

# Failure Analysis of a Service Tube

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**Abstract:** One tube was cracked used in the primary reformer furnace in a fertilizer plant for two and half years. In order to find out the causes of cracking, the methods for chemical composition analysis, macro- and microstructure analysis, penetrant testing, weld analysis, crack and surface damage analysis, mechanics property analysis, high temperature endurance performance analysis, stress and wall thickness calculation were adopted. The integrated assessment results showed that the carbon content of the tube was in the lower limit of the standard range; the tube effective wall thickness was too small; local overheating leads to tube cracking in use process.

## 1. Introduction

The converter furnace tube used in a fertilizer plant for 2.5years ruptured. Many kinds of analytical methods such as chemical composition, macro- and microstructure, mechanical properties and other checks are adopted in order to find out failure reasons.

## 2. Experimental Materials

The whole part of cracking tube was removed, dissected, and sampled. The segment of physical fracture of the tube is shown in Figure1. The crack in the outer wall of tube is longer than that in the inner wall, about 218mm and 203mm, respectively.



**Figure 1.** The object of cracking tube

## 3. Experiment Result and Analysis

### 3.1. Chemical Composition Analysis

In the cracking tube, three samples were taken at vicinity and wide berth ends of the fracture,



respectively.

The results of Chemical composition analysis meet basically the technical contract requirement and KHR35CT standard provided by Kubota. But there were three issues to be explanted:

(1) Cr content of the sample was close to the requirements of 24% with a minor difference, But the type of material, general control level is of 23~27% at home and abroad, and on behalf of 25%.The tube property and structure are all normal within the control level. So the Cr content was not as a problem, and the accuracy for different testing equipment is not the same. By KHR35CT standard, an allowable error is of 0.25%.

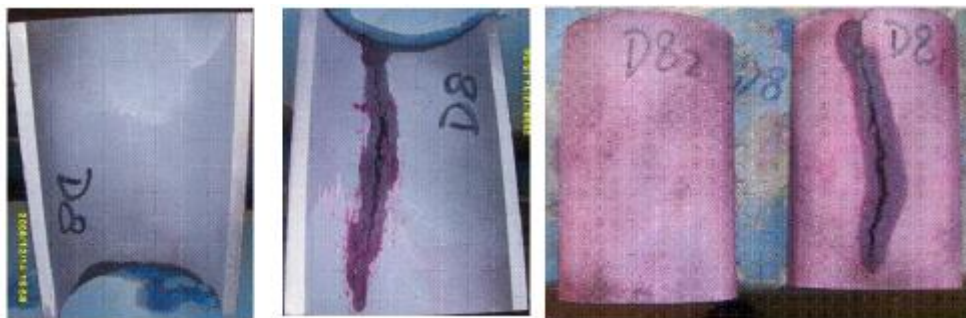
(2) The wall thickness of tube were relatively small, So the carbon content of tube should be taken at upper limit level of KHR35CT standard so as to increase high temperature strength, and ensure the operation safety, While carbon content of the tubes is lower, the possibility of explosion would raise up.

(3) The influence of alloy elements as Cr,Ni, Nb and trace elements on the tube property should be further researched.

Overall, the results of chemical composition meet the technical specification and KHR35CT standards, but lower carbon content in design of wall thickness for tube must be drawn attention.

### 3.2. Penetrant Testing

Diameter measurement of all parts of the tube sample were examined by dye perpendicular on the wall thickness of creeping expansion section. Each section of tube were made within the margin of manufacturing error, in addition to explosion vent with a little bulging. The results showed that the tube wall thickness was uniform.



**Figure 2.** Results of dye penetrant testing on the surfaces both inside and outside of sample

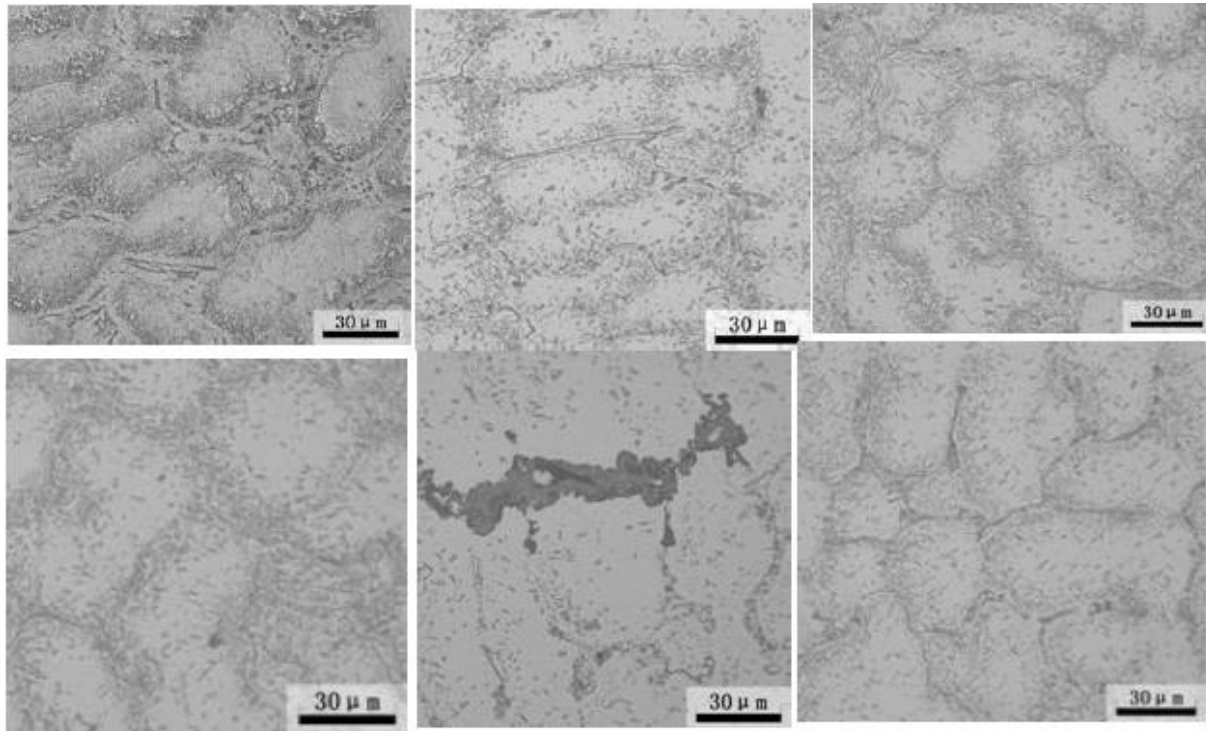
The dye penetrant testing were used in both inside and outside surfaces of the sample in which no other defects were found in addition to crack. The inner dissected surface and the annular section were inspected also by dye penetrant testing, the results have been shown in Figure2. The main results showed that there were many long cracks in inner surface, these cracks extended from inside to outside surfaces, and a bit small cracks were found in the front end and vicinity of the fracture.

### 3.3. Macro- and Microstructure Analysis

The macrostructure consists of the columnar crystals in outer surface and the equiaxed crystals in inner layer, which was normal. From up to down, the proportion of columnar crystal and equiaxed is different, and the changes in the proportion would not influence the service life of tube by a quantity of studies[1,2], There was no casting defect found in all of the three section tubes.

The microstructure of the tube can refleccused its used temperature condition and time. From upper to lower of the tube, the microstructure was shown in Figure3. The microstructure of upper tube was the complete cast eutectic structure with a lot of fine secondary carbide, the results showed that the tube had been used at low temperature. The part was basically in good state on the above. The microstructure nearby the cracking had changed obviously with eutectic carbide as a chain-like

intermittent network, and the number of secondary carbide decreased, Eutectic carbide particles began to grow up and a little of rod-like carbide occurred. Both of them were accessed at high temperature. A sample was taken in opposite of the crack. Its secondary carbide particles decreased, gathered, and grew up, and the rod-like carbides increased. The microstructure was deteriorated. The microstructure near voids was composed of original chain-breaking carbide and the amount of the secondary carbide aggregating to the big blocks. It was clearly caused by over high temperature. According to the microstructure analysis, the temperature would be more than 900 °c.

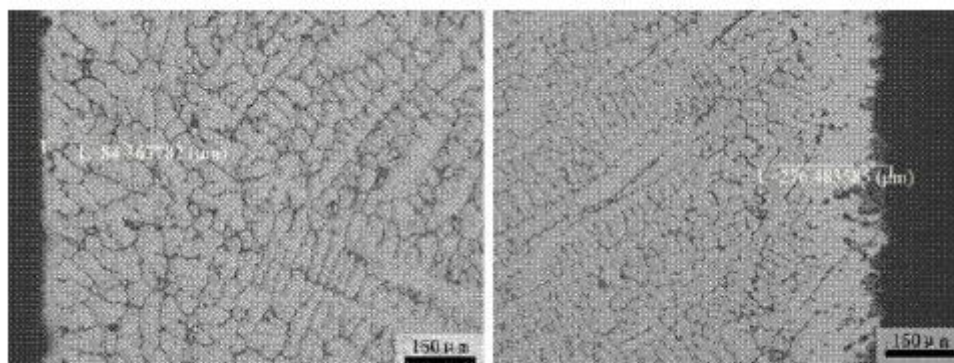


**Figure 3.** The microstructures of the crack and its upper part, near part, and lower part

By above analysis of various parts, the microstructure of the upper parts was normal. In the lower parts, where exists different degree of overheating structure, the microstructure was deteriorated obviously near crack. So the tube cracking was caused by local overheating

### 3.4. Crack Analysis

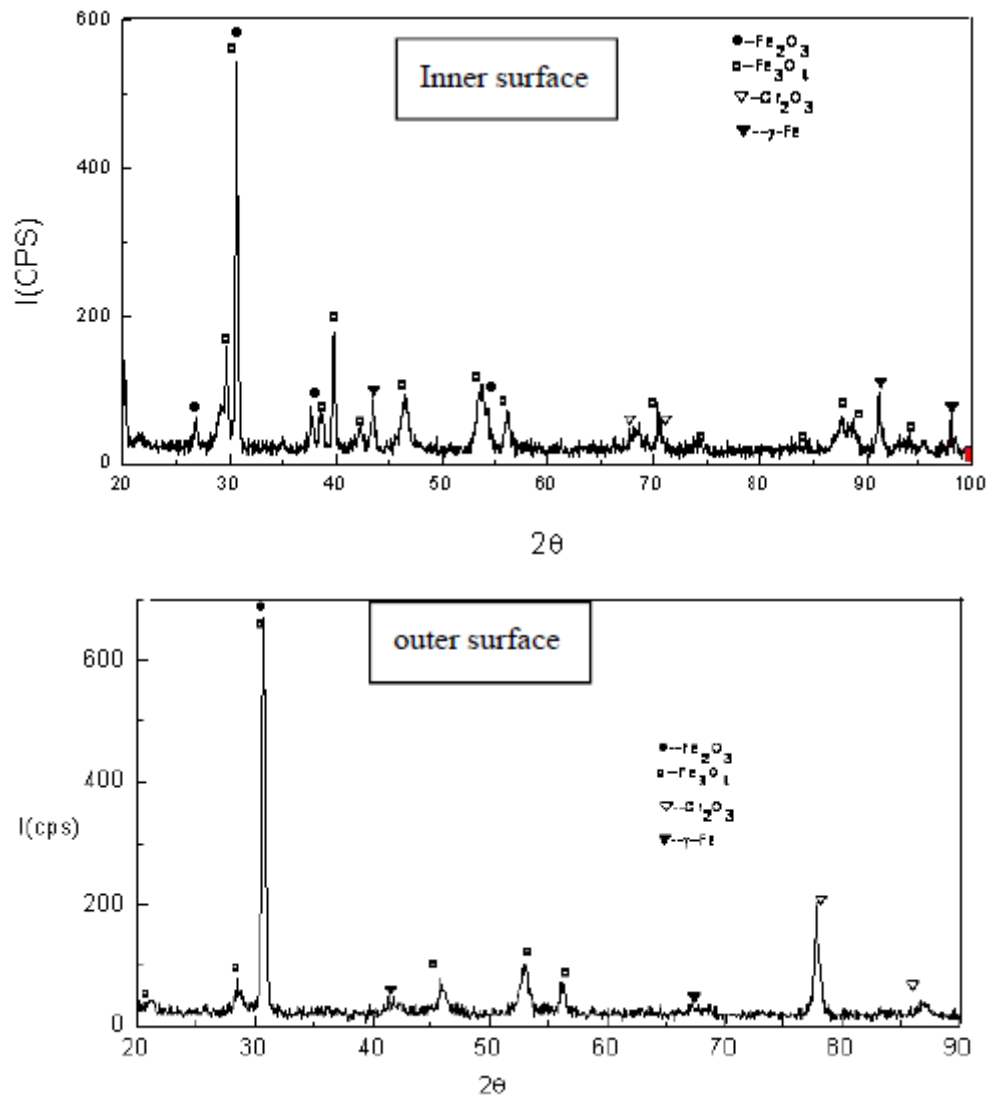
The microstructures on the internal and external surfaces are shown in Figure 4.



**Figure 4.** Damages of the internal and external surfaces

The damages of inner and outer surfaces were relatively minor, exception of the cracking, The damage in the outer surface was less than 0.5mm, and that about 0.1mm in the inner surface. This is normal oxidation corrosion in the use of furnace tube and it is not directly related to tube cracking.

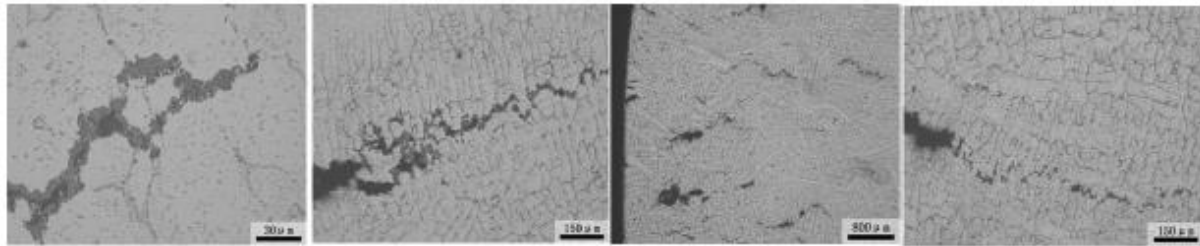
By x-ray diffraction analysis on inner and outer surfaces, there were Cr and Fe oxides shown in Figure5. Compared with other used tubes, the diffraction effects is basically the same.

**Figure 5.** X-ray diffraction analysis results of inner and outer surface

The observation and analysis on the dissection segments of the main crack were done in various parts. The edge of the main crack were made into a several dozens of samples for micro analysis, there was so many micro analysis pictures, not list all in the paper, but these results were consistent. After the observation it can be looked at the oxidation corrosion layer in internal and external surfaces, and there was no oxidation corrosion layer in the fracture part, The result showed that the main crack had been formed in a short time, not developed from those cracks extending to outside surface. Around the primary fracture and the secondary crack tips, where no original structure defects has been found, and

no inclusions existed also.

By the crack analysis, there were some creep voids existed in the front end of crack and in the vicinity of micro-cracks with a tendency of being gradually connected to micro-cracks. It was a typical structure characteristic of high temperature creep cracks caused by high temperature and stress [3,4]. All of them has no the original structure defects. The morphologies of the secondary micro-cracks in front end and creep voids were shown at Figure 6. The results showed that these creep cracks are the products of high temperature



**Figure 6.** Creep voids and micro-cracks

#### 4. Conclusion

- (1) The effective wall thickness of the original tube was too small, it was the root cause for the explosion of furnace tube.
- (2) The microstructure of the tube in the lower part (cracks and nearby) were significant over temperature. High temperature creep rupture was verified by the crack analysis, It was the direct reason for the tube cracking at a local overheating condition
- (3) According to the chemical composition analysis, the carbon content of tube was in the lower limit of the standard level; the possibility of tube bursting would increase.
- (4) All of the above analysis, there was no manufacturing defect found in the tube.

#### 5. References

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