Importance of Precision Cooling during Vacuum Heat Treatment of Hot Work Tool Steel

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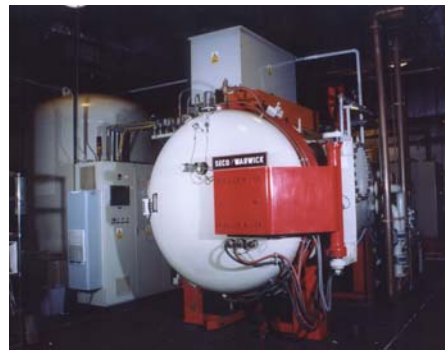
Programmable Cooling of H13 hot-work tool steel dies during vacuum heat treatment overcomes the problems associated with conventional heat treatment.



Heat treating finished tools made of chromium hot-work steels such as H13 (containing nominally 5% Cr and significant amounts of other alloys), 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.

New generation vacuum-furnace control system is capable of isothermal quench controlled cooling to a temperature range of 660 to 840°F (350 to 450°C). After reaching pre-transformation temperature, (Ms), the workload is held for a time necessary to equalize the core and surface temperature, to less than 200ºF (T_s-$T_c \leq$200ºF)[1] then cooled further in the transformation region without being subjected to stresses from the high-temperature discrepancy between the core and surface.

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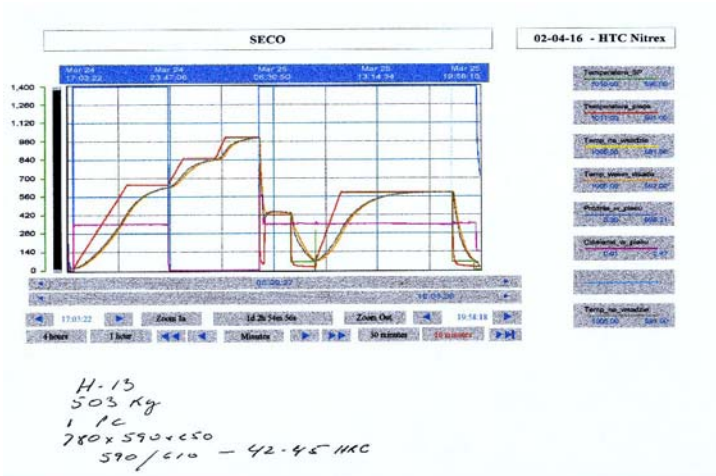

Figure 1. Shows trend graph (units in ºC) of hardening with Isothermal quench H13 Die 1100 lbs after two tempering 42-45HRC

MH/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 hp (135 kW) to 215 hp (160 kW). At one facility in the U.S., increasing motor capacity from 300 hp (225 kW) for a 36 in. × 32 in. × 48 in. (915 × 810 × 1,220 mm) furnace to 400 hp (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 (16 inches x 16 inches x 16 inches).

Cooling gas flow during quenching has critical influence on the cooling rate of the furnace. Nozzles system arranged 360 degrees around the charge and on the door, and exits on the back wall shorten the distance between the load - heat exchanger - the load and at the same time increase the volume of the gas flow to maximum. The 360º degrees 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.

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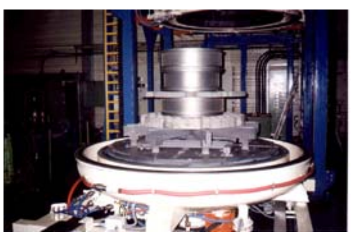
The 360-degree nozzle system is suitable for hardening both densely packed charges and single parts, including large-format forms and dies. SECO/WARWICK furnaces are equipped with a nozzle anti-convection flap system (ConFlap™), by which flow from side nozzles can automatically control according to load configuration. In horizontal and vertical furnaces axial flow is easy accomplished by opening the door nozzles and wall exit to the heat exchanger. To increase cooling uniformity in vertical furnace the entire load rotate 360º. The rotation of the load during cooling are especial important for a round shape loads such as palletizing dies. Furnaces with cylindrical hot zones are perfect for rapid and uniform cooling of heterogeneous or densely charge loads, including H13 molds and dies.



MH/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 70°F/min (28°C/min). The preferred solution to meet this requirement is to use a vacuum furnace having a cylindrical hot zones convection heating and programmable and 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.

MH/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 ×

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406 mm) H13 test block 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 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 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 . 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 with hot zones 24”x 24” x 36” and 36”x 32” x48” equipped with standard motor sizes used by SECO/WARWICK 180 hp (135 kW) for 24”x 24”x 36” and 300 hp (225 kW) for a 36 in. × 32 in. × 48 in. (915 × 810 × 1,220 mm) furnace. The cooling rate for both furnaces were 144ºF/minute (80ºC/min) and 108-144ºF/min (60-80ºC/min) respectively.

Denser load 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 1885ºF to 1000ºF/min of 50ºF/min (28ºC/min) are preferable in production heat treatment of H13 molds and dies.

1. Die Insert Material and Heat Treating Specification Spec.No.DC-9999-1 Revision 17

2. Originally published in Heat Treating Progress, revised and updated for current best practice 6/10/2005.