Back to basics: Quenching, tempering as heat treatments

A short look at the most common method of heat-treating steel.

This article describes the most common type of heat treatment of steel. This includes austenitizing, quenching, and tempering. In this process, the part is heated to the austenitizing temperature; quenching in a suitable quenchant; and tempering in a suitable quenchant. This is shown schematically in Figure 1.

In this example, the part is austenitized, and then quenched in a quenchant fast enough that the surface and center of the part miss the “nose” of the TTT curve and is completely through-hardened. The slowest possible quench to achieve through-hardening corresponds to the quench rate sufficient to just miss the “nose” of the TTT curve. Slower quench rates than the minimum will result in the formation of non-martensitic transformation products of ferrite, pearlite, and bainite. It should be noted that the TTT curve has no bearing on the tempering reaction.

This is the most common type of heat-treating of steels and is applicable to a wide variety of heat treatments of all type of components, including aerospace, automotive, and agricultural parts. For most applications, the austenitizing temperature is approximately 25-30°C above the A$_{s3}$ temperature. After properly soaking at temperature, the part is then quenched rapidly into brine, water, polymer, or oil. The quenchant is generally less than 80°C for oil, and at ambient temperature for the water-based quenchants (water, brine, and polymer). The part remains in the quenchant until it is at approximately the temperature of the quenchant. The part is then removed from the quenchant and immediately tempered. If the part is not tempered immediately (usually within 90 minutes of quenching), the part may be prone to quench cracking. This type of heat treatment is prone to distortion and residual stresses. To minimize distortion and residual stresses, the quenchant is selected to achieve properties and minimize distortion.

While the A$_{s3}$ temperature can be calculated for a specific chemistry, in most applications, the heat-treating temperatures are specified, as well as the quenchant. Examples are provided in Table 1.

In general, for most furnaces used in industrial practice, parts are heated using natural gas or electricity (including induction). This furnace can be a simple box furnace, or complicated like an integral quench furnace. The principle is the same. The part is heated to the austenitizing temperature and allowed to soak for some period of time, then quenched into the appropriate quenchant.

Heating of the part is usually monitored by a thermocouple, either placed with the parts (load thermocouple), or with the furnace (process thermocouple). The part is heated until the part reaches typically within 25°F (18°C) of the desired set point or austenitizing temperature when measured by the process or load thermocouple. Generally, the load thermocouple will lag the process couple. At this point, the soaking of the parts begins. Historically, the rule of thumb of “one hour per inch (2.5 cm) of cross section” is used to determine the appropriate amount of soaking time required. This was based on the response of the process thermocouple. It is likely that the “one hour per inch” rule of thumb is very conservative. Typical times for heating in furnace and salt baths, as well as soak times, are shown as a function of temperature in Figure 2.

Once the part has been properly heated and soaked, the part is withdrawn from the furnace and quenched. While previous articles have discussed quenchants, there has been little discussion of the quench tank. There will be a brief discussion of the quench tank here, and more in a later article.

The quench system, at its simplest, is a material handling system to transfer parts from the furnace to the tank; a container to hold the quenchant; the quenchant; and the agitation system. The material handling can be a man holding a pair of tongs like the village blacksmith, or it can be large overhead cranes transferring massive forgings to the quench tank (Figure 3).
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Agitation systems can be manually swirling the part by hand or complex agitation systems consisting of pumps or impellers. Whether the part is small and held by tongs or a massive forging, the principle is the same — to quench the part uniformly.

Historically, the focus of many heat-treating specifications has been on the quenchant, with specification and auditing agencies requiring monthly or quarterly testing of the quenchant. This testing could include cooling curve testing; kinematic viscosity; flash point (where appropriate); and other testing. However, no attention was paid to the quench tank. It was assumed that if the quenchant was good, then the parts would be acceptable.

The recent specification AMS 2759F [1] tries to address this issue, testing requirements on the oil and the entire quench system to verify that the “quench system” is capable of meeting process requirements. Whether it is successful in preventing heat treating failures or producing unnecessary “audit bait” remains to be seen.

CONCLUSION
In this short article, we have described the most common method of heat-treating steel. In the next article, we will be discussing martempering and austempering for distortion control.

Should you have any comments or questions, please write the author at smackenzie@houghtonintl.com.

REFERENCES


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