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A study of the microstructure and hardness of two titanium alloys: Commercially pure and Ti–6Al–4V

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ABSTRACT

In this paper, the microstructure and hardness of two titanium alloys was determined and the results are presented and briefly discussed. Samples of the alloy for microstructural examination were prepared from the as-provided stock using standard metallographic procedures and then examined in a low magnification light optical microscope. Both microhardness and macrohardness measurements were made across the polished surfaces of the two titanium materials. Both the microhardness and macrohardness of the Ti–6Al–4V alloy was noticeably higher than the commercially pure counterpart. The intrinsic influence of alloy composition and secondary processing, i.e., annealing, on microstructural development is presented and hardness of the two alloys is highlighted. The role of microstructure in governing the hardness of the two titanium materials is discussed.

1. Introduction

Titanium and its alloys have over the years proven themselves to be technically superior and cost effective materials for a wide range of applications spanning the industries of aerospace, industrial, marine, and even commercial products [1]. This is because of their good combination of mechanical properties to include excellent specific strength (σ/ρ), stiffness, immune to corrosion in sea water environment, good erosion resistance in environments spanning a range of aggressiveness, and importantly their acceptable mechanical properties at elevated temperatures coupled with an intrinsic capability to withstand and safely function at elevated temperatures [1,2]. The noticeable attractive properties of titanium alloys have facilitated in their selection and enhanced use in marine and a spectrum of other performance-critical applications [3].

However, exhaustive application of the products made from titanium and its alloy counterparts into the commercial sector has been limited by the high cost of the metal and its heat treatment. The price of a mill product is in excess of $50/kg when compared with the cost of mild steel, which is $10/kg [2,4,5]. The higher cost of titanium can be ascribed to the metal's strong affinity for oxygen, creating challenges both during extrusion and downstream processing. This limitation has engineered a considerable amount of scientific and technological interest in developing potentially viable and economically affordable manufacturing methods that aid in reducing the cost of the product.

In examining affordable manufacturing methods and viable processing techniques microstructural development is important since it exercises a close control over properties spanning, hardness, tensile, fracture toughness, fatigue resistance, creep and even fracture behavior [5–9]. The properties of the alloys of titanium can be varied over a wide range of heat treatments or thermo-mechanical treatment [10–14]. Through careful control of both primary processing and secondary processing the microstructure of an alloy can be changed from equiaxed through bimodal to fully lamellar. A bimodal microstructure has been reported to offer advantages in terms of yield strength, tensile strength, ductility and fatigue resistance. A microstructure that is fully lamellar has been characterized to have good fatigue crack propagation resistance and good fracture toughness [10]. The important parameters for a predominantly lamellar microstructure with specific reference to mechanical properties are size of the beta (β)-grain, size of the colonies of the alpha (α)-lamellae, thickness of the alpha (α)-lamellae and the nature of the inter-lamellar interface (beta-phase).

Most noticeably and worthy of noting is that titanium metal is allotropic and has a hexagonal close packed (HCP) $\{\alpha\}$ crystal structure at low temperatures and a body-centered cubic (β) structure at temperatures above 885 °C. Overall, the structural titanium alloys have been classified into three categories, denoted as: (i) alpha (α), (ii) alpha plus beta ($\alpha+\beta$), and (iii) beta (β)-phase alloys. The alpha-phase (α) alloys of titanium, which are categorized as commercially

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Table 1
A compilation of microhardness test data made on the two materials Ti–6Al–4V alloy and commercially pure titanium (Grade 2).

Alloy	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
Sample 2A Ti–6Al–4V						
Vickers hardness	340.41	325.20	332.72	334.61	340.46	334.68
R_c	25	27	–	30	25	26.75
Sample 2B, Ti–6Al–4V						
Vickers hardness	330.88	342.44	332.74	327.11	338.51	334.36
R_c	28	25	25	27	28	26.6
Sample 1A, CP Grade 2						
Vickers hardness	213.59	195.36	193.65	193.67	200.58	199.37
R_c	–	–	–	–	–	–
Sample 1B, CP Grade 2						
Vickers hardness	175.59	178.58	167.21	169.26	193.67	176.82
R_c	–	–	–	–	–	–

pure titanium, are relatively weak in strength but offer a combination of good corrosion resistance, good weldability, creep resistance, receptive to heat treatment coupled with ease of processing and fabrication [11,15]. The dual phase, i.e., alpha + beta (α + β) alloys have to offer a combination of excellent ductility and strength when properly heat treated, which makes then stronger than the alpha-phase (α) and even beta-phase (β) counterparts [2,5,15]. Overall, an optimum control of microstructure is essential to achieve the best combination of mechanical properties for a given application. In order to be able to do this a preliminary understanding of the relationship of microstructure and hardness is essential.

In this paper, we present the results of a recent study on microstructure and hardness of two titanium materials, commercially pure titanium and the "workhorse" alloy Ti–6Al–4V. Both the commercially pure, referred to henceforth in this manuscript as CP Grade 2, and the Ti–6Al–4V alloy were chosen in the fully annealed condition with the objective of establishing intrinsic microstructural influences on hardness of the alloy.

2. Materials and research approach

The materials chosen for this research study are the commercially pure (Grade 2) and the widely preferred and chosen alloy, also referred to as the 'workhorse' alloy, Ti–6Al–4V. The alloy chosen was provided by Allegheny Technologies ATI Wah Chang (based in Oregon, USA) while the commercially pure (Grade 2) titanium material was provided by TICO (based in Michigan, USA). The advantage with the Ti–6Al–4V alloy is that it is comparatively easy to produce coupled with good hot workability thereby enabling a lenient window of processing parameters. Both the commercially pure (CP Grade 2) and the Ti–6Al–4V alloy are receptive to heat treatment and can be solution heat treated and annealed to achieve the desired strength and properties.

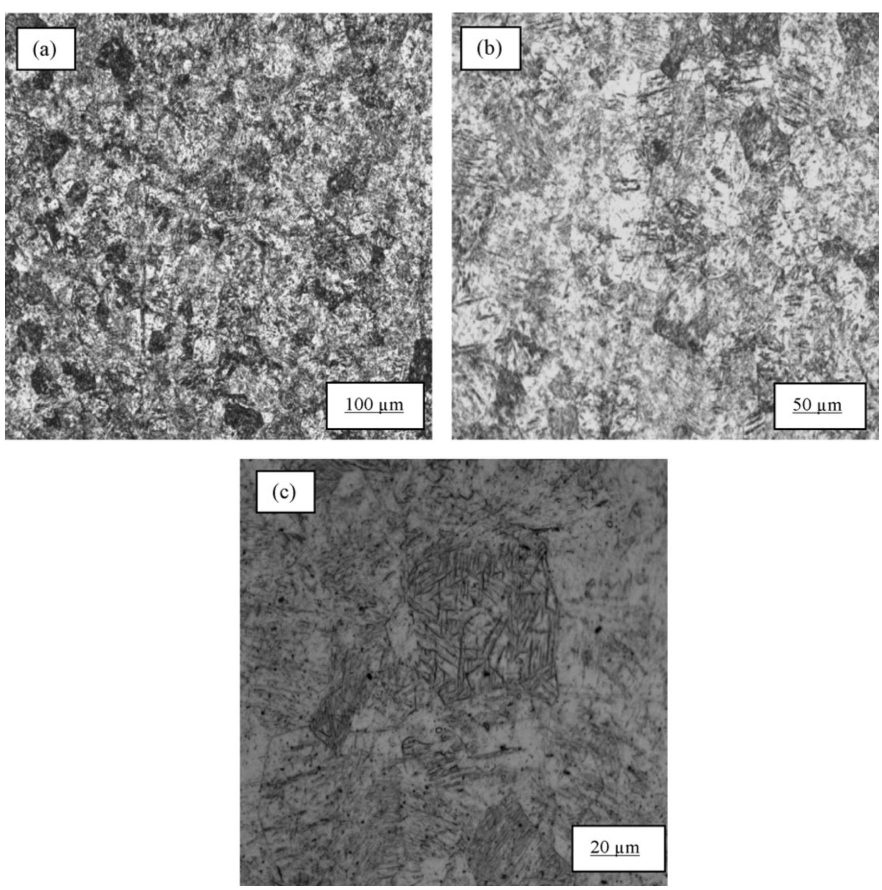

Fig. 1. Optical micrographs showing the key micro-constituents in the commercially pure (Grade 2) titanium at three different magnifications.