Vickers Hardness of thermal cycled Ti-64 Alloy Submitted to Heat Treatments

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ABSTRACT - The purpose of this study was to evaluate the effect of thermal cycled – heat treatments over Ti-64 on Vickers Hardness testing. Ti-64 is an alloy, which can be heat treatable to various temperatures that contains alpha and beta stabilizers. Ti-64 alloys are mostly used in the light weight structural applications viz., aerospace structural elements, engine components, air frames etc. The present study is focused on two different types of heat treatments on titanium (Ti-6Al-4V) alloy (stress relieve anneal, solution treated and aged). After the heat treatment, the specimens were exposed to thermal cycling by use of a specially designed apparatus which is capable of maintaining the stability and behaviour of materials for property development. The present study investigates the hardness for the heat treated and thermal cycled titanium alloy at various cycles in a newly designed thermal cycling apparatus.

Keywords: ***Thermal cycling, Heat treatment, Stress Relive Anneal, Solution Treated and Aged, Hardness, PLC.***

I. INTRODUCTION

Titanium is used in various high strength required and light weight structural applications. It is an alloys possessing with alpha and beta stabilizers. Due to which it can sustain high temperatures. It can be heat treatable to various gradations. Due to its strong influence of α stabilizers and β stabilizers, this titanium alloy has wide functionalities such as high corrosion resistance, low density, high strength to weight ratio, ductility can be seen high, thermal conductivity is low with suitable mechanical properties. Beta stabilizers plays a key role in retaining the beta phase after quenching process. Solution treatment method can increase its strength characteristics [1, 2].

To reduce stress development in the titanium alloys, they are heat treated during fabrication. By heat treating, alpha stabilizers act unto beta phase temperature raising the transformed alloys to be tougher and can resist to more temperatures, which means it can be used for high temperature applications. By heat treatment procedure the alloys properties can be optimized for special properties such as high temperature creep strength where the material can sustain for creep behavior under high temperatures, fatigue strength and fracture toughness.

Low density of the alloy is associated with a high melting point and viable chemical reactivity. When quenched this will come in advantage as it heaves the thermal capacity to with stand farther creep loads under high temperatures. As various alloys are designed for various purposes, heat treatment cycle differs accordingly to the transformation phases of the particular alloy. For obtaining an optimum compatibility with several operational factors like machinability, ductility stability, structural integrity the titanium alloy (Ti-64) is processed first to stress relieve annealing and later processes through solution treatment for upheaving the strength factor further ageing treatment to promulgate the thermal relative creep factors which indeed increases its hardness.

II. EXPERIMENTAL STUDY

The material compositions of different titanium labels has been presented in table 1. Pure titanium may represent the commercially pure titanium, grade 1 titanium is unalloyed titanium. There are two alloy specifications presented, one from reference [11] and the other one is in the interest of present study. The alloy specimens of present study interest have been processed through a systematic way in which

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machining, heat treatment, and other operations carried over.

The specimens were machined by using wire cut to a dimension of 10 mm in length and 8 mm in diameter. Later the specimens were subjected to a systematic heat treatments having two subsequent methods. In the first heat treatment, the specimens were heated to a temperature of 538 °C for 1 hour. After naturally cooling in the furnace to reach the atmospheric temperature the specimens were passed to the next subsequent heat treatment process. In the second heat treatment the specimens were heated to a temperature of 950°C for 1 hour. After heating the specimens were quenched in water, here quenching has a delay of 2 seconds for further processing. In later sequence, a process called aging was done at 524 °C for 4 hours [12]. This ensures that the alloy configures to its proportionate state and does not revert back to normal. After ageing process the specimens were placed outside furnace to reach atmospheric temperature so that it cools naturally.

After the two stage heat treatments, the specimens were thermally cycled in a thermal cycling apparatus which has an enclosed chamber specially designed, as shown in Figure 1. The thermal cycling apparatus consists of a PLC unit which consists of electronic experimental controls and timer, muffle furnace, forced air cooling unit. The PLC unit controls the heating and cooling time period of the cyclic process and regulates the flow of compressed air from compressor to the pneumatic cylinder through the electrically operated pneumatic valve.

Table 1. Composition (%) of the pure titanium and Ti-6Al-4V alloy.

	Al	V	O	C	Fe	N	H	Titanium
Pure Titanium [11]	-	-	0.15	0.08	0.18	0.02	0.007	Balanced
Grade 1 Titanium	-	-	0.40	0.18	0.05	0.20	0.015	Balanced
Ti-6Al-4V alloy [11]	6.2	3.8	0.17	0.01	0.22	0.02	0.003	Balanced
Ti-6Al-4V alloy*	6.36	4.12	0.1562	0.015	0.04	0.0037	0.0045	Balanced

* Present Study

Figure 1: Thermal Cycling Experimental Setup

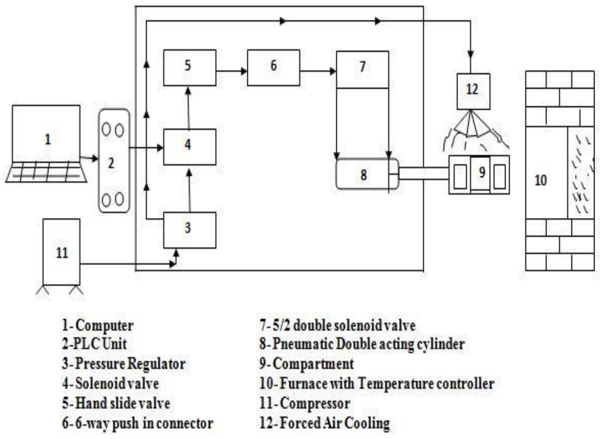

Figure 2: Schematic Setup of Experimental setup

Further the experimental set-up as shown in Figure 2 which consist of components like Computer, 5/2 double solenoid valve, PLC Unit, Forced Air, Solenoid valve, Furnace with Temperature controller, Hand slide valve, Double acting cylinder, 6-way push in connector, Compartment in which the test sample is placed. The compartment is made up of stainless steel with three divisions to carry similar test samples in it. The timer unit in PLC counts the number of cycles and stops the process after completing the required number of cycles which minimizes in Manual handling and monitoring of the sample during this thermal cycling process due to the automation. Double acting pneumatic piston actuator was built to cycle the specimen in and out of the furnace, where the constant temperature was maintained in the furnace. The thermal cycle setup which is imposed had dwell time of 2 minutes in and out of the furnace. Samples were cooled by forced air cooling at a pressure of 3 bars. Heat treated specimens were subjected to thermal cycling in the range of 250, 500, 750, 1000, 1250 and 1500 cycles. The hardness test was conducted for heat treated and thermal cycled Ti-64 specimens.

III. RESULTS AND DISCUSSION

Titanium (Ti-64) alloys are heat treated [Stress Relive Anneal (HT1), Solution treated and aged (HT2)]. The heat treated specimens and without heat treated specimens were subjected to thermal cycling. The number of thermal cycle range is selected from 250 cycles to 1500 cycles in steps of 250 cycles. The Vickers hardness test was conducted for these samples. Figure 3 shows the setup of Vickers Hardness test machine. Hardness of different heat treated and thermal cycled Titanium (Ti-64) alloy were investigated. (Manikandan and Ramanathan 2013)

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Figure 3: Vickers Hardness Testing Machine

IV. HEAT TREATMENTS

Ti-64 alloy specimens were subjected to two subsequent heat treatments. Primarily, the specimens of HT1 are heated to a temperature of 538 °C for 1 hour and it is furnace cooled to reach the atmospheric temperature. Then the specimens of HT2 are heated to a temperature of 950 °C for 1 hour and it is quenched in water. After quenching (delay of 2 second), aging was done at 524 °C for 4 hours and then it is cooled outside furnace to reach atmospheric temperature. Heating of Alpha and Beta Alloy to solution treating temperature, produces a higher ratio of Beta phase. The division of these Alpha and Beta phases is maintained by water quenching and subsequent aging and the decomposition of the unstable Beta phase occurs which provides high strength (oh et al., 2017). To obtain high strength in alloys with adequate ductility, it is necessary to solution treat at a temperature high in α-β field. Normally 25°C to 85°C which is below Beta transus of the alloy. If higher fracture toughness (or) improved resistance to stress corrosion is required, β Annealing or β solution treating may be desirable. However, heat treating Alpha and Beta alloys in which Beta causes a significant loss in ductility. These alloys are usually solution heat treated below the Beta transus to obtain an optimum balance of ductility, fracture toughness, creep and stress rupture properties (Srinivasan and Venugopal, 2008).

V. THERMAL CYCLING

The heat treated specimens were thermal cycled in a thermal cycling apparatus which is specially designed. The samples which are to be tested are subjected to programmed PLC Unit system which is designed for cyclic heating and cooling temperatures in a muffle furnace for desired time period. Pneumatic piston actuator was inserted to cycle the specimen in and out of the furnace. Where the required constant temperature was maintained inside the furnace. One heating and one cooling operation of the sample is considered as one cycle. The samples were subjected to different number of cycles during the experiment. The thermal cycle which is imposed had dwell time of 2 minutes in and out of the furnace. Samples were cooled by forced air cooling system which is provided at a pressure of 3 bars. Heat treated specimens were subjected to thermal cycling in the range of 250, 500, 750, 1000, 1250 and 1500 cycles. Manual handling of these samples in the thermal cycling process is very difficult, hard process and not more accurate in results. Hence PLC automation is necessary for material handling. Thermal cycling is a process of modulating the temperature, developed to improve the performance, longevity and strength of variety materials. During this thermal cyclic process, materials are alternately heated and cooled until they form molecular reorganization. This reorganization makes molecules optimize or tighten the structure of particulate throughout the material which helps in relieving stresses, and making the metal more closely compacted and more uniform which minimizes flaws or imperfections. The tighter structure also increases the heat distribution characteristics of the material and energy conductivity. The behaviour of materials under thermal cycling conditions is affected by a number of factors such as the thermal expansion, microstructure, loading level, thermal conditions and coefficients of micro constituents, (Hongbin et al., 1997; and Ismail and Kazim, 2004). Thermal Cycling reduces the hotspots, which enhances cooling, and hinder the ability and tendency of metals to vibrate.

VI. VICKERS HARDNESS

Vickers hardness for Without Heat treated (WHT), Stress Relief Anneal (HT1) and Solution treated and Aged (HT2) specimens are shown in Figure 4.

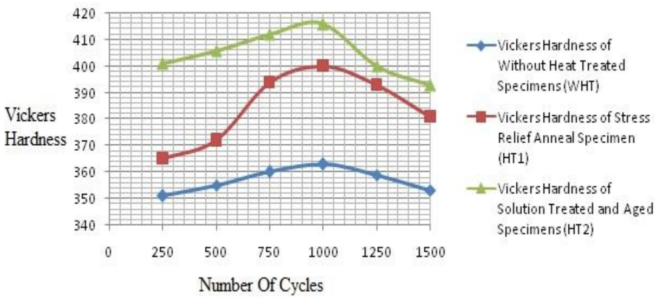

Figure 4: Vickers Hardness Results

It is observed that the Vickers hardness for Without Heat Treated specimens (WHT), Stress Relief Aneal Specimens (HT1) and Solution Treated and Aged specimens (HT2) are gradually Increased with increase of thermal cycles up to 1000 thermal cycles and then it slowly starts decreasing. Solution Treated and Aged specimens (HT2) found more than Without Heat Treated (WHT) and Stress Relief Aneal Specimens (HT1). A recent study by Sharmilee et al. (2008) confirmed that micro harness increases when the number of thermal cycles increases, indicating that strain

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hardening is caused by dislocation generation and movement. In addition, repeated quenching from a high temperature of range 200 to 400 °C is expected to add to the concentration of vacancies, which form prismatic dislocation loops and increase the hardness as a result. The decrease in hardness with the increase in number of thermal cycles is suggestive of softening by damage accumulation which is similar to those reported by Nikhilesh et. al., (2006)

VII. CONCLUSION

In the Present study, Ti- 6Al- 4V alloy is heat treated with two different methods to get the optimum combination of machinability, ductility and structural stability by Stress relief anneal and to increase the strength by solution treated and aged. Thermal cycling process was carried out for Ti-6Al- 4V alloy specimens for 250-1500 cycles at 427^{0}C and 2 minutes dwell time. Heat treated (Stress relief anneal and solution treated and aged) and thermal cycled Ti- 6Al- 4V alloy specimens were subjected to hardness test carried out at room temperature using a Vickers' hardness testing machine. The following conclusions are drawn from the present study.

- The hardness gradually increased at greater level up to 1000 cycles and slightly reduced from 1000 to 1500 cycles. When compared with WHT specimen the percentage of hardness increases up to 9.25% for Stress Relieve Anneal (HT1).
- The hardness gradually increased at greater level up to 1000 cycles and slightly reduced from 1000 to 1500 cycles. When compared with WHT specimen the percentage of hardness increases up to 12.7% for solution treated and Aged specimen.(HT2).
- Solution treated and 1000 cycled Titanium (Ti-64) alloy was found to have more strength.

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