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A VIEW FROM THE PENTHOUSE: USEFUL INFORMATION FOR THE WORLD OF BOILERS

HEAT-TREATMENT OF STAINLESS STEELS

There has been some confusion in the requirements for solution annealing of cold-worked austenitic stainless steels. More and more purchase specifications for replacement superheaters and reheaters fabricated with stainless steel mandate a high-temperature heat treatment, usually of the whole element. Often the request is based on inaccurate or incomplete information. I think it is time to bring some light into the darkness of misinformation on the necessity to solution anneal all cold work austenitic stainless steel pressure parts.

CODE REQUIREMENTS

Tubing for boiler components is purchased to a materials specification SA-213. The three common grades used in the fabrication of elements are 304(H), 321(H), and 347(H). Each has a given temperature for solution annealing. The specification requires that the purchased tubing be supplied to the pressure-part fabricator in the solution-annealed condition. However, Section I of the Boiler & Pressure Vessel Code has no specification requirement that the fabricated pressure part be heat-treated after bending. Thus the heat-treatment requirement is left either to the discretion of the manufacturer or as a contract agreement between buyer and fabricator.

EFFECTS OF COLD WORK

The effects of cold working on the microstructure depend, of course, on the amount of cold work. Up to about 15% strain, the changes in the grain structure are hardly visible, even at 500 magnifications. By 20% strain, slip lines and the early stages of distortion are visible. Above 20% strain, the grains themselves become visibly elongated.

During solution annealing two effects occur: any carbides present disappear and the grain structure changes. The cold worked grains go through a series of changes. The final stage, of course, is a large equiaxed grain size that is strain free. The process itself is known as "re-crystallization." The more severely distorted grains form small, equiaxed, strain-free, austenite grains first. During continued heating or time at the solution annealing temperature, these stress-free grain structures grow at the expense of the distorted ones. Thus, one of the stages during recrystallization is a grain structure which is mostly equiaxed but small.

The same sequence of transformations within the grain structure occurs during normal operation of pressure parts. The recrystallization can occur over a long period of time at temperatures as low as about 1100°F. 1100°F is the approximate temperature for the onset of creep in stainless steel. The problem is that as the cold worked grains recrystallize, the stage with fine, equiaxed, austenite grains has a lower creep strength than the coarse-grained size. Thus, under some conditions, cold-worked stainless steel during recrystallization in service will fail by a creep or stress-rupture mechanism. The finer the grain size, the poorer the creep strength; and therefore under normal conditions cold-worked stainless will lead to steam leaks during this recrystallization.

The problem has been reported in 321(H) stainless steel. To my knowledge it has not occurred in either 304 or 347 stainless steels. Of these three common grades of stainless steel the creep strength or stress-rupture strength of 321 is the most sensitive to grain-size variations. In fact, reference to SA-213 specification indicates that 321(H) has a specified grain size, ASTM 7 or coarser. None of the other grades has a specified grain size for assuring adequate creep strength. The stress-rupture strength of these other grades is not as susceptible to grain size variations as is 321(H).

RECOMMENDATIONS

Since it is impossible to fabricate a superheater or reheater element without cold bending, the question is how to best avoid the potential creep failures during service as cold-worked stainless recrystallizes. The obvious first step, of course, is to use either 304(H) or 347(H) rather than the 321(H). The second step is to limit the amount of cold work in any bend to approximately 20%. By using a bending-wheel diameter of at least four times the tube diameter, the cold work or strain in the extrados of the bend will be no more than 20%. Thus, for a 2" diameter tube, all of the bending should be done on at least an 8"-diameter bending wheel. This obviously works for most of the bending required in a superheater or reheater element, except for close-radius return bends. However, the amount of strain on the extrados of these bends can be kept below 20% by the use of a booster attachment to the bending machine and heat on the intrados. By pushing the tube through the bending operation with a hydraulic boost, the amount of wall thinning on the extrados of the bend can be kept below 20%. With the wall thinning less than 20%, the net strain is also less than 20%.

There will be a greater amount of strain on the intrados of the bend as the material thickens during bending. However, the stress within the intrados will be less as the wall thickness increases.

A convenient quality-control check is to measure the hardness on the extrados of the bend. The SA-213 specification limits the as-purchased hardness of austenitic stainless steels to Rockwell B 85. The inevitable consequence of any cold work is to increase this hardness. The greater the hardness increase, the more cold work and strain there is within the microstructure. As a reasonable compromise, an increase of some 20 points, Rockwell B, above the Code-specified 85 maximum is a reasonable amount of cold work that is not likely to recrystallize during service. Since 20 Rockwell B points puts the hardness at 105, which is off the Rockwell B scale, a hardness on the extrados of the bend of Rockwell C 25 is acceptable. For comparison, Rockwell C 20 is approximately equal to Rockwell B 100. Thus, Rockwell C 25 is approximately 20 Rockwell B hardness points above 85. Table I presents some data, courtesy of Leighton Industries, Inc., on the hardness changes as a function of strain for 304 stainless steel. Note the close-radius bend, sample #4, has the least amount of strain. This bend was made by heating the intrados of the bend to effect the close-radius bend. The amount of strain is approximately 7% on the extrados of the bend.

The final question to be addressed is whether individual bends or the entire element should be solution annealed after bending. Obviously one of the problems associated with solution annealing the entire element is the distortion that is likely, nay, certainly, to occur. The whole-element distortion needs to be straightened, which adds both time and is likely to lead to less-than-perfect alignment when complete.

The second problem, of course, is that during a 2000°F solution anneal, a certain amount of steam-side scale will form on the tube. This steam-side scale functions as a thermal barrier to the heat transfer; the net effect is to raise tube metal temperature during service. See VOL. I, No. 1 of this newsletter. In order to remove the steam-side scale before installation, individual elements will need to be chemically cleaned, which is an added expense. Thus, whole elements should not be solution annealed if at all possible. Individual bends could be solution annealed if the hardness increase is more than 20 Rockwell B hardness points, but this is somewhat awkward and leads to excessive handling. Again, the cost increase to perform the solution anneal does not seem to be justified. The best course of action is to use 304(H) or 347(H) stainless steels and bend in such a fashion as to keep the amount of strain below 20%. With less than 20% strain, neither recrystallization nor premature creep failures will be likely to occur during normal operation.

TABLE I

BEND CONDITIONS		% STRAIN	R_B HARDNESS		
TUBE DIMENSIONS	BEND DIAM.		BEND	END	INCREASE
1. 1 7/8" OD x 0.280" MWT	8"	19	95	72	23
2. 2 1/8" OD x 0.300" MWT	10"	17 1/2	95	75	20
3. 2" OD x 0.220" MWT	12"	15	92	70	22
4* 1 7/8"OD x 0.280" MWT	1"	7	85	71	14

* hot bend, intrados heated to∼1750°F.