Tech Sheet #134

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Heat Treatment of Tubes for Condenser, Feedwater Heater, and Shell & Tube Heat Exchangers

1. SCOPE

1.1 The purpose of this document is to provide an overview of the different types of heat treatment processes that are available for the production of welded and seamless tubing for condenser~~s~~, feedwater heater~~s~~ and shell and tube heat exchangers (balance of plant [BOP] heat exchangers) in power generation applications.

2.0 Heat Treatment Processes

2.1 Heat treatment is a process intended to make changes to metallurgical, corrosion and mechanical properties. It is a process that produces these changes by control of time, temperature and atmosphere using heating and cooling cycles. Some other commonly used terms for heat treatment are annealing, normalizing or stress relieving. Processes include in-line, continuous furnace, resistance, and batch heat treatment.

2.1.1 In-line - Tubing is heat treated continuously through an encircling induction heating coil. In-line heat treating may result in a shorter time at temperature than a furnace anneal.

2.1.2 Continuous furnace – Tubes are conveyed through the furnace by rollers, belts, or sleds. Multiple tubes may be heat treated during this process. The heat sources can be gas burners, electric glow bars or resistance heating elements. A continuous furnace heat treatment will provide a longer time at temperature than in-line heat treatment.

2.1.3 Resistance - Resistance heat treatment is performed by directly passing an electric current through the tube.

2.1.4 Batch - A group of tubes is placed in the furnace for the entire heating and cooling process. This process is rarely used for feedwater heater, BOP heat exchanger or condenser tubes.

2.2 The tube alloy, physical dimensions, requirements for the application, and the specific heat treatment process used, will determine the heat treatment parameters as follows:

- Temperature
- Time at temperature
- Cooling rate
- Atmosphere

2.3 Heat Treatment Atmospheres

Different types of atmospheres may be used for the heat treatment methods described.

2.3.1 Open-air –When tubing is heat treated without a protective atmosphere, the process is commonly called an oxide or open-air anneal. This process has the advantage that water quenching can be placed in close proximity to the high temperature zone providing rapid cooling rates. The oxide heat treatment forms a scale on the tube that may be removed by a chemical or mechanical process. For stainless steels and nickel alloys, removal of the oxide may be required for restoring corrosion resistance.

2.3.2 Inert gas – To prevent the formation of scale, the tube(s) are enclosed in a protective or inert atmosphere during the heat treatment operations. A thin oxide layer may be produced on the tube surface.

2.3.3 Bright anneal – A reducing gas is added to the atmosphere that protects the tube surface to prevent scale or visible oxide and detrimental chromium depletion in austenitic stainless steels . Common reducing atmospheres include hydrogen or disassociated ammonia. For copper alloys, a combustion gas may be controlled to produce a reducing environment. These atmospheres are not used during the production of titanium.

3.0 HEAT TREATMENT OF MATERIALS

3.1 Austenitic and nickel alloys - The heat treatment of stainless steels and nickel based alloys can have a very significant effect on corrosion resistance. In addition to the concern of chromium depletion, a proper heat treatment produces an optimum structure. For austenitic stainless steels, in some environments, and nickel alloys, homogenization of the microstructure is important. Examples of structures that should be avoided include casting segregation (common in longitudinal welds), secondary phases from slow cooling and sensitization (chromium carbide formation). An additional secondary phase that may or may not be detrimental depending on the application is delta ferrite, which can form in the welds of 300 series alloys or when these grades are heavily cold worked.

Note: The term “Solution Annealing” has been interpreted in two different ways: (1) To eliminate chromium carbide particles only; (2) To achieve full homogenization and elimination of delta ferrite. Therefore, the user needs to clearly specify the heat treatment method desired. It is strongly recommended that the end user discuss this with suppliers of the tubing.

3.2 Ferritic stainless steels - Unlike austenitic stainless steels that have high nickel content that slows diffusion rates, ferritic stainless steels homogenize much more quickly. Therefore, they normally do not require long heat treatment times to achieve optimum corrosion resistance. However, as the alloy content increases, the higher diffusion rates allow detrimental phases to form much more quickly. Quench rates of the higher alloyed ferritics is very important.

3.3 Duplex stainless steels – These materials have a structure which is a combination of approximately 50% ferrite and 50% austenite. Ideally, a ferrite matrix with austenitic islands is desirable. Heat treatment temperatures also have a significant impact on this mix. Secondary phases from slow cooling can severely degrade corrosion resistance. Although not as sensitive as the ferritic alloys, quench rates on the higher alloyed duplex stainless steel should be monitored closely.

3.4 Copper alloys – As copper alloys do not have the tendency to form secondary phases, heat treating of copper and copper alloys is predominately stress relieving or softening to increase ductility. Copper alloys' corrosion resistance can be degraded by "residual graphitic char" contamination. This can result from improper cleaning prior to heat treatment.

3.5 Titanium – Stress relief anneals are used for commercially pure (CP) grades. Since they are pure there should be no secondary phases to put in solution. Stress relief temperatures are lower than those commonly used for solution annealing. Welds or cast structure in such materials exhibit the same corrosion resistance as the base metal by virtue of this purity. Examples of CP materials are titanium grades 1-4.

3.6 Heat treatment process for carbon and alloy steel.

3.6.1 Normalizing is a thermal process specific to carbon and low alloy ferritic steel. During the normalizing process the crystal lattice is uniformly changed to a face centered cubic structure when the material is heated above 1650° F. All transition phases from previous thermal processes are dissolved. Upon cooling below 1340° F another phase change occurs and the material uniformly transforms to a body centered cubic lattice free of any transition phases. Corrosion and mechanical properties are restored. This process is required after seam welding of tubes made to specifications A/SA 178 and 214 but is optional and often used after cold work for tubes made to specifications A/SA 179, 192, 209, 210, 213 ferritic grades and 556.

3.6.2 Isothermal annealing is a combination thermal process that can be used for ferritic alloy grades to increase ductility and reduce hardness beyond what is possible by normalizing or stress relieving alone. During the isothermal anneal process the material is heated above 1650° F, then cooled and held for a period of time at temperature below 1340° F. This process is optional for tubes made to specifications A/SA 209 and 213 ferritic grades.

3.6.3 The stress relief anneal is a thermal process in which the material is heated to, and held for a period of time at temperature below 1340° F. This process is used to relieve stresses caused by cold work, thereby increasing ductility and reducing the strength and hardness of the material. It is required by specifications A/SA 179, 192, 209, 210, 213 ferritic grades, and 556.

4.0 CORROSION EFFECTIVENESS TESTS

4.1 A number of ASTM specifications have been developed to test the effectiveness of the heat treatment for stainless steels and nickel alloys. Each test method is specific for the type of resistance and/or secondary phase that needs to be detected. Contact the tube supplier for specific recommendations.

4.1.1 Intergranular corrosion – The tests developed for intergranular corrosion resistance for austenitic and ferritic stainless steels are described in ASTM A262 and ASTM A763 respectively. Each of these specifications provides for a quick, inexpensive screening test to allow for rapid examination without delay of production. Intergranular corrosion testing is not possible on duplex stainless steels.

4.1.2 Secondary phases in duplex stainless steels - Secondary phases appear to be the primary reason for reduction of corrosion resistance. ASTM A 923 can be used for TP2205 and higher alloyed duplexes. It also allows a quick screening method. Reference ASTM web site for information on corrosion testing on lower alloy duplexes.

4.1.3 Delta ferrite in austenitic welds – This test is identified in ASTM A249 Supplement 7. This is commonly referred to as a weld decay test. For relatively delta ferrite free welds, the user should specify a ratio of 1.0 or less.

4.1.4 Chloride resistance – One of the more common specifications used to determine chloride resistance in "chloride resistant" stainless steels is the ASTM G48 test. As it is very difficult to prepare a controlled crevice on a tube, a pitting test is commonly specified. The ASTM G48 method C meets this requirement. As this test can be very aggressive, it should only be applied to alloys with higher corrosion resistance. Alloys with lower corrosion resistance may be tested by the ASTM G61 method. Contact the tube supplier for additional information.

4.1.5 Chromium depletion – A number of ASTM test options developed for detection of surface chromium depletion on stainless steels are included in ASTM A967.

4.2 All of the above tests are used to determine common problems known to cause a reduction in corrosion resistance. The user should consult with a tubing manufacturer to determine which test is appropriate for the application and alloy.

5.0 MECHANICAL PROPERTIES

5.1 ASTM specifications have been developed to test the effectiveness of the heat treatment for mechanical properties. Typical tests may include tensile strength, yield strength, elongation, hardness, flare, flange, flatten and other manipulation tests. The specific mechanical testing requirements are identified in the appropriate ASTM product specifications.

6.0 SUMMARY

6.1 A significant number of candidate tube materials are available to the user today for use in steam surface condensers, closed feedwater heaters and shell and tube heat exchangers. A knowledgeable understanding of not only the selection criteria but the production processes is vital in achieving a high level of product quality. Open communication, due diligence and a working knowledge of the various heat treatment options and processes that will be used to produce the product in compliance with the required specification are paramount to a successful project.

6.2 Not all materials and processes are identified within this Tech Sheet. In addition, because heat exchanger tubing can be made from a variety of different materials, the needs of heat treatment may be highly variable. HEI recommends you consult with your selected supplier for further details.

7.0 REFERENCES

ASTM A249, Standard Specification for Welded Austenitic Steel Boiler, Superheater, Heat Exchanger, and Condenser Tubes

ASTM A262, Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels

ASTM A763, Standard Practices for Detecting Susceptibility to Intergranular Attack in Ferritic Stainless Steels

ASTM B338, Standard Specification for Seamless and Welded Titanium and Titanium Alloy Tubes for Condensers and Heat Exchangers

ASTM G48, Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution

ASTM G61, Standard Test Method for Conducting Cyclic Potentiodynamic Polarization Measurements for Localized Corrosion Susceptibility of Iron-, Nickel-, or Cobalt-Based Alloys

ASTM A923, Standard Test Methods for Detecting Detrimental Intermetallic Phase in Duplex Austenitic/Ferritic Stainless Steels

ASTM A967, Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts