The oxidation of Fe-30Al alloys in 1 atm of pure O_2 at 973 K and 1173 K

Yao CHEN[2], Xianchao XU[2], Long LI[2], Honghua ZHANG[1,2], Junhuai XIANG[1,2,a]

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

[2]School of Materials and Mechanical & Electrical Engineering, Jiangxi Science and Technology Normal University, Nanchang 330013, China

[a]xiangjunhuai@163.com

Key words: Fe-30Al, Isothermal oxidation, High temperature

Abstract. The isothermal oxidation of Fe-30Al alloys in 1 atm of pure O_2 at 973 K and 1173 K was investigated. Fe-30Al alloy oxidized slowly at 973 K but much faster at 1173 K, especially during the transient oxidation stage. The mass gain of the alloy at 973 K after 24 h oxidation is only about 0.1 mg/cm^2, much smaller than the corresponding value of 0.6 mg/cm^2 at 1173 K, indicating that the oxidation resistance at 973 K is much better than that at 1173 K. The scales formed at both temperatures are mainly composed of Al_2O_3, coupled with a little Fe_2O_3. It is obviously that the protective Al_2O_3 layer formed on Fe-30Al at 973 K show better homogeneity and integrality than that at 1173 K.

Introduction

Intermetallic materials combine excellent characteristics of both metals and ceramics due to the coexistence of the metallic bonds and covalent bonds in the structures. Among various intermetallics, iron aluminides possess many advantages including low densities and low materials. The Al-rich ferritic aluminides are generally considered to be of good oxidation resistance because of their ability to form a protective Al_2O_3 scale under some special high temperature environment. These advantages have led to the identification of several potential uses, such as structural member in aircraft, piping tubing for automotive industries. Furthermore, iron aluminides have also been considered as the materials for varieties of anti-wear applications. Due to their practical importance, the oxidation mechanism of complex alloys has been investigated frequently during last few years. However, effect of temperature on oxidation behavior of multi-component alloys is very complex [1-7].

The aim of present work is to investigate the influence of temperature on the oxidation behavior of Fe-30Al alloys, which is of great importance for establishing the basic high temperature oxidation theory of Fe-Al intermetallics and for understanding the effect of temperature on more complex systems.

Experimental

The experimental materials (Fe.99.9%, Al.99.99%) were all purchased from Jiangxi ketai advanced material Co., Ltd. They were cleaned with acetone and then alcohol in ultrasound oscillator. The alloys were prepared by repeated melting appropriate amounts of the two components under a Ti-gettered inert atmosphere using non-consumable tungsten electrodes. The alloy ingots were annealed for 24 h at 1173 K in vacuo (~1.3 Pa) to achieve a better equilibration of the alloy phases, and cut into 10×10×1.2 mm^3 pieces by spark-erosion machining, and then polished on SiC waterproof abrasive papers. All these specimens were washed in distilled water, acetone and ethanol and then dried in warm air.

Continuous mass change measurements of the specimens were carried out for 24 h by a Setaram Setsys Evo in 1 atm of pure O_2 at 973 K and 1173 K. The oxidized specimens were characterized using field emission scanning electron microscopy (FESEM) with energy-dispersive X-ray analysis (EDS).

Results and discussion

Oxidation kinetics

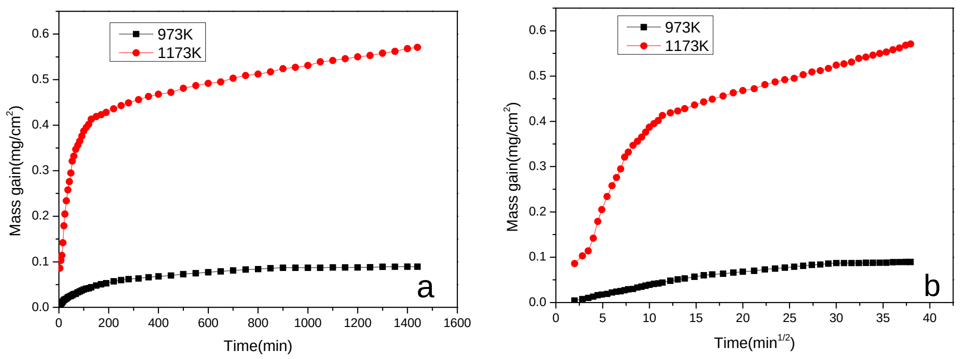

Fig. 1 Isothermal oxidation kinetics curves of Fe-30Al alloys at 973 K and 1173 K for 24 h (a) normal plots and (b) parabolic plots

Table 1 Approximate parabolic rate constants (k_p) for the oxidation of Fe-30Al system at 973 K and 1173 K

Temperature	Time interval（min）	k_p ($g^2 \cdot cm^{-4} \cdot s^{-1}$)
973 K	0-280	4.66×10^{-14}
	280-950	1.04×10^{-14}
	950-1440	3.15×10^{-16}
1173 K	0-150	4.03×10^{-12}
	150-1440	9.63×10^{-14}

The isothermal oxidation kinetics curves and the corresponding parabolic plots for the oxidation of Fe-30Al alloys at 973 K and 1173 K for 24 h are shown in Fig.1a and 1b, respectively. Approximately parabolic rate constants for the oxidation of Fe-30Al alloys are shown in Table.1. It indicated that the kinetic curve at each temperature can be approximately considered being composed of several quasi-parabolic stages. On the whole, Fe-30Al alloy oxidized slowly at 973 K but much faster at 1173 K, especially during the transient oxidation stage. The mass gain of the alloy at 973 K after 24 h oxidation is only about 0.1 mg/cm^2, much smaller than the corresponding value of 0.6 mg/cm^2 at 1173 K, indicating that the oxidation resistance at 973 K is much better than that at 1173 K.

Scale microstructure and composition

The EDS line scanning analysis of Fe-30Al alloys are shown in Fig.2. Cross-sectional morphology and corresponding element distribution maps of oxide scales are shown in Fig.3 (973 K) and Fig.4 (1173 K) respectively. At 973 K and 1173 K the scales were both composed of Al_2O_3 and Fe_2O_3. In fact, the content of Fe_2O_3 is very limited. Generally speaking, the scales formed at both temperatures are very thin. However, the scale formed at 1173 K is much thicker than that at 973 K. Internal oxidation region has not been found at both temperatures. It is obviously that the protective Al_2O_3 layer formed on Fe-30Al at 973 K show better homogeneity and integrality than that at 1173 K, in accordance with their corresponding oxidation kinetics.

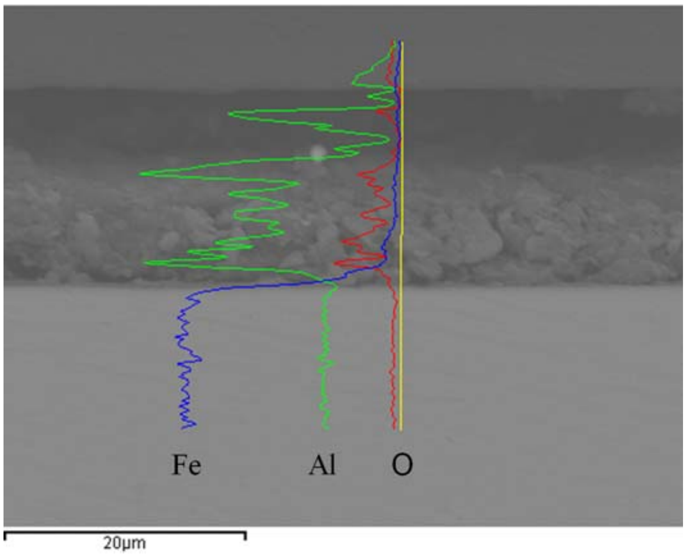

Fig. 2 EDS line scanning of oxide scales formed on Fe-30Al alloy at 973 K for 24 h

It is universally acknowledged that the property of oxidation resistance of Fe-Al alloy is based on the ability of forming protective Al_2O_3 scales on the surface of matrix. A series of studies were carried out to determine the effect of aluminum content and temperature on the oxidation behavior of Fe-Al alloy by SAEGUSA and LEE[8]. The oxidation resistance of Fe-40Al alloys in the temperature range of 1073-1473 K was studied by LANG[9], and the results revealed that Fe-Al intermetallic had excellent oxidation resistance at high temperature. It has been proposed that for a protective behavior at least 8% Al (mass fraction) is necessary at 1073 K[10]. Fe-2.5Al alloy (mass fraction) can form alumina scales which, however, are not fully protective due to the formation of iron oxides in a few period of time. From the description above, the present content of 30 at.% Al is enough to form a protective outer Al_2O_3 layer on the surface of the Fe-30Al alloy.

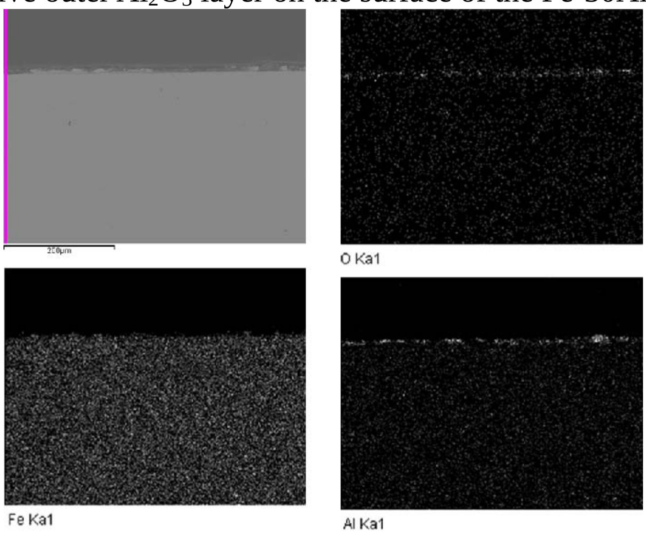

Fig. 3 Cross-sectional morphology and corresponding element distribution maps of oxide scales formed on as-cast Fe-30Al alloy at 973 K for 24 h

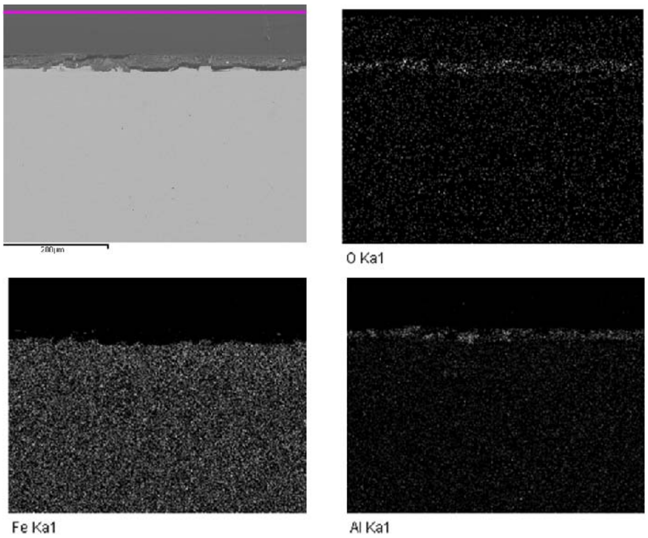

Fig. 4 Cross-sectional morphology and corresponding element distribution maps of oxide scales formed on as-cast Fe-30Al alloy at 1173 K for 24 h

Conclusions

The kinetic curves of Fe-30Al alloys oxidized at 973 K and 1173 K can be approximately considered being composed of several quasi-parabolic stages. The oxidation resistance at 973 K is much better than that at 1173 K. The scales formed at both temperatures are mainly composed of Al_2O_3, coupled with a little Fe_2O_3.The present content of 30 at.% Al is enough to form a protective outer Al_2O_3 layer on the surface of the Fe-30Al alloy.

Acknowledgements

This work was financially supported by Natural Science Foundation of Jiangxi Province (20132BAB206015, 20122BAB216018). and the Graduate Student`s Innovative Project of Jiangxi Province (YC2014-S428).

References

[1] J.H. Xiang, Q. Zhao, W.H. Zhang: T. Nonferr. Metal. Soc. China Vol. 17 (2007), p. 180
[2] H.H. Zhang, J.H. Xiang, H.Y. Sun, et al: Adv. Mater. Res. Vol. 560 (2012), p. 1064
[3] C. Houngniouc, S. Chevalier, J.P. Larpin: Oxid. Met. Vol. 65 (2006), p. 409
[4] C.H. Xu, W. Gao, S. Li: Corros. Sci. Vol. 43 (2001), p. 671
[5] Z.Q. Cao, Y. Niu, F. Gesmundo: T. Nonferr. Metal. Soc. China Vol. 11 (2001), p. 499
[6] D. Siemiaszko, S. Jozwiak, M. Czarnecki, et al: Intermetallics Vol. 41 (2013), p. 16
[7] S. Chevalier, P. Juzon, G. Borchardt, et al: Oxid. Met. Vol. 73(2010), p. 43
[8] F. Saegusa, L. Lee: Corros. Sci. Vol. 22 (1966), p. 168
[9] F.Q. Lang, Z.M. Yu, S. Gedevanishvilil, et al: Intermetallics Vol. 11 (2003), p. 697
[10] P. Tomaszewicz, G.R. Willwork: Oxid. Met. Vol. 19 (1983), p. 165