

Effect of Thermal Treatment on Microstructure Evolution and Mechanical Properties of CP-Ti and Ti-6Al-4V alloys

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Abstract— In the present study effect of heat treatment on room temperature flow behavior of CP-Ti and Ti-6Al-4V alloy was investigated. The heat treatment processes were carried out in the single phase β region. Depending upon the rate of cooling from the β region and subsequent heat treatment, the microstructural changes were observed.

Index Terms— Microstructure, Heat treatment process, Mill Annealing, Duplex Annealing, Solution Treatment, CP-Ti, Ti-6Al-4V

1 INTRODUCTION

Titanium is a chemical element with the symbol **Ti** and atomic number 22. It is a lustrous transition metal with a silver colour, low density, and high strength. Titanium is resistant to corrosion in sea water, aqua regia, and chlorine. Titanium can be alloyed with iron. Aluminium, vanadium, and molybdenum, among other elements, to produce strong, lightweight alloys for aerospace, military, industrial processes (chemicals and petrochemicals, desalination plants, pulp, and paper), automotive, agriculture, medical prostheses, orthopaedic implants, dental and endodontic instruments and files, dental implants, sporting goods, jewellery, mobile phones, and other applications. Titanium is widely distributed and constitutes 0.44 percent of the Earth's crust. The metal is found combined in practically all rocks, sand, clay, and other soils. It is also present in plants and animals, natural waters and deep-sea dredging, and meteorites and stars. The two prime commercial minerals are limonite and rutile. The preparation of pure titanium is difficult because of its reactivity. Titanium cannot be obtained by the common method of reducing the oxide with carbon because a very stable carbide is readily produced, and, moreover, the metal is quite reactive toward oxygen and nitrogen at elevated temperatures. Pure titanium is ductile, about half as dense as iron and less than twice as dense as aluminium, it can be polished to a high lustre. The metal has a very low electrical and thermal conductivity and is paramagnetic (weakly attracted to a magnet). Two crystal structures exist below 883°C (1,621 °F) hexagonal close-packed (α), above 883°C body-centred cubic (β). Titanium is important as an alloying agent with most metals and some non-metals. Some of these alloys have much higher tensile strengths than does titanium itself. Titanium has excellent corrosion-resistance in many environments because of the formation of a passive oxide surface film. No noticeable corrosion of the metal occurs despite exposure to seawater for more than three years. Titanium resembles other transition metals such as iron and nickel in being hard and refractory. Its combination of high strength, low density (it is quite light in comparison to other metals of similar mechanical and thermal

properties), and excellent corrosion-resistance make it useful for many parts of aircraft.

1.1 Microstructure evolution and mechanical properties of α - β heat treated Ti-6Al-4V alloys

The alpha-beta titanium alloys are relatively popular biomaterial for surgical implants due to their biocompatible nature. However, the major problem in using them for bio-application is their poor wear resistance. Generally, the mechanical properties of these alloys are determined by the morphology, volume fraction and individual properties of the two phases: α and β . The existence of α/β transformation means that a variety of microstructures can be achieved in these alloys via heat treatment, thus permitting the adaption of properties to specific applications. A range of properties of α/β alloys can be obtained by solution treatment just below the β -transus temperature followed by quenching then tempering or ageing at elevated temperatures to decompose the quenched structures. These changes that occur may be complex and it is necessary to study them in some detail. The current work was aimed at studying the influence of different heat treatment cycles on the microstructure and mechanical properties of the Ti-6Al-4V alloy.

1.2 Properties

The properties of titanium alloys are primarily determined by the arrangement, volume fraction, and individual properties of the two phases α and β . Compared with the body-centered cubic β , the hexagonal α is more densely packed and has an anisotropic crystal structure. Compared with β , α is characterized by the following properties:

- Higher resistance to plastic deformation.
- Reduced ductility.
- Anisotropic mechanical and physical properties.
- A diffusion rate which is at least two orders of magnitude lower.

- Higher creep resistance

1.3 Objectives

- To study the effect of heat treatment and microstructure evaluation of Cp-Ti and Ti-6Al-4V.
- To study the effect of heat treatment and microstructure evaluation on mechanical behaviour of Cp-Ti and Ti-6Al-4V alloy in the room temperature.
- To study the effect of heat treatment and microstructural evaluation on wear behaviour of Cp-Ti and Ti-6Al-4V.

1.4 Applications

- Aerospace and marine
- Industrial
- Consumer and architectural
- Jewelry
- Medical

2 LITERATURE REVIEW

In 1791 William Gregor the British reverend, mineralogist, and chemist discovered titanium. He examined the magnetic sand from the local river, Helford, in the Menachan Valley in Cornwall, England, and isolated “black sand”, now known as “ilmenite”. By removing the iron with a magnet and treating the sand with hydrochloric acid he produced the impure oxide of a new element. He named it “mechanite”, after the location. Four years later, the Berlin chemist Martin Heinrich Klaproth independently isolated titanium oxide from a Hungarian mineral, now known as “rutile”. Greek mythology provided him a new name from the children of Uranos and Gaia, the titans. The titans were utterly hated by their father and so detained in captivity by him in the earth’s crust, similar to the hard to extract ore – hence he named it Titanium.

It took more than 100 years before Matthew Albert Hunter from Rensselaer Polytechnic Institute in Troy, N.Y., was able to isolate the metal in 1910 by heating titanium tetrachloride (TiCl₄) with sodium in a steel bomb. Finally, Wilhelm Justin Kroll from Luxembourg is recognized as father of the titanium industry. In 1932 he produced significant quantities of titanium by combining TiCl₄ with calcium. At the beginning of World War II, he fled to the United States. At the U.S. Bureau of Mines, he demonstrated that titanium could be extracted commercially by reducing TiCl₄ by changing the reducing agent from calcium to magnesium. Today this is still the most widely used method and is known as the “Kroll process”. After the Second World War, titanium-based alloys were soon considered key materials for aircraft engines. In 1948 the DuPont Company was the first to produce titanium commercially. Today aerospace is still the prime consumer of titanium and its alloys, but other markets such as architecture, chemical processing, medicine, power

generation, marine and offshore, sports and leisure, and transportation are gaining increased acceptance.

Titanium is not actually a rare substance as it ranks as the ninth most plentiful element and the fourth most abundant structural metal in the Earth’s crust exceeded only by aluminium, iron, and magnesium. Unfortunately, it is seldom found in high concentrations and never found in a pure state. Thus, the difficulty in processing the metal makes it expensive. Even today it is produced only in a batch process, and no continuous process exists as for other structural metals. Titanium usually occurs in mineral sands containing limonite (FeTiO₃), found in the Ilmen mountains of Russia, or rutile (TiO₂), from the beach sands in Australia, India, and Mexico. Titanium dioxide is a very versatile white pigment used in paint, paper, and plastic, and consumes most of world production. Besides Russia, Australia, India, and Mexico, workable mineral deposits include sites in the United States, Canada, South Africa, Sierra Leone, Ukraine, Norway, and Malaysia. Of all the 112 chemical elements in the periodic system known today, about 85% are metals or metalloids. There are various ways to classify the metals, such as ferrous or nonferrous metals, ingot or sintered metals, light or heavy metals. Titanium is classified as a non-ferrous and light metal.

The properties of metals are essentially based on the metallic bonding of the atoms in the crystal lattice. This means that the free, mobile valence electrons in the lattice result in classic “metallic” properties such as electrical conductivity, plastic deformation by atomic slip in crystal lattices, and alloying by incorporation of impurity atoms into the crystal lattice with the consequence of increased hardness and strength as well as reduced ductility. Metals vary substantially in weight. At 0.5 g cm³ Lithium has the lowest density while Osmium and Iridium are the heaviest metals with a density of 22.5 g cm³. The separation point between light and heavy metals is 5 g cm³. Therefore, Titanium with a density of 4.51 g cm³ is the heaviest light metal. Although twice as heavy as the classic light metal aluminium, it has only about half the specific weight of iron or nickel

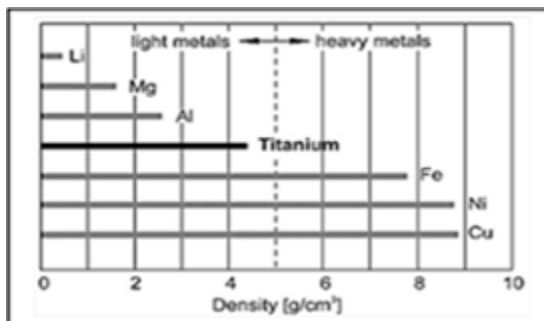


Fig 2.1 Density of selected materials with Titanium alloys and aluminides

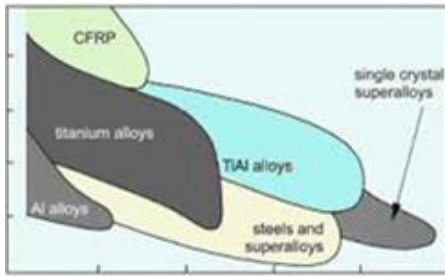


Fig 2.2 Specific strength v/s use temperature of selected Material

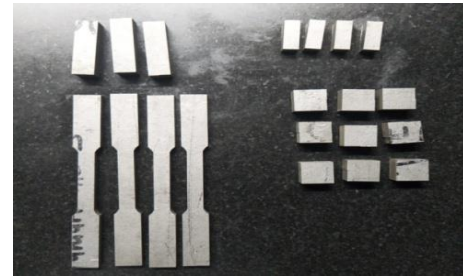


Fig 3.2 Specimen Samples

3 EXPERIMENTAL PROCEDURES

The proposed work is aimed at understanding the Effect of thermal treatment on microstructure evaluation and mechanical properties of Cp-Ti and Ti-6Al-4V. The work will comprise of following phases.

3.1 Selection of material

The Titanium alloys Cp-ti and Ti-6Al-4V is procured from Bagyashali metals, Mumbai India. Material is bought in the form of plate sized 150×60×8 were cut and used for experimental procedure. The stated composition of the substrate material is given in the below table.

Sl.no	Material	Ti %	Fe %	V %	Al %	Grade
1	CP-Ti	99.94	0.21	-	-	2
2	Ti-6Al-4V	89.00	-	4.40	6.00	5

Table 3.1 Chemical composition.

3.2 Machining process

The procured material were converted into no of specimen which is used for experimental purpose, using drafting and the machining process were done through Electro discharge machining (EDM) in Vishak Engineering pvt Ltd. Penya Bangalore



Fig 3.1 Machining process using EDM

3.3 Heat treatment

After the machining process the specimen were heat treated in 4 different heat treatment process The following processes are :

- Solution treatment and aging
- Mill annealing
- Duplex annealing

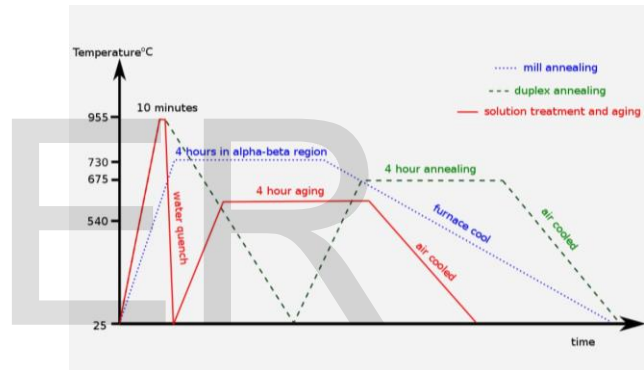


Fig 3.3 Time and Temperature various of heat treatment process of CP-Ti and Ti-6Al-4V alloys.

3.3 Microstructure

Metals have a preferred microstructure obtained by a specified processing or heat treatment to achieve desired material properties. We can perform micro structural testing across the broad spectrum of metals to identify a material's response to processing, such as heat treatment, welding or mechanical forming, or to evaluate material degradation and failure mechanisms, such as corrosion and creep. Microstructure analysis was performed on polished and thermally etched samples.

Once the specimen is heat treated, the specimen should be polished with the emery paper .The emery paper grades used for polishing are 600, 800, 1000, 1200 and 1500. This process helps to remove some rough patches on the specimen because of oxidation occurring during the heat treatment process. This helps the specimen to get some lustrous surface which helps to get better microstructure view for the analysis. After polishing with the Emery paper of different grades the specimen should be disc polished. Then the specimen should be involved in etching process. Etching is the process where the material is dissolved when immersed in a chemical solution. The etchants

used in this study is Nitric acid (HNO₃) and Hydrofluoric acid (HF). In this study the etchant solution composition is, for a 100ml of etchant solution, 8ml of (HNO₃), 4ml of HF and remaining 88ml of H₂O. After the disc polishing the specimens should be etched to remove the strain marks and scratches on the specimen surface which to be analyzed. The specimen should be immersed in the solution for about 20 seconds and immediately after 20 seconds it should be brought back and the specimen should be water dipped. Once after the specimen is water dipped the specimen should be microstructure analyzed with the help of microscope.

4 RESULT & DISCUSSION

The microstructures of the as-received sample and the samples after heat treatment are shown in Figure 5.1(a). Solution treatment in the current experiments was performed at two stages one at 955 °C and other at 540°C. Mill annealing process was performed at 730°C. Duplex annealing was performed at 675°C.

After solution treatment, the structure became more homogeneous, the structural morphology changed to interconnected β -network with relatively coarser α - grains. In mill annealing when it is heated at 730°C as the material was allowed to cool down under equilibrium conditions, the high temperature β -phase converted into lamellae of α and β . In duplex annealing, A duplex structure forms after slow cooling. Figure 5.1(c) shows such a microstructure, consisting of lamellar fractions and the globular "primary" α -phase, which remained unchanged during solution treatment.



Fig 4.1(a) CP-Ti as received

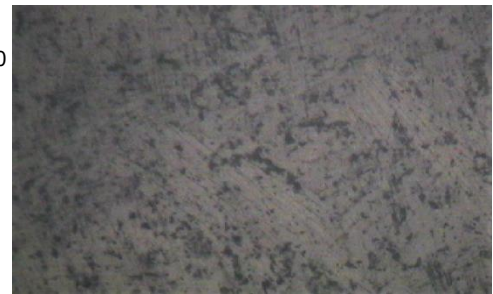
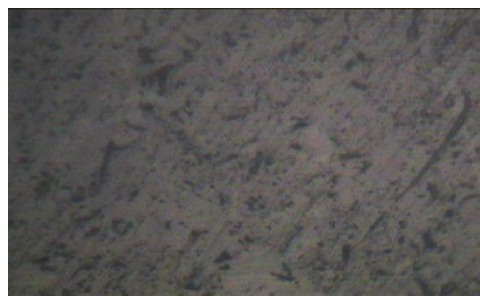


Fig 4.1(b) CP-Ti after mill annealing

Fig 4.1(c) CP-Ti after solution treatment

Fig 4.1(d) CP-Ti after duplex annealing

Fig 4.2(a) Ti-6Al-4V as received

Fig 4.2(b) Ti-6Al-4V after mill annealing

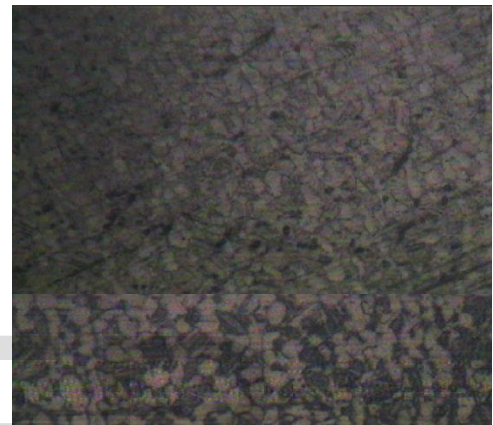


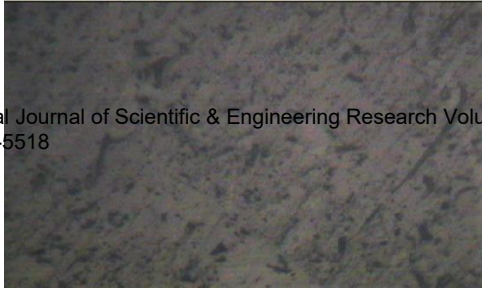
Fig 4.2(c) Ti-6Al-4V after solution treatment



Fig 4.2(d) Ti-6Al-4V after duplex annealing

5 CONCLUSION

- From the experimental results related to microstructure of Ti-6Al-4V and Cp-Ti alloy subjected to different heat treatment process, the following conclusion can be drawn.
- The mechanical properties of the alloy Ti-6Al-4V and Cp-Ti are affected considerably by the heat treatment and the developed microstructures.
- Within the framework of this study, the trade-offs in properties for different heat treatment strategies have been analyzed.



6 FUTURE WORK

Friction stir processing (FSP) is a novel solid-phase processing technique that is derived from friction stir welding (FSW). The microstructure of the base metal can be modified with the friction heat and stir function during processing. It can be used to fabricate surface composites by adding reinforced particles into the metal matrix via FSP. This can significantly improve the hardness, wear resistance, ductility of the material.

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