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Reliable Threaded Fastener Assemblies: Torque-Tension Relationship – K Factor

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In the most simplistic view, the objective of a threaded assembly is to hold members together. To accomplish this task reliably, the design specifies each fastener be tensioned to provide a clamping force, known as “clamp load” or “preload.” The magnitude of this clamp load must be sufficiently high to prevent any external forces from separating the members. While reliability is most commonly linked with maintaining this clamp load throughout the service life of the assembly, often obtaining the designed clamp load at the beginning of the service life (i.e.: after assembly) can be the root cause of a failure.

Direct measurement of bolt elongation can be measured using ultrasonic tools or micrometers and correlated to tension of the fastener; however, this is often impractical. Whether it is the lug nuts of your car or the assembly line of a large OEM, the most common practice is torque control. Torque control is based on the assumption that friction of the assembly is predictable. Theoretically, if that torque is applied, a known amount of energy will become tension in the fastener while the rest is dissipated to heat. This may be a reasonable assumption for a given assembly configuration but when a single variable is changed, so is the friction.

The torque-tension relationship is often described in its most simplistic form as:

$$T = KFD$$

where

T = Input Torque
K = K Factor or Nut Factor
F = Clamp Load or Preload
D = Nominal Diameter

This relationship uses the dimensionless constant “K” to summarize the friction of an assembly and the variable diameter under the head and in the threads where friction is acting.

As a manufacturer of “thread lubricants” such as threadlockers, thread sealants and anti-seize lubricants, we are often asked how our products affect this relationship. In the next section, this topic will be addressed and will show how this dimensionless constant oversimplifies the relationship.

One of the most common questions we receive is: “What is the K factor of this threadlocker or anti-seize? Since the K factor is a summary of many variables, it cannot be used to describe a product. When a K factor is quoted for a thread lubricant, it is describing the friction of the particular assembly in which it was tested.

There are many variables which affect friction of the assembly. These include:

- Fastener materials
- Thread pitch and fit
- Diameter of the bolt
- Length of thread engagement
- Speed of the assembly
- Surface finish
- Presence or absence of washer
- Torquing the nut vs. torquing bolt head
- Hole clearance
- Lubricants
- Etc.

The configuration tested for the quoted K factor of a thread lubricant must match the end use assembly for it to be useful. Even identically specified bolts will provide significant variance.

In an experiment conducted by Henkel, the variance between identically specified nuts and bolts was examined. Hardware specified as 5/8 in. x 11 UNC grade 5 zinc-plated steel was sourced from five different manufacturers. This grade of fastener was chosen because it was recommended by bolt suppliers as the most commonly sold to general industry customers. Identical hardened washers from a single manufacturer were used throughout the experiment to eliminate this as a variable.

Figure 1 - Identically specified bolts from five manufacturers

Using the most common practice used by those employing torque control, a torque value was selected from torque tables. Most torque tables list a dry torque specification as well as wet (or oiled) specification. To accommodate a threadlocker in the test, the wet torque specification was selected. This value was 112 ft-lbf (152 N-m). Each bolt was placed into a Skidmore-Wilhelm clamp load tester. These bolt testers are oil-filled reservoirs which, when their plate and bushing are compressed between the nut and bolt head, create a hydraulic pressure. That pressure is correlated using the effective area of an internal piston to the clamp load of the assembly. Once loaded into the bolt tester, the torque was applied to the nut using a calibrated torque wrench and the achieved clamp load was recorded.

The first evaluation compared the achieved clamp loads of the bolts in “as-received” condition. The result was a standard deviation in clamp load of 4,100 lbf (21%). The second evaluation compared the achieved clamp loads for the same five manufacturers with the application of a threadlocker. This resulted in a much lower standard deviation of 1,300 lbf (12.5%) across the five manufacturers. Within the individual sample sets for each manufacturer, the scatter using threadlocker versus “as received” assemblies was also reduced in every case.

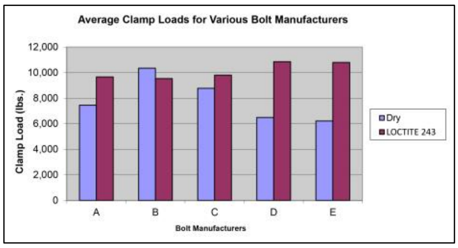

Figure 2 - Clamp load variance between bolt manufacturers

The results of these evaluations showed that even with identical specified bolts, there are considerable variations. From the surface finish of the zinc coating, thread tolerances or levels of cleanliness, there are many reasons why an input torque may not equate to a predictable clamp load. The use of a lubricating threadlocker however does diminish the variance by smoothing out the differences in friction.

Threaded fasteners are the most common detachable hardware and are used in the manufacturing of thousands of products, including automobiles, aircraft, household appliances, and industrial machinery. In a torque-controlled assembly, the unpredictability of friction is a major hindrance in ensuring the target clamp load is achieved. As shown in the experiments of this paper, the use of a threadlocker helps to minimize this issue. In critical applications, consistent use of threadlockers can substantially improve the reliability of the equipment.

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