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Research Article

Experimental Investigation on Effect of Heat Treatment on Mechanical Properties of Titanium Alloy (Ti-6Al-4V)

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Abstract

Titanium Alloy (Ti-6Al-4V) is the most widely used titanium alloy. It features good machinability and excellent mechanical properties when compared to the Pure Titanium. These alloys are widely used in the engineering field, namely in the aerospace, automotive and biomedical parts, because of their high specific strength and exceptional corrosion resistance. However, the machinability of titanium alloys is difficult due to their low thermal conductivity and elastic modulus, high hardness at elevated temperature, and high chemical reactivity. In this article to overcome this disadvantage of machinability the material is heat treated which increases the machinability but this article however reviews the effect of heat treatment on the mechanical properties of the titanium alloy by comparing the results obtained in the Universal Testing Machine (UTM) , Hardness Testing , Scanning Electron Microscope (SEM) for the both the Non Heat Treated Specimen and Heat Treated Specimen .

Keywords: *Titanium Alloy (Ti-6Al-4V) , Scanning Electron Microscope (SEM) , heat treatment*

1. Introduction

Titanium and its alloy are considered as important engineering materials for industrial applications because of good strength to weight ratio, superior corrosion resistance and high temperature applicability. Titanium alloys have been widely used in the aerospace and aircraft industry are due to their ability to maintain their high strength at elevated temperature, and high resistance for corrosion. They are also being used increasingly in chemical process, automotive, biomedical and nuclear industry (D. G. Lee, S. Lee *et al*, 2008). Titanium grade 5 has outstanding resistance to corrosion in most natural and much industrial process environmental (M. Imam *et al*, 1983)

The metallurgy of titanium has a large influence on the machining characteristics of Ti alloys. Pure titanium undergoes an allotropic transformation at 882,5°C, and changes from alpha to beta phase, from HCP crystal structure to BCC (C. Rhodes, *et al* ,1979) The precise temperature at which this transformation occurs can be affected by the presence of other chemical elements, some of which stabilize the alpha form and thus raise the effective transformation temperature, and some which stabilize the beta form and so have the opposite effect. These additions also alter the physical properties of the metal, and so change the machining characteristics. Titanium alloys can therefore be classified into four distinct groups: Unalloyed titanium –these possess excellent corrosion resistance but low strength properties. They are used largely in cryogenic applications (T. Morita *et al*, 2005)

Alpha structure–with alpha stabilizer elements present, these alloys possess excellent creep resistance. They are also used largely in cryogenic applications.

Alpha Beta structure – this group contains both alpha and beta stabilizer elements. This is the largest group in the aerospace industry.

Beta structure – with beta stabilizers this group has high hardenability and high strength, but also a higher density.

2. Need for Heat Treatment

Table 1 Composition of Titanium alloy (Ti-6Al-4v)

Material	Content
C	< 0.08 %
Fe	< 0.25 %
N2	< 0.05 %
O2	< 0.2 %
Al	5.5 – 6.76 %
V	3.5 – 4.5 %
H2 (Sheet)	< 0.015 %
H2 (Bar)	< 0.0125 %
Ti	Balance

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Titanium and titanium alloys are heat treated for several reasons:

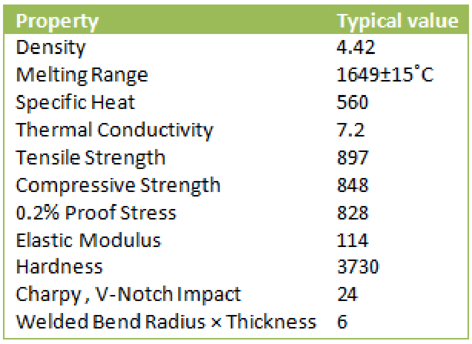
- To reduce residual stresses developed during fabrication (stress relieving)
- To produce the most acceptable combination of ductility, machinability, and dimensional and structural stability, especially in alpha-beta alloys (annealing)
- To increase strength by solution treating and aging
- To optimize special properties, such as fracture toughness, fatigue strength, and high-temperature creep strength (S. Madhukar *et al*, 2016)

Stress relieving and annealing may be used to prevent preferential chemical attack in some corrosive environments, to prevent distortion, and to condition the metal for subsequent forming and fabricating operations. Hot isostatic pressing, a specialized heat treatment process, can help narrow the fatigue property scatter band and raise the minimum fatigue life of cast components (G. A. Salishchev *et al*, 1996)

2. Properties of Titanium Alloy

Titanium is so highly valued due to its interesting properties. The key properties of titanium are:

Table 2 Properties of Titanium alloy (Ti6al4v)



Property	Typical value
Density	4.42
Melting Range	1649±15°C
Specific Heat	560
Thermal Conductivity	7.2
Tensile Strength	897
Compressive Strength	848
0.2% Proof Stress	828
Elastic Modulus	114
Hardness	3730
Charpy, V-Notch Impact	24
Welded Bend Radius × Thickness	6

- Strength-Titanium possesses high strength when alloyed with additional metals and elements. This can produce the desired level of strength or ductility. Titanium is just as strong as steel
- Lightweight - Titanium is also lighter than steel whilst having a similar strength. This quality is very desirable for medical and construction applications. Titanium's high strength-to-weight ratio is very appealing to builders as they continually look to produce buildings that are high in strength using lighter materials (V. K. Aleksandrov *et al*, 1979)
- Corrosion-resistant - Titanium is highly resistant to most types of corrosion. Most metals will corrode in the presence of salt water, acids, and other chemical solutions, however Titanium shows surprising resilience to these. Titanium is also very resistant to stress corrosion cracking unlike steel.
- Biological Compatibility - Titanium can be used within the human body due to its bio-inert qualities. This means that titanium is not toxic to the human body and will not be rejected as easily when used in processes such as Osseo integration; when a foreign object is fused to human bone in order to provide structural support for prosthetics or implants (F. H. Froes *et al*, 1996).

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3. Applications of Titanium Alloy

Because of the hugely diverse set of properties titanium possesses, it is an incredible metal to work with. Titanium is suitable for a range of applications including the following:

- Medical - In the medical field, titanium has become one of the most widely used metals. It is bio-inert, it does not react with anything inside the body, making it the prime candidate for use in procedures such as dental implants, orthopedic rods, bone plates, and other prosthetics. It can also be used to produce a range of medical instruments such as scalpels and drills.
- Aircraft - The most common use for titanium is in aircraft construction. Titanium is the leading metal used in the construction of jet engines and airframes. Its lightweight characteristics make it especially important for use in increasing jet efficiency.(R. Boyer, *et al* , 1994)
- Automotive - Titanium is staple for the car and motorcycle industry. Since these machines have several moving parts, the need for durable material is very high. Titanium alloys offer the ideal solution for car and motorcycle parts such as rods, valves and camshafts. Titanium parts such as these are crucial to the racing industry.
- Industrial - There are also different industrial applications for titanium. Constantly new uses for titanium in construction are being discovered. It makes an excellent building material for outdoor applications since it is lightweight and resistant to corrosion.
- Chemical Processing - Titanium is useful in the chemical and pharmaceutical world, where equipment is often in constant contact with hazardous and corrosive materials.
- Other - Titanium finds application in a variety of different industries, such as jewelry, clocks and watches, eyewear and golfing. These consumer goods last longer and have a lot of appeal. Marine industries have taken a special interest in titanium

as well since materials that are in consistent contact with salt water demand a higher resistance to corrosion (Vinogradov *et al* ,2003)

4. Experimental Details

4.1 Work Material and Equipment Used

Alloys of Titanium (Ti-6Al-4V) material of 10 mm diameter and 200 mm length were used for the heat treatment, Hardness Testing. Fractography study is undertaken for the tensile test specimens. In this present work the heat treatment was carried on Melting Furnace (Max Temp 1170), Tensile Test on FIE–UTM–40KN, Hardness Test on Brinell Hardness Machine and fractography analysis on Hitachi SEM S-3700N.

4.2 Experimental Procedure

In this experiment the properties of Heat Treated and Non Heat Treated bar of Titanium alloy (Ti -6Al -4V) are compared. The following is the process that is followed to compare the properties

- Heat Treatment
- Hardness Testing
- Tensile Testing
- Microstructure Analysis

4.2.1. Heat Treatment

The process annealing is carried out for one out of the two rods in the melting furnace for the improvement of the mechanical properties. The Annealing details are as given in Table 3 and furnace is shown in Figure 1.

Table 3 Annealing details

Temperature	450 ° C
Time	80 Mins
Type of Cooling	Furnace Cooling

Figure 1: Furnace used for Heat Treatment

4.2.2 Hardness Testing

The hardness test is carried out for the both rods i.e, Heat Treated Rod and the Non Heat Treated on the Brinell Hardness Testing Machine. The testing details are given in Table 4 and the results obtained in the test are given in Table 5.

Table 4 Testing details

Test Procedure	IS 1500 : 2005
Type of Hardness	BHN
Indenter	2.5 mm
Load Applied	187.5 Kgs
Location	Surface

Table 5 Results obtained

	Heat Treated Rod	Non-Heated Rod
Impression 1	332	332
Impression 2	342	342
Impression 3	352	332
Average	342	335.33

4.3.3 Tensile Testing

The Tensile test is carried out for the both rods i.e, Heat Treated Rod and the Non Heat Treated on the UTM Machine. The following are input data to the specimens (Table 6)

Table 6 Input data to the specimens

Specimen Type	Round
Initial Diameter	9.94 mm
Final Diameter	0 mm
C/S Area	77.6 mm^2
Original Gauge Length	50 mm
Final Gauge Length	52.67

The following table 7 shows the comparison of Heat Treated and Non-Heat Treated Rod tensile test results

Table 7 Comparison of Heat Treated and Non-Heat Treated Rod tensile test

	Heat Treated Rod	Non–Heat Treated Road
Ultimate Strength	83.680 KN	81.280 KN
Ultimate tensile Strength	1078.351 N/mm^2	1049.587 N/mm^2
Elongation	5.340 %	5.000 %
Yield Strength	60.200 KN	58.080 KN
Yield Stress	775.773 N/mm^2	750.000 N/mm^2

Figure 3 Graph of Heat Treated Rod

Figure 4 Graph of Non Heat Treated

4.2.4 Scanning electron Microscope (SEM) Analysis

To find out the changes in the microstructures at the breaking area occurred when tested on the UTM, a small specimen of size approx. 2 mm X 2 mm is cut from the breakage portion of the both rods and tested with the help of Scanning electron microscope (SEM). The following figure 5 shows the Specimens used and figure 6 shows the SEM equipment.

Figure 5 Scanning electron microscope

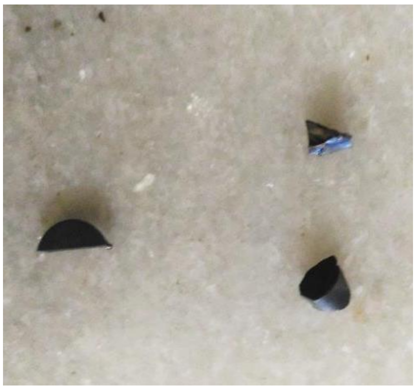

Figure 6 Specimens for SEM

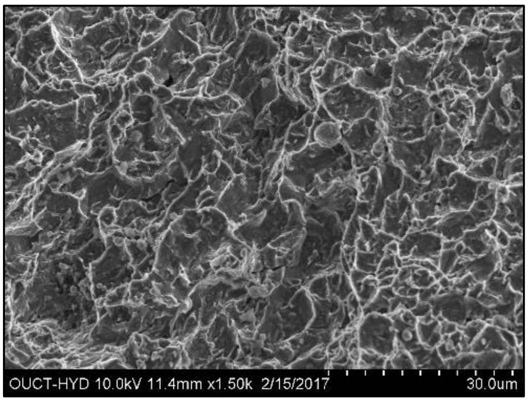

Figure 7 SEM capture of Heat treated Rod

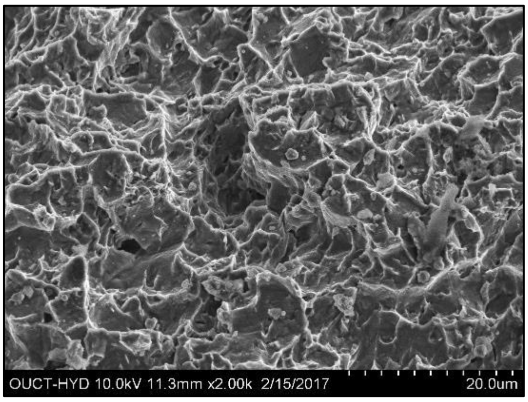

Figure 8 SEM capture of heat treated Rod

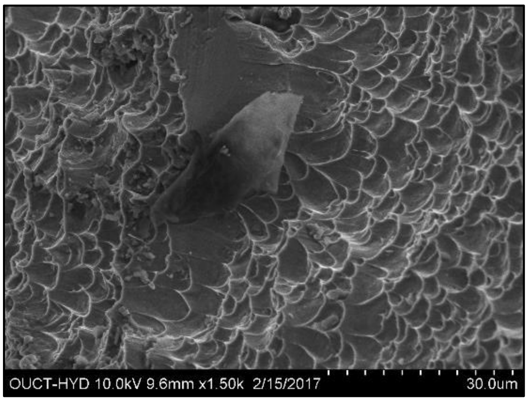

Figure 9 SEM capture of Non heat treated Rod

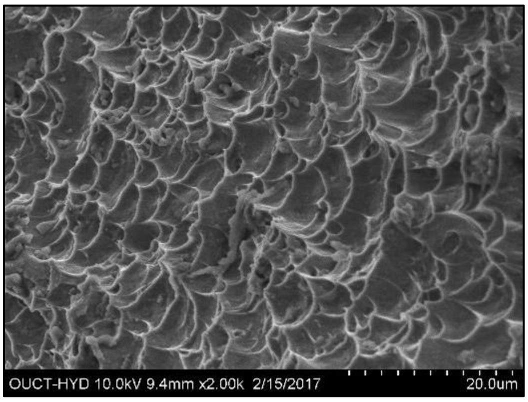

Figure 10 SEM capture of Non heat treated Rod

The figures 7-10 shows the fractography of the heat treated and Non heat treated specimens. The different properties analyzed for both heat treated and Non heat treated in Scanning electron microscope are explained in Table 8

Table 8 SEM Report Analysis

	Heat Treated	Non – Heat Treated
Type of fracture	Ductile	More ductile
Type of Dimple	Small	Big
Dimple Density	More	Less
Roughness	Less	More
Ridge Content	More	Less

5. Results and Conclusion

The present paper has investigated the effect of heat treatment on the mechanical properties of the Ti–6Al–4V alloy. The major results can be summarized as follows:

1) The Strength of Titanium alloy is more than the Pure Commercial Titanium
2) The ductility of the material decreased when heat treated using annealing process
3) The strength obtained is high in heat treated specimens than Non-heat treated specimens. It is attributed to the relieving of stresses and removal of compounds in the material.
4) When compared, the images captured in the SEM at 20 μm for the both heat treated and Non heat treated the facet size is different.
5) It can be clearly stated size of the facet increased due to the annealing process
6) It is clear from the fractographs that both looks ductile fracture, however the mechanical testing shows the change in ductility

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