Testing of Heat-Treated Fasteners

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Fastener reliability and performance is assured by testing. Since heat treatment can have a profound influence on final properties, it is important to test the product at this point in the manufacturing process.

The diversity of fastener types, sizes and end-use applications require a variety of test methods (**Table 1** on last page of this article) from simple dimensional checks to rigorous mechanical testing. Common types of tests include fatigue, tensile strength, wedge tensile (10°), double shear, hardness, stress rupture, stress durability, pull-out/push-out, vibration, engagement, wear, microstructure, chemical analysis and corrosion. Testing should be performed on the raw material, after heat treatment and on the finished product.

Fig. 1 — Forged bolts (photo courtesy of Instron®).

Mechanical Test Methods

In mechanical testing, fasteners are analyzed to determine their mechanical properties. Mechanical properties are those associated with elastic or inelastic behavior of a component when force is applied. It involves the relationship between stress and strain. A mechanical test shows whether the material or fastener is suitable for its intended application by measuring such aspects of performance as elasticity, tensile strength, elongation, hardness and fatigue limit.

Tensile. Tensile testing of fasteners (**Figure 2**) helps us understand the amount of force required to pull the fastener out of the base material. While straightforward, the many shapes and sizes of fasteners complicate the testing. High production demands necessitate a large number of tests and potential of violent fractures makes testing more complicated. Most manufacturers must not only test for ultimate tensile strength but also perform proof tests and ensure that no permanent deformation has occurred once the proof load is removed. In addition, they must find ways to test for thread quality and head strength.

Fig. 2 — Tensile testing apparatus (photo courtesy of Instron®).

Torque/Torque-tension. Fasteners are typically installed by applying a torsional force to the head or nut. This force (or seating torque) causes the fastener to stretch and effectively applies a preload to ensure a snug fit between components. One purpose of a torque-tension test (**Figure 3**) is to determine the appropriate tightening torque required. This type of test will allow the nut factor (sometimes referred to as the torque coefficient or k factor) to be determined as well as the overall coefficient of friction. Similarly one often needs to determine the torque force at which the fastener will fail. By completing several similar tests, the variation in the torque-tension relationship, due to frictional variation, can be established for a given application.

Fatigue. Fatigue is a measure of the stress that a material can withstand repeatedly without failure. A fatigue failure is particularly catastrophic because it occurs without warning. Three basic factors are necessary to cause a fatigue failure:

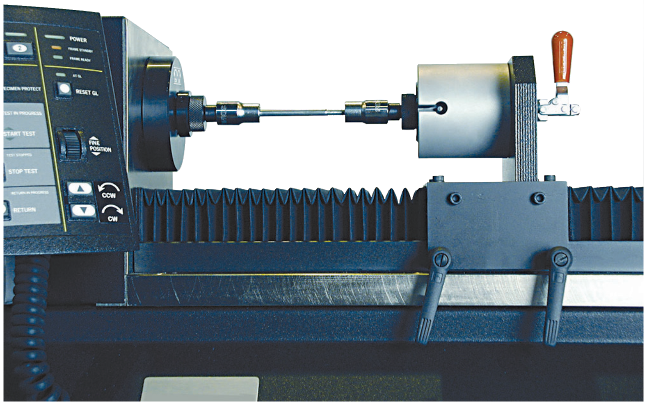

Fig. 3 — Torsion testing apparatus (photo courtesy of Instron®).

a maximum tensile stress of sufficiently high value, a large enough variation or fluctuation in the applied stress, and a sufficiently large number of cycles of the applied stress. Fatigue life tests are performed on threaded fasteners by alternating loading and unloading the part. Most testing is done at more severe strain than its designed service load but usually below the material yield strength.

Fatigue testing equipment is usually designed to induce cyclic loading and unloading to a known (peak) stress and measure the number of such cycles to failure of the specimen. Variants of the test include tensile, bending, and rotating. The average stress at which a steel can withstand 10 million loading cycles without failure is reported as the fatigue strength (also called the endurance limit). As stress increases, the number of cycles to failure decreases.

Shear Strength. Shear strength is defined as the maximum load that can be supported prior to fracture, when applied at a right angle to the fastener's axis. Simply stated, it is the force required to pull the base material in one direction and the top material in the other direction until failure. Modes of failure include deformation of the base material (i.e., the fastener pulls out of the base material) and fastener fracture. Bolted or riveted connections are those that are commonly subjected to shear stresses. Unlike tensile testing, determining the ultimate shear load and detecting specimen failure can be difficult. The test system must be flexible enough to define different end-of-test criteria for each style of fastener. Most, if not all, shear testing is done on the unthreaded portion of the fastener.

Single shear testing applies a load in one plane and results in the fastener being cut into two pieces, while double shear (**Figure 4**) produces three fastener pieces. Single shear values for fasteners are typically calculated based upon the nominal body diameter or body shear area. There is a relationship between the tensile strength of a material and its shear strength. For example, in alloy steel the shear strength is approximately 60% of its tensile strength. In corrosion resistant steels (e.g. 300-Series stainless steels) the tensile/shear relationship is usually only 50% to 55%.

Creep and Stress-Rupture. Creep is time-dependent deformation of a material while under an applied load (below its yield point). Stress-rupture is the sudden and complete failure of a material held under a constant load for a given period of time at a specific temperature. These tests are used by fastener manufacturers to determine how their products will perform when subjected to constant loads at both ambient and elevated temperatures.

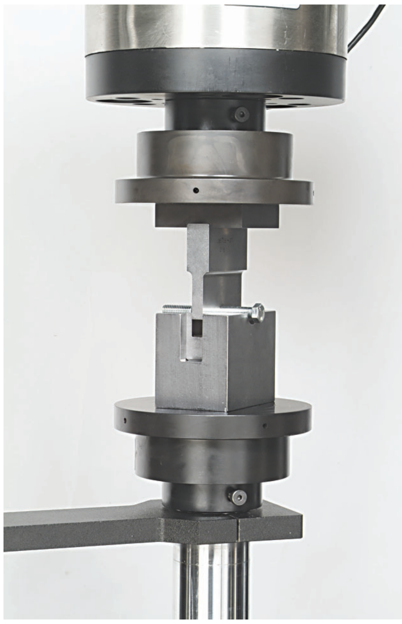

Fig. 4 — Double shear testing apparatus (photo courtesy of Instron®).

Stress Durability. Stress durability is used to test parts that have been subjected to any processing operation (e.g., electroplating) that may have an embrittling effect. It requires loading the parts to a value higher than the expected service load and maintaining that load for a specified time after which the load is removed and the fastener examined for the presence of cracks.

Hardness Testing. Microhardness testing (**Figure 5**) is often done to measure the core hardness of a fastener or measure the depth of case hardening. This type of hardness test helps characterize the fasteners durability or wear. For example, low core hardness measurements may indicate a premature yielding of the fastener leading to a ductile failure. By contrast, high core hardness may indicate the inability to properly yield and lead to a brittle type fracture. In either case, the integrity of the fastener may be jeopardized.

Fig. 5 — Microhardness testing (photo courtesy of Wilson® Instruments).

Vibration Tests. Vibration tests are used to determine a fastener's lifespan, and compare fastener's self-loosening characteristics under vibratory conditions. A transverse vibration test machine (commonly called a Junker machine) is used to produce a preload decay graph, an indication of resistance to self-loosening.

Metallurgical (Structure) Analysis

Metallurgical testing can be performed to evaluate fastener microstructure yielding invaluable information on grain size, surface condition (e.g., carburization or decarburization), and heat treatment response. The microstructure and grain size are most often influenced by heat treatment.

Chemistry. The chemical composition of a steel heat is established at the mill and reported on a material certification sheet issued. It is highly desirable to know not only the principal elements but also the trace elements present before heat treatment. Grain size, prior processing (e.g., mill annealing) and hardenability are also commonly reported.

Hydrogen Embrittlement. Steel fasteners exposed to sources of hydrogen (e.g. electroplating operations) can fail prematurely at stress levels well below the materials yield strength. The effect is often a delayed one meaning that it may occur in service. Higher strength steels are more susceptible to hydrogen embrittlement than lower strength steels. As a rule of thumb, steels below 30 HRC are considered to be far less susceptible. The problem can be controlled by careful selection of plating formulation, proper plating procedure, and sufficient baking to drive off any residual hydrogen.

Corrosion. Fastener failure due to corrosion can be relatively slow, or surprising rapid. It is usually defined as the amount of time before white or red rust appears on the surface of a fastener and is measured in terms of hours of resistance to a salt spray (fog) test.

Fastener Testing Specifications

Some of the more common fastener testing specifications are as follows:

- *NASM 1312-5* (Replaces *MIL-STD-1312-5*): Standard test method to determine Hydrogen Embrittlement (stress durability) of internally threaded fasteners.
- *NASM 1312-7*: Standard for accelerated vibration testing.
- *NASM 1312-8* (Replaces *MIL-STD-1312-8*): Standard test method to determine tensile strength of externally and internally threaded fasteners.
- *NASM 1312-10* (Replaces *MIL-STD-1312-10*): Standard test method for Stress-Rupture.
- *NASM 1312-11* (Replaces *MIL-STD-1312-11*): Standard test method for determining tension fatigue of bolts, screws and nuts at room temperature.
- *NASM 1312-12* (Replaces *MIL-STD-1312-12*): Standard test method for determining thickness of metallic coatings.
- *NASM 1312-13* (Replaces *MIL-STD-1312-3A*): Fastener Test Methods for Double Shear Tests.
- *NASM 1312-15* (Replaces *MIL-STD-1312-15*): Standard test method for determining the room temperature torque-tension relationship for threaded fasteners.
- *NASM 1312-20* (Replaces *MIL-STD-1312-20*): Standard test method to define procedures and apparatus for testing fasteners in single shear.
- *NASM 1312-28* (Replaces *MIL-STD-1312-28*): Standard test procedure to determine double shear strength, at elevated temperatures, for all structural fasteners.
- *NASM1312-31* (Replaces *MIL-STD-1312-31*): Standard test method for torque testing threaded fasteners.
- Tension Testing per *ASTM A574*.
- Fatigue Testing per: *NASM8831 Rev.3*; *MIL-S-5000 REV. E*; *NASM14181*; and *NASM85604*.
- *ASTM F606*: Standard test method to determine the mechanical properties of externally and internally threaded washers and rivets.
- *ASTM F606M*: Standard test method to determine mechanical properties of externally and internally threaded washers and rivets (metric).

Table 1. Summary of Common Test Methods for Fasteners.

Test	Method	Applicable Specifications
Chemical Analysis	Optical emission spectrochemical analysis	ASTM E415/ASTM E1086
Mechanical and Physical Testing and Inspection	Axial tensile strength of full-size threaded fasteners	ASTM A370/ASTM F606/ SAE J429/SAE J1216/ISO 6892
	Charpy Impact (V-notch)	ASTM A370/ASTM E23
	Compression Test of Washers	ASME B18.21.1
	Cone Proof Load of Internally Threaded Fasteners (nuts)	ASTM F606
	Drive Test	ANSI/ASME B18.6.4/SAE J933
	Embrittlement Test of Washers	ASME B18.21.1
	Hardness Preparation	ASTM F606
	Microhardness of Fasteners	ASTM E384
	Proof Load of Full-Sized Externally Threaded Fasteners	ASTM A370/ASTM F606/ SAE J429/SAE J1216
	Proof Load of Internally Threaded Fasteners (nuts)	ASTM A370/ASTM F606/ SAE J995
	Proof Torque Test	ASTM F912
	Rockwell Hardness of Fasteners	ASTM A370/ASTM E18/ SAE J417/ISO 6508-1
	Rockwell Superficial Hardness of Fasteners	ASTM A370/ASTM E18/ SAE J417
	Tension Testing of Machined Specimens from Externally Threaded Fasteners	ASTM A370/ASTM F606/ SAE J429/ASTM E8 ISO 6892
	Torsional Strength Test of Thread Rolling and Self-Drilling Tapping Screws	SAE J78/SAE J933/ ANSI/ASME B18.6.4
	Total Extension at Fracture of Externally Threaded Fasteners	ASTM F606/ISO 6892
	Twist Test of Lock Washers	ASME B18.21.1
	Wedge Tensile Strength of Full-Sized Threaded Fasteners	ASTM A370/ASTM F606/ SAE J429/SAE J1216/ ISO 6892
Microstructural Analysis	Decarburization and Case Measurement in Fasteners	ASTM E1077/SAE J121/ ASTM A574/ASTM E3/ ASTM A490
	Macroscopic Examination of Fasteners by Etching	ASTM E381/ASTM E340
	Surface Discontinuities of Externally Threaded Fasteners	ASTM F788/788M/ ISO 6157-1/ISO 6157-3/ SAE J123
	Surface Discontinuities of Internally Threaded Fasteners	ASTM F812/SAE J122/ ISO 6157-2
Nondestructive Inspection	Liquid Penetrant Inspection	ASTM E165/MIL-STD-271/ MIL-STD-6866/SAE J426/ ASTM E1417
	Magnetic Particle Inspection	ASTM E709/MIL-STD-271/ MIL-STD-1949/SAE J420/ ASTM E1444/ ASTM A275/A275M
	Ultrasonic Inspection	ASTM A388/A388M/ ASTM A577/A577M/ ASTM 745/A745M/ASTM E114 ASTM E273/MIL-STD-271

Summing Up

Determining the proper test methods for a particular fastener application, and executing them in such a way as to make sure that the actual testing does not introduce variability into the results, are important parts of any good quality control system. Often times practical shop tests have been devised that produce highly valid results for fastener systems and should not be discounted—provided there is adequate historical and field data to support the validity of the tests.

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