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CARDEROCK DIVISION

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IN REPLY REFER TO
9074
Ser 61/09-220
14 AUG 2009

From: Commander, Naval Surface Warfare Center, Carderock Division, Philadelphia, PA
To: Commander, Naval Sea Systems Command (05D)

Subj: **LIMITED APPROVAL OF HILTI, INC. X-BT DRILLING, POWDER-ACTUATED & THREADED FASTENING SYSTEM FOR USS SAN ANTONIO (LPD-17) CLASS**

Ref: (a) E-mail from W. Fowler (NSWCCD 9150) to A. Leofsky (NSWCCD Code 615) on 2 Jun 2009 @ 9:01
(b) MIL-STD-1689A (SH), "Fabrication, Welding, and Inspection of Ships Structure", dtd 23 Nov 1990
(c) E-mail from K. Y. Chin (SSGC) to R. G. Wadeson (SSGC) on 5 Dec 2008

Encl: (1) Material Selection Information for HILTI, Inc. X-BT Drilling, Powder-Actuated & Threaded Fastening System For USS SAN ANTONIO (LPD-17) CLASS

1. Reference (a) requested Naval Surface Warfare Center, Carderock Division, Ship Systems Engineering Station (NSWCCD-SSES) Applied Joining and NDE Branch Code 615 to compile, evaluate and provide a summary of available fastener/material selection information for the HILTI, Inc. X-BT drilling, powder-actuated and threaded fastening system with the intent of obtaining limited approval for use on USS SAN ANTONIO (LPD-17) Class. Outstanding risks have been identified. All known concerns have been addressed to the satisfaction of NSWCCD-SSES Code 615 for the intended applications, in the identified environment, within design allowables and when OEM recommendations are followed. Existing test data for HILTI X-BT 3/8-16UNC stainless steel stud shows it will not develop the full direct axial pullout strength of a traditional *welded* 3/8 stud but does meet all relevant acceptance criteria when the axial tensile load is applied by torquing. Reference (c) recommended approval for usage. Enclosure (1) is the consolidated final report. No additional material testing is recommended.

2. The HILTI, Inc. X-BT Threaded Fastening System is an easy to use powder-actuated stud "gun" with the purpose to allow Northrup Grumman Ship Systems Avondale Operations (NGSB) to permanently attach studs on interior bulkheads/decks that have been closed-out (painted). Although the HILTI studs cost approximately $6/each, as a repair method or when an otherwise-completed compartment requires a few studs for miscellaneous electrical applications it is advantageous when compared to welded studs because the HILTI equipment is

portable/cordless, requires little preparation and requires no re-work (hot-work/paint/insulation). HILTI reports that one user can set 100 studs/hour. The HILTI X-BT stud utilizes a hardened unthreaded shank that is 4.5 mm diameter and is interference fit into a 4.0 mm blind pilot hole. The unthreaded shank and threaded sleeve are friction welded as-provided by HILTI. The paint on the near-side is sealed with a neoprene washer and is not damaged on the far side.

3. The NSWCCD-SSES 615 Fastener Technical Authority Master Plan allows for shipbuilder input and lessons learned to promote safety, standardization and use of the most readily available fasteners. It is estimated that for some ships, depending on mission, 90 to 100% of the fasteners may be considered non-critical, and could make use of commercial standards to promote low cost, standardization, ease of ordering and rapid insertion of new technology into the Fleet.

4. In summary, NSWCCD-SSES 615 recommends limited approval for HILTI X-BTW10 24 6 SN12 R stainless steel studs with 3/8-16UNC threaded sleeve because they are considered equivalent to 3/8-16UNC *welded* studs when installed in the intended applications (below), in the identified environment, within design allowables and when OEM recommendations are followed.

Intended applications:

- Electrical cable wireway hanger
- T-bar slotted channel
- Milcom Systems Drop Box Types A & B
- Terminal Box (SYM 400.2)
- Outlet Box 11 K/O w/Mtg Holes (SYM 730.1)
- Grounding

5. NSWCCD-SSES Code 615 considers it the responsibility of NAVSEA 05D and PMS317 to provide this report to other tech codes for review and concurrence

6. The NSWCCD-SSES technical point of contact is A. Leofsky, Code 615, Commercial (215) 897-7504, Defense Switched Network (DSN) 443-7504, email: anthony.leofsky@navy.mil.

James P. Soisson
Head, Applied Joining and NDE Branch
By direction of the Commanding Officer

Subj: **LIMITED APPROVAL OF HILTI, INC. X-BT DRILLING, POWDER-ACTUATED & THREADED FASTENING SYSTEM FOR USS SAN ANTONIO (LPD-17) CLASS**

Copy to:
NAVSEA (00C53, 05P24)
PMS 317
Blind Copy to:
61, 615, 616 (U. Sorathia), 669 (J. Gosch), 9150 (W. Fowler), 9772 (R. Wagner)

Material Selection Information for HILTI, Inc. X-BT Drilling, Powder-Actuated & Threaded Fastening System For USS SAN ANTONIO (LPD-17) CLASS

References:

(a) NSTM MIL-STD-1689A (SH), Fabrication, Welding, and Inspection of Ships Structure, dtd 23 Nov 1990
(b) NAVSEA T9074-AX-GIB-010/100 Technical Publication, Material Selection Requirements, dtd 29 Jan 1999
(c) NSWCCD-TR-61-98/26, *150 ksi Yield Strength Fastener Material Certification Plan*, dtd Nov 1998
(d) Mtg btwn NSWCCD-SSES 615 (A. Leofsky, F. Kachele, E. Hakun, J. Allison, V. Zuwiala) / HILTI, Inc. (W. Gould, B. Deierlein, S. Havrilla) of 16 Apr 2009
(e) HILTI Specification Binder Edition 08/2008
(f) ANSI/ASSE A10.3 Safety Requirements for Powder-Actuated Fastening Systems Standard, dtd 12 Jun 2006
(g) http://www.wschulz.com/english/index.php?cid=51
(h) Metals Handbook, 10th Edition, Volume 1: Properties and Selection: Irons, Steels and High-Performance Alloys, ASM International, page 870, 1990
(i) NAVSEA S9074-AR-GIB-010/278 Technical Manual, Requirements for Fabrication Welding and Inspection, and Casting Inspection and Repair for Machinery, Piping, and Pressure Vessels, dtd 1 Aug 1995
(j) NAVSEA S9074-AQ-GIB-010/248 Technical Publication, Welding and Brazing Procedure and Performance Qualification, dtd 1 Aug 1995
(k) http://www.alleghenytechnologies.com/ludlum/Documents/AL4565.pdf
(l) http://www.outokumpu.com/applications/upload/pubs_4272642.pdf
(m) http://www.nirosta.de/fileadmin/media/PDF/4565_en.pdf

1. Purpose: This report summarizes the available material selection information which shipyards can use to support development of their own standard operating procedures or process instructions in accordance with reference (a) for using the HILTI, Inc. X-BT drilling, powder-actuated and threaded fastening system shown in **Figure 1** to install stainless steel studs 3/8 inch diameter for the intended applications as defined in paragraph 4, in the identified environment as defined in paragraph 6, within design allowables as defined in paragraph 13, and when all OEM recommendations, as described in this report, are followed.

2. General Information: NSWCCD-SSES Code 615 does not consider the intended applications to be critical as defined by reference (b), but those requirements are considered here because HILTI proprietary alloy CR-500 (used for the shank) is a new material in a new application for the U.S. Navy. Reference (c) was reviewed and is relevant because it provides a generic roadmap within which an application-specific certification plan can be developed for new or existing alloy candidates in new or existing fastener applications and further recommends, "Obtain reliable information (from open literature, manufacturers, etc.) to eliminate any testing that is not required for the candidate material. Depending on the prior performance of a given material, testing can be reduced in a particular area." Reference (d) included a hands-on demonstration of the system and HILTI provided reference (e) as a

summary of procurement and developmental testing information to NSWCCD-SSES Code 615.

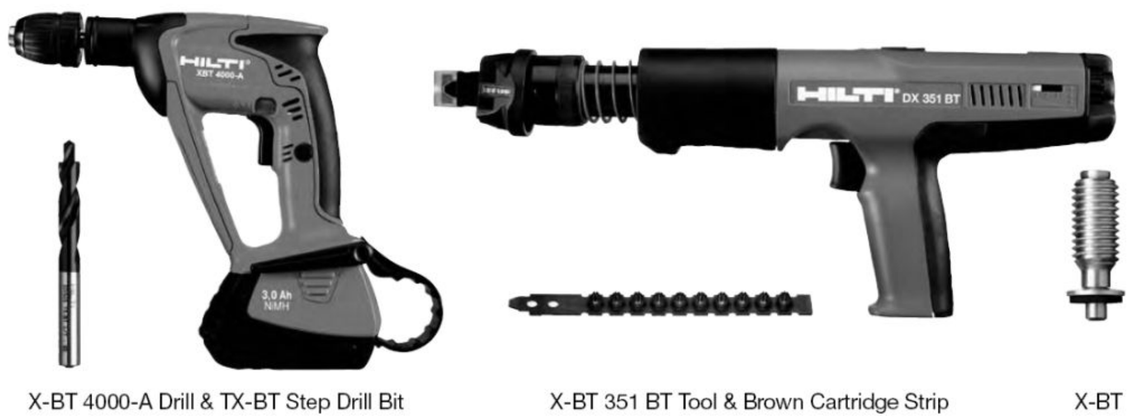


Figure 1. HILTI, Inc. X-BT drilling, powder-actuated & threaded fastening system.

3. Performance Requirement: The acceptance criteria for traditional *welded* studs per reference (a) is considered as a baseline – some criteria was found appropriate, some overly conservative and some applicable for quality control and/or risk reduction. It can be argued that the resultant joint between the HILTI X-BT stud and base metal is a solid-state (friction) weld but NSWCCD-SSES Code 615 considers the joint no more than a partial weld and, for all practical purposes, the joint is treated as a mechanical interference fit rather than a weld. It has not been shown that fusion occurs. HILTI reports with respect to the holding mechanism that “a definite interface exists along the entire perimeter of the fastener shank.”

4. Intended applications:
- Electrical cable wireway hanger
- T-bar slotted channel
- Milcom Systems Drop Box Types A & B
- Terminal Box (SYM 400.2)
- Outlet Box 11 K/O w/Mtg Holes (SYM 730.1)
- Grounding

5. X-BT System Equipment:
- HILTI X-BT 4000-A Cordless Drill.
- HILTI TX-BT 4/7 Step Drill Bit (for pilot hole) – 4 mm diameter x 7.2 mm deep.
- HILTI model DX-351BT powder-actuated gun.
- HILTI 6.8/11M “Brown” cartridge strip (cased, combustible propellant powder load) – “high precision” having a narrow energy band and specific energy level.
- HILTI stud: X-BT W10-24-6 SN12-R threaded fastener with neoprene sealing washer.
- HILTI Power Regulation Guide – Go/No-Go gauge for fastener stand-off (not shown).
- HILTI Coating Protector.

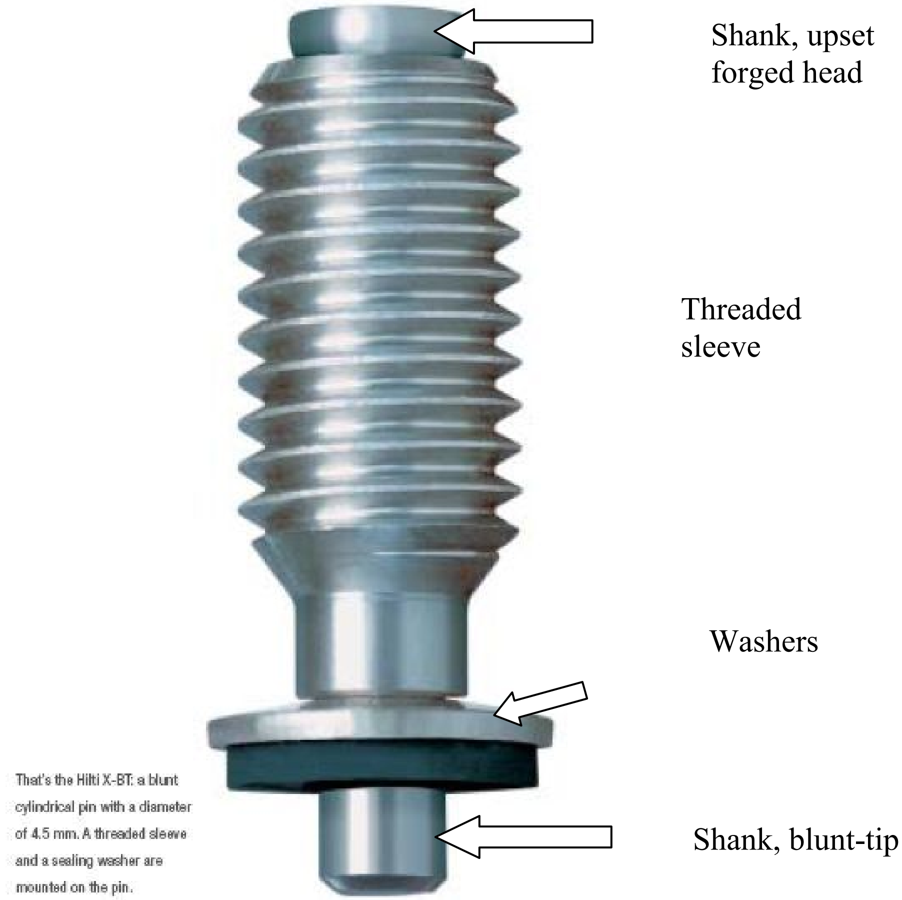
6. In-service environment: USS SAN ANTONIO (LPD-17) Class interior bulkheads/decks that have been closed-out (painted).

7. System overview: The drilling damages paint, just like welding does, but the step drill bit controls the removal of the protective coating and ensures the right depth of the blind hole. Furthermore, a sealing washer, larger in diameter than the area of bright steel around the hole, completely covers the hole and prevents moisture from entering. Reworking, like that required from welding, is unnecessary.

8. Stud description: The as-provided 3/8-16UNC threaded sleeve is pushed onto a hardened cylindrical pin (or shank) and friction welded. The shank has a blunt-tip on one end and the other is an upset forged head. The as-provided integral metallic washer is bonded to the neoprene washer and is held to the shank by friction until installation. The X-BT stud shown in **Figure 2** has the following dimensions and materials:

X-BT stud components	Length	Diameter	Material
Threaded sleeve	24 mm	3/8-16UNC	A4/A316 Stainless
Shank	31.3 mm	4.5 mm (0.177 inch)	CR-500 Stainless
Integral metallic washer	~	12 mm diameter (½ inch)	A4/A316 Stainless
Bonded sealing washer	~	12 mm diameter (½ inch)	Neoprene elastomer

9. Outline of HILTI X-BT installation steps:
   a. Using the provided Power Regulation Guide (stand-off gauge) check trial fastenings and set the power regulation on the DX-351BT powder-actuated gun (tool).
   b. Mark location for each fastening.
   c. Drill blind pilot hole w/step drill bit 4 mm (0.157 inch) diameter, 7.2 mm (0.276 inch) deep until shoulder bottoms. Note: The drill bit scrapes paint away providing an indication of having reached the correct depth. This ring scraped away is protected from corrosion by the sealing washer once the stud is installed.
   d. Clear drilled hole of debris.
   e. Manually insert forged head of stud into tool.
   f. Align and center chamfered end of stud with pilot hole. Note: Safety switch will not engage unless tool is held perpendicular with minimum axial force of 5 lbs.



i.

g. Figure 2. HILTI X-BT stud, magnified view.

h. Using tool, drive 4.5 mm shank stud into 4mm pilot hole – Note: The penetration depth or length of contact between the shank and base metal is 4-5 mm into 7.2 mm deep hole as shown in **Figure 3**.
i. Confirm proper fastener stand-off and compression of neoprene washer by inspection and measuring distance between top of stud and base metal surface compared to the HILTI Power Regulation Guide.
j. Install item to be fastened using shipyard supplied conventional washer(s) and nut(s).
k. Tighten nut(s) to specified torque.

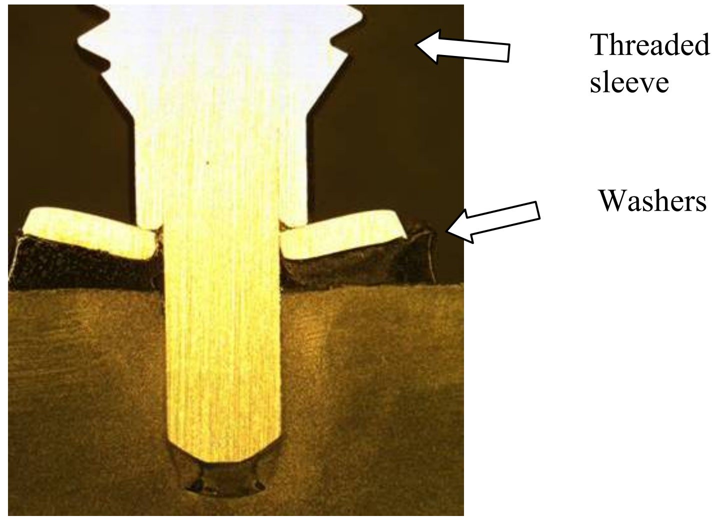


Figure 3. Cross section showing penetration depth/washer compression.

10. Base Metal: Structural steels - ordinary and higher strength carbon steels and stainless steel.

11. Base Metal thickness: minimum 5/16 inch thick (7.9 mm). May install on ¼ inch (approx. 6.4 mm) thick flange if shipyard procedure accurately locates the 7.2 mm deep pilot hole to coincide with the web of "T" and "I" beams as seen in **Figure 4**. If the hole is not accurately located the coating on the reverse side of the base metal will suffer damage, but the penetration depth is automatically limited by both the tool's piston brake and the integral stud washers.

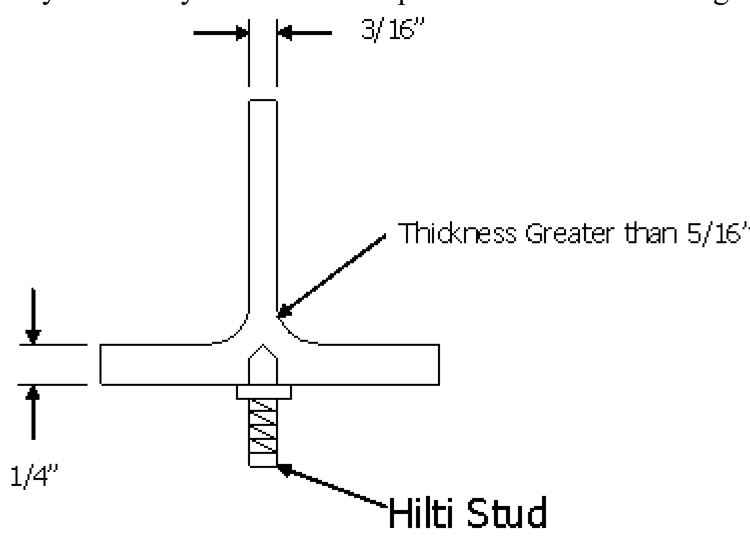


Figure 4. Cross section of stiffener showing stud location on flange coincident with web.

12. Position: Because the HILTI X-BT stud is driven into the base metal directly in a single operation under great force, it is considered independent of tool position (vertical, overhead,

horizontal, etc.) provided that the tool axis is perpendicular to the base metal. The design of the tool does not allow firing unless it is perpendicular.

13. Design allowables: 405 lbs tension, 585 lbs shear, 6 ft-lbs moment.

14. Maximum tightening torque of nut: 6 ft.lbs.

15. Thread lubricant: Assumed dry - lubrication factor K=0.20. NGSB shall adjust torque according to friction coefficient of any thread lube that is used.

16. Fastener stand-off: 1.012-1.055 inch.

17. Temperature: Ambient.

18. Operator Training: In cooperation with the shipyard, HILTI will provide familiarization/ installation/operator training which incorporates the requirements of reference (f), or equivalent.

19. Sealing Washer:

Neoprene, also known as chloroprene, is considered resistant to: oils, chemicals, sunlight (UV), weathering, aging and ozone. Neoprene retains its properties up to 250ºF, has superior resistance to compression set and does not support combustion but is consumed by fire.

20. Threaded Sleeve and Washer Alloy:

Hilti specifies austenitic stainless steel DIN Standard 17440 German Material no. 1.4401 (A4) DIN X2CrNiMo17132 / X5CrNiMo17-12-2+2H with the following properties:

- Ultimate tensile strength = 750-850 N/mm^2 (109-123 ksi)
- Yield strength ≥400 N/mm^2 (58 ksi)

These values are comparable to ASTM F593 grade 316/316L (UNS S31600/31603) in a cold worked condition which has 100-150 ksi tensile 65 ksi minimum yield and Rockwell hardness $95R_B$-$32R_C$. It was estimated to have 20% cold reduction based on Aerospace Structural Metals Handbook.

21. Hardened Shank Alloy:

Hilti standard HN 0433 specifies a proprietary "CR500" nitrogen alloyed austenitic stainless steel German Material no. 1.4565 DIN X2CrNiMoNbN25-18-5-4 chemistry:

%	**C**	**Si**	**Mn**	**Cr**	**Mo**	**Ni**	**Cb**	**N**	**P**	**S**
≥		0.30	3.50	23.50	2.00	14.50		0.40		
≤	0.03	0.50	4.50	25.00	2.50	15.50	0.15	0.50	0.03	0.03

made of 4.48 mm diameter wire with the following properties:

- Ultimate tensile strength ≥ 1850 N/mm^2 (268 ksi)
- Yield strength - NA

- Strain at fracture (A_5 elongation) ≥ 7%
- Reduction of Area ≥ 40%
- The wire is required to pass a 45º bending test.

This "CR500" material is sometimes referred to as "super austentic" because of the high content of alloying elements. It has no known U.S. specification equivalent for fasteners but is closest in chemistry to UNS S34565:

%	C	Si	Mn	Cr	Mo	Ni	Cb	N	P	S
≥			5.0	23.0	4.0	16.0		0.4		
≤	0.03	1.0	7.0	25.0	5.0	18.0	0.1	0.6	0.03	0.01

According to reference (g), UNS S34565 was originally developed for applications in chloride containing environments especially seawater. It is used for pollution control equipment (scrubbers), offshore oil and gas equipment, and seawater desalination plants. The alloy does cold-harden from working considerably faster than conventional austenitic grades. It was estimated that the CR500 is in the fully hardened condition (perhaps 60% cold reduction) by comparison to Figure 13 of reference (h) which shows the typical effect of cold reduction on the tensile strength of selected stainless steels. But CR500, due to the high nitrogen content, is not always like those other steels because the structure remains austenitic even with extensive cold reduction.

CR500 alloy is unusually strong and hard compared to traditional fasteners. HILTI reports both "To allow a stud to be driven into steel, its hardness and strength must be approximately 4-5 times that of the base material." and "X-CR austenitic stainless steel is 3 times harder than ferritic construction steel." Two available mill certs reported the hardness as 45.3-46.0 R_C for Bōhler heat number L04458 and 47.5-50.2 R_C for heat number L04459.

Some Navy shipbuilding specifications (such as the VIRGINIA Class submarine) identify "brittle material" as material having less than 10% elongation and further state "Brittle materials shall not be used unless specified otherwise, or where the Government approves their use for a particular application." MIL-S-901D also has guidance for the of 10% elongation rule-of-thumb in paragraph 6.4(c): "Desirable material properties for shock resistant design are high yield strength, high ductility (at least 10% elongation), high fracture toughness, and, in some cases, low density…" It must be noted that some high strength titanium alloys have single-digit values of elongation.

Tensile test elongation (strain at fracture) and reduction of area values are both measures of ductility but they measure different types of material behavior: elongation is "stretching" primarily influenced by uniform elongation and is dependent on the strain-hardening capacity of the material. Reduction of area is plastic "contraction" and more a measure of the deformation required to produce fracture because highly ductile materials are greatly reduced in cross section before breaking. Very ductile material will have high values of each and a nonductile material has near-zero values of each.

Elongation values are dependent upon the gage length of the test specimen. The European elongation method (A_5) is based on an initial gage length being set equal to five (5) times the specimen diameter (5D). The U.S. elongation method is based on an initial gage length being set equal to four (4) times the test diameter (4D). Because the total elongation consists of two components: the uniform extension up to necking and the localized extension once necking begins, the shorter the gage length the greater the reported elongation. Therefore, the European elongation data must be increased by some amount to obtain the equivalent U.S. elongation. Per ASTM A1058 table 2, to convert from 5D to 4D for austenitic steel the multiplication factor is 1.029 such that 7% * 1.029=7.2%. Two mill certificates for the wire show that the actual A_5 elongation was 8 and 9% - so the equivalent elongation values in the U.S.would be 8.2 and 9.3%.

NSWCCD-SSES Code 615 considers CR500 alloy with minimum A_5 elongation of 7% (7.2% in the U.S.) and reduction of area ≥40% to have adequate ductility in the intended applications. Additional rationale of bending ductility is provided below.

22. Axial Tensile by Torquing Load:

SSGC performed torque to failure tests in accordance with reference (a) on 21 studs and results ranged from 26-54 ft-lbs. The X-BT stud meets all criteria for traditional *welded* studs 3/8 inch dia. for both carbon steel and CRES as shown in **Figure 5**. All acceptance criteria in Navy fabrication documents (1689, 278 and 248) assumes a lubrication factor K=0.15. The preproduction criteria of reference (a) '1689' Table V is 7.2 ft.lbs, the production criteria of reference (i) TechPub 278 Table XII is 7.2 ft.lbs. for either carbon steel or CRES, the procedure qualification criteria of reference (j) '248' Table XVI is 12.8 ft.lbs. for carbon steel or 20.6 ft.lbs. for CRES. Interestingly, TechPub 278 and MIL-STD-278F have different criteria, and the failure torque values also meet the requirement of MIL-STD-278F Table XII (21 ft.lbs. for carbon steel and 17 ft.lbs. for CRES).

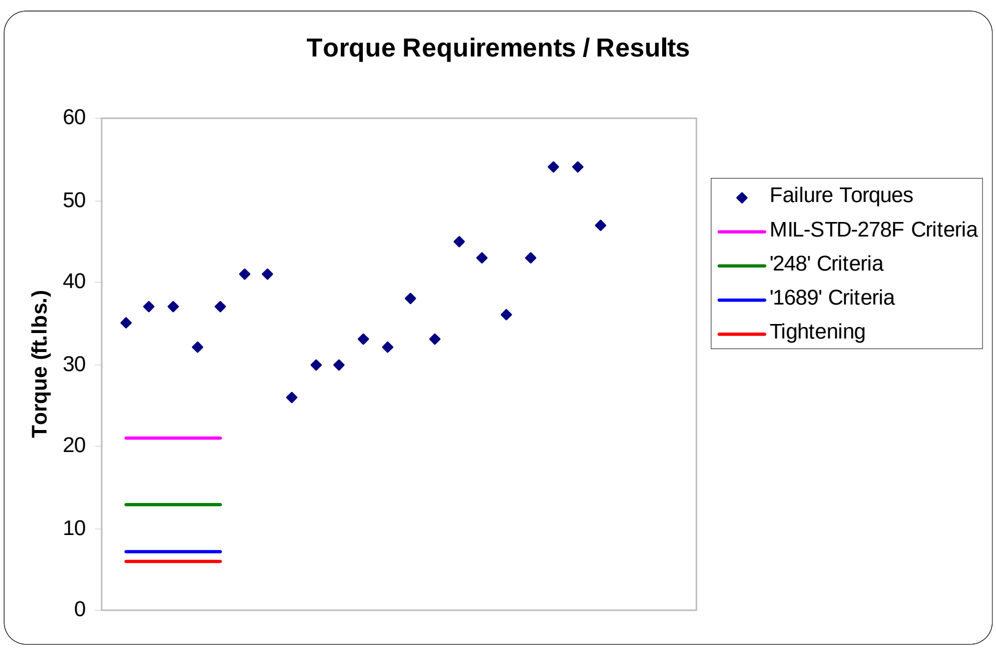
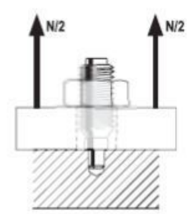


Figure 5. Comparison of failure torques, various criteria and tightening torque.

23. <u>Axial Tensile Load:</u>

Welded studs require testing by either axial tensile loading or by bending. The axial tensile load may be applied directly or by torquing. When the axial load is applied directly, the X-BT stud does NOT meet the criteria for traditional *welded* studs 3/8 inch diameter. Although X-BT studs are made from high-strength material, they cannot be pretensioned like high strength bolt joints. The full strength of 3/8 inch stud is not developed. HILTI reported that the studs were static tension tested to ASTM E1190 Standard test Methods for Strength of Powder-Actuated Fasteners Installed in Structural Members. **Figure 6** shows typical results for X-BT direct axial failure loads. Traditional *welded* studs are limited by the material strength of the stud/weld - notice that for the X-BT the stronger the base metal the higher the pullout load. For example, if the X-BT was attached to HY-80 alloy steel (95 ksi tensile) the mean load value expected is 3000 lbs. For typical structural steel base metal of 50 ksi tensile strength the mean load value expected is about 2000 lbs. but the 5% fractile is only 1350 lbs.

Base Material:	Steel, 6, 8, 10, 12 and 15mm thick, S235 and S355
Number of fastenings in test:	200 total, (20 per situation of thickness and steel grade)



Ultimate Pullout Load as a Function of Base Steel Ultimate Tensile Strength

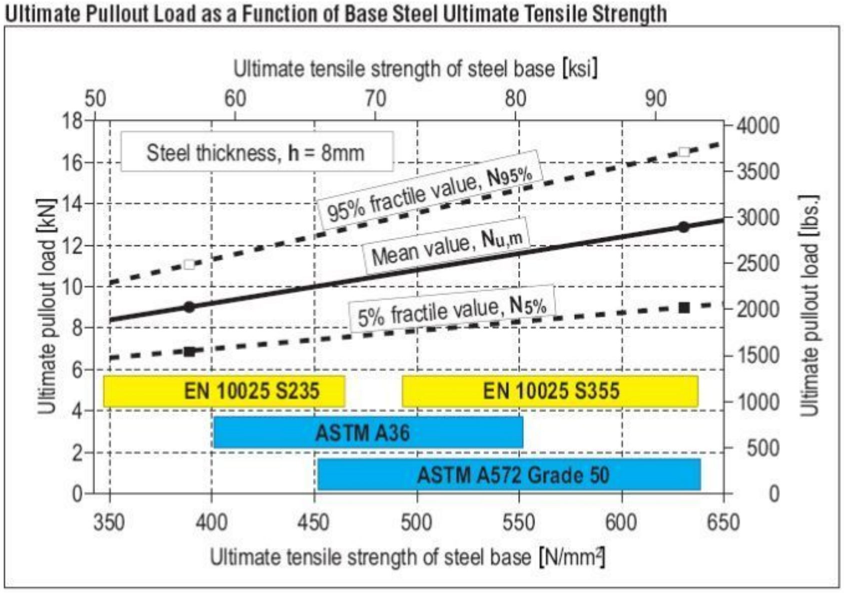


Figure 6. Typical direct axial failure loads for X-BT studs.

24. <u>Axial Tensile Load Criteria:</u>

The axial tensile load criteria for 3/8 diameter *welded* studs are summarized here:

Source of requirement	**Criteria Axial** (lbs.)	**Yield**	**Material Strength** (ksi)	**Criteria Torque** (ft.lbs.)
MIL-STD-1689	1940	80%	35	7.2
MIL-STD-278F Carbon Steel	3450	90%	50	21
MIL-STD-278F Stainless	2760	90%	40	17
TechPub 278 Criteria (Carbon and Stainless Steel)	1940	80%	35	7.2
TechPub 248 Carbon Steel	3465	90%	50	12.8

Table Note 1: there are obvious discrepancies that have no ready explanation, for example, MIL-STD-1689 is consistent with the current TechPub 278 requirements but MIL-STD-278F is not consistent with any of the other documents.

Table Note 2: TechPub 248 Table XVI provides stud *welding* procedure qualification criteria for both axial load and failure torque for common materials/sizes. It assumes *tensile* strength of 50 ksi for carbon steel. The last line of the table above is not applicable because Note 2 of Table XVI allows the lower torque values for carbon steel to be used when austenitic stainless steel studs are attached to carbon steel. A minimum direct axial load of 3465 lbs and torque value of 12.8 ft.lbs. is specified for carbon steel.

The X-BT direct axial pullout mean load value of 2000 lbs. for typical structural steel base metal of 5/16 inch thickness exceeds both the MIL-STD-1689 and TechPub 278 criteria for *welded* studs but does not meet either the MIL-STD-278F or TechPub 248 criteria. The X-BT direct axial pullout 5% fractile value of 1350 lbs. does not meet any criteria for *welded* studs.

25. MIL-STD-1689 Pre-production bend/tension testing:

MIL-STD-1689 para 6.9 requires pre-production (during setup) studs be inspected by either bending or tension testing to failure five consecutively *welded* studs. The tension testing requirement is *not* considered appropriate for future X-BT installations because it provides no added value in light of HILTIs documented developmental testing, procurement specifications, elimination of *welding* variables, visual Go/No-Go provided by the Power Regulation Guide for fastener stand-off, satisfactory scatter of test results and recommended installation torque of 6 ft.lbs (very low in comparison to failure values). HILTI's Power Regulation Guide is shown in **Figure 7**.

MIL-STD-1689 para 6.9.1 specifies as an alternative to tension testing, the bend testing of pre-production studs to be bent to an angle of 15º and returned. Acceptance criteria requires rejection of the 5 studs tested if any show signs of failure. Bending is another method for evaluating ductility – the severity of which is primarily a function of the angle of bend – but the severity also depends on whether it is bent one-way or bent and returned to the original position. This test is similar to the HILTI standard HN 0433 procurement specification for the wire which is required to pass a 45º bending test but it is not known whether it is bent in just one direction or bent and returned to the original position. HILTI does not bend test the stud itself but the pre-production bend test is considered appropriate for future X-BT applications requiring maximum assurance.

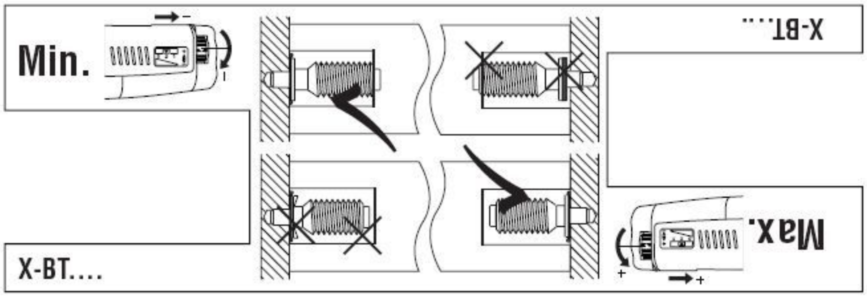


Figure 7. Power Regulation Guide for fastener stand-off providing visual Go/No-Go.

For information: MIL-STD-1689 states 5000 series aluminum alloys shall be bent to 10 degrees. TechPub 248 para 4.4.5.1 (c) states for titanium alloy studs, bend testing is applicable only to the ¼-inch stud, which shall be bent to an angle of 10º.

MIL-STD-1689 para 6.9.2 requires the “Studs shall be subjected to a torque (or an axial tensile load) which will develop not less than 80% yield strength of the stud material.” This requirement for *welded* studs is not a realistic requirement for the X-BT powder-actuated stud – typical welded studs have yield strength of 35 ksi whereas the X-BT shank material has yield strength on the order of 235 ksi.

26. <u>TechPub 278 Pre-and-Post production bend/tension testing:</u>

TechPub 278 para 11.5.1 requires studs be inspected both at the beginning and end of each set-up (diameter change) or shift operation by either bending or tension testing to failure five consecutively *welded* studs. There will be no diameter change with the X-BT stud. The rationale in the above discussion for MIL-STD-1689 also applies. The tension testing requirement is *not* considered relevant because it provides no added value. Bend testing either at the beginning or end is considered appropriate for X-BT but performing both at the beginning and end is not considered necessary because of the minimal variables compared to welding.

27. <u>Shear Testing:</u>

Shear strength of joint increases with base material strength but for ordinary strength carbon steel such as ASTM A36 HILTI reported the average ultimate load of 2700 lbs through displacement of 2.4 mm and the failure mode was 2/3 base metal pullout and 1/3 fastener fracture.

28. <u>Expected modes of failure:</u>

During a static axial pull-out test the studs typically pull out of the base metal. Concur with HILTI that the failure is “graceful” because the load reduction is gradual as shown in the **Figure 8** tension load-displacement curve. This curve shows that the fastener is very stiff up to the maximum load, there is significant resistance to pullout after relatively large displacements and the ultimate pullout load increases with increasing base metal strength.

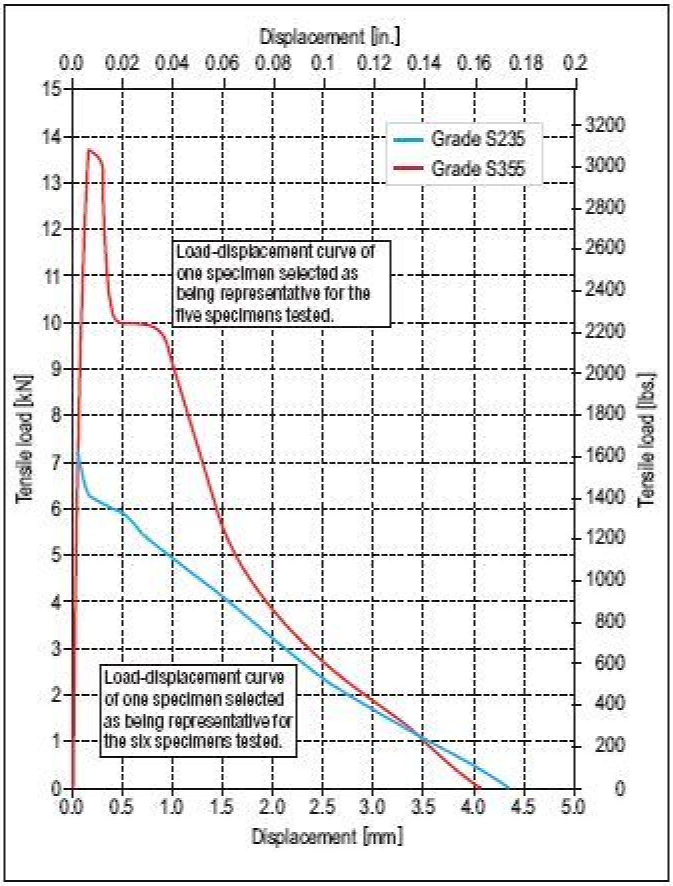


Figure 8. Tension load vs. displacement curve.

29. <u>Underwater explosion shock test and post-test inspection report:</u>

Fasteners generally neither receive "Shock qualification" nor are they required to pass shock testing by themselves - fasteners are usually tested as integral parts of specific equipment. However, HILTI performed shock testing on a lightweight shock machine for the following: electrical cable holder, electrical box and slotted channel. Hi-Test Laboratories, Inc. Report No. 1475 of 30 April 2007 was reviewed. The maximum loading was identified as 4.4 lbs. The shock test result was two bent studs (approximately 20º total) which does not affect performance in the intended applications. There were no other discrepancies.

According to HILTI report 51-07 "Post-Shock Test Functional Testing and Inspection of HILTI X-BTW10 Threaded Stud Fasteners" of 4 May 2007 the two bent X-BT studs were straightened in order to complete the static axial pull-out test. This 20º bending and straightening is equivalent to a more severe test than the 15º required by MIL-STD-1689. The mean axial pullout load values for the two bent studs were not less than those typical of new studs.

30. Vibration: HILTI's oscillation and vibration testing was found to have no damaging effect on the anchorage of the studs. Design is inherently vibration resistant. X-BT is considered equivalent to traditional *welded* stud.

31. Fatigue: Fasteners have been shown not to work loose during testing conducted by HILTI. The anchorage is not the decisive factor in eventual joint fatigue fractures of the threaded shank. Austenitic stainless steels such as cold- worked 316 is known to have good fatigue properties. Alternating fastener loads are low. X-BT is considered equivalent to traditional welded stud.

32. General, Pitting and Crevice Corrosion:

For 90 days at a time, the Hilti X-BT was subjected continuously to a fine spray of salt water in laboratory conditions. The results showed that ultimate pullout loads after the salt spray test were slightly lower than those before the test but was attributed to data scatter. The holes were clean with no visible corrosion – sealing washer provides effective seal.

CR500 is reported to have a pitting potential at least as resistant as AISI grade 316. According to reference (k), grade 316 has a Pitting Resistance Equivalent Number (PRE_N) about one half that of UNS S34565 (more resistant to pitting). According to reference (l), UNS S34565 "has such good resistance to pitting that common test methods are not sufficiently aggressive to initiate any corrosion." According to reference (m), crevice corrosion resistance for UNS S34565 is favorable. Commercial data for UNS S34565 is only available in the low strength condition but NSWCCD-SSES Code 615 expects that uncoated X-BT studs in interior ship compartment may, at worst, have slight rust staining.

33. Stress Corrosion Cracking:

According to HILTI, "The HILTI X-CR fastener is not susceptible to Hydrogen Assisted Stress Corrosion Cracking (HASCC)." According to HILTI, the X-BT and X-CR fasteners are made from the same wire at the same strength level.

According to LRA Laboratories, Inc. Report #HIL 30686 dated 1 Dec 1993 concluded that X-CR material of 45 R_c hardness was:

- Essentially immune to HASCC under very aggressive charging conditions simulating galvanic coupling to magnesium in seawater, cathodic potential of -1.2 volts.
- Calculated to have a tolerable flaw size on the surface 0.040 inch deep (0.080 inch long), semicircular flaw at stresses approaching the yield strength of the material.
- Calculated to have a K_{ISCC} to K_{IC} ratio =1 and damage tolerance index=0.26 such that threaded fasteners as large as 3/8 inch could be manufactured without any concern for HASC from galvanically produced hydrogen.

Edward J. Lemieux at NRL Corrosion Engineering stated that they had no experience with the CR500 alloy.

Per reference (k), UNS S34565 meets the requirements of NACE Standard MR-01-75 "Metals for Sulfide Stress Cracking and Stress Corrosion Cracking (SCC) Resistance in Sour

Oilfield Environments" but only up to values of 29 R_c hardness. UNS S34565 at a hardness of 50 R_c may be susceptible to SCC in an aqueous caustic or chloride environment, and therefore should be kept dry.

34. Toughness/Fracture control: This is not considered necessary for the intended applications. No direct measurement of toughness or impact testing is known for the X-BT stud but neither is the experimental methodology obvious. The design has been service proven in similar construction. X-BT is considered adequate for the intended applications.

35. Electrical resistance: Because the stud and base metal have an intimate metal-to-metal bond the electrical resistance is expected to be equivalent to a traditional welded stud. X-BT stud is UL listed for grounding, maximum 600 V, from testing conducted per Standard UL 467, Grounding and Bonding Equipment with a maximum of 6 AWG wire.

36. Fire resistance: Unknown. Hardness and strength of X-BT austenitic stainless steel is less affected by increasing temperature than ordinary strength carbon steel. Axial tensile pullout resistance could theoretically be reduced but there is no known data.

37. Galling resistance: Unknown. Austenitic stainless steels are at risk for galling of threads.

38. Listings/Approvals: Received ABS confirmation of product type approval 20 Mar 2009 including use as a grounding device under the Service Restriction clause, "Applications and locations where special care is recommended." Also listed by Underwriters Laboratories (UL) for use as grounding studs.

39. Other In-service experience: The HILTI X-BT System been on the market since 2003 and is used worldwide in the petrochemical industry and offshore platforms. X-BT has also been used in the following ship applications (some of which are exposed to the weather):

A. U.K. Royal Navy ships have used X-BT largely for "Naval Fleet refits" or minor rework on new ships.

1. HMS Cardigan Bay. (RFA - Royal Fleet Auxiliary vessel). Refit by A&P (Falmouth) with limited use for supporting electrical cable and T-bar connections.

2. HMS Bristol - Royal Naval Training Ship. Installation of blown-fibre optical mission systems, cable run supported of both ladder rack & cable basket.

3. HMS Ocean - (Helicopter Landing and Auxiliary support vessel). Refit by Babcock Marine with limited use for supporting cable basket and instrumentation.

4. HMS Daring & Duncan - Royal Naval T45 Destroyers (new ships). Minor rework on relocations of electrical cable and instrumentation boxes.

5. HMS Astute Submarines. Minor X-BT use in reactor compartment and rework on relocated cable and instrumentations runs.

B. Floating production storage and offloading (FPSO) vessels:
1. 2004 Petrobas PS2, Brazil.
2. 2004 Turkmenistan Barge, Dragon Oil, Dubai.
3. 2004 Sable Tier11 SVT, ISI Halifax Shipbuilding yard, US.
4. 2005 Golfinher, Siapem, Liampeill, Dubai.
5. 2006 Girassol, Eiffel Offshore, France (for the Angola field exploration)

C. Passenger ships:
1. 2003 Colour Fantasy, Kvaerner Masa yard, Finland.
2. 2004 Pride of America, Kvaener Kuhwerdenhafen yard, Hamburg.

40. Redundancy:
Other than the grounding application all intended applications are expected to have multiple fastenings and X-BT studs may be intermixed with traditional welded studs.

41. NSWCCD-SSES 615 concurs (without comment) with the following HILTI statements:
- The presence of the studs (and holes) in the base metal does not change the fundamental loadbearing characteristics of the construction steel in terms of its elasticity and plasticity.
- The notch effect of X-BT studs on base material is less pronounced than with welded studs.
- X-BT studs have very ductile load-displacement characteristics by the way in which shear loads are taken up via the sealing washer allowing loads to be distributed over several studs in the group making up the joint.

42. Specifically excluded from consideration:
- HILTI CR type (pointed, no pilot hole) studs.
- Base metal of aluminum.

43. Conclusions:
a. Based on the hands-on demonstration, the HILTI X-BT stud installation process is fast and efficient.
b. The system is independent from electric power sources.
c. The tools are simple to operate and have incorporated many safety features.
d. NSWCCD-SSES 615 considers the joint to be a mechanical interference fit rather than a weld.
e. Lab and service results have shown reliable, tight, repeatable joints with satisfactory scatter in both torque and direct axial pullout load values.
f. Visual/geometric inspection using the HILTI Power Regulation Guide assures a quality joint. A fit that was either too loose or too tight would be discovered by inspection of neoprene washer compression or measuring fastener stand-off. The penetration depth is

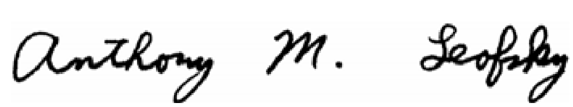
automatically limited by both the tool's piston brake and the integral stud washers.

g. The recommended installation torque of 6 ft.lbs is favorable in comparison to typical failure values which ranged from 26-54 ft-lbs.
h. The threaded sleeve and washer alloy German Material no. 1.4401 (comparable to UNS S31600/31603) in a 20% cold worked condition is widely used in many Navy applications and is considered satisfactory.
i. The hardened shank alloy "CR500" German Material no. 1.4565 (comparable to UNS S34565) in a 60% cold worked condition, with an A_5 elongation of 7% (U.S. 7.2%) and approximate hardness of 50 R_C is considered satisfactory for the intended applications because the X-BT meets the acceptance criteria for traditional *welded* studs per MIL-STD-1689, MIL-STD-278F, TechPub 278 and TechPub 248 when the axial tensile load is applied by torquing.
j. The X-BT direct axial pullout mean load value of 2000 lbs. for typical structural steel base metal of 5/16 inch thickness exceeds both the MIL-STD-1689 and TechPub 278 criteria for *welded* studs but does not meet either the MIL-STD-278F or TechPub 248 criteria.
k. The X-BT direct axial pullout 5% fractile value of 1350 lbs. does not meet any criteria for *welded* studs.
l. Unlike traditional *welded* studs, with X-BT the resilience of the displaced base material exerts a clamping pressure or compressive stress on the stud.
m. Unlike traditional *welded* studs, with X-BT the stress concentration at the joint is minimized.
n. Unlike traditional *welded* studs which are limited by the material strength of the stud/weld, with X-BT the stronger the base metal the higher the pullout load.
o. The static axial pull-out test results show the X-BT failure mode is "graceful" because the load reduction is gradual.
p. With respect to corrosion, the existing petrochemical industry, offshore platform and foreign Naval service (some of which are exposed to the weather) is considered more severe than any of the intended applications.
q. X-BT was found to be resistant to pitting, crevice corrosion and salt spray testing, the sealing washer provides an effective seal. The worst expected corrosion of uncoated X-BT studs in an interior ship compartment is a slight rust staining.
r. X-BT was found to be essentially immune to Hydrogen Assisted Stress Corrosion Cracking (HASCC) at 45 R_c hardness. It may be susceptible to SCC in an aqueous caustic or chloride environment at 50 R_c hardness, and therefore should be kept dry.
s. MIL-STD-1689 requirement for pre-production tension testing to failure of five consecutively *welded* studs is *not* considered appropriate for X-BT.
t. MIL-STD-1689 requirement for pre-production bend testing of *welded* studs is considered appropriate for X-BT for applications requiring maximum assurance.
u. NSWCCD-SSES considers the HILTI, Inc. X-BT 3/8 inch diameter drilling, powder-actuated and threaded fastening system satisfactory for the intended applications, in the

identified environment, within design allowables and when OEM recommendations are followed.

44. Recommendations:

a. No additional material testing is recommended.
b. Outstanding risk – Fire resistance is unknown. Can be mitigated by technical evaluation.
c. Outstanding risk – Galling resistance is unknown. Can be mitigated by specifying thread lube.
d. HILTI identify whether the HN 0433 procurement specification wire 45º bending test is bent in just one direction or bent and returned to the original position.
e. NGSB shall adjust torque according to friction coefficient of any thread lube that is used. A lube may reduce maximum recommended tightening torque of nut as much as 50% - from 6 ft.lbs. to 3 ft.lbs.
f. NGSB develop appropriate MIL-STD-1689 pre-production, workmanship, visual, and inspection requirements specific to HILTI X-BT.
g. NGSB incorporate following HILTI recommendations:
    1. Do not re-use an old pilot hole
    2. Reduce the allowable loads by factor of 0.75 when X-BT used on ¼ inch thick base metal.
    3. Service tool whenever: a cartridge misfires or inconsistent driving power occurs.
h. NGSB address use of "stack stud" (which was referred to by e-mail but not discussed here) and resultant increased moment arm.
i. NGSB address vendor qualification.
j. NGSB procurement specs must assure homogeneity of material properties, minimize heat-to-heat variability of chemical composition and consider supplemental material specification requirements.
k. NGSB address receipt inspection requirements of studs.
l. Future requests for approval of either new materials or existing materials in new applications can be reviewed faster if the user summarizes all available material selection information.



A. Leofsky