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Effect of Control Fluid on Surface Treatments of High Strength Bolts

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Abstract: This paper presents results of a series of tests performed using ¾ in. diameter A325 and A490 bolts. The resulting relationship between torque – tension for the bolt – nut – washer assembly is used to explain its behavior as the length and location of treatment surface are varied. Tests were performed upon one hundred sixty four bolts; eighty A325 of three inches in length, fifty-two A325 of six inches in length, twenty A490 of three inches in length, and twelve A490 of six inches in length. One hundred sixty four nuts and washers were tested, one hundred nuts type 2H, and fifty six nuts type C and eight nuts type D to determine the effect of the variables (nut type, bolt length, bolt type and Control Fluid) on the torque-tension relationship of the bolt-nut-washer assembly. Hundreds of experiments using replicate samples for statistical reliability were conducted to establish the effect of the variables on the tension-torque relationship of the bolt-nut-washer assemblage. The principal relationship in turn-of-nut installation is that between elongation and bolt pretension, the tension -torque relationship is the factor that reflects the bolt pretension in an installation to be expected in a properly tightened connection. Control Fluid was found to decrease the coefficient of friction on coated parts and to control the tension obtained with a given torque upon assembly.

Keywords: bolt pretension; high strength bolts; bolt treatment; bolt pre load; bolt lubricant.

1. Introduction

The usual purpose of a bolted joint is to clamp two or more parts together. The clamping force is achieved by applying torque to the bolt head or the nut; the mechanical advantage of the wrench and threads allows one to actually stretch the section of the bolt between the head and the nut (an area known as the *grip*), creating tension in the bolt. This tension is known as *pretension* because it exists before any other forces are applied to the joint. The minimum specified tension is 70% of the ultimate strength [1]. The required pretension, installation methods, and inspection of the installed fasteners in structural joints are covered by the Specification for Structural Joints using ASTM A325 or A490 [1].

Hex head bolts can be installed by the turn-of-nut method or by calibrated wrench.

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The Research Council on Structural Connection (RCSC)[1], has spent considerable effort in identifying the critical factors that affect these two tightening methods and developing specific requirements for each method to ensure the proper bolt tension. In both methods, enough bolts must be installed in the joint to bring component plates in firm contact, which is called the snug tight condition. Following the snug tightening operation, bolts are tightened further by additional prescribed rotation in the turn-of-nut method. Care must be taken that one end of the fastener is prevented from rotation while tightening the bolt.

The effect of different thread lengths within the grip are given in [2], The grip is the total thickness of material between the head of the bolt and the washer face of the nut, exclusive of washers. As the thread length within the grip decreases, the maximum strength increases but ductility decreases [3]. A490 bolts have reduced ductility in a torque-tension test compared to A325 bolts [4], and shows a desirable characteristic of a very significant drop in tension before breaking [5].

The presence of torsional stress has a very significant effect on the tension-turn response of a fastener assembly. The torqued tension is 10% to20% lower than the direct tension results [3]. The actual reduction is very sensitive to treated surface conditions; a good treated surface will keep torsional stress low.

A measured relation between torque and tension in an A325 and A490 bolt-nut-washer assembly is shown in Figure 1. for different treated surface conditions. The relationship is reasonably linear up to near maximum load. There are two basic methods that can be used to relate the torque to tension in a bolt. The first is an approximate one given by the relationship [6]:

$$T_{max} = 0.25 \, D \, P \quad (1)$$

Where:

T_{max}: maximum torque on bolt in foot-pounds,

D: nominal bolt diameter in feet,

P: measured bolt tension in pounds.

The second method relates torque to tension produced in the bolt and is based on modeling the inclined thread as a block being forced on an inclined plane. An equation, which relates torque to tension and includes factors for the geometry of the threads and the coefficient of friction, was developed in References [2, 7-10].

2. MACuGuard^{TM} Torque'n Tension Control Fluid

Torque'n Tension Control Fluid is a complete package formulation for applying a dry lubricating film to machined parts, especially threaded fasteners which have been protected from corrosion by sacrificial or barrier coating, i.e. electroplating, mechanical plating or mechanical galvanizing, hot dip galvanizing or organic coating. The object of this lubricant is to decrease the coefficient on coated parts and to control the tension obtainable with a given torque upon assembly.

The loss of obtainable tension when threaded fasteners are zink plated is well known. Through the use of Torque'n Tension Control Fluid plated parts, with their desirable corrosion resistant properties unchanged, can meet virtually any industry requirements for torque controlled fastening of threaded fasteners. Additionally, MACuGuard Torque'n Tension Control Fluid is commonly applied to coated high-strength fasteners in applications where turn-of-nut tightening systems are employed and where rotational capacity testing of the bolt, nut and washer assembly is required to determine assurance of acceptable lubrication. MACuGuard Torque'n Tension Control Fluid is supplied as a liquid concentrate with an indefinite shelf life. It is water dispersed, slightly viscous, translucent liquid. The product is non-flammable, non-toxic and is not hazardous to handle.Color milky white, flash point none, boiling point 212^{o} F (100^{o} C), and pH 7-8.

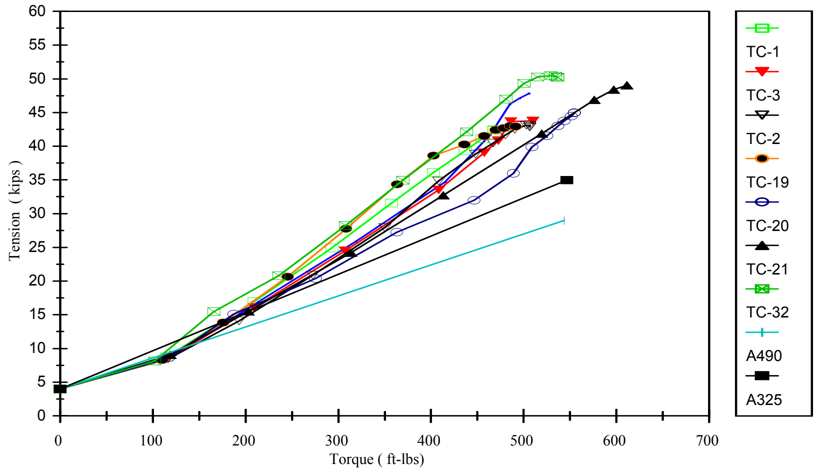


Figure 1. Effect of nut type on A325 bolts and A490 bolts, as-delivered condition

The lubricating film produced decreases the coefficient of friction, is dry (non-tacky), non-evaporating, non-toxic and colorless and will remain on the parts indefinitely until ready for use provided the parts are protected against high humidity. The coating will neither add to nor detract from the protective value of the plated finish.

MACuGuard Torqu'n Tension Control fluid can be used as received, in its concentrated form, or diluted. The concentration that is required will depend on a number of factors, the quantitative importance of which cannot be determined in advance for each individual application. These factors are as follows:

1. The particular torque-tension relationship being sought.

2. The type of equipment being used to apply the lubricant and to dry the parts. Equipment varies in the amount of liquid, which is shaken off before and while the parts are being dried.

3. The types of coated surface being treated. In most cases the concentration required would be between 1 and 40% by volume, with the more highly concentrated solution, 20-40%, usually being required on high-strength fasteners, which have been either mechanically galvanized or hot-dip, galvanized. The exact quantity required will have to be determined by the user experimentally.

Working solutions are prepared by adding the required amount of Torque'n Tension Control Fluid to a measured amount of tap water and mixing thoroughly. Application of of Torque'n Tension Control Fluid requires only that the parts be thoroughly wetted by the material diluted to the proper concentration with water. This requires only that the parts be wettable by water, in other words, free of oils. The application can be compared with dip painting of small parts, in that the amount of active material which remains on the parts to perform its function depends on how much liquid is allowed to stay on the surface when it is dried and how concentrated the active ingredients are in that liquid.

The treatment can be applied to wet parts immediately after electroplating, mechanical plating/galvanizing or chromating, or to dried parts at any time. The main requirement for equipment for applying the treatment is that it be uniformly consistent in its operation. The following methods of application can be used:

1. Dipping parts in a solution of Torque'n Tension Control Fluid using perforated or screened baskets to hold the parts. Dipping can be by hand or in barrel electroplates machine or the like.

2. Spraying the solution of Torque'n Tension Control Fluid on the parts in liberal volume using equipment such as parts washer.

Solution temperature can range from 50-100° F (10-38° C). Dipping times are not critical as long as all surfaces are thoroughly exposed and all parts are wetted; however, immersion times will generally fall within 30 to 60 seconds.

After the parts are wetted by the Torque'n Tension Control Fluid solution, they must be dried. They must not be rinsed before drying, as this would remove the adhering film of active ingredients. Nor should they be spun excessively to remove too much of the adhering solution. Any liquid, which drains from the parts, should be returned to the tank of working solution. In addition the process drain time after removal of the basket from the lubricant solution should be standardized; inconsistency in drain practice may also results in variations of torque-tension relationships.

Drying can be performed in any convenient way providing parts are not subjected to temperatures above 250° F (121° C). When drying in a heated spin drier, the speed of the spin drier should not exceed 400 rpm for a 10-inch diameter basket and 200 rpm for 20-inch diameter basket. Spinning parts at speeds higher than the recommended maximum can result insignificant and unwanted removal of the adhering solution.

The drying step does not serve to bake or chemically change the Torque'n Tension Control Fluid material; it only removes water, so the times, temperature, etc. are not at all critical. However, if the parts had received a chromate treatment prior to the Torque'n Tension Control Fluid application, drying temperature should not exceed 125° F (52° C) in order to retain the maximum protective value of the chromate film.

3. Objectives of research

The main purpose of this paper is to carry out a testing program in order to determine the effect of control fluid on bolt-nut-washer surfaces upon the tightening characteristics of high-strength bolts. In addition, six variables were studied to determine their effect upon the fastener-tightening behavior. These variables were the performance of the:

a- ¾- - 10 GR 2H HVX NUT PER ASTM A194-91.
b- ¾- - 10 GR DH HVX NUT PER ASTM A563-91C.
c- ¾- - 10 GR C HVX NUT PER ASTM A563-91C.
d- bolt lengths (3in. and 6in.), length (L) and diameter (D) of the bolt (see Figure 2).

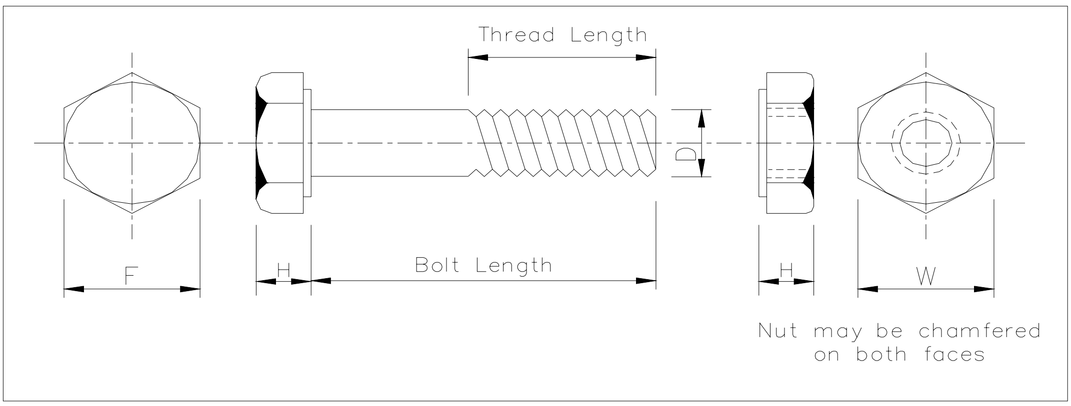


Figure 2. Bolt dimensions

e- bolt strengths (A325 and A490)
f- parts wetted by the Torque'n Tension Control Fluid.

The Rotational Capacity Test is designed to evaluate the presence and efficiency of a lubricant on the nut, and the compatibility of the bolt assemblies as represented by the components selected for testing such that, when installed, the desired bolt tension is achieved without excessive plastic deformation. The variables within this series of tests were: type of bolt, type of nut, length of bolt, and surface condition of the fastening system (bolts, nuts, washers). All bolts, both ASTM A325 and A490 where ¾ in. diameter. The Control Fluid study code, surface treatment condition, type and number of bolts tested are shown in Tables 1-3.

Table 1. Surface conditions

Condition code	Remarks
As-delivered	-------------
Clean surface	------------
FL	Torque Tension Control Fluid
FL1	4 part Fluid to 1 part H_2O
FL2	3 part Fluid to 2 part H_2O

Table 2. Summary of tested A325 bolts

Test code	Number tested	Length inches		Remarks		
TC-1	4	3		As-delivered – nut type 2H		
TC-2	4	3		As-delivered – nut type DH		
TC-3	4	3		As-delivered – nut type C		
TC-4	8	3		Clean – nut type 2H		
TC-5	8	3		Bolt threads – nut type 2H		
TC-6	4	3		Bolt threads – nut type C		
TC-7	4	3		Nut threads, face – nut type 2H		
TC-8	4	3		Nut threads, face – nut type C		
TC-9	4	3		Nut threads, face, washer face – 2H		
TC-10	4	3		Nut threads, face, washer face – C		
TC-11	4	3		Bolt threads, Nut threads, face, Washer face – Nut type 2H		
TC-12	4	3		Bolt threads, Nut threads, face, Washer face – Nut type C		
TC-13	4	3		Bolt threads, Nut threads, face–FL-nut type 2H		
TC-14	4	3		Bolt threads, Nut threads, face–FL-nut type C		
TC-15	4	3		Bolt threads, Nut threads, face–Fl1-nut type 2H		
TC-16	4	3		Bolt threads, Nut threads, face–Fl1-nut type C		
TC-17	4	3		Bolt threads, Nut threads, face–Fl2-nut type 2H		
TC-18	4	3		Bolt threads, Nut threads, face–Fl2-nut type C		
TC-19	4	6		As-delivered – nut type 2H		
TC-20	4	6		As-delivered – nut type DH		
TC-21	4	6		As-delivered – nut type C		
TC-22	4	6		Bolt threads – nut type 2H		
TC-23	4	6		Bolt threads – nut type C		
TC-24	4	6		Nut threads, face – nut type 2H		
TC-25	4	6		Nut threads, face – nut type C		
TC-26	4	6		Nut threads, face, washer face – 2H		
TC-27	4	6		Nut threads, face, washer face – C		
TC-28	4	6		Bolt threads, Nut threads, face, Washer face – Nut type 2H		
TC-29	4	6		Bolt threads, Nut threads, face, Washer face – Nut type C		
TC-30	4	6		Bolt threads, Nut threads, face–FL-nut type 2H		
TC-31	4	6		Bolt threads, Nut threads, face–FL-nut type C		
Total	132	3 in.	6 in	Nut type	2H	68
		80	52		C	56
					DH	8
					Total	132

Table 3. Summary of tested A490 bolts

<table>
<tr><th>Test code</th><th>Number tested</th><th colspan="2">Length inches</th><th colspan="3">Remarks</th></tr>
<tr><td>TC-32</td><td>4</td><td colspan="2">3</td><td colspan="3">As-delivered – nut type 2H</td></tr>
<tr><td>TC-33</td><td>4</td><td colspan="2">3</td><td colspan="3">Nut threads, face – nut type 2H</td></tr>
<tr><td>TC-34</td><td>4</td><td colspan="2">3</td><td colspan="3">Bolt threads, Nut threads, face–FL-nut type 2H</td></tr>
<tr><td>TC-35</td><td>4</td><td colspan="2">3</td><td colspan="3">Bolt threads, Nut threads, face–FL1-nut type 2H</td></tr>
<tr><td>TC-36</td><td>4</td><td colspan="2">3</td><td colspan="3">Bolt threads, Nut threads, face–FL2-nut type 2H</td></tr>
<tr><td>TC-37</td><td>4</td><td colspan="2">6</td><td colspan="3">As-delivered – nut type 2H</td></tr>
<tr><td>TC-38</td><td>4</td><td colspan="2">6</td><td colspan="3">Nut threads, face – nut type 2H</td></tr>
<tr><td>TC-39</td><td>4</td><td colspan="2">6</td><td colspan="3">Bolt threads, Nut threads, face–FL-nut type 2H</td></tr>
<tr><td rowspan="2">Total</td><td rowspan="2">32</td><td>3 in.</td><td>6 in</td><td rowspan="2">Nut type</td><td>2H</td><td>32</td></tr>
<tr><td>20</td><td>12</td><td>Total</td><td>32</td></tr>
</table>

* 1 in = 25.4 mm

4. Test setup

An examination of bolts with various bolt threads, nut, and washer friction conditions was made. This included the following:

1. Bolt threads, nut, and washer in the as-delivered condition.

2. Bolt threads, nut, and washer completely cleaned of all the as-delivered surface condition.

3. Bolt threads, nut, and washer cleaned as in item 2 above and then only the bolt surface is retreated with a Control Fluid.

4. Bolt threads, nut, and washer cleaned as in item 2 above and then only nut surfaces are retreated with a Control Fluid.

5. Bolt threads, nut, and washer cleaned as in item 2 above and then nut and washer surfaces are retreated with a Control Fluid.

6. Bolt threads, nut, and washer cleaned as in item 2 above and then all the component surfaces are retreated with a Control Fluid.

7. Bolt threads, nut, and washer cleaned as in item 2 above and then only the bolt threads and nut surfaces are retreated with a Control Fluid.

In each of the cases listed, all bolts came from the same supplier and 164 bolts were tested. Required device and material to conduct the test program are:

One. Calibrated bolt tension measuring device: (Skidmore-Whilhelm)
Two. Calibrated torque wrench
Three. Hand wrench
Four. Protractor
Five. Bolts, nut, and washer

Procedure:

1st. Mark off a vertical line on the face plate of the calibrated bolt tension measuring device. Using a protractor, mark off additional lines at 120 degrees and 240 degrees.

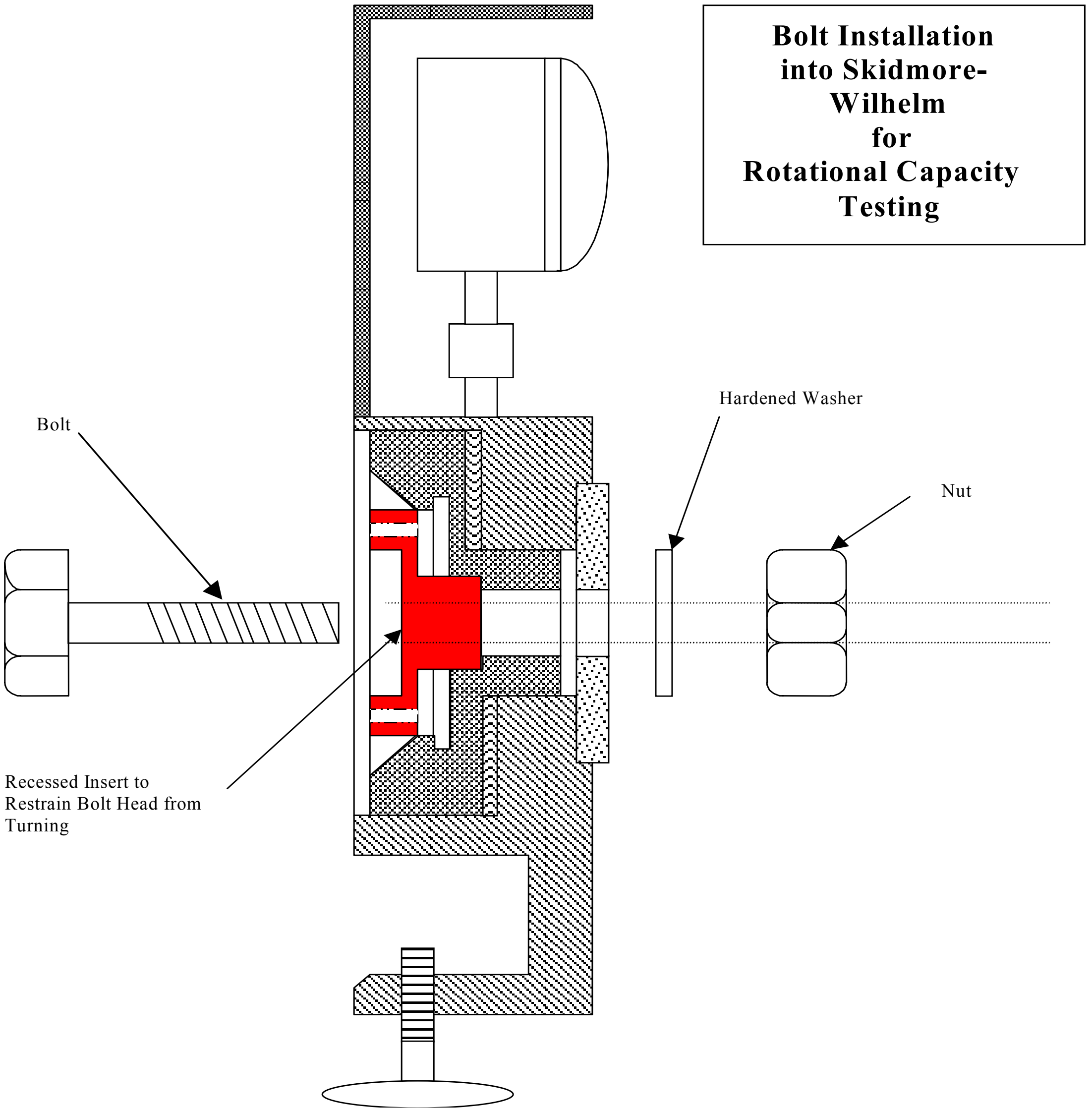
2nd. Measure the length (L) and diameter of the bolt.

3rd. The bolt, nut and washer shall be assembled into the calibrated bolt tension measuring device as shown in Figure 3. The bolt shall be sufficient length , 3 to 5 threads are located behind the bearing face of the nut as shown in Figure 3.

4th. Tightening the bolt using a hand wrench to achieve a snug tension 3 to 5 kips for ¾ in. diameter of the bolt.

5th. Match mark the nut to the vertical line marked on the faceplate in 4.2.A.

6th. Tighten the bolt by turning the nut using the torque wrench to the 1/3 (120 degrees) rotation for 3 in length bolt and ½ (180 degrees) rotation for 6-in. length bolt [6]. Obtain the bolt tension (P) from the dial of the device and the torque (T) from the wrench and record these values.



1: Gage guard
2: 110,000# gage (or 50,000 kg)
3: Gage saver
4: Bolt plate
5: Body
6: Mounting screw

Figure 3. Bolt installation into skidmore–wilhelm for rotational capacity system

7th. Further, tighten the nut to the rotation 2/3 (240 Degrees) rotation to 1 (360 degrees) rotation [6]. Obtain the bolt tension (P_{max}) from the dial of the device and the moment (T_{max}) from the wrench and record these values.

8th. Acceptance Criteria

The bolt and nut assembly is considered to be in conformance if all of the following requirements are met:

1. If the visual inspection as per 4.2.G shows no sign of stripping or fracture, the bolt assembly meets the requirements. If signs of stripping or fracture are visible, the bolt assembly fails the rotational capacity test. Some minor amount of stretch is expected to occur between the face of the nut and bolt head and does not constitute failure of the test.

2. If the bolt tension (P_{max}) measured in 4.2.G is equal to or greater than the tension required.

9th. Once the bolt assembly is prepared, the tightening sequence is started. The bolt, nut, and the washer assembly are inserted into the calibrator and the nut is brought into finger tight position. Whenever a control fluid is used in a particular test, the treated surface side of the washer is placed next to the nut.

The first load to be applied to the bolt is the snug – tight load (3 to 5) kips, since all rotations are measured from snug-tight position. During all loading steps, the bolt head is held to prevent it from turning. To confirm that the instalation procedure to be used for fasteners develops tension 5% higher than required tension given in Table 4 of the RCSC Specifications (28,000 and 35,000 pounds) for ¾ in. diameter A325 and A490. Obtaining the bolt tension (P) from the dial of the calibrated bolt tension measuring device, (Skidmore-Whilhelm, Figure 3.), and the torque from the wrench and tension and torque are recorded at the end of each loading increment (nut rotation). Further, tighten the "nut" to the required rotation (2/3 rotation, and 1 rotation) for 3in. In addition, 6in.bolt length [6]. Obtain the bolt tension (P_{max}) from the dial device at the specified rotation and record these values. After the required turns were achieved, the nut was loosened, the bolt assembly was removed from the bolt tension-measuring device, and visual inspection performed of the bolt assembly for evidence of stripping or fracture. Results of the turn test for A325 and A490 bolts are given in Tables 4-7.

5. Test results

5.1. As-delivered bolts

Information regarding the effect of nut type conditions for A325 bolts and 3in Long with 2H, DH, and C nut types reached 123.9%, 119.7%, and 112.9%, respectively, of their average pretension loads and 76.6%, 78%, and 72.4%, respectively of their required torques obtained using Eq. (1). For A325 bolts and 6 in. long with 2H, DH, and C nut types reached 137.1%, 138%, 128.6%, respectively of there pretension load and 74.76%, 81.1%, 71.6, respectively, of their required torques obtained using Eq. (1). For A490 bolts and 3 in. and 6 in. long with 2H nut type reached 93.6%, 120.4%, respectively of their average pretension load and 80.75%, 66.6%, respectively, of their required torques calculated using Eq. (1). The TC-32 failed, due to pretension lower than 100% and the TC-37 failed due to stripping. It appears that the type of nut affects the amount of pretension and torque. The results of this case are shown in Figure 1. The data plotted in Figure 1. Were the averages of four specimens.

5.2. Clean surface

The results of eight A325 bolts, which were cleaned with acetone failed due to high torque

(129.74%) of its required torque calculated using Eq. (1). It was very difficult to loosen the nut and it was very hot.

Table 4. Test results for 3 in. long A325 bolts

Test code	Torque (Eq. (1)) ft-lb.	Test results at 1/3 turn		Test results at 2/3 turn		Remarks
		Tension kips	Torque ft-lb.	Tension kips	Torque ft-lb.	
TC-1	542.1875	34.7	415.5	47.825	506	pass
TC-2	523.82813	33.525	408.5	43.75	510	pass
TC-3	493.75	31.6	357.5	42.45	468.25	pass
TC-4	448.82813	28.725	582.25			failed
TC-5	520.3125	33.3	521.5			failed
TC-6	477.7344	30.575	494.75			failed
TC-7	535.1563	34.25	312.5	42.825	406.5	pass
TC-8	493.75	31.6	238.25	41.25	313	pass
TC-9	505.8594	32.375	291	42.5	390.5	pass
TC-10	487.1094	31.175	211.25	42.075	272.75	pass
TC-11	548.0469	35.075	259.25	45.65	342	pass
TC-12	492.5781	31.525	199.75	42.25	268.5	pass
TC-13	521.0938	33.35	267.5	44.375	367.25	pass
TC-14	490.2344	31.375	233	42.5	318.75	pass
TC-15	553.5156	35.425	297.75	44.075	369.5	pass
TC-16	502.3438	32.15	252.25	43.45	340.25	pass
TC-17	542.1875	34.7	361.5	44.025	486.75	pass
TC-18	492.1875	31.5	304.75	41.825	405.5	pass

* 1 ft – lb. = 1.355 N-m, 1 kip = 4.445 kN

Table 5. Test results for 6 in. long A325 bolts

Test code	Torque (Eq. (1)) ft-lb.	Test results at 1/2 turn		Test results at 1 turn		Remarks
		Tension kips	Torque ft-lb.	Tension kips	Torque ft-lb.	
TC-19	599.60938	38.375	448.25	42.900	507	pass
TC-20	603.51563	38.625	489.25	42.950	555	pass
TC-21	562.5	36.000	403	44.975	491.5	pass
TC-22	570.3125	36.500	631.75	-----------	-----------	failed
TC-23	477.73	30.575	494.75	-----------	-----------	failed
TC-24	566.40625	36.250	300.25	-----------	-----------	pass
TC-25	494.14063	31.625	238.5	43.600	342.5	pass
TC-26	580.07813	37.125	300.5	43.125	388	pass
TC-27	562.10938	35.975	230.5	43.900	303	pass
TC-28	590.625	37.800	274	44.925	351.75	pass
TC-29	539.45313	34.525	220.5	44.325	293.75	pass
TC-30	573.04688	36.675	307.5	44.400	392.25	pass
TC-31	546.48438	34.975	255	44250	341.5	pass

* 1 ft – lb. = 1.355 N-m, 1 kip = 4.445 kN

Table 6. Test results for 3 in. long A490 bolts

Test code	Torque (Eq. (1)) ft-lb.	Test results at 1/3 turn		Test results at 2/3 turn		Remarks
		Tension kips	Torque ft-lb.	Tension kips	Torque ft-lb	
TC-32	511.71875	32.750	413.25	49.025	611.50	failed
TC-33	525.390625	33.625	352.25	51.675	513.75	failed
TC-34	550.78125	35.250	303.50	52.800	455.25	
TC-35	558.59375	35.750	352.00	52.525	533.25	
TC-36	546.875	35.000	362.25	52.750	543.75	

* 1 ft – lb. = 1.355 N-m, 1 kip = 4.445 kN

Table 7. Test results for 6 in. long A490 bolts

Test code	ASTM Eq. (1) Torque ft-lbs	Test results at 1/2 turn		Test results at 1 turn		Remarks
		Tension kips	Torque ft-lbs	Tension kips	Torque ft-lbs	
TC-37	658.59375	42.150	438.75	50.250	537.00	striping
TC-38	601.953125	38.525	305.25	52.250	448.75	
TC-39	609.765625	39.025	310.00	52.950	451.25	

* 1 ft – lb. = 1.355 N-m, 1 kip = 4.445 kN

5.3. Effect of control fluid

To treat the surfaces of the assembly bolt-nut-washer the following method was used:

1. Cleaning the assembly bolt-nut-washer with acetone.
2. Dipping parts in a solution of control fluid using screened basket to hold the parts.
3. Immersion times generally fall within 30 to 60 second
4. Temperature can range from 50-100^o F, while lab temperature is 72^o F.
5. After parts are wetted by Control Fluid, they are dried using any convenient way provided parts are not subjected to temperatures above 250^o F.

5.3.1. Bolt surface condition

The test results for the case in which the bolt surface (A325 bolt, 3 in. and 6 in.long), and (2H, C) nuts was treated with control fluid. It was anticipated that pretension would return to a value (118.9%, 109.2%, 130.4%, 109.2%)) of its required pretension force and a value of (100.3%, 104.2%, 110.8%, 103.6%)) its required torque calculated using Eq. (1). Such results did not pass the test, because the maximum torque was higher than the torque calculated by Eq. (1). The test results for TC-5, TC-6, TC-22 and TC-23 are shown in Figure 4.

5.3.2. Nut surface conditions

The test results for the case in which the nut surface (A325 bolt, 3 in. and 6 in. long and 2H, C nuts) and (A490 bolt, 3 in., 6 in. long and 2H nut) was treated with Control Fluid are shown in Figure 5. It was anticipated that the pretension force of TC-7, TC-8, TC-24, TC-25, TC-33 and TC-38 would return to a value of 122.3%, 112.9%, 129.5%, 108.9%, 96% and 110%, respectively, of their pretension force required, and 58.4%, 48.3%, 53%, 48.3%, 67% and 50.1%, respectively of their required torques. Treating the nut surface was found to decrease the pretension force by 8.4%, and 19.6% according to TC-19 and TC-20.

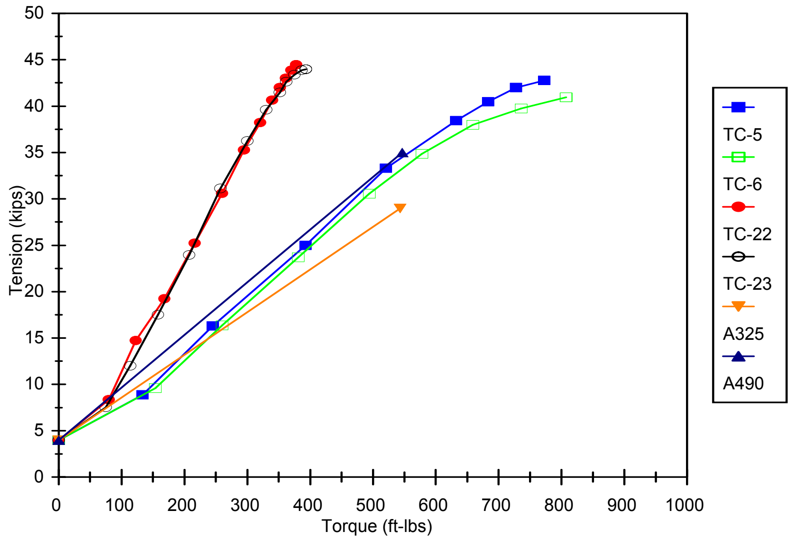


Figure 4. Effect of control fluid on the bolt surface with different nut types and lengths

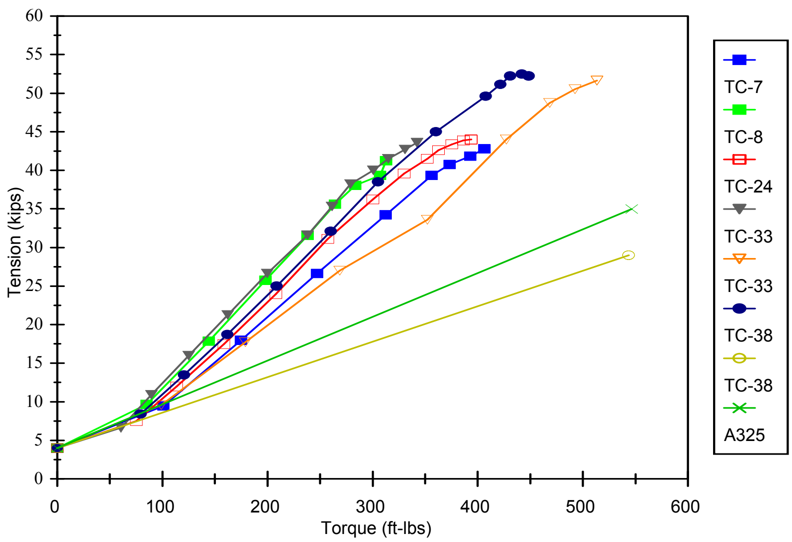


Figure 5. Effect of control fluid on the nut sureface and nut types and lengths

5.3.3. Nut-washer surface conditions

The tests in which the nut and washer were treated with Control Fluid do not show any dramatic differences for various nut surface conditions, as indicated in Figure 6 A325 bolts (3in. 6 in. long, 2H and C type). The following values were obtained (110%, 111.6%, 128%, and 124.1%) of their required pretension force and (48.3%, 57.5%, 51.8%, 41%) of their required torque calculated using Eq. (1). In this case the friction-torque became is less when the nut surface was treated by the values (-10.1%, 9.3%, -1.2%, 26%) and pretension loads were (-8.1%, + 2.6%, + 3%, + .18.9%).

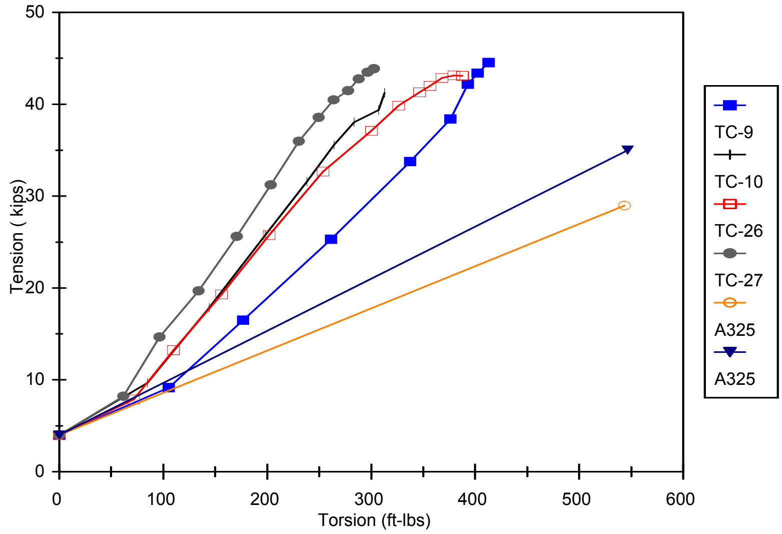


Figure 6. Effect of control fluid on the nut and washer surefaces with different nut types and lengths

5.3.4. Bolt-nut-washer surface conditions

The test in which the bolt-nut-washer were treated with control fluid provides the following information about the pretension and torque required, A325 bolts (3 in., 6 in., 2H, C nuts), (123.3%, 108.7%, 130.3%, 119.5%) of its required pretension load, which is quite close to the as-delivered condition and (47.3%, 40.1%, 46.4%, 40.9%) of its pre-required torque calculated using Eq. (1).

The results of TC-11, TC-12, TC-28, and TC-29 case showed a decrease in the torque required by the amount of 29.3%, 32.3%, 28.36%, 30.7%, respectively, from as-delivered condition case as showed in Figure 7.

5.3.5. Bolt-nut surface conditions

The tests in which the bolt-nut were treated with Control Fluid concerning the pretension and torque required, for A325bolts (3 in., 6 in. long, 2H, C nuts), and A490 bolts (3 in., 6 in. long, 2H nut), (115%, 108,2%, 126.5%, 120.6%), (100.7%, 111.5%), and the following information for torque (51.3%, 47.5%, 53.7%, 46.7%), (55.1%, 50.1%). When the concentrated amount of control fluid is 40% the following results reached for A325 bolts (3 in. long. 2H and C nut type), and A490 bolts (3 in. long and 2H nut type), the pretension reached to (122.2%, 110.9%), (102.1%) of its pretension, and (53.8%, 50.2%), (63%) of its pre-required torque calculated using Eq. (1). When the concentrated amount of control fluid is 20% the following results were achieved for A325 bolts (3 in. long, 2H and C nut type), and A490 bolts (3 in. long and 2H nut type), the pretension were (119.7%, 108.6%), (100%) of its pretension required, and (66.7%, 61.9%), (66.2%) of its pre-required torque calculated using Eq. (1). The test results for this case are shown in Figure 8.

The results of the (TC-12, TC-14, TC-10, TC-8, and TC-5), assemblies are shown in Figure 9, these A325 bolts, and 3in. Length treated by control fluid performed better than the as delivered one (TC-5). The results of the (TC-27, TC-29, TC-31, TC-39, and TC-22) are shown in Figure 10. The TC-27 performed the same as TC-29 and with 41% of the required torque calculated using Eq. (1).

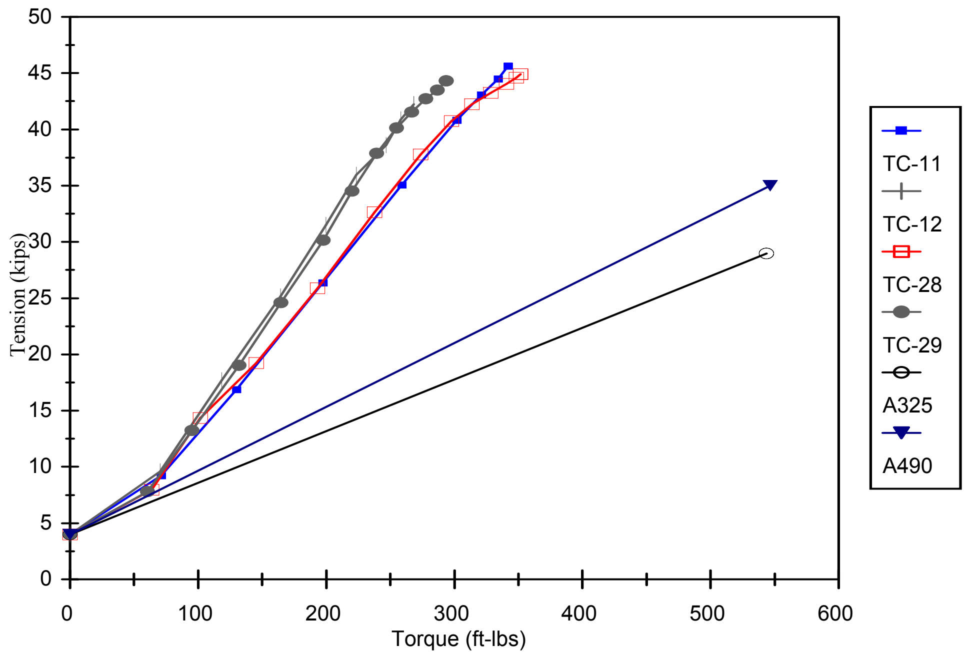


Figure 7. Effect of control fluid on the bolt, nut and washer surfaces with different nut types and lengths

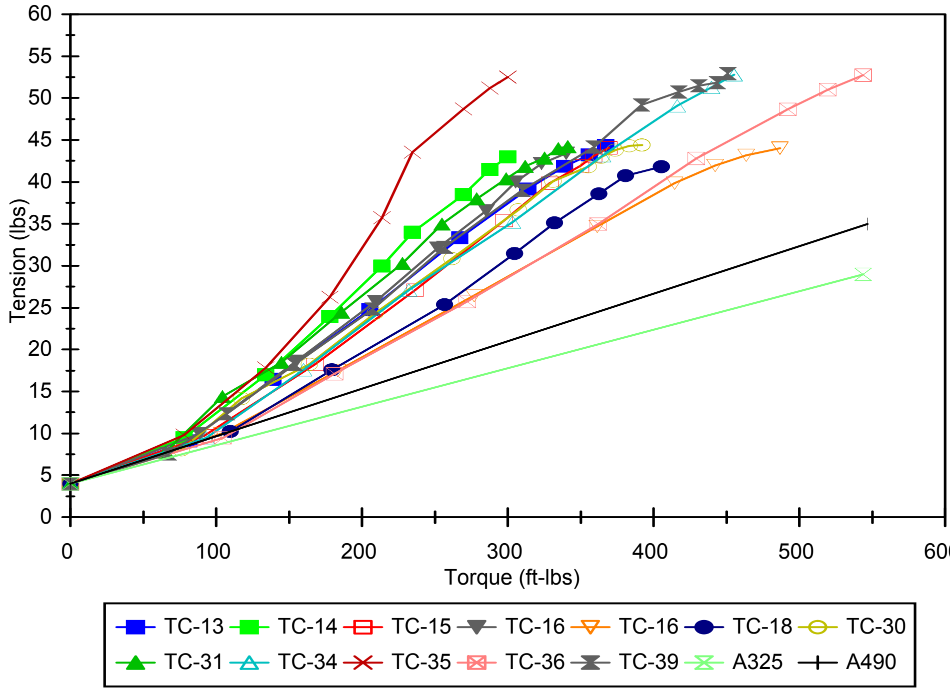


Figure 8. Effect of control fluid on the bolt and nut surfaces with different nut types, bolt strength and length

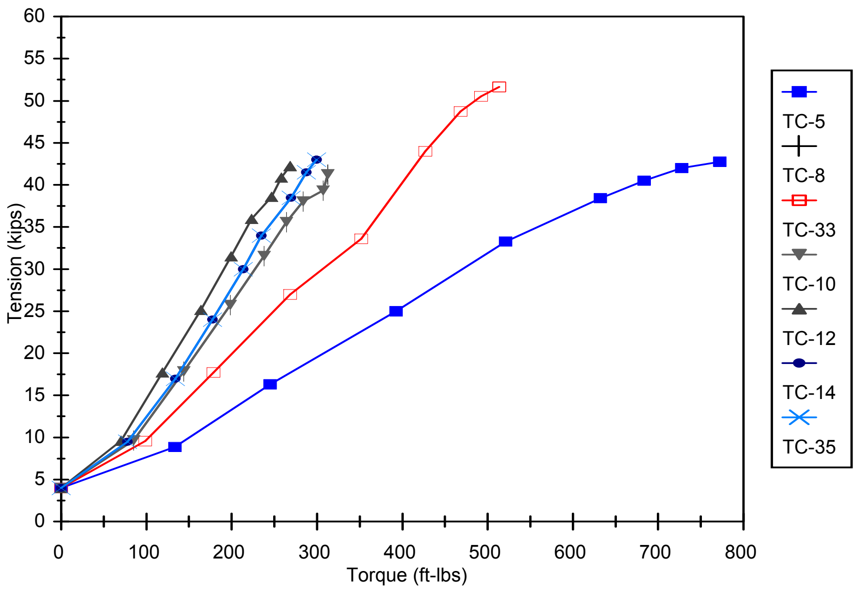


Figure 9. Comparison of the effect of control fluid on different surfaces for A325 and A490 bolts 3 in. length

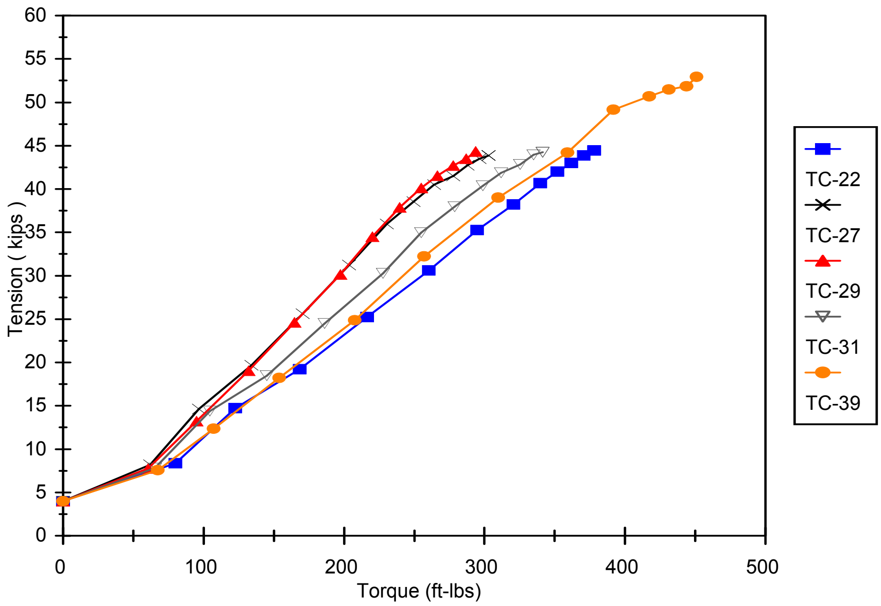


Figure 10. Comparison of the effect of control fluid on different surfaces for A325 and A490 bolts, 6 in. length

6. Conclusions

The present test program illustrated that the tension-torque behavior of the bolt assembly i.e. (bolt threads, nut and washer) was a strong reflection of the surface condition that existed on all components. The minimum specified pretension load was achieved in most performed tests. As the quality of the Control Fluid was decreased, the obtained pretension load was decreased, resulting in a higher coefficient of friction between the bolt threads, and nut threads and nut-washer interfaces.

In most cases, bolts treated with Control Fluid were found to perform better than the corresponding ones due to the as-delivered condition. The performance of 3-in. long bolts was found superior to those of the 6-in. long bolts using the same Control Fluid. The nut type was found to be of a great effect on the tension-torque behavior of the bolt assembly, while such effect was found to be negligible in respect to the treated washer surface.

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