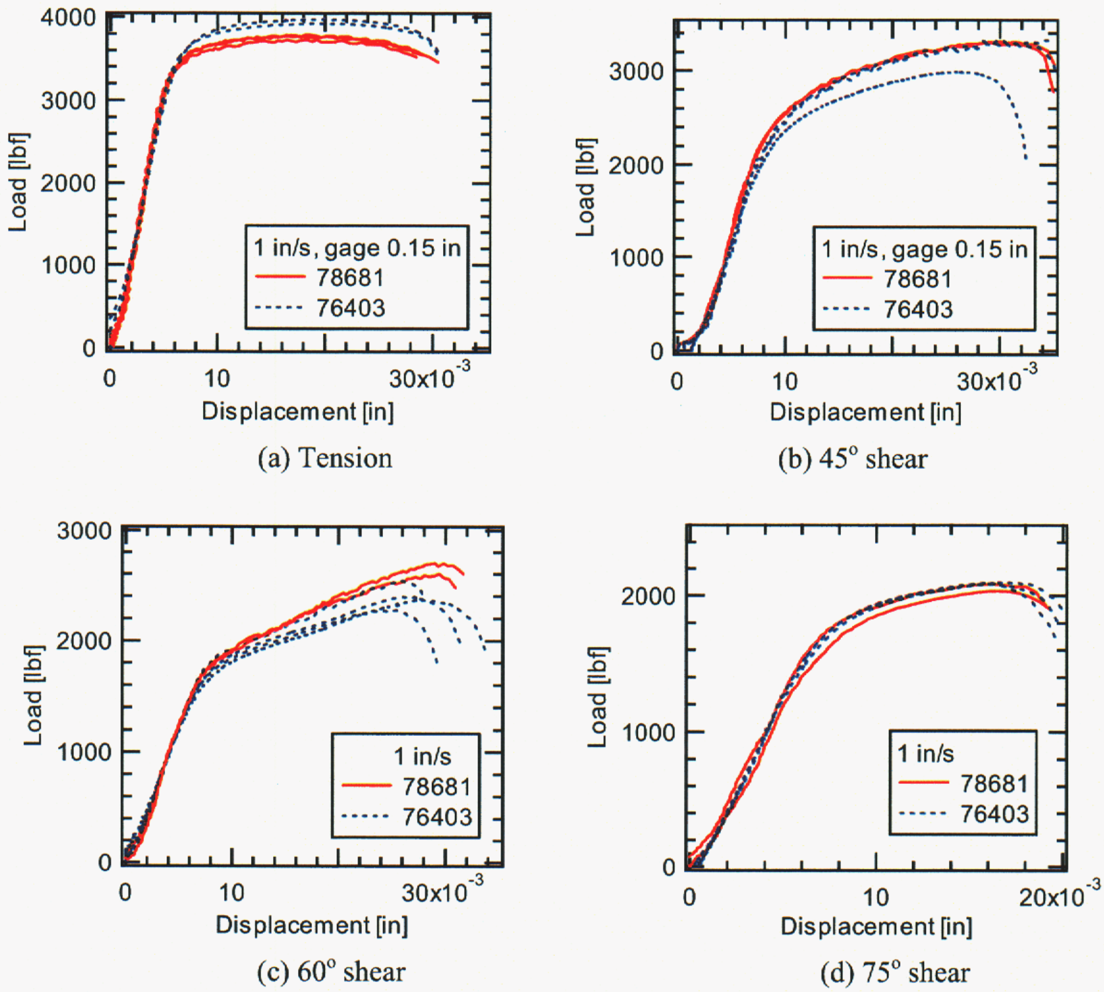
Appendix A

A.1 Lot-to-lot comparison of A286 #10-32 screws



(a) Tension

(b) 45° shear

(c) 60° shear

(d) 75° shear

Figure A.1 Comparison of A286 screws from lot 76403 with lot 78681 under various loading conditions. (a) Tension, (b) 45o shear, (c) 60o shear, (d) 75o shear.

A.2 Lot-to-lot comparison of 302HQ #10-32 screws

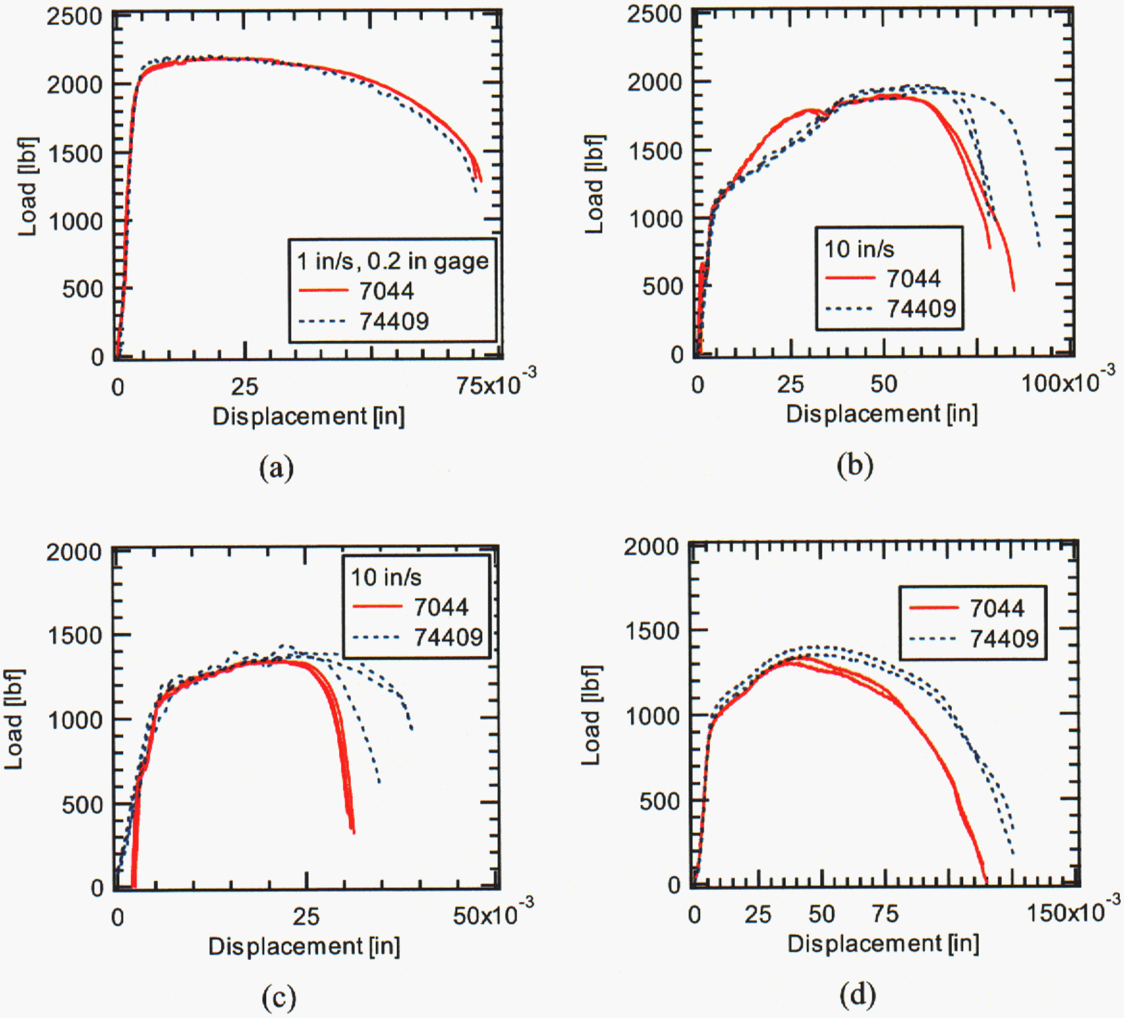


Figure A.2 Comparison of 302HQ screws from lot 74409 with lot 7044 under various loading conditions. (a) Tension, (b) 60o shear, (c) 75o shear, (d) 90o shear.

Appendix B

B.1 Certified test report for A286 screws, lot number 76403

B&B SPECIALTIES 4321 E. La Palma Ave. Anaheim, CA 92807	**CERTIFIED TEST REPORT**	Test Report Serial No: **52217** Test Report Date: 7/21/2003 CAGE CODE: **62206**

NOR-CAL SUPPLY CO. 40 DOOLITTLE DRIVE SAN LEANDRO, CA 94577	PO Number: 27374 Customer Part No NAS1351N3-10 REV. 9 Cross Ref:	MFG Number: **76403** Packing Slip No: 24402-1

B&B Part Number:	A2SHC10320625	Lot Quantity:	53815
Head Description:	SOCKET HEAD CAP	Length:	.625
Finish:	PASSIVATE AMS-QQ-P-35	Thread Form:	10-32 UNF -3A

QTY Shipped: 50

Material	A286	Specs:	AMS 5731, AMS 5732, AMS 5734, AMS 5737	Heat Treat:	FF-S-86
RM Heat No:	PY777	Supplier:	TECHALLOY COMPANY		

C:	MN:	P:	S:	SI:	CR:	NI:	CU:	MO:	FE:	CO:	V:	AL:	TI:	B:	H:	O:	Y:	N:	ZN:
.039	1.72	.01	.001	.182	14.80	24.49	.057	1.25		.135	.28	.16	2.06	.006					

Evaluation Performed	Specification	Results	Tech	Rejects/Sample	Test Method	Spec Value	Test Value
Dimensional Evaluation	ASME B 18.3	Accept	11	0/40			
Fastener Evaluation	Not Required	N/A	11				
Hardness	FF-S-86	Accept	17	0/13	QP1004	33 - 42 HRC	36 - 38 HRC
Axial Tensile	FF-S-86	Accept	14THD	0/13	QP-1006	160,000 MIN.	179,800/184,850
Stress Durability	Not Required	N/A	11				
Magnetic Permeability	Not Required	N/A	11				

Key Characteristic	Specification	Test Value	Rejects / Sample	Results	Inspector:	Sample Spec:
Socket Go/NoGo - Depth	ASME B 18.3	.097/.098	0/40	Accept	11	QP-1001
Head Diameter (A)	ASME B 18.3	.305/.311	0/40	Accept		
Head Height (H)	ASME B 18.3	.187/.189	0/40	Accept		
O/A Length (L)	ASME B 18.3	.598/.604	0/40	Accept		
Threads	ASME B 1.1	VISUAL	0/40	Accept		
Thread Functional	ASME B 1.1	.1688/.1692	0/40	Accept		
Thread Pitch	ASME B 1.1	.1684/.1688	0/40	Accept		
Thread Major	ASME B 1.1	.1875/.1890	0/40	Accept		

Test Type: Hardness — Spec Value: 33 - 42 HRC — Min / Max: 36 - 38 HRC
Spec: FF-S-86 — Sample Siz: 0/13 — Technician: 17

Sample	1:	2:	3:	4:	5:	6:	7:	8:	9:	10:	11:	12:	13:
Actual	68HRA	68HRA	68HRA	69HRA	69HRA	68HRA	69HRA	69HRA	69HRA	69HRA	69HRA	69HRA	69HRA
Conv	36HRC	36HRC	37HRC	37HRC	38HRC	36HRC	38HRC	37HRC	38HRC	37HRC	38HRC	38HRC	37HRC

Test Type: Axial Tensile — Spec Value LBS: 3,200 MIN. — Sample Size: 0/13 — Min / Max PSI: 179,800/184,850
TestSpec: FF-S-86 — Spec Value PSI: 160,000 MIN. — Technician: 14THD — Min / Max LBS: 3,596/3,697

Sample	1:	2:	3:	4:	5:	6:	7:	8:	9:	10:	11:	12:	13:
Force	3,663	3,695	3,596	3,601	3,665	3,635	3,697	3,647	3,656	3,643	3,640	3,626	3,627
Tensile	183150	184750	179800	180050	183250	181750	184850	182350	182800	182150	182000	181300	181350

Process Performed	Specification	Laboratory or Supplier	Rejects / Sample	Results
Heat Treat	FF-S-86	MILSPEC HEAT TREATING, INC.	N/A	Accept
Pentrant	FF-S-86	QUALITY CONTROL PLATING	0/500	Accept
Salt Spray Test	AMS-QQ-P-35	QUALITY CONTROL PLATING	0/50	Accept

B&B Specialties certifies that the product samples tested above conform to the latest referenced specifications listed and the original data is available for review with sufficient notice. This Certified Test Report can not be reproduced except in full. This Certified Test Report only relates to the samples of the above lot tested. The estimated uncertainty of scale measurement is +/- 3%. Our fasteners of size 1 in. and smaller are manufactured with UNR threads, whether UNR is specified or not. The product listed above is free of mercury to the best of our knowledge.

Revision:

Richard L. Smernoff
Vice President Quality

PRI Lic. No 0063 for ISO/IEC 17025, PRI Lic No 02-0331 for ISO 9001:2000 and AS9100 — Page 1 of 1 — Revised 0109-0

B.2 Certified test report for A286 screws, lot number 78681

B&B SPECIALTIES
4321 E. La Palma Ave.
Anaheim, CA 92807

CERTIFIED TEST REPORT

Test Report Serial No:	66580
Test Report Date:	2/4/2005
CAGE CODE:	62206

NOR-CAL SUPPLY CO.
840 DOOLITTLE DRIVE
SAN LEANDRO, CA 94577

PO Number:	29171
Customer Part No	NAS1351N3-10 REV. 9
Cross Ref:	
MFG Number:	78681
Packing Slip No:	37087

B&B Part Number:	A2SHC10320625	Lot Quantity:	52860
Head Description:	SOCKET HEAD CAP	Length:	.625
Finish:	PASSIVATE AMS-QQ-P-35	Thread Form:	10-32 UNRF -3A

QTY Shipped: 1000

Material A286 Specs: AMS 5731, AMS 5732, AMS 5734, AMS 5737 Heat Treat: FF-S-86
RM Heat No: 543285 Supplier: CARPENTER TECHNOLOGY PRI/NADCAP 100004

C:	MN:	P:	S:	SI:	CR:	NI:	CU:	MO:	FE:	CO:	V:	AL:	TI:	B:	H:	O:	Y:	N:	ZN:
.05	.21	.014	<.000	.19	13.94	24.24	.09	1.21		.10	.28	.16	2.18	.007					

Evaluation Performed	Specification	Results	Tech	Rejects/Sample	Test Method	Spec Value	Test Value
Dimensional Evaluation	ASME B 18.3	Accept	11	0/40			
Fastener Evaluation	Not Required	N/A	11				
Hardness	FF-S-86	Accept	21	0/13	QP1004	33/42 HRC	36/37 HRC
Axial Tensile	NAS1351	Accept	14THD.	0/13	QP-1006	160,000 MIN.	170,300/171,800
Stress Durability	Not Required	N/A	11				72 Hrs Min
Magnetic Permeability	Not Required	N/A	11				

Key Characteristic	Specification	Test Value	Rejects / Sample	Results	Inspector:	Sample Spec:
Socket Go/NoGo - Depth	ASME B 18.3	.097/.099	0/40	Accept	11	QP-1001
Head Diameter (A)	ASME B 18.3	.309/.312	0/40	Accept		
Head Height (H)	ASME B 18.3	.186/.188	0/40	Accept		
O/A Length (L)	ASME B 18.3	.602/.610	0/40	Accept		
Threads	ASME B 1.1	VISUAL-	0/40	Accept		
Thread Functional	ASME B 1.1	.1682/.1688	0/40	Accept		
Thread Pitch	ASME B 1.1	.1680/.1687	0/40	Accept		
Thread Major	ASME B 1.1	.1842/.1878	0/40	Accept		

Test Type Hardness Spec Value: 33/42 HRC Min / Max: 36/37 HRC
Spec: FF-S-86 Sample Size 0/13 Technician: 21

Sample	1:	2:	3:	4:	5:	6:	7:	8:	9:	10:	11:	12:	13:
Actual	68HRA	68HRA	68HRA	68HRA	68HRA	68HRA	68HRA	69HRA	68HRA	68HRA	68HRA	68HRA	68HRA
Conv	36HRC	36HRC	36HRC	37HRC	36HRC	36HRC	36HRC	37HRC	36HRC	37HRC	36HRC	36HRC	36HRC

Test Type Axial Tensile Spec Value LBS: 3,200 MIN. Sample Size: 0/13 Min / Max PSI: 170,300/171,800
TestSpec: NAS1351 Spec Value PSI: 160,000 MIN. Technician: 14THD. Min / Max LBS: 3,406/3,436

Sample	1:	2:	3:	4:	5:	6:	7:	8:	9:	10:	11:	12:	13:
Force	3,414	3,406	3,417	3,424	3,431	3,420	3,436	3,425	3,428	3,415	3,407	3,425	3,418
Tensile	170700	170300	170850	171200	171550	171000	171800	171250	171400	170750	170350	171250	170900

Process Performed	Specification	Laboratory or Supplier	Rejects / Sample	Results
Heat Treat	FF-S-86	BURBANK STEEL TREATING, INC.	N/A	Accept
Pentrant	FF-S-86	STORK (MMA) MATERIALS TESTING & INSPECTION	0/500	Accept
Salt Spray Test	AMS-QQ-P-35	STORK (MMA) MATERIALS TESTING & INSPECTION	0/50	Accept

B&B Specialties certifies that the product samples tested above conform to the latest referenced specifications listed and the original data is available for review with sufficient notice. This Certified Test Report can not be reproduced except in full. This Certified Test Report only relates to the samples of the above lot tested. The estimated uncertainty of scale measurement is +/- 3%. The product listed above is free of mercury to the best of our knowledge.

Revision:

Carpenter Technology has their own melting mill - therefore, parts were melted & manufactured in the USA.

Richard L. Smernoff
Vice President Quality

PRI Lic. No 0063 for ISO/IEC 17025, PRI Lic No 02-0331 for ISO 9001:2000 and AS9100 Page 1 of 1 Revised 0109-03

B.3 Certified test report for 302HQ screws, lot number 74409

B&B SPECIALTIES
4321 E. La Palma Ave.
Anaheim, CA 92807

CERTIFIED TEST REPORT

Test Report Serial No: **43158**
Test Report Date: 6/11/2002
CAGE CODE: **62206**

SAMPLES

PO Number: SAMPLES
Customer Part No: MS16996-11 REV. F
Cross Ref:

MFG Number: **74409**
Packing Slip No: **15625**

B&B Part Number:	SSSHC10320625	Lot Quantity:	115005
Head Description:	SOCKET HEAD CAP	Length:	.625
Finish:	PASSIVATE AMS-QQ-P-35	Thread Form:	10-32 UNF -3A

QTY Shipped

Material 302 HQ   Spec: ASTM A493, UNS30430   Heat Treat: N/A
RM Heat No: 1P958   Supplier: TECHALLOY COMPANY

C:	MN:	P:	S:	SI:	CR:	NI:	CU:	MO:	FE:	CO:	V:	AL:	TI:	B:	H:	O:	Y:	N:
.017	.63	.028	.001	.32	17.62	9.63	3.53	.11										

Evaluation Performed	Specification	Results	Tech	Rejects/Sample	Test Method	Spec Value	Test Value
Dimensional Evaluation	ASME B 18.3	Accept	11	0/40			
Fastener Evaluation	Not Required	N/A	19		WI-500-17		
Hardness Test	FF-S-86	Accept	19	0/13	QP-1004	80 HRB MIN.	93/97 HRB
Axial Tensile	FF-S-86	Accept	19	0/13	QP-1006	80,000 MIN.	102,200/104,550
					QP-1006		
Stress Durability	Not Required	N/A	11		QP-1008		
Magnetic Permeability	MS16996	Accept	11	0/500	QP-1011		

Key Characteristic	Specification	Test Value	Rejects / Sample	Results	Inspector:	Sample Spec:
Socket Go/NoGo - Depth	ASME B 18.3	.100/.101	0/40	Accept	11	QP-1001
Head Diameter (A)	ASME B 18.3	.307/.311	0/40	Accept		
Head Height (H)	ASME B 18.3	.186/.189	0/40	Accept		
O/A Length (L)	ASME B 18.3	.606/.609	0/40	Accept		
Threads	ASME B 1.1	VISUAL	0/40	Accept		
Thread Functional	ASME B 1.1	.1686/.1689	0/40	Accept		
Thread Pitch	ASME B 1.1	.1683/.1686	0/40	Accept		
Thread Major	ASME B 1.1	.1870/.1890	0/40	Accept		

Test Type: **Hardness Test**   Spec Value: 80 HRB MIN.   Min / Max: 93/97 HRB
Spec: FF-S-86   Sample Size 0/13   Technician: 19

Sample	1:	2:	3:	4:	5:	6:	7:	8:	9:	10:	11:	12:	13:
Actual	57HRA	58HRA	58HRA	59HRA	59HRA	59HRA	59HRA	58HRA	59HRA	58HRA	59HRA	58HRA	59HRA
Conv	93HRB	95HRB	95HRB	96HRB	96HRB	97HRB	96HRB	95HRB	96HRB	95HRB	96HRB	95HRB	96HRB

Test Type: **Axial Tensile**   Spec Value LBS: 1,600 MIN.   Sample Size: 0/13   Min / Max PSI: 102,200/104,550
TestSpec: FF-S-86   Spec Value PSI: 80,000 MIN.   Technician: 19   Min / Max LBS: 2,044/2,091

Sample	1:	2:	3:	4:	5:	6:	7:	8:	9:	10:	11:	12:	13:
Force	2,056	2,091	2,064	2,065	2,083	2,044	2,054	2,091	2,072	2,066	2,081	2,065	2,091
Tensile	102800	104550	103200	103250	104150	102200	102700	104550	103600	103300	104050	103250	104550

Test Type: Spec Value LBS   Sample Size   Min / Max LBS:
Spec: Results   Spec Value PSI: Technician: Min / Max PSI:

Process Performed	Specification	Laboratory or Supplier	Rejects / Sample	Results
Pentrant	FF-S-86	QUALITY CONTROL PLATING	0/500	Accept
Salt Spray Test	AMS-QQ-P-35	QUALITY CONTROL PLATING	0/50	Accept

B&B Specialties certifies that the product samples tested above conform to the latest referenced specifications listed and the original data is available for review with sufficient notice. This Certified Test Report can not be reproduced except in full. This Certified Test Report only relates to the samples of the above lot tested. The estimated uncertainty of scale measurement is +/- 3%. Our fasteners of size 1 in. and smaller are manufactured with UNR threads, whether UNR is specified or not. The product listed above is free of mercury to the best of our knowledge.

Revision:

The product listed above is free of mercury to the best of our knowledge.

Richard L. Smernoff
Vice President Quality

PRI Lic. No 0063 for ISO/IEC 17025, PRI Lic No 02-0331 for ISO 9001:2000 and AS9100   Page 1 of 1   Revised 4-24

B.4 Certificate of compliance for 302HQ screws, lot number 7044

BISCO

BISCO INDUSTRIES
185 NEW BOSTON ST.
FROM: WOBURN, MA 01801
(781) 938-8590

CR. REL.	DATE	PACKING LIST NUMBER
	10/07/05	082885-02

SERVING YOU AT:
660 COMMERCE DRIVE
ROSEVILLE, CA 95678
(916) 773-1634

PACKING LIST NO. 082885-02 P/T 03:32 AM PST O/E 10/06/05 101305

SHIP TO: US NNSA % SANDIA NTL LABS
Ken Lee Bldg 972 RM114 MS9721
7011 EAST AVE PROCURE CD SNLLA
LIVERMORE, CA 94550

SOLD TO: SANDIA NAT'L LABS
PO BOX 969
7011 EAST AVE
LIVERMORE, CA 94550

	TERMS	F.O.B.	TAX %	AREA
L U	CREDIT CARD	SHP PT	0	A70

PURCHASE ORDER NUMBER	PURCHASE ORDER NUMBER	BUYER	SALESMAN
KEN LEE CR CARD	KEN LEE CR CARD	00 MR. KEN LEE	G44

ITEM NO.	QTY. ORDERED	PART NUMBER	CODE	PRC	LOT #	PRICE		QTY. SHIPPED	DUE DATE	BACK ORDERED	COMPONENT P/L
01	100	MS16996-11	SN	360	T081605R	.50	/E	100	100605	0	
		STD. C OF C			7044 SO ✓						
		STD. C OF C THANKS KEN!									
		STD. C OF C LINDA									
		CREDIT CARD ORDER..AUTHORIZED!!									
		SHIP: UPS Ground									

PACKING AND HANDLING FEES WILL BE ADDED TO YOUR ORDER. RATES VALID UP TO 40 POUNDS. ACTUAL FREIGHT CHARGES MAY BE HIGHER. AS ACTUAL FREIGHT CHARGES MAY VARY DUE TO SIZE, WEIGHT, OR DISTANCE. BISCO RESERVES THE RIGHT TO INCREASE SHIPMENT CHARGES.

#10-32UNF x 5/8"

NO. PKGS.	WEIGHT	HANDLING CHARGES	DATE SHIPPED	VIA	QTY. TOTALS	100	5000 / 600	B	A62469

PULLED	INSPECTED BY		UPDATED	
D	0.00% T	20	T	0

IMPORTANT NOTICE: THIS DOCUMENT IS SUBJECT TO LEGAL STIPULATIONS. SEE REVERSE SIDE.

[signature], DIRECTOR OF WAREHOUSING

CERTIFICATE OF COMPLIANCE
THESE MATERIALS AND/OR PARTS WERE PRODUCED IN CONFORMANCE WITH ALL CONTRACTUALLY APPLICABLE GOVERNMENT AND/OR COMMERCIAL SPECIFICATIONS. TEST REPORTS AND/OR CERTIFICATES ARE ON FILE SUBJECT TO EXAMINATION AND INDICATING CONFORMANCE WITH APPLICABLE GOVERNMENT SPECIFICATIONS AND REQUIREMENTS.
*MANUFACTURED BY COMPANY OTHER THAN THAT REFERENCED BY PART NUMBER.

PACKING SLIP

References

1. D. Dawson *et. al.*, *Deformation and failure behavior of attachment screws for the W80 WES housing*, SAND2005-6036, Sandia National Laboratories, Livermore, CA.
2. B. L. Kistler *et. al.*, *ASC VV-4.1 FY04 abnormal mechanical milestones predictions and analysis,* CA, SAND2005-0810, Sandia National Laboratories, Livermore, CA.
3. D. E. Walrath and D. F. Adams, "The Iosipescu shear test as applied to composite materials", *Exp. Mech.*, 23(1), 105-110 (1983).
4. D. F. Adams and D. E. Walrath, "Further development of the Iosipescu shear test method", *Exp. Mech.*, 27(2), 113-119 (1987).
5. N. Iosipescu, "New accurate procedure for single shear testing of metals", *J. Mater.*, 2(3), 537-566 (1967).

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Distribution list

1	MS 0370	T. G. Trucano, 01411
1	MS 0372	J. T. Ostien, 01524
1	MS 0372	J. D. Gruda, 01524
1	MS 0372	K. W. Gwinn, 01524
1	MS 0372	C. S. Lo, 01524
1	MS 0372	J. Pott, 01524
1	MS 0372	J. Jung, 01525
1	MS 0380	K. F. Alvin, 01542
1	MS 0380	A. S. Gullerud, 01542
1	MS 0380	M. W. Heinstein, 01542
1	MS 0380	J. R. Koteras, 01542
1	MS 0380	K. H. Pierson, 01542
1	MS 0380	G. M. Reese, 01542
1	MS 0382	J. R. Stewart, 01543
1	MS 0384	A. C. Ratzel, 01500
1	MS 0384	H. S. Morgan, 01540
1	MS 0555	R. A. May, 1522
1	MS 0824	T.Y. Chu, 01500
1	MS 0824	W. L. Hermina, 01510
1	MS 0828	A. A. Giunta, 01533
1	MS 0828	W. L. Oberkampf, 01533
1	MS 0828	M. Pilch, 01533
1	MS 0829	B. M. Rutherford, 12337
1	MS 0847	F. Bitsie, 01523
1	MS 0847	P. J. Wilson, 01520
1	MS 0965	H. Duong, 05714
1	MS 1135	N. T. Davie, 01535
1	MS 1135	S. R. Heffelfinger, 01534
1	MS 1135	R. A. Jepsen, 01534
1	MS 9013	C. A. Lari, 8231
1	MS 9014	D. L. Gehmlich, 8241
1	MS 9014	R. M. Molle, 8241

1	MS 9014	D. A. Neutsel, 8241
1	MS 9014	B. R. Wagstaff, 8241
1	MS 9014	K. R. Hughes, 8242
1	MS 9014	A. H. Leung, 8241
1	MS 9014	A. R. Ortega, 8231
1	MS 9013	A. McDonald, 8221
1	MS 9042	E. P. Chen, 8776
1	MS 9042	D. J. Bammann, 8776
1	MS 9042	N. Bhutani, 8774
1	MS 9042	M. L. Chiesa, 8774
1	MS 9042	J. A. Crowell, 8774
1	MS 9042	J. J. Dike, 8774
1	MS 9042	R. D. Gilbert-O'Neil, 8774
1	MS 9042	M. D. Jew, 8774
1	MS 9042	B. L. Kistler, 8774
1	MS 9042	D. Kletzli, 8774
1	MS 9042	Y. Ohashi, 8774
1	MS 9042	V. D. Revelli, 8774
1	MS 9159	P. D. Hough, 8962
1	MS 9159	M. L. Martinez-Canales, 8962
1	MS 9404	D. M. Kwon, 8770
1	MS 9405	R. W. Carling, 8700
1	MS 9409	S. Lee, 8776
1	MS 9409	S. X. McFadden, 8776
1	MS 9409	J. S. Korellis, 8776
1	MS 9409	W. Lu, 8776
1	MS 9721	K. L. Lee, 8776
1	MS 9042	B.R. Antoun, 8776
1	MS 9001	P. A. Spence, 8000
2	MS 9018	Central Technical Files, 8944
1	MS 0899	Technical Library, 4536