Influence of Al Concentration on the High Temperature Cyclic Oxidation Resistance Behavior of Fe-15Cu Alloys

Lingyun Bai, Xianchao Xu, Junhuai Xiang[a], Songping Wang, Ting Wang

Jiangxi Key Laboratory of Surface Engineering, Jiangxi Science and Technology Normal University, Nanchang 330013, China

[a]xiangjunhuai@163.com

Keywords: high temperature oxidation resistance; Fe-15Cu; Al concentration; the oxide film

Abstract. The cyclic oxidation behaviors of Fe-15Cu alloys with different Al concentration at 800 ^{o}C were studied. The oxidation kinetics showed that the oxidation process of Fe-15Cu alloys followed the parabolic law, Fe-15Cu-5Al alloy was oxidized more seriously than that of Fe-15Cu-15Al alloy. Analysis of the XRD results indicated that the oxides obtained on the lower Al concentration alloy was more complicated and the matrix metals were oxidized heavily, on the other side, the oxides obtained on the surface of Fe-15Cu-15Al alloy were simple, while the Al_2O_3 broke off from the surface, there were mainly pure matrix metals left as detected by the XRD and the SEM methods. The higher Al concentration gave the higher oxidation resistance of the alloy, but the adhesion of the protective Al_2O_3 should be improved in the next work.

1. Introduction

High temperature oxidation resistance alloys are such kind of materials with fine structure stability and corrosion resistance, which could be used up to or higher than 650 ^{o}C. Usually these kind of materials comprises Co, Ni and Fe based alloys, and also contained Al, Cr or Si components, which would form the protective films, such us Al_2O_3, Cr_2O_3 or SiO_2[1-3]. Among theses matrix, Fe-Al alloys exhibit outstanding oxidation, corrosion resistance because of the formation of protective Al_2O_3 scale on the materials' surface and also fine high temperature mechanical properties (Ref 7-9) so they were widely studied[4-6].

Al concentration will affect the oxidation resistance properties obviously, but the practical data still not be founded, so in this work, the Fe-15Cu alloys with different Al concentration were studied to research the oxidation properties of these alloys, in order to investigate the mechanism of the higher Al component in improving the oxidation resistance properties of the alloy.

2. Experimental

The alloys were prepared by melting 99.9% Fe, 99.95% Cu and 99.99% Al in a vacuum arc furnace repeatedly. The ingots were annealed at 900 ^{o}C in vacuum annealing furnace (~1.3Pa) for 24 h and cut into $10\times10\times1.2$ mm^3 pieces by wire-electrode cutting, polished on SiC waterproof abrasive papers, then washed in distilled water, alcohol and acetone and dried immediately before use. The oxidation tests were carried out by oxidizing the specimen in atmosphere at 800 ^{o}C for 50 minutes, and then cooling in air for 10 minutes as one circle, the whole process included 24 circles. The mass change measurements of the specimens were carried out by electronic balance after cooling during each oxidizing circle. X-ray diffraction analysis (XRD), scanning electron microscopy (SEM) and energy-dispersive X-ray microanalysis (EDX) analysis were used to establish the crystal type, composition and spatial distribution of the oxidation products.

3. Results and Discussion

3.1 Oxidation Kinetics

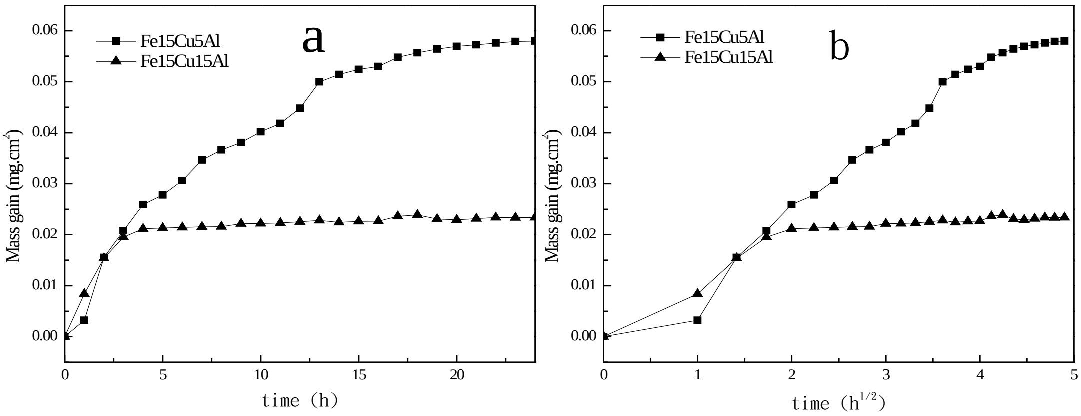

Fig.1 cyclic oxidation kinetics curves of Fe-15Cu alloys in atmosphere at 800 ^{o}C for 24 h (a, normal plots b, parabolic plots)

Fig.1 a, b showed the cyclic oxidation kinetics curves and corresponding parabolic plots for the Fe-15Cu-5Al and Fe-15Cu-15Al alloys at 800 ^{o}C for 24 h, respectively. It indicated that cyclic oxidation of the Fe-15Cu-5Al alloy approximately obeyed the parabolic rate law, and the parabolic rate constants were 2.89×10^{-10} $g^2cm^{-2}s^{-1}$ for the first stage (0 to 360 min), 5.37×10^{-11} $g^2cm^{-2}s^{-1}$ for the second stage (360 to 960 min), and 5.31×10^{-11} $g^2cm^{-2}s^{-1}$ for the last stage, respectively. The mass gain increased obviously at the initial stage and then gently. On the other side, the oxidation kinetics of Fe-15Cu-15Al alloy was composed of two stages, with the parabolic rate constant of 2.31×10^{-11} (0 to 300 min) and $2.07x10^{-12}$ $g^2cm^{-2}s^{-1}$ (300-1440 min), respectively.

3.2 XRD Analysis

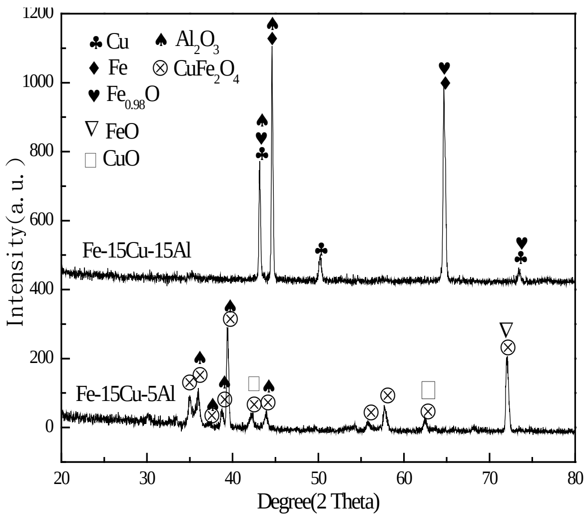

Fig.2 XRD curves of Fe-15Cu alloys in atmosphere at 800 ^{o}C for 24 h

Fig.2 showed the XRD analysis of the Fe-15Cu alloys. The oxidation film formed on the Fe-15Cu-5Al alloy after 24 h oxidation at 800 ^{o}C was more complex, which was composed of $CuFe_2O_4$ (34-0425), Al_2O_3 (49-0134), Cu_2O (34-1354) and FeO (06-0711). On the contrast, when the content of Al was heightened to 15 percent, that is for the Fe-15Cu-15Al alloy, the oxides on the surface were more simple. Because of bad adhesion between the protective oxide film Al_2O_3 and the matrix alloy, the main peaks were belong to the Fe (06-0696) and Cu (04-0836). From the analysis of the results, it could be see that, more Al_2O_3 film could be formed with higher Al content, and the other content of the matrix alloy were lightly oxide.

3.3 Cross-sectional Microstructure and Composition

Fig.3 showed the cross-sectional morphology and concentration distribution of elements of oxide scales formed on Fe-15Cu-5Al alloy cyclic oxidized at 800 ^{o}C for 24 h. The results showed that, serious and uneven oxidation was happened to the Fe-15Cu-5Al alloy. The outer region was mainly composed of oxides of Fe and Al, and the inner region was oxides of Al and Cu.

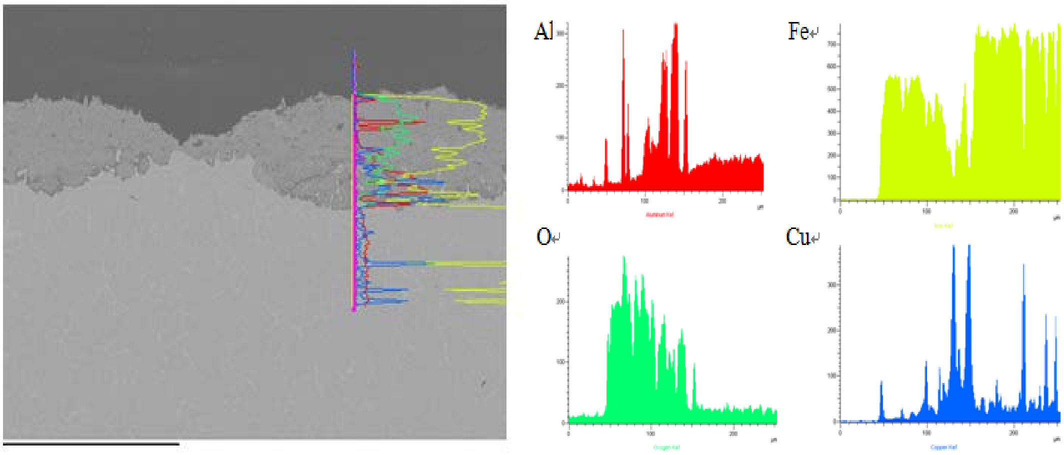

Fig.3 Cross-sectional morphology and concentration distribution of elements of oxide scales formed on Fe-15Cu-5Al alloy

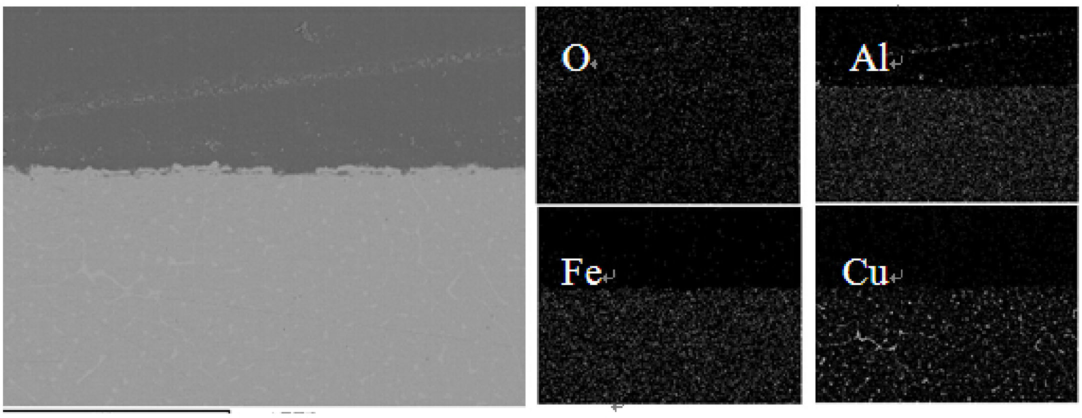

Fig.4 Cross-sectional morphology and concentration distribution of elements of oxide scales formed on Fe-15Cu-15Al alloy

Fig.4 showed the cross-sectional morphology and elements distribution of oxide scales formed on Fe-15Cu-15Al alloy cyclic oxidized at 800 ^{o}C for 24 h. The results showed that slightly oxidation was happened to the alloy, there was few oxides founded on the surface of the alloy and the outer Al_2O_3 layer was removed from the surface during the sealing progress, because of the poor adhesion between Al_2O_3 and the matrix. This result was consistent with the XRD result, which showed the obvious matrix peaks in the curve.

Al concentration affected the oxidation progress of the Fe-15Cu alloys obviously, lower concentration such as Fe-15Cu-5Al alloy was oxidized heavily, and the oxides were complex, there was no continuous Al_2O_3 layer which acted as the protective factor formed on the surface of the alloy. When the concentration of Al was heightened to 15 at.%, the oxidation resistance of the alloy oxidized at 800 ^{o}C was reinforced clearly. Few matrix elements were depleted during the oxidation progress, because of the high concentration of the Al which had more active property and was oxidized at first. On the other side, the protective Al_2O_3 layer formed on the surface of the Fe-15Cu-15Al alloy had poor adhesion with the matrix, which would affect the practical application of the alloy, so research on the fine adhesion of the Al_2O_3 film would be developed in the next work.

4. Conclusion

(1) The oxidation process of Fe-15Cu alloys followed the parabolic law, and the lower Al concentration caused more serious oxidation.

(2) Fe-15Cu-15Al alloy had favorable high temperature oxidation resistance, with the parabolic rate constant of 2.31×10^{-11} (0 to 300 min) and $2.07\text{x}10^{-12}$ $g^2cm^{-2}s^{-1}$ (300-1440 min), respectively.

(3) The adhesion of the Al_2O_3 film obtained on the surface of Fe-15Cu-15Al alloy was bad, so the cyclic oxidation resistance of the alloy was not good.

References

[1] Kurt P Rohrach. Development and selection of high temperature alloys[J]. Aerospace materials and technology, 2005, (01): 61~62

[2] Naoya Masahashi, Go Kimura, Masaoki Oku, et al. Corrosion behavior of iron-aluminum alloys and its composite steel in sulfuric acid[J]. Corrosion Seienee, 2006, Vol. 48(4):829~839

[3] Katarzyna Pietrzak, Dariusz Kalinskix, Marcin Chmielewski. Interlayer of A12O3-Cr functionally graded material for reduction of thermal stresses in aluminum-heat resisting steel joints[J]. Journal of the European Ceramic Soceiety, 2007, Vol. 27(2~3): 128

[4] N. Masahashi, G. Kimura, M. Oku, K. Komatsu, S. Watanabe, and S. Hanada, Corrosion Behavior of Iron-Aluminum Alloys and Its Composite Steel in Sulfuric Acid, Corros. Sci., 2006, 48, p 829–839.

[5] F. Lang, Z. Yu, S. Gedeyanishvili, S.C. Deevi, S. Hayashi, and T. Narita, Sulfidation Behavior of Fe-40Al Sheet in H_2-H_2S Mixtures at High Temperatures, Intermetallics, 2004, 12, p 469–475.

[6] Y.S. Li and M. Spiegel, Internal Oxidation of Fe-Al Alloys in a KCl-Air Atmosphere at 650 °C, Oxid. Met., 2004, 61, p 303–322.