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High Temperature Creep and Hydrogen Embrittlement Failure of a Steam Trap Bypass Tube

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Abstract. A coal fired power plant with its normal operation temperature of 540ºC in which its steam trap bypass tube in that power plant was totally fractured. The aim of this study is to explore the evidence related to the steam trap bypass tube failure and to determine the failure mechanism and the root cause of the failure and to give an appropriate recommendation. From the evidence with considering the contribution factors such as temperature, pressure and environment, a fault analysis was made and it can be concluded that the cause of failure to the steam trap bypass is due to multi causes which consists of creep failure and hydrogen damage.

Introduction

In most plants, steam is produced with a boiler. Once steam leaves the boiler, it begins to lose energy and cool. As its temperature falls, the steam condenses back into water. Failure to remove condensate from the steam system will set up a vicious cycle. In order to maintain optimum steam system performance, steam traps are used to remove condensate from the system [1]. The function of steam trap bypasses is to discharge air. This is to allow condensate to reach the steam trap as illustrated in Figure 1.

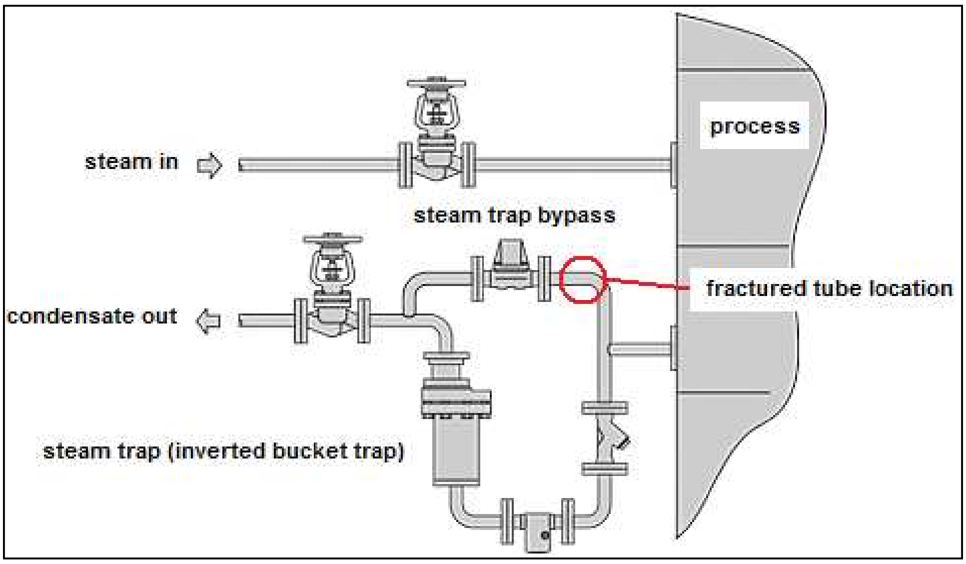

Fig 1 : Schematic diagram of the fractured steam trap bypass tube location.

This paper presents a failure analysis investigation of a steam trap bypass tube with ASME specification SA-335-P22 grade steel with 2.5in outside diameter, which is basically a 2.25 Cr-1Mo ferritic steel. The steam trap bypass tube was in five years in service till it completely failed.

Experimental Details

Visual inspection was documented by digital camera photography. The sample was cut and its cross sectioned surface was cold mounted parallel to the tube axis. Nital 4% solution and hot dilute hydrochloric acid was used for micro-etching and macro-etching respectively. The microstructure of the failed steam trap bypass tube was analyzed by optical microscope and scanning electron microscopy (SEM). The chemical composition of sample consists of C:0.1%, Mn:0.67%, Si:0.23%, P:0.0122%, S:0.02%, Cr:0.088%, and Mo:0.018% which was analysed using glow discharge spectrometer (GDS).

Results and Discussion

The tube had catastrophically fractured with a fishmouth appearance as shown in Figure 2. Visual inspection on fractured surface of the fractured surface exhibited bright and granular features. It has thick edge as shown as red mark in Fig. 2. With thick edge and fishmouth crack appearance, it is an indication of high temperature creep or long term overheating failures as reported by R.W Bryers [2]. Longitudinal cracks and oxide scale were found inside the tube surface. The oxide scale of 3.5mm thickness was measured on the inside tube surface.

Fig 2 : Digital camera image of fishmouth appearance that catastrophically fractured apart due to high pressure.

Base on the oxide scale thickness, estimation of metal temperature adjacent to the oxide scale was calculated using the equation below:

$$\text{Log } X= -6.839 + 2.838 \text{ x } 10\text{-}4(T)(13.62 + \log t)$$

where,
X is the thickness of oxide scale in mils (1mm=40mils)
T is the temperature in °R(R=F + 460)
t is the time of exposure in hours.
(In this case, t=43800 h, X=0.35mm=14mils.)

It can be estimated that the metal temperature adjacent to the oxide scale would be around 580°C, however the maximum temperature permitted for the tube steel is 649°C with the initial creep temperature of 537.8^{o}C [2]. The working estimated temperature of tube had not exceeded the maximum permitted temperature but was higher than the initial creep temperature which was an evidence of creep occurred.

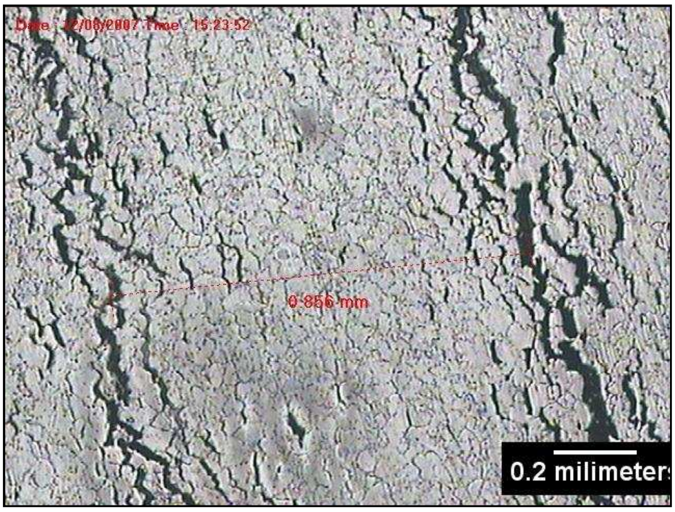

Fig. 3 : Optical metallograph of inside tube surface.

Intergranular microcracks had formed under the oxide scale with ferrite and pearlite grains (Fig 3). The grain growth rate near the inside tube edge was almost two times greater than that of the grains far from the inside tube edge which had reduced the strength and toughness of the tube. Graphitized microstructure, microvoids, pores and microcracks were also observed. These microstructural changes usually occurs in carbon or low alloy steels that are subjected to moderate temperatures for long period of time [2].

The fracture surface clearly revealed dimpled structures associated with brittle facets, cleavage fracture, ductile hairline cracks and micropores as shown in Figure 4. The fracture surface also indicates typical characteristics of hydrogen embrittlement [3] which in the form of a partially intercrystalline fracture with ductile markings on the grain boundaries (crow's feet). The indication of hydrogen embrittlement showed that hydrogen embrittlement had also occurred which was a result of chemical reactions between tube material and condensate.

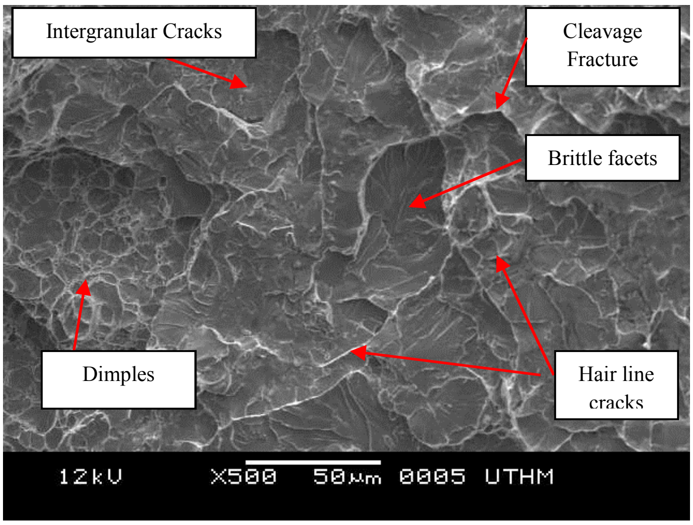

Fig. 4 : SEM micrograph of heterogenous structure including dimples, brittle facets, cleavage fracture and hairline crack.

The average hardness resulted was high inside tube and outside tube, however the hardness result reduced at the center of cross section of the tube. This high hardness value inside tube region and outside tube region was an indication of decarburization which had occurred. Carbon element from the center of cross section tube had depleted through the outer and inner side of the tube which resulted in a significantly higher brittle zone in the inner and outer side of the tube.

Conclusion

From the results, it can be concluded that the steam trap bypass tube had fractured due to high temperature creep and hydrogen embrittlement (multi causes). To avoid further failure recurrence, corrective actions have to be taken which includes replacement of the fractured tube with higher Cr-Mo tube material content for higher creep resistance and continuous steam trap operation monitoring to eliminate condensate.

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