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MICROSTRUCTURE AND MECHANICAL PROPERTIES OF γ-TiAl INTERMETALLIC ALLOYS PRODUCED BY IN-HOUSE MADE ARC-MELTING PROCESS

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ABSTRACT

Arc melting process using an in-house made arc melting furnace was satisfactorily used to produce γ-TiAl based intermetallic alloys with compositions of Ti-48Al, Ti-48Al-2Cr, and Ti-48Al-2Cr-2Mo (in at.%). The phases and microstructure of the produced alloys were characterized using X-Ray diffraction, and scanning electron microscope (SEM) respectively. Mechanical tests were performed at room temperature. The results show that the microstructure of Ti-48Al consists of regions containing α_2 and γ lamellae surrounded by γ grains. For Ti-48Al-2Cr and Ti-48Al-2Cr-2Mo, the microstructures consist of colonies containing α_2 and γ lamellae. In all microstructures, some Ti-rich phases in the lamellar grains and at grain boundaries were also revealed. Measured density had slightly increased when alloyed with Cr and heavy alloying element of Mo. The hardness values of γ-TiAl alloys are relatively high exceeding 50 HRC. Compared with Ti-48Al, the fracture strength in compression of Ti-48Al-2Cr at room temperature was increased, believed to be due to solid solution strengthening of Cr. For Ti-48Al-2Cr-2Mo, the highest fracture strength was achieved, as the results of solid solution strengthening of Cr and Mo. Compared with Ti-48Al, the presence of Cr in Ti-48Al-2Cr and Ti-48Al-2Cr-2Mo had enhanced compressive fracture strain.

Keywords: γ-TiAl; Arc-melting process; Microstructure; Hardness; Compression strength

INTRODUCTION

Gamma TiAl intermetallic based alloys are among the most promising intermetallics and have received a great deal of attentions as advanced materials for high temperature applications such as components in aerospace vehicles, aircraft turbine, and automotive engines, due to their high specific yield strength, high specific stiffness, good oxidation resistance, and good creep properties [1,2]. The constituent phases of γ-TiAl alloys always consist of γ-TiAl (ordered face-centered tetragonal $L1_0$ structure) as the matrix phase and α_2-Ti_3Al (ordered hexagonal DO_{19} structure) as the major second phase [1,3]. γ-TiAl alloys without α_2-Ti_3Al phase, even with low interstitial impurity levels (< 1000 wt. ppm), tend to fracture at room temperature before reaching 0.5-1.0 % plastic strain in tension. Engineering alloys based on the γ-TiAl phase usually have Al concentrations of 45-48 at.% and thus solidify peritectically according to the phase diagram shown in Figure 1 [3]. After solidification, binary γ-TiAl alloys pass through the single-phase field of α solid solution, which decomposes on further cooling according to the reactions $\alpha \rightarrow \alpha + \gamma \rightarrow \alpha_2 + \gamma$ or $\alpha \rightarrow \alpha_2 \rightarrow \alpha_2 + \gamma$.

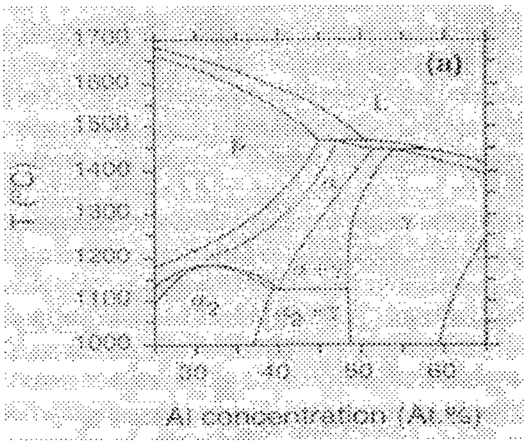

Fig. 1. Binary Ti-Al Phase diagram showing phase equilibria in a concentration range of 45-48 at.%Al [3].

It is well known that the mechan γ-TiAl alloys can be improved various alloying elements. The additions of Cr, Mn, and V were reported to lead to improvement of the room temperature ductility of two-phase alloys, since these elements can enhance plasticity by stabilizing thermal twins that provide nucleation sites for twinning dislocations [3-6]. The other researchers have found that Cr also contributes to α_2-dispersion strengthening in Cr-containing γ-TiAl alloys [7]. Alloying with Mo and Nb enhanced the tensile strengths at room- and elevated-temperatures. These elements are grouped into solid solution strengthening elements [3,8].

Basically, the as-cast microstructure would consist of colonies comprised of γ and α_2 lamellae. Fully lamellar microstructures are beneficial for high temperature strength, fracture toughness and creep resistance, but suffer from poor ductility at low and ambient temperature. For high temperature applications, lamellar alloys probably provide the best balance of mechanical properties [1-3,9].

In producing γ-TiAl alloys, arc-melting in vacuum condition is the most widely used process [10-11]. Then melting and casting process has been of greater interest for producing components such as turbine blades and automotive exhaust valves [10]. The advantages of the process are melting process conducted in short time, allowing to remelt several times to ensure good homogeneity of ingots, and it is appropriate for melting highly reactive elements.

In this study, γ-TiAl alloys with alloying elements of Cr and Mo were produced by arc melting process using an in-house made arc melting furnace. Microstructural features of the γ-TiAl alloys were presented. Physical property and mechanical properties were evaluated.

EXPERIMENTAL

Fig. 2 show an in-house made arc-melting furnace with important parts indicated. The DC power for this arc melting furnace is supplied by TIG welding machine. Argon gas is used to provide protective environment for melting. Melting is carried out in a water cooled copper crucible with the size of melting cell of 35 mm dia. x 20 mm in-depth.

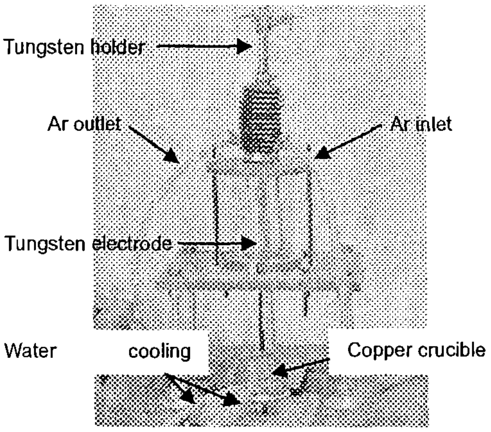

Fig. 2. Photograph of an In-house made arc-melting furnace.

The raw materials used in this study were in powder form. Powders of titanium (average size of 83.81 μm and purity of 99.7 %, STREM Chemicals), aluminium (average size of 72.53 μm and purity of 95.7 %, BDH Laboratory supplies), molybdenum (average size of 122 μm and purity of 99.96 %, STREM Chemicals), and chromium (average size of 50.92 μm and purity of 99 %, STREM Chemicals) were used as starting materials. The powders were initially prepared to the desired compositions of Ti-48Al, Ti-48Al-2Cr, Ti-48Al-2Cr-2Mo (in at.%) that are further designated as alloy 1, alloy 2, and alloy 3 respectively. Then they are thoroughly mixed in a plastic bottle for 5 hours. The mixture was compacted in a die by applying a hydraulic press with a pressure of 100 MPa. The size of pellet was 25 mm in diameter. The compact was then ejected from the die cavity at the top by using an ejector, which travels from bottom to top. The compacts were placed and melted in the melting cell of a copper crucible. The DC current of 200 amperes and the DC voltage of 18 V that generate a melting temperature of approximately 2000 °C were used for melting of compacts and a maximum quantity of 17 g ingot of γ -TiAl alloy can be produced. Melting was performed eight times to ensure good homogeneity of ingots.

Diamond-coated blade cutting tool was used to cut ingots into samples. X-ray diffraction (XRD) technique and SEM were used to analyze the phase formed and microstructural features of samples respectively. Metallographic samples were polished and etched in a solution of 10 vol.% HNO_3, 5 vol.% HF, and 85 vol.% water [12]. Density of cast samples was measured by applying gas pycnometer technique on an Accu Pyc 1330 Micromeritics. Hardness test was performed using a Rockwell type hardness tester LECO. A cubic specimen 7 X 7 X 14 mm in size was cut and used for the test in compression. All specimens were polished before testing. Compression test were carried out in air at room temperature by Shimadzu universal testing machine (UTM) with a crosshead speed of 0.5 mm/min.

RESULTS AND DISCUSSION

X-Ray Diffraction Patterns

Fig. 3 shows the XRD patterns of the as cast alloys produced from the arc-melting process. It can be found from the diffraction result that alloy 1 predominantly contains γ phase and a minor amount of α_2 phase (Fig.3a). This is expected since the equilibrium phase diagram indicates the presence of two phases for this nominal composition, Ti-48Al (in at.%). Based on the XRD pattern of alloy 2 (Fig. 3b), the addition of Chromium results in an increase in intensity of the second strongest line belonging to α_2 phase in alloy 2. Thus, the relative content of α_2 phase is higher in alloy 2 than in alloy 1. On the other hand, the addition of Cr combined with the refractory element of Mo in alloy 3 result in slightly higher content of the α_2 phase than that of the γ phase (Fig. 3c). This can be understood from the fact that the addition of 2 at.% Cr would stabilizes the α_2 phase and Mo is also α_2 stabilizer [13].

Microstructure of as-cast alloys

Fig. 4 shows back scattered electron (BSE) images of as cast alloys produced by arc-melting process. The microstructure of alloy 1 consists of regions (colonies) containing α_2 and γ lamellae surrounded by γ grains and of some Ti-rich phase in the lamellar grains and at grain boundaries (Fig. 4a). The chemical composition of the Ti-rich phase was measured by EDS, and its analysis results were 68.01 at.% Ti and 31.99 at.% C. Based on this results, It is suspected that incorporated carbon in Ti-rich phase most probably comes from raw elemental powders. With the addition of 2 at.% Cr, the microstructure of alloy 2 was found to consist of colonies containing α_2 and γ lamellae and there is also some Ti-rich phase in the lamellar grains and at grain boundaries (Fig. 4b). In a similar manner to the alloy 2, with the addition of 2 at.% Cr and 2 at.% Mo, the microstructure of alloy 3 consists of colonies containing α_2 and γ lamellae and of some Ti-rich phase in the lamellar grains and at grain boundaries (Fig. 4c). However, the relative content of Ti-rich phase in alloy 3 is lower than the content of that in both of alloy 1 and 2.

Properties of γ-TiAl Intermetallic Alloys

Measured density of γ-TiAl alloys produced by arc-melting process using in-house arc melting furnace is shown in Fig. 5. Alloy 1 has a density of 3.97 g/cm^3 and agrees well with measured density of γ-TiAl based alloys ranging from 3.9-4.1 g/cm3 that was well documented in literature [11]. Due to the additions of alloying elements, particularly heavy elements, density of γ-TiAl based alloys would increase. In this case, the density of alloy 2 alloyed with Cr slightly increase, whereas with the addition of 2 at.% Mo, density of alloy 3 was increased to 4.14 g/cm^3.

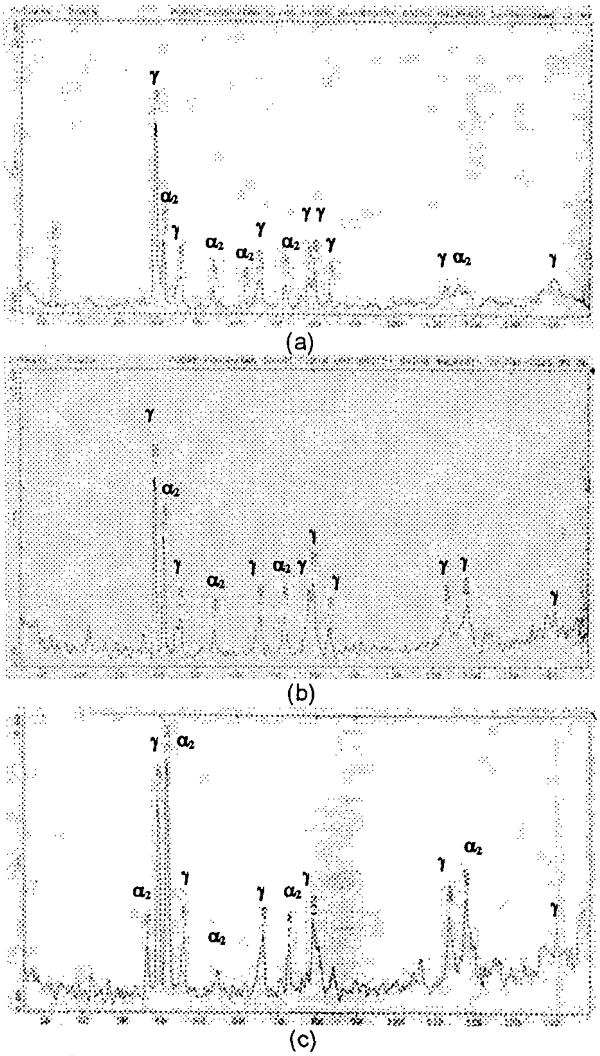

Fig. 3 XRD patterns of as-cast alloys: (a) Ti-48Al, (b) Ti-48Al-2Cr, and (c) Ti-48Al-2Cr-2Mo.

The results of hardness test of γ-TiAl based alloys are shown in Fig. 6. It can be seen that the hardness values of γ-TiAl alloys are relatively high exceeding 50 HRC. With additions of alloying elements, either the addition of Cr or the addition of both Cr and Mo, the hardness values had slightly decreased. In this case, it is clear that additions of alloying elements of 2-4 at.% show a weak sensitivity to little composition changes of alloying elements.

The fracture strengths in compression of three alloys at room temperature are shown in Fig. 7. The fracture strength in compression of alloy 1 is 755 MPa. With the addition of 2 at.% Cr for alloy 2 and with addition of both 2 at.% Cr and 2 at.% Mo for alloy 3, the fracture strengths had increased to 929 MPa and 1092 MPa respectively. The increased fracture strength in alloy 2 is most likely attributed to solid solution strengthening due to the presence of Cr. For the case of alloy 3, solid solution strengthening due to Cr and Mo plays an important role in obtaining higher compressive fracture strength than that of alloy 1 and 2.

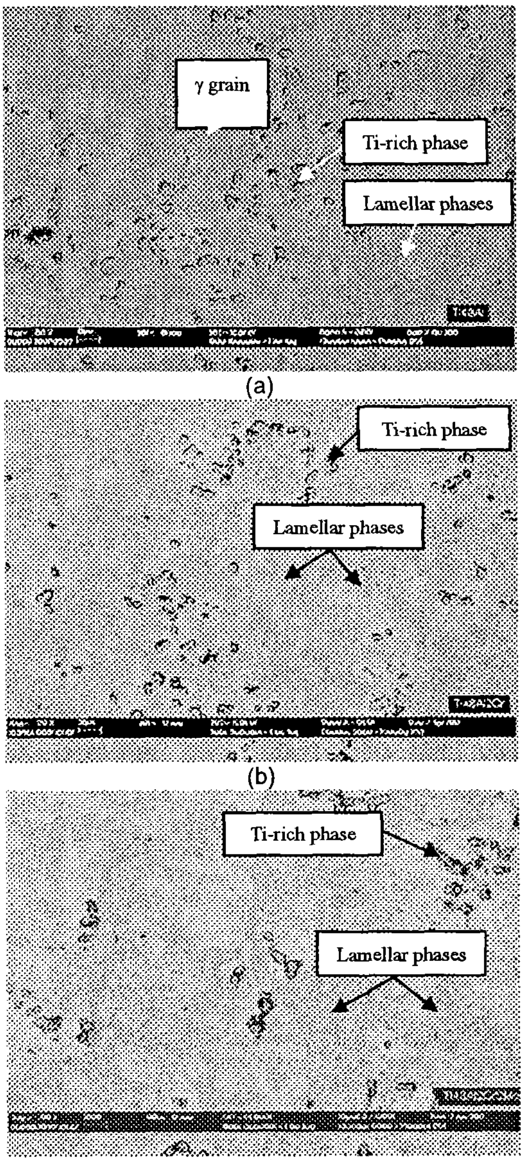

Fig. 4. Back Scattered Electron (BSE) images showing the microstructures of as cast alloys: (a) Ti-48Al, (b) Ti-48Al-2Cr, and (c) Ti-48Al-2Cr-2Mo.

Fig. 8 shows the fracture strain in compression (compressive ductility) of three alloys at room temperature. The fracture strain in compression of alloy 1 is 7 %. With additions of Cr to alloy 2 and 3, the compressive fracture strains were increased to 14 and 16 % respectively. Therefore, the presence of Cr in alloy 2 and 3 can enhance ductility in compression.

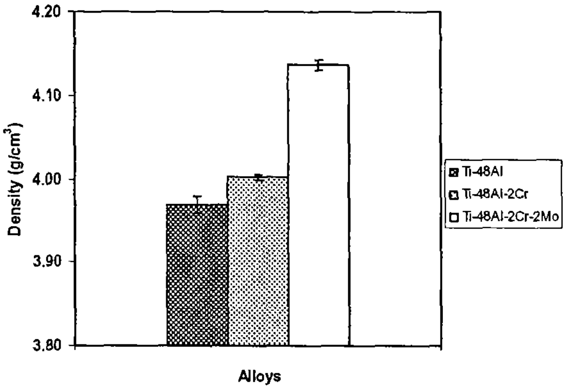

Fig. 5. Measured density of as cast Ti-48Al, Ti-48Al-2Cr and Ti-48Al-2Cr-2Mo alloys.

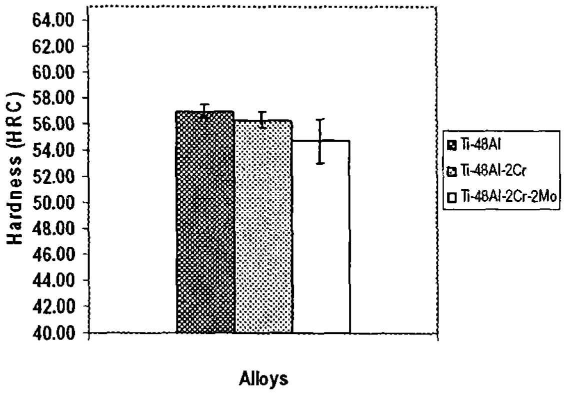

Fig. 6. Results of Rockwell Hardness test for as cast Ti-48Al, Ti-48Al-2Cr and Ti-48Al-2Cr-2Mo alloys.

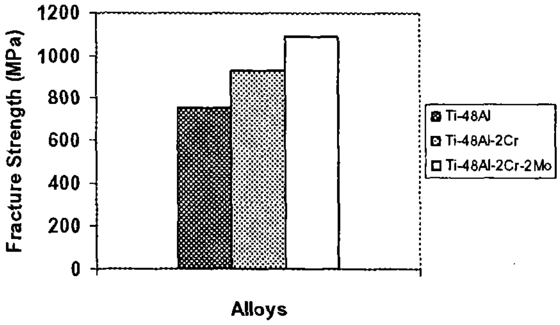

Fig. 7. Compressive fracture strength at room temperature for as cast Ti-48Al, Ti-48Al-2Cr and Ti-48Al-2Cr-2Mo alloys

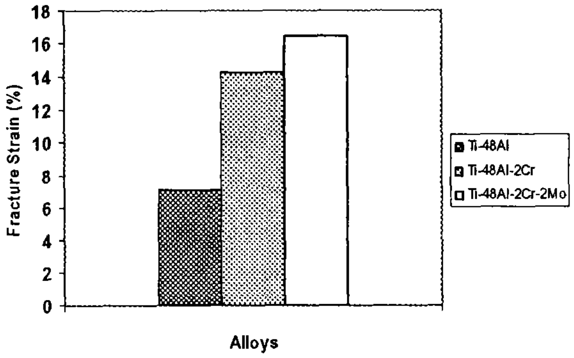

Fig. 8. Fracture strain (ductility) in compression at room temperature for as cast Ti-48Al, Ti-48Al-2Cr and Ti-48Al-2Cr-2Mo alloys

CONCLUSIONS

1. The microstructure of TiAl (alloy 1) consists of regions (colonies) containing α_2 and γ lamellae surrounded by γ grains and of some Ti-rich carbide phase in the lamellar grains and at grain boundaries. For the alloys alloyed with Cr and Mo: Ti-48Al-2Cr (alloy 2) and Ti-48Al-2Cr-2Mo (alloy 3), the microstructures consist of colonies containing α_2 and γ lamellae and some Ti-rich phase also is distributed in the lamellar grains and at grain boundaries. The content of Ti-rich phase in both alloy 1 and 2 was qualitatively found higher than the content of that in alloy 3.
2. The alloy 1 have a density of 3.97 g/cm^3, 4.00 g/cm^3 for the alloy 2, and 4.14 g/cm^3 for the alloy 3.
3. Hardness values of γ-TiAl alloys selected in this study are relatively high exceeding 50 HRC. With additions of alloying elements, either the addition of Cr only or the additions of both Cr and Mo, the hardness values had slightly decreased.
4. Compared with alloy 1, the fracture strength in compression of alloy 2 at room temperature was increased, resulting from solid solution strengthening due to Cr, whereas for alloy 3 the highest fracture strength was achieved, resulting from solid solution strengthening due to Cr and Mo.
5. The fracture strain in compression of alloy 1 is 7 %. The compressive fracture strains of alloy 2 and 3 were increased to 14 and 16 % respectively. The presence of Cr in alloy 2 and 3 can enhance ductility in compression.

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