Automotive Fastener Strength

by Laurence Claus

Automobiles are complicated machines with many different systems coexisting and interacting with each other. Although symbiotic to one another these systems each exist in different environments and have different performance requirements. Just as these systems make up the car in its totality, so each system is made up of multiple components, including many fasteners. Each of these fasteners has to be designed and validated to assure that they will perform as intended when eventually put into this complicated service environment.

One of the most critical choices that the designer must make is what strength the fastener will be. Although this sounds pretty straight forward, it is not. The ultimate strength required from a fastener is going to be a function of multiple different variables, including the severity of service the fastener will see in the automotive system it is being used, the environment the automobile is exposed to, the temperature range that it must operate within, how many other fasteners will be utilized, and many other similar factors.

Fastener strength is extremely important in determining whether the part and the system it is a part of will function properly. As an example, I recall a quality spill that involved a part where a breakdown in part handling during the heat treatment operation resulting in a mixture of properly heat treated parts and parts that had missed the heat treating operation and were dead soft. This was a particularly dangerous situation because the correctly processed part was high strength, providing all the preload necessary to generate the required tension. Although most of the parts that missed heat treating broke in torsion during installation and were, thus, easily detected, unfortunately not all were. The result was a series of actions to contain, inspect, and replace all offending product. As is typical of such frenzied activity, it took a significant emotional and financial toll on all the involved parties, but particularly for the fastener manufacturer that let the offending parts slip through their system.

What is Fastener Strength?

A property of a material is a characteristic or behavior of a material that doesn't depend on the size of a part. Stress or load is not a property. However, the limiting amount of stress or load that a material can take before something, usually bad, happens is a property. This is known as the strength of a material. In engineering terms, strength is given as the amount of load (or stress) distributed over an area that a material or part can endure. In the inch system this is usually given by psi (pounds per square inch or lbf/in^2) and in metric by MPa (Newtons per millimeter squared or N/mm^2). In this way, we come to understand why two distinctly different sized parts can share the same strength class but not be equivalent in their true mechanical capacities.

In the fastener world, there are several industrial standards that are recognized as providing guidance to the user for standard strength grades or classes. In the automotive realm the most commonly cited of these standards is ISO 898 Part 1 for Screws, Bolts, and Studs and ISO 898 Part 2 for Nuts. These documents define standard strength criteria by categorizing several strength classes, most notably Property Classes 5.8, 8.8, 10.9, and 12.9 for external fasteners and Property Classes 5, 8, and 10 for internal fasteners.

These property classes define three important strength levels, Yield, Tensile, and Proof. Figure 1 illustrates a standard stress-strain (bolt load vs stretch) diagram for three different bolt strength scenarios. The Y-Axis represents the value of stress and the X-Axis the amount of strain (or elongation) the material (or fastener) is undergoing. It is evident from the diagram that the material starts out behaving in a linear fashion over small amounts of elongation. This behavior eventually changes and the material begins to stretch plastically until it breaks. The Tensile Strength is the point of highest stress achieved before the material breaks. The point where the plot transitions from linear to non-linear (or elastic to plastic) behavior is the Yield Point (or Yield Strength). Proof Strength is a concept applied to fasteners and represents a strength that is somewhere between 85% and 95% of the Yield Strength. Achieving this load without plastically deforming provides us with confidence that the strength properties are correct. It is often used to validate fasteners without actually having to break them.

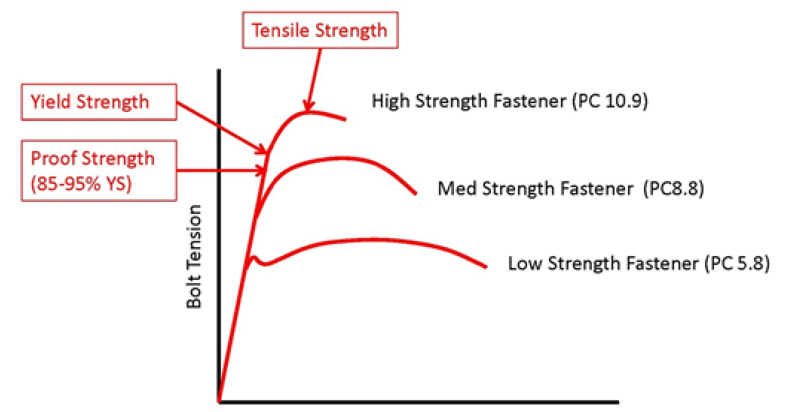

Figure 1

What are the Different Strength Designations?

In the metric system the strength designations are referred to as Property Classes. ISO 898 Part 1 has ten different standard Property Classes starting with Property Class 4.6 and ending with Property Class 12.9. In automotive the two most common are Property Class 8.8 and 10.9, with Property Classes 5.8, 12.9, and 12.9 being used more infrequently. ISO 898 Part 2, the nut standard has only five Property Classes; 5, 6, 8, 10, and 12.

The metric property class designations exhibit a little bit of intelligence. In other words, the numbers have some meaning. The first number represents the 1/100th of the minimum nominal Tensile Strength value in megapascals. Taking Property Class 8.8 as an example, the first "8" then tells us that the nominal minimum

Tensile Strength is 800 MPa. The second number (following the decimal point) provides insight into the minimum Yield Strength. However, it is not a numerical value like the first but rather 1/10th of the percentage that the minimum Yield Strength is to the Tensile Strength. So resuming with our example, the second "8" in Property Class 8.8 represents 80% of the Tensile Strength or a minimum Yield Strength of 640 MPa.

Although the inch world is similar in concept there are several differences. Obviously the values and units are in inches, but the strength designations are now referred to as Grades. The most common inch grades are provided by the SAE J429 standard for inch externally threaded fasteners and SAE J995 for inch internally threaded fasteners. These standards specify essentially three grades; 2, 5, and 8. Grade 5 is the rough equivalent to Property Class 8.8 and Grade 8 is the rough equivalent to Property Class 10.9. There is no standard equivalent to Property Class 12.9.

How do We Achieve the Different Property Classes and Strength Grades?

Fundamentally many fasteners start out either with the same or just slightly different raw material. If the starting inputs are about the same, how do we end up with a final product that exhibits these different strength classes? The answer is relatively simple; the manufacturing process influences how they are transformed to meet these requirements during their manufacturing. This may be accomplished by using different raw materials and/or adjusting the heat treating processes. All of the higher strength fasteners will undergo a Quench and Temper heat treating process. This is where the material is heated above a critical temperature until internally it has transformed to a homogeneous aggregation of the high temperature structure of steel, Austenite, quenched to transform the Austenite to the high strength structure of steel, Martensite, and then tempered to restore some toughness back into the part. By varying raw material and process parameters parts can be transformed to the desired Property Class 8.8, 10.9, and 12.9.

Where are Different Strength Fasteners Needed?

Referring back to Figure 1, in addition to illustrating the strength levels of different fasteners, this diagram also helps to illustrate that higher strength fasteners of the same size are able to generate higher joint tension. This is a very important concept for the designer to understand because it will help them to specify the proper fastener depending on service needs for preload. In other words, if a critical joint requires a maximum amount of preload, it is highly unlikely that the designer would choose a low strength fastener.

A couple of years ago I encountered a very poignant example of this. I was working on a project for a client that included going through several of their larger clients and reviewing each for potential cost saving application engineering improvements. I recall coming across an application where several bolts were being used to attach a wooden board to the bottom of the assembled product to protect it during shipping. These boards and the associated fasteners were removed and discarded once they reached their final destination. I took a look at the bolts being used to attach these temporary boards and was surprised to see that they were Grade 8 bolts. This was a surprise finding because in this particular application very minimal preload was needed (or actually capable of being generated), and, yet the bolt capacity to develop preload was high. All of that unused capacity came with a premium price that would never be returned to either the assembler or the end user.

In the automotive world, every automobile has a mix of different strength product. Most likely, about 80% of the metric thread forms utilized in construction of the car and systems are Property Class 8.8/8 and 10.9/10. Property Class 8.8/8 would account for standard, normal-duty applications where high preloads to maintain safe, long-term clamping is not of high concern. One might find typical examples of this with a quick reconnaissance of the engine compartment, trunk space, or underneath the dashboard. Likely many examples of Property Class 8.8/8 fasteners would be easily discovered being used for mounting items in these locations. Property Class 10.9/10 fasteners are going to be found on applications where higher preloads must be established. One will find ample examples of these when looking in the engine compartment, but many will be out-of-view and in applications involving the suspension, brakes, steering, and internal engine components. Finally, Property Class 12.9/12 is utilized for really severe duty applications like internal powertrain components. Connecting Rod Bolts, Main Journal Bolts, Head Bolts and many other critical internal engine parts may require this higher strength. The higher the performance of the engine the more likely such high strength fasteners will be required. Although the higher strength level provides the ability to generate higher preloads it does not come without some risk. These high strength bolts require tighter installation control because they have far less margin to survive poor installation conditions and they are significantly more susceptible to hydrogen embrittlement.

Figure 2:
Example of Property Class 8.8 Fastener on Underhood Bracket

Figure 3:
Example of Property Class 10.9 Fastener on Steering Shaft Linkage

It is important to note here that the previous discussion was limited to metric fasteners possessing a 60° thread profile. There are many other fasteners, including thread forming screws, rivets, and clips used throughout a standard automobile that are high strength or require care in the design and application. One such example that comes to mind are the fasteners used to mount seat belt anchors. These are often thread forming screws that must be highly engineered to assure proper performance in the event of a vehicle accident.

Strength versus Temperature

Although generally not as critical in automobile applications as it is around aircraft engines, the exhaust temperatures in an automobile can be high. Conceptually we understand from life experience that as materials get hotter they generally get easier to form or bend but also weaker. This response can be a dangerous development in some of those critical internal areas of the engine or components exposed to the hot exhaust stream, such as the EGR valve assembly, exhaust manifold studs, and the hot side of a turbocharger.

In these instances designers may require that the fasteners possess higher strength levels than normal steel materials or normal strength classes are able to maintain. When such a need arises the designer will be forced to utilize materials in the "Corrosion and Heat Resistant" class. These are generally Stainless and Nickel Alloys.

Where Heat Resistant Fasteners are Needed?

Although the interior of the engine gets hot, because moving internal components are lubricated with oil and cooled with water, most interior engine components can use standard high strength steel materials. The exception to this are the components in the exhaust gas stream, as there is no cooling of these areas. As such these components can be many hundreds of degrees and require fasteners made of more exotic materials. One example are the exhaust manifold studs. Although not always made of exotic materials, many of these are made with the nickel-iron alloy A286. A286 has the ability to achieve high strength levels and maintain those levels as temperatures increase to as high as about 1200° F. Another place that we see A286 used is in the fasteners on the exhaust or hot side of turbo chargers. Again, high strength integrity at elevated temperatures needs to be maintained. In a different example, the center electrode of an automotive spark plug is often made of Alloy 718 (Inconel), a nickel based superalloy. This is the component that generates the spark and would quickly break down if made out of a material not capable of such severe duty.

In Summary

In summary, strength is a very important criterion in the design of automotive fasteners. The designer must take into account how severe the duty of the fastener will be and which strength classes or material is best able to serve that purpose. The bar rises up several notches when the application is in a high temperature area. Fortunately, fastener manufacturers have an excellent arsenal of material choices and processes to meet the needs of their customers. ■