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

The Annealing Process Revealed Part One: Basic Principles

One of the most fundamental processes that must be performed on steel is annealing. While a relatively simple heat treatment to perform, there are a number of factors that must be carefully considered and controlled. In this article, we will discuss the basic principles behind the annealing process. Let's learn more.

Purpose of Annealing

Annealing serves many purposes. For example, steel wire is annealed to improve its ductility and to relieve internal stress created by drawing, cold forming or uneven cooling after hot rolling. Annealing will also help to refine the grain size.

Effect of Annealing on Microstructure

On heating, low-carbon (<0.030%) steels form ultra-fine particles of austenite as they reach, then exceed, the lower critical temperature (Ac_1). As the temperature rises, excess ferrite continues to dissolve, finally disappearing at the upper critical point (Ac_3). As the temperature continues to climb, the grain size increases.

The properties obtained as a result of annealing depend on the amount of carbon present, the coarseness of the ferrite and pearlite, and their relative distribution throughout the matrix. These factors are influenced by:

a. The size of the austenite grains; the smaller their size, the better the distribution of the ferrite and pearlite
b. The rate of cooling through the critical range
c. Time at temperature, which is necessary for carbon to uniformly distribute in austenite

On slow cooling through the critical range, ferrite formation begins at the austenite grain boundaries. Large, rounded ferrite particles are formed, evenly distributed among the (relatively) coarse pearlite. With a higher rate of cooling, a network structure of small ferrite grains is produced with fine pearlite distributed in the center of these grains.

Since annealing cycles are performed in and around the critical temperatures, it is important to remember that, as far as transformation is concerned, the cooling practice is critical. The rate with which the steel passes through this range will determine the microstructure, hardness and other properties of the transformed product. A very slow rate of cooling will result in the softer microstructure, which is spheroidic. A faster rate results in lamellar pearlite of varying degrees of coarseness and hardness. If the rate of cooling is too rapid, formation of the soft products of transformation will be suppressed and the harder constituents – bainite and martensite – formed. These latter microstructures are undesirable in the annealed structure.

Types of Annealing

Full Anneal

Full annealing involves heating to a temperature at least 50°F

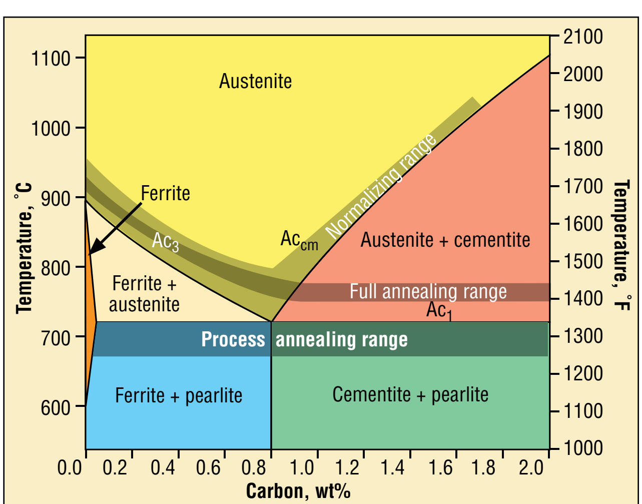

Fig. 1. Full annealing range

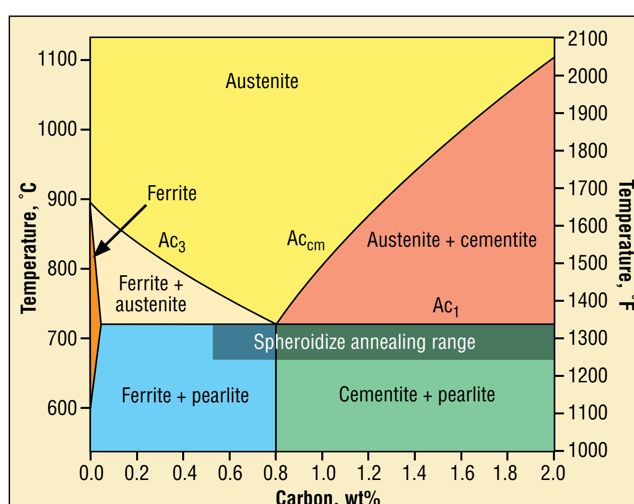

Fig. 2. Spheroidize annealing range

(28°C) above Ac_3. At this temperature, the steel is completely austenitic and the method and rate of cooling the austenite are very important for proper microstructure and other related properties. In full annealing, it is essential to know the critical temperatures on heating and cooling, the Isothermal Transformation (IT) diagram and the Continuous Cooling Transformation (CCT) diagram

The rate at which the steel cools from the annealing temperature to the upper cooling critical temperature is unimportant as long as the proper cooling rate is observed passing through the critical cooling range. Because of the difficulty of maintaining uniform temperature in a typical commercial annealing load, common practice is to cool from the annealing temperature, to and through the transformation range at a single uniform rate. Similarly, the rate of cooling after transformation is unimportant because it has no effect on the microstructure and hardness. However, it is common practice to maintain the uniform rate on cooling well past the lower cooling critical to ensure a proper anneal in case the critical temperatures were incorrect.

IT diagrams predict the microstructure after transformation, the temperature at which this transformation will take place and the time required so their use allows closer control of the end product. It is only necessary to cool the steel to the temperature where the desired microstructure will form, hold until transformation is complete and then cool in any convenient manner. The only precaution required is to cool the steel to the desired transformation temperature at a rate that will avoid underheating. CCT diagrams may also be useful to determine the rate of continuous cool that will result in a given product.

Spheroidize Anneal

Spheroidize annealing is beneficial when subsequent machining and/or hardening is required (since the microstructure consists of rounded cementite particles in a ferrite matrix). The spheroidized condition is the true equilibrium state of the steel and is its softest condition. The spheroidized microstructure also possesses good cold-forming characteristics. Generally, the larger the spheroids and the more distance between them, the greater the ability of the steel to be cold formed.

The simplest method of spheroidizing is to employ a subcritical anneal (see below). A more common commercial method consists of heating to a temperature of 50°F (13-26°C) below Ac_1, hold at this temperature, then increase the temperature setpoint between Ac_1 and Ac_3 and hold again. Following the second soak period, the temperature is decreased slowly. Another common method is to heat to a temperature of 50°F (5-26°C) below the Ac_3, holding at one temperature and then increase it to slightly above Ac_3 followed by slow (controlled) cooling.

It is essential in any of these practices that nuclei be present to ensure formation of spheroids. The nuclei may be undissolved cementite, carbon concentration gradients (inhomogeneous austenite) or, in some instances, nonmetallic inclusions. If excessively long annealing times are employed at relatively high temperatures, however, a very coarse and abnormal agglomeration of the cementite particles will result. This condition is extremely undesirable from the standpoint of machinability. Furthermore, cementite particles of this size are extremely difficult to dissolve in austenite and result in poor response in subsequent hardening operations.

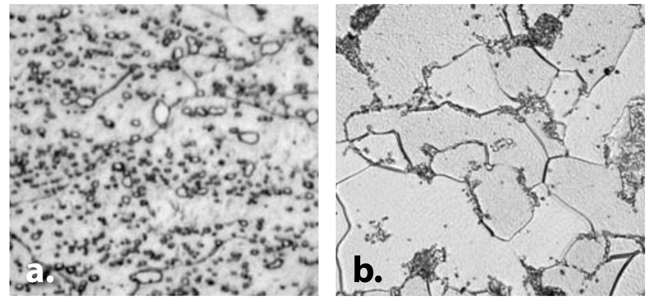

Fig. 3. Differences in annealed microstructures[2] (a) Spheroidize anneal (b) Process anneal *(Courtesy of Aston Metallurgical Services Co., Inc.)*

The importance of prior condition in spheroidize annealing applies to all steels regardless of carbon content, and the presence of coarse pearlite is undesirable because of resistance to spheroidization.

Process (Subcritical) Annealing

Subcritical annealing consists of annealing cold-worked steel to a temperature below the lower critical temperature (Ac_1) or transformation range and cooling by a convenient means. This method can be the same as recrystallization or process annealing.

In this procedure, the steel is heated to a temperature about 25°F (13°C) below the Ac_1 and held there for a prolonged period of time. As a result, the existing cementite particles coalesce (ball up) and form spheroids. For this type of annealing, a fine prior microstructure such as martensite, bainite or fine pearlite is desirable. Coarse cementite in the prior structure should be avoided because the large cementite particles do not coalesce as readily as the finer ones. Because of the comparatively long times required to spheroidize at the subcritical temperature, this procedure is seldom used in commercial practice.

The recrystallization temperature of pure iron is in the region of 930°F (500°C). Consequently, a higher temperature brings about rapid recrystallization.

In subcritical annealing, a degree of caution must be exercised in selecting the annealing temperature since the rate of heating also has an effect. For rapid heating rates, the Ac_1 will be higher than with slow heating rates. If Ac_1 has been incorrectly determined and the real value is exceeded, then austenite will form. This austenite may or may not transform upon subsequent cooling from the annealing temperature, resulting in unwanted retained austenite, untempered martensite or both. When subcritical (process) annealing large loads, it may be expedient to use a furnace temperature that is somewhat higher than Ac_1 to speed up the process. Such a method, however, demands close control to prevent any of the charge from becoming austenitized.

Prolonged annealing induces greater ductility at the expense of strength. A serious embrittlement problem can arise after prolonged treatment. With severe forming operations, cracks are liable to occur. **IH**

Next Time: Part two talks about the atmospheres used for annealing and some of the problems that can occur during the annealing process.

Figure 4 and references available online only