Understanding Fastener Strength

by Laurence Claus

To understand why fasteners are manufactured to different strength levels, one must first understand how a fastener is intended to work. To work properly, a fastener must possesses some elasticity and stretch as it is tightened. For many this is counterintuitive because, for example, a large 1" diameter steel bolt hardly seems like an item that would stretch. However, stretch it must if it is going to function the way it was intended.

Figure 1 illustrates a demonstration that one can use to understand the behavior of a bolted joint. To conduct this demonstration, one places their thumb, index, and middle fingers together, wraps a wide rubber band twice around, and then opens their fingers against the resistance of the rubber band. In the second part of the demonstration a third wrap of the rubber band goes around the fingers and reopening the fingers is, once again, attempted. Individuals attempting this demonstration should notice that with the third wrap in-place the rubber band is much more highly stretched and it becomes significantly more difficult to open the fingers.

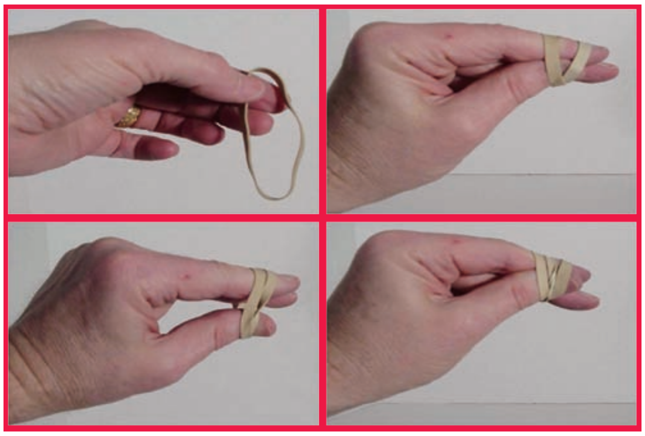

Figure 1: Bolted Joint Demonstration

This demonstration nicely illustrates how a bolted joint is supposed to work. As the bolt is further stretched, it clamps or holds the joint more tightly together making it much more difficult for the external loads to separate the joint. This illustrates the fundamental fact that the more one can stretch a bolt, the better it will hold the joint together. Although this may not be that important in all joints, it is crucial when the joint is a critical one.

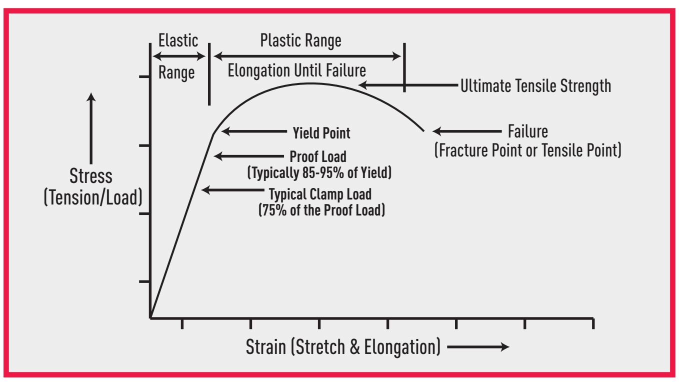

Figure 2: Load versus Elongation

Figure 2 shows this behavior in graphical form. One sees the two distinct regions of the graph. The lower section is a steeply sloped line. This is the elastic region where the bolt or screw stretches and generates a favorable compressive load in the joint. In this region, if the load is removed, the bolt or screw returns to its original length. This linear behavior, however, is not infinite. As the figure illustrates, there comes a point where the linear behavior is replaced by the graph flattening out and turning almost horizontal. In this region the material undergoes significant stretching and no longer returns back to the original length if the load is released. This is the plastic region. Continued pulling eventually results in an overload of the material and the part will break into two.

Figure 2 helps to illustrate some of the terms related to the behavior described above. First is the inflection point where the graph transitions from linear to non-linear behavior. This point is known as the Yield Point. As one progresses past the Yield Point, the graph continues to rise, but only marginally until it reaches a high point along the Y axis (load) and begins to decrease. This high point is where the material fails and is known as the Tensile Strength or Ultimate Tensile strength. When designing fasteners, most individuals either use or specify the tensile strength so this is, perhaps, the most commonly used strength criteria with fasteners.

One final, but important value is the Proof Strength or Proof Load. This is a value that is normally about 85% to 95% of the Yield Strength. The advantage of using the Proof Load is that a part can be tested to this value without destroying the part. A passing test provides the tester with confidence that the part will otherwise meet the desired mechanical requirements without sacrificing the part.

What is Strength?

A property is something that describes a characteristic of a material. Properties can be classified into several different categories such as mechanical, physical, and electrical. For fasteners, perhaps the most important properties are the mechanical properties; strength, ductility, toughness, and hardness.

What is the strength? This may be confusing to some. For example, we can pick up a 3/8 inch diameter Grade 8 bolt and 1 inch diameter Grade 8 bolt, hold them in opposite hands, and say they are the same strength grade. The holder of these two fasteners clearly recognizes, however, that the one inch diameter fastener has capacity to support a higher load than the 3/8" fastener. This leads us to seek the definition of strength. The limiting value of stresses acting on a material is the strength. That means two items can possess the same strength even though they are vastly different in size and actual capacity.

Strength is expressed as a load per area, such as pounds per square inch for inch fasteners and Newtons per square millimeter (Pascal) for metric fasteners. For example, a SAE Grade 5 fastener has a minimum tensile strength of 120,000 psi. Let's assume that fastener had a square cross section that was one inch per side. The resulting tensile load would be 120,000 pounds. Now assume that we have a similar square fastener but it is only ½ inch per side. This fastener would have a minimum tensile load of 30,000 pounds. Therefore, one can see that two parts can have the same strength but their size will dictate their ultimate load capacity.

In a similar comparison, assume that we have the same square fasteners described above but one is a SAE Strength Grade 2 and the other a Strength Grade 5. If we looked up what these grades represent, we would find that the Grade 2 has a minimum tensile strength of 60,000 psi and the Grade 5 has a minimum tensile strength of 120,000 psi. Therefore if we had two parts with 1 inch square sides, we would find that one has a minimum tensile strength capacity of 60,000 pounds and the other 120,000 pounds, even though both are made of steel and are the same size.

What Must a Designer Do?

Now that we understand a little about the basics of strength, we can better understand what the designer must do. A designer must seek out to understand all of the different loads that are going to exist in the joint and thus act on the part. This can often be a complex chore because there may be several different types of loads being exerted on a product or the product requires multiple bolts or screws to hold it together. In any event most designers weigh all of these variables and apply a safety factor for added insurance.

Once a designer has an idea of what loads the bolt or screw must withstand, they can begin to make choices of size and material. Although most fasteners are made of steel and steel provides the designer with a great deal of flexibility, not all designers are going to choose to use it. They may, in fact, have other requirements that they must also balance. For example, they may be weight restricted resulting in them looking at fasteners made out of aluminum or titanium. Or perhaps they are in a very oxidative environment and need a fastener that will not easily corrode. In these cases, they may have to forego steel and use one of the Stainless Steel varieties.

Once the designer has figured out the material, then they must choose the appropriate size and strength grade. For example, if they determine that they need to have a fastener that can hold 400,000 lbs., they clearly are not going to be able to accomplish this with a ¼ inch Strength Grade 2 fastener.

Different Strength Grades

There is a wide assortment of different fastener strength grades that can be found in commonly utilized consensus standards. Naturally the standards that will be most commonly used vary by region and industry. However the leaders for fasteners are ISO 898 Parts 1 and Parts 2 for metric externally threaded fastener product and internally threaded fasteners, respectively, and, SAE J429 and SAE J995 for inch externally threaded and inch internally threaded fasteners, respectively. There are many other standards that also supply this information, including standards by ASTM, JIS, and NAS, but ISO and SAE are the most widely recognized.

For steel fasteners, these specifications essentially provide guidance for strengths beginning at about 60,000 psi in SAE and 400MPa in ISO and go to 150,000 psi in SAE and 1000MPa in ISO. Although there are several higher strength options, and steel has the capacity, it is rare for steel fasteners to have strengths above 180,000 psi or 1200 MPa.

If a designer requires strength greater than 180,000 psi (1200 MPa) or the ability to retain high strength at elevated temperatures, then they must turn to the nickel based super alloys. Some of these materials possess room temperature minimum tensile strength in excess of 260,000 psi and maintain excellent tensile strength at temperatures over 1000°F.

What Material Do You Choose?

The most common denotation for material on a print is something like, “Material per ISO 898/1 Property Class 10.9”. This is where one must be very careful. When one references this specification they quickly find that there is not a guide providing them specific material types for specific sizes. Instead they are confronted with several choices of material types like low carbon steel with additives, medium carbon steel, or alloy steel and a table with ranges of allowable chemical constituents. How does one choose the right materials in this case?

Following are a couple of determining factors:

1. The limits of the chemical constituent range must be considered. For example if the Carbon range is from .25% to .55%, it immediately excludes a material that has less than .25% Carbon in it.
2. Size is an extremely important factor. The larger the part the more challenging it becomes to obtain uniform strength results throughout the part. This is a function of the material’s hardenability and some materials, even alloy steels, don’t possess the necessary hardenability to achieve a uniform strength throughout the part. Exceptional care, therefore, must be exerted in choosing the right material for larger diameter parts.
3. Footnotes often appear in tables related to strength requirements. Both ISO and SAE contain a footnote that requires 90% or more of the steel transforms into Martensite. This is the high strength form of steel that you are shooting for in a quench and tempering process. If the steel has insufficient hardenability it will not achieve enough of this desirable structure.
4. The most important item in determining what steel to use, however, is the Minimum Tempering Temperature. This usually appears in the table immediately following the list of chemical constituents that are allowed. After a part is quenched and has formed Martensite it is very hard and very strong, but also extremely brittle. For this reason the parts must be tempered. Tempering restores toughness, meaning that the parts will no longer be so brittle. This is a necessary step but comes at a price. To restore the toughness the part strength is reduced. This is normally not a problem, as the as quenched part is much higher in hardness and strength than the final strength requirement. The higher the tempering temperature the more quickly this occurs. Therefore, if the steel does not possess the requisite hardenability, a high tempering temperature will dip it below the standard requirement. For this reason, a minimum tempering temperature value is specified. If the material is unable to support this minimum tempering temperature it is an unacceptable option as a choice.

Getting the material right is a very important step. Fastener manufacturers must be knowledgeable about these rules, especially as part cross sections get larger.

Summary:

Part strength is extremely important. There are a lot of moving parts involved in getting this right, starting with the designer figuring out what loads a bolt or screw must withstand to the manufacturer knowing what material to make the part out of. Fortunately, there are many standards that help with this process and assure that fasteners are made and perform the way they were intended.