Which Heat Treatment is required?

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Heat Treatment is defined as controlling the heating, cooling and furnace atmosphere conditions to achieve specific properties or conditions within the steel.

Most modern materials are standardized and put into a "class of materials", this standardization has aided manufacturers and service providers to purchase the correct material and to ensure mechanical properties can be achieved every time. However there are deviations within the standards that need to be considered, standardized materials give a content range to which a certain element in that material must be controlled to. If too many of the critical elements (e.g. carbon, manganese and chrome) are on the lower end of the range, this can cause problems in regard to mechanical properties (e.g. low tensile results or not achieving desired hardness), so the correct selection is paramount if you require the material to perform towards the theoretical top end of the mechanical property range.

Heat Treatment has been around since the Bronze Age when material would be annealed after cold working. Most people think of the Iron Age and the forging of swords; but swords and daggers were first produced by the Egyptians, however they were just iron based. Centuries later additions of carbon to iron and its benefits were realized. The reason for Heat Treatment has not changed since those days, it has just become more efficient and more understanding of the science behind it. The main reasons for Heat Treatment are to improve or maximize the mechanical properties for the application it will be used for, namely strength, hardness, ductility and toughness.

Con Mech Engineers has over 25 years heat treatment expertise. We have a friendly and talented team of highly qualified and experienced engineers who can work with you to solve your heat treatment challenges and enhance your products' performance and value. This paper presents an overview of the main heat treatment processes and their applications.

<u>Austenising</u>

This is the process of heating a ferrous alloy above the phase transformation temperature to form a face centered cubic (FCC) phase. FCC Austenite only exists at elevated temperatures, depending how the alloy is cooled from this point depends on the phase produced and also the mechanical properties.

<u>Normalising</u>

This is the heating of a ferrous alloy above the phase transformation point (usually around 30°C - 80°C above) but it does depend on the material. Once in the austenite phase the material is allowed to cool in still air. The primary reason for this is grain size refinement which has previously been exposed to high temperatures during hot working operations like forging.

Normalising material such as rolled plate and bar before starting the manufacture (machining) routes can aid future distortion problems on subsequent heat treatment operations. The treatment also improves machinability, removes manufacturing stresses and causes the steel to respond more consistently to subsequent heat treatment processes, especially harden and temper. Con Mech recommends normalising prior to any quench and temper as this approach enhances our ability to achieve mechanical and impact values along with hardness specifications.

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Annealing

This is the heating of a ferrous alloy above the phase transformation point. Once in the austenite phase the material is allowed to furnace cool. The primary reason for this is to soften the material back and homogenization of the composition. Annealing is used to prepare steel for bending, spinning, cutting, machining or other manipulative mechanical operations.

Annealing reduces the force required for these operations but more importantly, the risk of fracture or tearing. The temperature for annealing is governed by the chemistry of the steel and is around the transformation temperature. This treatment will not cause any phase changes, but recrystallization may take place. Machining allowance sufficient to compensate for any deformation resulting from stress relieving should be provided. An example of this is sand castings in steel. Once the casting has been poured and allowed to cool, the grain size will be somewhat coarse and therefore suffer from brittleness. By annealing this material the coarse grain structure is replaced by somewhat finer grains. By furnace cooling the material it is ensured that all casting stresses which may lead to cracking or distortion are completely removed.

Solution Anneal

The primary reason for this process is to reduce the effects of cold work, it is usually applied to non-ferrous material and exotic material, like stainless steel, nickel based alloys etc. High process temperatures are usually applied to stainless steels and exotic material ranges at temperatures from 1000°C plus. Nonferrous materials are much lower at 500°C plus.

Stress Relieve

This treatment can be applied to the full range of steels to relieve internal stresses induced by welding, bending, severe machining or any other manipulative process. Material is loaded into the furnace at a low temperature then raised slowly so that thermal stresses are not induced. Once up to temperature the material is held there before cooling slowly to once again avoid the induction of thermal stresses. Finally the steel is still air cooled outside of the furnace to ambient.

The residual stress level after stress-relief will be maintained only if the cool down from the soak temperature is controlled and slow enough that no new internal stresses arise. New stresses that may be induced during cooling depend on the cooling rate, the cross-sectional size of the workpiece, and the composition of the steel. For plain carbon and low-alloy steels, the temperature to which the specimen is heated is usually between 450°C and 650˚C, whereas for hot-working tool steels and high-speed steels it is between 600°C and 750˚C

The reasons for stress relieving are : Thermal factors (e.g. thermal stresses caused by temperature gradients within the workpiece during heating or cooling, like welding).Mechanical factors (e.g., cold-working)

Quench Hardening

The rapid cooling of a ferrous material from its austenising temperature by immersing it in liquid or gas. The cooling method used will depend on the alloy and/or composition. The two main quench processes at Con Mech are water and polymer (comparable to oil) mediums.

Water Quench or Polymer Quench

Hardening of steel relies on the material's carbon and/or alloy elements. In general the temperature decreases from approximately 820°C as carbon content increases from 0.4% up to 0.8%, where temperature is approximately 780°C. Above 0.8% the temperature remains constant at 780°C, this does change as certain elements are added like chrome, manganese and nickel (alloyed steels) so always check the mill certification or references if you are not sure. The material is then water quenched or polymer (simulated oil) quenched.

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When a material is quenched, the quick cooling supresses any changes in the structure which will take place if the material was air or furnace cooled (i.e. it is possible to "freeze" the metallic structure which exists at a higher temperature, to preserve it at a much lower temperature). In most low alloyed materials the structure will now be Martensite/Bainite. It is used to create a harder finish for wear resistance and to improve mechanical properties like ultimate tensile strength and yield.

The type of quench you choose will be dependant on the percent carbon or alloy content. In general the quicker the quench the better the tensile properties are, but in reality the more alloyed the material is, the more susceptible to cracking/distortion on quenching. Different alloys also require different cooling rates therefore a more controlled quench is required, polymer quench is used to reduce the risk significantly of cracking and distortion. By varying the concentration and temperature of the polymer solution, a varied amount of quench speeds can be achieved.

Once the quench has been performed and the material is at ambient, it is in its fully hardened condition. This condition is generally when the material is at or near its highest tensile properties but will be brittle, therefore most hardening operations are performed with a tempering cycle to achieve the required mechanical properties the customer/specification desires.

Please note: Due to the *mass effect*, not all the section of a large component may be hardened due to too slow a cooling rate. This may leave a soft core, or in extreme cases prevent hardening altogether

<u>Tempering</u>

As stated above fully hardened steel is relatively brittle and the presence of quench stresses makes its use in this condition very limited. For this reason the material is normally reheated to reduce hardness and tensile strength and increase ductility and toughness. Therefore in all materials it is all about compromise on what mechanical properties you require

<u>Austempering</u>

This process is for certain grades of cast iron and steels. It involves heating the material to the austenising temperature, followed by quenching into a molten salt bath which is held at a temperature just above the martensite transformation temperature. This encourages bainite to form. In general this process can take a very long time to form the amount of bainite required to achieve the desired properties.

<u>Precipitation Harden or Age hardening</u>

This involves raising the temperature to a certain set point to encourage precipitation of a second phase. The supersaturated solid solution decomposes and the alloying elements form small precipitate clusters within the grains, the metal resists deformation and becomes harder in a specific material that has received a solution anneal prior to age hardening to dissolve the phase. This allows any precipitates or alloying elements to go into a supersaturated solid solution. It is common practice for aluminium, copper and nickel alloys and some steel grades can also harden this way such as 17/4PH or 13/4PH

<u>Carburising</u>

This process involves elevated temperatures of around 900°C and a carbon rich methane and endothermic gas. Prior to this it was a byproduct of charcoal burning, also the charcoal was in close proximity to the component (pack Carburising)) atmosphere. This combination encourages carbon to defuse into the surface of the metal up to 6.4mm. Depending how long it is exposed for will depend on the depth of penetration. Due to modern paints etc., a stop off paint can now be applied to areas on a component that does not require a hard surface. This treatment is applied to low carbon steel parts after machining, as well as alloyed steel like EN36. Generally used for bearings, gears, and other components. Carburising increases strength and wear resistance by diffusing carbon into the surface of the steel creating a case while retaining a substantially lesser hardness in the core (giving the core more toughness).

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Gas Carbonitriding

This is similar to carburising, except that a small addition of nitrogen (in the form of ammonia gas) is added to the atmosphere and the temperature is slightly lower. In comparison to carburising, the first noticeable difference will be the hardness being slightly lower, also the case depth but wear resistance and dimensional control are often superior. Carbonitriding is usually performed on carbon steels (unalloyed steels like mild steel), it can be used for all types of machined parts to make a strong, wear resistant product on the surface, economically viable.

Gaseous Nitrocarburising

There are 4 processes in this group and there applications are as follows:

- Ferritic Processes 550ºC to 600ºC can be a liquid salt (Tufftride) or a gaseous process - crankshafts, cam shafts, gears, gear shafts, worms, cylinder heads, pump shafts, mould components, pins, press moulds, forming rolls, extrusion dies
- Ferri-Austenitic Processes 600ºC to 650ºC - pressings, secateurs, cutting blades, lawn mower blades
- Austenitic Processes 700ºC to 750ºC - clutch plates, door latch components and hinges, pressings
- Extended Austenitic Processes 750ºC to 950ºC - under-car brake components(rail industry,) moulds, forming rolls, tractor drawn forks, tines, mining industry components

This process uses ammonia gas and endothermic gas at elevated temperatures to create a Carbon nitride compound surface layer of up to 40 microns in depth. As mentioned above, the ferritic process can also be performed using a unique blend of salts (tufftride salt) which becomes molten at the processing temperatures. The components are immersed into the molten salts for a period of time. Once the process is complete this salt must be neutralized in another (AB1 salt) bath.

I personally think these processes are under utilised and seem to have lost their recognition and momentum in the UK. The advantages of the process include the ability to harden materials which are not pre-hardened, the relatively low temperature of the process minimises distortion, and relative low cost in comparison to Carburising or other case hardening processes. This process is done mainly to provide an anti-wear resistance on surface layer and to improve fatigue resistance. It also very good in aiding lubrication and reducing the rate of corrosion.

Gas Nitriding

This is a surface hardening process, where nitrogen is added to the surface of steel parts using dissociated ammonia as the source. Gas nitriding develops a nitride compound surface layer of up to 40 microns in depth, which is very hard and is performed at a relatively low temperature, without the need for quenching so minimises distortion even further than the others previously mentioned.

Parts to be nitrided are heat treated (normally hardened and tempered) to the proper strength level (i.e. core strength requirements of the material), and final machined. The parts are then exposed to active nitrogen, where both dissociation of ammonia and temperature is controlled, typically in the range of 500°C to 550°C. This temperature is typically below the final tempering temperature performed during the hardening and tempering cycle, so that nitriding does not affect the base metal mechanical properties. As a result, a very high strength product with extremely good wear resistance can be produced, with little or no dimensional change.

In some cases, nitrided components are surface ground after nitriding to remove the most outermost brittle layer (known as the white layer) produced by the process, or to bring parts into a tight tolerance.

The most common material used for nitriding is EN40B. It is used for high end components such as crankshafts, cam shafts, gears, gear shafts, worms, cylinder heads, pump shafts, mould components, pins, press moulds, forming rolls and extrusion dies.