Failure Analysis of Gas Collection Tubes Cracking in Hydrogen Production Reformer

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Abstract: By means of OM, SEM and EPMA and grain size assessment, the cracking failure of gas collection tubes of hydrogen production reformer was investigated based on the process. In this paper, the damage characteristics of Incoloy 800H alloy under high temperature oxidation and the failure mechanism of cracking are explained. The microstructure characteristics of Incoloy 800H after servicing are analyzed. The general relationship theory between element segregation and material cracking is also analyzed. The results show that internal oxidation preferentially along grain boundaries and element segregation took place in the inner wall of Incoloy 800 H at high temperature, where the alloy might experience an evolution of reaction process such as internal oxidation, followed by carbide decomposition and then by carbide segregation, as a result, the precipitation strengthening effect was weakened and the grains were coarsened. During the whole process, the carbon content decreased, the high temperature creep resistance of grain boundary in melt zone decreased gradually, and the overall composite stress led to the initiation and propagation of cracking in Incoloy 800H alloy.

1. Introduction

Incoloy 800H is an alloy composed of Fe, Ni and Cr, which is widely used in hydrocarbon + steam converter. Due to the dispersion strengthening mechanism, Incoloy 800H alloy has good high temperature creep and corrosion resistance, which hinders the grain boundary sliding and improves the grain boundary strength [1]. It is found from the actual operation of the gas collection tubes at the outlet of the reformer in the hydrogen production unit that the tubes are made of Incoloy 800H nickel alloy by centrifugal casting process. The specification is generally Φ402.6mm×48mm, the working temperature is 785 ℃, the working pressure is 2.8MPa and the medium inside tubes is H2 + CO + CO2 + CH4 + H2O, wherein the volume ratio of H2 is 78%, the volume ratio of CO is 8.5%, the volume ratio of CO2 is 8%, and the volume ratio of CH4 is less than 7%. This is a complete set of gas collection tubes at the outlet of reformer in hydrogen production unit. After 9 years of use, cracking was found in the gas collection tubes at the outlet of reformer during the maintenance of hydrogen production unit. From the perspective of alloy, the service life of 9 years is not long, so why the cracking on the tube wall is caused? This is worthy of the discussion in this paper, especially the mechanism and reason. In this discussion, we also need to use optical metallographic microscope, scanning electron microscope (SEM) and other electronic equipment and probe microscope to analyze.

2. Failure Analysis of the Process of the Cracking on Gas Collection Tubes of the Hydrogen Production Reformer

2.1 Incoloy 800h, Centrifugal Casting Forging, 9-Year Service Analysis

The header wall thickness is 61 mm. According to Nb/t47013.6-2018--- “Nondestructive testing of pressure equipment”, the surface cracking morphology of forgings is detected by penetrant testing. In the field, 10 mm × 10 mm × 60 mm specimens are cut axially with a grinder, and regular specimens are made by wire cutting. According to GB / t14993-2015---” Classification and

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designation for superalloys and high temperature intermetallic materials", determination of chemical composition by wkx-9 portable spectrometer, the rust layer on the surface of the metallographic sandpaper was ground off and use ultrasonic to clean and be polishing with alcohol, chemical erosion treatment with aqua regia, using tajx-03 metallographic inverted microscope to observe metallographic structure, using gsm-80000f SEM and jxa-8250 EPMA to observe precipitates during forging and determinate precipitate composition. Macroscopically check the outer wall of the gas collection tubes and polish it to check the penetration. There are cracks along the circumference on the surface of the outer wall of the tubes. In order to check whether there is cracking in the gas collection tubes, the grinding machine is used to cut along the pipeline radial direction, and the temperature of base metal is controlled below 180 ℃ during cutting. Through penetrant testing, it is found that there are a lot of dense circular cracks in the pipe section.

2.2 Chemical Composition Analysis

The chemical composition of the scraped sample near the ring gap was analyzed. Compared with the change of chemical composition before the use of the gas collector, the carbon content after use is higher than the standard range, and a large number of carbon elements gather, making the tubes wall brittle. In the analysis of other elements content, it is found that there is no statistical change before and after use ($P > 0.05$), and there is no difference in the standard range [2]. The transverse specimen was taken near the circular crack for metallographic examination. The microstructure concludes austenite + carbide and grain boundary hole. Micro-cracks are formed by the connection of holes along the crystal. There are a lot of massive precipitates near the micro-cracks. According to gb6394-2018--- "Metal-methods for Estimating the Average Grain Size", the grain size of the gas collector after use is 1-2; according to the product quality certificate, the grain size of the gas collector before use is ASTM 6 and above. The results of metallographic analysis show that the structure of gas collector is deteriorated obviously, and there are creep holes and creep cracks in the structure. Particle size test shows that the structure of gas collector coarsens after use.

2.3 Precipitate Analysis

Some changes of morphology and characteristics in the structure near the crack were observed by SEM, mainly the dispersion and distribution of precipitates in the structure was found, which was the phenomenon of massive precipitation, gathered near the grain boundary, and the area was not small. And there are some massive sediments, which are also quantitatively analyzed. These components are mainly the products of chromium carbide and oxide, and the most of them are titanium carbide. It can also be seen that titanium material plays a major role in the cracking of gas collection tubes. As for the Incoloy 800H alloy used in the gas collection tubes of the hydrogen production reformer, the key to improve the process is to analyze the components of these different metal elements and get the improvement methods and their respective proportions.

3. Failure Analysis of Gas Collection Tubes Cracking in Hydrogen Production Reformer

3.1 The Binding Forces of Alloy Elements Cr, Fe, Ni and o Decrease in Turn

The alloy has been used in high temperature oxidation environment for a long time, which causes strong chemical changes. Under sufficient oxygen partial pressure, a large number of chromium oxides are preferentially precipitated at the grain boundary. With the diffusion of Cr in the grain boundary, the Cr carbide dispersed in the grain boundary decomposes and the Cr Element segregates to the grain boundary. When the gas collector is used for a long time in the high temperature process environment of $H_2 + CO + CO_2 + CH_4 + H_2O$, the external carbon concentration is hundreds of times higher, and the C atom is easy to penetrate and diffuse into the metal structure, forming the cementite Fe_3C at the grain boundary, resulting in the increase of carbon content in the chemical composition of the gas collector after use [4]. When the content of C atom in the grains increases and exceeds the solution limit of the matrix, excess C atom will combine with alloy elements and precipitate in the form of massive carbide [4]. A large number of

carbides precipitated and coarsened in the chromium poor area of the grain boundary, weakening the role of grain boundary strengthening. In the process of high temperature service, the grain coarsens gradually, resulting in the decrease of grain boundary creep resistance [5]. Micropores are formed at the interface between the massive carbide and the adjacent grains and grow towards the interface of the other side and the austenite grains. The adjacent holes are gradually connected to form a cracking source. The gas collector in use is manufactured by centrifugal casting process. It is inevitable that the grains in the internal structure grow along the circular wall gradually, and the cracking source will continue to grow along the overlapping grain layer [5], forming a circular crack.

4. Conclusion

In view of the cracking of Incoloy 800H alloy in the gas collection tubes of hydrogen production reformer, this paper has carried on the analysis regarding this. It is mainly the physical and chemical reaction under the high temperature oxygen environment, which leads to the decomposition and aggregation of Cr carbide in the crystal, especially the aggregation at the grain boundary is coarser, which also affects the role of the grain boundary itself, thus weakening the grain boundary strengthening. This is due to the gradual coarsening of grain size. However, chromium carbide segregates at the grain boundary, forming creep holes, which are very vulnerable to cracking under the action of relative stress. From this point of view, it is necessary to improve the alloy material to meet and realize the function of prolonging the service life of the gas collection tubes of the hydrogen production reformer.

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