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Lockbolt Qualification Testing for Wing Panel Assemblies

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ABSTRACT

This paper gives an outline of testing carried out in conjunction with Electroimpact to support the introduction of the A319/A320/A321 and A340-500/600 Panel Assembly Cells in Broughton, UK. Testing compared the percussion insert/EMR swaging of lockbolts with existing hydraulic installation methods. Tests included pre-load tension tests, ultimate tension load tests, tension fatigue tests, high-load lap shear fatigue tests, static lap shear tests, a pressure leak test, and metallurgical examination.

Fastener configurations tested covered diameters from 1/4, 5/16, 3/8, and 7/16 of an inch. Joint materials conformed to ABM3-1031 (7150-T651 plate), stump-type lockbolts to ABS0550VHK (Huck LGPS4SCV), and collars to ASNA2025 (Huck 3SLC-C). Some pull-type lockbolts to ABS0548VHK (Huck LGPL4SCV) were also tested as noted.

INTRODUCTION

Airbus UK Limited manufactures wings for the Airbus family of large commercial aircraft at their Broughton facility in the U.K. It is desirable and practical to have automated CNC machines install the lockbolts between stiffeners and panels for such aircraft. Please see Figure 1. When a new process was proposed for installing lockbolts at the facility, testing was needed to assure that the new process would provide a joint performance that meets or exceeds existing processes.

- Prior (baseline) processes: hydraulically pulled (manual pin-tail) or pushed (Drivmatic) lockbolts with hydraulically swaged collars.
- New (now current) process: pneumatically percussion driven lockbolts with EMR swaged collars.

Low-voltage EMRs have been developed to install lockbolts by Electroimpact since 1991. (Please see reference 1.) For production aircraft, test requirements were defined by the Materials and Process Group of Airbus UK Limited, Filton. As part of the risk share agreement, Electroimpact performed testing of the percussion insert/EMR swage of lockbolts. Material specimens, fasteners, and collars were provided by the airframe manufacturer. Joint materials conformed to ABM3-1031 (7150-T651 plate), stump-type lockbolts to ABS0550VHK (Huck LGPS4SCV), and collars to ASNA2025 (Huck 3SLC-C). Some pull-type lockbolts to ABS0548VHK (Huck LGPL4SCV) were also tested as noted. This test work verified the integrity of the electromagnetic installation process, helped set voltages of the EMRs for collar swaging, and extended the process for lockbolt diameters up to 7/16 inch.

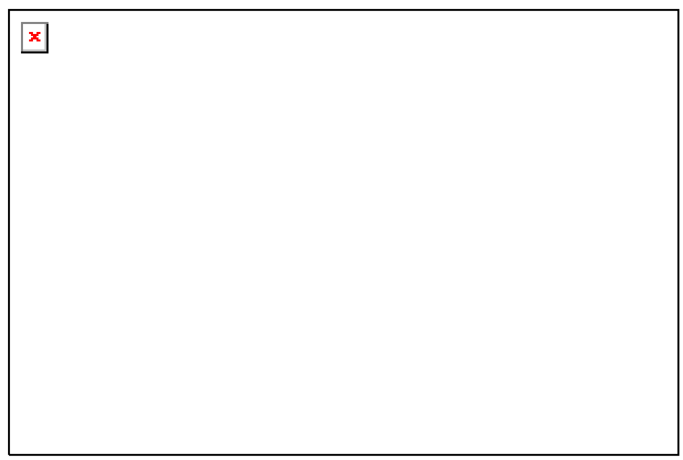

Figure 1. CNC Machine Fastening of Stiffeners to Panels

Unless noted, lockbolts for these tests were installed with a pneumatic percussion tool. Some pull-type lockbolts were installed with a hydraulic installation tool. EMR (electromagnetic riveter) swaging of the lockbolt collars was done on a test bench as similar to Figure 2. Fatigue testing of specimens was done on the author's MTS fatigue tester, see Figure 3. Fatigue coupons were also assembled for the airframe manufacturer's Technical Centre as laboratory controls.

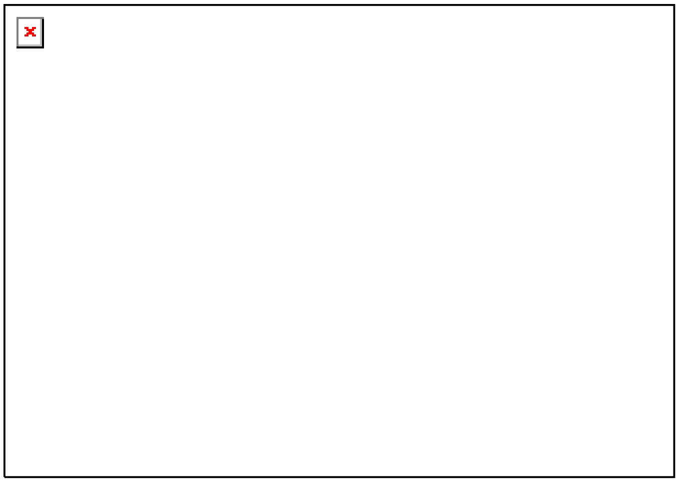

Figure 2. Test Bench for EMR Collar Swaging

Testing was carried out to verify pre-load, ultimate tensile strength, tension-tension fatigue, high-load lap shear fatigue, static lap shear, fuel retention and metalluragical properties.

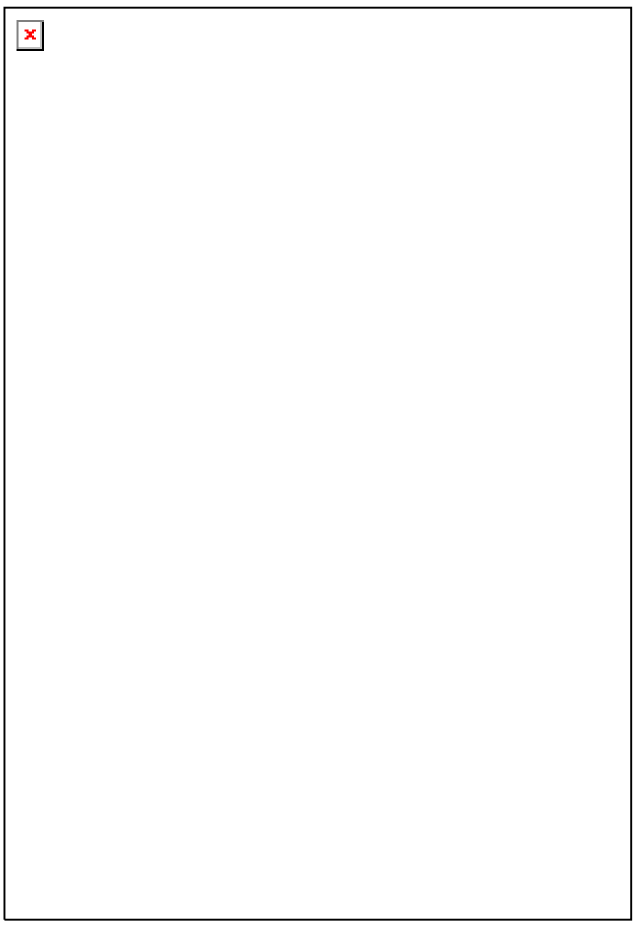

Figure 3. Fatigue Testing Machine.

TESTS PERFORMED ON LOCKBOLTS

A series of tests were used to verify the quality of the pneumatically driven, EMR swaged lockbolts. Although all tests are needed to verify different characteristics of the installed lockbolt/collar combination, special emphasis was placed on the pre-load and fatigue specimens.

PRE-LOAD TESTS

When a collar is swaged on the serrated end of a lockbolt, the entire shank of the lockbolt is put in tension. The amount of tension is known as "pre-load" and is a critical parameter for ensuring the integrity and the fatigue life of a bolted joint. Tests were performed for determining the optimum voltage setting range for 1/4, 5/16, 3/8 and 7/16 inch nominal diameter lockbolt collars. Tests were per MIL-STD-1312-16 as shown in Figure 4 below.

Inserting a lockbolt and swaging a collar between two thimbles with clearance fit holes as shown in Figure 4 makes the pre-load test specimens. A thin friction paddle is sandwiched between the two thimbles. There is hole through the center of both thimbles and the paddle. The ends of the thimbles are installed in a tensile test machine and axially loaded at a known rate, such as 6700 N/min (1500 pound/min). The paddle moves when the axial force matches the pre-load tension. Further, the axial load is increased until the collar fails in tension. The aluminum of the collar is sheared in the lockbolt grooves as shown in Figure 5.

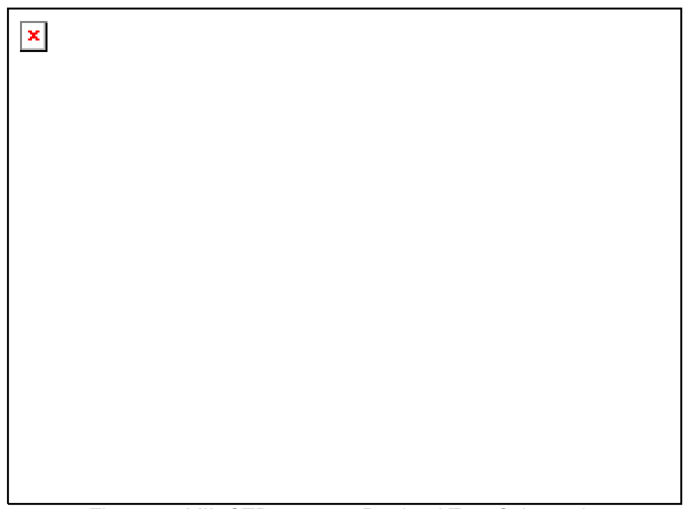

Figure 4. MIL-STD-1312-16 Pre-load Test Schematic

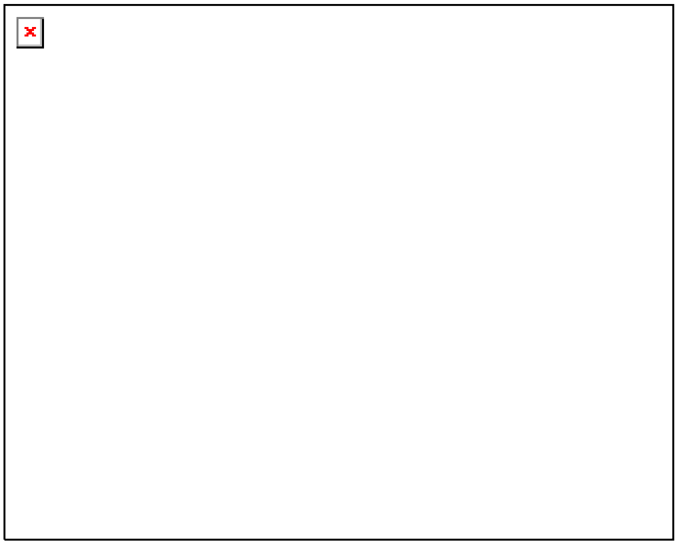

Figure 5. Several Pre-load Specimens after Testing

A series of pre-load test was performed for each fastener diameter. The voltage setting of the EMR on the collar side controls the amount of the swaging force. A range of acceptable EMR swaging voltages was found for each fastener diameter. Table 1 below lists the fastener manufacturer's minimum pre-load tension, minimum ultimate load, and the airframe manufacture's load for tension fatigue test.

lockbolt diameter	Minimum pre-load	Min. tensile ultimate	Tension fatigue load
in	N (lbf.)	N (lbf.)	N (lbf.)
1/4	6670 (1500)	13300 (3000)	5560 (1250)
5/16	11100 (2500)	22200 (5000)	8450 (1900)
3/8	15600 (3500)	31100 (7000)	13300 (3000)
7/16	22200 (5000)	44500 (10000)	17800 (4000)

Table 1. Lockbolt Tension Targets and Loads

<u>Figures 6 through 9</u> show the relationship between swaging voltage and pre-load. Taking Figure 7, for example, the minimum pre-load tension is 11,100 N (2,500 lbf.) and the minimum ultimate load is 22,200 N (5000 lbf.) Collar side voltages from 235 to 275 volts yield acceptable pre-loads for these 5/16 inch lockbolts. In production, acceptable pre-load for the minimum and maximum stack thickness for a given grip narrows the actual range of voltages used to approximately ±10 volts. EMR charging voltage is controlled within ±1.5 volts. This testing also identified a need to change the philosophy for establishing the swage gauge design.

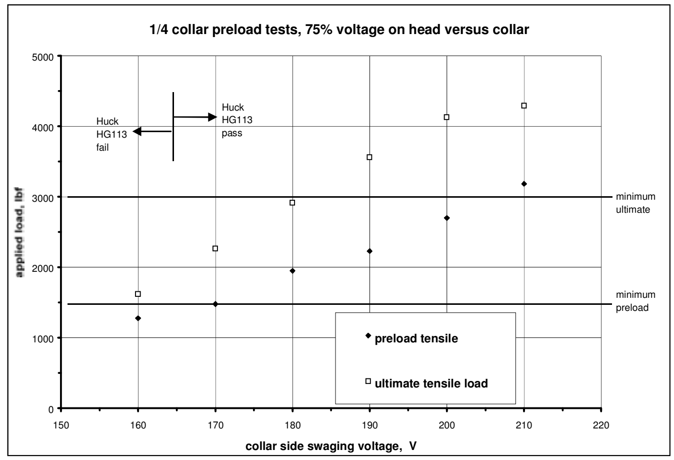

Figure 6. ¼ Collar Pre-load Tests

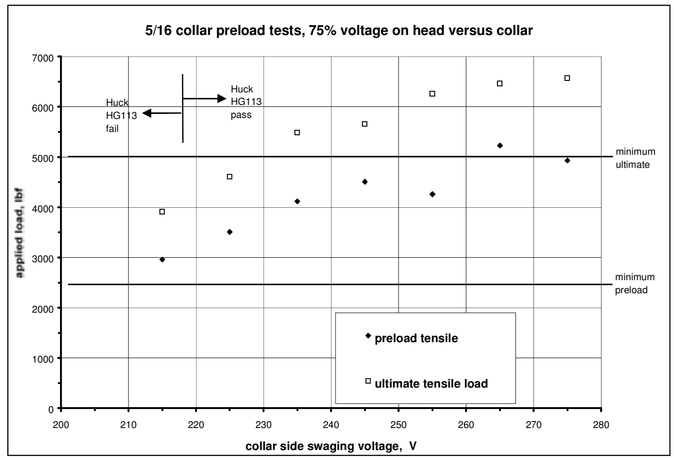

Figure 7. 5/16 Collar Pre-load Tests

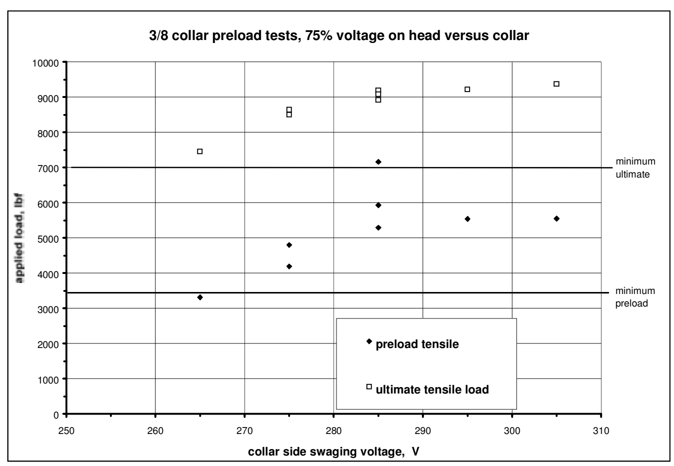

Figure 8. 3/8 Collar Pre-load Tests

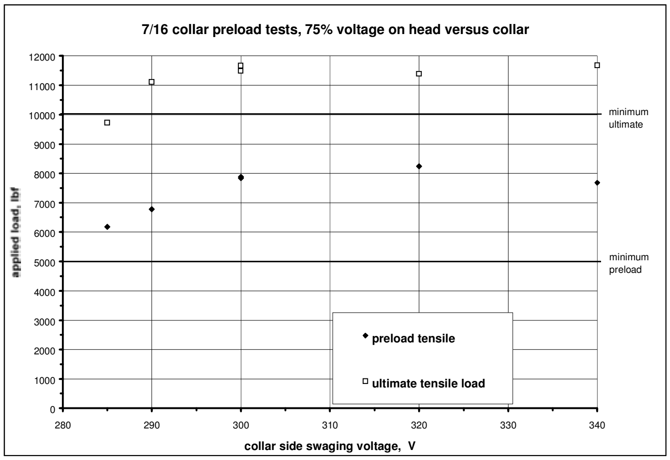

Figure 9. 7/16 Collar Pre-load Tests

TENSION-TENSION COLLAR FATIGUE TESTS

Tension-tension fatigue of lockbolt collars was performed to MIL-STD-1312 test 11. Cyclic tension is put on the lockbolt head and the swaged collar to the loads listed in the far right column of Table 1. Twelve collars were EMR swaged, three for each diameter 1/4”, 5/16”, 3/8” and 7/16”. All tests were stopped after 130,000+ cycles without failure. Collars were then tested to ultimate load. All tests exceeded the minimum required ultimate load of the collar. Tension fatigue life is a function of good fastener design. These tests again verified that the EMR collar swaging process provided adequate performance compared to existing processes.

HIGH-LOAD LAP SHEAR FATIGUE TESTS

These tests compared the lap shear fatigue life of 1/4-14 lockbolts with EMR installed collars to the existing hydraulic squeeze (Drivmatic) process. The test coupons conformed to the airframe manufacturer’s drawings. In addition, Electroimpact tested additional coupons with two bolt holes as shown in Figure 10. See Figure 11 for a photograph of a specimen in the fatigue test fixture. In practice, the jaws (plates) clamping the coupon were shimmed to center and parallel within 0.12 mm (0.005 inch.)

These coupons were subjected to a net alternating stress of 100, 150, or 210 MPa (14.5, 21.7, or 30.5 ksi) with a mean stress of zero. (Fully reversing tension and compression loads). Over 30 fatigue tests were performed by Electroimpact. 16 tests with specimens provided by the airframe manufacturer. 20 preliminary tests were also carried by Electroimpact with 7075-T6 aluminum coupon material.

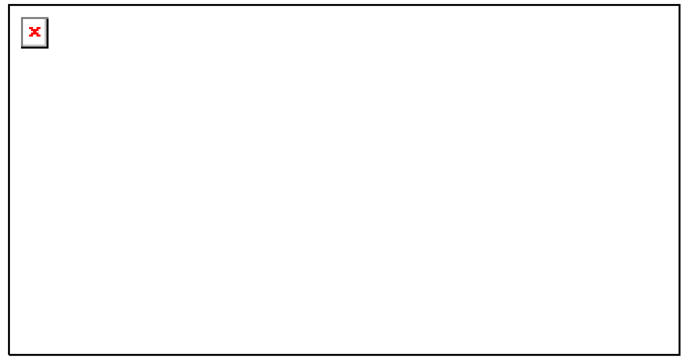

Figure 10 High Load Lap Shear Fatigue Test Coupon

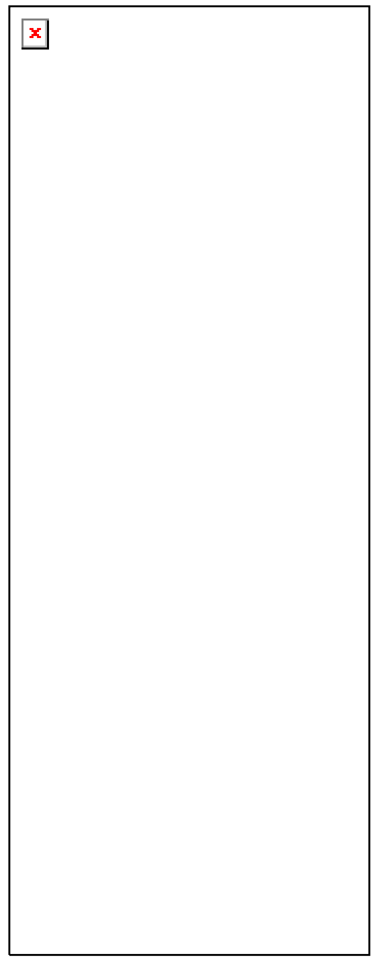

Figure 11. Fatigue Test Fixture – Loaded High Lap Shear Coupon

A comparison of the fatigue results for hydraulically pulled and swaged lockbolts versus pneumatically driven, EMR swaged lockbolts is given in Figure 12. For example, at a stress level of ± 150 MPa (21.7 ksi), both the hydraulically swaged and the EMR swaged specimens cracked around 100,000 cycles. Similar results can be seen at the higher and lower stress levels. Control specimens and further tests conducted by Airbus UK Limited at Filton verified the integrity of joints assembled by this process.

STATIC LAP SHEAR TESTS

These tests were carried out to verify the static shear strength of lockbolts with electromagnetic set collars. The specimens were two rectangular aluminum plates with a two lockbolts through the lap joint to the airframe manufacturer's drawings. The plates are pulled, causing shear stresses in the lockbolts. Laboratory control coupons were provided to the airframe manufacturer. In addition, two coupons with 7075-T6 material were tested. Both coupons failed by shearing the (1/4 inch nominal) titanium alloy lockbolts at 50.7 kN (11,000 lb.) and 50.5 kN (11,350 lb.) respectively. The EMR swaging process provided good static lap shear strength.

PRESSURE FUEL RETENTION TESTS

A pressure chamber test was used to verify the fuel retention capability of pneumatically driven/EMR swaged lockbolts. This test was per MIL-STD-1312-19. Airbus UK Limited provided the test plate as shown in Figure 13. Electroimpact applied sealant to the countersink, pneumatically installed the lockbolts, and EMR swaged the collars. Huck International performed the test at their Irvine, California test facility. Pressure in the test chamber was cycled to 50 psi for 1000 cycles. After the successful test, Figure 14 illustrates the top of plate with bolt heads under die penetrant developer.

METALLURGICAL EXAMINATION

Electroimpact provided (14) specimens to the airframe manufacturer's Technical Centre for metallurgical examination. Lockbolt sizes were 1/4-4, 1/4-15 and 5/16-7. Typical microsections are shown in Figures 15 and 16 in the following illustrations. Lockbolts were pneumatically/percussively driven and EMR swaged. Specimens were cut from the plates, potted in polymer, faced, polished, and photographed under a microscope. Microsections verify the integrity of EMR swaged collars.

CONCLUSIONS

Pneumatically driving and EMR swaging lockbolt collars met or exceeded the current Drivmatic (hydraulic) installation in terms of pre-load, lap shear fatigue life, and static shear strength. These and the other airframe manufacturer's tests provided confidence to invest in equipment for the electromagnetic swaging of lockbolts. Pre-load tests also identified a need to change the swage gauge design philosophy when using this type of process. A wide range of acceptable voltage settings can be used for EMR swaging. In addition, these tests give design engineers confidence that the allowable loads, strength, and fatigue life of these installed fasteners exceed the lockbolt manufacturer's minimum values.

Electromagnetic riveters (EMRs) have now installed millions of lockbolts in production on large commercial aircraft. They have been used on lockbolts from 1/4 to 7/16 inch diameter.

ACKNOWLEDGMENTS

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REFERENCES

1. "Low Voltage Electromagnetic Lockbolt Installation", John Hartmann, et.al., SAE Aerofast 1992 paper 922406

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DEFINITIONS, ABBREVIATIONS

CNC: computer numerically controlled, any machine or process controlled by a computer, where the computer controls the machine position and processes.

Collar: a cylinder (typically of aluminum alloy) that is cold formed on the serrated end of a lockbolt pin.

EMR: electromagnetic riveter. An electromechanical device that installs and forms aerospace fasteners.

Grip: the range of joint thickness that a fastener can assemble. For instance, a stump type lockbolt with a –11 grip can fasten a stack thickness from 11/16 inch (17.5 mm) down to 10/16 inch (15.9 mm).

Lockbolt: A two piece fastening system consisting of a headed parallel shank pin (generally titanium alloy) and a collar (generally alloy aluminum) swaged on to the serrated pin end.

Figure 12. Results – High Load Lap Shear, Hydraulic versus EMR Swage

Figure 13. Fuel Tightness test – Collar Side of Test Plate with Slotted Packing Ring

Figure 14. Fuel Tightness Test – Top of Plate with Bolt Heads Under Penetrant Developer

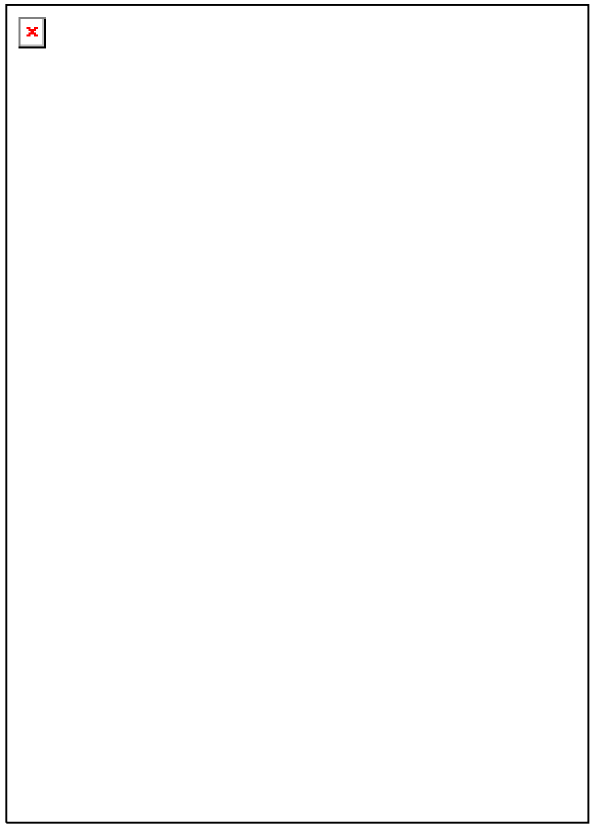

Figure 15. Typical Sectioned Lockbolt and Collar, 5/16-7 Shown

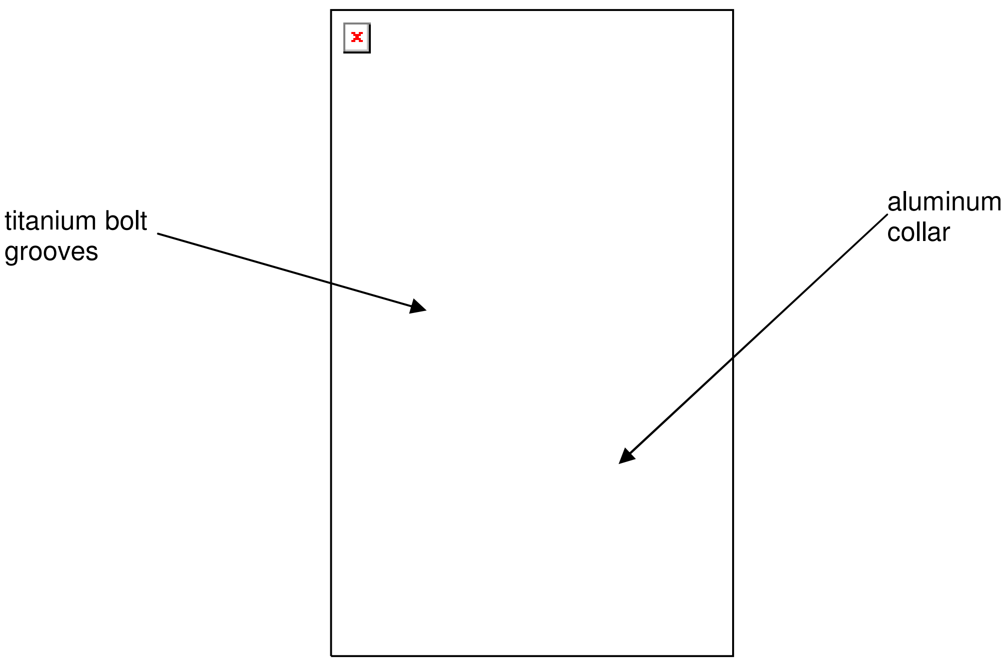

Figure 16. Microsection of Collar Groove Fill, Approximately 50x Scale