Part 2

Stainless Steels

High Temperature Bolting

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Some forms of mechanical and heat treatments are common for all stainless steel alloys to obtain different physical properties. When a material is plastically deformed (cold worked) it tends to become harder. However, the rate of work hardening decreases as the temperature increases (hot forming). Two opposing effects take place at the same time when a material is plastically deformed at an elevated temperature; a hardening effect due to plastic deformation and a softening effect due to recrystallization.

Whenever there is a distortion of the lattice structure, whether it is from plastic deformation, heat treatment or alloying, there will be an increase in strength and hardness of the material. Yield strength increases more rapidly than tensile strength so that as the amount of plastic deformation is increased, the gap between the yield and tensile decreases. Annealing widens the ratio between tensile and yield strengths but reduces residual stresses.

The ASTM (American Society for Testing and Materials) Standards A193 and F593 both have their own alloy and treatment identification methods. Both of these standards are inch standards. The A193 was developed for "Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service" and the F593 was developed for common use and general corrosion resistance for "Stainless Steel Bolts, Hex Cap Screws and Studs".

The F738M was a metric standard for hex head stainless products but was withdrawn in 2014 in favor of referencing the ISO 3506. However, there are other stainless steel standards in both inch and metric units for socket head cap screws, socket set screws and square head and slotted headless set screw products.

In 2004 the F2281 was published as the Standard Specification for "Stainless Steel and Nickel Alloy Bolts, Hex Cap Screws, and Studs, for Heat Resistance and High Temperature Applications". This specification is intended for fasteners from ¼" diameter and larger for use at temperatures up to 1800ºF (982ºC) as well as balancing the corrosion resistance of the alloys for specific applications.

It should be noted that several steel standards are referenced; ASTM A276 and A479, for example. Both have similar steel chemistries but have some differences. The A479 specifically refers to being used in boiler and pressure vessel applications. When the SA276 material specification was submitted for ASME Section II review and endorsement, it was for bars and shapes. The scope limits the use to non-pressure boundary applications.

Strain hardening is a form of work hardening whereby the material develops an increased resistance to further deformation. Strain hardening will increase the yield strength in the shank, whereas cold working will increase the strength in the threads. This is important since non-ferrous materials can and are allowed to yield in the shank area under tensile testing.

Carbide solution treated and strain hardened conditions are referenced in most all of the stainless steel material specifications. These conditions change the physical properties without affecting the corrosion resistance. These changes should be taken under consideration when calculating torque values because some alloys and conditions will have a drastic change in yield strength with different diameters. Some alloy conditions will have up to four different yield changes through 1 ½" diameters.

The F2281 does not reference strain hardening but instead references all annealed or solution-annealed stock with re-annealing the product within specific heat ranges for different Types and Classes. What is unique with this standard is that the tensile and yield strengths are consistent for all diameters in each Class with the exception of the alloys 410, 416 and 431.

There are three types of material specifications; Type I for heat resisting alloys for continuous service applications; Type II for heat resisting alloys for continuous and intermittent service applications; Type III for high temperature alloys for continuous and intermittent service applications.

There are also three Classes of alloy Grades; Class A, for heat resisting austenitic grades; Class B, for heat resisting martensitic grades; and Class C for heat resisting ferritic grades.

For example, to designate austenitic alloys, all product markings will have an F1, followed by a letter from A (F1A) through M (F1M). The austenitic alloys are Type I; Class A are 304, 304L, 316 and 316L. The 304 and 304L alloys are the most susceptible of the austenitic stainless steels to stress corrosion cracking (SCC). The 'L' suffix indicates low carbon, such as 0.03% for 304L vs 0.08% for 304. Exposure to halides, chloride ions as well as elevated temperatures will promote SCC due to their lower nickel content, which is why the proper solution-annealing and re-annealing processes are very important as is a slow cooling rate to prevent carbide precipitation.

The 316L has better resistance to intergranular stress corrosion but continuous operating temperatures from 800-1500ºF (427-816ºC) will cause chromium carbide precipitation in the grain boundaries weakening the fastener.

Because of the relatively low carbon content of the austenitic series, they may not be hardened by heat treatment. The martensitic and ferritic series may be hardened because of their higher carbon content and lack of nickel. The martensitic steel is a body-centered tetragonal (BCT) crystal and the ferritic steel is a body-centered-cubic (BCC) crystal structure: both are ferromagnetic and hardenable. The ferritic steels are more resistant to SCC but more susceptible to pitting and crevice corrosion.

The martensitic alloys of 410, 416 and 431 are of the Type I, Class B grades and the ferritic alloys of 430 and 430F are of the Type I Class C grades.

Type II, Class A heat resisting austenitic alloys for continuous and intermittent service include; 309, 310, 321, 330 and 347. Type II grades are designated with an F2 followed with a letter suffix of A through I. (F2A- F2I)

Type III, Class A for high temperature nickel alloys for continuous and intermittent service includes alloy 600 and 601. Type III grades are designated with an F3 followed by a letter suffix of A through G (F3A-F3C). Type III, Class B is for high temperature, precipitation hardened alloy 660 (F3D-F3F). Type III, Class C is for high temperature, precipitation hardened alloy 718 (F3G).

It should be noted that while the tensile strengths of these high temperature alloys are high, their tensile strengths and yield strengths begin to decrease significantly once the operating temperature is elevated beyond 1100º F (594ºC). For example, the Type III, Class B alloy (660) has a tensile strength of 138 ksi (952 MPa) at 800ºF (427ºC) but drops to 64 ksi (441 MPa) at 1400ºF (760ºC). The Class C alloy grade 718 retains its strength properties at a slightly higher strength and temperature level.

When making and using torque values, always check the specification and diameter requirements for any changes in the yield strength. The tensile strengths may be the same for some, but the yield strength may have changed which will significantly affect the connection. Then check the operating temperatures for the proper choice of alloy and condition. ■