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

DISSIMILAR METAL WELDS

In the 1950's when steam temperatures reached 1000°F, the need for stainless steels in the final stages of a superheater or reheater became apparent. Since stainless is required in only a portion of a SH or RH, the principal pressure part tubing remained low alloy ferritic steels. Thus the dissimilar metal weld (DMW) was born. Problems of premature failure of welds between austenitic stainless steels, usually 304, 321, or 347, and ferritic steels, usually T-11 or T-22, have plagued the boiler industry ever since. There are three root causes of these creep failures: 1. carbon migration from the heat affected zone of the T-22 into the weld metal, 2. expansion differences between the two varieties of steel, and 3. the differences in corrosion resistance to flue gas leading to the formation of an oxide wedge on the OD of t T-22 next to the weld.

1. CARBON DIFFUSION: When these DMW's are made with iron base alloys of stainless steel, carbon will migrate from the T-22 into the weld metal. A layer or particles of chromium-iron carbides will form along the weld interface in the stainless steel. The strength of T-22, especially the creep strength is a function of carbon content. As the chromium-iron carbides form, the metal immediately adjacent to the carbides is weakened by the loss of carbon. The loss of carbon reduces the creep strength just where the temperature induced strain is the largest. These two effects will lead to the formation of creep voids next to these carbide particles and ultimately to premature creep failure. In order to reduce the carbon migration and the formation of carbide particles, it is desirable to use a welding alloy that does not form a carbide as readily as does stainless steel. Such alloys are the nickel base materials. Nickel does not form a carbide and while these weldments do contain chromium, the tendency to form carbides is substantially reduced. Carbon remains in the T , the creep properties of the HAZ remain high, the temperature induced stresses are lower due to the compatibility of thermal coefficients, and so the formation of creep voids and failure is retarded.

2. EXPANSION DIFFERENCES: The coefficients of thermal expansion for ferritic and austenitic steels differ by about 30%, see table below

TEMPERATURE RANGE	FERRITIC STEELS	AUSTENITIC STAINLESS
	*(x 10^{-6} in/in-°F)	
0-600°F	6.4*	8.6*
0-800°F	7.0*	9.2*
0-1000°F	7.4*	9.6*
0-1200°F	7.7*	9.9*

Because of these expansion differences a two inch diameter tube of stainless steel will be 0.004 inch larger in diameter at 1000°F than a similar tube of T-22. This difference in expansion, the temperature induced strain, must be accomodated at the weld.

There are three likely combinations of expansion: (a) the weld metal may have the same coefficient of thermal expansion as the austenitic stainless, (b) in between the expansion of the two, and, (c) the same as the ferritic steels. When the weldment has the same expansion as the stainless steel, the temperature strain must be absorbed at the interface between the weld deposit and the T-22. As noted above, the long term creep strength of the T-22 is adversely affected by the loss of carbon. When the expansion coefficients are split, case b, the temperature strains are reduced but not to zero. Potential premature creep failures may still occur, but at a reduced frequency and over longer service times. If, however, the welding alloy has similar expansion to the ferritic steel, there is only limited temperature induced strain on the T-22. The maximum temperature strain is transferred to the stainless interface. Both the weld and stainless have much stronger creep strengths, suffer no carbon loss, and are much better able to last. No DMW has failed on the stainless steel side of the weld.

In the past, the most popular welding electrode was an E-309, an austenitic stainless steel. The use of ferritic alloy welding rods, for example E-9018, did not solve the problem. The creep voids and failures would still originate in the ferritic alloy, in this case the weld metal next to the stainless steel. The present day choice is a high nickel welding electrode similar to Incoweld A®. These nickel base alloys have thermal coefficients very close to ferritic steels of T-11 and T-22. Thus the temperature induced strains are nearly zero at the ferritic interface.

3. CORROSION: At the juncture of the weld and the T-22 on the OD surface an oxide wedge forms, whose volume is larger than the volume of metal from which it formed. Thus the wedge acts as a stress raiser and creates its own stress as well. With time this wedge penetrates the T-22 and may lead to failure. The cause of the formation of this oxide wedge is related to the differences in corrosion resistance between T-22 and the weld metal. The weld metal is more noble than the ferritic alloy. In effect a galvanic cell is created that leads to rapid oxidation at this juncture. The use of nickel base welding alloys will not prevent the formation of these external defects.

Stresses, regardless of origin are additive. The life expectancy of DMW's may be improved by careful attention to stresses over and above the pressure stress. To minimize the system stresses on the DMW's:

1. Place the welds close to a support; the support will carry the load, not the weld.
2. Make the welds in a vertical run of the tube rather than in the horizontal run to reduce the nonuniform bending stresses.
3. Locate the DMW's in the penthouse, out of the convection pass. The temperature gradient through the tube adds yet another stress that may be removed entirely.
4. Fabricate the welds with as few welding "defects" as possible, no undercut, a smooth radius fillet, without backing rings, suck back or lack of fusion at the root, etc., in short, using shop manufactured automatic weldments wherever and whenever possible.
5. Use nickel base welding alloys.

All of the above considerations will not guarantee three decades of trouble free operation, but will, on average yield 2½ times the life of stainless steel alloy weldments.

Once trouble begins in existing DMW's, the method of repair is dependent on whether the SH or RH is expected to last a few or many more years. If the condition is such that an overall general replacement is scheduled in the next "couple" of years, simply grind out the oxide wedge to a depth of about 3/4 of the tube wall thickness and reweld in place with a nickel base alloy. This procedure will last, if carefully done, several years, and will give satisfactory results until the replacement is made. If, however, more than 10 years of service are expected, the defective DMW's should be removed and it is desirable that the replacement DMW's be machine welded by an automatic TIG process.

While the previous discussion has focussed on the pressure parts, principally tube-to-tube butt welds, no less important are the attachment welds. Spacers, supports, allignment clips of stainless steel are routinely welded to T-11 and T-22. The preferred welding metals are also the nickel base alloys, and for exactly the same reasons. Note, however, that extra care needs to be taken with the shape of the fillet; a smooth blending to the tube with no undercut is especially important. Full penetration welds are not usually necessary or required; but it is better to have a continuous bead all around the attachment wherever possible. If an open gap is left, i.e., only welded from the sides and not around the ends, flue gas and elevated temperature will fill the space with an oxide and fly ash. In time this oxide will wedge open the attachment weld and cause failure. Since the load on a spacer is largest at the end, start and finish the weld pass toward the center of the weld, rather than at an end, so that any crater cracks are away from the highest stress zones.

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