HANSER

Sample Pages

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Heat Treatment

Master Control Manual

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Grade Heat-Treating Charts

16

Loading the Furnace

Loading the furnace sounds like a rather innocuous endeavor, doesn't it? But it's really a very important part of performing the heat-treating process.

Plus, there are a lot of various ways of protecting products from loss of hardness either in general or in spots. Deformation is a very serious hazard during the heat-treat process and much can be done to ward it off. We will explore some ideas to properly load a furnace, but we couldn't possibly be exhaustive because heat-treating can be performed on nearly any size, shape, or configuration of part and on a multitude of grades of material with several types of quenching needs. The other factor we can't deal with (because the number is so vast) is the multitude of furnace arrangements you might encounter, such as:

- Physical space in the chamber
- Heat-treat baskets that might be available
- Racks designed to reduce distortion
- Space for stackable racks, multiple identical parts, or various sized parts
- Two-, three-, four-, or six-sided heating element positions for a uniform hot zone
- Potential shielded areas to consider that could impede even temperature
- Atmospheric controlled vacuum or gas operation
- Explosive gases, must be controlled for safe operations
- Open atmosphere, box furnace design
- Decarburization protection
- Carburizing needs
- Quenching needs
- Operator safety
- Many, many more

In the end, it all comes down to the most variable factor, and that's the operator's experience and knowledge, mixed with his/her most educated determination that will provide the greatest protection to get the job done safely and correctly.

16.1 Racks

Racks have been used for years to hold parts in various positions to reduce deformation during the heat-treating process. The basic design parameter is to hold the parts with the least contact possible within the rack. The design also centers on reducing the shielding of radiant heat and allowing generous space for uniform heat flow to all the parts in the rack. Then it might need to be stackable to utilize the whole furnace chamber and built usable for quenching the parts in the rack themselves. If the rack deforms, they need to be built of a material or design that allows some degree of straightening. But most of all, racks need to be lightweight, with methods to load, unload, and quench the work.

Racks can be built with 304, 309, 316, 330 stainless steels, inconel, hastelloy, molybdenum, nickel alloys, or even low carbon steels. It often works better to use uncoated welding rod so there isn't any trouble taking alloyed material to higher temperatures. It all rests on the temperatures, the longevity needed at those temperatures, the design, the need for straightening, and so on. There are many firms across the U.S. that offers consultation, engineering design aid, and manufacture of racks to fit specific application needs.

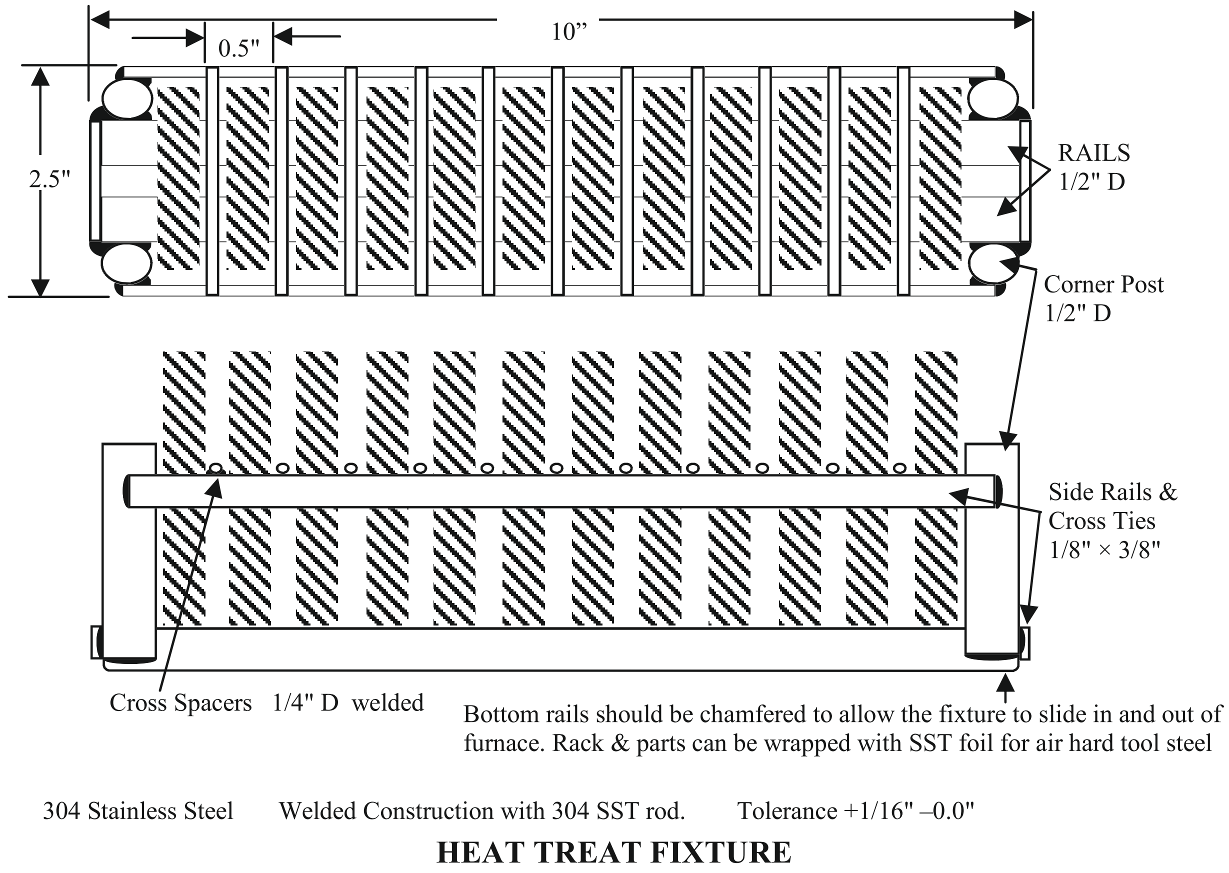


Figure 16.1 Sketch of a rack design used to prevent deformation for a part used in producing leather goods.

16.2 Fixtures

With fixtures, instead of compartmentalized racks or baskets, many fixture designs are open with protruding pins allowing bored out parts to stand on end. A good example is wrist pins that are basically a piece of tube with machined ends and surfaces. Pins like this heat treat best if standing on end. Hanging thin long parts also works great. Use a frame that will hold the weight of the parts hung on wires.

Another fixture for long, small size parts can be a tube, with threaded holes coming in on three sides. Bolts hold these skinny long rods in a straight position. Parts that are a couple feet long can be held straight in this type of fixture. Just stress relieve the pipe before you put the finished part in and if the tube might deform it can be nested in an angle iron to bump the deformation strength up. Quenching this type of fixture and part are more difficult because the oil quench needs to be agitated well. That

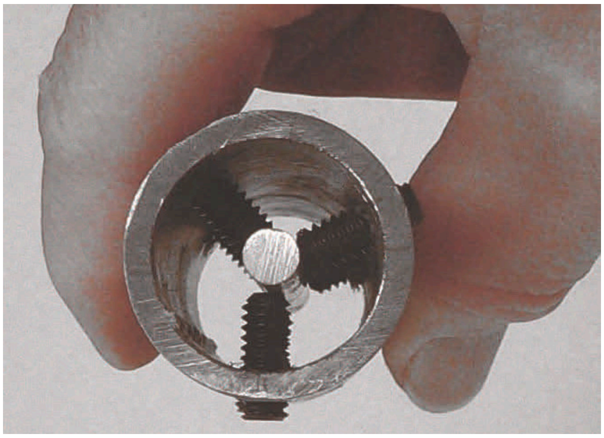


Figure 16.2 This is an example of a simple pipe fixture to hold long slender parts from distorting. The pipe can be as long as the furnace chamber. As many set screws or bolts as needed can be used to clamp the part in a straight and true position. It can even be used for liquid-quenching parts if using a pump type agitation system with a hose configured to keep oil circulated through the pipe and around the part. Air-hardening parts work very well in this fixture. Once the part goes dark, release just one screw in each junction and put the part onto a rack to cool down through the martensite transformation.

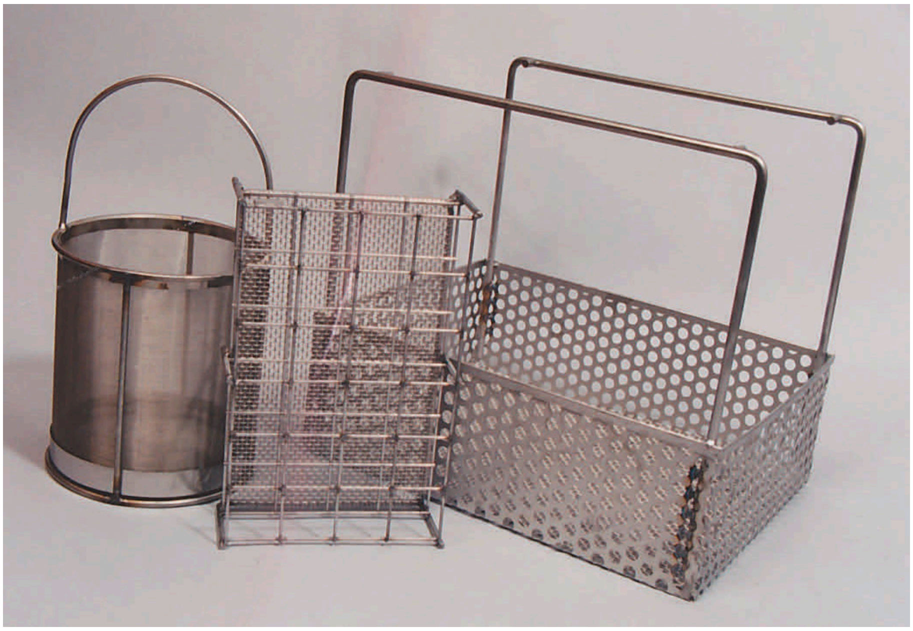


Figure 16.3 Racks, baskets, and fixtures are made to handle parts fast and efficiently during heat-treatment.

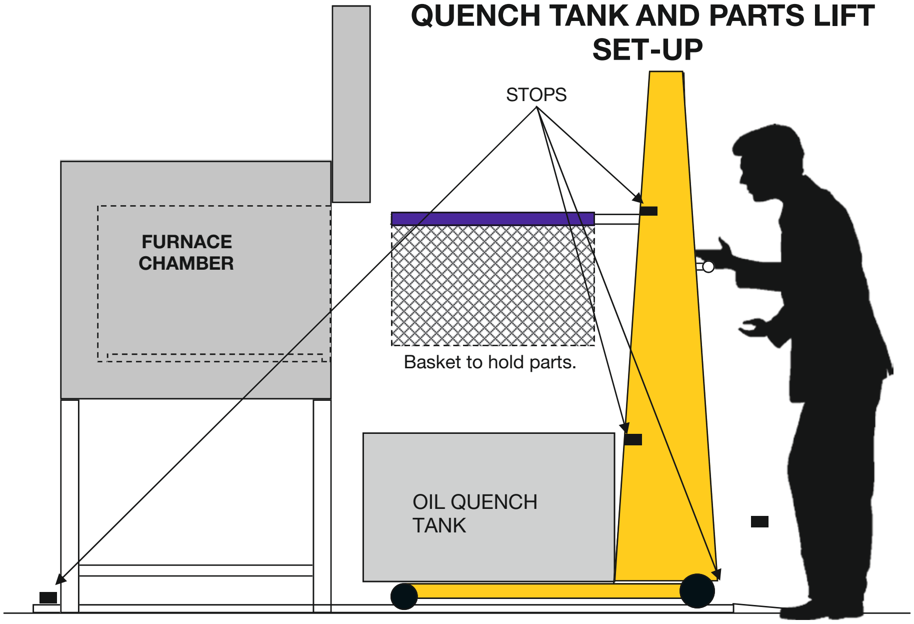


Figure 16.4 Loading, unloading, quench safety, and ease of use come with this simple, crank operated, die lift cart. The wheels are inverted ‘V-groove’ wheels that roll in and out on angle iron flattened to allow easy roll into the furnace. The stops prevent accidentally hitting the interior of the chamber or the electrical heating elements making the operation relatively foolproof. Die lift carts generally run under $1000, but you can easily save that in shorted-out elements, or busted insulation, as well as a sore back.

can be done if an auxiliary pump is used to agitate oil and it is moved temporarily to flush through the tube. A good general rule of thumb for space around parts is 1" of empty area between parts is the best choice, with ½" an absolute minimum, regardless of the quenching method. There isn’t any hard, fast rule for the shielding effect of racks or their weight. It just needs to be as little as feasible. One area that should be watched is the space under the load so that the heat will have unrestricted flow under and up through the load. The same holds true between stacked racks.

In order to load or unload a furnace safely, you may need to build and install a die lift cart mounted on ‘V-groove wheels’ to roll loads in and out of the furnace. The V-groove wheels ride on angle iron bolted to the floor. The die lift cart (see illustration) can have stops permanently fastened to protect the cart or the work load from hitting the furnace, ceramics and allow loads to be rolled safely in and out of the furnace. With a quench tank mounted on the die lift cart, the operation is fast, safe and easy to perform.

17 Heat-Treating Processes Step 1: Preheating

17.1 Why Preheat?

SPECIAL NOTE: In the recipes shown in Chapter 30 we generally show the preheat temperature different than other publications. The reason for this variation is our concern in the grain structure. For decades the preheat temperature has been 1200 °F, and now without reasonable explanation, it has changed. For example: A2 is now listed by others to preheat at 1450 °F to 1500 °F and we recommend 1200 °F. We prefer the 1200 °F temperature because it stays under the Ac_1 of 1421 °F where austenite starts to form. By exposing the parts to a longer, higher heat in the austenite stage, greater amounts of retained austenite may be found after the heat-treating is finished. Most of the firms that suggest the higher temperature preheat also do specify cryogenic processing that will transform the excess austenite into martensite, but in the real world, there are parts that will never be processed through cryogenics. In addition, it seems to this author that it's poor practice to make a bad part that requires a corrective process, when we can make a good part and then make it better!

Performing the preheat step on parts to be heat treated does several things to help do a better heat-treating job. Preheat is normally accomplished by raising the temperature of the part to just under the austenite start temperature (Ac_1). It reduces one of the main areas of distortion in the steel by reducing some of the stresses that occurred in producing the part. If really heavy machining has been worked on a part, or a part has a lot of various cross sections, or sharp inner or outer corners, or any troublesome design where distortion could affect the value of the part, a separate stress-relieving process should be used before heat treating. But if the part is a relatively simple and straight forward part, the preheat will act as a stress reliever to help the part to relax and therefore keep the part in tolerance and under control. Another area that the preheat step helps is in preparing the grain structure of the part to transform into an austenite structure easier when it goes into austenite solution.

POINT: If the preheat step is not used, the stresses in the part are going to be released unevenly, which allow the part to distort to its weakest side.

The dwell time at the preheat step doesn't need to be long and should be kept to a minimum; the general rule of thumb is 5 to 10 minutes maximum. The reason for the short dwell time is that when the part reaches the visible heat zone at 900 °F the conduction of heat starts to increase rapidly. When it does, the heat will conduct from the surface to the center of the part relatively quickly, and normally, also uniformly. However, it is slow enough to gradually release the stresses built up within the body of the part. Even though the part is just below the austenite start temperature (Ac_1), a long dwell at the preheat temperature can affect the austenite grain structure; thus, it's best to keep the step only as long as necessary for the temperature to equalize throughout the part.

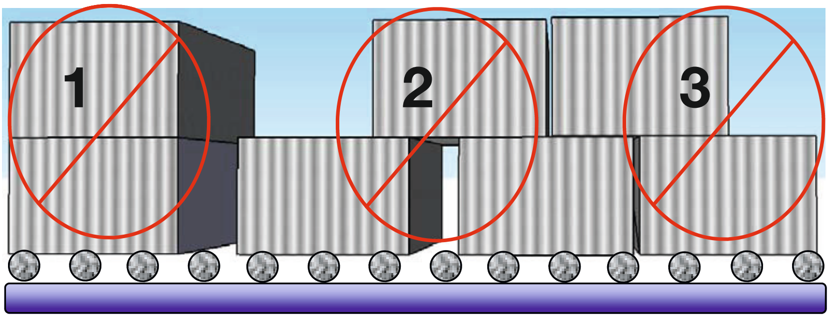


Figure 17.1
1) Stacking directly one on another means that the soak time should be based on the entire thickness of the parts.
2) Uneven stacking creates hot and cold spots in the stack, resulting in uneven hardness readings and potential plastic deformation.
3) No heat circulation between parts is a cause for erratic hardness.

17.2 Equalizing

IMPORTANT FACTS: This is the first of three major areas where distortion can take place, but here it is likely to be the most significant of the three possible occurrences.

Some producing mills are now suggesting a second preheat temperature, called an 'equalizing' temperature step. It does not appear to be a procedure getting any coverage in the latest ASM Handbook, Volume 4, which covers heat-treating. It may benefit the metals to some degree, but it is to some metal-working groups, a very questionable practice. In this author's opinion, the value of the second preheat step raises hard questions concerning the chances of increasing the odds of creating and experiencing more retained austenite, since the temperatures these mills suggest are at or very much beyond the austenite start point. Plus, it adds more heat exposure to the overall soak time, which is known to create transformation reluctant austenite. However, most of the mills do recommend deep cryogenic treatment after the first temper, which would finish the transformation of any retained austenite, **if performed properly**. Thus, perhaps that is the thinking, but the results are that it makes cryogenics a temporary fix. It's like a 'sweeping the dirt under the rug' type of application and all you have done is made a lumpy rug! Cryogenics should be used to make great heat-treated steel better and never used to make a poor, stinky, heat-treat smell nicer!

If deep −320 °F cryogenics is not used, which is most often the case, there is no evidence to date that there is a better grain structure formation in steel using this double preheat equalization step. Does it hurt anything? If there are greater amounts of retained austenite, then yes, that's a loss of tool life danger. I suggest that you use what you feel comfortable with, record your results, and then observe what works best and go with it.

The next step (Chapter 18) is austenization or the solution phase, and there are some steels, particularly high speed steels, that must be raised to the austenizing temperature as rapidly as possible for the best transformation results. If a lot of heat-treating of these materials is preformed regularly, an additional furnace may be required so that the work can be transferred from the preheat phase to the higher temperature furnace to speed up the best transformation process.

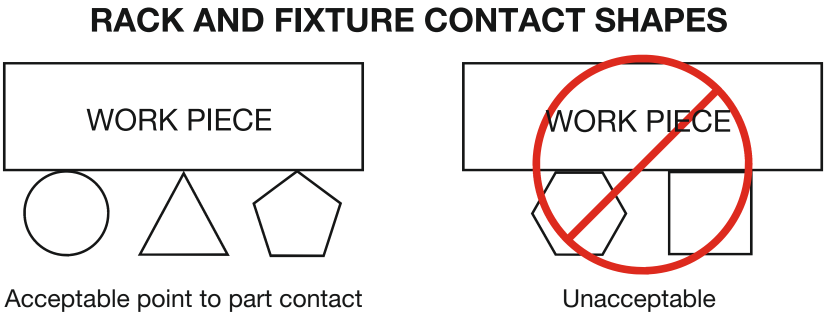


Figure 17.2 Various shapes can safely be used to make racks or fixtures. Why would we look at anything but round shapes? In some cases, a rack made with a flat-sided shape, used for fastening and removing with mechanical fasteners, is advantageous. It can be removed from the rack easily, straightened, or replaced. If your parts are delicate and must be kept flat, you may find a rack made this way gives you a great advantage.

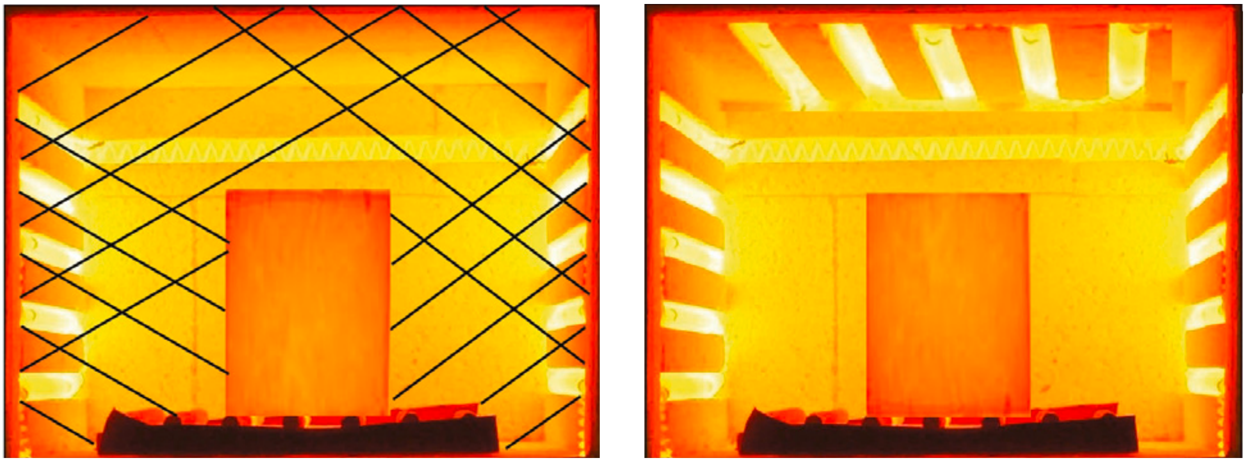


Figure 17.3 Left Chamber: The lines represent the cone of radiant heat transfer. Everything between each element cone gets direct heat transfer. The cone of radiant energy emitted from heating elements mounted on the side walls of a furnace chamber are significant in the performance of a good furnace. The part being processed is getting evenly bombarded with radiant heat from two sides. Notice that the top of the part doesn't get hit with direct radiant flow, and if there are multiple parts, the center pieces will not get the same exposure as the outer pieces. The ends of the part can also get the glancing effect if they are too close to the front and back of the furnace.
It is vital that the furnace purchased can handle the work correctly. Single pieces in the left chamber, like shown, will do fine, but look at the Right Chamber with a simulated heating element mounted on the inside chamber ceiling. This puts heat much more evenly on the part, and if there were a number of parts are being treated, it completely baths them with direct radiant energy.

17.3 Physical Loading the Furnace

When a furnace is being loaded there are things that need to be done correctly. As already pointed out in Section 11.1, parts should always be supported on a rack in the furnace that allows the flow of heat around the parts. Section 11.1 also points out that parts should not be touching for the same reason. You can put multiple parts in stainless steel envelopes, but they too, should have space between parts.

Stacking Methods that don't Work

If you stack parts on top of one another, the austenite soak must be doubled. However, the two faces that are in direct contact with each other may not have the same characteristics that a single layer part would have. Yes, the hardness may be nearly the same as on other faces, but the grain structure will probably not. So anytime you have parts in contact with other parts, there is a potential for upsetting the metallurgical balance.

The rack under the parts, and for that matter, any fixtures and racks, utilize round stock wherever there is fixture to part contact. The reason is straight

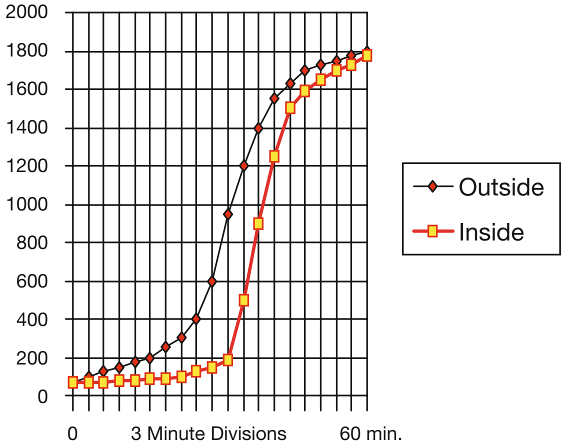


Figure 17.4 When a piece of steel is heat-treated from room temperature to 1800 °F, there is a considerable lag of temperature within the part. This graph represents the lagging response of a block of steel from outside to inside. The block of steel tested was 3 inches cubed, prepared with an 1/8" diameter hole drilled into the center of the block. One thermocouple was attached to the surface of the block; another thermocouple was placed at the center of the block. This illustrates the temperature variance from outside to the inside of the cube.
Look at the difference when the outer surface reaches 1200 °F. The center of the cube is still at 500 °F. During the dwell time at preheat, once the surface reaches 1200 °F, the heat becomes conductive and it heats up the cube relatively quickly. This test and results were run by Advisor In Metals using a Cress Furnace and the total run time was 57 minutes.

forward; point to point contact with parts lessens the chance of temperature shielding. Remember the heating elements are giving off radiant energy that reacts with the surface of the parts being processed. Elements in a furnace are placed so there is even distribution of radiant energy on all surfaces.

Positioning

When you perform heat treatment, try as best as possible to put your parts in dead center of the furnace. Depending of the furnace design, there is often a cooler area in the front, near the door, in most furnaces. A good furnace will see little variation, but leaky door insulation can mean quite a temperature difference. Obviously, the radiant energy is also a huge game changer. If you place your work too far forward or too close to the back wall, those ends will not have the advantage of the radiant energy. This is where it's important to know your furnace and understand where and how much temperature variation there is.

Furnaces are available with two sidewalls with elements, four walls (both sides, back, and inside door) or even six walls. You won't see many six-wall configurations except in very specific special needs. Four walls are considered very good, especially where lots of fixture parts are being processed, and then there might also be an element on the ceiling for complicated and difficult to heat treat work. The point is, the more uniform the temperature dispersion, the better the process control.

18

The Heat-Treating Processes Step 2: Austenization

18.1 Austenization or Solution Heat-Treating

Not many years ago, before heat-treating furnaces were commonplace, heat-treating was often accomplished in open forges. It may have looked peculiar but the craftsman would take a long steel rod with a magnet hanging from the end of the rod by a wire. He would lower the magnet unto the red hot steel. Once the magnet was no longer attracted to the steel, the craftsman knew the steel had reached its upper critical temperature. He would look at his pocket watch and start the timing of the soak. He understood that when the steel went in-solution, even though the part still held its physical shape, the carbon matrix and the alloy content were dissolving into a full solution, almost as a liquid. Thus, he knew because there was no longer any magnetism present. As the chemistry in steel became more complex, heat-treating furnaces and controllers were improved to give us more accurate control. In today's world we're fortunate to have very accurate heat-treating furnaces with good temperature controllers and pyrometers to track and control the temperature of the steel within a few degrees.

DEFINITION: In-solution austenization is sometimes referred to as being in-solution. That occurs when the Ac_3 critical temperature is achieved. What happens is the internal crystal structure is basically out of phase as it comes out of its ferrite phase and into austenite. The crystal size grows tremendously, it loses all magnetism, and if it lingers too long, will be resistant to further transformation without another process.

Good austenite grain structure formation is an important and critical step in our pursuit of good, tough, hard-wearing steel. Austenite is a rough, extremely coarse grained structure and is produced by soaking the metal at its specific critical temperature (austenizing temperature) for the proper length of time. The temperature and time is derived based on the chemistry of the metal and established as the standard for each grade of metal. If you have access to the TTT Diagrams for each of the metals you are going to heat-treat, you can view all the critical temperature phases. However, we have laid out a simple diagram that we call a recipe to use to follow for the critical information you will need. The processing timing is based on a 1" thick piece of steel for each of the various grades. It is set up using the proven and recommended method to obtain the correct heat-treating from information that is published by AISI, SAE, and ASM. It is also based on the optimum quality of the grade for hardness, wear, and working toughness. Most domestic producers also make the information available in writing, or on their website; but please ascertain that you check it for accuracy against the approved standards. If you are using imported materials, some of the producers are very good, while some are very questionable.

IMPORTANT FACTS: The greater the chemistry contained in the steel, the greater the requirement for an accurate temperature during the entire time of the soak. The time is also a great concern as is the quench and speed.

During this austenizing soak the carbide elements will dissolve into the iron/carbon matrix in the steel and grain structure transformations occurs. The transformation is also a change in crystal structure (from a body-centered cubic crystal structure) where a predominate ferrite (iron-based) structure transforms into austenite (a face-centered cubic crystal structure).

There are several areas of importance during this austenizing transformation.

In days gone by, simple chemistry alloy steels were heat treated every day with a torch, or in an open forge. Today we have higher-quality, complex chemistry, air-hardening steels that can no longer be heat treated in that manner. Some of the high-grade steels used today have a soak time of a few minutes, and oversoaking or undersoaking them, by even a half minute, can reduce their life and value as a tool.

The first ‘**T**’ in the TTT diagram is temperature. So how critical is the temperature? In some cases not much at all, in other cases it is extremely critical. Lower alloy steels and lower chemistry tool steels often have a wide temperature arena to work in. O1 tool steel, for instance, can easily be forged or flame hardened, and the resulting hardness will look just fine. Even the grain structure may be quite decent. But, if you add the second ‘**T**’ in the TTT diagram, which is time, results can change very quickly in the grain structure. Then look at higher chemistry content, tool, and high speed steels, and things can go sour fast.

D2 tool steel requires an 1850 °F austenization soak. If D2 is soaked at 1888 °F, there will be evidence of excess retained austenite formation. It will overcook the steel and that is further magnified into change if the soak time strays from its course. If that piece of D2 only reaches 1825 °F, it will never fully transform the mass into austenite and will never attain the correct grain structure.

Let’s examine what can affect steel in this austenizing step:

1. Oversoaking (overheating and heating too long) can affect the amount of austenite that will transform readily into martensite during the quench cycle. It also affects the austenite grain size. The excess austenite that refuses to transform to martensite in the quench is referred to as retained austenite because it resists the transformation phase. The amount of retained austenite in the steel that refuses to transform is critical to its wear resistance ability and its toughness. In some cases, heating too long is strongly influenced by the length of time the metal sat in the preheat step. Next is the furnace time of getting from preheat to austenization temperature. Many controllers allow the operator to set the ramp-up speed, but if the furnace and power available are not up to required standards, then other steps must be taken to correct the problem.

   Something often overlooked, even though it is often spoken of, is the **T**ime.

   Some high speed steels require a soak time at 2350 °F for 5 minutes per inch. Thus, if you have a drill bit you are heat-treating that’s a $^1/_4$" diameter, your soak time is probably right around 1 minute; 60 seconds for complete austenization. Not 75 seconds, or 45 seconds, but 60 seconds and then into the oil quench in 3–5 seconds. Does it make a difference? You bet it does. Purchase an inexpensive drill bit and another more expensive one that was produced for an additional 30 % more money and you will experience the difference. Remember the old adage; you get what you pay for. In most every trial, the inexpensive bit will not function anywhere near the premium cost bit results, and they may be the same exact high speed steel.

2. If excessive amounts of retained austenite exist after the quench, one of the indicators that something is wrong is if there is a partial loss of magnetism. Often the machinist will need to grind a piece of heat-treated steel, and he or she will observe that the steel is not as strongly attracted to the magnetic pull of the surface grinder. That is a strong indicator that retained austenite, which is out of phase was not transformed, and is causing the problem.

3. Observation may be made when excess-retained austenite exists in a part. The part will have physically shrunk in size. As a general rule, all tool steels and most alloy steels will grow in physical size because of the transformation of grain structure from the heat-treating process and the volume change of the crystal structure. Sounds wrong that the large, irregular grains of austenite are transformed into fine-grained martensite, yet the steel grows in size. But it’s true and is because the coarse austenite grains transforming become very prolific in quantity and the immense amount of fine grains cause the size to exceed the physical

volume of the austenite. A shrunken, nonmagnetic part can be salvaged and we'll deal with that later in the Chapter 21 on cryogenics.

During the austenizing phase, distortion will rear its head for the second time. Because the steel is going to reach a temperature where it is "in solution," we have to be concerned with plastic deformation. Plastic deformation is a fancy term used to describe a metal part that has sagged from a lack of proper support during this phase. A piece of metal must be properly supported during all steps of the heat-treating operation. Protecting the steel from sagging may require some special fixtures, hanging the parts, and putting proper support under them. If a part is put on the hearth plate, there will be a nonuniform temperature from the insulating effects of the hearth plate versus the ambient temperature.

The point is that there are lots of ways to support and reduce distortion with some careful planning and a few tools to get the job done.

Thin, flat parts can be press quenched, which we will cover in detail in the next chapter. Shaped parts can also be press quenched, which we'll also discuss.

M42 High Speed Steel

M42 is an oil-hardening high speed steel ideally designed for tough duty cutting tools. It has very good wear and heat resistance from a rich cobalt base, which makes it slow to lose hardness from heat build-up.

Typical Applications

- Broaches
- Drills
- End mills
- Form tools
- Gear hobs
- Lathe tools
- Milling cutting tools
- Reamers

Thermal Treatments

- **Annealing, full:** 1600 °F, hold 2 hr., cool 50 °F per hour to 1200 °F; finish by cooling in air
- **Annealing, in process:** 1600 °F, hold 2 hr., cool 50 °F/hr. to 1400 °F, hold 4 to 6 hours, air cool to room temperature
- **Annealing, spheroidize:** 1600 °F, hold 2 hr., cool 25 °F per hour to 900 °F; finish by cooling in closed furnace.
- **Forging:** 2000–2050 °F (do not forge below 1700 °F)
- **Stress relieving (annealed material):** 1100–1300 °F, air cool
- **Normalize:** do not normalize
- **Preheat:** First stage: 25–40 °F/min. to 1200 °F; Second stage: 50–100 °F/min. to 1500 °F; dwell twice the austenizing time at both stages.
- **Austenize:** 2150 to 2200 °F, soak 2–5 minutes for first 1", add 2–4 min. for each additional inch. Vacuum or salt-bath austenization is preferred to reduce decarburization. Protective chemicals are also available. Soak time is critical; hold long enough to heat through.
- **Quench:** Quench in oil at a fixed 1000° to 1100 °F temperature, followed by still room air quenching to under 150 °F. Air quenching can be used, but not recommended, expect loss of hardness of 2 to 7 points.
- **Tempering:** All high speed steels must be double or triple tempered (recommended) to get the best life and grain structure from the steel. Cryogenic treatment is used to complete the transformation, improving wear and toughness.
- **Ac$_1$:** 1560 °F, austenite, start critical temperature
- **Heating rate:** (preheat to austenization) as rapidly as possible.

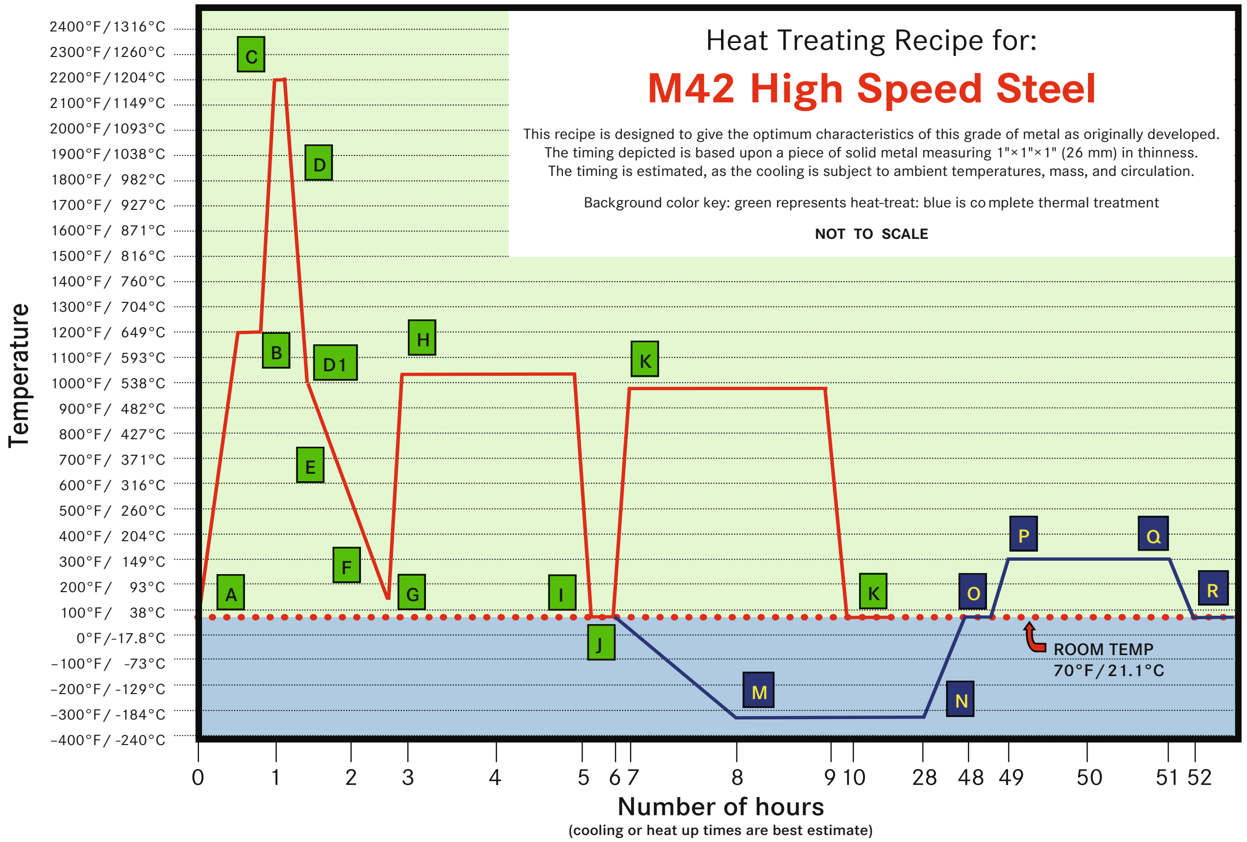
Chemistry—Chemical Content in % of Weight

Carbon	C	1.05–1.15
Chromium	Cr	3.50–4.25
Cobalt	Co	7.75–8.75
Manganese	Mn	0.15–0.40
Molybdenum	Mo	9.00–10.00
Phosphorus	P	0.030 max.
Sulfur	S	0.030 max.
Silicon	Si	0.15–0.50
Vanadium	V	0.95–1.35
Tungsten	W	1.15–1.85

Tempering Hardness Scale Reference

°F	°C	Rc
2175 °F quenched in:		**Oil**
As quenched		64–66
1000	(540)	66–69
1025	(550)	67–68
1050	(566)	64–66
1100	(593)	60–62
1150	(631)	56–58
1200	(649)	48–50

Optimum work hardness: 67–68 Rc
Machinability: 35 on 1 % carbon tool steel scale
V-notch charpy toughness: 10 ft./lb. (14 Joule)
Depth of hardness: deep
Toughness: low
Distortion: low (air cool/salt-bath quench); medium (oil quench)



Heat Treating Recipe for:

M42 High Speed Steel

This recipe is designed to give the optimum characteristics of this grade of metal as originally developed. The timing depicted is based upon a piece of solid metal measuring 1"×1"×1" (26 mm) in thinness. The timing is estimated, as the cooling is subject to ambient temperatures, mass, and circulation.

Background color key: green represents heat-treat: blue is complete thermal treatment

NOT TO SCALE

Step by Step Recipe Sequence

A	Preferable to begin at room temperature
B	Preheat
C	Austenization or soak (austenite formation)
D	Quench in oil
D1	Transfer from oil to air
E	Martensite start
F	Martensite stops forming
G	Temper heatup begins (between 100–150 °F) into a preheated furnace
H	Temper time starts
I	Temper time complete
J	Rest at room temperature
K	Second temper starts
L	Third temper recommended
M	Cryogenic treatment begins
N	Twenty hour soak at –320 °F
O	18–20 hour slow warming complete
P	Final tempering starts
Q	Tempering ends
R	Room temperature
S	Part complete: thermal treatment complete

M42 is a very good wear resistance HSS. It is adapted well for a broad range of general cutting tool applications. It can achieve a 68 Rc with reasonably good grain structure if austenized at 2175 °F. Grain structure will be reduced, which increases toughness, by lowering the austenizing temperature.

M42 HEAT-TREATING PROCESS

Heat M42 to the preheat temperature in two stages. In the first stage, slowly raise the temperature 25–40 °F/min. to 1200 °F; in the second stage, raise the temperature 50–100 °F/min. to 1500 °F. Dwell twice the austenizing time at each stage. Heat to the austenizing temperature by transferring to a preheated furnace or as heat as rapidly as possible in the original furnace. Soaking time is 5–10 minutes for first inch and 2–4 minutes for each additional inch. Thinner sections must be adjusted downward and tested on salvage material. Quench in preheated 1000–1100 °F oil, and then move to an air-cooling rack for even heat dissipation. Recommended is a double or triple temper immediately. Cryogenics processing will greatly improve the characteristics of the metal.

O1 Tool Steel

O1 is an oil-hardening, low alloy tool steel, which is suitable for general purpose applications.

Typical Applications

- Gauges
- General purpose applications
- Fixtures
- Jigs
- Short run dies

Thermal Treatments

- **Annealing, full:** 1450 °F, hold 2 hr., cool 50 °F per hour to 1000 °F; finish by cooling in air
- **Annealing, spheroidize:** 1450 °F, hold 2 hr., cool 25 °F per hour to 900 °F; finish by cooling in closed furnace
- **Forging:** 1825–1925 °F (do not forge below 1500 °F)
- **Stress relieving (annealed material):** 1100–1300 °F, air cool
- **Normalize:** heat to 1600 °F and cool in air
- **Preheat:** 1200 °F (refer to Chapter 17)
- **Austenize:** 1475 °F, soak 5–10 minutes per inch after reaching temperature. Quenching from high heat can cause cracking.
- **Quench:** well agitated oil
- **Ac_1:** 1330 °F, austenite, start critical temperature
- **Heating rate:** (preheat to austenization) 25–30 °F/min.

Tempering Hardness Scale Reference

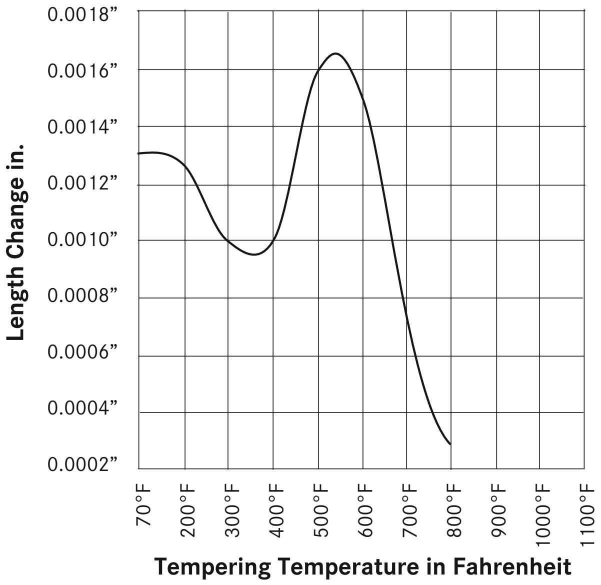
°F	°C	Rc
As quenched		63–65
300	(150)	63–65
400	(205)	61–63
500	(260)	58–60
600	(315)	55–57
700	(379)	51–53
800	(425)	48–50
900	(480)	43–45
1000	(540)	39–41

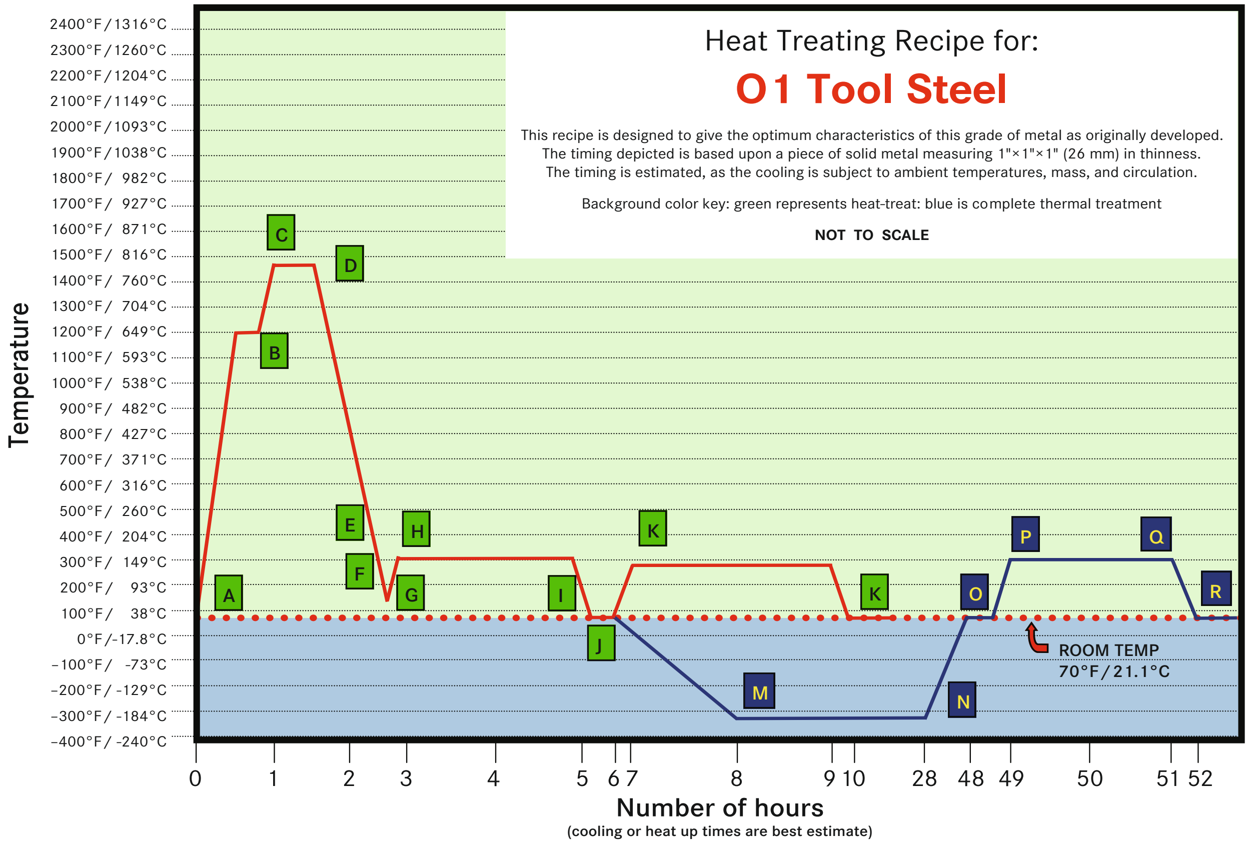
Optimum work hardness: 63–65 Rc
Machinability: 70 on 1 % carbon tool steel scale
V-notch charpy toughness: 33 ft./lb. (45 Joule)
Depth of hardness: medium
Toughness: medium
Distortion: very low

Chemistry—Chemical Content in % of Weight

Carbon	C	0.85–1.00
Chromium	Cr	0.40–0.60
Manganese	Mn	1.00–1.40
Phosphorus	P	0.030 max.
Sulfur	S	0.030 max.
Silicon	Si	0.50 max.
Tungsten	W	0.40–0.60

Tempering Size Change





Heat Treating Recipe for:

O1 Tool Steel

This recipe is designed to give the optimum characteristics of this grade of metal as originally developed. The timing depicted is based upon a piece of solid metal measuring 1"×1"×1" (26 mm) in thinness. The timing is estimated, as the cooling is subject to ambient temperatures, mass, and circulation.

Background color key: green represents heat-treat: blue is complete thermal treatment

NOT TO SCALE

Step by Step Recipe Sequence

A	Preferable to begin at room temperature
B	Preheat
C	Austenization or soak (austenite formation)
D	Quench
E	Martensite start
F	Martensite stops forming
G	Temper heatup begins (between 100–150 °F) into a preheated furnace
H	Temper time starts
I	Temper time complete
J	Rest at room temperature
K	Option: second temper starts
L	Option: part complete or third temper
M	Cryogenic treatment begins
N	Twenty hour soak at –320 °F
O	18–20 hour slow warming complete
P	Final tempering starts
Q	Tempering ends
R	Room temperature
S	Part complete: thermal treatment complete

O1 exhibits good toughness, and is typically used as a general purpose steel. It needs to be fully oil quenched below 150 °F, and then tempered immediately. O1 is often used for quick repairs and although it does not reach its full potential; small parts can be hardened using flame from a torch or forge.

O1 Heat-Treating Process

Heat O1 to the preheat temperature in the range of 25–40 °F per minute. Once it has dwelled at preheat for 5–10 minutes max., heat it to its austenizing temperature at 25–30 °F per minute. Soak time is 5–10 min./in. at austenizing temperature to assure the metal is heated through to its core. Quenching in well agitated oil to below 100–150 °F may cause distortion and, in some cases, cracking at weak areas in harsh designs can result. Temper immediately.