Dr. Fastener: Questions on Fastener Heat Treating

Heat treating fasteners is a complicated topic with many details to keep track of. The following are some questions and answers that should shed some light on basic concepts.

by Laurence Claus

Q: Why do You Heat Treat Fasteners?

A: There are a number of reasons that one might choose to heat treat a fastener. We can, however, break the reasons into three main categories; 1. To make the part stronger, 2. To make the surface harder and stronger, and 3. To improve workability and/or refine the microstructure. Processes such as Quench and Tempering and Austempering fit the first category, Case Hardening the second category, and Process Annealing the third category.

Q: Are All Fasteners Heat Treated the Same Way?

A: No. The heat treating mechanisms of different materials are often distinct and unique. Take for example a heat treatable 7075 aluminum bolt, the mechanism that drives strengthening is completely different than the mechanism that will strengthen a 4140 alloy steel fastener. Also, fasteners that utilize similar material may be heat treated differently depending on the desired outcome. For example, a steel thread forming screw is very likely to be Case Hardened while a steel bolt is Quench and Tempered. In this case, although the heat treating mechanism may be similar, the process is very different.

Q: Explain the Importance of Tempering?

A: When steel parts are quenched the FCC Austenite crystal is rearranged to form the Body Centered Tetragonal (BCT) Martensite crystal. When this happens the new crystal lattice is highly strained resulting in steel that is much harder and stronger than it was prior to heat treating, but also much more brittle. In fact, it is too brittle to release a fastener into service in this condition. If we were to do so, it is likely that the parts would break easily when exposed to certain types of service loads. So, we have to fix this. We do that by tempering. We re-introduce the parts to a furnace that is set at a temperature below the critical Austenite Transition temperature for a specified length of time. The result is that the parts become less brittle but also lose some of their hardness. The proper tempering temperature and time are two important parameters that the heat treater must control. If the tempering temperature is not high enough or parts are not allowed to soak at that temperature long enough, the parts will emerge insufficiently tempered, meaning they will still be somewhat brittle.

Q: What is Quench and Tempering?

A: Quench and Tempering is likely the most utilized heat treating process for steel fasteners and the one used for most medium (Property Class 8.8 and Grade 5) and high (Property Class 10.9, 12.9 and Grade 8) strength fasteners. Sometimes this process is referred to as Through Hardening or Neutral Hardening. The process occurs in three basic, but equally important steps:

1. Fasteners are heated for a sufficiently long time to fully reach the critical, Austenitizing temperature (this is the temperature where the steel will realign itself into the Face-Centered Cubic (FCC) crystalline structure of steel known as Austenite).

2. When fully transformed to 100% Austenite the parts are quenched in a substance that will rapidly lower their temperature. The act of quenching forces a non-equilibrium transition from the FCC Austenite to the Body-Centered Tetragonal structure known as Martensite. Martensite is very hard and strong, but also, unfortunately, very brittle.

3. Immediately after quenching the parts are too brittle to be put into service. To fix this problem, the third step is to reheat the parts to a temperature a little below the critical Austenite transition temperature (we do not want the steel to transition back to Austenite) and hold there for a time. This has the effect of relaxing the stresses in the crystal lattice caused by the shock of quenching and making the parts less brittle.

Q: Why do Some People Call It Through Hardening?

A: It is called "Through Hardening" because the end result of the process is a part that is effectively the same hardness through the entire cross section. Of course, there may be a slight variation from one location to another, but it is controlled by specification to a maximum of only a couple of hardness points.

Q: Why do Some People Call it Neutral Hardening?

A: When steel is heated to high temperatures (for example the Austenitizing Temperature), the atoms are excited and subject to move about. This means that they are more likely to react to surrounding substances when an in-balance between the surrounding atmosphere and the parts exist. Therefore, when parts are in the Austenitizing furnace and have been raised to this high temperature level, they must be protected from these substances that will start deleterious chemical reactions. The heat treater does this by negatively pressurizing the furnace (i.e. preventing atmospheric air from seeping into the furnace openings) and surrounding the parts with a neutral atmosphere that will not react with the parts. This is why the process is sometimes called "Neutral Hardening".

Q: What is Decarburization?

A: The answer to the question above describes how the heat treater surrounds the parts with a neutral atmosphere. The element that the heat treater has to worry about is Carbon. If the furnace either lets unwanted substances into the furnace, which trigger the unwanted reactions that strip Carbon from the part or the atmosphere has a lower concentration of Carbon than the parts, then the parts are subject to losing Carbon. The longer parts are exposed or the greater the imbalance, the more Carbon that will be extracted from the part. This phenomenon is known as Decarburization and is always unwanted. If the surface of a part has experienced significant Decarburization it will lack the necessary Carbon to strengthen when quenched. This can lead to problems like soft threads that collapse when applied or a surface that is more vulnerable to fatigue crack initiation. Of course, Carbon can flow in the opposite direction as well. If the atmosphere has more Carbon in it than the parts, Carbon will move into the parts rather than out of it. This is known as Carburization. Although Carburization is not desired in a Neutral Hardening situation, there are many applications, where the desired end result is for a hardened surface, so that Carburization is desired.

Q: What is Austempering?

A: Quench and tempering results in the formation of Martensite, a strong and hard structure of steel. Another steel structure that is hard and strong is Bainite. Like Martensite, Bainite will not naturally occur, and requires a special process to produce it. This process is known as Austempering. In many ways Austempering is similar to Quench and Tempering, but with two very distinct differences. Austempering starts out like Q&T by soaking parts at Austenitizing temperatures long enough for the structure to fully transform to Austenite. Like Q&T parts are then quenched. Along the way, however, is where the two processes diverge. Instead of cooling the parts nearly all the way to room temperature the quench is arrested at about 300°-350°C and held there for a sufficient length of time for the parts to transform to Bainite. This special quenching process is accomplished by quenching in a molten (liquid) salt, substances that remain liquid at very narrow temperature bands, thus allowing this isothermal cooling process to be feasible. The second significant difference between Austempering and Q&T is that unlike Martensite, Bainite does not require tempering. The process is complete when full transformation has occurred.

Q: Is There an Advantage to Austempering?

A: Austempering is not possible for all materials or in all instances. However, it is particularly advantageous for parts that are prone to distortion. It is favored, for example, by manufacturers of spring steel clips because it results in less distortion than Q&T.

Q: What is Induction Hardening and How is It Utilized on Fasteners?

A: Induction Hardening is the only process that can be applied selectively. Instead of heating the entire part, only the area of interest is rapidly heated above the Austenitizing temperature using an induction heating coil. The parts are then quenched, selectively hardening just the heated area. This is a common heat treating practice on the tips of certain thread rolling screws and for products like bi-metallic drill screws.

How are Parts Surface Hardened?

A: There are three main methods of surface hardening; 1. Carburizing, 2. Nitriding, and 3. Carbonitriding. Although any of these three processes could be utilized for fasteners, most fasteners are Carbonitrided. An earlier question and answer described Carburizing. By review, this is the process of driving Carbon into the part. The longer a part remains in the furnace under carburizing conditions, the deeper the Carbon will extend into the part and the deeper and harder the resulting “case” will be. Because it takes a long time to generate a deep case by Carburizing, this process would almost certainly have to occur in a batch furnace, which is slow and rarely used for a bulk product like fasteners. In Nitriding the heat treater diffuses Nitrogen into the surface. The process results in this Nitrogen addition forming nitrides on the surface which are hard and strong. Once again, this is a slow, diffusion process that requires a batch furnace and would rarely be employed with fasteners. Surface hardening of fasteners is almost entirely accomplished by Carbonitriding or what is more informally known as Case Hardening. The heat treater will inject dissociated Ammonia into a Carbon enriched atmosphere in the Austenitizing furnace. The result is an atmosphere that is rich in both Carbon and Nitrogen. Together these elements are absorbed and work together to form a case more quickly than using just Carbon or Nitrogen alone. However, because fasteners are processed in bulk using the furnace equipment to move parts, and there are limitations based on speed and furnace length, case hardening is possible, but the depth of the case cannot be developed as deeply as can be developed by Carburizing or Nitriding parts in a Batch Furnace for extended periods of time.

Is There a Difference Between Stress Relieving and Annealing?

A: Yes. Stress Relieving processes parts at temperatures below the critical Austenitizing Temperature. As such, the effect is to relieve residual stress left by the forming process. Annealing takes parts above the Austenitizing Temperature and, depending on the process employed, results in a homogenous, soft and workable Pearlitic structure.

What is Untempered Martensite?

A: Remember that after quenching Martensite is very brittle. If the heat treating process is not conducted properly there may be several ways that a part can contain untempered Martensite. This is never good and parts with untempered Martensite present are vulnerable to failure.

What Causes Quench Cracking?

A: Quench cracking is the result of a complicated series of events revolving around the quenching process. In essence, when steel transforms from Austenite to Martensite there is a volume expansion as the atoms rearrange themselves into the new crystal lattice. When large diameter parts (or parts with areas of large cross section) are quenched, the outside transforms first followed by the inside (or core). When the expanding core interacts with the already expanded and now hard and strong outer shell, it creates residual stress. If the generated residual stress exceeds the local tensile strength a crack can form which quickly propagates throughout the part. Parts made of Alloy Steel are generally much more prone to quench cracking than parts made of Plain Carbon Steel. ■