Daniel H. Herring | 630-834-3017 | heattreatdoctor@industrialheating.com

Frequently Asked Questions about Tool Steel Heat Treating

Tool steel heat treatment is fun! But, like French cooking, everyone seems to want to use a slightly different recipe, and we all know that too many cooks can spoil the soufflé. Let's learn more.

Tool steel heat treatment today is based on a simple premise: 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 correctly.

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 to help us achieve the proper balance of desirable properties: hot (red) hardness, wear resistance, deep hardening and toughness (Table 1).

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. [c]Toughness is achieved via grain refinement.

Frequently Asked Questions

Many questions arise as heat treaters strive for perfection. Here are a few of them:

1. How does the raw material affect the heat treatment?

Chemical non-homogeneity, size and distribution of alloy carbides, grain size, banding, surface decarburization and hardenability response are critical considerations when selecting a raw material. For example, if banding or agglomeration of carbides due to chemical non-homogeneity are present, neither the preheat temperature/time nor the time at austenitizing temperature will resolve this issue, and the service life of the product can be adversely impacted (Fig. 2). It is for this reason that a metallographic examination of the raw material is highly recommended prior to heat treatment.

2. Is one preheat enough?

It is often said that single or double preheating depends on how high the austenitizing temperature is. Preheating is necessary to ensure that the tools are uniformly heated throughout the load, minimize the time at austenitizing temperature and minimize distortion. A common practice is to heat and soak at a preheat temperature just below the lower critical temperature (A_1) of the steel and once again somewhere above this temperature after the crystallographic transformation has taken place to relieve these stresses. In the case of large load sizes, preheats can also serve to ensure that the center and outside of the load reach high-heat temperature at or around the same time.

3. What austenitizing temperature do I need, and how long should I stay there?

Heating to the proper austenitizing temperature (to adjust the chemistry of the austenite) and holding at this temperature just long enough (to control grain size and prevent coarsening with subsequent reduced fracture toughness) is key. This varies with each tool steel composition. It is important to be at temperature long enough to dissolve the various alloy carbides present, which go into solution at different rates, maximize martensite formation (on quenching) and balance the martensite/retained austenite ratio, but not stay so long as to allow excessive grain growth to occur.

4. What quench medium is the best (and why)?

As long as the rate of cooling achieves transformation to martensite and the critical-cooling velocity suppresses the formation of pearlite, any quench medium can be used. Traditionally, the com-

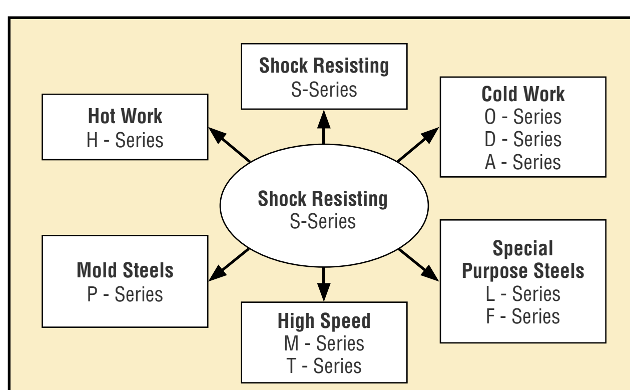

Fig. 1. Tool steel types[1]

position of the steel (alloying elements present) and ruling (thickest) section of the tool have dictated whether water, oil, high-pressure gas, salt or air is needed. Grain size and the degree of carbide solution are important secondary issues.

5. Do all tool steels respond the same way to tempering?

Response to tempering[2] can be divided into a number of characteristic curves, or classes (Fig. 4). For carbon and low-alloy (Class 1) steels, tempering improves certain mechanical properties such as toughness and fracture resistance, except in certain temperature ranges where embrittlement can occur. By contrast, hardness decreases as tempering temperature is raised.

In more highly alloyed tool steels, various precipitation mechanisms produce tempering effects such as increased hardness and improved red hardness (i.e. resistant to coarsening due to temper, alloy, carbide dispersion). Medium-to-high alloy cold-work die steels are examples of Class-2 tool steels in which carbide precipitation and softening are retarded by alloying elements. Steels with low to medium alloy additions fall somewhere between a Class 1 and Class 2.

Highly alloyed high-speed steels are examples of Class-3 tool steels that undergo secondary hardening associated with precipitation of alloy carbides in the tempered martensite matrix. Finally, Class 4 is representative of medium-to-high alloy hot-work die steels in which secondary hardening develops, but overall hardness is lower (than Class 3) due to lower carbon contents in these steels.

6. What does "temper immediately" really mean?

The Heat Treater's Guide[4], among many other sources, tells us that it is important to "temper immediately" after hardening. One of the most common questions asked is, "What does this really mean?" Do I have 5 minutes, 15 minutes, an hour, a shift, a day? And what are the consequences of not tempering immediately?

The risks of not tempering a tool within 5-15 minutes of cooling to "handling" temperature, 150°F (65°C), are cracking and failure to develop optimum properties. Practically speaking, being able to transfer a load into a tempering furnace within 2-4 hours seems to be a realistic shop floor practice, but recognize the risk being taken. Oftentimes, there is a temptation to run multiple hardening loads and temper everything at one time so parts sit for a minimum of a shift, perhaps as long as 24 hours. This type of practice can get us into real trouble.

7. How many tempers are enough?

Double, triple or even quadruple tempers are mandatory on some types of tool steels (e.g., M-series, T-series), while single tempers are allowed in other cases (e.g., A-series). A general rule is that tool steels always benefit from multiple tempers. Tempering allows austenite to transform to coarse carbides and converts retained austenite to untempered martensite on cooling. Either of these conditions increases the sensitivity of a tool to brittle fracture. Multiple tempers improve toughness (by spheroidization of coarse carbides) and the tendency toward premature failure (by tempering the martensite).

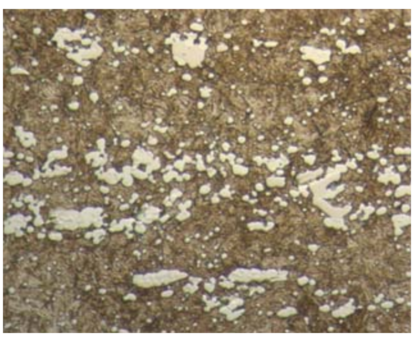

Fig. 2. Large M2 tool steel plate (3/4" thick x 8" wide x 12" long) exhibiting coarse and fine carbides in a martensite matrix – note heavy banding at 1000X. *(Photograph courtesy of Aston Metallurgical Services Company, Inc.)[3]*

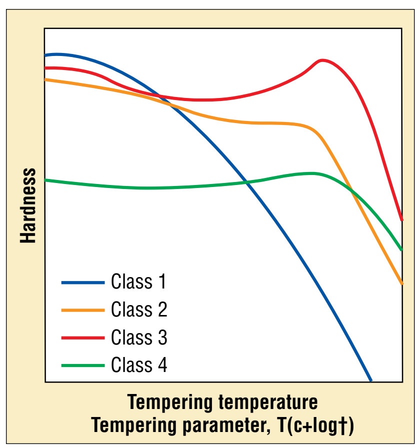

Fig. 3. Tool steel heat-treatment steps[2]

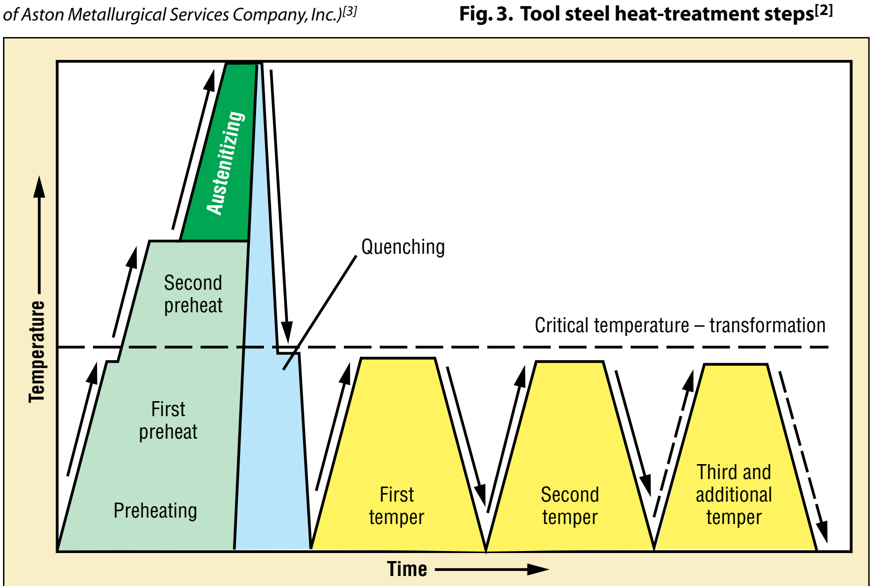

Fig. 4. Characteristic shape of tempering curves by class[2]

8. Why do I have to cool down to 150˚F (65˚C) between tempers?

Balancing the important characteristics of tools (wear, hot hardness, toughness, deep hardening) requires completion of the transformation process at each step, and tempering is no exception. In addition, slow cooling minimizes the formation of internal (residual) stress.

9. What is secondary hardening?

Secondary hardening is a consequence of two reactions: the conversion (transformation) of retained austenite to untempered martensite on cooling from tempering temperature and the precipitation of finely dispersed temper (alloy) carbides throughout the matrix. Tungsten (W_2C), molybdenum (Mo_2C), vanadium (VC) and chromium (CrC) carbides are reported to contribute to this rehardening effect.

10. Can I achieve the same microstructure with vacuum hardening as I can with salt?

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.

References

1. Elgun, Serdar Z., *Tool Steels*, Farmingdale State College (http://info.lu.farmingdale.edu)
2. Roberts, George, George Krauss and Richard Kennedy, *Tool Steels, 5th Edition*, 1998.
3. *Heat Treater's Guide, 2nd Edition*, Chandler, Harry (Ed.), ASM International, 1995.

Online-Only Portion:

11. What are the pros/cons of using salt?

Salt-bath technology has process capability over the full range of tool steel grades. It is capable of achieving temperature uniformity at austenitizing temperature in the range of ± 5°F (± 3°C). When using salt-bath equipment, the critical issues are:

- Control of operator-induced variability
- Properly maintaining bath chemistry and integrity

Salt Bath Advantages

- The heat-transfer rate between the liquid salt and the steel is in the order of 3-4 times faster than between a radiant or convection (gas) environment and steel.
- Work immersed in salt is "automatically preheated" as a "cocoon" of frozen salt is formed on immersion, which melts fairly rapidly.
- Uniformity of heat transfer (conduction) is more efficient for short process cycle times.

Other noteworthy features:

- Component distortion minimized by the buoyancy effect of the salt (e.g., a component that weighs 10 pounds in air weighs only 3.3 pounds in liquid salt)
- Finer (prior) austenitic grain sizes due in large part to shorter times at preheat temperature
- Use of convection or electro-chemical stirring can achieve temperature variations in the salt bath of ±3.5°F (±2°C)

Salt-Bath Disadvantages

- Limited protection of the tool steel parts from oxidation and decarburization either in the bath or during bath transfers
- Numerous environmental issues (air pollution, water pollution, waste disposal, permits, etc.)
- Operating range of the bath must be controlled by adjusting salt composition
- Control systems (programming, computer controls, etc.) lack sophistication
- High operator dependency for accuracy and repeatability
- High heat discharge to the environment
- Labor intensive
- Maintenance intensive – chemistry and equipment (type and complexity)

12. What are the pros/cons of using vacuum for tool steel heat treating?

Vacuum technology has process capability over the full range of tool steel grades. It is capable of achieving temperature uniformity at austenitizing temperature in the range of ±5°F (±3°C). When using vacuum furnaces, the critical issues are proper design and careful control of:

- Part loading and racking
- Ramp rates
- Preheating temperatures and times
- Austenitizing temperature and time at temperature
- Cooling rates of parts

Vacuum-Furnace Advantages

- Variable heating rates – convection heating in lower (<1600°F/870°C) temperature ranges
- Clean parts (extreme surface finishes), particularly if the parts are gas quenched
- Ability to handle physically large part sizes, complex shapes and heavy load weights
- Flexibility for intermediate heating and cooling
- Superior programming capability and cycle flexibility
- Load documentation (time/temperature cycles)
- Environmental, energy consumption and safety

Vacuum-Furnace Disadvantages

- Initial capital equipment cost
- Slight loss of surface hardness (0.5-1.0 HRC) for certain tool steel grades (Note: this can be overcome but special features/options are required)