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Technical note: AFI/03/003

TENSION OR TORQUE: WHICH IS MORE IMPORTANT?

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Introduction
Applying a torque to a bolted joint is a very common practice in the industry. This has become so popular and taken for granted that even some engineers refer to the clamp force or a tension of a joint in terms of torque (Nm) which is the prescribed torque to achieve a desired tension. We all know that the force is measured in N, kN or lbs and torque is measured in Nm, kNm or lbft. It is therefore not correct to indicate a tension or clamp force in Nm or lbft.

In the absence of a robust economical method of measuring and monitoring direct tension in a bolted joint the industry has resolved to torque as a measure of tension as it is believed that there is a relationship between torque and tension. This paper describes the uncertainties associated with the torque tension relationship.

Why Tension?
As discussed in many publications including Fernando 2001 [1] the tension or the clamp force is the most critical parameter in a tensile bolted joint. The clamp force makes the joint to fit together so that the two or more members of the joint act in unison. Without proper tension in the joint the individual members of the joint work separately and under go all the effects of dynamic loading. This significantly increases the risk of, fatigue failure of bolts, cracking of joint members, vibration loosening, bolt bending and fretting, gasket failures and leaks, etc.

Why Pre-tension?
Pre-tension is the pre-load applied on the bolted joint. By applying a pre-load certain amount of strain energy will be stored in the joint. This energy will be working against the possible

separation of the joint during its life span. More the energy stored in the joint better the joint performance.
There is even more important function of a pre-tensioned joint. The elastic energy stored in the clamped members share the most of the applied loads hence only a fraction of the applied load is passed on to the bolt. In a dynamic loading situation only a very small component of the applied load will be seen by a pre-tensioned bolt. This will significantly improve the fatigue life of the bolt. A theoretical analysis of this effect is thoroughly discussed in Fernando 2001 [1].

Why Torque?

The threaded fastener acts as a mechanical ramp. Rotation of the screw will impart an axial movement. When the head and nut of the bolt are set against joint members further tightening of the nut or the bolt will cause elongation of the bolt and compression of the joint. This is how a clamp force is imparted. It has found that more torque will produce more clamp force or tension in the fastener.

It must be remembered at all times that torque is only a means of achieving tension and the tension is the most critical parameter of a bolted joint. Our research around the world has found that over 90% of fastener failures are due to in correct bolt pre-tension in the joints. These failures were mostly occurred as a result of the industry focusing on only torque without giving due consideration to the resulting tension.

The industry has developed devices to accurately measure the torque. There are torque wrenches that will measure to ±2% accuracy. Unfortunately, some of the practitioners in the industry believe that they are getting a similar accuracy in the resulting tension by using these highly accurate torque wrenches. Extensive tests carried out by AFI has shown even after using a highly accurate torque wrench the resulting tensions could have an error of ±30-35% depending on the type and condition of the joint.

Why not Torque?

Torque has been considered synonymous with tension in the past with the unavailability of an economical and reliable bolt tensioning method. Several approximations has been used in the design of bolted joints at varying success and confident level in order to relate the torque to tension.

The Nut Factor approach is the most commonly used. The simplified torque tension relationship;

$$T = K.D.F$$

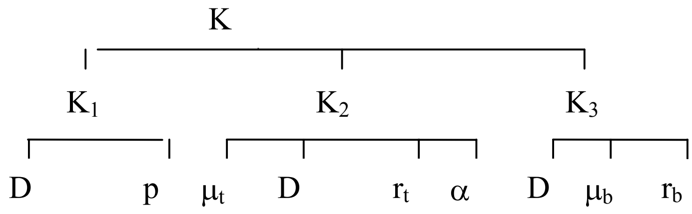
where K – Nut Factor, D – Bolt Diameter and F is the Bolt Tension has been extensively used.

This formula can be further expanded to;

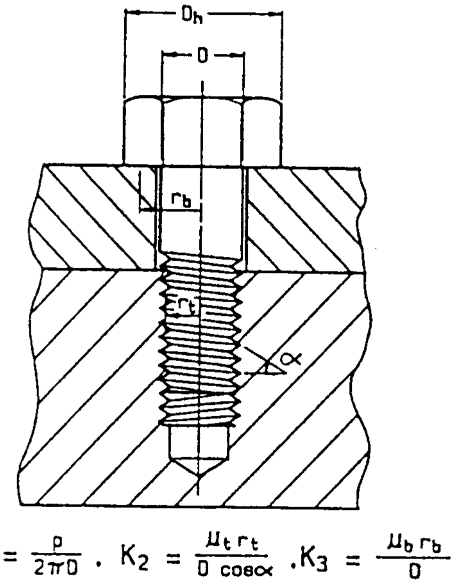
$$T = (K_1+K_2+K_3).D.\ F.$$

where K_1, K_2 and K_3 are contributions due to bolt stretch, thread friction and under head/under nut bearing friction respectively.

The following chart describes these parameters.



Using energy balance principals a first order relationship between the torque (T) and Tension (F) can be derived as follows;



In a rotation of the nut by 360 °;
work done by torque = $2\pi T$
work done by tension = F.p
work done by thread friction = $2\pi F. r_t. \mu_t/\cos\alpha$
work done by under head friction = $2\pi F. r_b. \mu_b$

Now for energy balance;

$$2\pi T = Fp + 2\pi F\frac{r_t\mu_t}{\cos\alpha} + 2\pi F r_b \mu_b$$

$$T = F.D.\left[\frac{p}{2\pi D} + \frac{r_t\mu_t}{D\cos\alpha} + \frac{r_b\mu_b}{D}\right]$$

$$T = F.D.(K_1 + K_2 + K_3)$$

Term K_1D represent the contribution of the torque towards bolt elongation and joint compression, K_2D the fraction of torque spent on overcoming thread friction and K_3D the fraction of torque spent on overcoming under head friction.

For a M12 bolt;
Pitch p = 1.75mm
Thread friction μ_t = 0.15
Thread radius r_t = 6mm
Thread angle α = 30°
Under head friction μ_b = 0.15
Effective under head radius = 8mm

By substitution;

T = F (0.28+1.04+1.2)

Now the contribution on the torque from the first term is 0.28/(0.28+1.04+1.2)=11%, the second term is 41% and the third term is 48%. From this simple analysis it is evident that typically, approximately 10% of the effort is going to the stretch of the bolt and compression of the joint, 40% of effort is going to overcome thread friction and the remaining 50% is going to

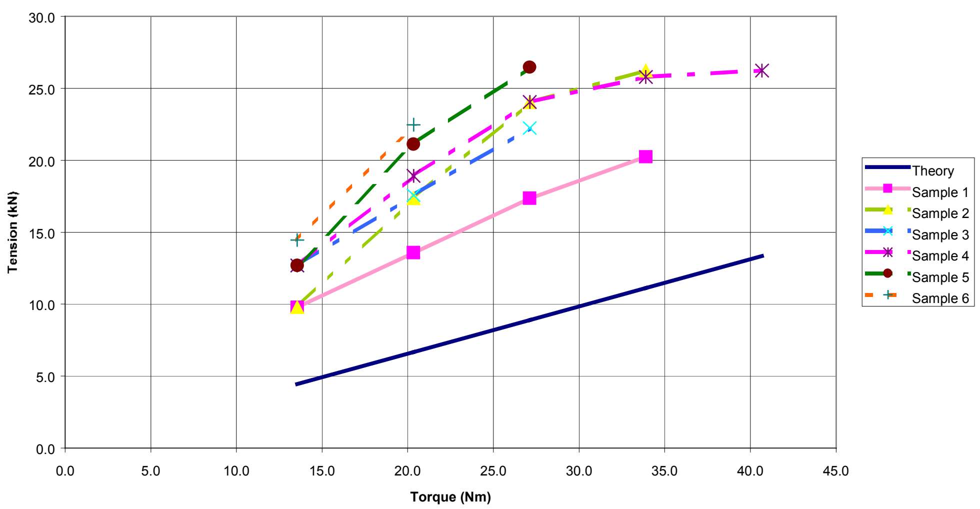
overcome bearing friction. This implies that approximately 90% effort is going to overcome friction while only 10% is doing useful work.
To make things worse there are a large number of parameters such as, surface finish, hardness, lubricants, among other things, that can alter the friction coefficients associated with a bolted joint. A 10% reduction in friction contribution (from 90% - 81%) will increase the bolt stretch-joint compression contribution from 10% - 19% which is a 90% increase. As such, it shall be understood that the torque tension relationship is not a reliable way of ensuring the tension of the bolt under most situations. The sensitivity on friction coefficient alone is too large. The value of K can vary from approximately 0.2 to 2.0 (factor of 10) depending on the condition of the bolted joint.

Any irregularity or damage to the thread can also be seen as an increased friction hence adding to the overall variability of the friction coefficient. Therefore, if the torque is used as a measure of tension it shall be made sure that the thread is in perfect shape. Galling of threads can also contribute to significantly large friction forces.

Torque tension scatter varies largely with the size of the bolt, coatings, interface friction, and joint geometry. Non-parallel or non-fitting surfaces in a joint can also lead to large variations in torque tension relationship that hasn't been treated in the above analysis. With large bolts (>M30) this scatter may be as high as 300%.

Figure 1 shows the torque vs tension relationship measured for M8, property class 8.8, Zinc electro plated bolts and nuts (without any lubricant) tightened on the same joint. Each bolt

Figure 1: **Torque vs Tension - M8, Class 8.8, Zinc Plated, First Tightening of six assemblies**
Proof Load 21.2kN, Breaking Load 29.2kN



assembly is used only once. The solid line shows the theoretical relationship between tension and torque assuming typical friction values for Zn coated interfacing surfaces. The spread between the six samples is quite significant. The recommended assembly torque for the above bolts is 15.4Nm to achieve a tension of 13.8kN which is 65% of the proof load. At a 15.4 Nm torque the six samples achieved tension values from 11 to 17 kN. The spread of 6kN is a 43% variation on the desired tension value. If a 90% of the proof load was desired (19.1kN) the torque values from 17.5Nm to 33Nm were required to achieve the desired tension on different bolts. If a 33Nm torque is applied to each bolt, that would have failed several of the above bolts!!!

Figure 2 shows the first and subsequent four tightening of the Sample 2 bolt in the above experiment. For a tightening torque of 15.4Nm, tension values from 13 to 6 kN were achieved depending on how many times the bolt was loosen and re-tightened. Again the spread on the desired tension is over 50%. The above figures are typical for all bolt sizes, and the large bolts will have even greater variations in the torque tension relationship.

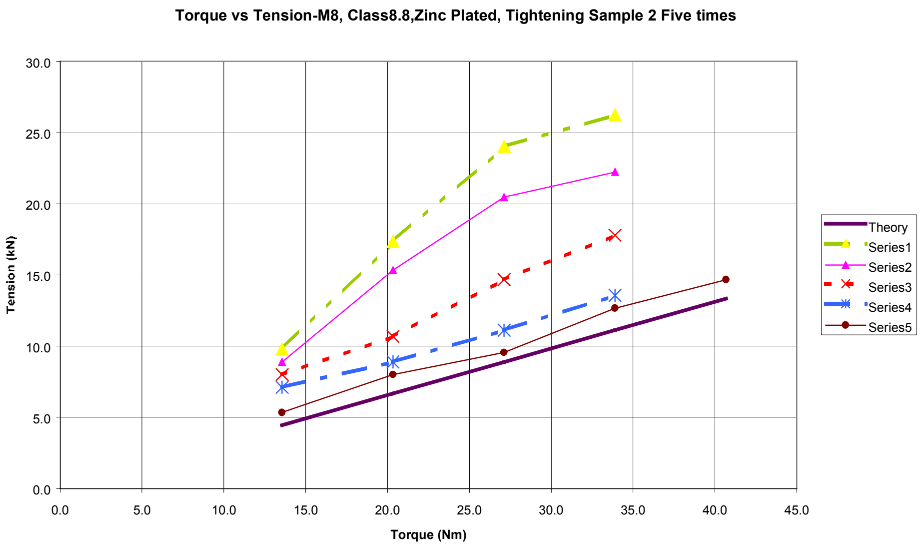


Figure 2: Repeated tightening of the above Sample 2 for five times.

AFI has several case studies where the above results were substantiated in field studies. These are listed in our web site www.ajaxfast.com.au.

Conclusion:

It is tension not the torque that is important in a bolted joint. Higher the tension one can achieve without breaking the bolt higher the energy one can store in a bolted joint. More the energy stored in a joint makes the joint robust and sound. Torque is only an approximate method of achieving a desired tension. If the joint is critical it is highly recommended to use a direct tension measuring and monitoring method such as SMARTBOLT™ . Otherwise, one should take care to manage variables that affect the torque tension relationship.

References:

1. S. Fernando, "An Engineering Insight to the Fundamental Behaviour of Tensile Bolted Joints", Journal of the Australian Institute of Steel Construction, Vol. 35, No 1, March 2001.

Ajax Fastener Innovations (AFI) offers a consulting service to assist in the design of bolted joints in specific applications. AFI has the experience; test equipment, analysis methods, and analysis tools developed over many years, to provide our customers with a greater level of confidence in the design of critical joints. Furthermore, AFI is dedicated to developing fastening solutions that cater for the specific needs of industry.

If you need any further assistance please contact us.