Torque vs Torsion and Tension

by Guy Avellon

These seem like simple terms that many of us should know; however there are just as many users who may either confuse the terms, or more importantly, fail to understand the implications of improper usage and the many variables which affect the results that are expected.

Both actions of torque and tension are measures of force; one is used to accomplish the other. Units of force are measured as an amount of applied energy times a unit of distance. Tension is the result of the application of torque and torsion.

When torque is applied to a fastener, we are rotating the nut onto the threads of a bolt. Therefore, torque is a twisting force causing rotation about an axis: the bolt. This force is measured in Newton-meters (N-m) or pound-feet (lb.-ft.). As the nut contacts the joint surface and begins to compress the joint, the nut encounters resistance. Now the torque becomes measurable as the amount of exerted force required to continue to rotate the nut against the joint at a distance of 1 meter or 1 foot.

As the nut has additional torque applied to it, the shank of the bolt may now experience a certain amount of twisting caused from the contact pressure between the thread flanks of the nut and the bolt. This contact pressure is related to friction. The torsion is a force that is now measurable as Newtons-per-meter squared (Pa, which is a Pascal) or as pounds-per-square inch (psi). However, we don't really measure torsion, we measure its resultant force: clamp load. As soon as the nut stops rotating, the torsional forces immediately dissipate and we have pure tension on the bolt.

Because the nut can still advance on the threads of the bolt, the entire bolt does not experience as much torsion as does turning the bolt head, just the portion around the nut. However, when tightening the head of the bolt, the torsional forces create twist from the top of the bolt head to the nut or bottom threads of a tapped hole. This is the reason why it requires more torque to tighten from the head of the bolt than the nut; about 10 – 15% more. Then the bolt relaxes back to 'normal'.

Besides the outward appearance of having the bolt head or nut crush themselves against the joint surfaces to gain clamping force, the mechanical purpose of applying torque is to cause the bolt to become physically stretched so that the elastic mechanical properties of the bolt will cause an equal and opposite reaction of wanting to return to its original length. This is what creates clamp load.

However, just because you applied torque and torsion to the bolt to cause tension, does not mean you have the desired clamp load.

When any type of work is performed there is friction. Friction must first be overcome before any measurable amount of work is accomplished. Friction is the resistance we feel as we rotate the wrench during tightening. Regardless of the type of tool we use, torque wrench or box wrench, we physically feel the joint becoming tighter as the frictional resistance increases and builds to a point where further rotation becomes limited to impossible.

Therefore, there are two sources of friction; the interface between the joint and washer face of the bolt head or between the bearing surface of the nut and joint or washer and the friction between the flanks of the mating threads, as they are being ground together while attempting to apply enough strain on the fastener to produce clamp load. All of this may seem like it would produce 100% friction but it also produces a certain amount of required work.

Laboratory tests have shown that we consume 50% of our wrench effort, friction, at the rotating surface of either the bolt head or nut, while there is 40% friction created between the thread flanks. This means that 90% of our wrenching effort is consumed by friction before any further work is done to place the bolt into elastic tension to create clamping force. This distribution seems to be fairly straight forward, so what causes discrepancies in our results when fasteners are assembled?

Friction

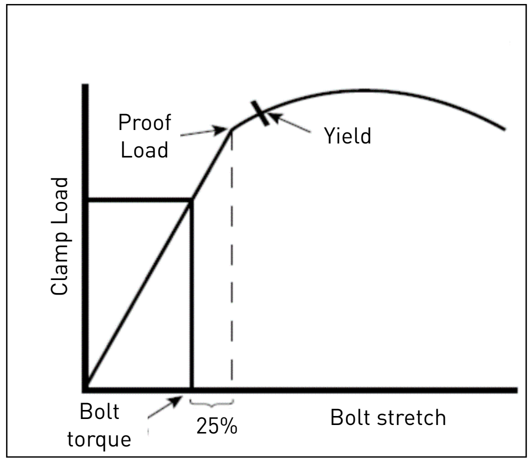
It is extremely important to realize: torque is a function of friction. The torque wrench is actually measuring friction. Your arm feels friction.

Work is accomplished when friction is overcome. For example, take a box sitting on the ground. In order to move it a certain distance, the friction of gravitational weight must first be overcome to start the box to move. So, how does this friction affect the clamp load of a joint? Significantly.

Next, assume the box was on a smooth surface and now the same box is placed on a much rougher surface. The weight of the box remains the same but the surface between the box and the ground has become much rougher, which increases the friction between the two surfaces. It now requires an additional amount of work to overcome the increased friction to move the box the same distance. Conversely, if only the same amount of work energy was applied to the box as before, the box would not move as far.

When a torque value is commonly calculated for a fastener, there is a 25% safety factor added below the Proof Load to avoid stretching the fastener into yield. However, the applied work energy that friction leaves us with is still only 10%.

Applying this relationship between torque, tension, friction and clamping force, we can express this in terms of the following graph:



Graph 1 Graph depicting forces of proof load and clamp force for cap screws

This graph should illustrate how important torque and friction control are to the relationship of clamp force. Because so much of our tightening energy was consumed to friction and only 10% remains to actually stretch the bolt, it becomes apparent how fragile this relationship is if the external friction changes even slightly.

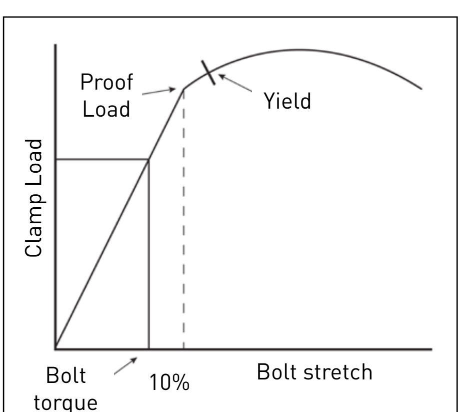
Here, it can be clearly seen what happens to the clamp load with just a 2% increase in friction. With this increase, the applied torque is now at 92% friction, leaving only 8% to stretch the bolt. Since the bolt is not stretched as much, only 8% instead of 10%, the bolt does not produce the amount of clamping force that was expected. The joint now becomes susceptible to loosening and possible metal fatigue failure.

There are many ways that friction may be increased; the surface condition of the joint materials, rust, warpage, the condition of the thread flanks on the mating parts, burrs, metal shavings, embedment, etc.

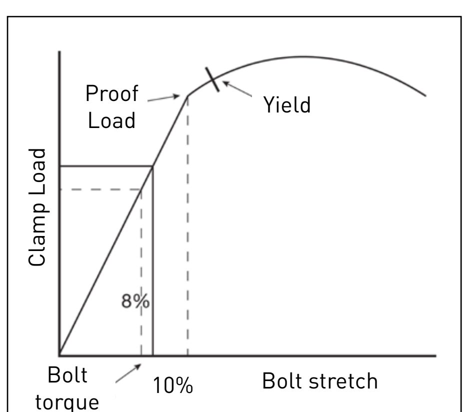
Recall the example with the box on the ground? What if you now added wheels to that box? The friction is greatly reduced and it now requires much less work to move the box. However, if the same amount of energy is used as when there was a high amount of surface friction, the box will move much farther. This can cause serious problems if not expected.

The dotted line to the right of the solid line represents a decrease in friction. If the friction is now decreased by 10%, this means that 20% of the torque energy is applied to stretching the bolt. Too much of a reduction of friction can become dangerously close to the safety factor and yield point of the bolt.

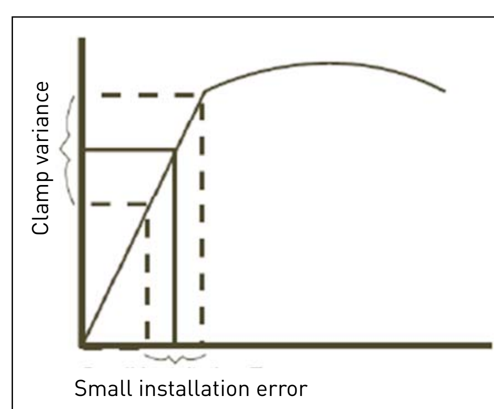
As illustrated, a small variance in friction can create a much larger variance in the resulting clamping force. It is extremely important to avoid variables and keep consistent in assembly techniques.



Graph 2 Relationship between torque, tension, friction and clamping force



Graph 3 How a 2% increase affects clamp load



Graph 4 Installation v.s. Clamp variance