9

FABRICATION OF γ-TiAl INTERMETALLIC ALLOYS VIA HOT PRESSING TECHNIQUE

H. Usman, A. Fauzi M. N., and R. Astrawinata

School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang

E-mail address: husni@eng.usm.my, afauzi@eng.usm.my, arizal@eng.usm.my

ABSTRACT

Gamma titanium-aluminide (γ-TiAl) based alloys are potentially suitable as advanced structural materials for high performance applications such as components in aerospace vehicles, aircraft turbine, and automotive engines due to their unique and superior properties at high temperatures. Hot pressing combined with mechanical alloying (MA) has been reported as favourably as fabrication route to produce various alloys from elemental powders since they offer high densification, particularly for consolidation of reactive elements, as well as elements with significantly different melting points. In this study, formation and densification behavior of γ-TiAl alloys was investigated using mechanical alloying and hot pressing at temperatures ranging from 950-1100 °C. The resulting phases were analyzed using X-Ray diffraction (XRD, the physical and mechanical properties were also determined.. The hot pressing and MA was found to be effective to obtain densification up to 99 % at hot pressing conditions of 1100 °C and 60 min, with γ-TiAl phase as dominant phase.

Keywords: γ-TiAl, mechanical alloying (MA), hot pressing, densification.

INTRODUCTION

Gamma-TiAl intermatallic alloys are potentially suitable as advanced structural materials for high performance applications such as components in aircraft turbine engines, aerospace vehicles and automotive engines due to low density, high strength and high elastic modulus, excellent creep and oxidation resistance at high temperatures (Noda, 1998 & Wilshire, 1994). However, in processing of γ-TiAl intermatallic alloys using powder metallurgy route , the presence of reactive elements such as titanium, aluminum and chromium has become a challenge in order to achieve fully densified components.

Literature showed that vacuum hot pressing, which combines pressure and sintering process, has been successfully used to compact superalloy powders (Gessinger, 1984). Similarly, hot pressing has been used to consolidate mechanically alloyed γ-TiAl alloys resulting in the production of fully dense bulk alloys with fine grained microstructures (Dutkiewicz et. al., 2003 & Szewczak et al., 1999). Recent work carried out to study densification behaviors of conventional titanium alloy powder (Ti-4Al-4V) using hot pressing can also produce compacts with high relative density (Kim & Yang, 2001).

In this study, hot pressing was used to fabricate γ-TiAl intermatallic alloy. Effects of hot pressing temperature and holding time on densification, as well as the phases obtained are reported.

EXPERIMENTAL PROCEDURE

Powders of titanium (size under 83.81 μm and purity of 99.7 %, STREM Chemicals), aluminium (size under 72.53 μm and purity of 99 %, STREM Chemicals) and chromium (size under 50.92 μm and purity of 99 %, STREM Chemicals) were used as starting materials. The powders were initially mixed to prepare a composition of Ti-48Al-2Cr (in at.%). The mixing and milling were carried out at room temperature in the planetary mill (Fritsch Pulverisette P5/4) at a rotation speed of 125 rpm for milling time of 3 hrs. The milling jars and milling media are made from steel. A ratio of ball to powder weight was 10:1 (Szewczak & Wyrzykowski, 1999). A small amount (1 wt. %) of methanol was added to avoid the sticking of powders to milling media (Calderon, 2002). The milled powders were hot pressed at 950-1100 °C and a holding time range of 1-2 h under 29.24 MPa in vacuum condition.

A schematic process of uniaxial die hot-pressing is shown on Fig. 1. A cylindrical die assembly is made from high strength graphite. Interior surfaces of that are protected from reaction with the powders by a boron nitride coating, which has high-temperature lubrication and mold release properties (Mao et al., 2003). The dimensions of hot pressed samples were approximately 33 mm in diameter and 5 mm in thickness. Density measurements were measured on samples by using Archimedes's Method. Hot pressed samples were characterized by X-ray diffraction (XRD) using CuK radiation on a Philips PW 1877. Rockwell hardness tests were carried out using Rockwell Hardness Tester, LECO.

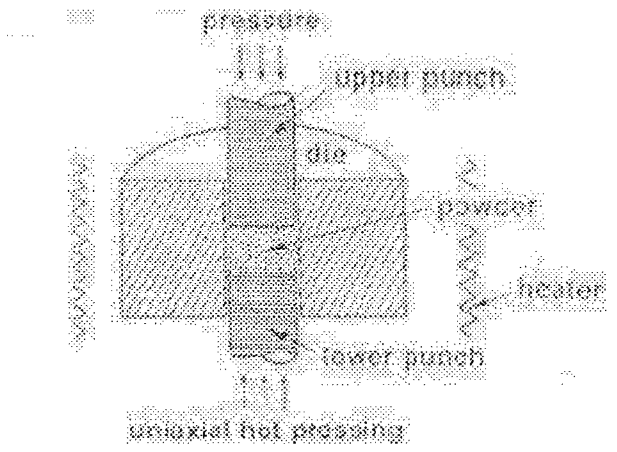

Fig. 1. A schematic process of uniaxial die hot-pressing

RESULTS AND DISCUSSION

Fig. 2 shows densification behavior of the samples densified over hot pressing temperatures at three different holding times. Generally, increasing the temperature of hot pressing would increase the densification. A densification of about 99 % could be achieved with a temperature of 1100 °C with holding times of 60 min and 120 min. Therefore hot pressing is seen as a process potentially to produce highly densified compact. However, influence of holding time is also crucial. Short holding time (in this work, 60 min and 120 min) produced good densification. In fact, as plotted in Fig. 2, it can be seen that a holding time of 100 min had almost achieved high densification, and increasing temperature increased densification slightly (98.3 % to 99.2 % when temperature increased from 950 °C to 1100 °C). With 60 min and 950 °C, lower densification attained, and increasing temperature substantially increased densification. However, a low temperature with longer holding time (950 °C, 120 min) did not produce good densification due to melting of aluminium, hence leaked out of graphite die. At this stage, the leaking from die need to be overcome.

XRD patterns of Ti-48Al-2Cr samples consolidated via hot pressing at various hot pressing conditions are shown on Fig. 3. It was determined that on Fig 3a (for all holding times), Fig 3b and 3c (holding time of 60 and 100 min.) the samples had formed intermetallic phases of γ-TiAl and α_2-Ti_3Al with the first strongest line belonging to γ-TiAl, except for Fig. 3c (holding time of 100 min) in which the first strongest line belongs to α_2-Ti_3Al. In addition to γ-TiAl and α2-Ti_3Al, there is also another phase, which might be a β (B2) phase. The presence of β phase can be understood due to the addition of alloying element of Cr (Jewett, 1997). Chromium and other alloying elements such as Mo, Nb, Mn and V are recognized as β stabilizing elements (Shao & Tsakiropoulus, 1999).

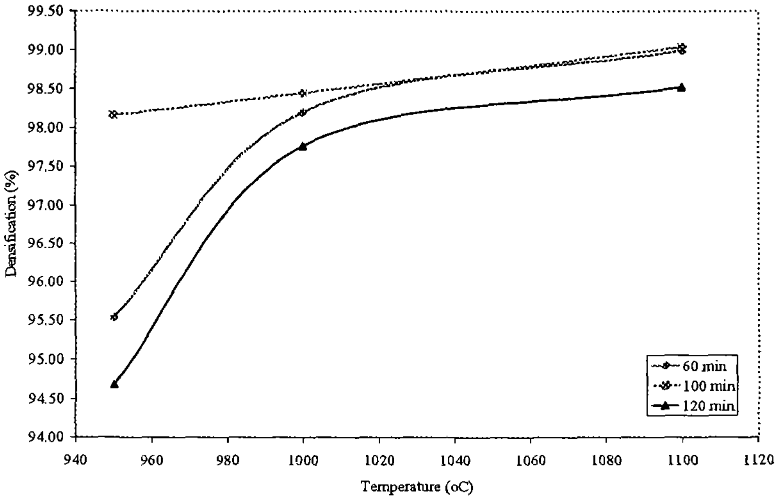

Fig. 2. Effect of hot pressing temperatures and holding time on densification

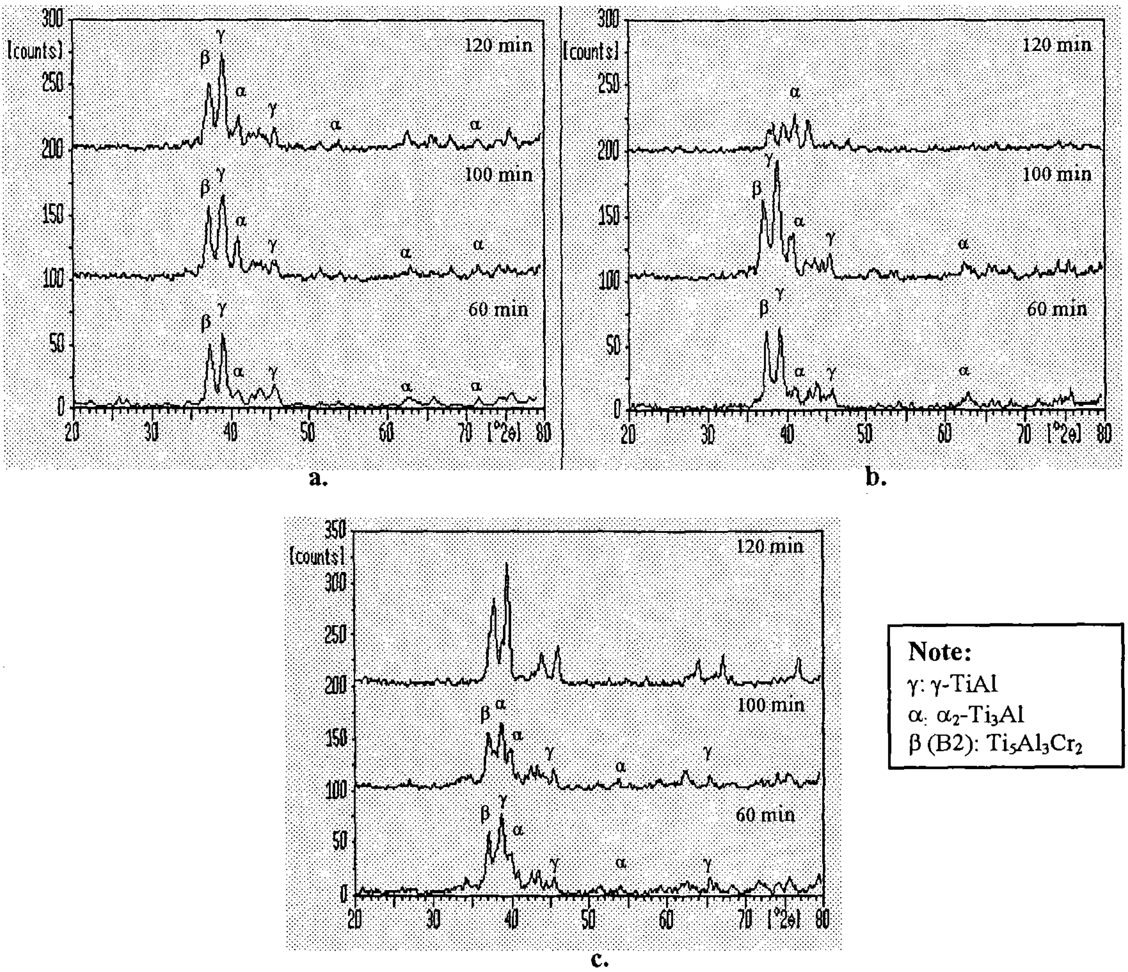

Fig. 3. XRD Patterns of Ti48Al-2Cr samples hot pressed at (a) 950 °C, (b) 1000 °C and (c) 1100 °C

On the other hand, by increasing holding time up to 120 min Fig. 3b, there is no γ-TiAl phase present and only one peak matches with α_2-Ti_3Al phase. At Fig. 3c (holding time of 120 min.) the phases of γ-TiAl and α_2-Ti_3Al are also not present.

Effect of hot pressing temperature on hardness is shown on Fig. 4. In this case, by increasing hot pressing temperature the hardness of samples increases until reaching a maximum hardness at 1100 °C, holding time of 60 min. From Fig. 2 and Fig.3 it was found that as hot pressing temperature increases, at certain holding time, the increase of densification as well as the phase formed had resulted in the increase of hardness.

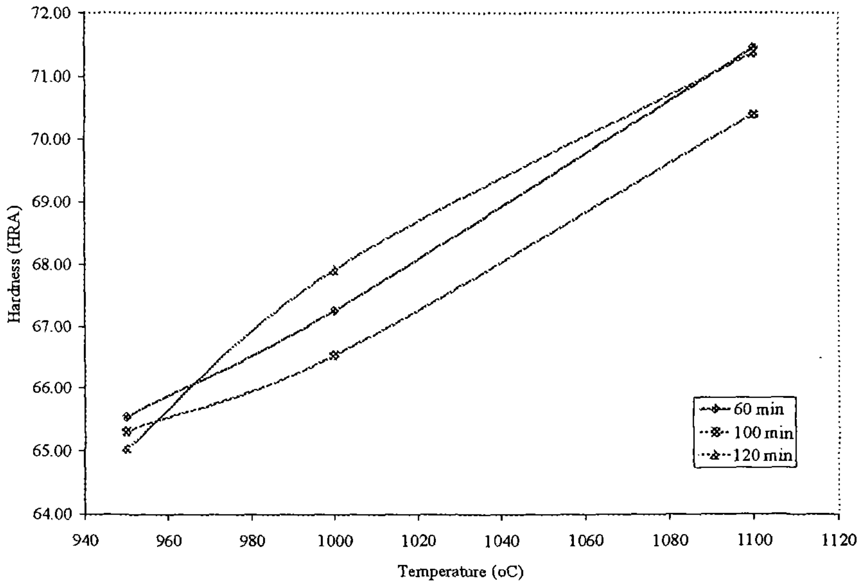

Fig. 4. Hardness of samples versus temperature hot pressed at various holding time

CONCLUSIONS

The hot pressing combined with mechanical alloying is effective to produce near dense bulk samples of γ-TiAl intermetallic. Densification up to 99 % and high hardness can be achieved at hot pressing conditions of 1100 °C, 60 min and the present phases are γ-TiAl, α_2-Ti_3Al and β (B2) with γ-TiAl as dominant phase.

ACKNOWLEDGEMENTS

The authors would like to acknowledge JICA for AUN/SEED-Net for research fund under collaborative research program, for support from USM's FRGS grant and are also grateful to Ceramics Technology Group, SIRIM Berhad for performing the hot pressing.

REFERENCES

1. Calderon, H.A., Garibay-Febles, V., Umemoto, M. and Yamaguchi, M., 2002. Mechanical properties of nanocrystalline Ti-Al-X alloys. *Mater. Sci. and Eng.*, A329-331, p.196-205.
2. Dutkiewicz, J. and Maziarz, W., Heinrich, H. and Kostorz, G., 2003. Structure of Ti-Al-Nb intermetallics produced by mechanical alloying and hot-pressing technique. *Mater. Chem. And Phys.* Vol. 81, p. 414-416.
3. Gessinger, G.H., 1984. *Powder metallurgy of superalloys*, 1st edition, Switzerland: BBC Brown Boveri & Co. Ltd.
4. Jewett, T.J., Ahrens, B. and Dahms, M., 1997. Stability of TiAl in the Ti-Al-cr system. *Materials Science and Engineering*, A225, p. 29-37.

5. Kim, K.T., and Yang, H.C. 2001. Densification behavior of titanium alloy powder during hot pressing. *Mater. Sci. and Eng.*, A313, p. 46-52.
6. Mao, S.X., McMinn, N.A. and Wu, N.Q. 2003. Processing and mechanical behavior of TiAl/NiAl intermetallic composites produced by cryogenic mechanical alloying. *Mater. Sci. and Eng.* A363, p.275-289.
7. Noda, T., 1998. Aplication of cast gamma TiAl for automobiles. *Intermetallics.* Vol. 6, p. 709-713.
8. Shao, G. and Tsakiropoulus, P., 1999. Solidification structures of Ti-Al-Cr alloys. J. *Intermetallics,* Vol. 7, p. 579-587.
9. Szewczak, E., Presz, A., Witek, A., Wyrzykowski, J.W. and Matyja, H. 1999. Microstructure and composition of mechanically alloyed and hot pressed Ti-Al alloys. *Nanostructured Materials,* Vol. 12, p. 167-170.
10. Szewczak, E., and Wyrzykowski, J.W., 1999. Influence of The mechanical Alloying parameters on Crystallite Size of Ti-Al Powders. *Nanostructured Materials,* Vol.12, p.171-174.
11. Wilshire, W., 1994. Recent developments in materials for high temperature service. *RAMM,* p. 1-10.