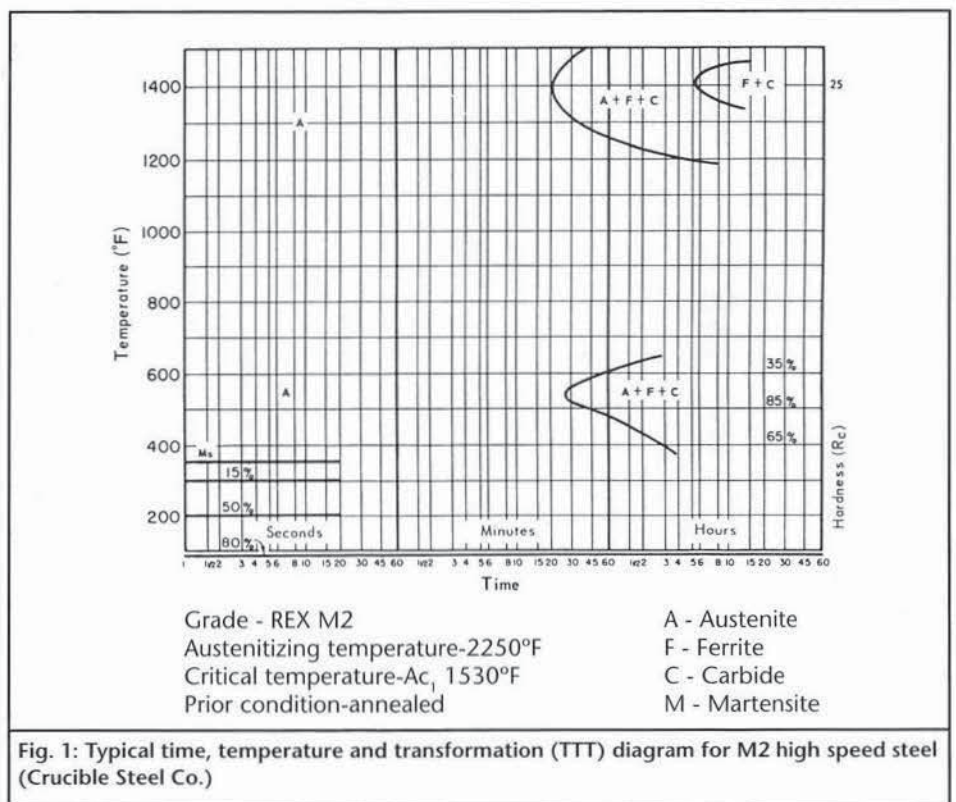# Hardening high speed steels: metallurgical benefits of salt

Why are heat treating results—particularly for hardening high speed tool steels—always compared with the results obtainable by processing in salt? A commercial heat treater explains salt's unique capabilities, and why salt is still often the best—or only—medium for high speed steel.

by GREGORY W. DEXTER

The technologies of vacuum, fluidized bed and protective atmosphere batch furnaces have undergone tremendous improvements with respect to heating and cooling of high speed and high alloy tool steels. In particular, the recent improvements in pressure gas quenching by several manufacturers of vacuum equipment show great promise for the future with respect to the hardening of high speed steels having lower alloy content and larger cross-sectional mass. Still, new equipment manufacturers, after evaluating the results of R&D test programs, compare the performance of those processes to salt bath heat treatment. Why?

The technology of molten salt bath heat treatment is generally recognized as a superior method for processing a variety of metals, ranging from austempered ductile iron (ADI) to high speed tool steels. At Metallurgical Solutions, a commercial heat treat started up this summer, we work with fluidized bed, vacuum and high-temperature at atmosphere equipment. However, salt bath technology, one of the oldest methods conceived for the heat treatment of tools and components, still continues to provide the superior metallurgical characteristics and properties necessary for the optimum performance of high speed steel tools. Because we believe salt bath controllability, versatility and heat transfer efficiency are second to none in today's heat treating industry, we are

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Fig. 1: Typical time, temperature and transformation (TTT) diagram for M2 high speed steel (Crucible Steel Co.)

Grade - REX M2
Austenitizing temperature-2250°F
Critical temperature-Ac, 1530°F
Prior condition-annealed

A - Austenite
F - Ferrite
C - Carbide
M - Martensite

specializing in salt hardening. This article has been written to explain some of the metallurgical results that can be achieved by hardening high speed tool steels in salt.

Salt Basics

The term "salt bath" describes a medium created by melting one or more chemical salts to form a liquid bath into which materials can be immersed for heat treatment. The composition of the salt to be used is determined by the temperature range in which the bath will be operated.

Salts used for the heat treatment of high speed tool steels are sodium, potassium and barium chlorides. The percentage of barium chloride used in the bath increases with temperature requirements. The high-temperature bath in the line is typically composed of 100% barium chloride.

The hardening line usually is composed of three baths—preheat, high heat and quench. The preheat bath is generally operated between 1500° and 1600°F (816° and 871°C). The high heat bath operates from 2000° to 2350°F (1093° to 1288°C). The quench is normally maintained between 1000° and 1150°F (538° and 621°C). The three baths are typically constructed with ceramic pots to

Salt's benefits

hold the salt, and are heated by electrical resistance between two or more metal electrodes immersed in the molten salt.

How distortion's reduced

When a high-speed-steel tool at room temperature is initially immersed into the preheat molten salt bath, a "cocoon" of frozen salt is formed, encasing the entire tool. This layer of frozen salt acts as an insulator, preventing temperature shock to the tool and, thus, reducing distortion. This frozen layer of salt is generally melted in a minute or less, allowing the tool to be heated to the temperature of the bath.

The salt bath heats the tool by conduction, providing uniform heat transfer, which is superior to radiation and convection heat transfer. Molten salt's buoyancy further supports the tools immersed in the bath, significantly reducing tool distortion during the heating cycle. Long, slender tools, such as broaches, are suspended in the molten salt during the heating cycle, in order to maintain straightness.

Bath neutrality

The neutrality of the salt is maintained to prevent harmful reactions between the salt and the surface of the steel. The high-heat salt bath is the critical operation in salt line hardening. This bath is periodically and routinely cleaned using either silica or methyl chloride rectifiers in conjunction with a carbon or graphite rod.

Over a period of time in operation, insoluble and soluble metal oxides build up, which may cause the bath to become decarburizing. Silica will combine with these oxides and form silicates that will settle to the bottom of the bath. These silicates are removed by de-sludging.

Methyl chloride is introduced into the molten salt as a gas bubbles into the bath. It also combines with and scavenges metal oxides and contaminants that are subsequently removed as sludge.

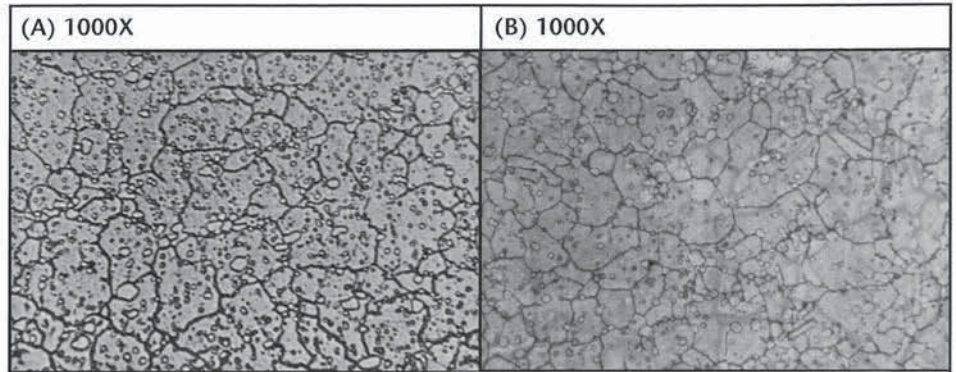The graphite or carbon rod, when immersed into the bath, reduces the

Fig. 2: M2 high speed steel test samples, 4-inch-dia. (A) austenitized at 2200° F (1204° C) for 5 minutes in salt, salt quenched to 1100° F (593° C), then air cooled to room temperature. (B) 2275° F (1246° C) for 1 hour in vacuum, followed by gas quenching to room temperature (light photomicrographs, Nital reagent).

oxides to pure metal which attach to the rod. The rod is removed and cleaned by scraping off the contaminants.

High-heat austenitizing

The austenitizing phase of the hardening cycle begins during the preheating stage of heat treatment. The tools to be heat treated are preheated to around 1550°F (843°C) and held at temperature for between 3 and 5 minutes. Preheating allows the tools to uniformly reach a temperature that is usually above the AC_1 stage (beginning of austenite phase transformation).

Once the tools have uniformly reached the required preheating temperature, they are transferred to the high-heat salt furnace for heating to the critical austenitizing temperature. This temperature varies depending on the grade of high speed to be hardened. The tools are usually held at temperature for 3 to 5 minutes. Tools having large cross-sections, (4 inches or larger) may be held at temperature for several minutes longer.

Following austenitizing in the high-heat bath, the tools are transferred to a salt quenching bath maintained between 1000° and 1100°F (538° and 598°C). The tools are allowed to equalize in temperature within the bath for several minutes, after which they are removed and air cooled to room temperature.

During transfer of the tools between preheat, high heat, and quench furnaces, the tools are protected by a thin film or "cocoon" of frozen salt. Decarburization and oxidation of the tool surfaces during high-temperature exposure to room air is thus virtually eliminated.

High-Speed-steel tools processed in fluidized bed furnaces, on the other hand, experience some surface decarburization during transfer from the high heat austenitizing furnace to a quenching bath. The inert particles within the fluidized bed (usually aluminum oxide) do not adhere to the tool surfaces. Paint-on compounds or materials have been used to eliminate this surface decarburization problem during fluidized bed processing with some success. However, the benefits achieved by paint-on materials are limited by the care and consistency with which they are applied.

Salt bath hardening of high speed tool steels also allows "zone" or selective hardening to be performed. Twist drills are typically austenitized by immersing the drills into the bath only to a depth that covers the drill flutes. The shank end of the twist drills is not heat treated and remains in the annealed, or soft, condition. Selective hardening of twist drills in vacuum furnaces or atmosphere batch furnaces, while not impossible, is not economically feasible.

Zone hardening using a fluidized bed process is possible. However, the rolling motion of the bed, resulting from the protective atmosphere gases flowing through the aluminum oxide medium, makes it very difficult to maintain a uniform line of demarcation between hardened and annealed areas along the length of immersed tools.
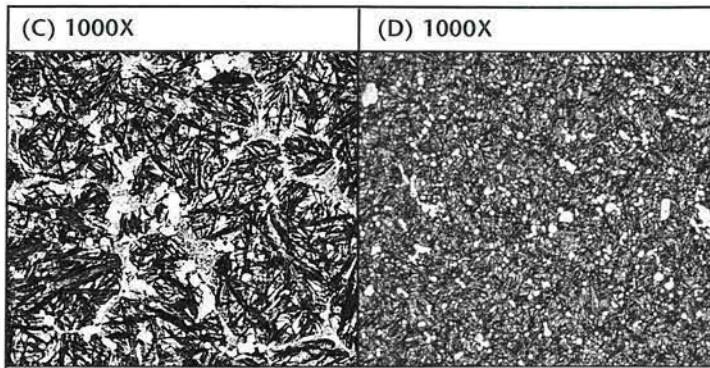
Fig. 3: M4 high speed steel test samples, 4-inch-dia. (C) austenitized at 2250° F (1232° C) for 1 hour in a vacuum furnace, gas quenched to room temperature. (D) austenitized at 2125° F (1163° C) for 5 minutes in salt, salt quenched to 1100° F (593° C), then air cooled to room temperature. (light photomicrographs, Nital reagent).
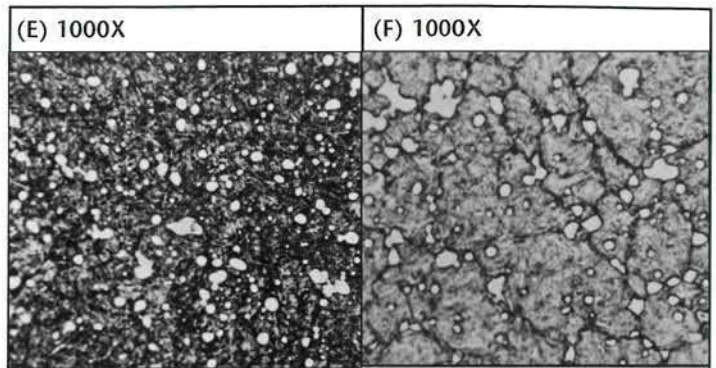
Fig. 4: T15 high speed steel test samples, 2-inch-dia. (E) austenitized at 2225° F (1218° C) for 3 minutes in salt, salt quenched to 1100° F (593° C), then air cooled to room temperature. (F) austenitized at 2275° F (1246° C) for 20 minutes in an atmsphere pusher furnace followed by cooling, in a water-jacketed chamber, to room temperature. (light photomicrographs, Nital reagent).

Salt and microstructure

For the purpose of this article, the heat treated high speed steels to be discussed are M2, M4, and T15. The M series represents molybdenum alloyed steel; the T series represents tungsten alloyed grades.

A typical time, temperature and transformation (TTT) curve for M2 high speed steel is provided in Fig. 1. M2 steel begins austenite phase transformation (AC_1) at 1530°F (832°C). This steel is routinely heat treated at critical austenitizing temperatures ranging from 2200° to 2225°F (1204° to 1218°C) in molten salt.

One of the benefits of conductive heating in salts is the use of lower austenitizing temperatures. High speed tools heat treated in salts also require much shorter holding times at temperature. Shorter holding times at the critical austenitizing temperatures will minimize austenite grain growth and primary alloy carbide agglomeration (Fig. 2). The M2 steel test sample hardened in molten salt, (A), reveals a prior austenite grain size, measured by the intercept method, of 11.8. The M2 sample processed in vacuum, (B), developed an austenite grain size of 9.4. The primary undissolved alloy carbides in the sample processed in salt are smaller, randomly dispersed and of a greater abundance than the sample processed in vacuum.

The undissolved primary alloy carbides in the vacuum heat treated sample are beginning to "fuse" or coalesce along the prior austenite grain boundaries. This condition is not uncommon for high-speed-steel tools that have experienced long holding times during austenitizing near or at the upper limit of their hardening temperature range. Primary carbide agglomeration and austenite grain growth can significantly impair the wear and toughness of a tool, resulting in reduced performance.

Once the tools have been properly austenitized, the cooling or quenching cycle is performed. This is accomplished by cooling the tool quickly to room temperature. Care should be exercised to cool quickly enough to eliminate the formation of pro-eutectoid phases in the microstructure. However, the cooling rate must also be slow enough to minimize tool distortion and avoid cracking.

The microstructure for a test sample of M4 steel hardened in vacuum and gas quenched is shown in Fig. 3 (C). Austenite grain coarsening and primary alloy carbide agglomeration are apparent. Slight incipient melting at the prior austenite grain boundaries has occurred. Pro-eutectoid phases of cementite are also present along the austenite grain boundaries.

The cooling rate for this sample was slow enough to allow the formation of pro-eutectoid grain boundary phases. The actual cooling curve for this sample passed through the upper nose of the TTT curve for M4 high speed steel.

The microstructure of the M4 test sample processed in salt, followed by salt quenching, contained no pro-eutectoid grain boundary phases (Fig. 3 (D)). (It should be noted that this sample was tempered at 1000°F (538°C) to color the martensite for better optical resolution.) The martensite is fine and acicular. Grain

coarsening in the salt bath treated sample was not apparent. The microstructure shown in Fig. 3 (C) representing the vacuum treated sample consists of coarse, equiaxed prior austenite grains, untempered martensite, pro-eutectoid cementite and a random dispersion of primary alloy carbides.

Photomicrographs for test samples of T15 high speed steel processed in a protective atmosphere, high-temperature pusher furnace and in salt are shown in Fig. 4. Both samples were tempered once at 900°F (482°C) to color the martensite to enhance the resolution and contrast between the undissolved carbides and the martensitic matrix.

The microstructure in Fig. 4 (E), representing the salt-hardened sample, consists of fine grained, acicular tempered martensite with a random dispersion of primary alloy carbides. The microstructure for the T15 sample processed in the pusher furnace is coarse, acicular tempered martensite with some retained austenite visually apparent. Primary alloy carbides have experienced some "fusing" and agglomeration. The effects of a higher austenitizing temperature and longer holding time for the T15 sample heat treated in the pusher furnace were apparent. The lower hardening temperature and shorter holding time for the salt-bath treated T15 sample has produced a superior microstructure that will significantly improve the metallurgical performance of this tool in service. **HT**