The Long and Short of Bolt Failures

by Guy Avellon

There are many reasons why fasteners fail and many different ways to cause failure. Small fasteners are prone to fail when assembled with power tools, especially if the thread length is too short and long fasteners are prone to fail when used in high dynamic loading applications.

How Many Threads do We Really Need to be Within the Joint?

Under certain conditions, a fastener that is too long can fail as fast as one that is too short.

First of all, the number of threads on a fastener does not change the strength of a fastener. The fastener may be subjected to a force, or forces, that will cut the fastener in two or stretches it into yield. However, the performance of the fastener will change and be greatly affected by how the fastener is installed, whether the entire components match for strength and grade, how many threads are left inside the joint or grip area and if there is full thread engagement with the threads of the nut.

Strength is not determined by how many threads are protruding beyond the nut as long as there is full thread engagement, or complete thread contact, with all of the threads of the nut. What really matters is the number of threads within the joint. The total material thickness being clamped together is known as the joint and is also called the 'grip' area of the fastener. The threads within the grip are called the 'unengaged' threads, as they do not contact any mating threads. Of course, the number of unengaged threads is determined by how many threads protrude from the nut.

A threaded fastener is a series of different spring rates; each portion of the fastener, from the head, shank and threads, experience a different stress load and stretches at a different rate. It is the threaded portion of the fastener that is between the fastener head and the thread run-out and the first thread outside the nut, or grip area in a tapped hole, that experiences the highest amount of stress concentration of the fastener under tension. These unengaged threads will act as shock absorbers under dynamic loading.

Fig. 1 illustrates a fastener in a connection with no threads protruding beyond the end of the nut. The first thread in the nut is incomplete as a lead-in thread and therefore, will not carry much of any applied service load. The threads of the nut may even strip while tightening or cause joint failure from incomplete load distribution.

Also, in **Fig. 1**, it is important that the threads of the bolt are not within the shear plane of the joint.

Fig. 2 illustrates a correct assembly. There are about two threads sticking out beyond the end of the nut allowing the maximum number of unengaged threads inside the grip of the connection. This provides shock absorbers to absorb any shock or vibration loads or heavy impacting during installation.

A fastener's threads are very important. They stretch significantly more than the rest of the fastener and therefore have a much higher level of stress. During axial tensile testing, the ASTM Test Method Standards of F606 and F606M require a minimum of six complete threads between the test grips for a standard fastener, and a minimum of four complete threads for the shorter thread length of a structural fastener, such as an A325 (F3125/F3125M) cap screw.

If the nut or test mandrel is too close to the thread run-out, the tensile readings will not reflect the actual properties of the fastener. The stresses will be much greater on the few remaining threads.

Structural fasteners (A325 and A490 for example) have a shorter thread length than standard SAE Grade 5 and 8 and their respective ASTM counterparts ASTM A449 and A354. This is to ensure that the full diameter of the fastener's shank is completely within the shear plane of a structural joint and will protect the threads from joint shear.

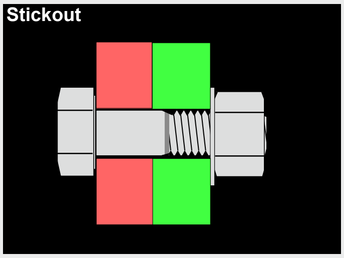

Fig. 1. A fastener in a connection

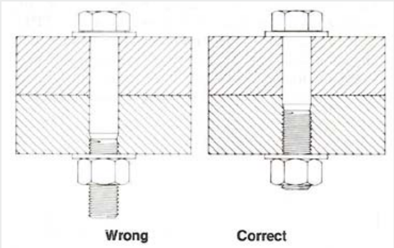

Fig. 2. Correct and wrong assembly

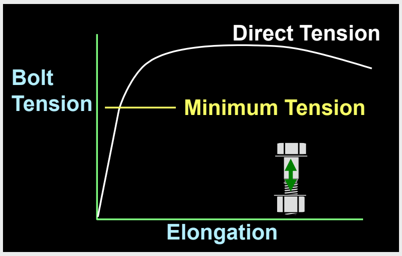

Fig. 3. Tension - Elongation

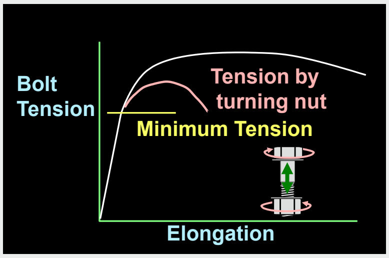

Fig. 4. Tension - Elongation

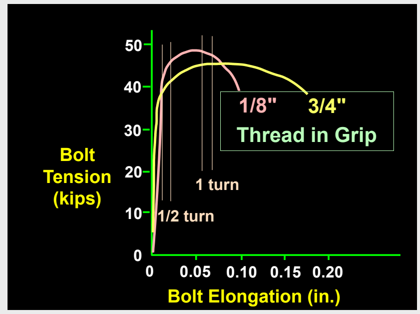

Fig. 5. Reduced Ductility for One Thread in Grip

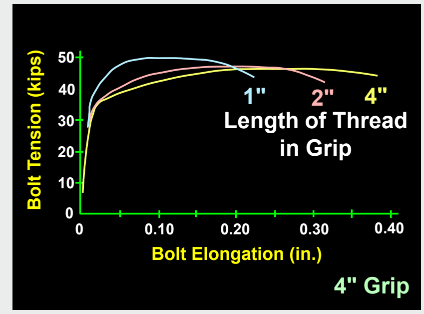

Fig. 6. Effect of Thread Length in Grip Area

This now leads into assembly variables because **the most critical time of a fastener's life is when it is being tightened.** Fig. 3 depicts a pure axial tensile load of only one force: tension.

However, when tension is combined with another force, as with torsion during tightening, the combination of forces acting on the fastener drastically reduces the amount of force required to cause it to fail. The illustration of Fig. 4 shows what happens when tension and torsion are combined when installing a fastener. Once the torsional forces stop, that load dissipates and only pure tension remains on the fastener.

During assembly, any quick, sharp or jerking motions while tightening the nut or bolt head can also become very detrimental. This is why the use of power assembly tools or impact wrenches can cause fasteners to fail prematurely if these power tools are not properly regulated.

A fastener cannot achieve clamp loads much beyond its minimum yield strength. Any further tightening may cause the fastener to fail. However, the load by direct tension, as depicted above in Figure 3 and compared in Figure 4 with the tension by turning the nut, illustrates the ductility of the fastener and its capacity to sustain further loads. Service loads would include shear and direct tension. Torsion will not occur again. Note the reserve strength of the fastener above the minimum tension in Fig. 4 as well as the increased elongation potential.

The unengaged threads are critical during installation. A fastener must be able to absorb a certain amount of torsion during assembly. The more threads there are within the joint (grip), the better the threads will be able to absorb these loads with less stress. (Fig. 5). Therefore, a fastener with very few unengaged threads is subject to failure if the assembly speed of the power wrench is too fast or the torque is at the upper limit.

For example, the closer the nut comes to the thread run-out, the higher the torsional stresses are on the threads. For one, we certainly do not want the fastener so short that the nut is actually tightening against the fastener's shank and not creating any tension of the fastener.

Suppose we place three identical fasteners into joints where one fastener has only one inch of unengaged threads, the second has two inches of threads and the third has four inches of unengaged threads. Then, using a load indicating torque wrench, tighten each to failure.

In Fig. 6, it is easy to see that the fastener with the shorter thread length in the grip of the joint develops its full tension more quickly while the longer fasteners can be stretched further than the ones with the shorter number of unengaged threads. However, these longer fasteners need to be stretched further in order to develop their full clamp load potential. The longer the fastener, the more absorption to torsional twist there is.

This may also be illustrated by applying Hooke's Law. Simplifying the computations, if we stretch a fastener in tension by 0.001" we will generate a clamp load of approximately 30,000 psi for each inch of unengaged threads within the grip area. Therefore, a fastener with a grip length of 2" will need to be stretched 0.002" to achieve the same 30,000 psi clamp load.

Simply put; the more unengaged threads there are within the joint, the greater the resilience in the connection. Figure 6 shows that the fastener with 4" of unengaged threads is almost twice as 'ductile' as the fastener with 1" of threads. Greater rotation of the nut also is needed to tighten the longer fasteners. This can be realized when using the Turn of the Nut method.

The stiffness decreases with more threads in the joint, and its ability to resist metal fatigue increases. Threads act as shock absorbers. The greater the number of unengaged threads, the more the external shock or cyclic load is evenly divided among all of the unengaged threads, which reduces the stress on the individual threads.

For example, suppose the clamp load of the joint was at 10,000 pounds and the fastener we used was too long for the joint, leaving us with only two unengaged threads within the joint. A sudden impact causes the joint load to increase to 10,500 pounds. The fastener must absorb the excess 500 pounds between the bearing surface of the nut and bolt head: the threads. This now means each of the two threads must support an instantaneous shock of 250 pounds each. This will eventually lead to the formation of stress raisers and metal fatigue in the thread roots.

If a shorter fastener was selected that fit the joint which provided 10 unengaged threads, each thread now only needs to absorb 50 pounds of excess shock load rather than 250 pounds. This fastener may last a lot longer in service life and may never develop metal fatigue, as the stress levels are significantly lower.

So yes, **it does make a difference how many threads stick out beyond the nut. Too many will not leave many threads within the joint to absorb assembly torque; too few may mean there is not full thread engagement in the nut to support the bolt's load and the nut's threads might strip. There should be at least two threads beyond the end of the nut to assure full thread engagement.**

When performing a visual inspection of joints with multiple fasteners, take note if some threads are protruding from one nut more than the others and you know that all the bolts were the same length. find out where those extra threads came from. The threads should all be extending beyond the end of the nut the same amount. Most likely, the fastener has been stretched into yield.

Find out why and Replace them.