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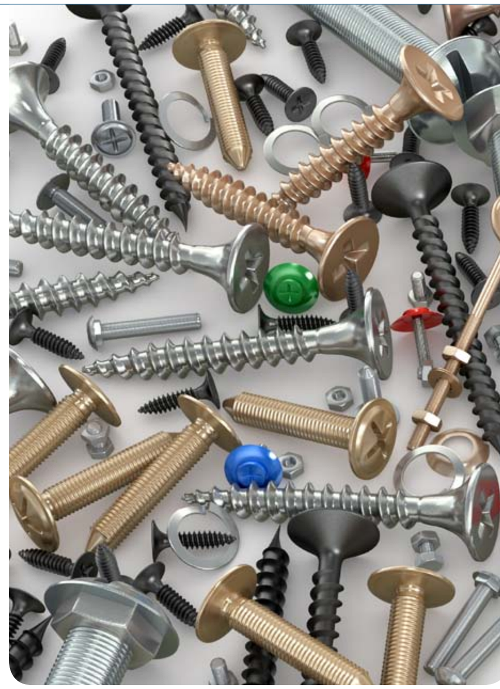

What's In Your Fasteners?

by Guy Avellon

Many times, we take products for granted. We know one type of fastener should have so much strength, but how does an engineer know if the properties will provide suitable performance for some of the applications they require? As a guide, this article will provide what the steel chemistry numbers mean to users.

Carbon steels are called such as they contain a certain amount of carbon. The amount of carbon present determines the steels ability to be heat treatable. The addition of certain alloying elements will provide the performance characteristics desired of the finished product.

The base steel or alloy composition type is identified by a series of digits in the steel number, as developed cooperatively by the AISI (American Iron and Steel Institute) and the SAE (Society of Automotive Engineers). For example; the first digit of a four or five digit steel number indicates a category, such as ① carbon steel, ② nickel steel, ③ nickel-chromium steel, etc. The second number indicates the approximate percentage of the alloying element, while the last two or three digits indicate the approximate 1/100ths weight percentage of carbon content.

Typical AISI/SAE steels, but not limited to, used for fastener products are as follows:

- 10xx—Plain Carbon Steel
- 15xx—Manganese Steel
- 40xx—Molybdenum Steel (0.25%)
- 41xx—Chromium-Molybdenum Steel (1.0% Cr, 0.20% Mo)
- 43xx---Chromium-Manganese-Molybdenum Steel
- 50xx---Nickel Steel (50B46)
- 51xx—Chromium Steel (51B60) (0.80% Cr)
- 86xx---Chromium-Nickel-Molybdenum Steel
- 87xx—Chromium-Nickel-Molybdenum Steel (0.55% Ni, 0.50% Cr, 0.25% Mo)
- 94xx---Nickel-Chromium-Molybdenum Steel (94B40)

To be considered an alloy steel, one or more alloying elements must be added to the steel. The American Iron and Steel Institute has defined that a steel is considered to be an alloy when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits: manganese, 1.65%; silicon, 0.60%; copper, 0.60%; or in which a definite minimum quantity of any of the following elements is specified or required within the limits of the recognized field of constructional alloy steels: aluminum, chromium up to 3.99%, cobalt, columbium, molybdenum 0.30%, nickel 0.30%, titanium, tungsten, vanadium 0.10%, zirconium, or any other alloying elements added to obtain a desired alloying effect. Where elements are specified in combinations of two, three or more and have alloy contents less than described above, the limit value to be applied for steel class determination is 70% of the sum of the individual values of the concerned elements.

Fastener Grades:

All fasteners, regardless of standard or specification, are identified by a unique marking on the head, in addition to the manufacturer's unique registered marking. The following is a typical list of the common inch and Metric fasteners used in commerce. See SAE J429 and SAE J1199.

SAE Grade 2 (Metric Property Class 5.8): Hex Head Cap Screws are produced from low carbon steels, ranging from AISI/SAE types 1010 to 1022 and are not heat treated.

SAE Grade 5 (Metric Property Class 8.8): Hex Head Cap Screws are produced from several different steel types, ranging from, but not limited to, 1032 to 1038, and are classified as medium carbon steels or high manganese steels, such as 1541 or 1335. The ASTM equivalent is the A449.

SAE Grade 5.2: SEMS bolts, flanged head cap screws and studs, made for specific automotive applications, made from low carbon boron steel.

SAE Grade 8 (Metric Property Class 10.9): Hex Head Cap Screws are also produced using many different steel types depending upon their final use. SAE J429 allows the use of non-alloy steels by some manufacturers for their special applications. The similar ASTM product requires that all A354, Grade BD cap screws be manufactured from alloy steels and have documented proof-load testing performed on the products. All Grade 8 and A354 cap screws are heat treated and oil quenched and tempered.

SAE Grade 8.2: Typical of flanged head cap screws, used for specific automotive and truck applications, is usually made from low carbon boron steels, due to easier formability for the flanged head.

Socket Head Cap Screws:

Metric Socket Head products come in different grades, or Property Classes, from 8.8, 10.9 and 12.9; therefore these products will use a variety of steels for each Property Class, as listed above, for their mechanical properties.

Inch series standard socket head products are all the same strength grade depending upon diameter; 180 ksi for sizes up through ½" and 170 ksi for larger diameters. Typically, socket head cap screws use 4140-4145 alloy steels for their products. Exceptions for high tensile strengths are the button and flat head products, which produce tensile strengths between 145 to 135 ksi. The ASTM product standards are found under Standard A574 and A574M.

Steel Chemistry:

So, what part do all of these chemical and metal elements play in the development of a steel fastener? The most common alloying elements are listed below, along with their effects. It must be noted that when some elements are combined, a synergistic effect may occur that further enhances the quality and performance of the steel.

Aluminum: While not always intentionally added, it is usually present in steels. It serves as a deoxidizer or to produce a fine grain size, increases notch toughness in medium carbon steels but may also lower creep strength.

Boron Steels: The strength of some steels can be enhanced with the addition of a small amount (0.0005 to 0.003%) of the element boron. It is normally used with low carbon steels (10B20) that have complex geometries to save die life; such as with flange head cap screws and drive screws. However, some alloy steels with large cross-sections, large diameters or complex head geometries will also benefit with the addition of boron; such as 41B37 or 51B60.

When used with a low carbon steel, such as a 1030 or lower, the new boron alloy steel can now be heat treated to produce a hardness and tensile strength equivalent to that of a Grade 8 bolt. This is permissible if used in a shear or static load and is used properly by the purchaser. However, this alloy combination appeared as a critical problem in the mid-1980s when low carbon boron steel was used on hex head cap screws with SAE Grade 8 markings.

Obviously, this was quite a cost savings and garnered huge profits when sold as a Grade 8 product. This sparked a problem with failures from counterfeit fasteners since the presence of a boron steel was virtually undetectable by standard test methods. Hence, the fastener industry and US Government created the Fastener Quality Act (FQA) in the early 1990s.

Aside from not being able to withstand dynamic or cyclic loading, low carbon boron steels have a maximum operating temperature limit. The low carbon boron steels are quenched and tempered to 650° F (340° C), compared with a Grade 8 whose tempering temperature is 800° F (425°C). If the user did not know of the lower operating temperatures of the boron steel and subjected the fasteners to conditions that a full alloy grade 8 could withstand, then a very dangerous condition would exist. These steels were very susceptible to stress corrosion cracking.

Carbon Content: For fasteners, the last two digits in the steel number indicate the carbon content in 1/100ths of weight percent. For example, a 1541 steel has 41/100 (0.41) percent carbon in its analysis. The amount of carbon and trace elements in the steel will determine its hardenability or ability to respond to heat treatment; too hard and the steel becomes brittle, too soft and there is no strength. Alloying elements are added to the steels to enhance their ability for through-hardening, while the carbon content determines the maximum hardness achievable in a steel.

Carburization: Machine screws and sheet metal screws are typically made from low carbon steels, such as 1010 or 1022. However, there is insufficient carbon present to make the steel any harder by heat treating. Therefore, these products do not have great strength but do possess rather high ductility. They are considered as a Grade 2 fastener. Thread cutting or self-drilling screws, also made from low carbon steels, are surface hardened by the process of carburization, which is the addition by diffusion of carbon at the surface of the part. Carbon is artificially added to the surface to form a carbon-rich mixture of the furnace gas to produce a much harder surface. The depth of hardness is known as ‘case depth’ or ‘case hardness’ and is typically a few thousandths of an inch in depth, while the core remains relatively soft.

Chromium: Chromium is essentially a hardening agent. It will increase corrosion and oxidation resistance. When alloyed with nickel, the combination produces superior mechanical properties of toughness and hardness. It is also used to form austenitic stainless steels.

Manganese: Also contributes to strength and enhances hardenability during quenching. These properties increase proportionately with an increase in carbon with manganese. Surface quality is also improved with manganese steels.

Molybdenum: Another element that promotes hardenability but with a minimal effect on cold forming characteristics and provides greater control of its hardenability. The tempering temperature is higher to obtain ductility, but alloy steels containing 0.15 to 0.30% molybdenum exhibit a minimized susceptibility to temper embrittlement.

Nickel: A ferrite strengthener, nickel does not form any carbide compounds in the steel, thereby creating a toughness in the ferrite phase. Nickel lowers the critical cooling rate and is therefore very heat treatable. Alloyed with chromium, the resultant alloys have greater fatigue resistance, higher impact strength with higher hardenability than is possible with ordinary carbon steels.

Phosphorus: A high phosphorus content is beneficial in low carbon steels for improved machinability but is detrimental in quenched and tempered steels as it decreases fatigue resistance and ductility. Therefore, in these steels, the phosphorous is kept at a specified maximum amount of 0.025%.

Silicon: One of the primary deoxidizers in the refinement of steel in amounts of up to 0.30%. Silicon aides in promoting notch toughness and provides for a more uniform ferrite grain.

Sulfur: Will improve machinability in some steels, sulfur will also produce a detrimental effect on surface quality with manganese steels and lowers the toughness and ductility in the transverse direction as the content increases. For these reasons, there are maximum limits for most steels.

Vanadium: Used to inhibit austenitic grain growth to promote a fine grain structure. A fine grain structure will enhance tensile strength and toughness to steels. Vanadium has also been used with Boron in steels, such as 41BV37, etc.

Many steel specifications will explicitly state that there shall be no intentional additions of bismuth, selenium, tellurium or lead to the steel. All of these elements are used to enhance machinability, which is not a desirable trait in a quenched and tempered alloy steel fastener. In fact, selenium can form with manganese to form inclusions of manganese selenides.

Next, we will explore heat treating the steels.