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Vacuum Heat Treating for M2 High Speed and D2 Tool Steels

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Abstract

A series of large cross section D2 and M2 tool steels have been obtained and cross cut prior to heat treatment. Similar heat treating, time and temperatures, will be run in a salt bath furnace and a vacuum furnace. All parts will be tracked for process temperature via deep imbedded thermocouples. Data reported, including metallurgical results, from an independent laboratory.

TOOLING MANUFACTURED from high speed and tool steels are heat treated using salt bath, vacuum, fluidized bed and controlled atmosphere furnaces.

Recent engineering developments in the vacuum furnace heat treating field have resulted in more effective heating and cooling of high speed steels during hardening. Improvements in gas quenching - increased gas pressure, higher gas flow rates - have increased the hardening response of some high speed and tool steel alloys.

Background

During the 15th ASM Heat Treating Conference and Exposition held in October of 1994, two commercial heat treating companies began the planning of a joint program that would compare salt bath and vacuum furnace heat treating processes for hardening high speed and tool steels. One company specializes in hardening high speed and tool steel components using salt bath while the other performs vacuum furnace heat treating.

Both felt that such a study would allow the heat treating industry to learn what the realistic limitations for either process might be.

It was decided that the goal of this comparative heat treating study would be to identify which sizes of high speed steel and tool steel could be hardened most effectively in salt bath and vacuum furnaces. The participants felt that such a study would help dispel any "myths" that existed regarding the ability of either heat treating process to effectively harden tool steels.

Heat Treating Study

During subsequent meetings, it was agreed that this heat treatment study would consist of the following:

1. The grade of high speed steel heat treated would be standard carbon M2 and the tool steel grade D2. Both are popular steels used in the tooling industry today. The steels would be furnished as round bar in the hot rolled and full annealed condition. The outer diameter of the bars would be machined to remove surface scale and decarburization.
2. The bar diameters heat treated would be 1-1/2, 3 and 6" for the M2 and 3, 6 and 12" for the D2. All test bars would be 12" in length. The steel would be supplied by one mill, all bars would be furnished from the same heat of steel and the chemical analysis for each bar size would be submitted as verification of composition.
3. The 6" diameter test bars would be saw cut longitudinally along the centerline axis of the bar. The bars would be mechanically re-joined to simulate the heating and cooling characteristics of full bar diameters. Splitting the annealed bars in half was done to facilitate future sectioning during the metallurgical testing phase of the study.
4. Thermocouple wells (approximately 1/4" diameter for Type K thermocouples) would be machined into one end of each test bar. The well location for the 1-1/2 and 3" test bars would be in the center of the bar diameter. The well location for the 6 and 12" bars would be at the mid-radius of the bar diameter. Each thermocouple well would be drilled to a depth of approximately 6". This would allow the temperature of each test bar to be monitored during the heat treatment cycle.
5. The hardening processes selected would represent standard heating and cooling practices used by vacuum and salt bath furnace operators for the routine production heat treatment of these steels. Each test bar would be hardened to develop maximum metallurgical properties.
6. The hardening cycles used would be recorded to establish the actual heating and cooling rates experienced by each test bar.
7. After hardening, the test bars would be examined metallurgically to determine their response to heat treatment. This examination would consist of metallography to evaluate the heat treated microstructure and hardness testing. The outer diameter, mid-radius and center of each test bar would be examined.

Large cross sections and mass of both grades were selected knowing that the M2 would be a challenge for the vacuum furnace, and the even larger cross section and mass of the D2 would be a challenge for the salt bath furnace. Figures 1 and 2 represent cross sections and mass.

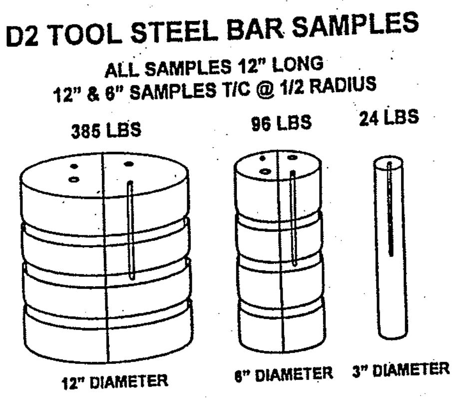

Fig. 1 - D2 Tool Steel Bar Samples

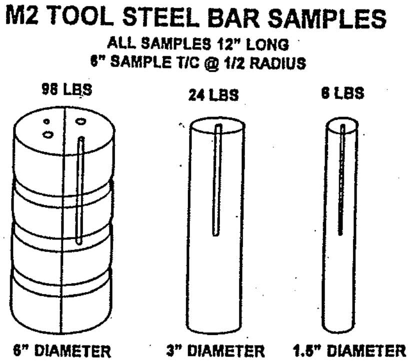

Fig. 2 - M2 Tool Steel Bar Samples

Vacuum Furnace Heat Treatment

It was decided for the vacuum heat treating process to run all the D2 sizes in <u>one heat</u> and also all the M2 sizes in <u>one heat</u> as this is the most economical cycle for the vacuum furnace. Admittedly, this would put the M2 smaller cross sections at risk due to oversoaking and possible grain size enlargement. This, however, did not turn out to be a major concern.

Both process cycles were run in a VFS Model HL36, 24" W x 24" H x 36" D vacuum furnace with a 75 hp gas blower operating at 30 psig (3 bar) for gas quench. The furnace hot zone was fitted with 39, one inch (1") ID venturi graphite gas nozzles to provide nozzle velocity in excess of 200 miles per hour. Gas quenching was done with nitrogen gas. Figure 3 is a view of the vacuum furnace hot zone ready to run.

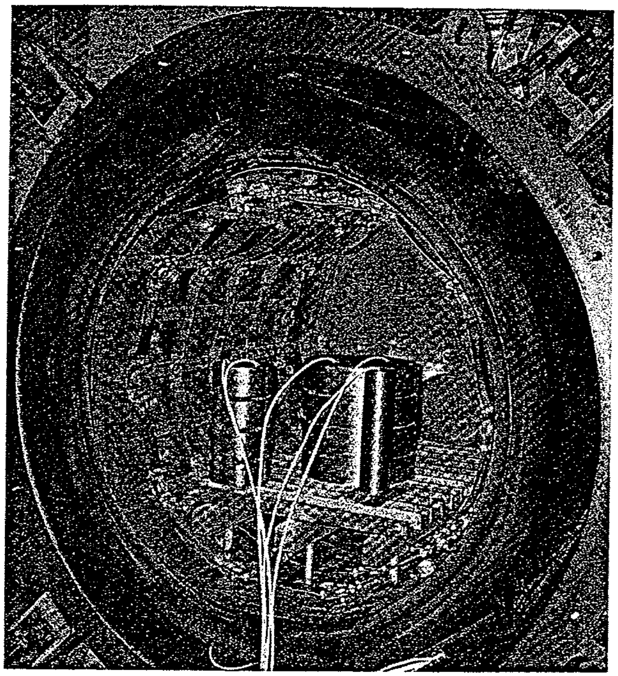

Fig. 3 - Vacuum Furnace hot zone with D2 tool steel load in place and thermocouples inserted.

For both process cycles, primary heating and soak times were controlled off of the largest cross section round of each grade in order in ensure full soak of the larger mass. As a result, the smaller cross sections were oversoaked, and this was an accepted risk for this particular trial.

Following are the process cycles for each tool steel grade for the vacuum furnace:

<u>D2 Process Cycle</u>

1) Rough pump down to 100µ vacuum and start flow 75 SCFH nitrogen partial pressure.
2) Ramp at 30°F per minute to 1500°F ±50°F.
3) Hold at 1500°F ±50°F for two (2) hours (work thermocouple).
4) Ramp 30°F per minute to 1775°F ±25°F.

5) Hold at 1775° F ±25° F for one (1) hour and 45 minutes (work thermocouple).
6) Ramp 30° F per minute to 1875° F -25° F +0° F.
7) Hold at 1875° F -25° F +0° F for 20 minutes (work thermocouple).
8) Nitrogen quench to room temperature at +30 PSIG.
9) Deep freeze -100° F immediately and leave in 12 hours.
10) Air warm to room temperature.
11) Record as-quenched hardness.
12) Air temper 300° F for one (1) hour minimum (work thermocouple).
13) Record resultant hardness on all three (3) sizes.

M2 Process Cycle

1) Rough pump down 100μ vacuum and start flow 75 SCFH nitrogen partial pressure.
2) Ramp at 30° F per minute to 1475° F ±25° F.
3) Hold at 1475° F ± 25° F for two (2) hours (work thermocouple).
4) Ramp 30° F per minute to 1900° F - 1925° F and hold for two (2) hours (work thermocouple).
5) Ramp at 30° F per minute and hold at 2125° F - 2150° F for one (1) hour (work thermocouple).
6) Ramp 30° F per minute to 2200° F to 2225° F.
7) Hold at 2200° F - 2225° F for 20 minutes (work thermocouple).
8) Nitrogen quench to room temperature at +30 PSIG.
9) Deep freeze -100° F immediately and leave in 12 hours.
10) Air warm to room temperature.
11) Record as-quenched hardness.
12) 1st air temper 900° F. Hold for 15 to 30 minutes (work thermocouple).
13) Air cool to room temperature.
14) 2nd air temper to 975° F. Hold for 15 to 30 minutes (work thermocouple).
15) Air cool to room temperature.
16) Record resultant hardness on all three (3) sizes.

Heating Response

Figures 4 and 5 represent the heating and soak response from the <u>inserted</u> <u>thermocouples</u> in each cross section for D2 and M2 respectively.

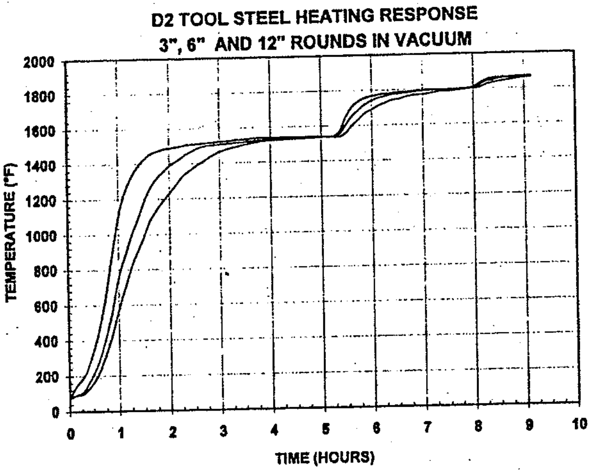

Fig. 4 - D2 Tool Steel Heating Response
3, 6 and 12" Rounds in Vacuum

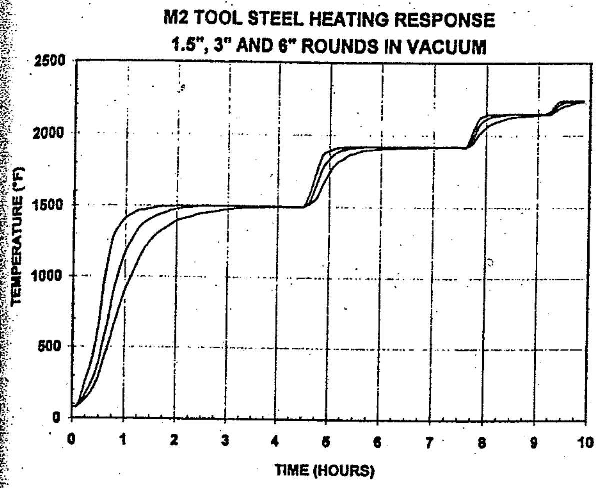

Fig. 5 - M2 Tool Steel Heating Response
1.5, 3 and 6" Rounds in Vacuum

Note the heating response delay for the larger cross sections to reach temperature as compared to the smaller cross sections is not as severe as one might expect.

As a result, preheat soak temperature for both grades are excessive and could be dramatically reduced for future production cycles for overall cycle time reduction.

Cooling Response

In quench, the smaller diameter and mass rounds quench considerably faster for both grades. The larger and heavier D2 grades are considerably slower.

The cooling curves and cooling rates presented in Figures 6 and 7 are core temperature of the rounds. Surface cooling rates would be considerably faster.

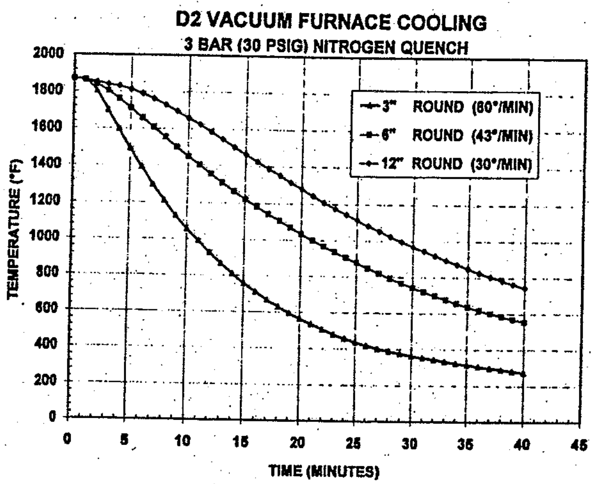

Fig. 6 - D2 Vacuum Furnace Cooling
3 Bar (30 psig) Nitrogen Quench

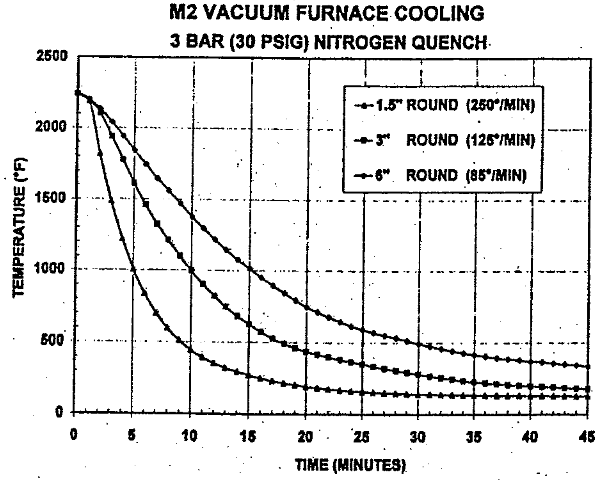

Fig. 7 - M2 Vacuum Furnace Cooling
3 Bar (30 psig) Nitrogen quench

Discussion of Results

Heating rates for vacuum are slower as compared to salt bath heat treatment. Quench rates for the vacuum furnace are comparable and somewhat unexpected as generally quoted by salt bath processors.

Experience has indicated that a -100° F deep freeze immediately following the austenitizing cycle is desirable to provide maximum metallurgical transformation and improved hardness results.

It should be noted that care in tempering is essential. Not only the oven control temperatures but soak times are important. Thus part thermocouple tracking to prevent overtempering is not only recommended but necessary. Note Figure 8 and the rapid hardness fall off on oversoak time at temperature.

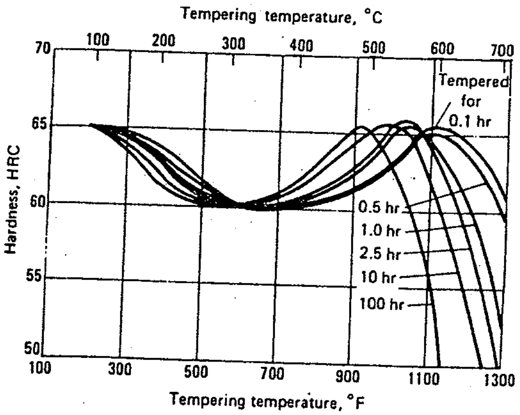

Fig. 8 - M2 hardness vs time at tempering temperature. Austenitized at 2225°F and tempered at the times indicated.

Summary

Surface and core hardness data and metallurgical microstructure were carefully studied by Thielsch Engineering Associates, an independent laboratory. This data and comparing the salt bath versus the vacuum results are reported as a separate paper presented during these proceedings by John C. Hebeisen of I.M.T. Inc., acting as an independent reporting metallurgist. Probably his most important comment follows:

> "The most remarkable feature is the similarity between the harness scans for the two processes. The hardness level in the M2 bars has fallen off somewhat with bar size and is a minimum at the ID of the 6" bar as one would expect, but the relative performance of the two processes is pretty close."

It should be noted that both processors attempted to adopt a heat treating cycle that in their opinion was best suited for each type furnace. Since these were basically "one off" runs, both processors have learned a number of points that would allow for improvement in expected results. The use and value of deep inserted tracking test thermocouples cannot be overstated. It is expected to continue this cooperation to obtain these improvements and report at a future conference.

A number of engineering meetings were held to plan our procedure, processing and testing. Mr. Karl-Heinz Kopietz, Chief Metallurgist of Ajax Electric Co. also added considerable insight to this work and this is to be acknowledged.