Tensile Flow Behaviour and Fracture Studies of Beta Titanium Alloys at Elevated Temperatures

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ABSTRACT

Tensile testing on metastable beta alloy with various microstructures was carried out in this study. Beta 21S is a metastable alloy that exhibits a wide range of material characteristics depending on the processing techniques used. Three different sheets that have been used in this paper which has the same substance but three different microstructures. At a strain rate of 0.001/s, the tensile test was done on a single sheet at five different temperatures. The sheet has developed varied microstructures, the tensile nature of the material varies the alloy's characteristics. Mechanical characteristics for 400°C, 500°C, 600°C, and 700°C are described for 21S sheets. The alpha phase sheet elongated at room temperature by 1-3 %, whereas the pure beta phase sheet elongated by 22-24 %. There is a significant improvement in the extension of the sheet with the variation in temperature for the alpha phase. The elongation of the pure beta phase does not alter as the temperature rises. The fracture surface was tested at all temperatures and the optimal temperature for forming the sheet has been determined.

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Received: October 26, 2021; **Accepted:** November 02, 2021; **Published:** November 20, 2021

Keywords: FE, Tensile Testing, Power Law, XRF, XRD

Introduction

Beta Titanium is gaining importance in the aerospace, biomaterials, and automotive sector, due to its strength and corrosion-resistant property [1]. Titanium alloys are broadly classified in α , $\alpha+\beta$, and β , α is HCP, and β is BCC structure. Metastable Beta alloy can become harder by precipitating the Alpha phase during aging. This makes it very suitable for heat treatment and aging [2]. In-room temperature the Beta alloy is not stable, so Molybdenum is added that stabilizes the Beta at room temperature. The stability of the Beta can be determined by equation (1) [3].

$$Mo_{eq} = 1.0(wt.\%Mo) + 0.67(wt.\%V) + 0.44(wt.\%W) + 0.28(wt.\%Nb) + 0.22(wt.\%Ta) + 2.9(wt.\%Fe) + 1.6(wt.\%Cr) - 1.0(wt.\%Al) \dots\dots (1)$$

Mo equivalent varies from 10 to 30 for metastable alloy. For β 21S it value is between 13-14. This makes this alloy excellent for heat treatment and deeply hardened [4]. It has a BCC structure having high stacking fault energy. This leads to multiple and cross-plane slips. It makes it very formable, unlike other alloys of Titanium [5]. The result of the heat treatment on the beta alloy will be dependent on the temperature and its composition [4]. The formability or strength of the metastable alloy can be increased by solution treatment followed by aging. The solution treatment of Beta alloy should be done above beta trans temperature [6].

Form material is confirmed to be Beta 21S. X-ray diffraction (XRD) test of the sheet is performed to investigate the characteristics of the phases present in the sheet. The XRD of the sheet is shown

in Fig 1. The 2 mm sheet shows a peak in the concentration of the beta particles corresponding to the planes (011), (002), and (112) whereas the sheet of the other two thicknesses (0.8 and 1.2 mm) shows distinct peaks for both alpha and beta particles. This indicates that the forming of the 2 mm sheet will be much higher than the other sheet. Also, we can conclude that the metastable beta alloy can have only beta or alpha+beta particles depending on the processing technique. The presence of alpha particles in the sheet has also been verified with optical studies.

For Optical study, the sheet is polished by emery paper from grade 100 to 2000, followed by cloth polishing and applying the alumina paste. Then the sample is etched by using Kroll's reagent. The Krolls reagent contains 92 ml of distilled water, 2ml of HF, and 6ml of HNO₃. The prepared sample is observed under the optical microscope to analyse the formation of grain boundaries. The optical image of the sheet is represented in Fig 2. The figure shows the grain boundaries for the 0.8 mm sheet. Small darkened spots can be seen dispersed on the grain boundaries of the 0.8 mm thick sheet. These spots can also be observed on the 1.2 mm sheet. These dark spots represent alpha particles present in the sheet, which has also been verified by the XRD images before. But the 2mm sheet, shows a pure beta titanium alloy. Grain boundaries with distinct features have been observed for this sheet.

The as-received Ti-55531 alloy has a composition (in wt.%) of 5.21 aluminium (Al), 5.06 molybdenum (Mo), 4.96 vanadium (V), 3.01 chromium (Cr), 1.07 zirconium (Zr), 0.25 iron (Fe), 0.12 others, and balanced Ti. The β -transit temperature is 845 °C. The initial microstructure is shown in Fig. 1(a), which consists of a fine,

bimodal $\alpha+\beta$ structure of approximately 45% (volume fraction) equiaxed α phase (denoted by white arrow) and 55% transformed β phase, where the α phase has an average grain diameter of 2–3 μm [7].

To study, the mechanical property of the metastable alloy, the microstructure needs to be observed. As there is a Nano precipitate of alpha inside the beta grain, this makes the grain boundary softer. As a consequence, this type of material undergoes intergranular fracture [8]. The intergranular failure properties of grain boundaries and the material response to grain interior have a great effect on the ductility and fracture toughness of the material [9]. Simulation of intergranular fracture has been done in the literature using the GTN model [10]. In this paper, the ductile damage model is developed using the tensile test result, and the formed depth prediction has been made.

Material Characterization

The 0.8 mm, 1.2 mm, and 2 mm thick Beta 21S sheets have been procured from DMRL Hyderabad for this Study. Initially, X-ray Fluorescent Spectroscopy (XRF) was performed on the sheets to verify the composition. The result of the XRF is given table below.

Table 1: Material Composition of the as-Received Sheet of Different Compositions

Element	Al	P	Ti	Mn	Fe	Ni	Nb	Mo
0.8	.963%	.557%	79.52%	.149%	.26%	.042%	2.970%	15.468%
1.2	.923%	.578%	80.01%	.152%	.26%	.127%	3.09%	15.12%
2	.960%	.560%	79.51%	.150%	.23%	.045%	2.950%	15.488%

Figure 1: XRD of the as-received sheet of different thickness

Figure 2: Optical Image of (a) 0.8mm Sheet, (b) 1.2mm Sheet and (c) 2mm Sheet

Scanning Electron Microscopy (SEM) is performed on the sheet to investigate the micro features of the sheet. Fig 3a (1) shows the granular microstructure of the sheet with 0.8 mm thickness. Fig 3a (2) shows the alpha precipitating into the grain boundary. The alpha particles are larger for the sheet having 1.2 mm thickness as shown in Fig 3b (2). The images of the 2 mm thickness sheets as shown in Fig 3c (1) & (2) depict no presence of the alpha particles and can be considered as a pure beta alloy. These results agree with the

XRD tests and optical testing done previously on the same thickness sheet. These alpha particles can significantly change the forming Behavior of the sheet. The alpha particles are made up of Hexagonal closed pack (HCP) crystals, thereby making the component not fit for tensile testing. Tensile testing is carried on sheets of 0.8mm, 1.2mm, and 2mm sheet on RT at (270°C), 4000°C, 5000°C, 6000°C, and 7000°C. To carry out the test subsidized specimen has been prepared according to ASTM standards. The dimension of the specimen as shown in the figure is measured in μm .

The specimens were heated at the rate of 10 °C/s and held at that temperature for 5 min before deforming and undergoing a true strain of 0.6. The compression tests were carried out on a Gleeble_3800 simulator in the temperature range of 750°C - 850 °C at an interval of 50 °C and constant true strain rates of 0.001, 0.01, 0.1, 1, 10 and 63 s⁻¹. Then, specimens were rapidly quenched in water to preserve the microstructure after undergoing hot deformation [11]. The extent of flow softening decreases with the increase in the experimental temperature. One mechanism involved in flow softening is suggested to be deformation heating [12]. The real temperature of samples increases (Table 2) because the deformation heating cannot be conducted at ambient conditions due to the short deformation time and the low thermal conductivity of titanium alloys. With increasing temperature, atom diffusion and dislocation movements occur more easily, which causes the flow stress to decrease. Meanwhile, when compression reaches adiabatic conditions, adiabatic heating can cause flow localization leading to flow instability. In addition, super plasticity, dynamic recovery (DRV), and dynamic recrystallization (DRX) can also cause softening [13-14].

Figure 3: SEM of as Received Sheet (a) is 0.8mm (b) is 1.2mm and (c) 2mm

The tensile test data of the Beta 21S is performed at different temperatures, and the result is given in Fig 4. It has been demonstrated that the properties of the same material with varying forms of crystal vary dramatically. At 600°C degrees Celsius, the formability of 0.8 mm sheet is outstanding, with 16 percent elongation. At ambient temperature, the 1.2mm sheet exhibits poor formability, but at 500°C, there was a 25% strain with strain hardening. When the temperature was altered, the elongation of a 2 mm sheet did not vary appreciably. Despite the fact that the material softened, the elongation remained relatively constant.

The chavioul data has been created for the 1.2 mm sheet to calculate the material property at different temperature. The properties of the 1.2mm sheet at different temperature is given in Table 2.

Table 2

TempI	Strain Rate(S)	Flow Stress(Mpa)	Ultimate Strength(Mpa)	Young's Modulus(GPa)	K(Mpa)	n	% Elongation
600	0.01	576.85	640.055	80			15
500	0.001	609.80	774.42	82	1328	0.242	23-25
700	0.0001	90.52	106.221				40
400	0.001	603.20	638.93	85	774.38	0.09	10-12
27(RT)	0.001	865.940	865.940	87	-	-	1-2

Figure 4: Tensile Test Result (a) 2mm, 0.8mm and 1.2 mm at Room Temperature, (b) 0.8mm Sheet at Different Temperature, (c) 1.2mm Sheet at Different Temperature, (d) 2mm Sheet at Different Temperature

Fractography: The fractography of the fractured surface is performed to understand the type of fracture in different sheets at different temperatures.

Figure 5: Fractures surface the specimens at different temperature

Conclusions

From the above work following conclusions can be drawn. At low strain rates (<1 s⁻¹), the flow stress drops rapidly and all curves exhibit an initial sharp peak, i.e. discontinuous yielding [3]. After this peak, the continuous softening behaviour and steady-state flow can be observed at a strain rate of 0.001 s⁻¹. But at the strain rates of 0.1 and 0.01 s⁻¹, discontinuous yielding is followed by a slight degree of strain hardening, flow softening, and eventually steady-state flow. Based on the above analysis and a lot of previous researches, the dominating softening mechanism is DRV at high strain rates and DRX at low strain rates, respectively [13-21]. From the tensile test result following

1. The nature of B21S is very versatile depending on the microstructure.
2. The microstructure (2mm) having pure beta phase showed 19% elongation at room temp
3. 1.2 mm sheet having some both alpha and beta showed 21% at 500°C

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