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**Research Article**

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# Effect of Heat Treatments on Microhardness and Roughness of Al-4Ti/1wt% MgO Composite

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**Abstract** This work aims to study the effect of annealing, normalizing and tempering on optical microstructure, microhardness and roughness of Al-4Ti and its composite with 1 wt% MgO. The heat treatments were achieved at 500 $^{o}$C. The results showed that normalizing and tempering led to decreasing the presence of main phase in Al-Ti alloy which is $Al_3Ti$ through breaking up the phase in alloy, while the heat treatment led to enhance this phase in composite due to the incorporation between MgO and $Al_2O_3$ (which formed by convert aluminum to it) to form $MgO.Al_2O_3$. Therefore, in the optical examination of tempered Al-4Ti/MgO can be seen coarse $Al_3Ti$ platelet particles in addition to MgO particles. Microhardness highly influenced by heat treatments, the base alloy had microhardness more than composite with MgO before heat treatment due to presence of porosity which can occur due to the difficulty in the wetting of the ceramic-based reinforcement elements by the matrix material Al. While heat treatments made the microhardness of composite is more than that for alloy due to the broken in hard intermetallic ($Al_3Ti$) in Al matrix. The data of roughness were higher for base alloy than composite due to decreasing and increasing the presence of $Al_3Ti$ phase in alloy and composite respectively.

**Keywords** Heat treatments; Al-Ti alloy; Microhardness; Roughness.

## Introduction

Many composites used today are at the leading edge of materials technology, with performance and costs appropriate to ultra-demanding applications such as spacecraft. The current and potential applications of aluminium based composites are concentrated on three specific areas: the automotive industry, the aerospace sector and the leisure market. However, interest is also growing in the field of mechanical applications and in the field of electrical and electronic applications. At the present, the exploitation of improved mechanical properties (stiffening and/or strengthening of aluminium alloys), is receiving most attention, combined with a substantially improved wear resistance. But the most exciting and economically challenging area is the development of materials with tailor made properties: composites can be produced with a combination of physical and mechanical properties, which is ideal for a given application.

Mg, Cu, Zn and Si are the most commonly used alloying elements in aluminium, which have sufficient solid solubility. Cr, Mn and Zr are used primarily to form compounds which control grain structure. Maximum solid solubility in binary aluminium alloys occurs at eutectic and peritectic temperatures. In Al-Ti alloys, the peritectic transformation L + ($Al_3Ti$) $\leftrightarrow$ (Al) is presented.

Mechanical properties of aluminium alloys are controlled by a number of principal microstructural features; (1) Coarse intermetallic compounds (or constituent particles), (2) Smaller submicron particles or dispersoids (0.05-0.5 μm), (3) Fine precipitates (up to 0.1 μm), (4) Grain size and shape, (5) Dislocation structure and (6) Crystallographic textures.

There are many researchers studied the mechanical properties of Al matrix composites [1-12] and they tried to discuss the effect of different reinforcements on properties of matrix. Others focused the heat treatments and how may be affect mechanical properties [13-17].

The current work related to study the heat treatment at 500 $^oC$ of Al-4Ti alloy and Al-4Ti/1%MgO composite through optical microscopy and study the effect of these treatments on microhardness and roughness of fabricated materials.

## Materials and Procedure

### Preparation of Specimens

Al wires and powders of Ti and MgO were used as matrix and reinforcement elements in the production of composite specimen. The particle size of Ti and MgO was 165 and 53 µm respectively. For the production of composite specimen, matrix material Al was put in the crucible and the melting process was started and continued until the temperature of the liquid matrix reached 700 °C. Stirring apparatus was immersed in the liquid metal and stirring was started. The appropriate amount of Ti and then MgO corresponding 4 and 1 wt.% respectively was added in the liquid metal by a funnel during the stirring process. After the addition of reinforcements to liquid matrix, the mixture was stirred for about 4 min at 500 rpm in order to allow homogeneous distribution of MgO particles in the mixture. When stirring was completed, the crucible was taken out of the furnace, the liquid melt was poured in to steel containers of 20 mm diameter and 170 mm height and was allowed to cool down to room temperature.

### Preparation of the Samples

The specimens were cut as cylindrical shapes for characterization and measurements with dimensions of 20 mm diameter and 4 mm high. Grinding and polishing was done with emery papers 220, 400, 500, 800, and 1000 mesh grit and then rinsed with acetone.

### Heat Treatments

The specimens were subjected to annealing, normalizing, and tempering processes. During annealing, the specimen was heated to 500 $^oC$, held for one hour, and allowed to cool in the furnace. For the normalized, the specimens were heated to 500 $^oC$, held for one hour, and allowed to cool in air and water, respectively. The tempered specimen was heated to 500 $^oC$, held for one hour, quenched rapidly in water, reheated to 100 $^oC$, held at this temperature for one hour, and then allowed to cool in air.

### Optical Microscopy

The microstructure evolution was investigated by means of optical microscope using (BEL photonics) microscope was connected to computer. The specimens were etched by Killers solution (2 ml HF +3 ml HCl + 5 ml $HNO_3$ + 190 ml $H_2O$) as etchant for 10-30 sec for optical examination.

### Microhardness

Microhardness of samples measured by HVS-1000 micro hardness tester from LARYEE according to micro-indentation hardness principle ASTM E384 and ISO 6507. Vickers indenter used in the measurement, which has a diamond shape and is known to produce similar indentations at all testing forces, with a load of 9.8 N for 15 seconds in the micro hardness tester. Averages then obtained from these measurements.

### Roughness

The roughness was tested by TA 620 measuring platform with TR200 hand-holding roughness gauge and TR240 portable roughness gauge.

## Results and Discussion

Microstructure study as shown in Figure (1) indicates the petal-like $Al_3Ti$ particles in α-Al solid solution of base alloy according to following reaction:

$$Al_{(liq)} + Al_3Ti_{(crys)} \rightarrow \alpha - Al \textit{ alloy solid solution} \quad ....(1)$$

$Al_3Ti$ crystals act as nuclei for grains to grow. Multiple nucleations of averagely eight sites may occur on each particle. Heat treatment by annealing shows little change in microstructure. While in the normalizing and tempering, $Al_3Ti$ is growing up and breaking up in smaller parts. This process is continuing with increasing of the solution hat treatment time. The titanium of the particles is going into the matrix [2, 10]. Also Chen et al. indicated that increasing the testing temperature, decreasing the $Al_3Ti$ content or the hardness of materials [18].

Heat treatments indicate the reduction of the presence and size of the intermetallic precipitations. Due to the heat treatment performed the precipitations get dissolved in the solid solution in the quenching process.

Microstructure examination also revealed that MgO particles were distributed uniformly in the Al-4Ti matrix as shown in Figure (2). As seen from these images in Figure (2), the reinforcement was generally distributed homogeneously. This situation can be clarified by precipitation of reinforcement during the cooling of liquid mixture due to its higher specific gravity than that of the matrix material Al [12]. During the casting, some aluminum may be converting to $Al_2O_3$. At the same time, the aluminum content oxidizes and then reacts with MgO to form a nonstoichiometric spinel:

$$MgO_{(s)} + Al_2O_{3(s)} \rightarrow MgO.Al_2O_{3(s)} \quad \text{……(2)}$$

The coarse grain structure of heat treated specimen is increase due to the recrystallization and grain growth is observed by MgO particles. In addition to get coarse $Al_3Ti$ platelet particles and grains of Mg.

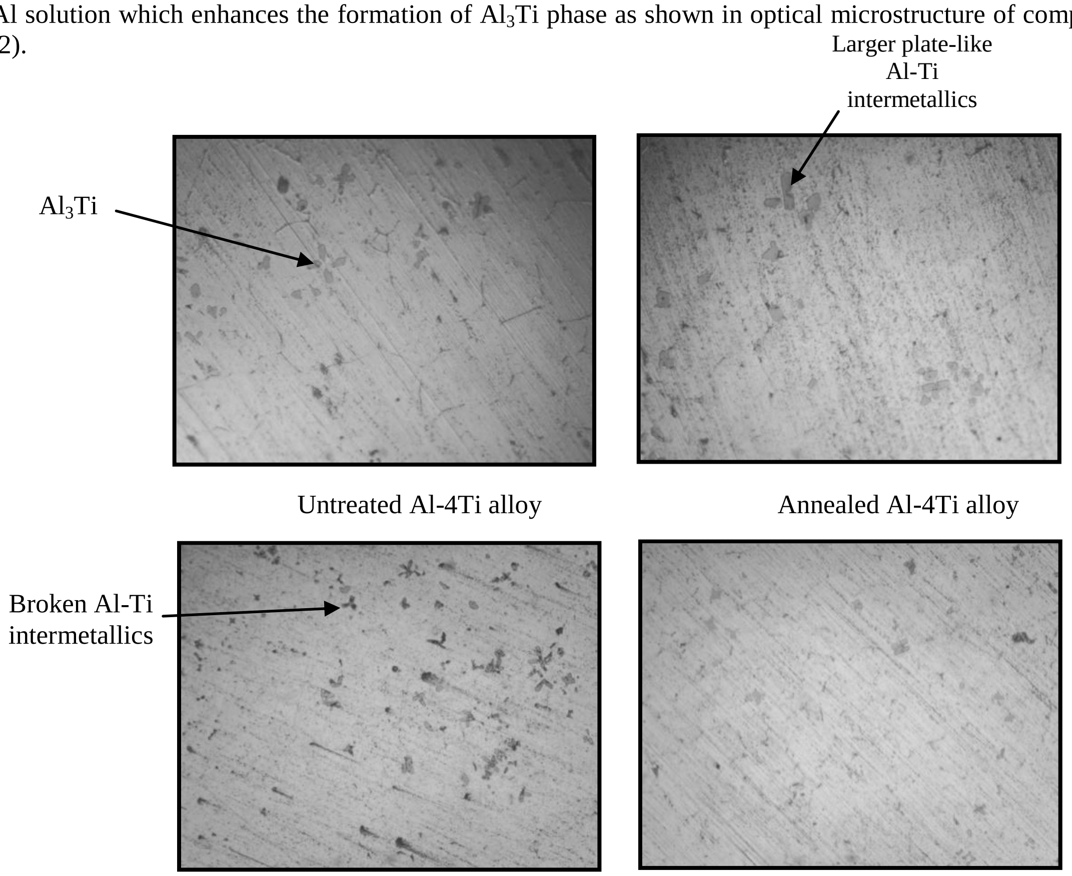
**Microhardness**

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting. Hardness is one of the longest used and most widely accepted parameters used to characterize the surface contact response of various engineering materials and systems. The data of microhardness for untreated specimen indicates that Al-4Ti alloy has hardness more than for Al-4Ti/MgO composite due to the porosity which formed in structure of composite. In addition to clustering effect of Mg particles within the aluminum alloy. The data of microhardness are listed in Table (1)

Also the decreasing in microhardness may be due to that the particles are growing together so that the embedded phase in the supersaturated Al solid solution is no more uniform spread; this lead to decreasing of the hardness, because the strengthening influence of small dispersive particles is loosed.

The most stable intermetallic phase in the investigated Al-Ti system is the $Al_3Ti$ phase and this phase is hard. After heat treatments, the microhardness was changed due to breaking up in $Al_3Ti$ phase. The lowest microhardness obtained for normalized Al-4Ti alloy due to decreasing of intermetallic phase and this lead to decreasing of the hardness.

The comparison between the behavior of base alloy and composite reinforced by MgO indicates that the composite has microhardness more that for base alloy after heat treatment. This result may be due to incorporation of MgO with α-Al solution which enhances the formation of $Al_3Ti$ phase as shown in optical microstructure of composite in Figure (2).




Normalized Al-4Ti alloy Tempered Al-4Ti alloy

*Figure 1: Optical microscopy of Al-4Ti alloy before and* after heat treatments.

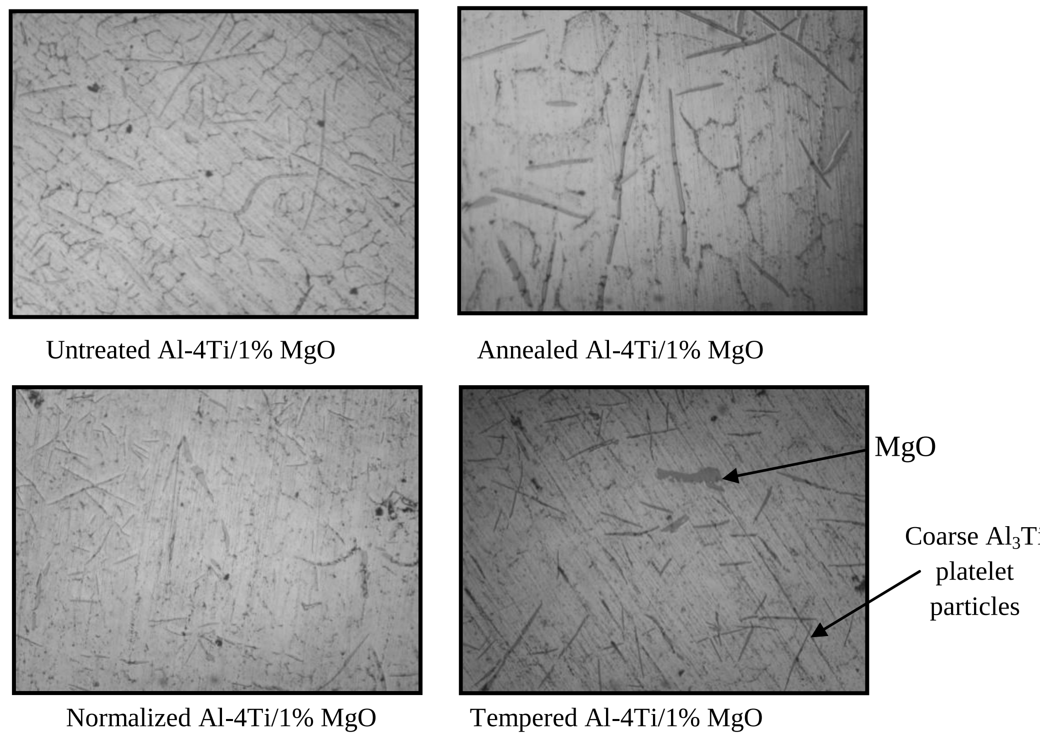



*Figure 2: Optical microscopy of Al-4Ti/1%MgO composite before* and after heat treatments.

**Roughness**

The roughness of fabricated materials related to composition and structure of them. Generally, the data of roughness in Table (1) show that the Al-4Ti alloy has roughness more than that of composite with little increases due to decreasing in hard $Al_3Ti$ phase during heat treatments. The tempering process led to obtain high roughness for base alloy compared with composite and other heat treated specimens. This due to increasing the broken $Al_3Ti$ intermetallic and presence of debris of $TiO_2$ by quenching and reheating process.

**Table 1:** Microhardness and roughness of untreated and treated Al-4Ti alloy and Al-4Ti/1 wt% MgO composite.

| **Treatment** | **Microhardness (HV)** | | **Roughness (µm)** | |
|---|---|---|---|---|
| | **Alloy** | **Composite** | **Alloy** | **Composite** |
| Untreatment | 36.93 | 33.86 | 0.059 | 0.044 |
| Annealing | 22.83 | 29.13 | 0.110 | 0.105 |
| Normalizing | 18.33 | 25.46 | 0.109 | 0.074 |
| Tempering | 24.00 | 28.00 | 0.449 | 0.081 |

**Conclusion**

From the study of optical microscopy of Al-4Ti alloy and its composite with 1 wt% MgO, can be concluded that the presence of $Al_3Ti$ phase in base alloy and uniformly distribution of MgO in matrix for composite. The heat treatments of these fabricated materials led to breaking up the $Al_3Ti$ phase in base alloy and enhancing it in Al-4Ti/MgO composite because of combination of MgO with $Al_2O_3$ in matrix. The presence of MgO with heat treatment in composite led to enhance the microhardness and roughness of composite compared with Al alloy.

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