The Study on High Temperature Degradation of AISI 1020 Low Carbon Steel in the Carburization State

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Abstract

This research was aimed to study the high temperature degradation of AISI 1020 carbon steel pipe under the carburizing atmosphere. This environment was prepared by a mix of powdered charcoal and $CaCo_3$ catalysts and then simulated at temperature of 1000°C for 1, 2 and 4 hours. The variation in the weight of the aged steel specimens was obtained by the measured metal loss at various working periods. The light optical microscope was used to observe the microstructural changes of aged steel samples. The results revealed that the prolonged operating period decreases the weight of samples and the degradation occurs on the outer surface of the pipes. The study also indicated the microstructural difference between the inner and outer wall of the steel pipe, which is resulted from the changes in chemical compositions during the carburizing process.

Keywords: Low Carbon Steel; High Temperature Degradation; Carburization

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1. Introduction

Low carbon steel AISI 1020 is widely used in different industries due to its versatilities, e.g. its relatively low cost, attractive machinability, and excellent weldability (Lai et al., 1990) In addition, this steel is a ductile material. It also possesses a good forming ability. Thus, various applications of this steel can be found in our society, such as Infrastructures, automobile parts, and food containers. This steel is also frequently used in the high temperature applications, i.e. the pressure vessel and piping, heat exchanger system, flue-gas stack, and waste incinerator. In this application, this steel has to be subjected to the severe service conditions like the oxidizing / carburizing atmospheres at very high temperature. In the carburizing environment at the elevated temperature conditions, the decomposition of carburizing gases (CO_2/CH_4/CO) can release the carbon atoms, which can further diffuse to the steel structure and subsequently reduce the ductility of steel by changing the steel microstructure (Hong-shi et al., 1999) Besides, the high temperature oxidation conditions can cause the rapid thinning rate on the steel surface. Hence, this environment substantially decreases the mechanical performance of this steel. This obviously leads to the premature failure of equipment made from this steel, resulting in the unplanned shut down in many industrial processes. So, the investigation on the high temperature degradation with the evolution of the degrading microstructure of this steel exposed to this severe environment is of great essential. In addition, this information can further be developed to be a Fitness – For - purpose assessment method (API 579) for the AISI 1020 carbon steel pipe exposed to the high temperature degradation.

In this current research, the degradation of the AISI 1020 carbon steel pipe was investigated. The main aim of this study is to study the high temperature degradation with the microstructure evolution of this steel exposed to this simulated oxidizing / carburizing atmospheres.

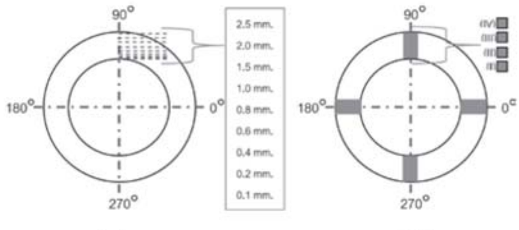
2. Research Methodology

2.1 Specimen and simulated oxidizing/ carburizing environment preparation

AISI 1020 carbon steel pipe with the dimension of 76 mm. (Outside Diameter) x 100 mm (length) x 3 mm (thickness) was used as the specimens of this study. The composition of this steel was (wt. % Fe bal.): 0.2C, 0.22Si, 0.66Mn, 0.01P, and 0.02S. The simulated oxidizing / carburizing environment was prepared in the closed chamber using the mix of powdered charcoal and $CaCO_3$ catalysts with the ratio of 8:2. The simulated environmental conditions in this chamber were maintained at 1000°C for different holding time at 1, 2 and 4 hrs. Each specimen was then placed inside the chamber to subject to the simulated oxidizing / carburizing atmospheres at elevated temperature. Each test was repeated three times to observe the correlation between the weight loss and the number of testing.

2.2 The examination of the degraded steel

The physical degradation examination of steel exposed to the simulated oxidizing / carburizing environment was initially carried out on both fresh and aged specimens. To obtain the degradation rate of specimens, the weight change of specimens before and after exposure was performed using the electric balance. The hardness profile of steel after exposure was conducted in accordance with NACE Standard TM 0498-98 using micro-vicker hardness test (HMV).



(a) (b)

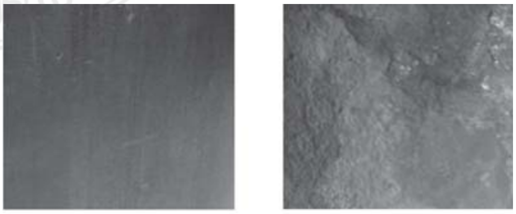
Figure 1 The positions of this microstructure observation (a) hardness profile and (b) microstructure

The hardness measurement was performed at the position of 0°, 90°, 180° and 270°, respectively. Each of measurement in hardness profile was carried out at 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0 and 2.5 mm from inner to outer pipe, as indicated in Figure 1 (a). The observation of changes in the microstructure after exposure to the simulated oxidizing / carburizing atmosphere was examined using the light optical microscope. For the observation in microstructure, the experiments were carried out at (I), (II), (III) and (IV) in the positions of 0°, 90°, 180° and 270°, as shown in Figure 1 (b).

3. Result and Discussion

3.1 The examination in the surface appearance of specimen

Figure 2 shows the surface conditions of the outside of the steel pipe specimen before and after exposure in the simulated oxidizing / carburizing environment with the controlled temperature of 1000°C.



(a) (b)

Figure 2 Surface appearance of the outside surface of the specimens (a) before and (b) after exposure to the simulated oxidizing / carburizing environment

From Figure 2 (a), it is evident that the surface condition of the fresh specimen was smooth. Nevertheless after exposed to the simulated oxidizing / carburizing environment, the rough surface of the specimen was observed. The presence of the remaining oxide products or scales on the steel surface was also noticed. Usually, the oxidizing / carburizing environment contains gas constituents such as CO, CH_4, CO_2 and H_2O (Hung-Wen et al., 2000) All can be considered as the corrosive agents to steel. In addition, the high temperature can cause the decomposition process of those gas components, causing the release of carbon, hydrogen, and oxygen to steel substrate. In this condition, the high temperature can also enhance the kinetic activity of carbon, hydrogen, and oxygen (Revie et al., 1994) This results in the rapid oxidation on the steel surface, leading to formation of the oxide scales on the steel surface.

Figure 3 Oxide scales spalling from the surface of the aged specimen

Normally, the oxide product layers in of steel under the simulated oxidizing / carburizing environment are discontinuous and loosely adhered to the surface (Jones, 1992). Thus, it is non-protective. The different thermal expansion of steel can potentially enhance the spalling of the corrosion scales (McCafferty, 2010), as displayed in Figure 3 The prolonged exposure time and the increase in the number of the exposure cause the rapid formation of the oxide scales.

3.2 The variation of specimen weight and the microstructure evolution

The variation in the weight of the steel samples after the simulated oxidizing / carburizing environment with the different holding times and number of exposure is shown in Figure 4.

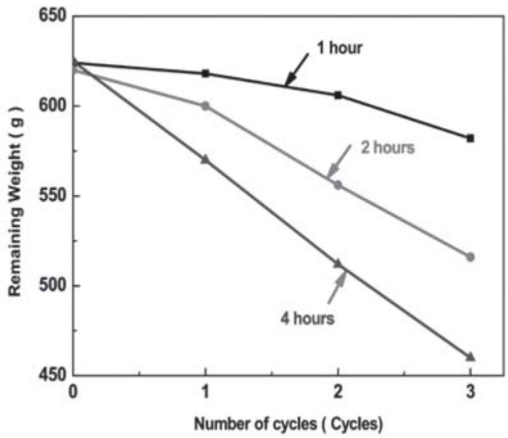


Figure 4 The variation in the weight of the steel specimens exposed to the simulated oxidizing / carburizing environment with the different holding times and number of exposure

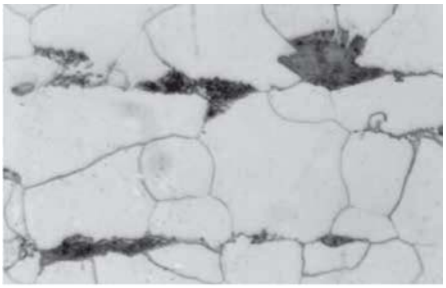


Figure 5 The microstructure of fresh specimen from Figure 4, the weight of specimens basically decreases after exposure and when the exposure time is longer and the number of the exposure is increased, the weight of specimen significantly decreases

Figure 5 exhibits that the microstructure of fresh specimen has the ferrite matrix containing the small amount of pearlite.

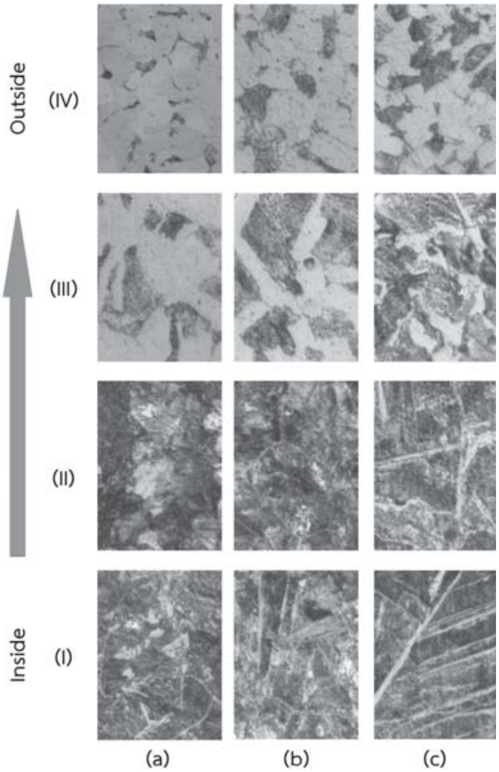


Figure 6 The microstructure evolution of steel exposed to the simulated oxidizing / carburizing environment (from the inside to outside of the specimen as indicated by (I) - (IV) with the difference in the holding times of 1-4 hrs. labeled by (a) - (c))

Figure 6 reveals the microstructure evolution of steel in four parts (from the inside to outside of the specimen as indicated by (I), (II), (III) and (IV) with the difference in the holding times (1, 2 and 4 hrs. labeled by (a), (b) and (c)). The evolution of microstructure of steel in four parts in Figure 6 explains as follows:

In region (I) and (II), the microstructure of these areas is composed of pearlite, carbides and, carbide networks. Actually, these regions are close to the inside of the pipe specimens. So, the ingress of excess carbon atoms from the simulated carburizing environment can take place directly in region (I) and (II), leading to the formation of carbides and carbide networks. Thus, the presence of carbides and carbide networks indicates the fact that region (I) and (II) had experienced more carburation (Shreir et al., 2000) On the contrary, in region (III) and (IV), the microstructure of this area consists of ferrite and pearlite. In fact, these kinds of the microstructure are commonly found in the fresh specimen as shown in Figure 5 In addition, region (III) and (IV) are close to the outer part of the pipe specimens and the increase in the distance from the inner pipe decreases the amount of the carbon atom taken up (Kaya, et al., 2002) Then, this condition does not promote the occurrence of carbon-enriched phases, i.e. carbide and carbide networks, in both regions (Kaya, 2002). Hence, the presence of ferrite and pearlite points out that region (III) and (IV) had undergone less carburization (Serna et al., 2003) Therefore, the difference in the microstructure is related to the amount of carbon atoms, released from the simulated carburizing environment.

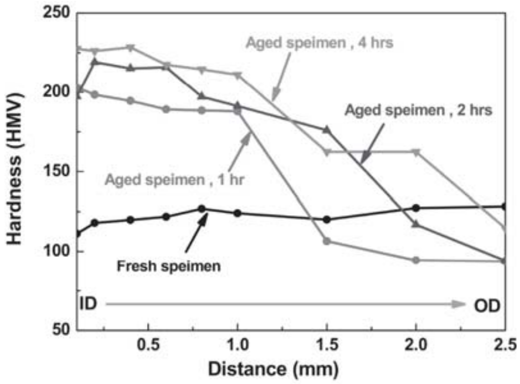


Figure 7 The hardness profile of the fresh specimen and aged specimens after exposure to the simulated oxidizing/carburizing environment at 1000°C with different holding times of 1, 2 and 4 hrs

Figure 7 shows the hardness profile of the fresh specimen and aged specimens after exposure to the simulated oxidizing/carburizing environment at 1000°C with different holding times of 1, 2 and 4 hrs. The hardness measurement was carried out from the inside to the outside of the specimen (0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, and 2.5 mm). It can be seen from Figure 7 that the harness of all positions increases with increasing in the holding time. Usually, the presence of carbides and carbide networks in steel increases the hardness of steel (Xinga et al., 2006) Hence, the formation of carbide and carbide networks observed from the microstructure evolution in region (I) and (II) of Figure 6 contributes to the increased hardness of aged samples. However, the hardness tends to decrease with increasing in the distance from the inside of the specimen. Besides, after the distance around 1.5 mm from the inside of the specimens, the hardness tends to significantly decrease and becomes less than that of the fresh specimen. Normally, low carbon steel can be greatly degraded after exposed to the high temperature oxidation environment (Chowwanonthapunya et al., 2016) Oxidation, decarburization and grain growth can possibly occur (Anzel et al., 2012) and then deteriorate the desired mechanical properties of steel, particularly hardness and strength (Rahmel et al., 1998) Thus, the degradation of steel subjected to the high temperature oxidation environment accounts for the decreased harness profile. All findings are in agreement with Figure 6 that the different microstructure results in the different harness.

4. Conclusions

The high temperature degradation of AISI 1020 low carbon steel exposed to the simulate oxidizing /carburizing environment was systematically investigated. The study revealed that the steel was further degraded when the time of exposure is prolonged. The microstructure evolution showed that the degradation initially started at the outside of the specimen. Besides, the difference in the microstructure from the outside to inside of the pipe specimen was clearly noticed, which can be ascribed to the change in the chemical compositions in the different carburizing stages. The hardness profile suggested that the highest hardness was found at the inside of the specimen and it gradually decreased with increasing in the distance from the outside of the specimen.

5. Acknowledgment

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