TYPES OF HEAT TREATMENT

There are four basic types of heat treatment in use today: annealing, normalizing, hardening, and tempering.

The following sections describe the techniques used in each process and show how they relate to Steelworkers.

Annealing

The objective of annealing is the opposite of hardening. You anneal metals to relieve internal stresses, soften them, make them more ductile, and refine their grain structures.

The process includes all three stages of heat treatment already covered (heat the metal to a specific temperature, hold it at a temperature for a set length of time, cool it to room temperature), but the cooling method will depend on the metal and the properties desired.

You may need to furnace-cool some metals or bury others in ashes, lime, or other insulating materials to achieve the appropriate characteristics.

Under certain job conditions, or without proper preheating, welding can produce areas of molten metal adjacent to other areas at room temperature. Given specific conditions, welding can actually weaken a metal, for as a weld cools, internal stresses occur along with hard spots and brittleness.

Annealing is just one method for correcting these problems and relieving the stresses.

Ferrous Metal

To anneal ferrous metals and produce the maximum softness (ductility) in steel, you slowly heat the metal to its proper temperature, soak it, and then let it cool very slowly by burying the hot part in an insulating material, or by shutting off the furnace and allowing the furnace and the part to cool slowly together.

Soaking periods depend on both the type and the mass of the metal involved.

Nonferrous Metal

Annealing nonferrous metals may or may not follow the same process as ferrous metals. For example, copper becomes hard and brittle when mechanically worked, but it can be made soft again by annealing at a temperature between 700°F and 900°F.

However, copper may be cooled rapidly (normally associated with hardening) or slowly since the cooling rate has no effect on the heat treatment.

One drawback experienced in annealing copper is the phenomenon called "***hot shortness***." Copper loses its tensile strength at about 900°F and if not properly supported, it could fracture.

Aluminum also has the characteristic of "hot shortness," and reacts similarly to copper when heat treating. With the large number of aluminum alloys in use, you must provide special care while heat treating aluminum to produce the best properties for each alloy.

Normalizing

The intent of normalizing is to remove internal stresses that may have been induced by heat treating, welding, casting, forging, forming, or machining. Uncontrolled stress leads to metal failure; therefore, you should normalize steel before hardening it to ensure maximum results.

Normalizing applies to ferrous metals only, and it differs from annealing; the metal is heated to a higher temperature, but then it is removed from the furnace for air cooling.

Low-carbon steels do not usually require normalizing, but if they are normalized, no harmful effects result.

Castings are usually annealed rather than normalized; however, some castings require the normalizing heat treatment.

Normalized steel has a higher strength than annealed steel; it has a relatively high strength and ductility, much tougher than in any other structural condition. Metal parts that will be subjected to impact and those requiring maximum toughness with resistance to external stress are usually normalized.

In normalizing, since the metal is air cooled, the mass of a metal has a significant influence on the cooling rate and hence on the resulting piece’s hardness. With normalizing, thin pieces cool faster in the air and are harder than thick ones, whereas with annealing and its associated furnace cooling, the hardness of the thin and thick pieces is about the same.

Hardening

The purpose of hardening is not only to harden steel as the name implies, but also to increase its strength. However, there is a trade off; while a hardening heat treatment does increase the hardness and strength of the steel, it also makes it less ductile, and brittleness increases as hardness increases. To remove some of the brittleness, you should temper the steel after hardening.

Many nonferrous metals can also be hardened and their strength increased by controlled heating and rapid cooling, but for nonferrous metals, the same process is called heat treatment rather than hardening.

For most steels, hardening consists of employing the typical first two stages of heat treatment (slowly heat to temperature and soak to time and temperature), but the third stage is dissimilar. With hardening, you rapidly cool the metal by plunging it into oil, water, or brine. (Note: Most steels require rapid cooling [quenching] for hardening, but a few can be air cooled with the same results.) The cooling rate required producing hardness decreases when alloys are added to steel; this is advantageous since a slower cooling rate also lessens the danger of cracking and warping.

The follow provides hardening characteristics for a few irons and low-carbon steel.

- Pure iron, wrought iron, and extremely low-carbon steels - very little hardening properties; difficult to harden by heat treatment
- Cast iron- limited capabilities for hardening
  - Cooled rapidly, it forms white iron; hard and brittle
  - Cooled slowly, it forms gray iron; soft but brittle under impact
- Plain carbon steel - maximum hardness depends almost entirely on carbon content
  - Hardening ability increases as carbon content increases to a maximum of 0.80 % carbon
  - Increased carbon content beyond 0.80 % increases wear resistance but not hardness
  - Increased wear resistance is due to the formation of hard ***cementite***

Adding an alloy to steel to increase its hardness also increases the carbon's effectiveness to harden and strengthen. Consequently, the carbon content required to produce maximum hardness is lower in alloyed steels than it is for plain carbon steels with the result that alloy steels are usually superior to carbon steels. When you harden carbon steel, you must cool the steel to below 1000°F in less than one second. When you add alloys to steel and increase the carbon's effectiveness, you also increase the time limit (more than one second to drop below 1000°F). Therefore, you can use a slower quenching medium to produce the desired hardness.

You usually quench carbon steels in brine or water, and alloy steels in oil. Quenching steel produces extremely high internal stresses. To relieve them, you can temper the steel just before it becomes cold by removing the part from the quenching bath at a temperature of about 200°F and allowing it to air cool. The temperature range from 200°F down to room temperature is called the "cracking range," and you do not want the steel to pass through it in the quenching medium. Further information on tempering follows in another section.

The following presents different commercially used methods of hardening. In the Seabees, a rapid surface hardening compound called

SURFACE-HARDENING (CASE)

Tempering

After hardening by either case or flame, steel is often harder than needed and too brittle for most practical uses, containing severe internal stresses that were set during the rapid cooling of the process. Following hardening, you need to temper the steel to relieve the internal stresses and reduce brittleness.

Tempering consists of:

- Heating the steel to a specific temperature (below its hardening temperature)
- Holding it at that temperature for the required length of time
- Cooling it, usually in still air.

If this sounds familiar, you are correct; it is the same three-stage process as in heat treatment. The difference is in the temperatures used for tempering, which will affect the resultant strength, hardness, and ductility.

You temper a steel part to reduce the brittleness caused by hardening, and develop specific physical properties; it always follows, never precedes hardening. Tempering reduces brittleness, but it also softens the steel, which you cannot avoid. However, the amount of hardness lost is controllable and dependent on the temperature you subject the steel to during the tempering process. That is true of all steels except ***high-speed steel***; tempering increases the hardness of high-speed steel.

The annealing, normalizing, and hardening processes all include steps at temperatures *above the metal's upper critical point*. Tempering is always conducted at temperatures *below the metal's low-critical point*.

When you reheat hardened steel, you begin tempering it at 212°F, and continue as the temperature increases toward the low-critical point. You can predetermine the resulting hardness and strength if you preselect the finite tempering temperature. For planning your tempering time, the minimum should be one hour, or if the part is more than one inch thick, increase the time by one additional hour for each additional inch of thickness.

With most steels, the rate of cooling from the tempering temperature has no effect on the steel. After a steel part is removed from the tempering furnace, it is usually cooled in still air, just like in the normalizing process.

However, there are a few anomalies; a few types of steel must be quenched from the tempering temperature to *prevent* brittleness. Known as blue brittle steels, they can become brittle if heated in certain temperature ranges and cooled slowly. Some nickel chromium steels are subject to this temper brittleness.

Providing there is any hardness to temper, you can temper steel that has been normalized, but you cannot temper annealed steel. What would be the purpose? If you will remember, the purpose of both normalizing (air cooled), and annealing (controlled cooling environment) was to relieve stress, the same as tempering.

Tempering relieves internal stresses from quenching, reduces hardness and brittleness, and may actually increase the tensile strength of hardened steel as it is tempered up to a temperature of about 450°F; above 450°F, tensile strength starts to decrease. Typically, tempering increases softness, ductility, malleability, and impact resistance, but again, high-speed steel is an exception to the rule. High-speed steel *increases* in hardness on tempering, provided you temper it at a high temperature (about 1150°F). Remember, to temper a part properly, you need to remove it from the quenching bath before it is completely cold and proceed with the tempering process. Failure to temper correctly can result in a quick failure of the hardened part.

Permanent steel magnets are made of hardened and tempered special alloys whose most important properties are stability and hardness. They are tempered at the minimum tempering temperature (212°F) by placing them in boiling water for (2 to 4 hours), and because of this low-tempering temperature, are very hard. Do not temper case-hardened parts at too high a temperature or they will lose some of their hardness. A temperature range of 212°F - 400°F is high enough to relieve quenching stresses for case-hardened parts. The design of the part can help determine the appropriate tempering temperature, and some metals do not require tempering at all.