The Influence of Heat Treatment on the Microstructure and Hardness Properties of Ti6Al4V and MgAZ91D Alloys

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ABSTRACT

Ti6Al4V alloy and MgAZ91D alloy have excellent combinatorial properties. However, in many cases their applications are limited because of weaknesses in their mechanical properties such as low fatigue strength for MgAZ91D and low modulus elasticity for Ti6Al4V. In this work, the proposed solution is to improve their hardness properties by applying the suitable heat treatment process on these alloys. The heat treatment temperature of Ti6Al4V was performed at 950^{o}C and 900^{o}C, while for MgA91D at 500^{o}C and 450^{o}C. This is followed by water and air quenching and aging treatment at 400^{o}C/4 hours for Ti6Al4V and 200^{o}C/8 hours for MgAZ91D. The results show that the heat treatment process with water quenching medium helps to improve the properties of Ti6Al4V and MgAZ91D alloy in terms of microstructure's changes and generally the value of hardness and roughness was increased after the heat treatment process.

Keywords: *Ti6Al4V, MgAZ91D, Heat Treatment, Microstructural, Mechanical Properties*

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Introduction

Ti6Al4V and MgAZ91D are in the low density alloys group that have a density less than $4.5g/cm^3$ [1]. Ti6Al4V is a titanium alloy that composed of 6% Aluminium, 4% of Vanadium and the balance of 90% is titanium [2]. This alloy has been widely used in various applications including aerospace, chemical plant and automotive applications due to lightweight property, good corrosion resistance and excellent high temperature properties [1, 2]. In medical application, Ti6Al4V has been used in orthopedic implants, bone screws, trauma plates, dental fixtures and surgical instruments.

MgAZ91D is a magnesium alloy that consists of 9% Aluminium, 0.6% Zinc, 0.4% Manganese and the balance is Magnesium [3]. MgAZ91D has the highest strength among magnesium alloy, light in weight and superior in specific strength. The most common application of MgAZ91D is used as die casting part for automotive industry such as for vehicle modules drive train, interior, body and chassis and also for other applications [4].

However, both of these alloys have weaknesses in their mechanical properties such as low fatigue strength for MgAZ91D and low antifriction characteristic for Ti6Al4V [1]. Because of low fatigue strength, MgAZ91D cannot be applied to power train components such as transmission cases and engine castings where at the operating temperature (around 150-175ºC) it will start to creep [5]. Same as the Ti6Al4V, due to low antifriction characteristic, it requires special covers and lubricant usage on friction surface [2].

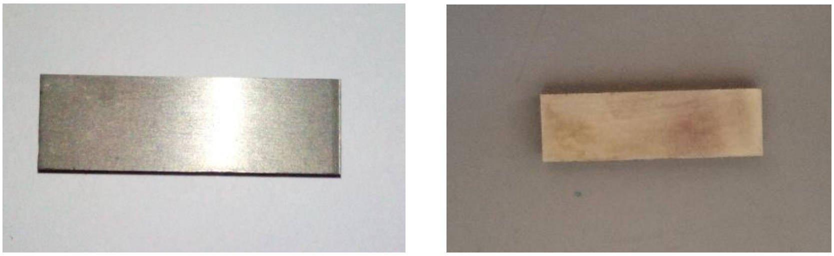
Due to the weaknesses, many studies has been done to investigate the solutions [3]. One of the proposed solutions is to improve their mechanical properties by applying the suitable heat treatment process. According to [3], MgAZ91D alloy requires heat treatment process to improve their corrosion resistance behavior while, the tensile strength of Ti6Al4V alloy also can be increased with the heat treatment process [6].

Heat treatment process involves the heating and cooling method applied to metal and alloy in a solid state so as to obtain the desired properties. There are four types of heat treatment processes which consists of annealing, normalizing, hardening and tempering and not all the heat treatments processes are applicable to all type of materials. For example, normalizing process is applicable to ferrous metals only [2]. Based on the literature study, the preferred heat treatment process for the Ti6Al4V and MgAZ91D alloy is annealing heat treatment process. The annealing process is to relieve internal stress, soften, make more ductile and refine the grain structures of the materials. This process involves heating a metal to a specific temperature, holding it at that temperature for a set length of time and followed by the cooling process.

Therefore, the aim of this study is to understand the effect of heat treatment temperature and the quenching medium to the microstructure and mechanical properties of heat treated Ti6Al4V and MgAZ91D alloy.

Experimental Procedure

Titanium alloy, Ti6Al4V and magnesium alloy, Mg AZ91D are used in this study as shown in Figure 1 (a) and (b). The composition of these materials is shown in Table 1. The bar type shape of Ti6Al4V and Mg AZ91D with dimensions of 3cm (length) x 1cm (width) was ultrasonically cleaned in water solution for 15 minutes to remove dirt and grease on the surface of the material prior to the heat treatment process.



(a) (b)

Figure 1: Sample of (a) Ti6Al4V and (b) MgAZ91D (as received)

Table 1: Chemical Compositions of Ti6Al4V and MgAZ91D

Material	Chemical	Composition (%)
Ti6Al4V	Aluminium	6
	Vanadium	4
	Titanium	90
MgAZ91D	Aluminium	9
	Zinc	0.6
	Manganese	0.4
	Magnesium	90

In this study, the heat treatment process is done using Naberthem furnace model N41/H. The furnace temperature was calibrated using the thermocouple to verify the actual condition of the furnace temperature against the controller. During the heat treatment process the furnace was incorporated with the Argon gas to remove any oxygen inside the furnace.

The Ti6Al4V is being heat treated at temperature of 950^{o}C and 900^{o}C for 1 hour soaking time (Figure 2). While, for the MgAZ91D, heat treatment process at temperature of 500^{o}C and 450^{o}C at 8 hours soaking time (Figure

3) is performed. Then each of the samples was quenched using water and air medium till they reached the room temperature condition. After the quenching process, the Ti6Al4V undergo aging process at temperature of 400^{o}C for 4 hours and 200 ^{o}C for 8 hours for MgAZ91D alloy. The process of heat treatment temperature was summarized in Table 2.

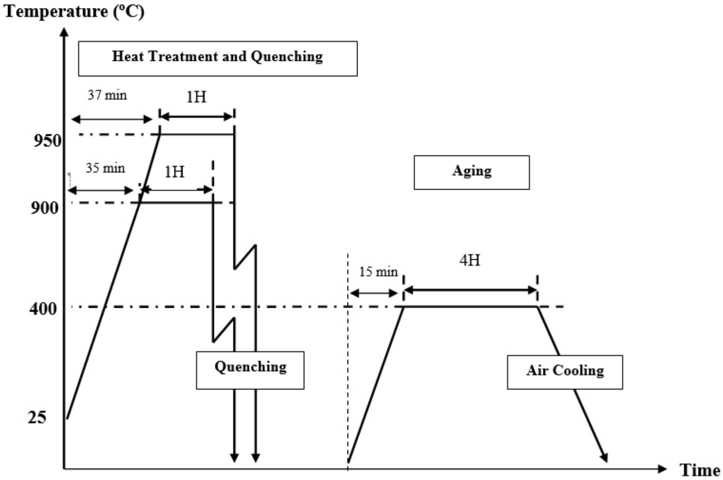


Figure 2: Heat treatment profile for Ti6Al4V

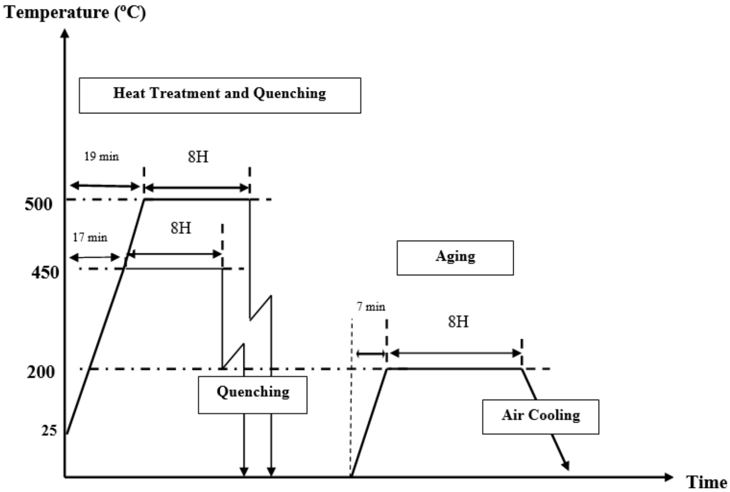


Figure 3: Heat treatment profile for MgAZ91D

Table 2: Heat treatment process parameters

Material	Heat treatment Temperature	Quenching medium	Aging
Ti6Al4V	950°C/ 1 hours	Water Air	400°C/ 4 hours
	900°C/ 1 hours	Water Air	
MgAZ91D	500°C/ 1 hours	Water Air	200°C/ 8 hours
	450°C/ 1 hours	Water Air	

The surface roughness of the heat treated samples were measured using a Mitutoyo SJ401 surface profilometer to determine the changes in the surface property after the heat treatment process. The microstructure analysis was done using optical microscope. Prior to that, the surface area was ground and polished to produce a mirror like surface finish and the surface were etched using Kroll's reagent for Ti6Al4V and Nital reagent for MgAZ91D to reveal the microstructures. For the purpose of mechanical property study, a Mitutoyo Rockwell hardness C test was employed with spherical diamond indenter repeated 20 times to measure the surface hardness.

Result and Discussion

Surface Roughness Analysis

In general, the value surface roughness analysis of heat treated Ti6Al4V samples were found increased after the heat treatment process except for samples at 900°C in a water quench (refer to Table 3). The highest value of surface roughness obtained by the sample of heat treatment 950°C in a water quench with 2.85μm. Based on the observation, for water quenching sample, it has cracked on the outer layer of the surface and become crusty after the water quenching process was performed compared to the air quenching process. Figure 4 shows the condition of the Ti6Al4V sample surface after the heat treatment with water quenching medium.

Meanwhile, the value of surface roughness analysis of heat treated MgAZ91D samples shows no significant changes after the heat treatment process is carried out (refer to Table 4). The highest value of surface roughness is obtained by the sample of heat treatment at 500°C in water quenching and the lowest value is at heat treatment process 450 °C in air quenching medium.

Table 3: Surface roughness value (Ra) for Ti6Al4V as received and heat treated samples

Samples	Ti6Al4V				Ti6Al4V As received
	950ºC/ 1 hours		900ºC/ 1 hours		
	Water	Air	Water	Air	
Ra	2.85	1.82	1.22	1.08	1.09

Figure 4: Ti6Al4V Surface condition after the heat treatment process in water quenching medium.

Table 4: Surface roughness value (Ra) for MgAZ91D as received and heat treated samples

Samples	MgAZ91D				MgAZ91D As received
	500ºC/ 1 hours		450ºC/ 1 hours		
	Water	Air	Water	Air	
Ra	1.42	0.76	1.06	0.75	0.74

Hardness Analysis

For the surface hardness analysis, it shows that for Ti6Al4V samples with higher heat treatment temperature experience a higher surface hardness value compared to as received sample, particularly for sample in water quenching medium (refer to Figure 5). The growth of the hardness property can be explained by the decomposition of martensite structure [7]. Whereas, for MgAZ91D samples, hardness analysis was unable to be carried out as of restriction in indenter type and size.

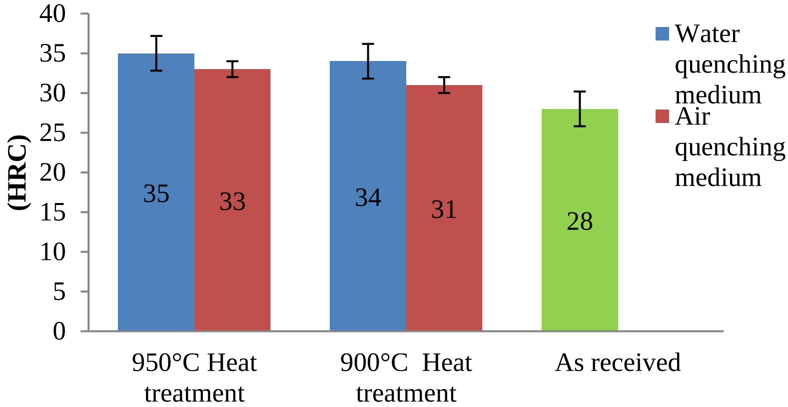
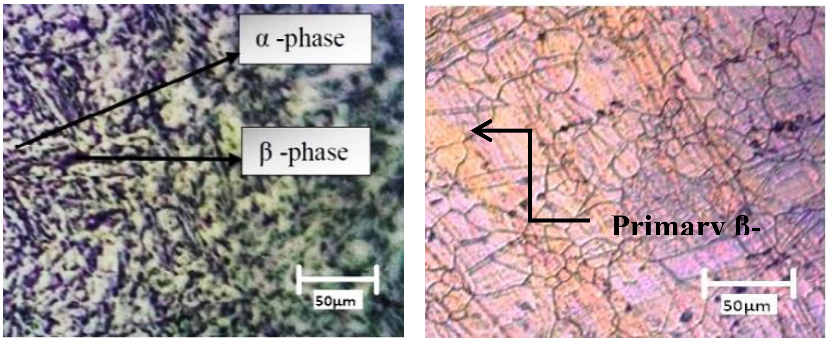


Figure 5: Average value of Ti6Al4V surface hardness analysis after the heat treatment process

Microstructure Analysis

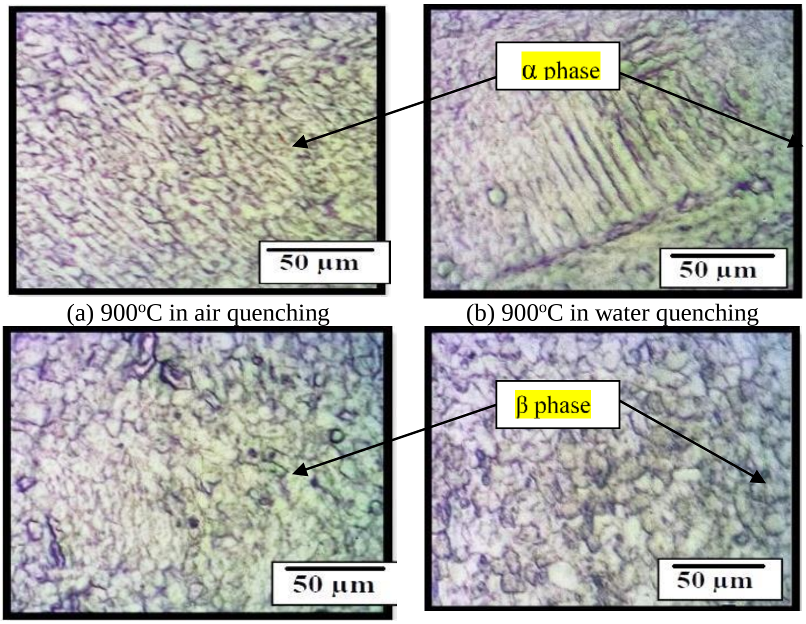
Figure 6 (a) and (b) shows the optical micrograph of the as received samples of Ti6Al4V and MgAZ91D alloy. For Ti6Al4V shows the lamellae structure of α phase (shown light) and β phase (shown darker).While for MgAZ91D alloy show bigger primary β-phase.



(a) Ti6A14V (b) MgAZ91D

Figure 6**:** Microstructure of As received samples

Figure 7 presents the optical micrograph of the heat treated Ti6Al4V samples. It is observed that the grain size of Ti6Al4V increased as the heat treatment temperature is increased. It is also observed that the volume fraction of β phase in Ti6Al4V decreased with the heat treatment process. At the same time, a part of prior β was transformed to acicular α martensite. Since the volume fraction of prior β phase decreased with a heat treatment process, the concentration of vanadium which is a β stabilizer decreased in prior β phase. Then the acicular α phase was generated in prior β phase through quenching [8].



(a) 900°C in air quenching (b) 900°C in water quenching

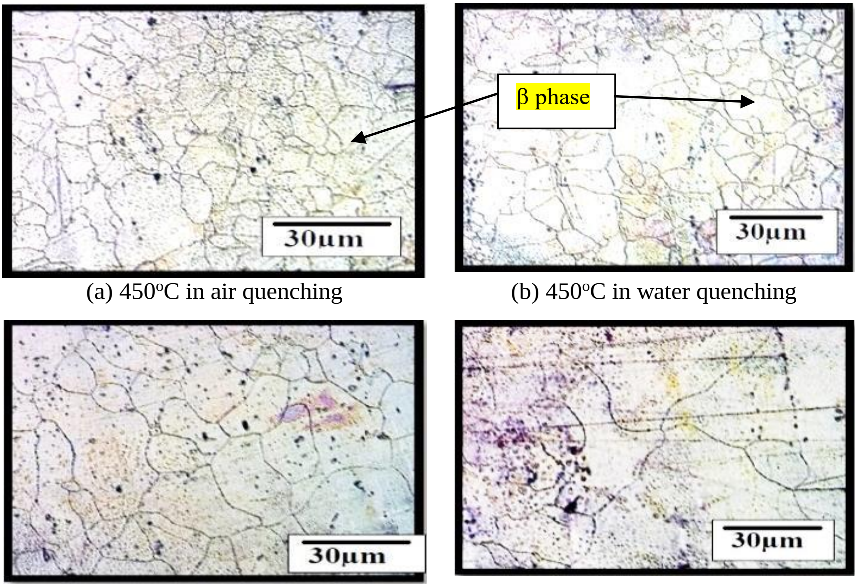
(c) 950°C in air quenching (d) 950°C in water quenching

Figure 7: Microstructure of Ti6Al4V after the heat treatment process

This result is also equivalent to what is experienced by MgAZ91D samples, where the grain size of microstructure increases as heat treatment temperature increases and sample with water quenching shows larger grain size compared to air quenching samples (Figure 8). From the microstructure of MgAZ91D obtained, it shows that β phases precipitate again the grain boundaries and within grains of the supersaturated α phase [3].

Conclusion

It is observed that the heat treatment process has a major influence on the microstructural and mechanical properties of Ti6Al4V and MgAZ91D alloy. The observations also show that the heat treatment process is able to improve the hardness property of these alloy. The improvement is considered to be primarily due to the changes in grain size of the microstructures obtained.



(a) 450°C in air quenching (b) 450°C in water quenching

(c) 500°C in air quenching (d) 500°C in water quenching

Figure 8: Microstructure of MgAz91D after the heat treatment process

Acknowledgements

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