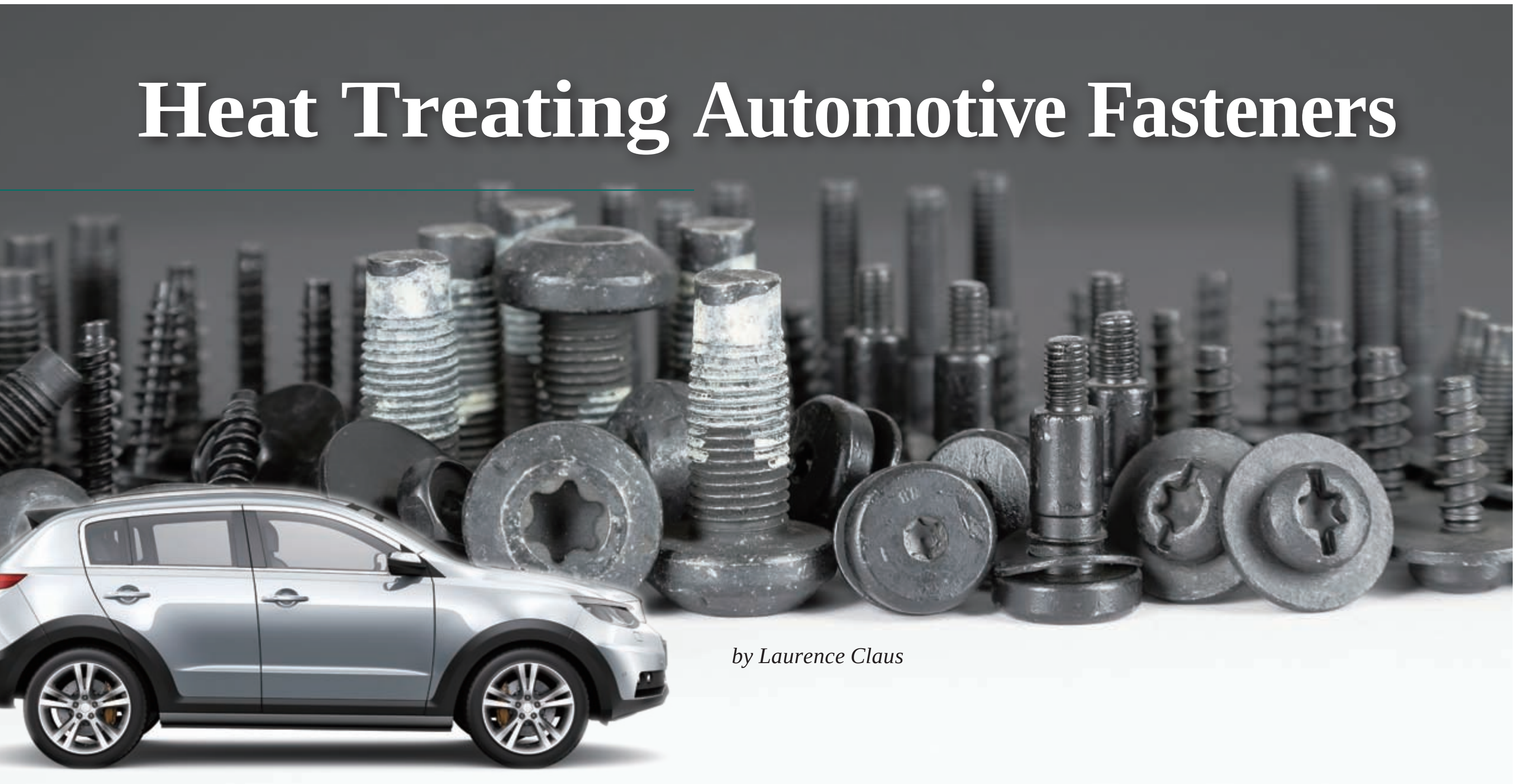
Heat Treating Automotive Fasteners



by Laurence Claus

About twenty years ago I was working with an automotive foundation brake supplier when catastrophe struck. One of this company's calipers utilized a Collette Style Pin brake caliper design. These calipers operate by sliding along a two piece pin system. There is a Collette Pin with a tapped hole in the head and a Mounting Bolt. The Mounting Bolt connects the face of the Collette Pin to the back side of the Piston Body Flange, providing unfettered access for the caliper bracket to slide along these pins when the brake is functioning.

One day the brake manufacturer was assembling calipers when they ran into an occasional bolt breaking during the Mounting Bolt tightening process. As nothing had changed in their assembly process and breakage was infrequent, they immediately made an investigation of the bolts. They would quickly discover that the broken bolts, although intended to possess a Property Class 10.9 strength, were, in fact, almost dead soft. Parts that were not failing possessed the proper 10.9 strength rating.

It would eventually be determined that the heat treating vendor had failed to completely empty the parts onto their furnace belt and pushed the, supposedly empty, tub around to the back of the furnace to collect the heat treated parts at the end of the process. In doing so, they inadvertently mixed a handful of unheat treated parts in with those that were heat treated. The parts would be subsequently coated with a dip spin coating that hid any traces of difference between heat treated and unheat treated parts.

In a similar example, in July of 2017 Ford Motor Company initiated a product recall, NHTSA 17V-472 of 117,000 2014 F Series Pick-up trucks, 2015 E Series vans, 2015 Ford Escapes, and 2015 Lincoln MKZs because of seat and seat belt anchor bolts that were cracking or vulnerable to cracking. Ford Central Labs would investigate this problem and concluded that there was a tempering problem in the heat treatment of the parts. Subsequently it was determined that the Tier 2 heat treater experienced a power failure on April 17, 2014 while processing a portion of this lot of parts. This power outage would ultimately result in the parts being improperly tempered.

Although these are stories of process failures, they are excellent illustrations of the importance of proper heat treating of automotive fasteners and the imperiling consequences when things go wrong. Many automotive systems rely heavily on fasteners for proper functionality. Therefore, it really becomes critical that the proper heat treating process is designed, specified, and executed. This article will take a closer look at three common heat treating processes utilized by automotive fasteners.

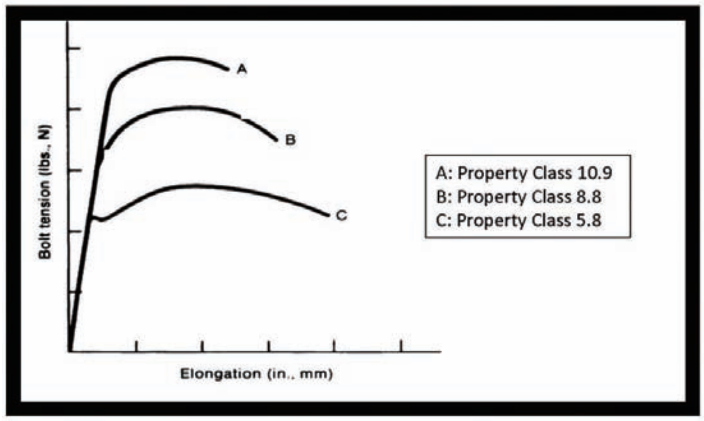
Quench and Temper:

Before we look at the actual process of strengthening a part through quench and tempering, we must first consider how fasteners used in bolted joints are intended to function. Remember that in a bolted joint there is an externally threaded bolt or screw and an internally threaded free spinning nut or fixed nut member. In either case once the joint is "snugged" into place, additional tightening of the screw should result in the screw beginning to elastically stretch and generate loads which effectively compress and hold the joint together. Therefore, for a bolt or screw to be functioning properly, it must possess the ability to elastically stretch. This behavior, however, is not unlimited and eventually the fastener reaches a point where the material is no longer able to sustain the loads being exerted on it and it begins to plastically deform. Depending on the strength level of the bolt, some will tolerate more plastic deformation than others, but ultimately all will eventually break.

Figure 1 illustrates this behavior and shows by comparison the behavior of low strength bolts compared to high strength bolts. More importantly than the comparison between strength grades, this figure clearly illustrates two very important principles. The first is that if the designer needs to generate a lot of "holding power" (what the industry calls Clamp Load and this figure defines as Tension), they must use high strength bolts. Secondly, we see that as strength increases parts become more brittle. This is shown in the relative distance that the low strength part plastically stretches before breaking when compared with the high strength fasteners.

Considering the first point, as soon as the designer concludes that a higher strength bolt is needed, if using steel, it dictates that the part must be strengthened through heat treating. The most common process to achieve this strengthening is what is called "Quench and Tempering", "Through Hardening" or "Neutral Hardening". Regardless of the term used, the end result is the same, a part goes through the heat treating process and comes out uniformly harder and stronger.

Figure 1



In the automotive world, almost all fasteners are now designed and manufactured in metric. Therefore, designers use metric material standards to dictate the desired strength of their parts. In automotive, each OEM usually has their own internal standard to provide guidance and requirements for bolt, screw, and nut strength. Even though each OEM publishes their own standard, almost all are based on ISO 898 Part 1 for externally threaded components and ISO 898 Part 2 for internally threaded components.

These standards set out different strength levels called Property Classes. They begin at four and generally go to twelve (usually with gaps in-between numbers). Thus for externally threaded parts one has a choice of Property Classes 4.8, 5.8, 8.8, 10.9 and 12.9. For internally threaded parts, there are corresponding property classes but they do not have the second number after the decimal point, thus are 4, 5, 8, 10, and 12. With the external series, these part numbers mean something. The first number represents the nominal minimum tensile strength multiplied by 100 MPa (Megapascals). The second number represents the percentage multiplied by ten that the Yield Strength is relative to the Tensile Strength. As an example, a Property Class 8.8 part must have a nominal minimum Tensile Strength of 800MPa and a yield strength that is 80% of that value or 640MPa.

Automotive designers utilize all of these property classes for automotive fasteners but 8.8 (8) and 10.9 (10) by far exceed any of the others in common utilization. Some applications call for Property Class 12.9 fasteners, but many vendors are cautious to supply these because of their high strength, critical nature, and susceptibility to Hydrogen Embrittlement. However, inescapably some applications may require the added strength that a 12.9 Property Class provides.

So what is the Quench and Temper process? The names Quench and Temper, Through Harden, and Neutral Harden all actually provide us with different clues we need to understand the process. The first, Quench and Temper, describes the general process of heating the parts up, quenching them and then finishing them by reheating them to a lower temperature than was used in the first part of the process. The second, Through Harden, describes the fact that when done properly the microstructure and its performance is uniform throughout. This means, for example, that a M12 part will exhibit the same performance characteristics and microstructure at the center as at the surface. The last, Neutral Harden, describes the part of the process where parts are first heated up. The atmosphere surrounding the parts must protect them so that there are no changes to the surface through chemical reactions with surrounding atmospheric elements.

The process is essentially broken into three parts, austenitizing, quenching, and tempering. The first process is austenitizing. This is the process of raising and holding the parts at temperature until the entire microstructure has transformed into steel's high temperature structure, Austenite. There are multiple variables defining how long this will take so that the heat treater must carefully set their process parameters to make sure that they achieve complete transformation of all parts in the heat treat lot. At the temperature needed for this to occur, steel gets very reactive with certain elements in our atmosphere. Therefore, another important consideration in this first phase of the process is to assure that the atmosphere surrounding the parts is "neutral" and not subject to deleterious reactions.

After the parts reach austenitizing temperature and are held there long enough for complete transformation the next step is to quench the parts. This entails quickly cooling them is some substance that quickly removes the heat from them. Common quenching materials include oil solutions, water, and water mixed with other constituents.

Although there are some materials out there that do not respond to quenching, steel does. This quenching process quickly cools the parts and forces the Austenite to transform into a new structure known as Martensite. Martensite is exceptionally strong and hard, and, thus is a desirable structure for the steel to take when the heat treating process is intended to strengthen. Unfortunately, at this stage the Martensite, known as "untempered Martensite", is too brittle for practical use.

Therefore, the final stage of the process is to temper the parts. This part of the process restores some metallurgical toughness (reduces its brittleness) to the parts. This restoration is not, however, without trade-offs and the part strength and hardness decrease. Tempering is done at temperatures lower than the austenitizing temperature, as the heat treater wishes to preserve the Martensite structure they just formed in the earlier stages of the process.

By far, the majority of automotive fasteners utilize this heat treating process. Of course this makes sense as the majority of fasteners are being called on to perform this load multiplication function where the bolt or screw is intended to stretch and generate a load which tightly compresses and holds the joint together.

Carbonitriding:

Carbonitriding or more commonly, Case Hardening, is another process typical of some automotive fasteners. The name, Case Hardening, is suggestive of the condition of the final product after undergoing this process. In this instance, the process develops a very hard and strong outer shell without having a great deal of strengthening of the interior. Case Hardened parts are sort of similar to a gumball with a hard outer shell and a softer inside.

Before we go much further, we should again look at the product and reasons for this type of heat treatment. It is used almost exclusively on Thread Forming Screws, especially those forming threads in mild steel. Although they may be used in thread forming into plastic or Aluminum, more commonly today these materials utilize thread forming screws that are Through Hardened. (The reason being that the high hardness and surface strength are not needed to form these materials and the Through Hardened parts are simply not as brittle.)

Consider, therefore, this application. One has a steel screw attempting to form its own internal threads in a mild steel substrate. If the strength of the two are similar, thread forming will simply never occur. For thread forming to occur, the threads on the screw must be relatively hard and strong to hold up and survive the rigors of thread forming. The screws, therefore, must be much stronger and harder than the substrate they are going into. Although there is a hardness and strength difference between a mild steel material and a Through Hardened fastener to property classes 10.9 or 12.9, it likely will not be enough to prevent the threads of the screw from collapsing in on themselves.

Thread Forming Screws, therefore, must have a high differential in hardness and strength compared to the substrate they are forming a thread in to be effective and work. Normally, this is achieved through Case Hardening. Unfortunately there are downsides to Case Hardening. The most significant is that the screws are more brittle and especially vulnerable to scenarios where they might be exposed to bending. Likewise on smaller parts or parts with thin thread profiles, the possibility of totally Case Hardening the thread exists. Although this makes a strong thread, it is also very brittle and quite vulnerable to breaking or shearing during installation.

The process of Case Hardening is similar to quench and tempering. In fact, most Case Hardening lines can be easily converted to a Through Hardening line and vice versa. The part is austenized, quenched, and tempered. The most significant difference, however, is that the atmosphere around the parts is no longer neutral. In fact, in Case Hardening the atmosphere is enriched with both Carbon and Nitrogen. The atmosphere being thick with these elements and not balanced with the same concentration of these elements in the part will cause the part to soak up these elements. This results in the surface of the part becoming enriched with Carbon and Nitrogen which respond to the quench by getting harder and stronger than the areas below which have less Carbon and little to no Nitrogen.

Again, Case Hardening results in fasteners that are generally well suited to thread forming screws or other requirements where surface hardness and strength are important. The biggest drawback, however, is that case hardened screws are not very “tough”. They are brittle on the outside and the core rarely possesses much strength. In addition they are vulnerable to bending, being over cased (where the case extends through the part cross section), or susceptible to Hydrogen Embrittlement.

Through Hardened and Induction Hardened Combinations:

There are some applications in automobiles where designers are likely to choose a thread forming screw, but require that it is not brittle. Take for example the Anchor Bolts that hold seat belt brackets or seat tracks to the automotive structure. In rare instances where an automobile is in a severe collision these fasteners are expected to perform flawlessly, meaning that they keep the seat or seat belt anchored and don’t break.

A Case Hardened part, however, would be quite vulnerable to breaking under the extreme conditions of a severe automobile accident. Therefore, how does one design a part that has the requisite toughness to withstand the collision without breaking but still be strong and hard enough to form threads in mild steel?

The solution is to use a two-step heat treating process. Step one is to Through Harden the part, most likely to Property Class 10.9. Step two is to selectively harden the point through Induction Hardening. This gives the point area, where the thread forming occurs, the requisite strength to conduct the thread forming process while the body is not brittle and can, thus, withstand the severe impact loads exerted during a collision.

Induction Hardening is the only selective hardening process. That means the process can be implemented on only a selective portion of a part. It can be used for this Anchor Bolt application to harden just the point or, in another common automotive application, suspension and steering ball joints, used to selectively harden a portion of the ball shaped head to prevent wear and scoring.

In this process the parts pass through an induction coil. This is essentially a strong electric field which rapidly heats up just the area of the part within the coil. This heated area transforms to Austenite. The part is removed and quenched, forming Martensite. In some cases the parts are tempered and in other cases they are not.

In the case of the Anchor Bolt application described above, parts commonly do not get tempered. This is acceptable as long as the induction hardened point passes all the way through the fastened joint. The point area may be brittle but it doesn’t matter because the material inside the joint is not. The hardened point performed its function to generate threads and is then rendered irrelevant because the portion of the Anchor Bolt actually in the joint is all in a Through Hardened condition.

On rare occasions other heat treating processes such as annealing, carburizing, or ferritic nitro carburizing, may be used on automotive parts, but the three methods discussed in this article are clearly the mainstays for automotive fasteners. As the stories in the introduction illustrate, however, it is critical that both the designer and heat treat vender get it right. All too often important things like the lives of our passengers and fellow motorists are riding on getting small details like this right. ■