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Effect of cooling medium on Solution treatment response of Titanium alloy Ti-5Al-5V-2Mo

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Abstract. Titanium alloys are widely used in aerospace industry in the areas of pressure vessels, airframe structures, landing gears, aeroengine compressor blades etc. The principal qualities of titanium alloys required for these applications are high specific strength, low density and high specific modulus. Among the families of Ti alloys, high strength titanium alloys come under martensitic α + β and metastable β alloys. Titanium alloy Ti-5Al-5V-2Mo (BT-23) is an important example of martensitic α + β alloy similar to the work horse Ti6Al4V alloy which exhibits good combination of strength and ductility in solution treated and aged conditions. But due to quenching from solution treatment temperature, the alloy tends to retain good amount of residual stresses. The severity of residual stress increases with increase in solution treatment temperature as well as severity of quench. An attempt has been made to study the effect of air cooling subsequent to solution treatment to compare the strength of the alloy vis-à-vis that achievable during water quenching. An attempt has also been made to correlate the microstructure evolution, hardness with variation in solution treatment temperature and quench severity in titanium alloy Ti-5Al-2Mo-5V. Samples subjected to air cooling subsequent to solution treatment exhibited higher microhardness when compared to water quenched samples. It is proposed that dynamic aging and/ or stress relieving occurs during air cooling from solution treatment temperature down to room temperature. Also the fine α precipitates formed during air cooling may be resulting in higher hardness compared to the α''/α' formed during water quenching. The same has been supported by thermal analysis of air cooling and water quenching processes employed subsequent to solution treatment.

1.0. Introduction

Martensitic α + β alloys derive their high strength due to the formation of α' during quenching in water and fine precipitation of α in transformed β matrix during subsequent aging. In α+β Ti alloys, the growth of a primary phase in a supersaturated matrix under isothermal or continuous cooling conditions may be diffusion controlled, interface-reaction controlled, or *via* a mixed mode [1-3] . Higher strength and ductility are developed if heat treatment is done in the alpha+beta field to produce a final microstructure of globular alpha in a matrix of transformed beta. The specific properties that are obtained in the alloy are a function of the volume fraction and size of the primary alpha grains/particles and the characteristics of the secondary (platelet) alpha. In turn, these microstructural features are a function of the soak temperature in the alpha + beta field and the cooling rate [4]. Hence it becomes all the more important to study these aspects before arriving at a final heat treatment cycle for the alloy. Extensive literature is available on the heat treatment of the work horse α+β Ti alloy Ti6Al4V [5,6] , BT-14 [7] etc., but no literature is available on BT-23 alloy. Quench severity and its effect on the mechanical properties has been reported in Ti6Al4V alloy [6]. An attempt has been made to evaluate the microstructure- property correlations in as solution treated BT-23 alloy.

2.0. Experimental Details

The alloy BT-23 was processed through double Vacuum Arc Remelting (VAR) and the chemical composition is given in Table.1. Samples of 10 x 10 x 5 mm were cut by wire EDM from the as hot rolled bar of Dia.75 mm to carry out solution treatment at temperatures in the range of 1123 -1278 K followed by subjecting one set to air cooling and other set to water quenching. These samples were subjected to optical microscopy using Olympus make metallurgical microscope after conventional metallographic polishing and etching with Kroll's reagent. Microhardness survey on ten locations per specimen was performed on all these samples using Wilson make Vickers micro-hardness tester with 300 gf load for 30 seconds and their average is reported. Nanoindentation was performed on five different samples selected from the heat treated specimens using Berkovich nanoindenter at a load of 50 mN for 10 seconds. Nine indentations were performed on each specimen. Thermal analysis was carried out using Ansys software to evaluate the time-temperature profile of all the heat treated samples to reach room temperature during cooling from solution treatment temperature.

Table.1. Chemical composition of BT-23 alloy used in this study

Element	Al	Mo	V	Cr	Fe	Zr	Si	C	O	N	H	Ti
Wt. %	5.1	1.9	4.6	1.1	0.7	0.10	0.07	0.03	0.119	0.006	0.003	Bal.

3.0. Results and Discussion

The as-forged microstructure consists of primary α-lamellae in transformed β-matrix as shown in Fig.1.a. Beta transus (T_{β}) temperature of the alloy has been reported as 1153 – 1203K [8]. The microstructures of samples were in agreement with the T_{β} reported. All samples heat treated above 1158 K (i.e. fig. 1c and 1d). consisted predominantly martensitic α' / α'' phase [9] where as samples solution treated below this temperature consisted of primary α in transformed β phase as is evident in Fig.1b-1d.As observed from Fig.2., samples subjected to air cooling after solution treatment at 1123 -1278 K exhibited higher microhardness when compared to the samples subjected to water quenching. This may be due to dynamic aging and/ or stress relieving occurring during air cooling from solution treatment temperature down to room temperature. The same has been supported by thermal simulations of samples subjected to air cooling and water quenching as shown in Fig.3 by FEM in Ansys software. As observed from Fig.3., air cooling from the solution treatment temperature to 300 K requires 400-500 s whereas water quenching will require only 18-20 s to reach the ambient temperature. It may also be noted that the water quench time-temperature profile is more or less uniform irrespective of solution treatment indicating superior quench severity. Air cooling permits sufficient time for nucleation of fine α precipitates. Also relief of small amount of thermal residual stresses may occur due to less thermal gradient during air cooling compared to water quenching to ambient temperature. It can be observed that the samples are resident at temperatures in the aging regime of the alloy for time duration of 30-40 s which is just sufficient for fine α phase precipitation/ nucleation. It is postulated that the fine α laths/precipitates formed/ nucleating during air cooling as proposed by Jones et. al. [10] may be resulting in higher hardness compared to the α'' phase formed during water quenching [9]. From Fig.4a & 4b. and Table.2., it can be observed that the samples exhibited nanohardness similar to the trend of microhardness in samples subjected to water quenching and air cooling after solution treatment. It can also be observed that the scatter in nano indentation in samples solution treated at 1123 K and 1278 K showed higher scatter compared to the samples solution treated at 1203 K. The reason for this needs to be further investigated.

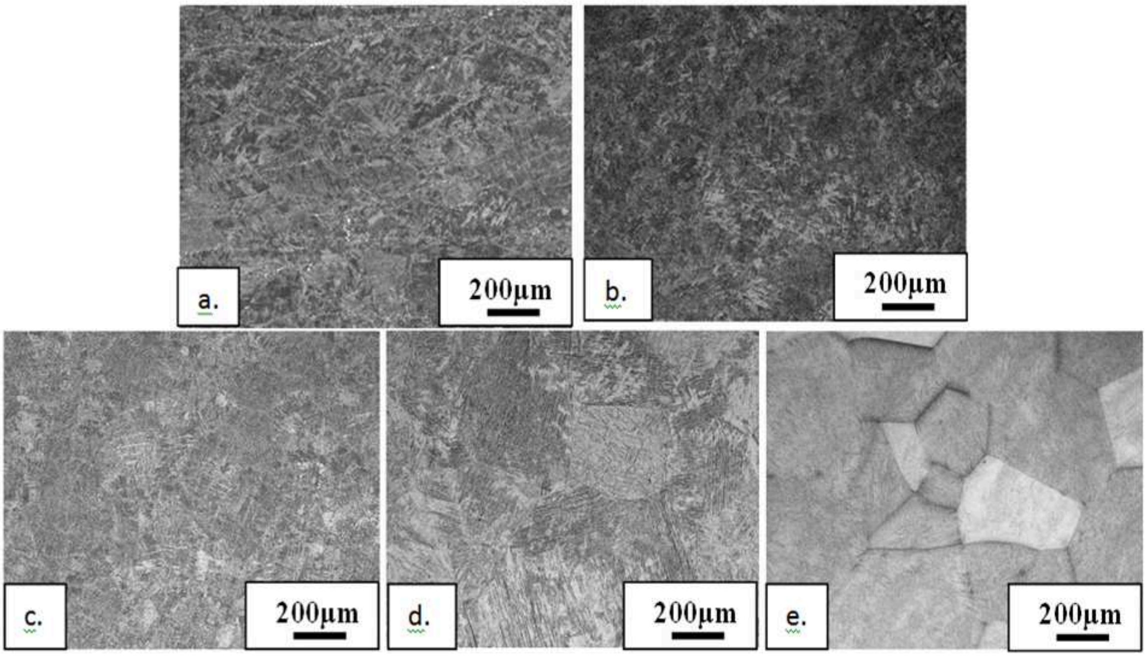

Fig.1. Optical photomicrograph of a). as-hot rolled sample; sample solution treated at 1123 K followed by (b). water quenching , c). air cooling and 1278 K followed by d). water quenching and e).air cooling

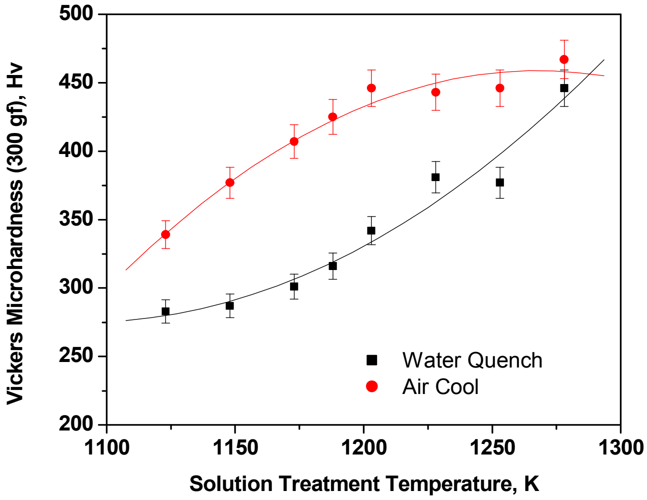

Fig.2. Microhardness vs solution treatment temperature and cooling media

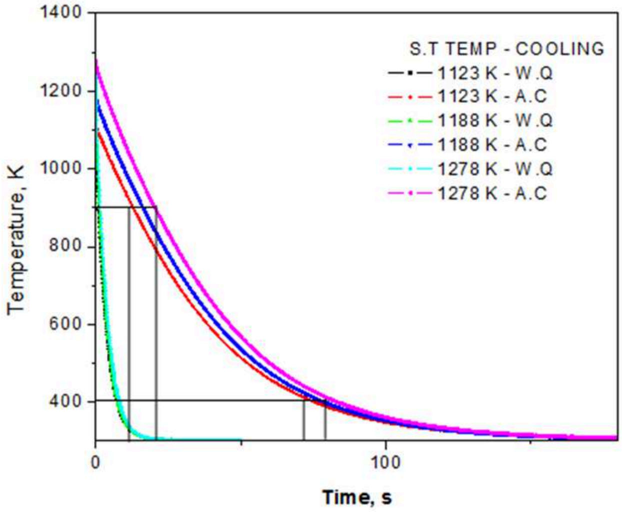

Fig.3. Time vs temperature profile obtained by 2D - thermal analysis using FEM - Ansys on samples subjected to solution treatment from different temperatures and quenching media.

Table.2. Nanoindentation on BT-23 alloy samples

Sample/ HT condition	B1 (1123K-A/c)	B5 (1203K-A/c)	A5 (1203K-W.Q)	B8 (1278K-A/c)	A8 (1278 K-W.Q)
E*, GPa	120±7.8	136±5.8	114±11	150±10	127±12
Hv	464±72	575±25	454±42	596±39	477±52
H, MPa	5012±786	6212±461	4909±272	6436±428	5153±564

E* - Corrected Modulus; Hv- Vickers Hardness; H – Hardness

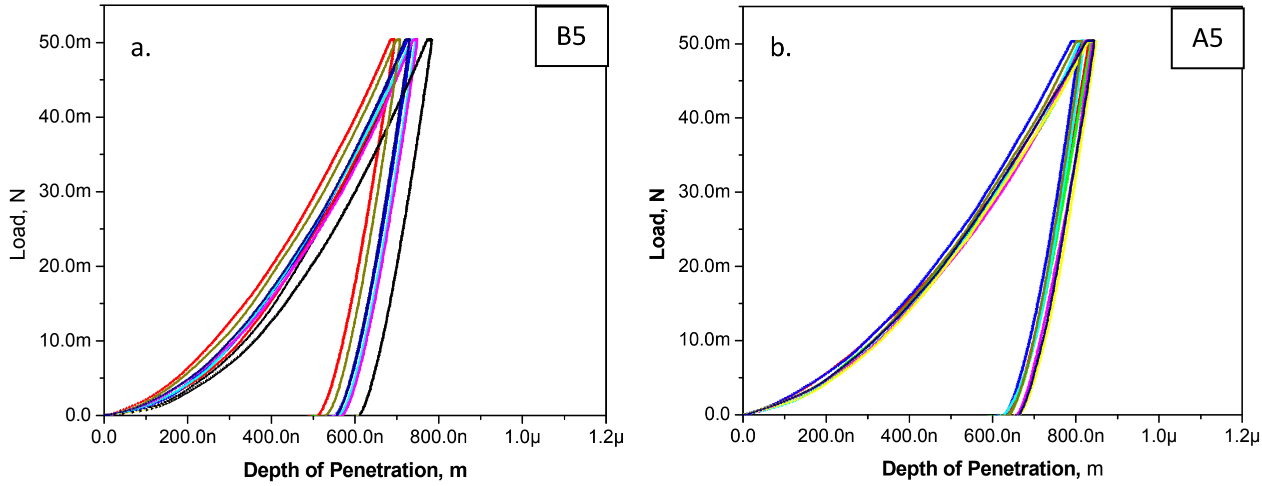

Fig.4. Typical Nanoindentation curves of samples subjected to various S.T. conditions

4.0. Conclusions:

1. Specimens heat treated above T_β consist of higher V_f of Martensitic α'/α'' compared those heat treated below T_β in both air cooled as well as water quenched conditions.
2. Specimens subjected to air cooling after solution treatment exhibited similar trend of higher micro/nano hardness compared to those subjected to water quenching.
3. The resident time of 30-40 seconds at aging regime may be leading to fine α phase nucleation/precipitation in the transformed β-matrix during continuous cooling and may be the reason for showing higher micro hardness in solution heat treated and air cooled samples.

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