



# HOTSEAT

jackTITUS

Director of process and developmental engineering, AFC-Holcroft

One of the most critical functions of heat treating doesn't involve heat at all. Hardening ferrous alloys concerns the removal of heat at very precise schedules and heat transfer rates.

**IN HIGHER-ALLOY MATERIAL**, such as precipitation hardening steels (PH), hardening requires a two-step application—one of removing heat by quenching followed by adding heat to produce aging by the precipitation of complex carbides, supplementing the wear resistance of the martensite. If the quench in either case of ferrous material and PH is not fast enough, carbon/iron compounds will form into ferrite, pearlite, or bainite and reduce the quantity of martensite and, consequently, thus hardness and strength.

In addition, during cooling if it's not fast enough, martensitic stainless steels will lose their ability to resist corrosion as alloy combine with carbon to precipitate carbide reducing the chromium in solid solution in the austenite matrix. And as the alloy precipitate as carbide, the austenite will lack adequate alloy to depress the martensite start temperature and move the isothermal transformation (I-T) diagram to the right. As the primary austenite promoting elements like carbon, nickel, chromium, manganese and moly are reduced the nose of the I-T diagram will be allowed to drift to the left drastically reducing the time to cool.

The "X" axis (time) of the diagram is displayed in the log of seconds 1, 10, 100, 1000, etc. making the time appear much longer than it actually is. In the carburizing grade steel of 8620 (C, 0.18 – 0.23, Ni, 0.4 – 0.7, Cr, 0.4 – 0.6, Mn, 0.7 – 0.9, Mo, 0.15 – 0.25) the nose of the A (austenite), F (ferrite), C (carbon) region barely allows one second to avoid any non-martensitic transformation product (NMTP).


So how is it possible that any size part, especially a gear weighing even just a few pounds, in a 3,000 pound load of other gears can transform to martensite when just one second is allowed to miss the A-F-C nose of the I-T diagram? Pearlite, a lamellar formation of ferrite and  $Fe_3C$ , does not transform from austenite instantaneously but requires time also indicated on the I-T diagram. Ferrite, however, requires little time since the carbon composition is only 0.04% and forms in those areas commensurate with the austenite grain size. Pearlite emanates from the grain boundaries where carbon tends to concentrate and progresses across the grains. The longer the steel is held at 1000° F (538° C) the more pearlite is formed. Since the gear is continuously cooling it passes through the pearlite region quickly so only a small fraction if any of the austenite

transforms to pearlite before reaching the martensite start temperature of 760° F (404° C).

More so than pearlite, bainite is generally the indicator that a poor quench has taken place. Even though the part has passed through the I-T nose rapidly and a fractional portion of the austenite has transformed to ferrite if the cooling rate, in oil for example and has progressed to the reduced heat transfer stage of convection, it may enter the bainite region prior to cooling to the Ms point. Thus bainite is the problem not pearlite. And in gears especially those of large modules the teeth roots are the biggest problem.

The process described above occurs in the core or sub-case of the gear tooth where the carburized case has not penetrated and the carbon remains at 0.18 to 0.23%. Since carbon added via carburization is an austenite former it retards the formation of martensite thus lowering the Ms point and moving the I-T nose to the right. There is a kind of thermodynamic balance that takes place between the higher-carbon-lower-Ms point at the tooth surface and the lower-carbon-higher-Ms point of the sub-case and core that depends on the quantity of carbon gradient in the case. And it's this phenomenon that allows for improved distortion when employing HPGQ (high pressure gas quenching).

But there's more to the story besides uniform convection cooling. The closer the martensite start temperature in the carburized case is to that of the gear mass at the sub-case depth the lesser are the stresses and the tendency to create differential strain and distortion; and what is a major contributor to the Ms temperature: the carbon content of the steel.

It stands to reason then that the lower the carbon content of the carburized case, the higher the Ms temperature and closer it will be to that of the sub-case, thus one could expect lower distortion. I believe you'll find in most, if not all, of the LPC/HPGQ systems in operation today the maximum surface carbon is no higher than 0.75%. The quantity or percent carbon trapped in the body-centered cubic lattice when the Ms point is reached dictates the maximum hardness that can be achieved. Providing the quench severity is adequate for the gear mass the maximum hardness of martensite that can be achieved does not increase above 0.7% carbon. Any increase of the carbon concentration above the eutectoid level of 0.83% produces iron carbide ( $Fe_3C$ ) and is intended to improve wear not increase the martensite hardness. 

## ABOUT THE AUTHOR:

Jack Titus can be reached at (248) 668-4040 or [jtitus@afc-holcroft.com](mailto:jtitus@afc-holcroft.com).  
Go online to [www.afc-holcroft.com](http://www.afc-holcroft.com) or [www.ald-holcroft.com](http://www.ald-holcroft.com).

\* For an additional "Hot Seat" column by Jack Titus, See the Fall/Winter issue of *Thermal Processing for Gear Solutions* issue for the rest of the story.