The Heat Treatment of Fasteners – *Tips for Operation*

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In part 6 of this latest installment of the Heat Treating Fastener series, the authors provide advice on the operation of fastener heat treating furnaces and quenching systems.

Most heat treat shops (**Figure 1**) will have at least two different styles of furnaces: high-temperature furnaces that are used for normalizing and austenitizing; and low-temperature furnaces for annealing, stress relief and tempering. In addition, they have one or more quenching systems. As previously discussed in this series of articles, the important process variables for these heat treatments are temperature, time, atmosphere and cooling rates. The importance of these process variables will be discussed in this article.

High Temperature Furnaces

Temperature control is critical for these furnaces. Temperature variation with time and within the furnace should be limited to ±10°F. The time variation is controlled by the furnace controller's response to thermocouple data. Typically there is a controlling thermocouple near a furnace wall. Depending on the depth of insertion and location relative to the heating elements or radiant tubes, the thermocouple reading may be higher or lower than the temperature of the load.

Ideally, recording thermocouples should be included in the furnace load to accurately measure the actual temperature of the fasteners as a function of time and location in the furnace. In the real world, this is usually done only on a quarterly or semi-annual basis. Adjustments in loading density or racking/fixturing can be made to reduce variations. Temperature variations within the load should be minimized by atmosphere circulation and part loading. At high temperature the heat is transferred from the wall by radiation. Radiation is a line of sight process and the "view factor" should be maximized for each part. In addition, heat is also transferred from the atmosphere to the parts by convection. Therefore, uniform circulation around each part is necessary to minimize temperature variations.

Within a part, the heat is transferred by conduction. If the parts are large, a significant temperature variation will develop within the part. For fasteners with large variations in cross section, this issue will be enhanced. The impact of this variation may be reduced by careful design of the heating schedule to increase the heat transfer to the parts by, for example, slowing of the furnace belt. Variations in heating time from part to part and within a part will impact the result of the process by its effect on the time at the high temperature. Parts exposed for longer times at high temperature may develop a larger austenite grain size that will affect the phase transformations on cooling. Parts at high temperature for a short time may not completely dissolve their carbides or may not develop a proper case depth. This poor solutionizing will cause a reduction in alloy content of the austenite and reduce the hardenability of the steel.

Atmosphere Issues

Heat treating steels at high temperature requires careful control of the atmosphere. Typically an Endothermic gas generator is used to control the carbon potential (Cp) of the atmosphere. Endogas is formed outside of the furnace by heating a mixture of natural gas and air at a specific air/gas ratio. The atmosphere that is formed contains nitrogen, hydrogen, carbon dioxide, carbon monoxide, water vapor and methane. Depending on the ratio of the natural gas to air and the water content a carbon potential is created. If this potential is greater than the carbon content of the steel the steel will be carburized. For the carburization process an enriching gas is injected directly into the furnace to increase the Cp to 0.8 to 1.2 wt% Carbon. For carbonitriding, ammonia is added as well to supply a source of nascent nitrogen.

If the Cp is too high for long periods of time then sooting may occur. Sooting is the formation of carbon (graphite) on the furnace walls and fixtures. Sooting will cause a reduction in heat transfer in the furnace as well as prevent proper case depth development. Soot must not only be removed from the load, but also the furnace and quench medium. This is an expensive and dirty job. In addition, it increases the downtime for the furnace. Sooting should be avoided by carefully measuring and controlling the Cp and methane content in the furnace.

On the other hand, if the Cp is below the carbon content of the steel the parts will be decarburized. An extreme case of this prob-

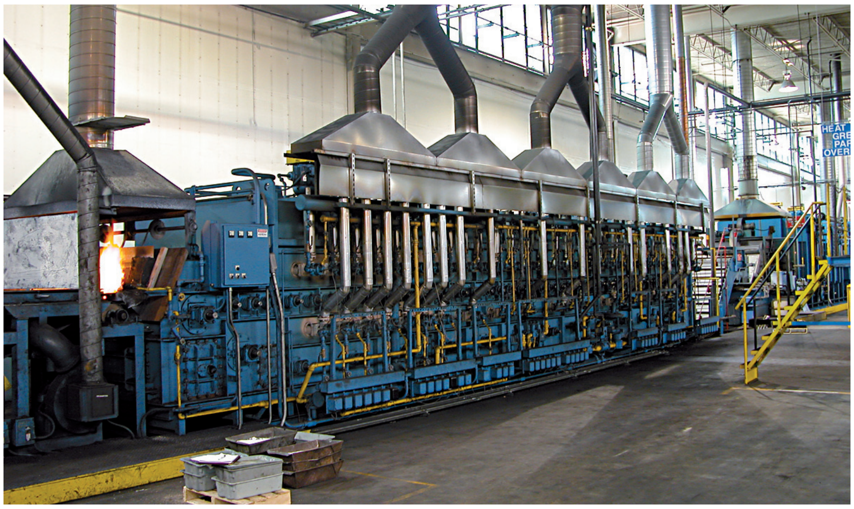

Fig. 1 — Typical mesh belt conveyor system for fastener heat treatment (hardening and case hardening, oil quench, temper).

lem occurs when the parts are heat treated in air or in a direct gas fired furnace. The result of decarburization in through hardenable steel will be a soft surface layer after quenching and tempering. In steels like 4340 or 4140, the Cp is controlled directly from the Endothermic gas generator by producing a gas with a Cp close to 0.40% and the corresponding dew point. A high water content or dew point will also reduce the Cp and cause a low Cp problem for case hardening (e.g., carburizing and carbonitriding) as well as neutral hardening heat treatments. This will reduce the surface carbon content of these steels.

Low Temperature Furnaces

Tempering, annealing and stress relief furnaces operate at much lower temperatures than their high temperature counterparts. Heat transfer in these furnaces is mainly by convection heating; air is circulated past heating elements or radiant tubes and then the hot air is circulated around the parts. Heat transfer is very efficient under these conditions and temperature uniformity, typically ±10°F or better, is easily achieved. Atmosphere control is often not critical; an air atmosphere is commonly used. However, cleaning of the fasteners after quenching in oil is strongly recommended to avoid burning the oil and creating a smoky workplace, a contaminated and potentially dangerous furnace condition and dirty, difficult-to-clean parts.

Tempering temperature, time at temperature, cooling rate from tempering temperature and steel chemistry are the variables associated with tempering that affect the mechanical properties and microstructure of the finished part. Changes to the microstructure by tempering typically decrease hardness and strength (tensile and yield) while increasing ductility and toughness. Tempering results in an increase in softness, malleability, impact resistance and improved dimensional stability. In most cases, the higher the tempering temperature the softer the steel. The longer the tempering temperature, the softer the steel.

A good rule to remember is that all steel should be tempered soon after being removed from the quench and before it is completely cold. Failure to temper correctly may lead to a myriad of performance problems such as premature failure or shorter than normal service life.

For some steels certain tempering temperatures must be avoided to avoid temper embrittlement. The various forms of temper embrittlement will be discussed in a future article.

Quenching

Steels used in the fastener industry are heated to high temperature to form austenite, quenched to form martensite and tempered to form tempered martensite. After austenitizing, fasteners need to be rapidly cooled in order to properly transform. Quenching is the rapid cooling of a part to avoid the formation of ferrite, pearlite or bainite. The cooling must be rapid enough to "miss the nose" of the time—temperature—transformation (TTT) curve for the steel in question. On the other hand, if cooling is too rapid distortion and/or cracking may occur.

Quenching can be done in a wide variety of fluids; air, oils, polymer solutions, liquid salts, water or brine. The heat transfer from the part to the fluid is mostly due to convection and some boiling heat transfer for liquids (water, oils and polymers).

When selecting a quenchant system, the first decision is the composition of the quenchants. The process variables for a particular quenchant are the temperature of the fluid, the agitation rate and velocity direction of the fluid.

Water or brine is used when rapid cooling rates are required. Quenching in rapidly agitated cold water will cool the parts very quickly and will cause many steels to crack. A simple technique to reduce the severity of a water quench is to heat the water to high temperature. This slows the heat transfer and reduces the severity of the quench. High agitation will increase the severity of the quench.

Oils are frequently used for a controlled quench. Typically these are mineral oils with various additions to control the quenching rates. The temperature of the oil must be carefully controlled to minimize variations in cooling rates and therefore the microstructure of the steel. While increased oil temperature frequently reduces the cooling rates, for some oils a temperature increase can decrease the viscosity of the oil and cause a more rapid quench. The agitation must also be controlled to provide for uniform flow through a load of parts. This may also require some racking or fixture design for critical parts to ensure uniform flow around each part. A main cause of distortion and residual stress in quenched steel parts is nonuniform flow in the quench tank and around each part. Unfortunately most quenching oils are not transparent and therefore it is difficult to determine flow rates. The use of flow meters or sample parts for destructive examination may be necessary to achieve the desired flow pattern. Computational fluid dynamics may be necessary to assist in quench system design for critical parts.

Vegetable oils are becoming more popular due to their low environmental impact and nonhazardous waste classification. Several commercial products are currently available for selected quench systems.

Aqueous polymer quenchants are also becoming more popular for environmental reasons as well as cooling rates equivalent to several oils. These polymers have an inverse temperature solubility in water. When a hot part is quenched polymer condenses on the part surface and insulates the cooling of the part at high temperature. As the temperature cools the polymer dissolves back into the solution. The cooling rates for polymer quenchants are controlled by the percent polymer in the solution, the solution temperature and the agitation. Agitation is necessary to keep the polymer in the solution.

For some applications forced air or water sprays are used to cool the parts. This type of cooling is used for continuous processes. The cooling rates are controlled by the gas or water velocities. The challenge in this method is achieving uniform flow and cooling around the steel. Liquid salts or hot oils are used for marquenching or austempering. These quenchants are used at temperatures above the martensite start temperature for the steel. As described above, the cooling rates depends on the process variables of fluid temperature and agitation.

Conclusions

The quality of a fastener heat treating process depends on the consistent control of the process parameters that determine the properties of the part. For repeatability and control of the furnace operation these parameters are temperature, time, atmosphere (flow and carbon potential) and part orientation or racking. For quenching systems, these process parameters are the selection of the quenchant, the quenchant temperature and agitation. *www.heat-treat-doctor.com* **FTI**

Article Series: This article is the sixth in a series on the subject of heat treating fasteners. Future topics will include: Common Fastener Problems; Hydrogen Embrittlement