HOT
SEAT

***Jack Titus***
**Heat Treat Analyst**
AFC-Holcroft

# HEAT TREATING AND UNINTENDED CONSEQUENCES

## A major element of successful heat treating is knowing the capability of your equipment.

**LOAD SIZE, TOTAL WEIGHT, AND SURFACE** area are important considerations for several reasons when heat treating. First, surface area must match the carbon content of the atmosphere when carburizing. Too much area versus available carbon results in a non-uniform and lean case depth and potentially low hardness. On the other hand, excessive carbon versus available surface area can result in higher concentrations of iron-carbide ($Fe_3C$) and retained austenite.

Another reason relates to quenching. Whether it's high pressure gas quench (HPGQ) or oil quench — quenching when the load surface area-to-weight ratio is large can have catastrophic consequences. For example, instantaneous heat transfer from a high surface area load to the oil can raise the oil temperature above the flash or fire point quickly. Conversely, if the water flow to the HPGQ is too low for the rapid heat transfer, steam can form in the heat exchanger, creating a severe over-pressure condition.

While carburizing and quenching comprise the majority of heat treating processing, oversize loads under any circumstance have consequences.

Here are a few situations where the load size had a profound impact on the outcome of the parts and equipment:

The first items in question were small 1-quarter-pound investment cast levers used in a transmission. Due to air contacting the hot parts, the casting process decarburized the part's surface, which is a typical occurrence in casting. In this circumstance, the heat treating process was carbon restoration of the decarburized surface. This involved using endo gas as the carburizing media in an integral quench batch furnace with a top cool chamber. Because decarburization only affects a shallow depth of the part's surface, the time required to restore the base carbon (in this case, 0.40 percent) takes only an hour or two after bringing the load to 1,570°F (854°C). Following carbon restoration, the parts are oil-quenched to complete the hardening process.

For production reasons, the carbon-restored parts were randomly loaded in two stacks of five 6-inch rod-frame stacking baskets with each basket fully loaded. The second item was of similar size but a different alloy and one that required annealing.

Two separate issues surfaced: the oil-quenched 4140 parts developed micro-cracks on several parts, and the annealed load had a negative effect on the top cool chamber.

4140 is a high hardenability grade, but with such a large load yet with parts that were fairly small, gas cooling in the top cool was not fast enough to harden the alloy. Because endo gas was the carbon source and with austenitizing at 1,570°F (854°C), the carbon potential (CP) directly from the generator with a 35°F (1.6°C) dew point was too high, 0.85 percent. 4140 required a CP of 0.40 percent to match the base carbon, so dilution air was continuously added to the furnace to reduce the CP.

Through several investigative efforts, the root cause was determined to be as implausible as it sounds — the result of a relative of intergranular oxidation (IGO). While investment casting produces a smooth surface, the elevated hardenability of 4140 steel and the part design aggravated the crack potential of the alloy. Even though the time at temperature was too short for the typical IGO to form, the dilution oxygen required to reduce the CP from 0.85 percent to 0.40 was enough to initiate micro-cracks on some parts. Increasing the dew point at the generator reduced the CP in the furnace, avoided the need for dilution air, and eliminated the micro-cracking problem.

Annealing parts of the same load size by slow cooling in the batch furnace top cool chamber presented a different problem, but one that was still related to the extreme surface area. Top cool chambers of batch furnaces have a simple task — raise the load into the black-body, high emissivity environment with a recirculating fan to allow the heat to be transferred to the interior wall. Recirculated quench oil within the top cool chamber walls carries the energy to an air-to-air heat exchanger. However, recirculated cooling oil within the top cool wall could not keep the inner wall facing the load from overheating and buckling, causing welds to crack and leak. Many solutions were tried, but the ultimate fix was achieved by attaching a radiation shield to the top cool interior walls and decreasing the load size, thus reducing the heat flux to the interior oil-cooled surface.

Here's another example related to surface area. Inverted 1-quarter-inch grid-lined rod-frame stacking baskets were used to hang 6-inch-long roofing screws by an AFC-Holcroft customer without our guidance. The customer attempted to fill every 1-quarter-inch opening for maximized production. Obviously, thousands of screws made up the two- and three-tier load. This situation prompted our help to stop the oil-induced explosions they were experiencing. We were shocked at the quantity of surface area composed in the load. The small threads on the 1-eighth-diameter screws amounted to tiny fins that gave up heat to the oil instantaneously, creating a fireball through all vented openings in the furnace vestibule. Not only did the surface area cause the problem, but the density of the load also prevented sufficient oil from passing up through the load, creating additional overheating. Eliminating every other screw while reducing the load allowed better oil flow and corrected the overheating.

**ABOUT THE AUTHOR:** Jack Titus can be reached at 248-668-4040 or jtitus@afc-holcroft.com. More information can be found online at www.afc-holcroft.com or www.ald-holcroft.com.