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

## REHEAT CRACKING

Reheat cracking occurs, on occasion, in the heat-affected zones of low-alloy steels. SA213 T-11 and T-22 are the most commonly used boiler steels that are subject to this form of weld cracking. The root cause is inadequate preheat which leads to hard and brittle, martensitic, heat-affected zones. Cracks form during post-weld heat-treatment as the component is "reheated" from the ambient condition. Hence, the term "reheat cracking".

There are two conditions that are necessary: 1) a martensitic heat-affected zone, and 2) constraint or restraint which adds additional strain to the weld heat-affected zone. The heat-affected zone is formed as a result of the thermal cycle, the heating and rapid cooling during and after welding. The room-temperature microstructure of ferrite and iron carbide transforms to austenite as the temperature is raised above the upper critical-transformation temperature of about 1550°F. The exact temperature depends on the chemical composition of the steel. Upon cooling, the austenite will revert to ferrite and iron carbide if the cooling rate is slow enough. Rapid cooling rates will transform the austenite to martensite. There is a volume change from the elevated-temperature austenite to either ferrite and iron carbide or martensite. When the volume change occurs at a relatively speaking high temperature (temperatures in the neighborhood of 1100° to 1200°F), the material surrounding the heat-affected zone is ductile enough to easily accommodate the volume change by plastic deformation. Such plastic deformation may appear as distortion in the welded assembly. More rapid cooling rates prevent the transformation to ferrite and iron carbide. The transformation that does occur is to martensite at temperatures that are below about 600°F. At these lower temperatures, there is less ductility and the strength is higher in the surrounding material. The volume change from austenite to martensite is larger, which leads to greater residual stresses within the heat-affected zone.

During post-weld heat-treatment, the relief or easing of these strains associated with the martensitic transformation in the heat-affected zones will lead to distortion during the elevated temperature heat-treatment. When there is added restraint or constraint that prevents the distortion that relieves residual stresses, cracks develop in the heat-affected zone.

The simple explanation is that the brittle, martensitic heat-affected zone does not have sufficient ductility to absorb the release of residual strain and thus forms cracks to ease the strain.

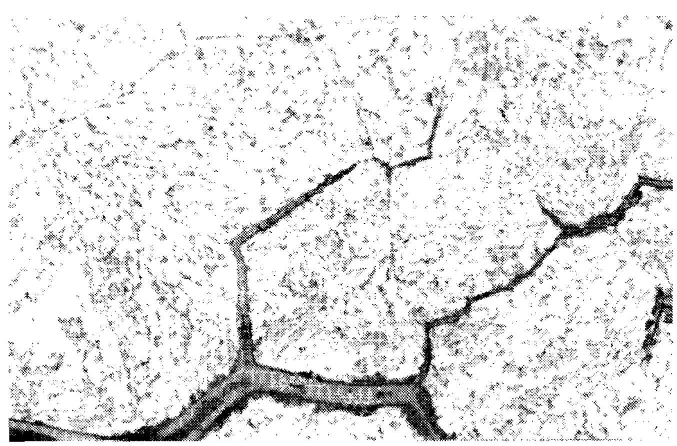

Figure 1

The cracks follow the prior austenite grain boundaries, as these regions are the weak link. Figure 1 shows the crack morphology associated with reheat cracking. In order to prevent martensitic heat-affected zone formation, the cooling rate needs to be slowed down to allow the transformation from austenite to ferrite and iron carbide. The easiest way to achieve a slower cooling rate is by the use of preheat. Heat-affected zones that contain reheat cracks may have hardnesses in the Rockwell C 25-30 range or even higher, while heat-affected zones that do not crack have Rockwell B hardnesses in the 90-100 range. Ferrite and iron carbide are considerably softer than martensite, and the hardness of the heat-affected zone is one indication of the microstructural condition.

All of the preceding discussion has centered on the heat-affected zone of the T-11 or T-22 material. There has been no discussion of the composition of the welding electrode used; because the weld metal is unimportant, as the damage is in the base metal heat-affected zone. The examples below have three different welding alloys.

The following is a catalogue of examples of reheat cracking failures. The common thread through all of them is that the welds were made without proper preheat.

Superheater outlet header

An SA335 P-22 superheater-outlet header was designed with 3½-ft long tube connectors socket-welded to the header pipe with E9018 welding electrodes. With such long tube connectors, measurable distortion would have occurred during both welding and post-weld heat-treatment. To minimize the repair that would have been required to re-align the tubes, a 10-gauge piece of sheet metal was tack-welded to the ends of the stub tubes to prevent movement. Following post-weld heat-treatment, cracks were clearly visible in the heat-affected zone on the header-pipe side of these socket welds.

Dissimilar-metal weld

Tube-to-tube butt joints between SA213 T-11 and SA213 TP304H were made in the boiler using an E309 stainless-steel electrode. Steam leaks developed within a few weeks of start-up. The leaks were in the heat-affected zone of the T-22.

Reheater-alignment clips

Finally, an example of the failure of a T-22 reheater tube at a stainless-steel lug welded with a nickel-based electrode - cracks and steam leaks developed in the tube several months after installation. The crack initiated at the toe of the fillet weld. The crack then either separated the lug from the tube, or grew into and through the tube to form a steam leak.

In summary, reheat cracks can most easily be avoided by use of adequate preheat that will assure a soft, more ductile, heat-affected zone within the T-11 and T-22 materials.

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