# Technical Resource

## AN INTRODUCTION TO HEAT TREATING PROCESSES

The history of modern man is often segmented into time periods that are defined by the metals that were widely used. The discovery of, and obtaining these materials, was secondary in importance to learning how to manipulate the metal's properties so that it had the characteristics that made it a useful item. Consider having a metal blade that was too soft to allow you to cut wood. You might want to stick with using a stone-cutting edge. The development of heat treating metals provided a means of changing a metal's properties to fit a particular application's requirements.

Man has been using various methods to heat treat metals for thousands of years. In Homer's Odyssey, from the 7th or 8th century B.C., we see the following: "As the smith dips the glowing axe into the cold water, the iron hisses and with gurgling becomes stronger, tempered in fire and water."

So what exactly is heat treating? Heat treating may be loosely defined as a group of processes that alter the physical and/or chemical and/or magnetic properties of a material. These processes include temperature changes and associated cooling processes in various environments. Changes to the metal may be in its internal structure through the application of heat. Thermomechanical processes modify both structure and shape (as working a part physically will change its internal physical properties). Thermochemical treatments may modify both surface chemistry and structure. As there are many types of heat treating processes, we will focus on those applicable to ferrous metals such as steel.

Some process affect the entire part, all the way through. These homogeneous processes have great effect on the parts hardness, strength and ductility (the ability to stretch the metal without breaking). Other parts are subjected to processes that change the characteristics of the surface and tend not to effect the internal properties of the part. These processes will be referred to as heterogeneous processes.

So why not just make the steel as hard as possible? Hard steel is also more brittle and more prone to fracture. Parts that require a hard surface to prohibit wear may also require the ability to resist fracturing. Think of a gear, it needs to have a hard surface so it doesn't wear down quickly, but must also be able to absorb shock so it doesn't crack. In this example, we need a part with a hard surface and a softer interior. Another common example is a knife. You want the knife to hold a sharp edge but not fracture when under pressure. In machining parts to the correct shape/dimensions, softer metals are much friendlier to work with. After the part has achieved the correct shape, we can then harden the part to the desired degree.

A very general way to think of the various changes associated with the heat treating processes is to consider them as one of the three following categories. Softening removes residual stresses within the part (often from previous processes), improves toughness (resistance to fracture), increases ductility, refines grain size (uniformity of structure), changes electromagnetic properties and reduces hardness and strength (strength in the sense that it will resist plastic deformation). Hardening increases hardness but reduces ductility. Case Hardening is a selective hardening process that is specific to the outside layer of the part (the case) and is generally inconsequential to the properties of the part's interior.

The following represents common processes utilized today.

**Hardening & Case Hardening** - Hardness in steel is a function of the alloy type, structure and carbon content. Hardening involves heating a part to a specific temperature, holding it there for a specific time and quickly cooling it in a specific media. It is these variables that affect the material's molecular structure. Heat allows the carbon and other alloys to rearrange their structure and the quick cooling of the quenching process locks this structure in place.

**Flame & Induction Hardening** - These processes impart hardness to the surface of parts in a process where the steel surface is heated by direct application of a flame or by induction heating through the application of an alternating magnetic field. The part is then rapidly cooled, generally using water, which creates a 'case' of harder material at the surface. These processes are generally used with a 0.3 – 0.6% carbon content (by weight). Flame hardening is often used to harden a portion of the part surface, not the entire surface. Induction hardening may harden only a selected portion of the part. This is often referred to as selective heat treating.

**Carburizing** – In this process the steel is heated in a carbon-rich environment and quenched to lock the additional carbon in the steel's surface. As carburization is a diffusion controlled process, the longer the steel is in the carbon-rich environment the greater the carbon content and depth will be. A very simple form is to heat a part with an acetylene torch and quench in oil. The carbon-rich environment may be a solid source (pack carburizing), a liquid (often a molten carbon containing material) or a carbon containing gas (such as methane). Carburizing works with low carbon steel (0.1 – 0.3%) because the surrounding media provides the carbon required. Low carbon steel is not only easier to form into the desired shape but is also less costly.

**Nitriding** – This process heats the part in an atmosphere of ammonia gas. The hardness is realized through the formation of nitrides so it must contain nitride forming elements such as chromium, aluminum or molybdenum. This process doesn't use a quench and causes little dimensional distortion.

**Carbonitriding** – This process is similar to carburizing but includes nitrogen in the process. Both the nitrogen and carbon are diffused into the part surface and the nitrogen provides a stabilizing effect. It too is followed by a quench to lock the structure in place.

**Cyaniding** – This case hardening process is used on low carbon steel and is fast and efficient. The carbon contributing media is a bath of heated sodium cyanide. The part is quenched, and rinsed, in water or oil. This is a very fast process, which lowers the chance of distortion, and is popular on small parts such as screws and bolts. The downside is the cyanide salts are poisonous.

**Ferritic Nitrocarburizing** – In this process, more nitrogen than carbon is diffused into the metal surface and this is done below the critical temperature (the temperature where the steel phase will change). This means that the crystalline structure of the steel remains the same. NOTE: In steel, a phase is the type of crystal formed. Most steels are polymorphic, meaning they can form different crystalline structures within the same material. Different crystalline structures have different physical properties.

**Cold and Cryogenic Treating** – As mentioned above, steel exists in different phases. These phases can change depending on the temperature and how quickly they are cooled. If continued cooling to lower temperatures is introduced immediately after quenching, the steel can be manipulated to solidify in a greater percentage of one phase versus another. This technique is often employed in the manufacturing of tools and other products that use high-carbon steel.

**Softening** - The processes in this group provide a number of characteristics that may be beneficial in the final product. These qualities include a less hardened surface, a product that is more easily machined, a more homogeneous material and stress relief. Internal stress may be caused by a number of processes including casting, welding, forming and the rapid temperature change associated with quenching. If this stress is not relieved, the part will be more prone to fracture. These distortions that cause the stress may lessen by themselves over time but the stress relief may be accelerated by some of the processes below. Heating for homogenization is a process that lessens segregation in the chemical composition of the metal after non-uniform crystallization. This non-uniformity may cause the material to be more brittle. The homogenization heating process also raises ductility and corrosion resistance. Re-crystallization removes deviations in structure caused by plastic deformation (from forming processes…).

**Annealing –** This process is often used to soften metal so it may be easier to machine, better suited for cold working and be more conductive. In ferrous alloys, the parts are generally heated above the critical temperature and then very slowly cooled to produce a refined microstructure. This uniform microstructure is the main objective of the annealing process.

**Normalizing** – This process is used to provide uniformity in grain size and composition throughout the alloy. Normalizing generally refers to the parts being cooled in open air. This process would not be expected to produce steel that is as ductile as steel that is 'fully annealed', but would provide a stronger and harder product.

**Stress Relieving** – In this version of heat treating, the steel is heated to a point below the critical temperature and then uniformly cooled.

**Tempering** – This process is a means of lowering the hardness of a metal by heating the product below the critical temperature to impart some toughness, be less prone to fracturing and sometimes to improve ductility. An added benefit is that tempering may help stabilize the microstructure. Most parts that are quenched require tempering. An interesting quality associated with tempering is that historically the temperature realized by the parts could be estimated by the finished parts color. Lower temperatures produce a yellow, then brown, then purple finish and higher temperatures produce a blue finish. As temperature is associated with the products' finished properties, the color is an indicator of the products expected qualities.

D**ecarburization** – High carbon content may be required to produce malleable (the quality of being able to be permanently hammered or pressed out of shape without breaking or cracking) cast steel, but a lower carbon content may be desired in the finished product. When steel is heated in a reducing environment, carbon diffuses into the metal, but when steel is heated in an oxidizing environment the opposite is true. The carbon diffuses out of the metal making it less hard.

There are many variations on the above processes and still others not listed. The one common factor in all heat treating processes is that 'low quality steel with superior heat treating is always preferable to high quality steel with poor heat treating.' Heat treating remains as much of an art as a science.