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High temperature failure of natural gas feed burner pipe

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ABSTRACT

The degradation of AISI 310 austenitic stainless steel pipe, which was used at high temperature in carbonaceous reducing atmosphere, was investigated in this work. In order to examine the causes of failure, various techniques including on-site investigation, optical microscopy, scanning electron microscopy, energy dispersive spectroscopy, X-ray diffraction, metallography, and micro-hardness measurement were carried out. Scale separation and spallation were only observed at the internal surface of the pipe as a result of overheating service condition at the tip portion. The scale separation and spallation caused nozzle block and subsequent furnace shutdown. Growth of carbide precipitates and disintegration of alloys into dusts of coke and particles suggested carburization and metal dusting failure. It is recommended to monitor service temperature periodically at the tip portion. The service temperature should not exceed the designed value. Careful control of oxidizing/carburizing burning condition is strongly advised. Material selection is also discussed as an alternative means of failure prevention.

1. Introduction

The energy crisis due to an increasing oil price may cause growing production cost for Thai industries, especially high productivity plants. According to this critical situation, many industries in Thailand, particularly refractory kilns, tend to use natural gas as an alternative fuel due to its relatively low cost and high heat flux. The incentive is not only for cost reduction, but also to comply with the Royal Thai Government policy. However, many problems during production occurred during the initial and transitional periods.

In the present work, the refractory production has experienced the failure of pipes and nozzles used for natural gas feeding. The pipes were made of heat-resistant AISI 310 stainless steel and were severely degraded after being in service for only 1 month. AISI 310 stainless steel is a conventional austenitic iron-based alloy, which is widely used for high temperature application and aggressive environment, especially in petrochemical, chemical, power, and nuclear industries [1,2] due to their good heat and corrosion resistance [3,4]. Moreover, high chromium and nickel contents in these materials also enhance their resistance to carburization and hot gas corrosion.

The pipe has an outside diameter of 34 mm, thickness of 3.5 mm, and length of approximately 1 m. Natural gas consisting of CH_4 (75%), CO_2 (13%) and a small amount of other hydrocarbon were transported through a pipe at pressure up to 100 mbar above atmospheric pressure. The initial temperature inside the pipe is in the range of 313–323 K. The pipe was externally heated to the temperature of approximately 1173 K, which is the maximum designed value. The deterioration of the burner pipe occurred in a short service time relative to downtime and replacement cost. Detailed investigation of the failure of the burner pipe is presented in this paper.

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2. Experimental

On-site investigation was conducted to monitor the service condition including temperature measurement using the infrared pyrometer, and the specimen collection for laboratory testing. The selected pipe was thoroughly examined visually using a stereo microscope in order to identify the characteristics of the failure that occurred. Thickness measurements were performed to evaluate the material loss using a vernier caliper. Later, a bulk composition of the damaged pipe was analyzed using a spark emission spectrometer in comparison with the specification. Structure and surface morphology of the spalling scale were investigated using X-ray diffraction (XRD) and scanning electron microscope (SEM), respectively. After that, the samples were cross-sectional cut and prepared for microstructural analyses following these steps; cold mounting in resin, grinding with silicon carbide paper, polishing with diamond suspension, and etching in a solution containing one part of HNO_3 and four parts of HCl with H_2O_2 as a catalyst. The microstructural analyses were done using a reflected light microscope and SEM together with chemical microanalyses with an energy dispersive spectroscopy (EDS). At the final step, Vickers micro-hardness tests with a load of 300 g were used to obtain hardness profile along the cross-section in order to confirm the carburization behavior.

3. Results

3.1. Visual examination

During on-site investigation, the end of the pipe was observed during operation as orange-yellow in color as shown in Fig. 1. It is consistent with a pipe that has been used above normal operating temperature (1173 K). After taking out the pipe from the furnace and immediately measured the temperature, it was found that the temperature of the outer surface of the pipe is in the range of 1323–1373 K, which is higher than the designed value (1173 K). The temperature inside the furnace monitored using an infrared pyrometer was 2003 K. After sampling the specimens for laboratory testing, the degraded pipe (Fig. 2a) was visually examined. Severe degradation was mostly found on the inner surface of the tip portion. This indicated that pipe was exposed to severe carburising environment. Formation of blackish-gray scale with a thickness of about 0.4–0.5 mm and separation of the scale from the base material were observed (Fig. 2b). Careful examination of the spalling scale revealed the characteristics of deposited carbon or coke and metal particles. Material cracking and bulging were not noticed.

Thickness measurements of the failed pipe were done at the end part of three samples and showed that the thickness was reduced from 3.5 mm to 2.8 mm. This suggested that the spallation of scales was rapidly removed from the surface and failure of the pipe was observed after one month of service.

3.2. Chemical composition analyses

Bulk chemical composition of the tested specimen using spark emission spectrometer is presented in Table 1. The results are in agreement with the specification of AISI 310 standard [5].

Furthermore, in order to identify the structure of the spalling scale, XRD with Cu Kα as a radiation source was employed to characterize the structure of the phase. It can be seen that the scale consists mainly of chromium oxide and chromium-iron carbide as shown in Fig. 3. Such compounds are frequently formed on the alloy surface exposed to reducing/carburizing environment [2].

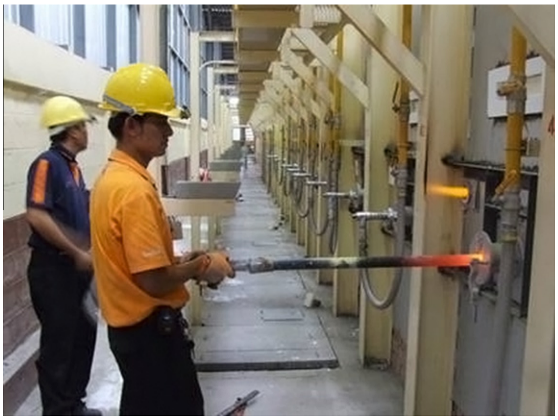

Fig. 1. The appearance of pipe during operation.