Vacuum Heat Treating of Tool Steels

by
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Tool steel refers to a variety of carbon and alloy steels that are particularly well-suited to be made into tools but where special attention to needs to be paid during their heat treatment so as to achieve the best properties for a given application. Tool steel heat treatment today is based on a simple premise, that to obtain the optimum performance from any given grade, every step of the heat treating process, including stress relief, preheating, austenitizing, quenching and tempering must be done exactly correct.

The selection of any tool steel (Fig. 1) depends on a combination of factors including component design, application end use and performance expectation. For any given application the goal of heat-treating is to develop the ideal microstructure (Fig. 2) to help us achieve the proper balance of desirable properties: hot (red) hardness; wear resistance; deep hardening; and toughness (Table 1).

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Figure 1 [1]
Tool Steel Types

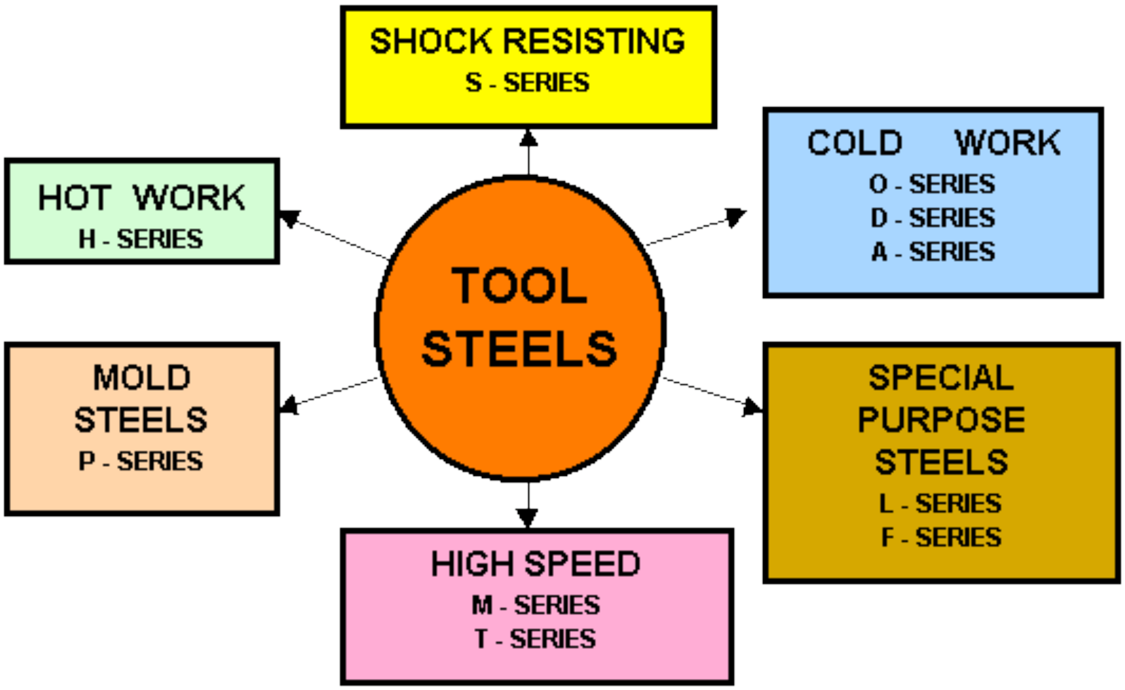

Table 1
Effect of Alloying Elements on Tool Steel Properties [2]

Tool Steel Characteristic [a]	Alloying Element (by potency)
Hot (Red) Hardness	W, Mo, Co (with W or Mo), V, Cr, Mn
Wear Resistance	V, W, Mo, Cr, Mn
Deep Hardening	Mn, Mo, Cr, Si, Ni, V [b]
Toughness [c]	V, W, Mo, Mn, Cr

Notes:

[a] Distortion is best managed by additions of: Mo (with Cr), Cr, and Mn.
[b] Tool must be austenitized at a high enough temperature to dissolve the vanadium carbide.

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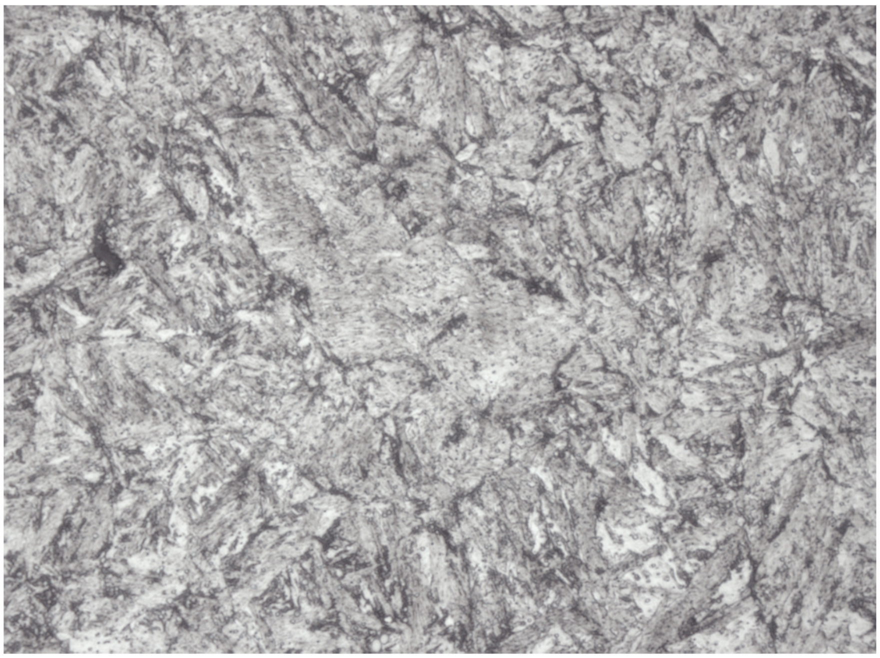
[c] Toughness is achieved via grain refinement.

Figure 2
Typical H13 Tool Steel Microstructure (1000X)
(Photograph Courtesy of Aston Metallurgical Services Company)



Tool and Die Industry Needs

A key question asked of Heat Treater's by makers of tools is, "Can I achieve the same microstructure with vacuum hardening as I can with other heat treatment methods such as salt?" The simple answer is yes. Advances in vacuum furnace technology, particularly in the area of high gas pressure quenching, produce microstructures with the type and distribution of carbides throughout the matrix equivalent to those microstructures traditionally limited to salt bath heat treating.

The tool and die industry requires the processing of a variety of materials, geometry, cross sectional areas and load sizes (Fig. 3). Heat treatment specifications can be

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extremely diverse. The principal application areas (Table 2) include: plastic processing; hot/warm working steels (e.g. H11, H13); cold working steels (ASP 23, M4, T15, CPM 9V, SPM 10V, CPM 15V); and high-speed steels.

Table 2 [18]
Typical Tool Steel Applications

Tool Type	**Material**	**Typical Hardness Requirement (HRC)**
Molds/holder blocks	4135, 4150 P20 J13, S7 NAK 55 (Ni + Al PH) 420, 420 modified 17-4, 15-5 Maraging steels A2, D2, 440C CPM 9V, CPM 10V, 440V, M390	25 – 30 28 – 38 42 – 55 38 – 40 48 – 52 30 – 42 48 – 56 56 – 60 54 – 62
Injection molding	Alloy and nitriding steels H13, S7 A2, D2, 440C 17-4 CPM 9V, CPM 10V, CPM 15V, MPL-1	28 – 32+ 42 – 55 56 – 60 30 – 42 54 – 62
Pelletizing/ Granulating Knives	Hard-faced alloy steels D2, 440C 17-4 M4, CPM 9V, CPM 10V, 440V	58+ 58+ 40 – 42 54 - 62

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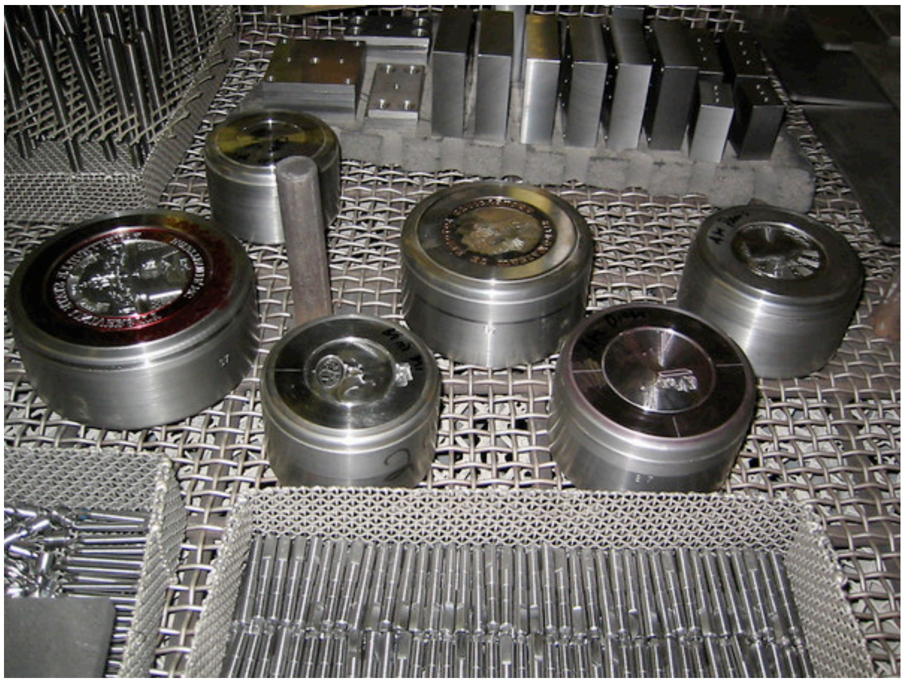
Figure 3
Typical Load of Tool & Die Components for Vacuum Heat Treating and High Pressure Gas Quenching (Photograph Courtesy of Nevada Heat Treating, Inc.)



What is pressure quenching?

The description most often used to define high pressure gas quenching is "accelerating the rate (speed) of quenching by densification and cooling of gas."[2] One of the many reasons for the intense interest in this quenching technique is related to improved part distortion with full hardness. A critical concern in using this technology is to avoid sacrifice of metallurgical, mechanical, or physical properties, that is, retain the ability to transform a material to a microstructure that is similar, identical or superior to that of a known quenching medium (e.g. oil or salt).

Common quench gases include nitrogen, argon and helium. Hydrogen, although excellent with respect to heat transfer is seldom used as a quench gas due to safety considerations.

Pressure Levels

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Selecting the optimum gas pressure for quenching is highly dependent on a number of factors including material, component geometry, loading, net to gross load ratio, gas parameters, and equipment design (Fig. 4). Pressure ranges (Table 3) are typically classified as sub-atmospheric, low, medium, high and ultra-high pressure irrespective of the type of gas used.

Figure 4
Typical Vacuum Heat Treating Furnaces
(Photograph Courtesy of Nevada Heat Treating, Inc.)

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Table 3
Classification of Gas Quenching Pressure Ranges

Classification	Pressure Range bar (psig) [a]
Vacuum cooling	< -0.67 (-9.7)
Sub-atmospheric pressure	-0.67 to -0.17 (-9.7 to -2.5) [b]
Low pressure	2 – 4 (29 – 58)
Medium (mid-range) pressure	5 – 9 (72 – 130)
High pressure	10 – 20 (145 – 290)
Ultra-high pressure	>20 (290)

Notes:

[a] Gauge pressure (psig) is the measurement of the difference between the absolute pressure and local atmospheric pressure (which can vary due to such factors as temperature, altitude, and relative humidity).

[b] Pressure is normally limited to -0.17 bar (rather than 0) to prevent the furnace from reaching atmospheric pressure and the door opening.

Summary

The key to understanding the factors that influence gas quenching is to achieve a balance between the speed of quenching and the uniformity of quenching. The former requires holding constant as many of the process variables as possible while the later involves uniform heat extraction. In this way, both repeatability (quality) and performance (productivity) will be achieved with an optimized microstructure.

Many commercial heat treaters either do not have gas quenching technology readily available or if they do they are limited either in pressure or cooling effectiveness. As such, the parts maker should define his requirements (e.g. hardness, dimensional tolerances) on his purchase order so as to avoid unwanted surprises. Gas quenching should be applied in those applications where its advantages outweigh its disadvantages and, as with all technologies, having as complete an understanding as possible of the performance requirements of the product helps to evaluate which quenching choice is best for the end-use application.

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