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# A TORQUE, TENSION, AND STRESS CORROSION EVALUATION OF HIGH STRENGTH A286 BOLTS

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16. ABSTRACT

This report addresses the problems associated with overtorque applied to the Booster Separation Motor (BSM) Igniter Adapter high strength [200 KSI (1379 Mpa)] A286 CRES bolts and the threaded holes of the 7075-T73 aluminum alloy BSM cases. Our evaluation included torque, tensile, and stress corrosion tests incorporating the A286 CRES bolts and the 7075-T73 aluminum alloy BSM cases.

The tensile test data includes ultimate tensile load (UTL), Johnson's 2/3 yield load (J2/3YL), proportional limit load (PLL), and total bolt stretch. Torque tension data includes torque, torque induced load, and positive and negative break-away torque.

Stress corrosion test data reflect the overtorque and the resulting torque induced loads sustained by the A286 CRES bolts torqued into a 7075-T73 aluminum alloy forged dome with threaded holes. After 60 days of salt fog exposure, the positive and the negative break-away torques, the subsequent mechanical property tensile test results, and the BSM dome threaded hole axial tensile pullout loads are reported.

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TECHNICAL MEMORANDUM

# A TORQUE, TENSION, AND STRESS CORROSION EVALUATION OF HIGH STRENGTH A286 BOLTS

## SUMMARY

The mechanical properties, including tensile and torque data, of high strength [200 KSI (1379 MPa)] A286 CRES bolts were determined at ambient temperature for unstressed and for highly overtorqued bolts as related to the overtorquing problem associated with the Booster Separation Motor (BSM) Igniter Adapter and the 7075-T73 aluminum alloy BSM cases. Test results indicate that overtorquing did not reduce the bolt load carrying capability but did reduce the total stretch as determined in subsequent tensile tests.

The mechanical properties of the A286 CRES bolts were not adversely affected after being highly overtorqued into the threaded holes of a 7075-T73 aluminum alloy dome and exposed to 60 days of salt fog.

## INTRODUCTION

On Thursday, May 12, 1983, Metallic Materials Division personnel participated in a United Space Boosters Incorporated (USBI) flight readiness review of Space Transportation System (STS) 9 at the Marshall Space Flight Center (MSFC). The purpose of the review was to determine what action must be taken in regard to possible damage sustained by overtorquing A286 CRES bolts during the attachment of the Igniter Adapter to the 7075-T73 Aluminum Alloy Booster Separation (BSM) Cases.

A 50 in.-lb (5.65 Nm) torque is specified for the 1/4-28 EWB 0420 [200 KSI (1379 MPa)] A286 CRES bolts used to attach the Igniter Adapter (B12016) to the 7075-T73 Aluminum Alloy Booster Separation Motor Case (B12001-01-01). However, a technician following a lockwire diagram illustration had established a technique for bolt installation which duplicated the illustration shown in Figure 1 for STS-7 bolts. During his installation procedure, he was careful to use a torque wrench and supposedly never exceeded the 50 in.-lb (5.65 Nm) of torque when he was aligning the bolt heads to the lockwire. One day the technician inadvertently used a socket wrench to align the bolt heads after he had installed the fasteners to a 50 in.-lb torque. The possibility exists that the bolt heads were turned as much as 90 deg from the 50 in.-lb (5.65 Nm) installed position, producing an overload of unknown magnitude.

The review and discussion with USBI led to an agreement to perform torque tension tests on new bolts and on bolts recovered from STS 7, using an electronic torque wrench and a load-indicating washer. Particular emphasis was placed on a 90 deg advancement of the bolt head beyond the 50 in.-lb (5.65 Nm) torque. The tests were performed in used motor cases with threaded holes lubricated with MIL-T-5544 and with MIL-T-83483 lubricants. Additional tests were made to determine the pull-out strength of the threaded holes in the BSM cases.

When the torque tension data was plotted it revealed that bolts torqued 90 deg beyond the recommended 50 in.-lb (5.65 Nm) installation torque showed a yielding of either the bolts or the BSM aluminum alloy threaded holes. This yield indication prompted us to perform a stress corrosion test in a salt fog cabinet using the same loading technique.

## EQUIPMENT

The equipment used in the torque tension evaluation included a GSE Torque Indicator and a Lebow Load Cell.

The tensile tests were performed on a Satec Baldwin M120/HVL Machine with a testing speed of 0.050 in./min (0.127 cm/min). The A286 CRES bolts were tested with approximately 7 bolt threads engaged in a test fixture and 3 bolt threads exposed.

## STRESS CORROSION TEST PROCEDURE

A 60-day salt fog exposure test was performed on EWB 0420-4H-4 A286 CRES bolts, which were torqued to 90 deg beyond 50 in.-lb (5.65 Nm) into a 7075-T73 aluminum alloy Martin BSM case dome with USBI drilled and tapped holes. Actual installation conditions were simulated by using MS20002-4C countersunk washers, MIL-T-83483 lubricant and 303 stainless steel spacers, which provided bolt thread engagement similar to the 303 S.S. igniter housing flange.

The salt fog test followed the procedures of ASTM-B-117-64, "Standard Method of Salt Spray (Fog) Testing," which specifies a 5 percent salt solution at a pH of 6.5 to 7.2 and a temperature of 95°F (35°C).

## RESULTS AND DISCUSSION

### 1. Tensile and Torque Tests

The tensile test and torque test results are tabulated in Tables I through VII and summarized in Table VIII.

#### a. Tensile Tests – New A286 Bolts

Ten tensile tests were performed on new EWB 0420-4H-4 A286 bolts to determine the ultimate tensile load (UTL), Johnson's approximate 2/3 yield load (J2/3YL) (as described in the HIAD AFSCM Vol. 1, Part B, Chapter 4), proportional load limit (PLL) and the total bolt stretch taken from the load-strain curve. These results are shown in Table I. The average UTL of 8402 lb (3819 kg) is well within the 7270 lb (3304 kg) minimum load requirement for the EWB 0420-4H-4 bolt load as stated in SPS-B-640, Appendix 4.5.

b. Overtorque Tests – STS-6 BSM Case

Table II contains torque and tension test data for new bolts which were torqued to approximately 180 deg past 50 in.-lb (5.65 Nm) into a recovered STS-6 BSM motor case. In three of the four threaded holes the overtorque produced shear yielding in the aluminum alloy case threads. The subsequent tensile tests on the overtorqued bolts showed mechanical properties comparable to those shown in Table I for bolts which had not been overtorqued.

c. Overtorque Tests – Aluminum Alloy Plate, STS-6 BSM Cases, and New BSM Case

Overtorque tests data for the high strength A286 bolts torqued into a 7075-T73 aluminum alloy plate, recovered STS-6 BSM aluminum alloy cases, and a new BSM aluminum alloy case, are reported in Table III. The torque, torque induced loads, and negative break-away torques are tabulated for bolts which were torqued to approximately 90 deg passed 50 in.-lb (5.65 Nm).

d. STS-7 Bolts

The positive break-away torque values recorded when bolts were removed from a STS-7 BSM case are reported in Table IV. These values are extremely high when compared to the correct installation torque of 50 in.-lb (5.65 Nm). Four of the six A286 CRES bolts removed from STS-7 were subjected to various overtorque loads prior to tensile testing. The two bolts which exhibited high positive break-away torque values [165 and 185 in-lb (18.64 and 20.90 Nm)] were not subjected to additional torque induced loads. When tensile tested they showed the highest UT loads of the STS-7 bolts tested.

All of the STS-7 bolts tested, regardless of installation torque or additional torque, showed excellent mechanical properties which were well within specification values for new EWB 0420-4H-4 bolts. This data illustrates the excellent ductility and notched tensile properties of cold worked A286 CRES under conditions which might easily produce failure in other alloys of the same strength level.

e. Torque Tests With and Without MIL-T-83483 Lubricant

Table V shows the increase in the torque induced load with the MIL-T-83483 lubricant as opposed to torquing without a lubricant. Note that bolt No. 46 had a significantly higher UTL and J2/3 YL than any of the ten new bolts which are reported in Table I; however, these high values are not higher than those from bolts removed from STS-7, reported in Table IV.

f. Threaded Hole Pullout Test – STS-6 BSM Case

Table VI lists the results of the threaded hole axial tensile pullout tests on the STS-6 Aluminum Alloy BSM Martin Case 0196. Four of the seven threaded holes were subjected to various torque induced loads, which actually produced shear yielding in two of the threaded holes, prior to the tensile pullout tests. Threaded hole area No. 3, shown in Figure 2, is indicative of the mode of deformation.

2. Salt Fog – Stress Corrosion Tests

Table VIIA lists the torques obtained at 90 deg past 50 in.-lb (5.65 Nm) for the six bolts that were torqued into a drilled and tapped Martin BSM 7075-T73 aluminum alloy forged case dome and subjected to a stress corrosion test. Note that each of the threaded holes was exercised three times to 50 in-lb (5.65 Nm) of torque prior to the installation of the identified test bolts. These exercises were performed using the MIL-T-83483 lubricant and an A286 CRES bolt which was not used in the stress corrosion test.

A 60-day salt fog exposure test was conducted on EWB 0420-4H-4 A286 CRES bolts which were torqued to 90 deg beyond 50 in.-lb (5.65 Nm) into a 7075-T73 aluminum alloy Martin BSM case dome with USBI drilled and tapped holes. Actual installation conditions were simulated by using MS20002-4C countersunk washers, MIL-T-83483 lubricant and 303 stainless steel spacers, which provided bolt thread engagement similar to the 303 S.S. igniter housing flange. Figure 3 shows these components prior to salt fog exposure and after 14 days, 30 days, and 60 days exposure.

Table VIIB is a continuation of the stress corrosion test as described in Table VIIA. The installation torque and the positive and negative break-away torque values are reported after 60 days of salt fog exposure.

There were no bolt failures or dome threaded hole pullouts. Positive break-away torques, measured after 60 days, indicated good load retention values. Tensile tests performed on the six test volts showed excellent mechanical properties. Threaded hole axial tensile pullout tests produced high loads, indicating good load carrying capability in the aluminum forging threads.

The MS20002-4C cadmium plated steel washers began rusting in less than 18 hr and the 7075-T73 aluminum forging began corroding after two to five days exposure. The A286 CRES fasteners and the 303 S.S. spacers showed no signs of corrosive attack.

The case dome experienced some pitting corrosion as shown in Figure 4, especially where the rust from the alloy steel washer contacted the aluminum. The areas under the 303 S.S. spacers and the threads showed no evidence of corrosion. One of the threaded hole areas which was cross-sectioned and examined metallographically was found to be in good condition inasmuch as there were no corroded, cracked, or badly distorted threads (Fig. 5).

The 60-day stress corrosion test of highly overtorqued A286 CRES bolts in a 7075-T73 aluminum forging dome showed the ability of A286 CRES to resist an adverse chloride environment and to retain excellent tensile properties. It also indicated that, when adequately protected, the highly stressed threaded areas in the 7075-T73 aluminum forging did not fail from the adverse environment. However, if the salt fog had reached the highly stressed threaded area, undoubtedly corrosion and probably failure would have occurred in the aluminum case within the 60-day exposure period.

3. Summary of Test Results

Table VIII is a summary of the tensile test which was performed on the EWB 0420-4H-4 A286 CRES bolts and on the 7075-T73 aluminum alloy BSM case threaded holes.

## RESULTS AND DISCUSSION

In considering what, if any, detrimental effects were produced in the 1/4-28 A286 CRES EWB 0420-4H-4 bolts by the 90 deg beyond 50 in-lb (5.65 Nm) torque, the following must be evaluated:

1) Torque induced loads

2) Comparison of the torque induced loads to the loads obtained in the tensile tests.

3) Determination of the stress produced by the torque induced loads.

The torque induced loads reported in Table VIIA were obtained by using MIL-T-83483 lubricant and new A286 CRES bolts torqued into drilled and tapped 7075-T73 aluminum alloy dome holes. These holes were exercised three times to 50 in.-lb (5.65 Nm) torque using the MIL-T-83483 lubricant prior to installation of the new bolts. The 90 deg beyond 50 in-lb (5.65 Nm) torque produced a torque of 180 in-lb (20.34 Nm) and a torque induced load of approximately 6800 lb (3084.48 kg).

Using the bolt manufacturer's recommended cross sectional area of 0.03637 $in.^2$ (0.2346 $cm^2$) found in SPS-2-1510 for a diameter of 1/4-28 threads/in. the resulting stress in this bolt would be 186.97 KSI (1289.12 MPa).

For comparison purposes, the average J 2/3 Y load for the new EWB 0420 bolts (Table I) used in this evaluation was 7745 lb (3513.13 kg) which converts to 212.95 KSI (1468.25 MPa).

For bolts tensile tested after the stress corrosion test, the lowest J 2/3 Y load was 7800 lb (3538.08 kg) which converts to 214.46 KSI (1478.67 MPa).

Certainly the values obtained in this investigation of overtorqued A286 CRES bolts exceeds our conservative requirements found in MSFC STD 486-(4) General Requirements which specifies that the torque (torque induced load) will not exceed 65 percent of the J 2/3 tensile yield strength (load).

What has been determined in this investigation is that torque induced loads have not been produced in any of the 90 deg passed 50 in-lb (5.65 Nm) torque which exceeded or equalled the J 2/4 Y load for new or previously torqued EWB-0420-4H-4 A286 bolts.

Extreme overtorque of 180 deg past 50 in-lb (5.65 Nm) produced shear yielding in the 7075-T73 aluminum alloy case threads; however, subsequent tensile tests of the overtorqued bolts (Table II) indicated mechanical properties comparable to those obtained with new bolts (Table I). Repeated reuse of the bolts in an overtorqued condition will eventually deplete all of the elongation potential in the threads and will produce failure.

## CONCLUSIONS

The results of the torque, tensile, and stress corrosion tests indicate the following:

1) The high strength A286 CRES fasteners used in this application were not adversely affected by torquing the bolts to 90 deg beyond the recommended 50 in-lb (5.65 Nm) installation torque. This overtorque equalled approximately 180 in-lb (20.34 Nm) and produced a torque induced load of approximately 6800 lb (3084.48 kg). Using the bolt manufacturer recommended stress area, this load translates to 186.97 KSI (1289.12 MPa).

2) The 90 deg beyond 50 in.-lb (5.65 Nm) torque did not produce torque induced loads which exceeded or equalled the Johnson's 2/3 yield load for new or previously torqued EWB-0420-4H-4 A286 bolts.

3) The load carrying capability of the threaded holes in the BSM cases, which were loaded to 90 deg beyond 50 in-lb (5.65 Nm) torque, was good. However, shear yielding of the threads is possible depending on the lubricant used and the number of reuse cycles.

4) Overtorque to 90 deg beyond 50 in.-lb (5.65 Nm) and exposure to salt fog did not adversely affect the EWB 0420-4H-4 A286 bolts. Threaded hole axial tensile pullout tests produced high loads illustrating the good load carrying capability of the 7075-T73 aluminum alloy forging threads.

5) Due to the variables associated with torque (lubricants and the number of reuse cycles) and the resulting torque induced loads, especially in the aluminum alloy forging threads, caution is recommended when applying the results obtained from this investigation to any similar flight hardware torque anomaly. Repeated reuse of the bolts in an overtorqued condition will eventually use up all of the elongation potential in the threads and will result in failure.

TABLE I

TENSILE TESTS OF EWB 0420-4H-4 (200 KSI) A286 BOLTS (1/4-28 UNJF)

| | Bolt Ident. # | Ultimate Tensile Load Lbs. | Johnson's 2/3 Yield Load* Lbs. | Proportional Limit Lbs. | Bolt Stretch Inches |
|---|---|---|---|---|---|
| | 13 | 8388 | 7700 | 6820 | .0440 |
| | 15 | 8386 | 7675 | 6850 | .0425 |
| | 22 | 8335 | 7625 | 6800 | .0440 |
| | 23 | 8430 | 7850 | 6820 | .0430 |
| | 24 | 8359 | 7625 | 6800 | .0440 |
| | 35 | 8358 | 7650 | 6750 | .0430 |
| | 37 | 8488 | 7900 | 6750 | .0415 |
| | 40 | 8451 | 7800 | 6800 | .0430 |
| | 41 | 8381 | 7825 | 6850 | .0440 |
| | 43 | 8447 | 7800 | 6850 | .0440 |
| AVG. | -- | 8402 | 7745 | 6809 | .0433 |

NOTES:

Testing Machine: Satec Baldwin M120/HVL

Testing Speed: .05 Inches/Minute (.27 cm/Minute)

Bolt Thread Engagement: ~7 Threads Engaged in Test Fixture and 3 Threads Exposed

*Johnson's 2/3 Approx. Method: HIAD USAF AFSCM Vol. 1-Part B-Chapter 4 or MIL-STD-1312-Test 8-Tensile Strength

1 KSI = 6.8948 Mega Newtons/$m^2$ = 6.8948 Mega Pascals/$m^2$

1 Pound = 453.6 Grams = .4536 Kilograms

1 Inch = 2.54 cm

# TABLE II

## OVERTORQUE AND TENSILE TESTS OF NEW EWB 0420-4H-4 (200 KSI) A286 BOLTS TORQUED INTO RECOVERED STS-6 BSM MARTIN CASE 0196 (LUBRICANT MIL T 5544)

| | | TORQUE TEST | | | TENSION TEST | | | |
|---|---|---|---|---|---|---|---|---|
| Bolt Ident. # | Case 0196 Hole Number | Torque Inch-Lbs. | Angle Degrees >50 In-Lbs. | Torqued-Induced Load Lbs. | Ultimate Tensile Load Lbs. | Johnson's 2/3 Yield Load Lbs. | Proportional Limit Lbs. | Bolt Stretch Inches |
| 25 | 5 | 186 | 186° | 6944 | 8468 | 8150 | 6800 | .0380 |
| 30 | 3* | 175 | 127° | 7054 | 8422 | 8000 | 7250 | .0400 |
| | | 199 | 185° | 6438 | | | | |
| 31 | 2* | 196 | 115° | 6896 | 8480 | 8150 | 7200 | .0375 |
| | | 220 | 165° | 6588 | | | | |
| 32 | 1* | 171 | 135° | 6904 | 8341 | 7900 | 7200 | .0390 |
| | | 188 | 188° | 6731 | | | | |

*NOTES:

Case Holes 3, 2, & 1/Reduction of Torque Induced Load with Increased Torque Indicates Shear Yielding of Case 0196 Threads

1 KSI = 6.8948 Mega Newtons/$m^2$ = 6.8948 Mega Pascals/$m^2$

1 Pound = 453.6 Grams = .4536 Kilograms

1 Inch Lb = .113 Newton Meter

TABLE III

OVERTORQUE TESTS OF EWB 0420-4H-4 (200 KSI) A286 BOLTS TORQUED INTO KAISER PLATE MATERIAL, RECOVERED STS-6 BSM CASES, AND NEW BSM CASE (LUBRICANT MIL T 5544)

| Bolt Ident. # | Case or Plate | Torque In-Lbs. | Angle Degrees >50 In-Lbs. | Torque Induced Load Lbs. | Negative Break-Away Torque In-Lbs. |
|---|---|---|---|---|---|
| 16 | Kaiser Plate | 180 | 90° | 6062 | 92 |
| 17* | Kaiser Plate | 181 | 107° | 6039 | 102 |
| 18 | 0244 | 142 | 91° | 6964 | 52 |
| 19 | 0244 | 155 | 92° | 6644 | 72 |
| 20 | 0279 | 195 | 90° | 5851 | 110 |
| 21 | 0279 | 171 | 90° | 6152 | 90 |
| 25 | 0196 | 145 | 102° | 6118 | -- |
| 30 | 0196 | 170 | 102° | 6904 | -- |
| 31 | 0196 | 190 | 99° | 6889 | -- |
| 32 | 0196 | 144 | 91° | 6670 | -- |

NOTES:

Bolts 16 & 17: Torqued into Kaiser 7075-T73 Aluminum Alloy Plate - 3.0 Inch Thick with USBI Drilled & Tapped Holes (1/4-28 UNF).

Bolts 18 & 19: Torqued into Recovered STS-6 Martin Case 0244.

Bolts 20 & 21: Torqued into New Martin Case 0279 Dome with USBI Drilled & Tapped Holes (1/4-28 UNF).

Bolts 25, 30, 31 & 32: Torqued into Recovered STS-6 Martin Case 0196.

*Bolt #17: Previously Torqued to 44 Degrees Beyond 50 Inch-Lbs Producing 140 Inch-Lbs of Torque and 4393 Lbs.

1 KSI = 6.8948 Mega Newtons/$m^2$ = 6.8948 Mega Pascals/$m^2$

1 Pound = 453.6 Grams = .4536 Kilograms

1 Inch Lb = .113 Newton Meter

# TABLE IV

## TENSILE TESTS OF EWB 0420-4H-4 (200 KSI) 1/4-28 A286 BOLTS REMOVED FROM STS-7 BSM(1000015/A52-5-6/X33C13)

| Bolt Ident. # | Positive Break-Away Torque In-Lbs. | Ultimate Tensile Load Lbs. | Johnson's 2/3 Yield Load Lbs. | Proportional Limit Lbs. | Bolt Stretch Inches |
|---|---|---|---|---|---|
| 1 | 165 | 8847 | 8400 | 7550 | .0425 |
| 2 | 185 | 8821 | 8350 | 7600 | .0415 |
| 3* | 95 | 8677 | 8175 | 7550 | .0440 |
| 6* | 75 | 8775 | 8150 | 7250 | .0390 |
| 7* | 130 | 8353 | 7825 | 7350 | .0455 |
| 8* | 95 | 8583 | 8100 | 7550 | .0435 |

*NOTES:

Bolt #3: Torqued to 245 Inch-Lbs./139° Beyond 50 Inch-Lbs. into Threaded Aluminum Adapter made from BSM Case 0179. A Tensile Test Performed on the Torque Loaded Bolt & Adapter Resulted in Thread Pullout in the Aluminum Adapter at 8012 Lbs. The bolt was then tested to failure in a steel adapter.

Bolt #6: Torqued to 230 Inch-Lbs./65° Beyond 50 Inch-Lbs. into Threaded Steel Adapter. Bolt Removed from Adapter and Tensile Tested.

Bolt #7: Torqued to 156 Inch-Lbs./7398 Lbs./91° Beyond 50 Inch-Lbs. into STS-6 Case 0226 (Hole #7).

Bolt #8: Torqued to 175 Inch-Lbs./6312 Lbs./95° Beyond 50 Inch-Lbs. into STS-6 Case 0226 (Hole #8). Bolt Removed and Reinstalled w/303 S.S. Spacer & an MS20002 C2 Washer. Case Thread Failure Occurred at 192 Inch-Lbs..

1 KSI = 6.8948 Mega Newtons/$m^2$ = 6.8948 Mega Pascals/$m^2$

1 Pound = 453.6 Grams = .4536 Kilograms

1 Inch Lb = .113 Newton Meter

## TABLE V

## OVERTORQUE (WITH AND W/OUT LUBRICANT) AND TENSILE TESTS OF EWB 0420-4H-4 (200 KSI) A286 BOLTS TORQUED INTO RECOVERED STS-6 BSM MARTIN CASE 0226

| | | TORQUE TEST | | | | TENSION TEST | | | |
|---|---|---|---|---|---|---|---|---|---|
| Bolt Ident. # | Case Hole Number | Torque In-Lbs. | Angle Degrees >50 In-Lbs. | Torque Induced Load Lbs. | Positive Break-Away Torque In-Lbs. | Ultimate Tensile Load Lbs. | Johnson's 2/3 Yield Load Lbs. | Proportional Limit Lbs. | Bolt Stretch Inches |
| 16 | 5* | 50 | 0° | 2069 | 55 | 8397 | 7950 | 7650 | .0455 |
| (MIL T 83483 Lube) | | 70 | 11° | 2987 | 76 | | | | |
| | | 90 | 21° | 3849 | 98 | | | | |
| | | 120 | 34° | 4954 | 126 | | | | |
| | | 140 | 42° | 5619 | 142 | | | | |
| | | 160 | 71° | 6883 | 170 | | | | |
| | | 180 | 107° | 7173 | 180 | | | | |
| 46 | 4** | 50 | 0° | 1367 | 58 | 8773 | 8250 | 7800 | .0430 |
| (No Lubricant) | | 70 | 11° | 1929 | 77 | | | | |
| | | 90 | 18° | 2547 | -- | | | | |
| | | 100 | 22° | 2846 | 108 | | | | |
| | | 120 | 33° | 3465 | 122 | | | | |
| | | 140 | 40° | 4092 | 144 | | | | |
| | | 160 | 50° | 4738 | 168 | | | | |
| | | 180 | 60° | 5385 | 182 | | | | |
| | | 200 | 68° | 5947 | ~210 | | | | |

NOTES:

* CASE HOLE No. 5: Bolt #16 Previously Torqued into Kaiser Plate Tapped Holes Lubricated With MIL-T-5544 Lubricant to 90 Degrees Beyond 50 Inch-Lbs. Producing 180-Inch-Lbs. of Torque and 6062 Lbs. Load

** CASE HOLE NO. 4: Bolt #46 Torqued into Case Hole No. 4 Without Lubricant

1 KSI = 6.8948 Mega Newtons/$m^2$ = 6.8948 Mega Pascals/$m^2$

1 Pound = 453.6 Grams = .4536 Kilograms

1 Inch Lb = .113 Newton Meter

TABLE VI

THREADED HOLE AXIAL TENSILE PULLOUT TESTS ON STS-6
ALUMINUM ALLOY 7075-T73 BSM MARTIN CASE 0196

| Hole Ident. # | Proportional Limit Lbs. | Pullout Load Lbs. | Lubrication |
|---|---|---|---|
| 8 | 7100 | 7664 | MIL T 83483 |
| 7 | 7050 | 7470 | " |
| 6 | 7200 | 7814 | None |
| 5* | 7100 | 7657 | MIL T 83483 |
| 3* | ---- | ---- | " |
| 2* | 6220 | 6702 | MIL T 83483 |
| 1* | 6450 | 7050 | " |

*NOTES:

Bolt Hole #5: Previously Torqued to 186 Inch-Lbs/6994 Lbs/185° Passed 50 Inch-Lbs

Bolt Hole #3: Previously Torqued to 175 Inch-Lbs/7050 Lbs/127° Passed 50 Inch-Lbs
Torque Continued to 199 Inch-Lbs/6438 Lbs/185° Passed 50 Inch-Lbs
(Metallographic Sample)

Bolt Hole #2: Previously Torqued to 196 Inch-Lbs/6896 Lbs/115° Passed 50 Inch-Lbs
Torque Continued to 220 Inch-Lbs/6588 Lbs/165° Passed 50 Inch-Lbs

Bolt Hole #1: Previously Torqued to 171 Inch-Lbs/6904 Lbs/135° Passed 50 Inch-Lbs
Torque Continued to 188 Inch-Lbs/6731 Lbs/188° Passed 50 Inch-Lbs

COMMENT:

The reduction of torque induced load with increasing torque indicates shear yielding of Holes #1 & 2.

1 Pound = 453.6 Grams = .4536 Kilograms

TABLE VIIA

EWB 0420-4H-4 (200 KSI) A286 BOLTS TORQUED TO 90° BEYOND 50 INCH-LBS. INTO A MARTIN BSM CASE 0451 DOME WITH USBI DRILLED AND TAPPED HOLES SUBJECTED TO 60 DAYS OF SALT FOG* EXPOSURE

| Bolt Ident. # | Dome Hole Number | Torque In-Lbs. | Angle Degrees >50 In-Lbs. | Torque Induced Load Lbs. | Negative Break-Away Torque In-Lbs. |
|---|---|---|---|---|---|
| None | 1 | 51 | -- | 627 | 40 |
| | | 51 | -- | 1037 | 32 |
| | | 50 | -- | 1634 | 29 |
| | | 51 | 0° | 2228 | -- |
| | | 180 | 90° | 6832 | 99 |
| 27 | 1 | 196 | 90° | ---- | -- |
| None | 2 | 50 | -- | ---- | 40 |
| | | 50 | -- | ---- | 30 |
| | | 50 | -- | ---- | 24 |
| 29 | 2 | 176 | 90° | ---- | -- |
| None | 3 | 50 | -- | | -- |
| | | 50 | -- | | 21 |
| | | 50 | -- | | 19 |
| 28 | 3 | 180 | 90° | | -- |
| None | 4 | 50 | | | 37 |
| | | 50 | | | 29 |
| | | 50 | | | 21 |
| 33 | 4 | 191 | 90° | | -- |
| None | 5 | 50 | -- | | 32 |
| | | 50 | -- | | 28 |
| | | 50 | -- | | 23 |
| 39 | | 184 | 90° | | -- |
| None | 6 | 50 | -- | | 29 |
| | | 50 | -- | | 21 |
| | | 50 | -- | | 20 |
| 38 | 6 | 185 | 90° | | -- |

NOTES: 1 Inch Lb = .113 Newton Meter

Each Dome Threaded Hole Lubricated and Exercised 3 Times to 50 Inch-Lbs. of Torque Prior to Installation of Identified Bolt.

BSM Case 0451 Dome: 7075 T73 Aluminum Alloy Forging.

Bolts: A-286 CRES per EWB 0420 (1/4-28)

Washers: Cadmium Plated Alloy Steel per MS20002-4C.

Spacers: 303 Stainless Steel (0.273 Inch Thick).

Lubricant: MIL T 83483

* Salt Fog per ASTM-B-117-64
5% NaCl Solution at a pH of 6.5-7.2 and a Temperature of 95°F (35°C).

# TABLE VIIB

## EWB 0420-4H-4 (200 KSI) A286 BOLTS TORQUED TO 90° BEYOND 50 INCH-LBS. INTO A MARTIN BSM CASE 0451 DOME WITH USBI DRILLED AND TAPPED HOLES SUBJECTED TO 60 DAYS OF SALT FOG EXPOSURE

| | | TORQUE TEST [1 Inch Lb = .113 Newton Meter] | | | | TENSION TEST [1 Pound = .4536 Kilograms] | | |
|---|---|---|---|---|---|---|---|---|
| Bolt Ident. # | Dome Hole Number | Installation Torque In-Lbs. | Positive Break-Away Torque In-Lbs. | Negative Break-Away Torque In-Lbs. | Ultimate Tensile Load Lbs. | Johnson's 2/3 Yield Load Lbs. | Proportional Limit Lbs. | Bolt Stretch Inches |
| 27 | 1 | 196 | 150* | 96 | 8608 | 8325 | 7900 | .0395 |
| 29 | 2 | 176 | 178 | 93 | 8573 | 8250 | 7950 | .0390 |
| 28 | 3 | 180 | 180 | 100 | 8389 | 8050 | 7600 | .0390 |
| 33 | 4 | 191 | 188 | 102 | 8293 | 7800 | 7350 | .0455 |
| 39 | 5 | 184 | 178 | 94 | 8298 | 7800 | 7400 | .0460 |
| 38 | 6 | 185 | 178 | 101 | 8391 | 7850 | 7600 | .0445 |

### THREADED HOLE AXIAL TENSILE PULLOUT TEST

| Dome Hole Number | Proportional Limit Lbs. | Pullout Load Lbs. |
|---|---|---|
| 1 | 7050 | 7312* |
| 2 | 7550 | 7898 |
| 3 | 7550 | 7798 |
| 4 | 7500 | 7799 |
| 5 | (Metallography Sample) | |
| 6 | 7250 | 7655 |

NOTES: *Dome Hole #1: Lower Postive Break-Away Torque of Bolt and Lower Pullout Load of Threaded Hole Attributed to Deformation Caused by Previously Torquing Hole to 180 Inch-Lbs.

## TABLE VIII

## SUMMARY OF TENSILE TESTS

## A. BOLTS JOINING THE IGNITER ADAPTER PLATES TO BSM CASES

TABLE I - TENSILE TEST - (10) NEW A286 CRES BOLTS

| | Ultimate Tensile Load | Johnson's 2/3 Yield Load | Bolt Stretch |
|---|---|---|---|
| Average | 8402 Lbs. | 7745 Lbs. | .0433 Inch |
| Range | (8335 to 8488) | (7625 to 7900) | (.0415 to .0440) |
| Requirement | 7270 Lbs. Minimum per EWB-0420-4 | | (SPS-B-640 Appendix 4.5) |

TABLE II - TENSILE TEST - (4) A286 CRES BOLTS TORQUED TO ~180° BEYOND 50 IN.-LBS. (5.65 Nm)

| | Ultimate Tensile Load | Johnson's 2/3 Yield Load | Bolt Stretch |
|---|---|---|---|
| Average | 8428 Lbs. | 8050 Lbs. | .0386 Inch |
| Range | (8341 to 8480) | (7900 to 8150) | (.0375 to .0400) |

TABLE IV - TENSILE TEST - (2) A286 CRES BOLTS RECOVERED FROM STS-7

| | Ultimate Tensile Load | Johnson's 2/3 Yield Load | Bolt Stretch |
|---|---|---|---|
| Average | 8848 Lbs. | 8375 Lbs. | .0420 Inch |
| Range | (8821 to 8874) | (8350 to 8400) | (.0415 to .0425) |

TABLE V - TENSILE TEST - (2) A286 CRES BOLTS TORQUED WITH AND WITHOUT MIL-T-83483 LUBRICANT

| | Ultimate Tensile Load | Johnson's 2/3 Yield Load | Bolt Stretch |
|---|---|---|---|
| With Lube | 8397 Lbs. | 7950 Lbs. | .0455 Inch |
| Without Lube | 8733 Lbs. | 8250 Lbs. | .0430 Inch |

TABLE VIIB - TENSILE TEST - (6) A286 CRES BOLTS - AFTER SALT FOG EXPOSURE

| | Ultimate Tensile Load | Johnson's 2/3 Yield Load | Bolt Stretch |
|---|---|---|---|
| Average | 8425 Lbs. | 8012 Lbs. | .0422 Inch |
| Range | (8293 to 8608) | (7800 to 8325) | (.0390 to .0460) |

TABLE VIII. (Concluded)

## B. OVERTORQUED BSM CASE THREADED HOLE PULLOUT TESTS

TABLE VI - TENSILE TEST - PULLOUT STRENGTH OF STS-6 BSM CASE 0196 THREADED HOLES (6)

| | Ultimate Tensile Load | Proportional Limit Load |
|---|---|---|
| Average | 7649 Lbs. | 7117 Lbs. |
| 3 Tests-As Rec. Holes | | |
| Range | (7470 to 7814) | (7050 to 7200) |
| Average | 7140 Lbs. | 6590 Lbs. |
| 3 Tests-Overtorqued Holes | | |
| Range | (6702 to 7657) | (6220 to 7100) |

TABLE VIIB - TENSILE TEST - PULLOUT STRENGTH OF MARTIN BSM CASE 0451 THREADED HOLES (5) AFTER OVERTORQUE & 60 DAY SALT FOG EXPOSURE

| | Ultimate Tensile Load | Proportional Limit Load |
|---|---|---|
| Average | 7692 Lbs. | 7380 Lbs. |
| Range | (7312 to 7898) | (7250 to 7550) |

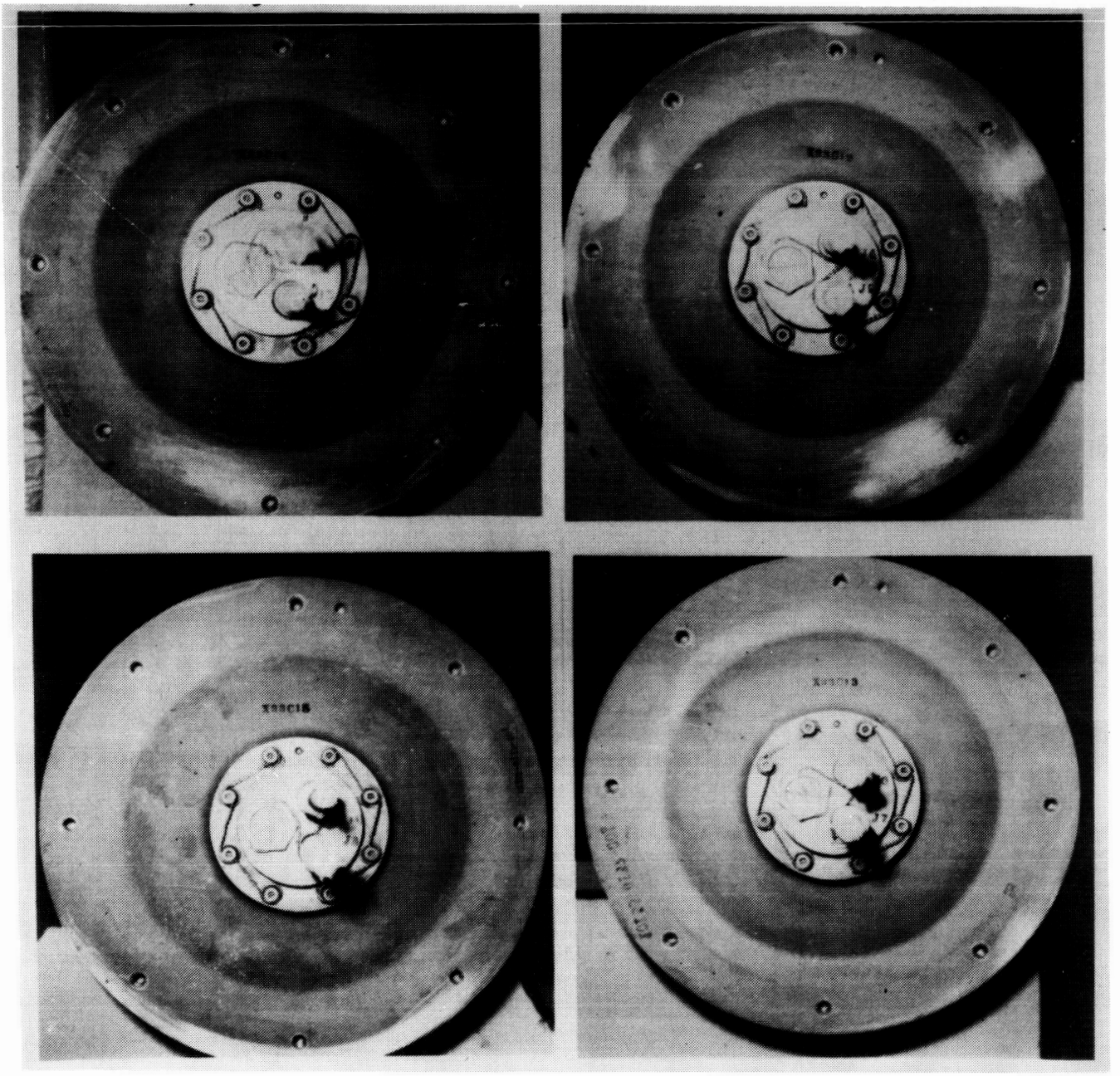

Figure 1. End Views of Recovered STS-7 BSMS (Forward Ends) Showing Lockwire Patterns Produced by Rotation of BSM Igniter Retention Bolt Heads.

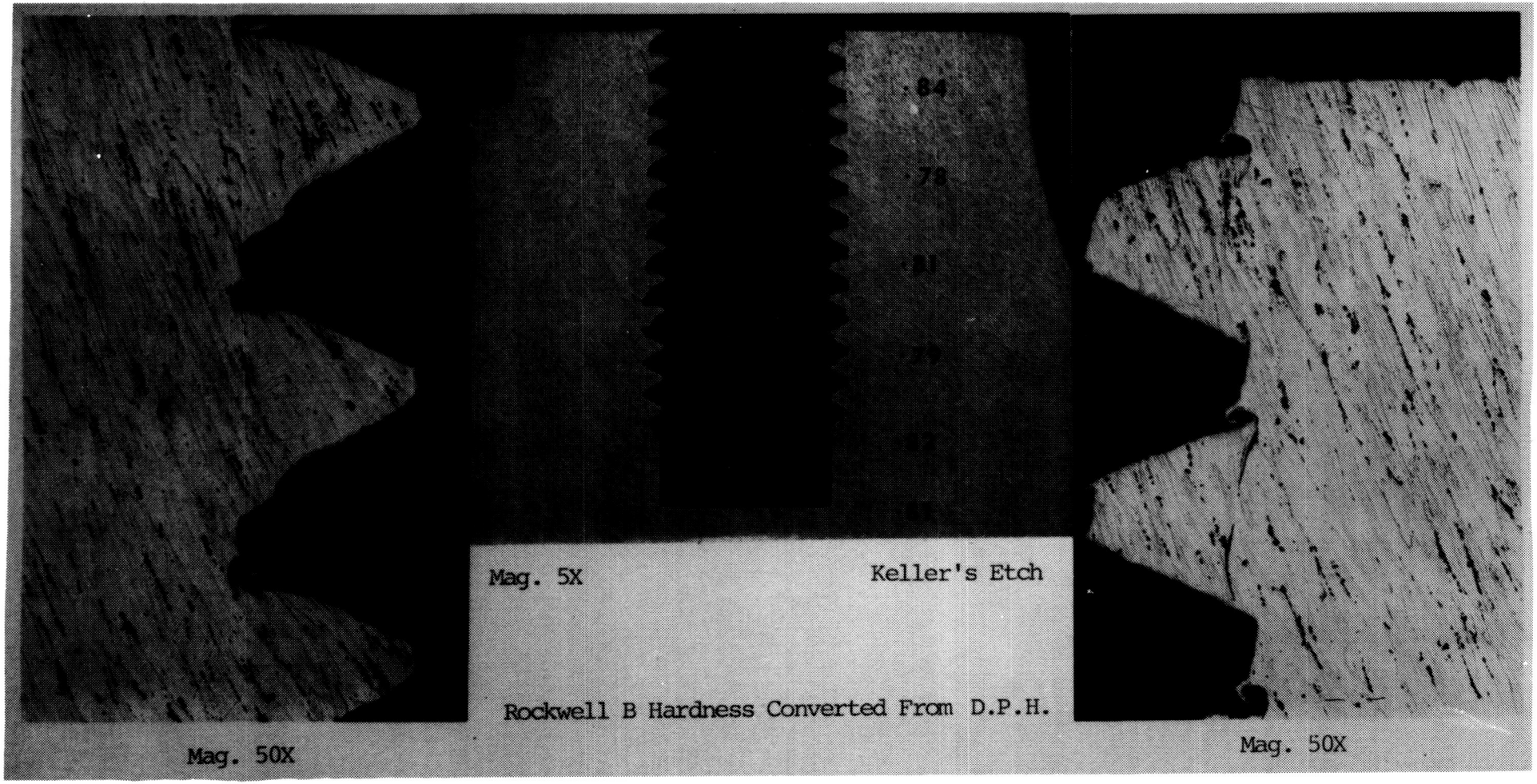


Figure 2. Microstructure and Hardness of STS-6 BSM Martin Case 0196 Threaded Hole Area #3 Showing Shear Deformation Produced by 199 in.-lb (22.49 Nm) Torque [Reference: Table VI].

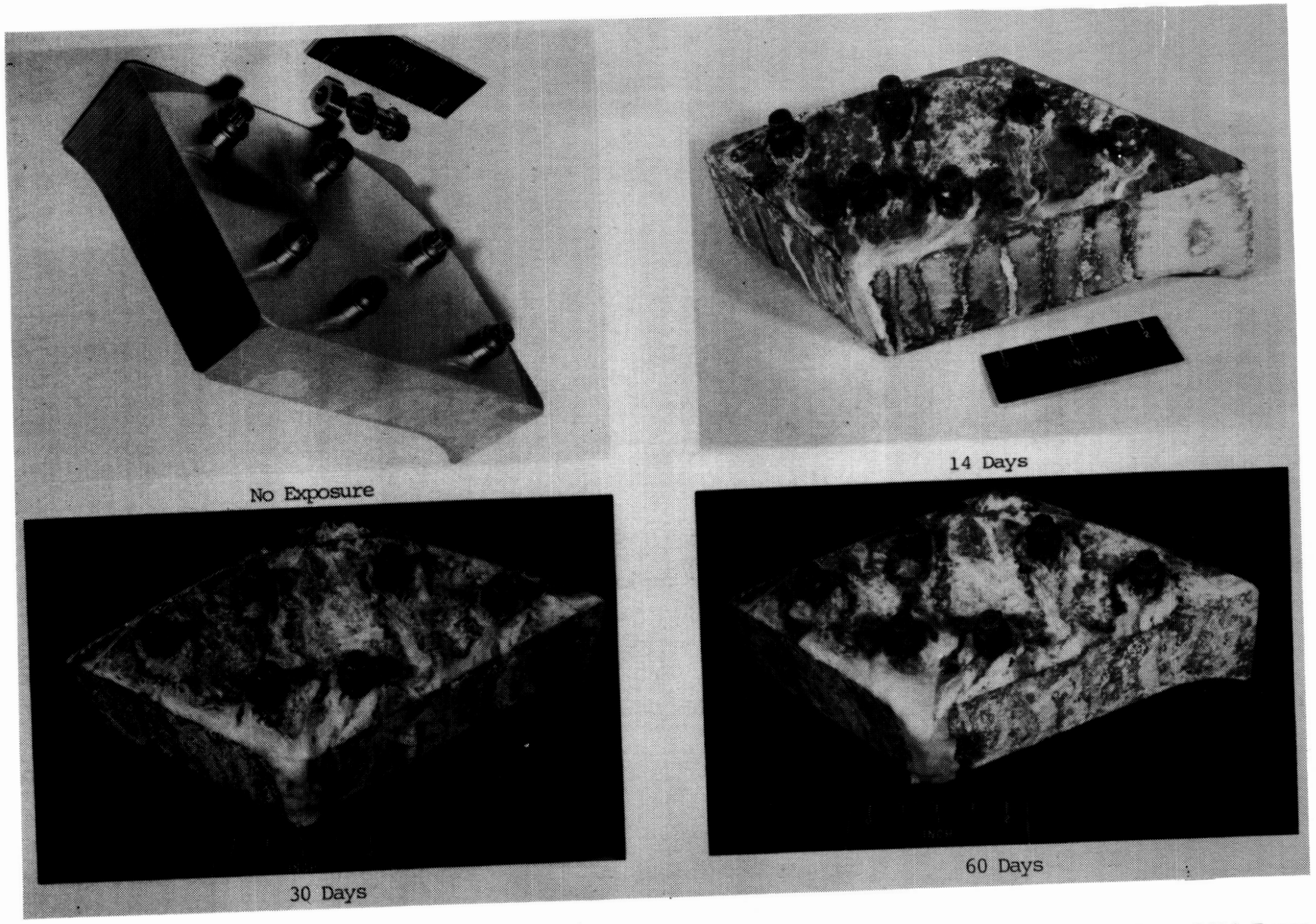


Figure 3. A286 CRES Bolts Torqued to 90° Beyond 50 in.-lb (5.65 Nm) Into a Martin BSM Case 0491 Dome Subjected to 60 Days of Salt Fog Exposure
[Reference: Tables VII A and B]

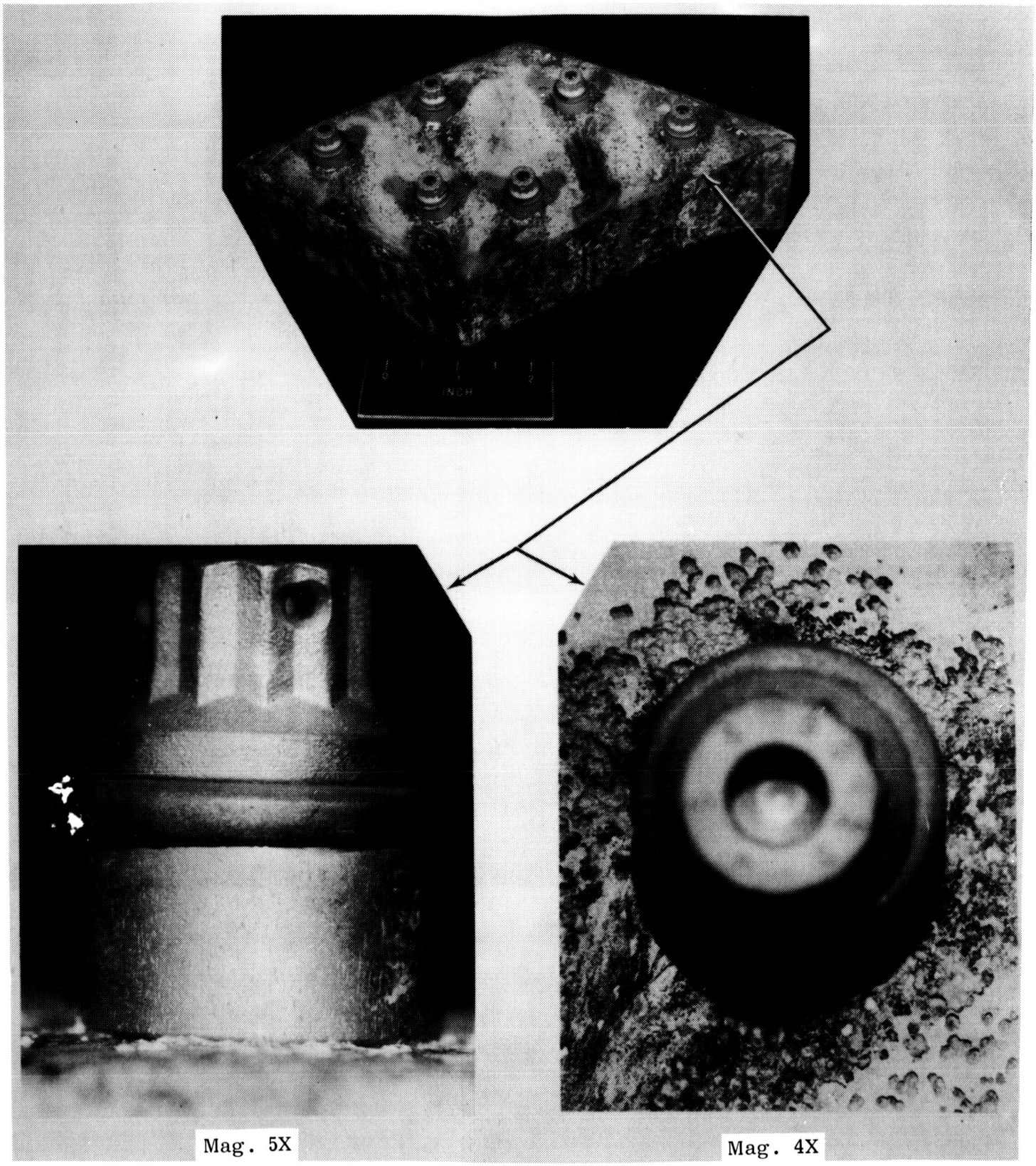


Figure 4. A286 CRES Bolts and 7075-T73 Aluminum Alloy BSM Case Dome Wet Grit Blast Cleaned After 60 Days of Salt Fog Exposure [Reference: Tables VII A and B]

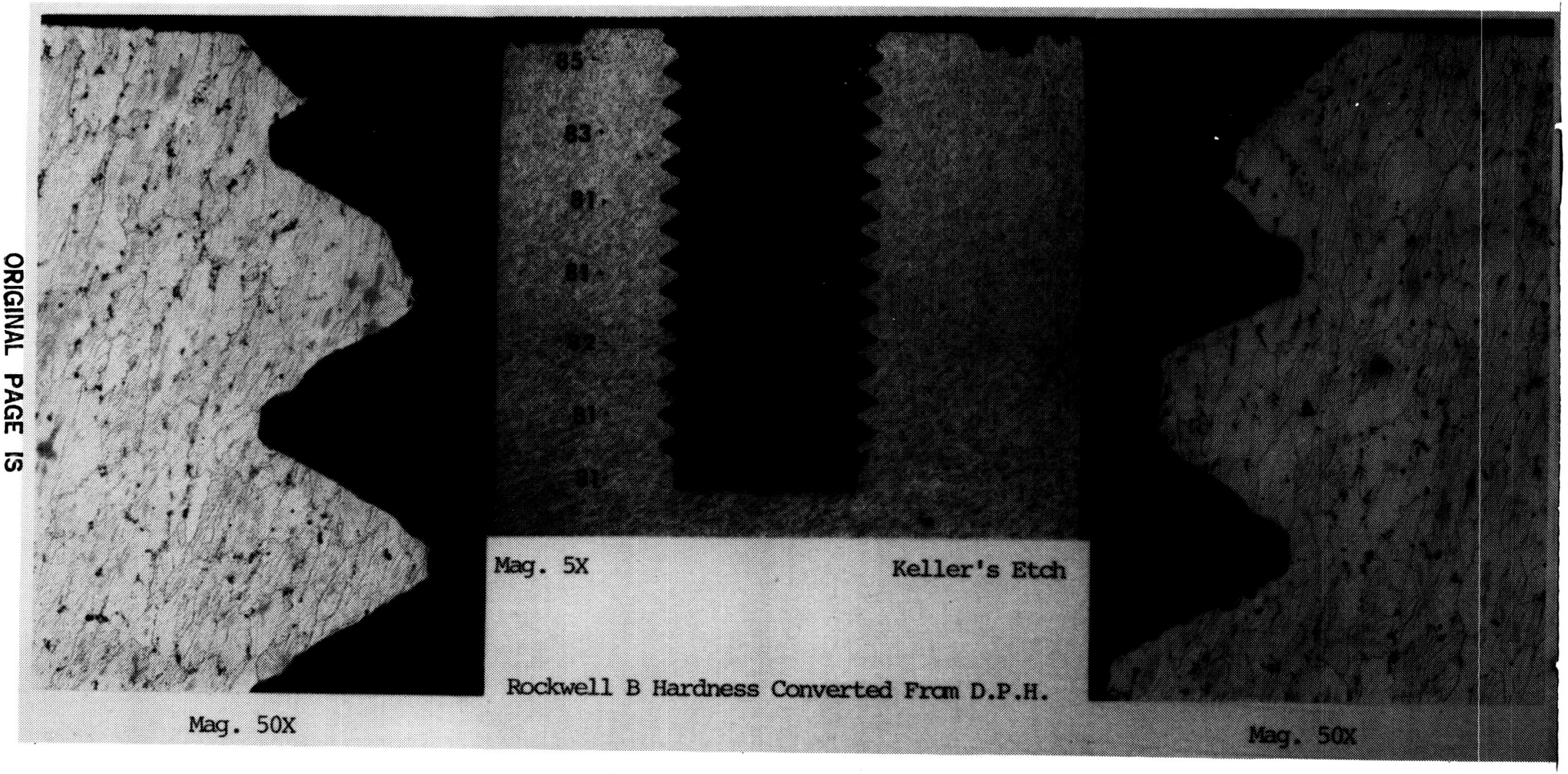


Figure 5. Microstructure and Hardness of Martin BSM Case 0451 Threaded Hole Area #5 After 184 in.-lb (20.79 Nm) Torque and 60 Days of Salt Fog Exposure [Reference: Table VII A and B].

## APPROVAL

## A TORQUE, TENSION, AND STRESS CORROSION EVALUATION OF HIGH STRENGTH A286 BOLTS

By J. W. Montano

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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