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Studying the Microstructure of Al-Ti Alloy Prepared by Powder Metallurgy using Three Different Percentages of Ti

Sahib Mohammed Mahdi
Assist Prof.
Materials Engineering
Al-Mustansiriyah University
Iraq, Baghdad
E-mail:
saheb.m.mahdi@uomustansiriyah.edu.iq

Nadia Ghadhanfer Hikmat
M.Sc. Student
Materials Engineering
Al-Mustansiriyah University
Iraq, Baghdad
E-mail:
nadiaghadhanfer@yahoo.com

Dalmn Yaseen Taha
Engineer
Mechanical Engineering
Al-Mustansiriyah University
Iraq, Baghdad
E-mail:
delmnyaseen@gmail.com

ABSTRACT

The effect of different Ti additions on the microstructure of Al-Ti alloy prepared by powder metallurgy was investigated. A certain amount of Ti (10wt%, 15wt%, and 20wt%) were added to aluminium and the tests like microhardness, density, scanning electron microscope (SEM), optical microscope (OM) and X-Ray Diffraction (XRD) were conducted to determine the influence of different Ti additives on the Al-Ti alloy properties and microstructure. The results show that the grains of α-Al changed from large grains to roughly spherical and then to small rounded grains with increasing Ti content, the micro-hardness of the alloy increases with increasing Ti, and XRD results confirm the formation of $TiAl_3$ intermetallic compound during sintering.

Keywords: Powder metallurgy, Microstructure, Intermetallic compound, Al-Ti alloy.

دراسة التركيب المجهري لسبيكة الالمنيوم-تيتانيوم المحضرة بطريقة تعدين المساحيق باستخدام ثلاث نسب مختلفة من التيتانيوم

*** صاحب محمد مهدي**
أستاذ مساعد
قسم هندسة المواد
الجامعة المستنصرية

نادية غضنفر حكمت
طالبة ماجستير
قسم هندسة المواد
الجامعة المستنصرية

دلمن ياسين طه
مهندسة
قسم الهندسة الميكانيكية
الجامعة المستنصرية

الخلاصة

تأثير اضافات التيتانيوم المختلفة على التركيب المجهري لسبيكة الالمنيوم-تيتانيوم المحضرة بطريقة تعدين المساحيق قد تم دراستها. كمية معينة من التيتانيوم (10%, 15%, و 20%) قد اضيفت الى الالمنيوم, والفحوصات مثل الصلادة المجهرية, الكثافة, المجهر الالكتروني الماسح (SEM), المجهر الضوئي (OM) و اختبار حيود الاشعة السينية (XRD) قد اجريت لحساب تأثير محتويات التيتانيوم المختلفة على الخواص والتركيب المجهري لسبيكة الالمنيوم-تيتانيوم. النتائج أظهرت بأن حبيبات α-

*Corresponding author
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الالمنيوم تغيرت من حبيبات كبيرة الى كريات خشنة وثم الى حبيبات مدورة صغيرة مع زيادة محتوى التيتانيوم، وأن الصلادة المجهرية للسبيكة تزداد مع زيادة التيتانيوم وأن نتائج حيود الاشعة السينية تؤكد تكون الطور $TiAl_3$بين المعدني خلال التلبيد.

الكلمات الرئيسية: تعدين المساحيق، تركيب مجهري، مركب بين معدنين، سبيكة المنيوم-تيتانيوم.

1. INTRODUCTION

The system of Al-Ti alloy had been studied extensively in the past years as structural materials used in elevated temperature applications **(Liu, et al., 1996. Loo and Rieck, 1973. He, et al., 1994)**. This is because of their excellent performance and properties like good resistance to oxidation at high temperature and high resistance to corrosion as well as low density **(Chan, et al., 2004. Lapin, 2006. Wu, 2006)**. For instance, airplanes engineers are seeking for components used as structural materials having high stiffness, high strength, wear resistance, corrosion resistance, good tensile properties besides low density, in other words, a combination of formidable characteristics **(Kalel, 2018. Hussein, et al., 2018)**. Therefore; in order to improve the microstructure and enhance the **mechanical** and physical characteristics of Al-base alloys, intermetallic compounds needed to be formed in the structure of the alloy like titanium aluminates, by adding Ti to it. These compounds have high hardness and they are being very coherent to the base and thus enhancing physical and mechanical properties of the aluminium-base alloys **(Dursun, et al., 2015).** Also, titanium can serve as nucleation site for these aluminates, and forms primary dendrites in aluminium. So, more dendrites formation means large numbers of small grains. Therefore, Ti is considered as grain refining element **(Rana, et al., 2012)**. Different types of titanium aluminates are created in the system of Al-Ti alloy; having distinct chemical and physical properties **(Jiang, et al., 2008)**. Among these aluminates is $TiAl_3$ intermetallic compound, which possess lower value of density and better resistance to oxidation compared to other intermetallic compounds in Al-Ti system. Such excellent characteristics can make $TiAl_3$ a possible candidate to use in high strength with low-density and elevated temperature applications **(Peng, et al., 2000)**. Many studies in the this scope were published such as **(Çam, et al., 2016).** who investigated the influence of $TiAl_3$ on wear behavior of Al alloy (A356), whereas $TiAl_3$ was formed by adding Ti to the Al alloy in different contents (4wt%; 6wt%; and 8wt%) by means of mechanical alloying. **(Rezaei and Hosseini, 2017)** studied the mechanical characteristics and microstructural evolution of aluminum matrix composite having 5wt%Ti addition prepared by powder metallurgy followed by hot extrusion. This study showed that the mechanical properties of this composite, like tensile strength and hardness, were increased as the time of hot extrusion reached 6 hours, because of the rising in the amount of the formed$TiAl_3$ intermetallic compound. While, as the duration of hot extrusion exceeding 6 hours, the ductility of Al composite was declined. **(Tochaee, et al., 2016)** focused on the fracture toughness of mechanically alloyed Al-Ti composites, in which Ti is added into Al at two different ratios (10wt% and 20wt%). It was revealed that the voids were absent in Al-20wt%Ti system, and it has the maximum value of fracture toughness. While Al-10wt%Ti system has low density and an observed debonding of some particles at the fracture surface of the sample.

The biggest problem with Al-Ti alloys is their manufacturing. Forging, extrusion and casting processes were utilized to produce parts from Al-Ti alloy; but the costs of processing were very high **(Wu, 2006)**. Powder metallurgy process is relatively effective in lowering the cost since the wasted material is little, and in avoiding the various defects and limitations that may associate with the other manufacturing methods, so it considered as a cost- effective method **(Abouelmagd, 2004)**. Aircrafts' impellers, mobile phone as casing material, and artificial limbs are some applications of Al-Ti alloys **(Wei, et al., 2018)**.

2. Experimental work

2.1 Al-Ti alloy preparation

Powder metallurgy process is utilized to fabricate Al-Ti alloy at maximum desired characteristics. Ti elemental powder was supplied from Fluka Company with 99.8% purity, and Al elemental powder was supplied from CDH chemical company with 99.9% purity. Three weight percentages of Ti were used in this work research (10%, 15%, and 20%). The powders mixtures were mixed using an electrical parallel mixer (having 70 rpm) for 2 hours. Then the mixed powders were cold pressed using double action tool steel die to form cylindrical green compacts (diameter 14mm X height10 mm) at pressure of 146 MPa, with speed of compaction about 0.5 mm/min according to study achieved by **(Guo, et al., 2015)**. The green compacts were sintered under vacuum atmosphere at 550 ˚C for 5 hours with 10^{-3} bar to get successful sintering process according to study achieved by **(Chianeh, et al. 2009)**.

2.2 Microstructure examination

After sintering, the prepared specimens were etched for microstructure examination, using a solution consist of 2.5ml HNO_3, 95ml distilled water, 1.5ml HCl and 1ml HF for 20 sec. The measurements of alloy density were done by using Archimedes' method. The specimens were characterized by XRD test using Shimadzu (model 6000) device, SEM test by using VEGA3 LM-TESCAN, optical examination by using MIJI optical microscope with 50X, and microhardness measurement were achieved by using TH-715 device, by applying 4.9N load (F) and 10 seconds dwell time, with pyramid indenter having 55.7µm diameters (d), using Eq. (1) **(Chuenarrom, et al. 2009)**:

$$HV = 1854\ (f \div d^2) \qquad (1)$$

3. Results and Discussion

3.1 SEM test and Optical Microscope test results

During sintering, $TiAl_3$ intermetallic compound was resulted from Ti and Al diffusion reaction and it was observed in the images of SEM **Fig. 1** and optical microscope images **Fig. 2**, which is appear to be very small and surrounded by the alloy matrix. Also there is an obvious refining in the α-Al grains due to the effect of Ti addition, which acts as grain refining element. The images of optical microscope illustrate the obvious change in the size of aluminum grains with increasing Ti content, from large grains to roughly spherical grains and finally to small rounded grains.

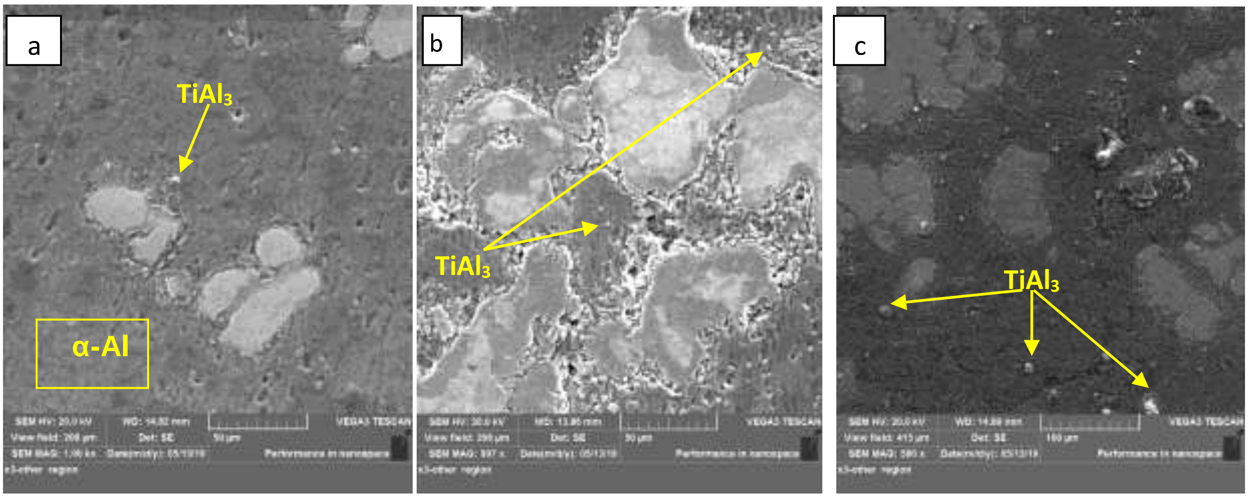

Figure 1. Al-Ti alloy SEM images show the microstructure and $TiAl_3$ intermetallic formation in α-Al: a)10%Ti; b)15%Ti and c)20%Ti.

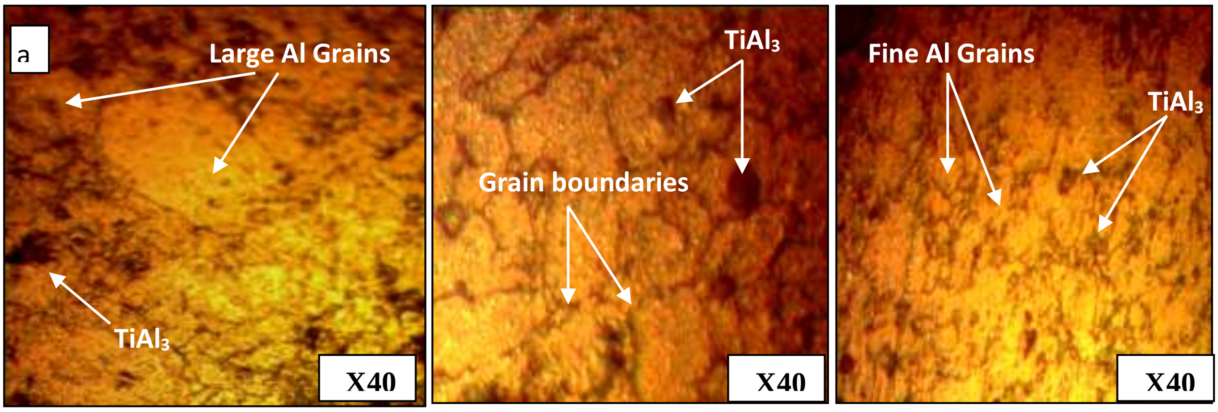

Figure 2. Al-Ti alloy OM images show the formation of $TiAl_3$ intermetallic and the microstructural changes in α-Al grains: a)10%Ti; b)15%Ti and c)20%Ti.

3.2 XRD test results

The XRD results of the three weight percentages of Al-Ti alloy are in **Fig. 3**. These figures show that $TiAl_3$ was actually created in Al-Ti alloy at (64, 77, 81 and 38) angles of diffraction by a diffusion reaction take place between Ti and Al powders during sintering at 550˚C as below:

$$3Al + Ti \rightarrow TiAl_3$$

The existence of $TiAl_3$ intermetallic compound in Al-Ti alloy is quite effective, since it has high hardness (about 465 to 670 Kg/mm^2) as well as high melting point (about 1360˚C). It helps in rising stiffness and strength and improves many properties of Al-Ti alloy like hardness, wear resistance and elevated temperature resistance **Hsu, et al. 2006**.

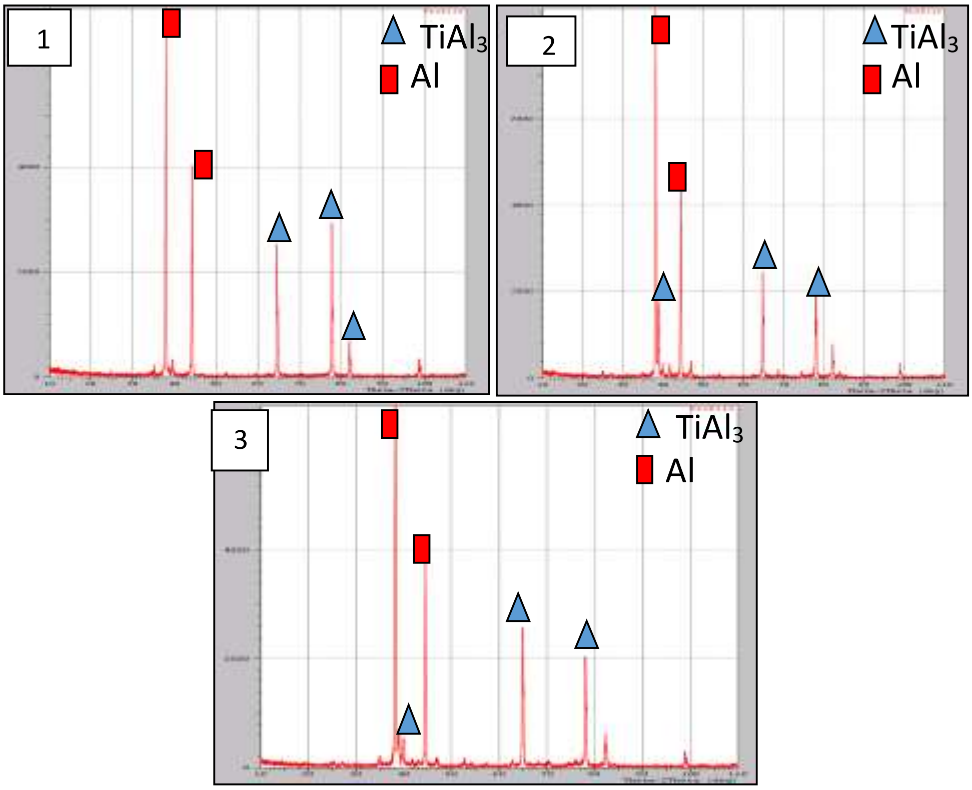

Figure 3. Results of XRD for: 1) Al-10%Ti; 2) Al-15%Ti and 3) Al-20%Ti.

3.3 Micro-hardness test results

The resulted values of microhardness test showed an increase in the microhardness of Al-Ti alloy as the weight percent of Ti increases in the prepared samples, as shown in **Table 1**. This increase in microhardness is generally attributed to the increased amount of the hard intermetallic compound which is $TiAl_3$, and this in turn increases the strength of the prepared Al-Ti alloy. **Fig. 4** illustrates the micrograph of Al-Ti alloy sample examined by Vickers test, the bright regions represent α-Al, while the small dark spots represent $TiAl_3$ intermetallic compound, and the pyramid represent the used indenter.

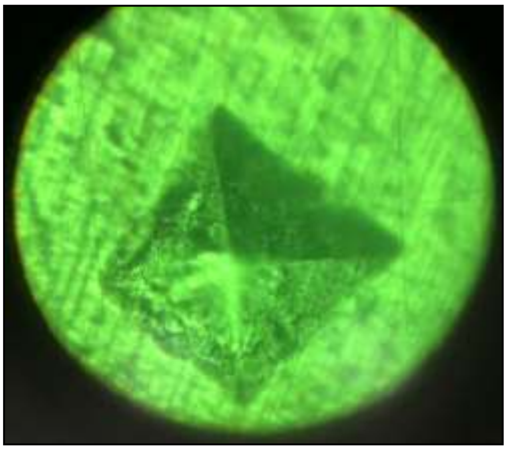

Figure 4. Micrograph from Vickers microhardness test.

Table 1. Microhardness of the prepared Al-Ti alloys.

Ti percentage (%)	Microhardness of Vickers (HV) (Kg/mm^2)		
	α-Al	$TiAl_3$	Interface
10wt%Ti-90wt%Al	259.8	646.2	425.8
15wt%Ti-85wt%Al	298.4	662.1	477.5
20wt%Ti-80wt%Al	366.4	698.9	557.7

3.4 Density test results

The bulk density test results of the sintered specimens are affected directly be the ratio of the added titanium as illustrated in **Table 2**.

Table 2. Bulk density of the prepared Al-Ti alloys.

Ti percentage (%)	Bulk Density (gm/cm^3)
10wt%Ti-90wt%Al	2.8042
15wt%Ti-85wt%Al	2.8968
20wt%Ti-80wt%Al	2.9892

In a previous study made by **Tochaee, et al. 2016**, it was reported that Al-20wt%Ti alloy has (2.946 gm/cm^3) bulk density, while Al-10wt%Ti alloy has (2.544 gm/cm^3) bulk density, in which they were prepared by mechanical alloying method. In this present study, it can be seen from **Table 2,** that the bulk density of Al-20wt%Ti and Al-10wt%Ti besides 15wt%Ti are higher, in which they were prepared by powder metallurgy. This can reveals the success of pressing and sintering stages of the used powder metallurgy technique.

4. CONCLUSIONS

- The intermetallic compound $TiAl_3$, which has great effect on increasing the strength and enhancing the microstructural properties of Al-Ti alloy, was generated successfully during sintering from diffusion reaction occurs between Ti and Al, and it was detected and confirmed by XRD and SEM tests.
- By adding Ti in different weight percentage into Al, the grains of α-Al were changed from large grains into roughly spherical particles and then become small rounded grains as the Ti addition increases. This is because Ti is acting as nucleation site of $TiAl_3$ intermetallic compound, which leads to form large number of dendrites in Al-Ti alloy, so titanium is considered as grain refining element.
- The increase in the amount of $TiAl_3$ intermetallic compound depends on the increase in the percentage of the added Ti.
- With increasing Ti amount in the structure of Al-Ti alloy, the values of microhardness increase.
- The bulk density values of Al-Ti alloys samples prepared by powder metallurgy method are higher compared to the bulk density values of Al-Ti alloy samples prepared by mechanical alloying method. Besides that, the values of bulk density increase as the Ti content increases in the Al-Ti alloy.

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