Characterization the wear behavior of Al-Ti alloy having different Ti ratios prepared by powder metallurgy

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Abstract. In this study, the Al-Ti alloy was fabricated by powder metallurgy method using three different Ti ratios (10wt%; 15wt%; and 20wt%Ti); and the wear behavior of these three alloys was investigated. The mixtures of powders were compacted at 146 MPa and sintered for 5 hours at 550-˚C under vacuumed atmosphere. The samples were characterized using X-Ray Diffraction test (XRD), Scanning Electron Microscope test (SEM), microhardness and density tests. The tests of wear were achieved by employing a pin on disk machine under constant normal load 15N for four different sliding times 5, 10, 15, and 20 minutes. The results illustrate that the density and microhardness of Al-Ti alloy were increased as the Ti content increased. Also, it was observed that Al-Ti alloy with 20wt%Ti had the highest wear resistance and lowest weight loss.

Keywords: Wear Behavior; Powder Metallurgy; Al-Ti Alloy; Microhardness.

Introduction

Aluminium and its alloys are widely employed in aerospace and automotive sectors due to their easy formability and low density, whereas, titanium element is a material that has a special attention, owing to its good resistance to fatigue, low density and high strength [1]. By adding titanium into aluminium, high performance structural materials can be produced that are capable to use in many engineering industries and elevated temperatures applications [2]. This type of alloying can be achieved by various processes such as powder metallurgy, mechanical alloying, and melting [3-6]. Powder metallurgy is considered the most popular manufacturing method used in producing intermetallics, metallic or composites with small sizes and complex shapes. It can produce parts with very high precision and lower cost since the wasted material is little [7]. The mechanical and physical characteristics of powder metallurgy products are related closely to their density. Reducing the gradients of density in the components is a very important consideration if high mechanical performance and consistent response is required [8]. Improving the mechanical performance and tribological characteristics like wear behaviour of Al alloys can be achieved by forming a class of materials called intermetallic compounds. These materials are harder and stronger than the base alloy [9]. In general, the system of Al-Ti alloy has several intermetallic compounds, known as titanium aluminides. Among these compounds, TiAl3 has a considerable interest because of its elevated temperature resistance, high wear resistance, excellent resistance to corrosion, good resistance to creep, low density and high hardness [10]. TiAl3 intermetallic compound results from diffusion reaction that occurs between Ti and Al during sintering at a range of temperature about (500 to 600-˚C) [11]. Tribology can be defined as the technology and science of contact or interacted surfaces as well as particles being in relative movement against each other [12]. This present work aims basically at developing a new material with enhanced wear characteristics; through adding titanium at three
different percentages to aluminium and chooses the best ratio. The effect of TiAl₃ intermetallic compound, which formed during sintering, on the wear properties of Al-Ti alloy was investigated.

1. Experimental Method

1.1. Preparation of Al-Ti alloy

Al-Ti alloy was produced by powder metallurgy using Al powder from CDH Company with 99.8% purity, and Ti powder from Fluka Company with 99.8% purity added at three different weight percentages (10wt%; 15wt%; and 20wt%). The powders were mixed and blended for two hours using electrical parallel mixer with 70 rpm, as demonstrated in Figure 1a. The mixed powders were compacted under 146 MPa pressure with 0.5 mm/min compaction speed; employing a double-action die (Figure 1b), and producing cylindrical compacts (14mm diameter × 10mm height).

Figure 1a: Electrical parallel mixer  
Figure 1b: Double-action die

These green compacts then subjected to sintering in a vacuumed atmosphere furnace, with 10⁻³ bar pressure of vacuum, at 550- °C for five hours, as illustrated in Figure 2.
1.2. Examination of Al-Ti alloy

The sintered specimens were etched using etching solution include 1ml HF, 2.5ml HNO$_3$, 1.5ml HCl, and 95ml distilled water for twenty seconds for Scanning Electron Microscope (SEM) examination. Archimedes' rule was employed to measure Al-Ti alloy density. The values of microhardness were measured by means of TH-715 device. The Al-Ti alloy examinations were achieved using X-Ray Diffraction (XRD) test by means of Shimadzu device (model 6000), Scanning Electron Microscope (SEM) test by means of VEGA3 LM-TESCAN. A pin on disk machine (as shown in Figure 3) was used to achieve the wear tests under constant normal load (15N) and (18 cm) diameter of the disk, with 490 revolution per minute (rpm) velocity of sliding, at four different sliding times: 5, 10, 15, and 20 minutes. The resulted worn surfaces were examined using optical microscope having 50X magnification. The specimens were weighted before and after every test using digital balance of ±0.0001 gm sensitivity, and the differences in weight were calculated. Equation (1) was used to determine the wear rates (W.R.) in (gm/cm) for each alloy [13]:

$$ W \cdot R = \frac{\Delta W}{\pi D N t} $$

$$ \Delta W = W_1 - W_2 $$

Where:

$W_1$= Specimen weight before wear test (gm).

$W_2$= Specimen weight after wear test (gm).

$D$= Diameter of the used steel disk (cm).

$N$= Number of revolutions (rpm).

$t$= sliding time (min).
Figure 3: Pin on disk machine

2. Result and discussions

2.1. Results of XRD test

The examination of XRD was achieved to detect the intermetallic compound (TiAl₃). In a previous study made by Baisong et al. [14], it was reported that TiAl₃ intermetallic compound was resulted during sintering for five hours at 630 °C temperatures under 10MPa pressure. In this study, the XRD results of the three ratios of Al-Ti alloy show that Al was detected besides TiAl₃, which formed from a diffusion reaction that occurred between Ti and Al at 550- °C for 5 hours. This reaction includes [15]:

\[
\text{Ti} + 3\text{Al} \rightarrow \text{TiAl}_3
\]

Figure 4 illustrates XRD patterns of the three prepared Al-Ti alloys with different ratios of Ti.
Figure 4: XRD pattern of a) 10wt%Ti-Al; b) 15wt%Ti-Al; c) 20wt%Ti-Al

In Table (1), the angles of diffraction ($2\theta$) and the intensities (I) of the X-ray beam are illustrated, and they referred to the formed intermetallic compound TiAl$_3$ in the three prepared Al-Ti alloys at approximately close angles but with different intensities.

Table 1: The data of XRD test results for TiAl$_3$ of the three Al-Ti alloys

| Type of Al-Ti alloy | $2\theta$ (deg) | I        |
|---------------------|----------------|----------|
| Al-10wt%Ti          | 64.5, 77.7, 81.9 | 41, 44, 11 |
| Al-15wt%Ti          | 38.8, 64.7, 77.9 | 19, 32, 32 |
| Al-20wt%Ti          | 39.9, 64.8, 78.0 | 6, 45, 39 |

2.2. SEM test results

From Figure 5, it is obvious that the addition of Ti into Al is done at dissimilar ratios (10w%; 15%; and 20%), and this is appeared in different distribution patterns in the microstructure of the prepared Al-Ti alloys. The SEM examination illustrates also the existence of TiAl$_3$ intermetallic compound, which resulted during the sintering from diffusion reaction between titanium and aluminum powders. The SEM results showed that the amount of TiAl$_3$ increases with increasing Ti content.
2.3. Al-Ti alloys Density results

The results show that 20wt%Ti-80wt%Al alloy has the highest value of bulk density about 2.989 gm/cm$^3$, compared to 10wt%Ti-90wt%Al alloy which has the lowest value of bulk density about 2.804 gm/cm$^3$, while 15wt%Ti-85wt%Al alloy has a moderate value of bulk density about 2.896 gm/cm$^3$, as shown in Figure 6.

This is back to the reason that Ti possesses higher density (about 4.506 gm/cm$^3$) than Al (which is about 2.7 gm/cm$^3$). Therefore, with increasing Ti ratio, the Al-Ti alloy bulk density would be higher [15].

![Figure 6: Bulk density of the three prepared Al-Ti alloys](image)

2.4. Al-Ti alloys microhardness results

As the amount of titanium increase, the values of microhardness increases due to the increase in the generated TiAl$_3$ intermetallic compound, as shown in Figure 7.

![Figure 5: SEM images of Al-Ti alloys: 1)10wt%Ti; 2)15wt%Ti; 3)20wt%Ti](image)
The wear test results demonstrate that the highest wear rate was obtained in the Al-10wt%Ti alloy that possesses the lowest bulk density (2.804 gm/cm³) and the lowest microhardness value (646.2 HV), while the lowest wear rate was obtained in Al-20wt%Ti that has the highest bulk density (2.989 gm/cm³) and the highest microhardness value (698.9 HV) as shown in Figure 8.

The mechanism of wear is generally based on the hardness of the specimen which is considered as a key parameter that determines the amount of removed material, in which the sample is losing weight by sliding on a hard solid surface. The bright smooth regions with continuous grooves represents abrasive wear characteristics, while the dark regions with craters elongated in the direction of sliding represents the characteristics of adhesive wear [16].
Figure 9, reveals two types of wear mechanisms, but generally the results of optical microscope images showed that the adhesive wear tended to be the dominant type of wear mechanism at the Al-10wt%Ti alloy surface under the normal load 15N, which represents the dark regions in the image. While abrasive wear was more likely to appear as the predominant type of wear mechanism at Al-20wt%Ti alloy surface, which represents the bright regions, under the same normal load. In Al-15wt%Ti alloy, a combination of adhesive and abrasive wear mechanism was found at the worn surface.

These types of wear mostly appear clearer with the increase in sliding time. The adhesive wear can be attributed to the plastic deformation occurrence at the worn surface of Al-Ti alloy specimens which can leads to severe dislocations. These dislocations might cause cracks formation that would initiate and propagate in the direction of sliding as a result of the generated temperature between the sample and the disk with increasing time periods, and finally forms wear debris [9]. This plastic deformation could be reduced by increasing the alloy hardness. Therefore; the TiAl3 plays an important role in improving the wear behavior of Al-Ti alloy by increasing the microhardness and decreasing the weight loss.

Figure 9: The worn surfaces of 1)10wt%Ti; 2)15wt%Ti; 3)20wt%Ti alloys tested under 15N load after 20min sliding time

3. CONCLUSIONS

1. TiAl3 amount increases with increasing Ti content.
2. The values of microhardness and bulk density increases as the Ti weight percent increase.
3. Two types of wear mechanisms were observed on the worn surfaces of Al-Ti alloys that possess three different ratios of Ti, adhesive and abrasive wear mechanism.
4. The adhesive wear tends to be the predominant type of wear mechanism on the surface of Al-Ti alloy, having low Ti content; and it was observed that the adhesive wear increases with an increase in the sliding time and decreases with an increase in the Ti content.
5. In Al-10wt%Ti alloy, adhesive wear occurred due to plastic deformation that takes place on the worn surface and because of the low microhardness values of this alloy, the adhesive wear increases with an increase in the time of sliding. Further, abrasive wear is the predominant type of wear mechanism on the worn surface of Al-20wt%Ti alloy due to its high microhardness of this alloy which results from a higher content of TiAl3, which helps to increase the wear resistance of the alloy and decrease the plastic deformation on the surface.
6. Al-15wt%Ti has a combined mechanism of wear which consists of adhesive and abrasive wear mechanisms, due to its moderate content of TiAl3.

Acknowledgements
The authors acknowledge with gratitude the support of Al-Mustansiriyah University, and University of Technology, to achieve this work.

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