

# **KNOW WHAT IS STRESS CORROSION CRACKING**

By K.K.Parthiban, Boiler consultant

## **INTRODUCTION**

Please do not hesitate to read further. For most of you it may sound hi-fi. Actually it is not. Steel is not a homogeneous material. It is made of lot of grains. Each grain is a kind of organized atomic structure. The grains may be very strong and do not allow any bigger atom to enter in between atomic structure. But hydrogen being the smallest atom, given chance it can seep through the grain boundary and cause cracks in boiler tube / pipe material. Now read further and compare your experiences.

## **STRESS CORROSION CRACKING (SCC)**

Stress corrosion cracking (SCC) is caused by simultaneous tensile stress and corrosion. SCC will only occur if three conditions are fulfilled at the same time, these are;

- The material must be sensitive to SCC.
- The environment must be aggressive.
- Tensile stresses applied to the structure must be sufficient.

Stress-corrosion cracking (SCC) results from the combined action of stress, a cracking (electrochemical) environment, and temperature to cause cracks to initiate and grow in susceptible steel. Individual cracks are generally oriented perpendicular to the maximum stress and parallel to the tube / pipe axis. Groups of cracks usually occur in what is known as a "colony." In extreme cases, these colonies may be several mm long and extend nearly around the circumference.

SCC colonies are considered sparse if the cracks are far apart in the circumferential direction and dense if the cracks are circumferentially close together. Individual cracks can range from shallow to deep. Many cracks in the middle of dense colonies have a depth less than ten percent of the wall thickness. In sparse colonies and in some dense colonies, the cracks can grow in a stable manner until they reach nearly through the wall.

As nearby cracks grow, individual cracks can coalesce or join to form a single, larger crack. If the coalesced crack is long enough, it can rupture. The consequences of a rupture are usually more severe than those of a leak. Sections of metals are blown away due to loss of strength.

Two forms of SCC have been encountered: high pH and low pH. The surfaces of most low and high-pH stress-corrosion cracks are not smooth but irregular. High-pH stress-corrosion cracks are typically intergranular (with a cracking path along the grain boundaries of the material), with essentially little or no separation or opening between the crack faces. Low-pH cracks are often transgranular, where the fracture surfaces are smoother than intergranular fracture surfaces, but they are not as

smooth as fatigue cracks. Also, both forms of cracking can branch as cracks grow through the wall thickness.

### **MECHANISM**

Hydrogen diffuses into the metal and reacts with carbon present in the iron carbide present in steel to form methane bubble. Reduction of carbon in steel leads to decarburization. The large methane molecules trapped produce very high-localized stresses leading to micro fissures which link up and form cracks. This reaction is irreversible. The metal sections are blown out in such locations where hydrogen attack has taken place. This is also known as hydrogen embrittlement.

### **POTENTIAL LOCATIONS / COMPONENTS FOR FAILURE**

Plain carbon steel, low and high alloy steels, martensitic and ferritic stainless steel are steels used in boiler / power plant are susceptible for failure. Header to tube stubs, tube bends, stress induced zones due to weldments, pipe bends, condensers, water headers, bolts, nuts and fasteners. Locations where debris / loose scales/ suspended solids could accumulate are prone for localized high pH concentrations which would subsequently lead to hydrogen damage. However it is necessary they are stressed locations due to weldment / thermal expansion / cold working during fabrication. Improper flushing after chemical cleaning / improper chemical cleaning could provide chances for hydrogen embrittlement. Lack of proper Heat treatment after cold work / after weldment would be the locations immediately attacked by Hydrogen. Steels containing Chromium / Molybdenum are easily attacked by Hydrogen. The reason is the high hardness of microstructure of steel and hence they are likely to crack on any cold work. Similarly the Heat Affected Zones (HAZ) is harder with large residual stresses. Rolled ends Stainless steel tubes are work hardened and they are susceptible to cracks on low pH environment.

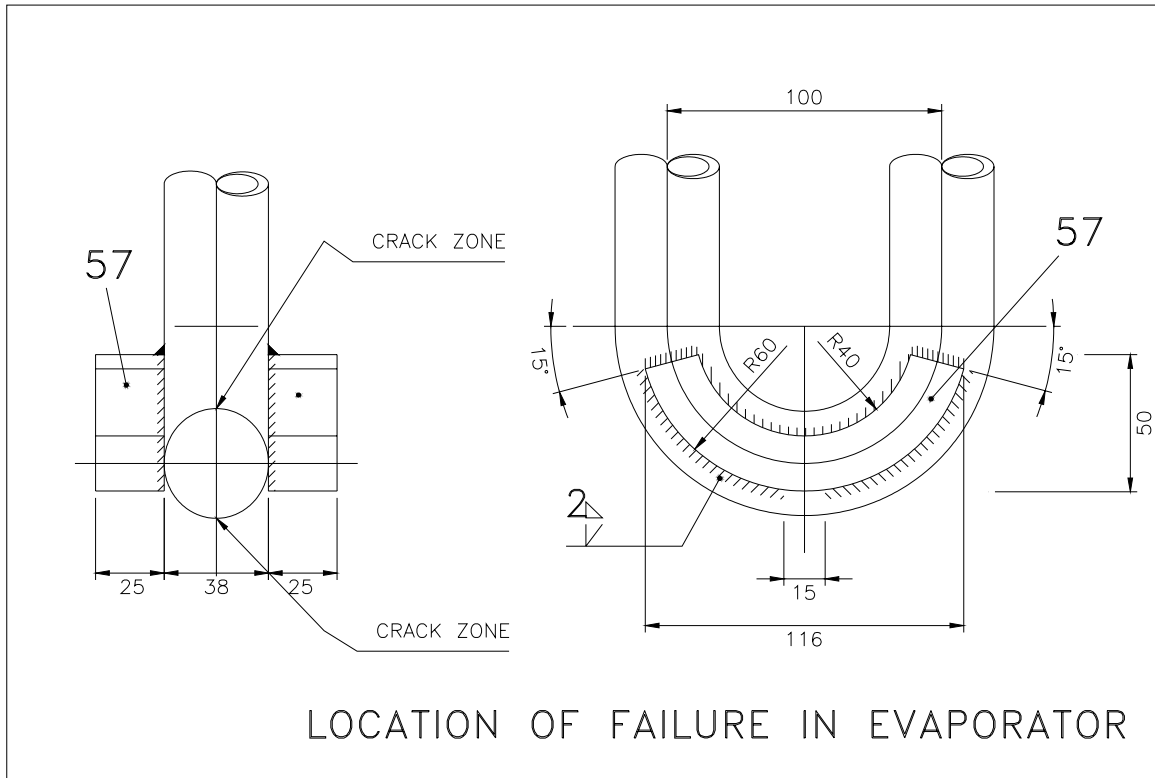
### **A CASE OF FAILURE:**

Recently I had an opportunity to investigate tube failures of a new boiler while the pre-commissioning operations were going on. The boiler is designed with a forced circulation evaporators and the failures have taken place in the non-drainable tube bends. The failed tube bends were many and all were in the hottest zone. As many of you know, alkali boil out is done at lower pressure, say at 10 - 15 kg/cm<sup>2</sup>g. In the second stage alkali boil out itself the failures had showed up.

I had discussions with commissioning engineers and had a look at failed tubes. I took a straight portion of the tube and had it analyzed for chemical and mechanical properties and it perfectly matched code specifications. The doubt on spurious material was eliminated. All the bends had failures cracks along the innermost bend radius and outermost bend radius. It was clear that the bends are highly stressed along these two planes. The suspicion was now on possibilities of Stress corrosion cracking.

The commissioning engineers explained that during the first stage alkali boil out only DM water was used with a pH of 7. Afterwards the chemicals were added in to the steam drum. Being a forced circulation boiler, the circulating pumps were used. However during the process of alkali boil out the power supply for the pump was

unavailable. Unfortunately the burners could not be switched off for certain reason in the process side and hence the heat input to the boiler continued for 20 minutes. Like this few interruptions were there for few more times but for shorter durations. Incidentally the pH of the water used for hydraulic test about a month back was also of pH of 7.0 instead of recommended value of 8.5.



It had been customary not to anneal tube bends in the case of boiler tubes if it is carbon steel. The attachment weld done on the tube bends must have induced considerable residual tensile stresses. When it came to corrosive chemical environment, the low pH environment was available after hydro test. Low pH / high pH environments were available during alkali boil out process. Heat was available and the circulation was unavailable for certain duration. The three factors such as residual stress, high / low pH chemical environment and Heat were available for the execution of Stress induced corrosion. See the hairline crack along the outer circumference of tube bend.

#### PREVENTION OF SCC

- Low or high pH environment chances are to be eliminated. Use only water with pH of 8.5 to 9.5 for even hydro test.
  - Avoid heavy attachment welds, which leave behind residual tensile stresses. Carryout stress relieving to remove the residual stresses. Depending on the material, the tube bends are to be stress relieved.
  - Wherever residual stresses are likely, the design must be modified / reviewed to avoid the residual stress.
  - Most importantly during the boiler usage time, low pH environment should not occur. Even if occurs once, the failure mechanism gets started and the failure is irreversible. I have heard of an incident that a battery of boilers had immediate failures at certain locations when the pH of boiler water went down for a day.
  - Follow proper preheating procedures for T91 / P91 materials during fabrication and welding.
  - During fabrication extensive care is to be taken to avoid moisture ingress into weldments.
  - Wrong selection of electrodes / welding consumables could lead to weld failures. I had seen a case where SS tube spacers welded to low alloy steel came off due to alloy dilution that took place at weldment.
  - Inadequate removal of rust / paint / lubricant/ water before weldment could be a source for hydrogen ingress in to weldment.
-