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Technical Report

Variations of the microstructure and mechanical properties of HP40Nb hydrogen reformer tube with time at elevated temperature

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ABSTRACT

Hydrogen reformer furnaces have been widely used in the petrochemical industry to produce the hydrogen-rich gas from a mixture of hydrocarbons and steam at high temperature. However, the degradation of material microstructure was frequently encountered in the tubes due to high temperature service, leading to their premature failure. The aim of this paper was to address the variations of the microstructure and mechanical properties of HP40Nb hydrogen reformer tubes after aging treatment and long-term service at temperature of 900 °C. The results showed that the grain boundaries became coarsening due to the precipitation of the chromium-rich carbides and the secondary carbides precipitated in the matrix after aging treatment and long-term service. The mechanical properties of the HP40Nb tube obviously degraded after short-term service and then almost kept unchanged. The interdendritic carbide content can be used as a key index for the life predication of the used tube since there was a linear relationship between the logarithm of carbide content and the logarithm of time.

1. Introduction

Reformer furnace tubes are the key components to produce hydrogen-rich gas from a mixture of hydrocarbons and steam at elevated temperature. Normal operating conditions of these reformer tubes are rather severe with working temperature around of 800–1000 °C and working pressure of 5–40 kgf/cm^2 [1]. These tubes act as reaction vessels for the catalytic conversion of steam and natural gas to hydrogen to produce ammonia, methanols, etc. [2–4]. According to the American Petroleum Institute Recommended Practice 530 [5], the furnace tubes are generally designed for a nominal life of 100,000 h (11.4 years). However, since these tubes are exposed to high temperature and high pressure, cracking and premature failures of the tubes due to creep and fatigue [6–8] often occurred within the normal expecting lifetime of the tubes. The actual service life varies from 30,000 to 180,000 depending on the quality of materials and the service conditions [9].

Centrifugally cast creep-resistant austenitic stainless steels such as HP Grade (25Cr, 35Ni, and 0.4C) have been widely used as alloys for fabrication of the tubes in reforming operations. After short-term service at elevated temperature, the material microstructure was generally subjected to degradation which accumulated with time. Carbon precipitation occurred in the early stages. The coalescence and coarsening of the carbides may result in embrittlement and reduction of strength. Further degradation may lead to creep cavities, cavity coalescence, microcracking and final propagation of macro-cracks. As the damage occurred inevitably in the tubes, a lot of researches have been performed in the past two decades to describe the mechanisms of the premature failures and propose the model for the life prediction of tubes [2,4,10]. Most of these models were proposed considering the service temperature and internal gas pressure with suitable and frequently large safety factors applied to laboratory stress rupture data. In such a case, the microstructure and mechanical property changes of the tube were often ignored and the material properties were considered to be constant. Hence, most of the existing model may lead to large error in the life prediction. Therefore it is necessary to illuminate the variations of microstructure and mechanical properties of the tubes during the operation along with time to determine the remaining lifetime of the tubes prior to tube failure.

The purpose of this paper was to investigate the material microstructure and evaluate the mechanical properties of the HP40Nb hydrogen reformer tubes after different service time. This work, in turn, will provide some insights into the material design and development of a modified model for the life prediction for the tube.

2. Experimental procedures

The chemical compositions of as-cast HP40Nb tube were listed in Table 1. The experiments in this work can be categorized into two groups. In the first group, the microstructure and mechanical properties of the aging-treated specimens with different aging

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