Australian Journal of Basic and Applied Sciences, 8(19) Special 2014, Pages: 234-237

AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com

Effect of Sintering on Porosity Changes in Ti-10at%Mo-10at%Cr Alloys

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ARTICLE INFO

Article history:
Received 15 April 2014
Received in revised form 22 May 2014
Accepted 25 October 2014
Available online 10 November 2014

Keywords:
powder metallurgy; porosity; sintering; density, diffusion

ABSTRACT

The objective of this work is to investigate the effect of sintering temperature on porosity of Ti-10at%Mo-10at%Cr alloy. The sample was fabricated using powder metallurgy technique, sintered in a vacuum condition at temperatures of 1273, 1373 and 1573 K followed by furnace cooling. Porosity of each sample was characterized by optical microscopy and scanning electron microscopy (SEM). ImageJ software has been applied to analyze the volume fraction of pores. The volume fraction of pores decreased as sintering temperature increased. Constituted pores changed with increasing sintering temperature. Change in volume fraction of porosity indicates that diffusion of alloying elements is dependent on the temperature. On the other hand, density and hardness of the sample increased. This investigation has revealed that the sintering temperature has significant influence on the porosity changes of a powder metallurgy component.

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To Cite This Article: Eko Kurniawan, Junaidi Syarif, Mohammad Rasidi Rasani., Effect of Sintering on Porosity Changes in Ti-10at%Mo-10at%Cr Alloys. ***Aust. J. Basic & Appl. Sci.,*** *8(19): 234-237, 2014*

INTRODUCTION

Ti and its alloy are attractive in many aerospace and medical applications due to its mechanical properties that are include high specific strength and excellent corrosion resistance (Christop, L., M. Peters, 2003). Ti alloys can be fabricated using powder metallurgy (PM) method, because it is low-cost and suitable for production of near net shape components (Froes, F.H., 2012). However, the porosity is unavoidable and almost always present and it has undesirable effects on mechanical properties in PM components (Angelo, P.C., 2008).

One way to control porosity is through sintering temperature. This is because of the porosity of a PM component is greatly dependent on the sintering temperature (Upadhyaya, G.S., 2002). Thus, sintering temperature have a significant effect on the porosity and mechanical properties. In previous study, a new Ti alloys was developed by PM method and showed that the β phase stability in 10at%Mo (Rohmannudin, T.N., 2009). Therefore, the effect of sintering temperature on porosity of Ti-10at%Mo-10at%Cr alloy was investigated to reveal influence of sintering temperature on the porosity changes in this study. Moreover, density and hardness of the Ti-10at%Mo-10at%Cr alloy are also investigated.

Experimental Procedure:

A Ti-10at%Mo-10at%Cr alloy was used as a specimen in this study. The raw material used were commercial pure Ti, Mo and Cr powders. All powders were supplied by Alfa Aesar Co (USA). Table 1 shows the purity and particle size of the powders used. The powders were mechanically blended for 3.6 ks and followed by cold pressing at 9 ton of pressure for 3.6 ks at room temperature to form green compact with diameter of 10 mm. All samples were sintered at temperature of 1273, 1373 and 1573K for sintering time of 7.2 ks in vacuum condition and then furnace cooled. Porosity of each sample were characterized by optical microscopy and scanning electron microscopy (SEM). ImageJ software was applied to analyze volume fraction of pores. Samples were etched with Kroll's solution to observe the microstructure. X-ray line scan using SEM - energy-dispersive X-ray spectroscopy (EDS) was applied to analyze elemental distributions. The density of the sample was determined by the Archimedes method. The hardness was measured by Vickers hardness testing with load 19.6 N and dwell time of 15 s.

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Table 1: Particle size and purity of powders used.

Powders	Particle size (μm)	Purity (%)
Ti	44	99
Mo	88	99.5
Cr	44	99

RESULTS AND DISCUSSION

Microstructural observation:

Figure 1 shows the microstructure of the Ti-10Mo-10Cr alloy. The pores were observed in the sample that was sintered at sintering temperature 1273, 1373 and 1573 K respectively. It was found that the size and amounts of pores were obviously changed. Figure 1a clearly shows a large amount of pores in almost all regions at sintering temperature of 1273 K. At 1373 K, the amount of pores began to decrease and was accompanied by shrinkage of the size of pores (Figure 1b). After the sintering temperature was increased to 1573 K, a number of pores had disappeared, whereas the remaining pores were more dominant at grain boundaries (Figure 1c).

The formation of pores was thought to be due to a Kirkendall effect, was due to difference of elemental diffusion through the mechanism of atomic vacancies (Kakani, S.L., 2004; Shewmon, P.G., 1989). Figure 2 shows the elemental distribution of alloying element on pore area. The Cr atom diffuses faster in the alloy because Cr atom has greater a diffusion coefficient than the Mo atom (Carman, A., 2011). In addition, the changes formation of pores due to increasing sintering temperature has shown the dependence of diffusion coefficient on temperature (Kang, S.J.L., 2005; Shewmon, P.G., 1989). So it is obvious that the temperature plays an important role in the porosity change during the sintering process.

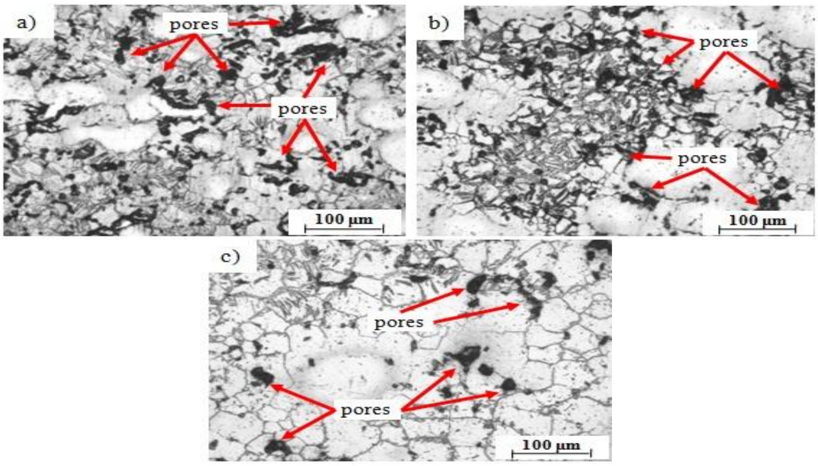

Fig. 1: Micrograph of the samples after sintered at temperature (a) 1273 K; (b) 1373 K; (c) 1573 K and followed by furnace cooling.

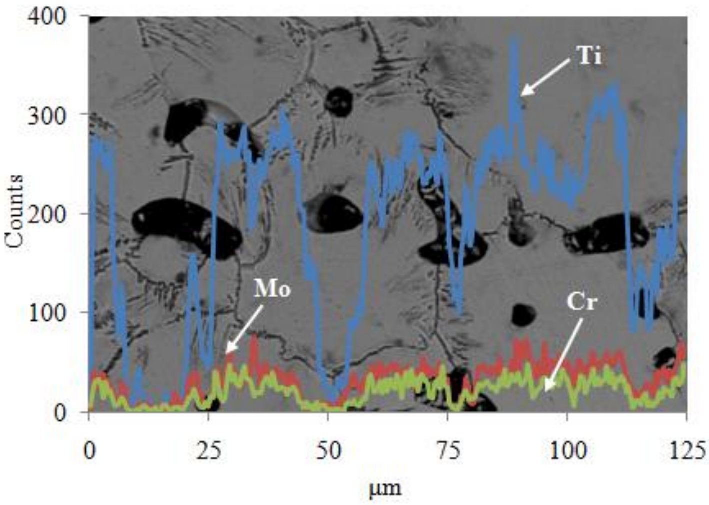

Fig. 2: Micrograph of the samples after sintered at temperature 1573 K with elemental line-scans.

Change in volume fraction of porosity and density:

Figure 3 represents a change in volume fraction of porosity and density as function of the sintering temperature. The volume fraction of pores decreased while density was slightly increased, as sintering temperature was increased. It could be noted in the relationship between porosity and temperature, that the increasing of the temperature resulted the diffusion coefficient of the atoms were improved so that the movements that fill the vacancy were increased. So, the decrease in porosity are caused by the vacancies annihilation during sintering [10,11]. These results showed that the increasing of the sintering temperature has affected on porosity and density of the sample.

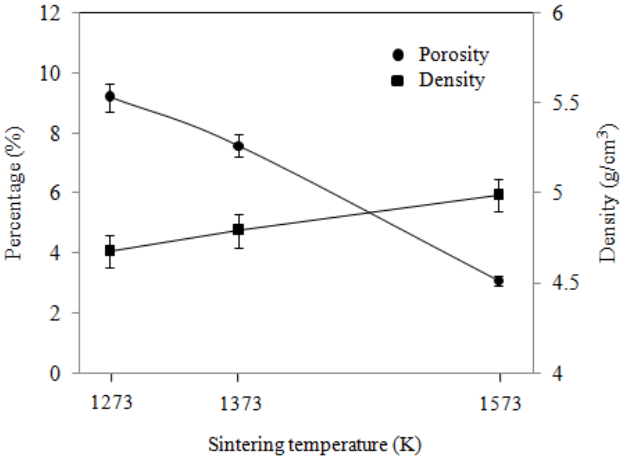

Fig. 3: Effect of sintering temperature on the porosity and density after sintering process followed by furnace cooling.

Hardness of Ti10at%Mo-10at%Cr:

The hardness value of the Ti-10Mo-10 Cr alloys are shown in Figure 4. The hardness increased as the sintering temperature increased. The increase in the hardness was due to the decrease of the porosity, which led to the increase in density as the temperature was increased. It is thought that the enhancement of hardness in the alloy was dominated by the reduction of porosity.

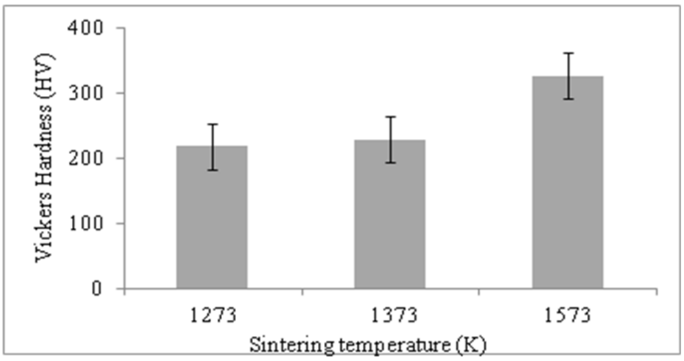

Fig. 4: Hardness of Ti-10at%Mo-10at%Cr alloys.

Conclusion:

The effect of sintering temperature on porosity of Ti-10at%Mo-10at%Cr alloy had been investigated together with their influence on density and hardness. The microstructure show that the pores changed with the increasing sintering temperature. In addition, change in volume fraction of porosity indicates that diffusion of alloying elements is dependent on the temperature. It is thought that the hardness and density of the alloy was increased because of the reduction of porosity during sintering.

ACKNOWLEDGEMENT

The authors would like to acknowledge Universiti Kebangsaan Malaysia (UKM) and Ministry of Higher Education (MOHE) for funding this research under Grant Arus Perdana UKM-AP-NBT-14-2010 and ERGS/1/2012/TK04/UKM/02/5, respectively.

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