THE HEAT TREAT DOCTOR: Stainless Steels Part Two: Heat Treatment Techniques

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Heat treating of stainless steels depends to a great extent on the type (wrought or cast) and grade of stainless steel, as well as the reason for the treatment, most often to ensure that the properties altered during fabrication are restored (e.g. corrosion resistance, ductility, or hardness) so that the stainless steel component can perform in its intended service environment. There are quite a variety of different heat treatments available. Let's learn more.

Cleaning

An often-overlooked step, cleaning is necessary before any heat-treating operations are performed on stainless steels to remove oils, grease, and other types of residue. Left on the stainless steel surface during heat treating, localized carburization may occur degrading the corrosion resistance or other properties of the material.

Annealing

A number of different annealing methods (full, isothermal, subcritical) are commonly used for stainless steel. Austenitic stainless steels cannot be hardened by heat treatment, but they do harden by cold working. Annealing not only allows recrystallization of the work hardened grains but also places chromium carbides (precipitated at grain boundaries) back into solution. Annealing can also be used for homogenization of castings or welds, and to relieve stresses from cold working. Annealing temperatures usually are above 1900°F (1040°C), although some stainless steel types may be annealed at closely controlled temperatures as low as 1850°F (1010°C) when fine grain size is desired. Time at temperature is often kept short to minimize surface oxidation and to control grain growth, which may lead to a surface phenomenon called "orange peel."

Quench Annealing

Annealing of austenitic stainless steel is occasionally called quench annealing because the metal must be cooled rapidly through the temperature range of 1900°F (1040°C) to below 1100°F (600°C), and preferably below 900°F (480°C), to prevent precipitation of carbides at the grain boundaries (sensitization). The exception is for stabilized and extra-low carbon grades. This can be achieved by very rapid fan accelerated gas or water quenching.

Subcritical (Process) Annealing

Subcritical annealing is recommended for all applications that do not require maximum softness. All martensitic and most ferritic stainless steels can be subcritical annealed by heating into the upper part of the ferrite temperature range or full annealed by heating above the critical temperature into the austenite range followed by slow cooling. Typical temperatures are between 1400°F (760°C) and 1525°F (830°C) for subcritical annealing. When material has been previously heated above the critical temperature, such as in hot working, at least some martensite is present, even in ferritic stainless steels (e.g. 430). Relatively slow cooling at 75°F (25°C) per hour from full annealing temperature, or holding for one (1) hour or more at subcritical annealing temperature, is required to produce the desired soft structure of ferrite and spheroidized carbides. However, parts that have undergone only cold working after full annealing can be subcritically annealed satisfactorily in less than 30 minutes.

The ferritic types retain predominantly single-phase structures throughout the working temperature range (e.g. 409, 442, 446) and require only short recrystallization annealing in the range 1400°F (760°C) - 1750°F (955°C).

Repeated Process (Stabilize) Annealing
A stabilize anneal is sometimes performed after conventional annealing for grades containing titanium or niobium (e.g. 321 and 347). Most of the carbon content is combined with titanium in grade 321 or with niobium in grade 347 when these are annealed in the usual manner. A second anneal between 1600°F (870°F) and 1650°F (900°C), for several hours followed by rapid cooling, precipitates all possible carbon as titanium or niobium carbide and prevents subsequent precipitation of chromium carbide. This special protective treatment is sometimes useful in extremely corrosive service conditions, especially when service also involves temperatures in the 750°F (400°C) to 1600°F (870°C) range.

Bright Annealing
All grades of stainless steels can be bright annealed in highly reducing controlled atmosphere furnaces running under hydrogen, dissociated ammonia, or nitrogen/hydrogen atmospheres at dew points less than -60°F (-50°C) or in vacuum furnaces to prevent or minimize surface oxidation. Martensitic grades (depending on carbon content) and even some ferritic grades are susceptible to hydrogen embrittlement.

Hardening, Quenching, and Tempering
Martensitic stainless steels are hardened by austenitizing, quenching and tempering much like low alloy steels. Austenitizing temperatures between 1800°F (980°C) and 1850°F (1010°C) are typical. As-quenched hardness increases with austenitizing temperature to about 1800°F (980°C) and then decreases due to the presence of retained austenite. For some grades, the optimum austenitizing temperature may depend on the subsequent tempering temperature.

A slow heating rate, or preheating before austenitizing, is recommended to prevent cracking in high carbon grades (e.g. 440C) and in intricate sections of low carbon types. Preheating at 1450°F (790°C), followed by heating to the austenitizing temperature, is a common practice.

Air cooling from the austenitizing temperature is usually adequate to produce full hardness, but oil quenching is sometimes used, particularly for larger sections. Parts should be tempered as soon as they have cooled to room temperature, particularly if oil quenching has been used, to avoid delayed cracking. Tempering at temperatures above 950°F (510°C) should be followed by relatively rapid cooling to below 750°F (400°C) to avoid embrittlement at 885°F (475°C).

Precipitation-hardening, martensitic grades (e.g. 17-4, 13-8) typically require full annealing followed by austenite conditioning, transformation cooling, and age (precipitation) hardening. Semi-austenitic precipitation-hardening types (e.g. 17-7, 15-7) may require annealing, trigger annealing (to condition austenite for transformation on cooling to room temperature), sub-zero cooling (to complete the transformation of austenite), and aging (to fully harden the alloy). Hardening improves strength and toughness and typically takes place in the 900°F (480°C) to 1150°F (620°C) range.

Sub-Zero Treatment
Stainless steel components can be cryogenically treated before tempering to transform retained austenite, particularly where dimensional stability is important (e.g. 440C). Temperatures in the range of -100°F (-75°C) to -150°F (-100°C) are common, and deep cooling below -300°F (-185°C) is being used.

Stress Relieving
Austenitic stainless steels are typically heated between 800°F (425°C) and 1700°F (925°C) to achieve an adequate stress relief. One (1) hour at 1600°F (870°C) typically relieves about 85% of the residual stresses. Stress relieving in this temperature range, however, can also precipitate grain boundary carbides, resulting in sensitization that severely impairs corrosion resistance. To avoid these effects, it is strongly recommended that a stabilized stainless steel (e.g. 321 or 347) or an extra-low-carbon type (e.g. 304L or 316L) be used, particularly if extended stress relief times are required.

Stress relieving reduces residual stresses, avoids stress corrosion cracking, improves notch toughness, and improves dimensional stability in service. Full solution treatment (annealing), generally by heating to about 1975°F (1080°C) followed by rapid cooling, removes all residual stresses, but is not a practical treatment for most large or complex fabrications.

A great deal of stainless steel is welded during fabrication. When full annealing is not possible, such as on large components or intricate shapes, weldments can be heated to an intermediate temperature to decrease high residual stresses. Stress relieving is performed when joining dissimilar metals such as austenitic stainless steel and low alloy steel. Stress relief of martensitic or ferritic stainless steel weldments will temper heat affected zones and restore some corrosion resistance.

Low Temperature Stress Relieving
When austenitic stainless steels have been cold worked to develop high strength, low-temperature stress relieving will increase the proportional limit and yield strength (particularly compressive yield strength). Low temperature stress relief in the 325°F (160°C) to 775°F (415°C) range will reduce residual stress with little or no effect on the corrosion resistance and/or mechanical properties. Temperatures up to 800°F (425°C) may be used if resistance to intergranular corrosion is not required.

Carburizing and Nitriding
Low-temperature nitriding and carburizing processes have been developed for austenitic stainless steels and are rapidly gaining acceptance for improving resistance to wear and

corrosion. The soft matrix hardness limits these processes in heavily loaded applications.

Coatings

The most commonly applied coating is titanium nitride (TiN), which is used both for improved surface durability and for aesthetic purposes, having an attractive gold color and mirror-like finish.

References:

1. Stainless Steel Handbook, Allegheny Ludlum Steel Corporation
2. The A-Z of Materials, www.azom.com.
3. ASM Handbook, Vol. 4: Heat Treating, ASM International, 1991.
4. Chandler, Harry editor, Heat Treater's Guide, 2nd Edition, ASM International, 1995.

Additional related information may be found by searching for these (and other) key words/terms via BNP Media LINX at www.industrialheating.com: stainless steel, annealing, process annealing, subcritical annealing, stress relief, quench annealing, stabilization annealing, carburizing and nitriding stainless steels

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