Precision Cooling of Vacuum Heat Treated Hot Work Tool Steels Is Critical

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Programmable precision cooling of H13 hot-work tool steel dies during vacuum heat treatment overcomes the problems associated with conventional heat treatment.

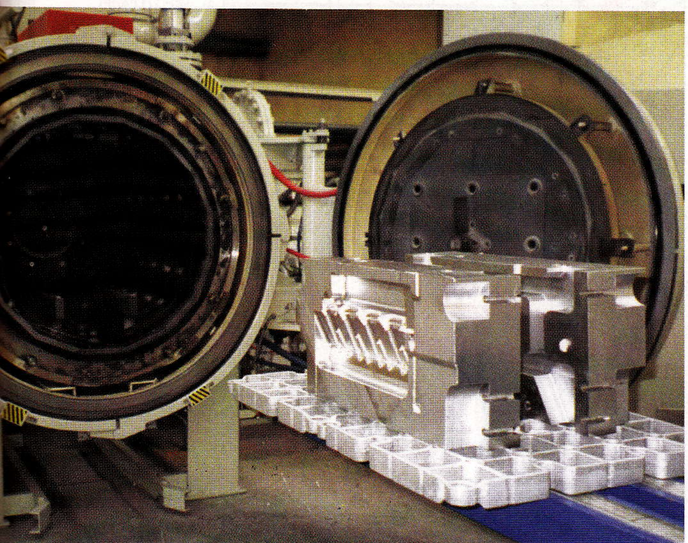
Chromium hot-work tool steels have excellent resistance to high-temperature impact loading, resistance to softening during high-temperature exposure and resistance to thermal fatigue. These properties are achieved by the use of medium carbon content and relatively high concentrations of chromium and other strong carbide-forming elements. The medium carbon promotes toughness, and good high temperature strength is achieved by tempering at high temperatures to precipitate fine, stable dispersions of chromium and vanadium alloy carbides, which coarsen slowly in service. The high alloy content of these steels provides excellent hardenability and permits hardening of heavy sections with the use of the proper cooling rate. Many tools and dies are made of H13 hot-work tool steels, which is characterized by significant hardenability and good ductility, as well as by its resistance to drawing (softening), oxidation and, in particular, thermal fatigue.

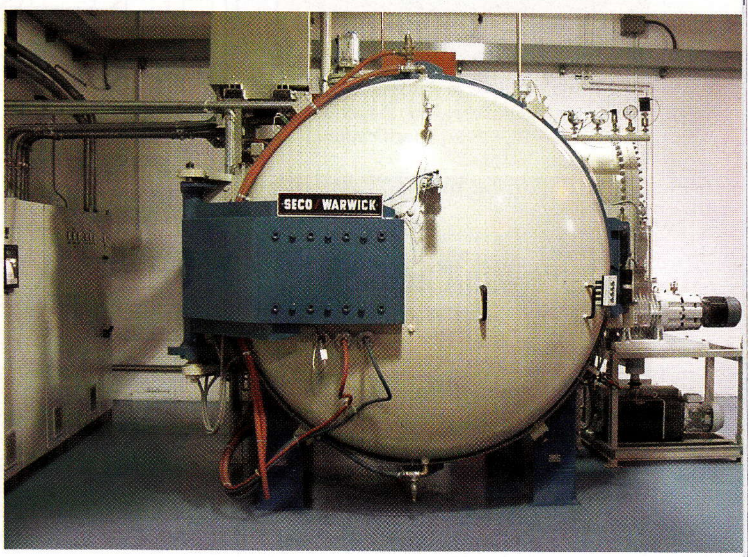
Heat treating finished tools made of chromium hot-work steels such as H13 (containing nominally 5% Cr and significant amounts of other elements), particularly large ones, requires experience and a clear understanding of the phase changes and associated stresses occurring during the heating and cooling of the part. It is necessary to achieve a fully martensitic or banitic structure throughout the entire piece without creating excessive stresses from the hardening treatment.

Heat-treating requirements are outlined in steel manufacturer's recommendations, as well as in several standards documents such as those from NADCA, General Motors (GM Powertrain DC-9999-1) and Ford Motor Co. (Ford AMTD-DC2010). These standards list detailed heat treating requirements including precise temperatures for particular heat treatment operations, both recommended and required heating and cooling rates, allowable differences in part surface and core temperatures, the method of locating thermocouples in the charge and the methods to be used to perform mechanical tests for material strength.

In the heat treatment of H13 steel, the industrial practice of heating to the austenitizing temperature and soaking for the appropriate time is well known. Cooling, on the other hand, is a difficult operation, and is largely responsible for the resulting functional qualities and the finishing costs of the tool. The vacuum furnace system should have programmable, controlled cooling capabilities after austenitizing to meet these requirements.

Based on experience with isothermal quenching of H13 steels, the intensity of high-pressure gas quenching can cause part cracking and distortion, especially parts having thick cross sections. Using a controlled cooling cycle like isothermal quenching can minimize these problems, improving the microstructure of the hardened material to the extent that often only a single temper is required. For example, isothermal quench-





Typical furnaces used to heat-treat H13 tool steel molds and dies ing 18 in. × 18 in. × 3 in. (460 × 460 × 75 mm) H13 dies and tempering at 1020°F (550°C) produced a hardness of 57 HRC. By comparison, conventional hardening and tempering at 550°C produces a maximum hardness of only 54 HRC. Figure 1 shows an isothermal quench sequence.

The new-generation vacuum-furnace control system is capable of programmable, fast and precise cooling to a temperature range of 660 to 840°F (350 to 450°C). The workload is held for a time necessary to equalize the core and surface temperature to less than 200°F (Ts-Tc≤200°F), then cooled further in the transformation region without being subjected to stresses from the high-temperature cooling region. Recent advances in a control system have made it possible to cool a load at pre-programmable changeable and accurate cooling rates.

Boosting cooling rates

Increasing the cooling gas pressure from 6 to 12 to 15 bar proportionally increases the cooling rate. The cooling rate can be increased further on vacuum furnaces by installing blowers with higher capacity motors per furnace, such as increasing the motor for a 24 in. × 24 in. × 36 in. (610 × 610 × 915 mm) furnace from 180 to 215 hp (135 to 160 kW). At one facility in the U.S., increasing motor capacity for a 36 in. × 32 in. × 48 in. (915 × 810 × 1,220 mm) furnace from 300 to 400 hp (225 to 300 kW) allowed achieving a cooling rate of 215°F/min (120°C/min) at a 10-bar abs. cooling gas pressure in a GM test block.

Cooling gas flow during quenching has a critical influence on the cooling rate of the

Cooling rate vs. material strength

H13 tensile and fatigue strengths are higher at higher cooling rates. In the temperature range of 980 to 550°C (1800 to 1020°F), the cooling rate must be fast enough to prevent the onset of pearlite transformation, grain boundary carbide precipitation and the formation of bainite (or at least must inhibit its precipitation). The parameters specified in standard GM DC-9999-1 to cool a 16 in. × 16 in. × 16 in. (406 × 406 × 406 mm) H13 test block (Fig. A) from 980 to below 550°C are a cooling rate higher than 28°C/min (50°F/min) at a cooling gas pressure of not less than 9 bar (10 bar) measured using thermocouples placed in the center of the lateral surfaces at a depth of 16 mm (0.63 in.) in accordance with NADCA recommendations.

A cooling rate significantly higher than that required by NADCA recommendations was achieved in tests carried out in standard Seco/Warwick furnaces (Fig. B) at a cooling gas pressure of 10 bar (9 bar overpressure). The temperature plots for the cooled test block are compared with those for the minimum rates recommended by NADCA on the continuous cooling transformation (CCT) diagram for H13 steel (Fig. C). Test cooling curves are significantly better than the minimum NADCA requirements. In addition, there are differences in cooling for the same furnace design depending on the size of the heating chamber due to differences in the coefficient of heat transfer, which decrease with increasing furnace size and decreasing linear velocity of the gas through the hot zone. The linear cooling-gas flow velocity across the charge has a similar effect on the coefficient of heat transfer as the gas pressure.

Two tests according to GM-DC-9999-1 specification were run in furnaces having 24 × 24 × 36 in. and 36 × 32 × 48 in. hot zones equipped with standard motor sizes used by Seco/Warwick: 180 hp (135 kW) for the smaller and 300 hp (225 kW) for the larger. The cooling rates were 144°F/min (80°C/min) and 108-144°F/min (60-80°C/min), respectively.

Denser loading improves cooling conditions in the furnace due to less space between parts and a higher flow rate of cooling gas through the load. Cooling rates greater than recommended by NADCA from 1885 to 1000°F/min of 50°F/min (28°C/min) are preferable in the production heat treatment of H13 molds and dies.

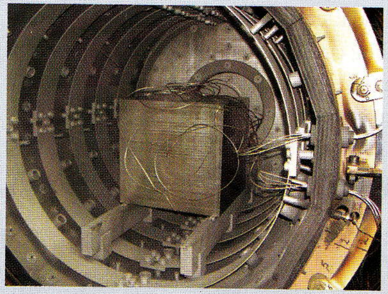


Fig A Test block used to determine conformance with quench cooling rate requirements of GM-DC-9999-1 specification.

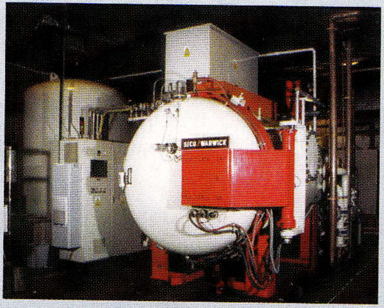


Fig B Standard SECO/WARWICK furnace used to perform quench cooling rate tests at a cooling gas pressure of 10 bar (9 bar overpressure)

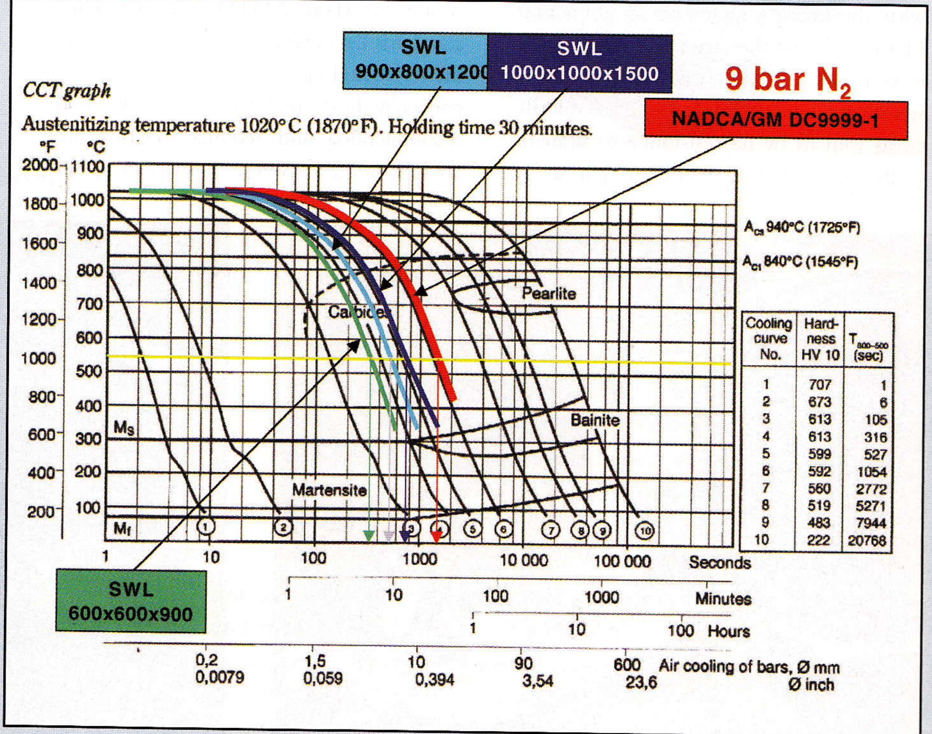


Fig C Temperature comparison for cooled test block and minimum rates recommended by NADCA on the continuous cooling transformation (CCT) diagram for H13 steel

furnace. A nozzle system is arranged 360 degrees around the charge and on the door. Gas exits through the back wall reducing the distance between the hot zone to the heaat exchanger, simultaneously developing the maximum volume of gas. The 360 degree nozzle system directs the flow of cooling gas throughout the load, ensuring the highest cooling rate. It also provides more uniform cooling compared with a rectangular heating chamber with reverse gas flow from hatches positioned, for example, above and below or side to side of the charge.

The 360-degree nozzle system is suitable for hardening both densely packed charges and single parts, including large-format forms and dies, such as those shown in Fig. 2. However, it is recommended to quench a plate-like charge using an axial gas flow through the charge. Seco/Warwick furnaces are equipped with a nozzle anti-convection flap system (ConFlap™), by which flow from side nozzles can automatically be closed while maintaining either up or down and door wall nozzles open. Other flow schemes can be programmed such as asile flow through the furnace (door back wall bung). In horizontal and vertical furnaces, axial flow is easy accomplished by opening door nozzles and rear (top) wall exist bung. To increase cooling uniformity in vertical furnace, the entire load rotates 360 degrees. The rotation of the load during cooling is especially important for round shaped loads such as palletizing dies. Furnaces with cylindrical hot zones are ideal for rapid, uniform cooling of heterogeneous or densely packed loads, including H13 molds and dies.

Summary

Satisfactory heat treatment of H13 hot-work tool steel requires close control of heat up, austenitization and cooling. Proper cooling is the most difficult operation technically, requiring a cooling rate of greater than 50°F/min (28°C/min). The preferred solution to meet this requirement is to use a vacuum furnace having a cylindrical hot zone convection heating and programmable, controlled cooling rate system. Such equipment has been demonstrated to achieve cooling rates up to 215°F/min (120°C/min) in accordance with GM DC-9999-1 requirements. **IH**

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Additional related information may be found by searching these (and other) key words/terms via BNP Media LINX at www.industrialheating.com: H13 tool steel, vacuum heat treatment, vacuum furnace, high pressure gas quenching, isothermal quenching, programmable cooling, quench gas nozzles,

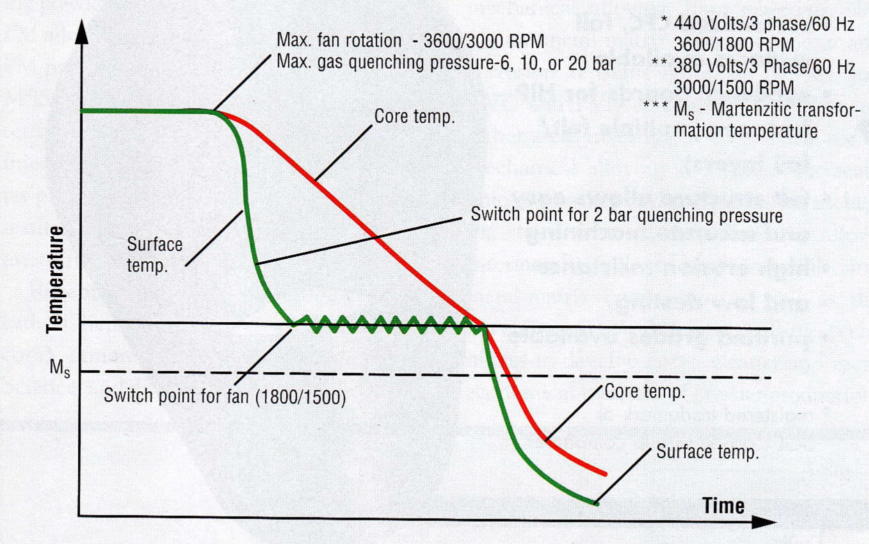

Fig 1 Isothermal quench sequence

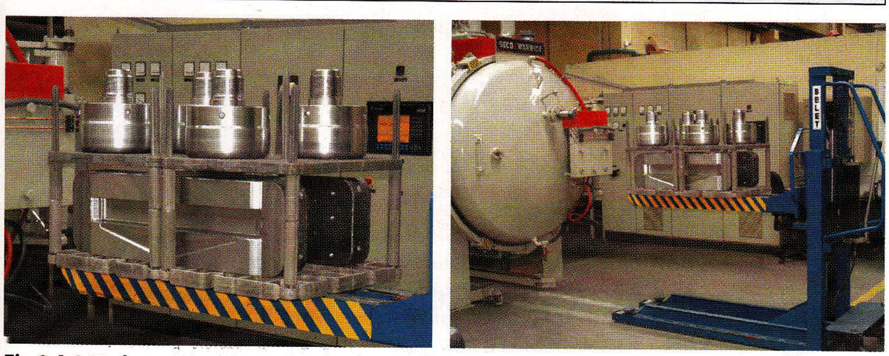

Fig 2 A 360-degree nozzle system is suitable for hardening both densely packed charges and single parts, including large-format forms and dies.