"What are Ultra High Strength Bolts?"

Advantages, Disadvantages and Shared Experiences

by Ralph White

Introduction

Ultra High Strength (UHS) bolts are also known as austemper heat treatment bolts that have a higher hardness and subsequent tensile strength than bolt property classes specified within ISO 898-1 [1]. In August 2011, the VDA published a Material Data Sheet VDA 235-205 [2] that defines the requirements of property classes 14.8, 15.8 and 16.8 by bainitic heat treatment for the automotive industry. As these bolts increased in acceptance and released on automotive applications there became a need to document some precautions, effects on joint design and to establish a special property class designation.

Because of this increase in strength and performance, SAE/USCAR and IFI (Industrial Fastener Institute) established a "USCAR – IFI Guide for Ultra-High Strength Externally Threaded Fasteners" [3] which is based on the VDA 235-205. This technical guide provides uniformity in materials, austemper heat treatment processing, inspection, and property class identification. These UHS bolts are suitable for high volume production with predictable physical properties (fatigue, tensile and yield strengths) that are different from industry standard oil quench and temper bolts. **Unique head markings display a capital U after the property class designation to denote an Ultra high strength bolt (14.8U, 15.8U and 16.8 U).** The guide also provides some precautions regarding the processing of UHS bolts and effects on joint design.

UHS bolts are commonly used on critical applications to optimize the clamp load potential by using smaller nominal diameter bolts and achieving the tensile strength of a larger diameter bolt. These bolts support weight reduction on vehicles especially on critical engine and chassis applications requiring high clamp loads. They also support special torque to yield power tool assembly strategies to optimize clamp load because the ductility in the elastic region. The same nominal diameter UHS bolt property class 14.8U is about 25% stronger than a property class 10.9 with the ductility of a property class 8.8. Some applications consider UHS bolts as a "Problem Solver" for marginal designs and process sensitive applications.

There is an increase cost because of the longer austemper heat treatment process time with fewer bolts than standard oil quench and temper. The process takes about 16 minutes for the bolts to pass through the furnace followed by a salt bath for about 40 minutes. The time in the furnace is based on the size and weight of the parts. Most furnace belt processes recommendations are for a single layer thick of bolts. Other austempered fasteners are hexagon flange nuts, multi-threaded U-nuts and loose washers.

Austempering Heat Treatment Overview

The austempering process uses a salt bath not an oil to quench cools the parts after being subjected to high furnace temperatures. The result is a lower Bainitic Structure compared to Martensitic Structure from a conventional oil quench. An excellent article titled "Basics of Austempering" by Laurence Claus, President NNI Training and Consulting Inc. [4] describes the metallurgical and austempering process in detail.

Fastener Manufacturers state that the preferred material is SAE 8640 steel for austempering bolts to achieve uniform results. There are a few manufacturers that have a slightly modified chemistry to the basic SAE 8640 to aid cold heading and provide focused physical properties after austempering. Other steels investigated have been SAE 6150, 5140, 4340, 4140 and SAE 4130 but 8640 performed better. Changes in material trace elements other than specified as SAE 8640, like Ti (Titanium) and S (Sulfur) may require furnace adjustments. Also, an increase in part core hardness could be a result of the wire draw change in microstructure. The type of wire annealing for cold forming the bolts has shown to be important for consistency of heat treatment results (i.e., spheroidized, subcritical spheroidized, stress relief, etc.). To aid the austempering process, the parts received from the fastener manufacturers should be clean (no phosphate) with a light water base rust inhibitor.

UHS bolt sensitivity to hydrogen embrittlement (hydrogen induced stress corrosion cracking) is the same or slightly less susceptible than industry standard oil quench and temper bolts. But not eliminated. See test procedures ISO 15330 "Fasteners — Preloading test for the detection of hydrogen embrittlement — Parallel bearing surface method." [5] Therefore, the corrosion protection recommendation is to avoid electro plating and consider dip spin coatings. Many automotive OEM's require baking after heat treatment. Because of this concern, some automotive OEM's have developed a 12.8U that has a core hardness 34-39 HRC.

Typically, the austemper process is evaluated and documented per AIAG CQI-9 "Special Processes: Heat Treatment Systems Assessment" [6] Section 4 - Job Audit prior to production quantity business activities. Inspection procedures include industry standard hardness checks, tensile pulls and bainitic microstructure testing. The Microstructure inspection uses Sodium Metabisulfite (SMB) Etchant analysis method on epoxy-based mounting compound specimen for detecting bainite and martensite. Some fastener manufacturers conduct torque vs. tension testing after corrosion coating prior to shipping to their customers.

Because of the increased hardness, UHS bolts can become magnetized if subjected to magnetic feeding equipment. The concern is that if the bolts become magnetized, they tend to attract small metallic particles that can interfere with assembly. While the exact industry standard is unknown, there is an acceptable level of magnetism from 0 to 3 gauss on parts to prevent picking up chips and will not interfere with vehicle electronics. A recommendation is to have demagnetizers installed when using magnetic feeding equipment.

Austempering is a proven heat treatment process applied for many years on parts such as springs, clips, U-nuts, long rods, long small diameter bolts, washers, small assemblies, etc. This process has provided volume production of property grade 14.8U bolts for the automotive industry for over 10 years.

Properties of Austemper Bolts: Property class 14.8U bolts can have an increase of fatigue strength up to +20% versus 10.9 bolts when threads are rolled after heat treatment. Advantages of lower bainitic structure vs. martensitic structure are lower internal stresses within crystal microstructure, better ductility at comparable strength, higher fatigue properties per ISO – 3800 [7] , less distortion by austemper heat treatment due to lower residual stresses, and less probability for quench cracks.

Also, an MJ16 x 2.5 property class 14.8U bolt was Charpy Impact evaluated per ISO 148-1 [8] and the results are shown in (**Figure 1.**). The absorbed energy level for Charpy Impact test improved significantly with austempered 14.8U bolts with bainitic condition versus property class 14.9 martensitic condition.

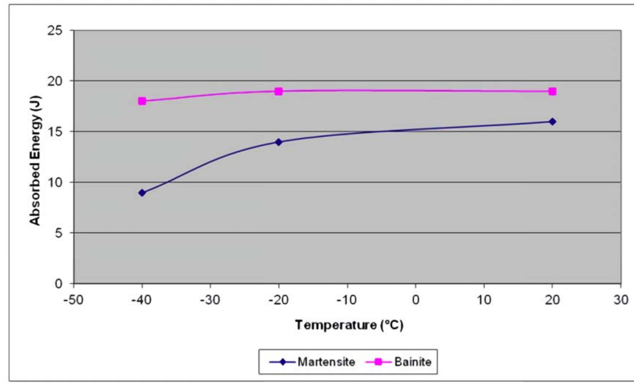

Figure 1. MJ16 x 2.50 property class 14.8U (bainite) vs 14.9 (martensite) Charpy V-Notch test results.

Automotive Applications

There are critical Internal engine, driveline, powertrain, and chassis applications that use 12.8U and 14.8U bolts because of the "torque to yield" or "torque and angle" power tool tightening strategy. Some connecting rod bolts have a multiple tightening strategy where the UHS bolt has an increase of clamp load at yield point during second tightening. The long yield curve optimizes the power tool shut-off accuracy. Also, internal engine UHS fasteners can be smaller (i.e., M7 replaces an M8). Chassis joints tend to use 14.8U because the joints can have longer thread engagement to optimize the bolt high tensile strength.

Also, UHS bolts are on applications where an increase in nominal diameter size cannot be packaged in the assembly. They support weight reduction initiatives and used where the joint requires increased strength. As mentioned above, some applications consider UHS bolts as a "Problem Solver" for marginal designs and process sensitive applications.

Important Design and Application Factors

Design

The bolt under head fillet design is important because of the change in the mass area and heat retention between the cylindrical body and the larger head. For fatigue applications consider specific requirements for fillet radius size and/or shape, such as special designed fillet (double radii or elliptical) using FEM simulations. Also of importance is the location of thread run out (distance of the first thread to under head bearing surface) based on the joint geometry and imposed load forces. Increase bearing surface pressure under the bolt head from the higher clamp load could exceed the compressive strength of the joint.

It is preferred that the UHS bolts have a MJ thread form per ISO – 5855 "Aerospace – MJ threads" [9,10] (MJ12-1.25) and thread rolling after treatment. The tensile stress area of a MJ thread will be slightly larger than a standard ISO M threads (M12-1.25) of the same size and pitch. Because of the MJ thread profile there is higher cost in die wear and slower thread rolling tool piece rate. Thread rolling after heat treatment dramatically decreases roll die life. There are special thread rolling dies made of M42 tool steel has shown improves thread rolling life when thread rolling fasteners after hardening. Rolled threads after heat treatment show improved fatigue life and optimize the purpose of the UHS bolt properties.

Commonly dip spin surface corrosion protective coatings are specified on most UHS fasteners provide consistent friction properties for predictable torque and clamp load performance. The coatings have uniform thickness to provide improved corrosion resistance plus the coating application process does not introduce the potential for hydrogen embrittlement.

Figure 2. Desired bolt 2-piece failure at 3.5 x diameter of thread engagement.

Application

If the UHS bolt is replacing an existing ISO grade (say a 10.9) the tightening specification may need adjustment to optimize the UHS bolt special properties. A key design rule is that the bolt breaks into two pieces without the nut threads stripping (**Figure 2.**). Stripping of the nut is not acceptable. The mating component material and internal thread engagement are important considerations when using UHS bolts. Often the thread engagement is increased to optimize the UHS bolt high tensile strength. Aluminum tapped holes can be problematic because of the many types of material physical properties. It is recommended to conduct power tool torque to failure testing to establish a safety factor for a failure mode. An example is the internal thread engagement of an aluminum knuckle using a power tool torque to failure on a M10 x 1.5 property class 14.8U bolt. The internal threads had strippage at 2 x dia., 2.5 x dia., 2.75 x dia. (**Figure 3.**). At 3.5 x dia. The bolt broke in two. Also, higher clamp loads of UHS bolts increase bearing surface pressure that may result in bolt embedment into mating surface.

Figure 3. Aluminum internal thread strippage at 2 x dia., 2.5 x dia., 2.75 x dia.

Summary

The increase clamp load and ductility of UHS austemper heat treatment bolts are an essential contribution to weight reduction supporting the trend for downsizing engines, drivetrain, and chassis components. There is extra cost for UHS bolts compared to martensitic quench and temper property classes, i.e.,10.9. Because UHS bolts use SAE 8640 steel wire, have a slower volume austemper heat treatment process, forming MJ thread profile and threading after heat treatment.

The outlook has a slowly expanding market demand on automotive critical applications. UHS bolts are used to support weight reduction initiatives and considered a "Problem Solver" for marginal designs and process sensitive applications. There is evidence that UHS bolts are steadily moving mainstream and used by automotive engineers by expanding the VDA classifications to include an additional property class 12.8U. ■

References

1. ISO 898-1: Fifth edition 2013-01-15, "Mechanical properties of fasteners made of carbon steel and alloy steel" Part 1: Bolts, screws, and studs with specified property classes – Coarse thread and fine pitch thread

2. VDA 235-205, August 2011, " Ultra strength fasteners with bainitic heat treatment for automotive industry – property classes 14.8 to 16.8"

3. "USCAR – IFI Guide, November 23, 2015, for Ultra-High Strength Externally Threaded Fasteners GUIDE Number: UHSFG-1416U-2014"

4. "Basics of Austempering" by Laurence Claus, President NNI Training and Consulting Inc., Fastener Technology International, February 2014.

5. ISO – 15330: First edition 1999-09-01, Fasteners – Preloading test for the detection of hydrogen embrittlement – Parallel bearing surface method.

6. AIAG CQI-9: Version 3, Special Processes: Heat Treatment Systems Assessment.

7. ISO – 3800: 1993, Confirmed in 2021, Threaded fasteners – Axial load fatigue testing – Test methods and evaluation of results

8. ISO – 148-1: Third edition 2016-10-15, Metallic materials – Charpy pendulum impact test.

9. ISO – 5855-1: 1999, Confirmed in 2021, Aerospace – MJ threads - Part 1: General requirements

10. ISO – 5855-2: 1999, Confirmed in 2021, Aerospace – MJ threads - Part 2: Limit dimensions for bolts and nuts.