EFFECT OF ALUMINA-FORMERS ADDITION ON THE ISOTHERMAL OXIDATION OF TI-AL BASED INTERMETALLICS

TAN MING JIUN

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Mechanical- Material)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

DECEMBER 2008

ABSTRACT

The main objective of this study is to investigate the effect of adding the alumina former elements on the isothermal oxidation behavior of Ti-Al based intermetallics. High temperature oxidation test was carried out on Ti-Al based intermetallics namely the Ti-48Al-0.5Ag, Ti-48Al-2Cr-1.5Ag and Ti-48Al-2Cr-1.5Ag-0.5W oxidized isothermally at 900°C. The kinetic rates of oxidation for the intermetallics were near to parabolic and the addition of Chromium (Cr) increased the kinetic rate of oxidation. Examination on the surfaces of oxide scales by using the Field Emission Scanning Electron Microscopy (FESEM), Atomic Force Microscopy (AFM) and the X-ray Diffraction (XRD), revealed that the phases formed on the scale surfaces were dependent on the composition of the base alloy and the kinetic rates of oxidation. Analysis of the scale cross section found that the adherence of the scale to the base alloy improved by the addition of the alumina former elements. Based on the Energy Dispersive X-ray (EDX) spot and line scan analysis performed on the cross sectional of the scale, all the intermetallics showed an Al-depleted zone and the formation of aluminum oxide in the scale even at the early stage of the scale development. This indicated that the outward diffusion of aluminum to form Al_2O_3 is promoted by the addition of alumina former elements. Microhardness-indentation results revealed that the hardness values were different across the cross section of the scale. The hardness was the highest in the scale due to the presence of high TiO_2 content.

ABSTRAK

Tujuan utama kajian ini adalah untuk mengkaji kesan penambahan pembentuk alumina terhadap kelakuan pengoksidaan sesuhu sebatian antara logam Ti-Al. Ujian pengoksidaan suhu tinggi dijalankan ke atas sebatian antara logam Ti-Al seperti Ti-48Al-0.5Ag, Ti-48Al-2Cr-1.5Ag dan Ti-48Al-2Cr-1.5Ag-0.5W secara pengoksidaan sesuhu pada suhu 900°C. Kadar kinetik pengoksidaan untuk sebatian antara logam yang dikaji adalah hampir kepada bentuk parabolik dan penambahan kromium (Cr) telah meningkatkan kadar kinetik pengoksidaan. Pemeriksaan permukaan dengan menggunakan Mikroskop Imbasan Elektron Pancaran Medan (FESEM), Mikroskopi Tekanan Atom (AFM) dan Analisis Pembelauan Sinar-x (XRD) menunjukkan bahawa fasa yang wujud di permukaan kerak adalah bergantung kepada komposisi aloi asas dan kadar kinetik pengoksidaan logam tersebut. Analisis keratan rentas kerak menunjukkan juga perekatan kerak pengoksidaan kepada aloi asas adalah lebih baik dengan penambahan elemen pembentuk alumina. Berdasarkan analisis imbasan garisan dan titik malalui teknik serakan tenaga sinar-x ke atas keratan rentas kerak, terdapat satu kawasan sustan-Al dan kewujudan oksida aluminium di dalam kerak pada peringkat awal perkembangan kerak. Ini membuktikan bahawa resapan keluar aluminium untuk membentuk Al_2O_3 lebih cepat dengan penambahan elemen pembentuk alumina. Keputusan pelekuan mikro-kekerasan menunjukkan nilai kekerasan adalah berbaza di sepanjang keratan rentas kerak. Nilai kekerasan adalah tertinggi pada kerak disebabkan kandungan TiO_2.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Background of the Research

The attractive physical and mechanical properties of ordered intermetallic alloys have been recognized since early in this century. However, periodic attempts to develop intermetallics for structural application were unsuccessful, due to major part to the twin handicaps of inadequate low- temperature ductility and toughness, together with poor elevated temperature performance (Stoloff and Sikka, 1994). After the discovery by researchers in Japan in year 1979 that the ternary alloying elements in the intermetallics are able to improve and overcome these problems, the intermetallics are gaining more and more importance in the structural applications. Intermetallics, specifically the titanium aluminides (Ti-Al) are among the most attractive intermetallics to be used in many industries, for instant in thermal protection systems, engines, aerospace structural materials and aircraft turbines (Uenishi and Kobayashi, 1996; Loria, 2000; Appel *et al.*, 2000; Yamaguchi *et al.*, 2000). This is due to the advantage in terms of low density, specific modulus, specific high temperature strength, creep resistance and oxidation resistance (Kim and Dimiduk, 1995)

1.2 Problem Statement

A high strength to density ratio is of great importance for the design of components, such as blades in aero and industrial gas turbines, which rotate with high speed during service. Most of the recent efforts to develop high strength, lightweight construction materials concentrated on the improvement of the mechanical and oxidation properties of intermetallics compounds containing aluminium.

The lack of oxidation resistance at temperature higher than 800°C however hinders them from being used in industries. Therefore, research works are undertaken in the past decade or so has been concentrated not only on the improvement of mechanical properties but also on the oxidation resistance. So far, the effects of some alloying elements and environmental atmospheres on the oxidation behavior of Ti-Al have been investigated in detail.

Experimental evidence has shown that titanium aluminides with an aluminium content roughly below 50 at.% essentially form nonprotective mixed TiO_2 + Al_2O_3 scales in air in elevated temperature rather than the protective Al_2O_3 scale (Taniguchi *et al.*, 1991; Wallance *et al.*, 1992; Shimizu *et al.*, 1992; Fish and Duquette, 1993; Rakowski *et al.*, 1993). There are little works done on the effects of alumina formers on the high temperature oxidation of these materials. This research focuses on the effect of the alumina formers on the oxidation of titanium aluminides.

1.3 Significance of Research

To improve the performance of the titanium aluminides at elevated temperature, the ternary or even the quarternary elements are added. The additions of these elements are able to alter the activities of the titanium and aluminium, thus changing the thermodynamics and kinetics of the oxidation process.

Alumina formers such as the Niobium (Nb), Silicon (Si), Silver (Ag), Chromium (Cr), Tungsten (W), Vanadium (V), Molydebnum (Mo) etc. are usually added into the binary alloys to enhance the formation of the alumina scales and increase the oxidation resistance at elevated temperature (Liu and Narita, 2004). The research done by Liu and Narita also showed that the TiAl-10~15 Cr and TiAl-Ag are both alumina formers. Besides improving the oxidation resistance of the Ti-Al alloys, the addition of silver also slightly increase the surface hardness at 900°C due to the Ti (Al, Ag) precipitates. The effects of the element addition are highly dependent on the amount of addition, type of alloying element and the working environment subjected. For example, the implantation of the carbon (C) on the titanium aluminides to increase the oxidation resistance however showed a dentrimental effect on its oxidation resistance (Li and Taniguchi, 2004). Besides that, previous research also showed that the Ti-52Al-5Cr-2Ag was an alumina former in 'dry' air but it formed non- protective oxides such as "cauliflower" like TiO_2 and the mixture of TiO_2 and Al_2O_3) in "wet" air. It was also observed that when 3%Ag was added, the continuous Alumina scale was formed, which increases the oxidation resistance (Liu and Narita, 2004).

The previous work performed on the titanium aluminides were more focused on the effects of the ternary elements on the mechanical properties and little work was carried out on the effects of alumina formers on the oxidation kinetics. As the titanium aluminides are emerging as potential candidates in the applications of structural and high temperature field, the oxidation resistance is also becoming more importance. This research will focus on the kinetics and behavior of these materials with addition of different alumina formers elements.

REFERENCES

Liu, Zhenyu and Narita, Toshio (2004). *Oxidation Behavior od TiAl (Cr, Ag) at 900°C in Water Vapor*, Intermetallics 12 (2004) 459- 468.

Zheng, Kai, Gao, Wei and Liang, Jing (2004). *Molten Salt Vapour Corrosion of Ti-Al- Ag intermetallics*, Intermetallics 12 (2004) 539- 544.

Liu, Zhenyu and Narita, Toshio (2004). *The Effect of Water Vapor on the Oxidation Behavior of γ- TiAl-Ag coatings at 1073K in air*, Intermetallics 11 (2003) 795- 805.

Gerling, R., Schimansky, F.P., Stark, A., Bartels, A., Kestler, H., Cha, L.,Scheu, C. and Clemens, H. (2008), *Microstructure and Mechanical Properties of Ti 45Al 5Nb + (0-0.5C) Sheets*, Intermetallics xx (2008) 1-9.

Li, X.Y. and Taniguchi, S. (2005). *Oxidation Behavior of a γ- TiAl- based Alloy implanted by Silicon and/ or Carbon*, Materials Science and Engineering A398 (2005) 268- 274.

Schumacher, G., Dettedwanger, F., Schutze, M., Hornauer, U., Richter, E., Wieser, E. and Moller, E. (1999), *Microalloying Effects in the Oxidation of TiAl Materials*, Intermetallics 7 (1999) 1113-1120.

Kofstad, P. (1988). *High Temperature Corrosion*, Elsevier Applied Science Publisher Ltd., New York, 1988.

Jones, Denny A. (1996). *Principles and Prevention of Corrosion*, Prentice Hall, Upper Saddle River, NJ 07458.

Birks, N. and Meier, G.H. (1983). *Introduction to High Temperature Oxidation of Metals*, Edwards Arnold Ltd., London.

Fontana, Mars G. (1987). *Corrosion Engineering*, McGraw-Hill, Inc.

Sauthoff, Gerhard (1995). *Intermetallics*, Weiheim; New York; Basel; Cambridge; Tokyo: VCH, 1995.

Khana, A.S. (2004). *Introduction to High Temperature Oxidation and Corrosion*, ASM International.

Huang, S.C. and Chesnutt, J.C. (1995). *Gamma TiAl and its Alloys*, John Wiley & Sons Ltd.

Astuty Amrin (2004). *High-Temperature Oxidation of Titanium Aluminides*, Ph.D. Thesis,Universiti Teknologi Malaysia, Skudai.

Nurfhashahidayu binti Mohd Badri (2006). *Cyclic Oxidation of Ti-Al Based Intermetallic in Laboratory Air*, Bachelor Degree Thesis, Universiti Teknologi Malaysia, Skudai.

Stoloff, N.S. and Sikka, V.K. (1996). *Physical Metallurgy and Processing of Intermetallic Compounds*, Chapman & Hall.

Kekare, S.A. and Aswath, P.B. (1997). *Oxidation of TiAl Based Intermetallics*, Chapman & Hall.

Wu, Y., Umakoshi, Y., Li, X.W. and Narita, T. (2006). *Isothermal Oxidation Behavior of Ti-50Al Alloy with Y Additions at 800 and 900°C,* Springer Science and Business Media, LLC.

Jiang, Zh.G., Chen, B., Liu, K. and Li, Y.Y. (2006), *Effects of Boron on phase transformation of high Nb containing TiAl-based alloy*, Elsivier Intermetallics 15 (2007) 738-743.

THIRUMAHRAN A/L SELVARAJA (2006). *A Study of Scales Development on High Temperature Isothermal Oxidation of Titanium Aluminide in Flowing Dry Air*, Bachelor Degree Thesis, Universiti Teknologi Malaysia, Skudai.