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Research Article

Experimental Investigation on Effect of Heat Treatment on Mechanical Properties of Steels and Titanium

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Abstract

Titanium present in the earth's crust at a level about 0.6% and is therefore the fourth most abundant structural metal after aluminum, iron, and magnesium. High strength, low density, and excellent corrosion resistance are the main properties that make titanium attractive for a variety of applications. The major application of the material is production of airframes, engine components, steam turbine blades, superconductors, missiles etc. The titanium has good corrosion resistance which makes it excellent use in marine services, chemical, petrochemical, electronics, biomedical industries. Titanium and its alloys are among the most difficult materials to machine, mainly because of the metal reactivity at medium to high temperatures, from which a tendency to weld to the tool while machining leads to chipping and premature tool failure. Additionally, its low heat conductivity increases the temperature at the tool-workpiece interface. Finally, the low elastic modulus of Ti allows relatively large deflections of the workpiece, which affect adversely the tool life. In this paper we mainly study the effect of annealing (heat treatment) on the mechanical properties of materials Mild Steel , Stainless Steel and Titanium But our main focus will be on titanium material . The other two materials are studied for the comparison of mechanical properties of the materials with the titanium. Here the effect of heat treatment on the mechanical properties of the materials is found out by comparing the results obtained in the Universal Testing Machine (UTM) , Hardness Testing , Scanning Electron Microscope (SEM) for the both the Non Heat Treated Specimens and Heat Treated Specimens .

Keywords: *Scanning electron microscope , heat treatment , annealing , steels , titanium , tensile testing , vickers hardness testing*

1. Introduction

Titanium (Ti) is an element of atomic number 22. It occurs in two allotropic forms: Tiα and Tiβ. Variation α is crystallized at room temperature in a hexagonal configuration and at a temperature of 882.5 °C is converted to a high temperature Tiβ crystallizing in the regular system. Ti is characterized by a very low thermal conductivity of 11.4 W m−1 K−1, which is 3–4 times smaller than for iron and up to 16 times lower than for copper. In soft state, Ti has a tensile strength Rm = 460– 590 MPa. Titanium has a high ductility and excellent corrosion resistance to sea water, chlorides, organic acids, and air atmosphere; no oxidation at 200 °C and has a high creep resistance at high temperature. Pure, unalloyed titanium is used mainly in the construction, which is required to have high corrosion resistance. These include chemical equipment and rigs working in the surrounding seawater as well as elements used in medical technology and watch making.

Titanium is a metal showing a high strength-weight ratio which is maintained at elevated temperatures and it has exceptional corrosion resistance. These characteristics were the main cause of the rapid growth of the titanium industry over the last 40 years. The major application of the material in the aerospace industry, both in air frames and engine components (D. G. Lee, *et al* , 2008) Non aerospace applications take advantage mainly of their excellent strength properties, for example steam turbine blades, superconductors, missiles etc ; or corrosion resistance, for example marine- services ,chemical petro-chemical, electronics industry ,bio- medical instruments etc.

However, despite the increased usage and production of titanium, they are expensive when compared to many other metals, because of the complexity of the extraction process, difficulty of melting and problems during fabrication. On the other hand, the longer service lives and higher property levels counterbalance the high production costs. The poor machinability of titanium has led many large companies (for example Rolls-Royce and general electric) to invest large sums of money in developing

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techniques to minimize machining costs. Similarly, tool makers are looking for new tool material which could extend tool life in the presence of such a challenge. While improving the machining rates would go a long way towards increasing the usage of the material, it must be noted that this is only one of a number of factors affecting the use of the material. Others which include material cost must also be considered in any specific application. The present paper proposes the heat treatment (Annealing method) to change the mechanical properties which make the machinability of the material easy (M. Imam , *et al* , 1983).

2. Applications

Grade 2 titanium is called the "workhorse" of the commercially pure titanium industry, thanks to its varied usability and wide availability. It shares many of the same qualities as Grade 1 titanium, but it is slightly stronger. Both are equally corrosion resistant (T. Morita , *et al* , 2005)

Titanium Grade 2 may be considered in any application where formability and corrosion resistance are important, and strength requirements are moderate. Some examples of aerospace applications have included airframe skins in "warm" areas, ductwork, brackets, and galley equipment.(Aitha Shravan, *et al* , 2017) Ti Grade 2 has also been widely used in marine and chemical applications such as condensers, evaporators, reaction vessels for chemical processing, tubing and tube headers in desalinization plants, and cryogenic vessels. Other uses have included items such as jigs, baskets, cathodes and starter-sheet blanks for the electroplating industry, and a variety of medical applications (C. Rhodes , *et al* ,1979).

Titanium grade 2 is widely used in heat exchangers, where despite the low thermal conductivity of titanium the efficiency of heat transfer is high due to good strength, high resistance to erosion corrosion and the fouling resistance of the hard, smooth surface. At room temperature grade 2 is an alpha alloy. It transforms to beta phase at 913 ±15°C, and the alpha phase returns on cooling 890 ±15°C. Titanium is reactive, with a very high affinity for oxygen, which forms a skin of very stable and highly adherent oxide. The skin gives excellent corrosion resistance, despite the reactivity of the metal. The oxide layer forms spontaneously and rapidly on exposure to the atmosphere. However, when new parent metal is exposed to anhydrous conditions or in the absence of air, rapid corrosion may occur. Care should also be taken if titanium is to operate in contact with hydrogen, as hydrogen embrittlement from hydride formation can increase strength, with loss of ductility. Titanium grade 2 has many applications, the most important applications are:

- Architecture
- Power generation
- Medical industry
- Hydro-carbon processing
- Marine industry
- Exhaust pipe shrouds
- Airframe skin
- Desalination
- Chemical processing
- Chlorate manufacturing

3. Need for Heat Treatment

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 (F. H. Froes, *et al*, 1996)

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 (S. Madhukar , *et al* , 2016)

4. Experimental Procedure

In this experiment the mechanical properties of Heat Treated and Non Heat Treated bars of Mild Steel, Stainless Steel and Titanium are compared. The following is the process that is followed to compare the properties

- Material chemical Composition Testing
- Heat Treatment
- Hardness Testing
- Tensile Testing
- Microstructure Analysis

4.1. Material chemical Composition Testing

The following are the materials selected for the experiment

- Mild Steel (Low Carbon)
- Stainless Steel (SS 304)
- Titanium (Grade – 2)

The optical Emission Spectrometer is used to find out the chemical composition of the above materials. The following is the results of the tests.

Table 1 Chemical Composition of Mild Steel

C %	0.17
Si %	0.20
Mn %	0.54
P %	0.16
Fe %	98.7

Table 2 Chemical Composition of Stainless Steel

Cr %	18.66
Ni %	8.22
Mn %	1.27
Fe %	71.85

Table 3 Chemical Composition of Titanium

V %	0.17
Al %	0.61
Ti %	99.10

4.2. Heat Treatment

The process annealing is carried out for one out of the two rods in the furnace for all the three materials for the improvement of the mechanical properties. The Annealing details are as given in Table 3 and Table 4 and furnace is shown in Figure 1

Table 4 Annealing details for Mild Steel and Stainless

Temperature	200 °C
Holding Time at required temperature	100 -120 mins
Type of Cooling	Furnace

Table 5 Annealing details for Titanium

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

Figure 1: Furnace used for Heat Treatment

4.3. Hardness Testing

The hardness test is carried out for the both rods i.e, Heat Treated Rod and the Non Heat Treated of the three materials on the Vickers Hardness Testing Machine. The testing details are given in Table 4 and the results obtained in the test are given in Table 5 (Samatham Madhukar, *et al* , 2017).

Table 6 Testing details

Test Procedure	IS 1501 : 2002
Type of Hardness	HV
Indenter	Diamond
Load Applied	5 kgs
Location	Surface

Table 7 Results obtained

	Mild Steel	Stainless Steel	Titanium
Heat Treated Rod	166.67	340	207.67
Non-Heated Rod	167.33	350	170.33

4.4. Tensile Testing

The Tensile test is carried out for the both rods i.e, Heat Treated Rod and the Non Heat Treated of the three materials on the UTM Machine. The following are input data and results to the specimens

- Mild Steel

Table 8 Input data to the specimens

Specimen Type	Round
Initial Diameter	10.57 mm
Final Diameter	0 mm
C/S Area	87.74 mm²
Original Gauge Length	50 mm
Final Gauge Length	62.6

The following table 9 shows the comparison of Heat Treated and Non-Heat Treated Rod tensile test results

Table 9 Comparison of Heat Treated and Non-Heat Treated Rod tensile test

	Heat Treated Rod	Non–Heat Treated Road
Ultimate Load	46.480 KN	44.880 KN
Ultimate tensile Strength	529.687 N/mm²	528.311 N/mm²
Elongation	25.200 %	21.920 %
Yield Strength	31.960 KN	41.400 KN
Yield Stress	364.217 N/mm²	487.345 N/mm²

- Stainless Steel

Table 10 Input data to the specimens

Specimen Type	Round
Initial Diameter	12.7 mm
Final Diameter	0 mm
C/S Area	126.677 mm²
Original Gauge Length	50 mm
Final Gauge Length	70.9.67
Extensometer Gauge Length	25 mm

The following table 11 shows the comparison of Heat Treated and Non-Heat Treated Rod tensile test results

Table 11 Comparison of Heat Treated and Non-Heat Treated Rod tensile test

	Heat Treated Rod	Non–Heat Treated Road
Ultimate Load	89.040 KN	79.520 KN
Ultimate tensile Strength	702.873 N/mm^2	697.299 N/mm^2
Elongation	41.800 %	24.880 %
Reduction in Area	68.750 %	64.690 %
Yield Stress	369.002 N/mm^2	401.064 N/mm^2
Yield Strength	46.744 KN	45.738 KN

- Titanium

Table 12 Input data to the specimens

Specimen Type	Round
Initial Diameter	12.82 mm
Final Diameter	9.1 mm
C/S Area	129.082 mm^2
Original Gauge Length	50 mm
Final Gauge Length	56.32
Extensometer Gauge Length	25 mm

The following table 13 shows the comparison of Heat Treated and Non-Heat Treated Rod tensile test results

Table 13 Comparison of Heat Treated and Non-Heat Treated Rod tensile test

	Heat Treated Rod	Non–Heat Treated Road
Ultimate Load	72.00 KN	71.560 KN
Ultimate tensile Strength	547.487 N/mm^2	554.385 N/mm^2
Elongation	18.200 %	12.640 %
Reduction in Area	44.960 %	49.610 %
Yield Stress	452.700 N/mm^2	323.980 N/mm^2
Yield Strength	59.535 KN	41.820 KN

4.5. Scanning electron Microscope (SEM) Analysis

To find out the changes in the microstructures of the material a small specimen of size approx. 2 mm X 2 mm is cut from the breakage portion of the both rods (Heat Treated and Non Heat Treated) of the three materials. These specimens are tested with the help of Scanning electron microscope (SEM). The following figure 3 shows the Specimens used, figure 2 shows the SEM equipment and figure 4 shows the SEM specimen mounting stand.

Figure 2 Scanning electron microscope

Figure 3 Specimens for SEM

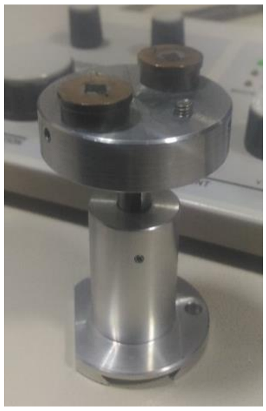

Figure 4 SEM Specimen Mounting Stand

The following figures shows the fractography analysis of the three materials for both Heat treated and Non-Heat Treated Materials.

- Mild Steel

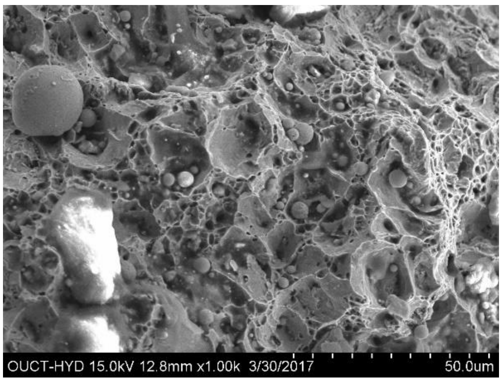

Figure 5 SEM capture of heat treated Rod

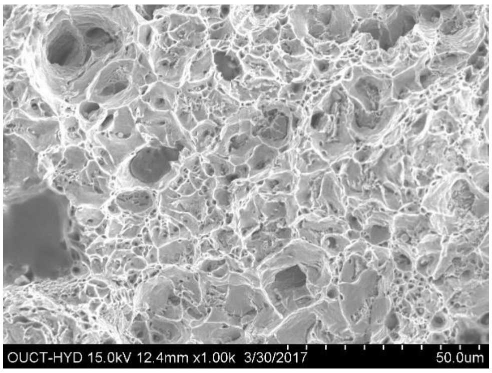

Figure 6 SEM capture of Non- heat treated Rod

- Stainless Steel

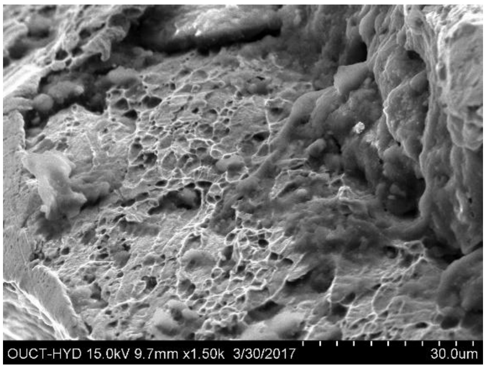

Figure 7 SEM capture of Heat treated Rod

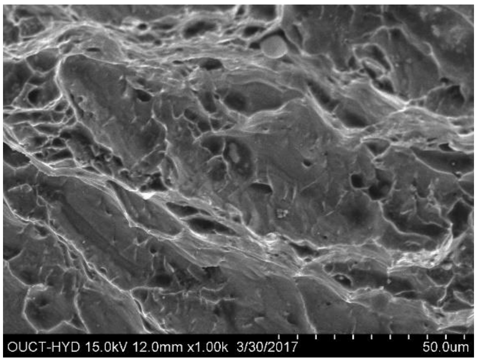

Figure 8 SEM capture of Non heat treated Rod

- Titanium

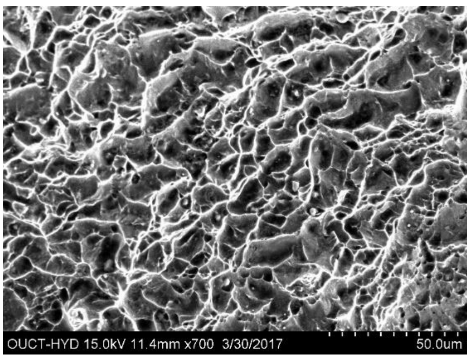

Figure 9 SEM capture of heat treated Rod

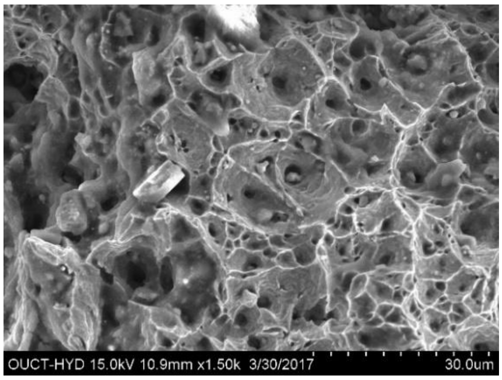

Figure 10 SEM capture Non-heat treated Rod

The figures 10-10 shows the fractography of the heat treated and Non heat treated specimens. The different properties analyzed for both heat treated and Non heat treated for the three materials in Scanning electron microscope are explained in Tables 14 – 16.

Table 14 SEM Report Analysis for Mild Steel

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

Table 15 SEM Report Analysis for Stainless Steel

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

Table 16 SEM Report Analysis for Titanium

	Heat Treated	Non – Heat Treated
Type of fracture	More Ductile	Ductile
Type of Dimple	Small	Big
Dimple Density	Less	More
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 three materials. The major results can be summarized as follows:

1) The ductility of the material decreased when heat treated using annealing process for stainless steel and increased for the Titanium and Mild steel
2) The tensile test report for the three materials attributed to the relieving of stresses and removal of compounds in the material.
3) The ductility is characterized by inclusions separated by matrix regions with dimple structure exhibited by the three materials
4) A Kind of laminar tearing is observed with heat treated titanium due to dispersion of oxides

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