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Ageing time optimization for a low-cost beta (LCB) titanium alloy

Khaled M. Ibrahim[a], Abd El-Fattah M.Khourshid[b], Saad Ebied[c]

Abstract— in this work The effect of ageing time on microstructure and mechanical properties of low-cost beta (LCB) titanium alloy with a chemical composition of Ti−6.6Mo−4.5Fe−1.5Al- was evaluated. Increasing ageing time tended to increase the volume fraction of the secondary α-precipitates, β-grain size and partial spheroidization of primary α-phase. the samples aged at 500 °C for 0.5 h shows The maximum tensile strength 1565 MPa, while sample aged at 500 °C for 0.25 h shows the minimum one of 1310 MPa .

Index Terms— low cost beta Ti alloy; Ti−6.6Mo−4.5Fe−1.5Al alloy,ageing, primary α, secondary α, tensile strength, microstructure .

1 Introduction

Metastable β-titanium alloys are essential materials for aerospace and nonaerospace applications due to their high strength-to-density ratio, good hardenability, excellent fatigue/crack-propagation behavior, and corrosion resistance [1],[2]. The superiority of β-titanium alloys is most pronounced in the solution-treated-and-aged (STA) condition with a fully β-transformed, precipitation-hardened microstructure in which the volume fraction and morphology of the α precipitates control the strength level, while the β grain size determines the ductility. For example, strength levels above approximately 1500MPa with acceptable ductility require average β grain sizes of not more than 10μm [3]. the higher cost of this alloys restrict their wide use in industry. To overcome this difficulty new processing routes are developed. This is the case for the new TIMET Ti LCB (for low cost beta) that presents a lower cost compared to other Ti alloys by using an inexpensive Fe-Mo master alloy widely used in the steel industry .[4]The primary cause for selection and design of titanium into aerospace applications including engine and airframe components is Elevated specific strength . The expansion use of titanium in non-aerospace industries (e.g., automotive, chemical, energy, marine, biomedical, sports and architecture) requires refinements in the understanding of titanium metallurgy, progresses in processing methods, ability to manufacture components without defects and developing of low-cost Ti alloys [5],[6]. One of the important developed Metastable β-titanium alloys is the low-cost beta titanium alloy (LCB) which has a chemical composition of Ti−1.5Al−4.5Fe−6.8Mo (mass fraction, %) and developed specially for automotive industry . The first application dates back to the year 2000 when the rear axle of the Volkswagen Lupo FSI was equipped with LCB springs [4].

[a] A.Prof., Central Metallurgical R&D Institute (CMRDI), Manufacturing Technology Dept., P.O. Box 87 Helwan, Cairo-Egypt
[b] Prof., Production Engineering and Mechanical Design Department, Faculty of Engineering, Tanta University.
[c] B.Sc, Production Engineering and Mechanical Design Department, Faculty of Engineering, Tanta University.

LCB Ti alloy is heat treated to obtain 1400 MPa ultimate strength with 13% elongation [7],[8]. LCB is considered a metastable β titanium alloy which is primarily strengthened by precipitating of the secondary phases α and ω. The mechanical properties of LCB Ti alloy are strongly dependent on the type, morphology, size, coherency and volume fraction of these precipitates resulting from β phase decomposition [9],[10].

Therefore the present work aims to select the optimum ageing time at 500 °C ageing time required to obtain a combination of strength and ductility .

2 Experimental work

LCB titanium alloy was first casted using a vacuum induction furnace as rods of 30 mm in diameter and 300 mm length. Turning process was used to eliminate 2.5 mm from the samples. Hot swaging was applied at 760 °C to reduce the cross-section diameter from 25mm to 10 mm in 11 steps and to refine the microstructure from 200 μm to 3-5 μm. The chemical composition of the studied LCB titanium alloy is given in Table 1. The schematic drawing of the six thermal treatment processes used in this study are shown in(Fig. 1.) The swaged rods were solution treated at 760 °C for 0.5 h followed by water quenching (denoted as RX). Ageing processes were applied at 500 °C for 0.25, 0.5, 4 and 16 h, respectively. Microstructure investigation was carried out using an optical microscope and volume fraction of α-phase was estimated by using an image analyzer software. Mechanical properties were determined for the solution treated and aged samples. Tensile test was performed on threaded cylindrical specimens having a gage length and diameter of 36 mm and 6 mm respectively.[11] .

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Table 1: Chemical compositions of the raw LCB alloy used for casting samples

Nominal composition	Chemical composition, Wt.%				
	Al	Mo	Fe	O	Ti
LCB alloy	1.5	6.6	4.5	0.142	Rest

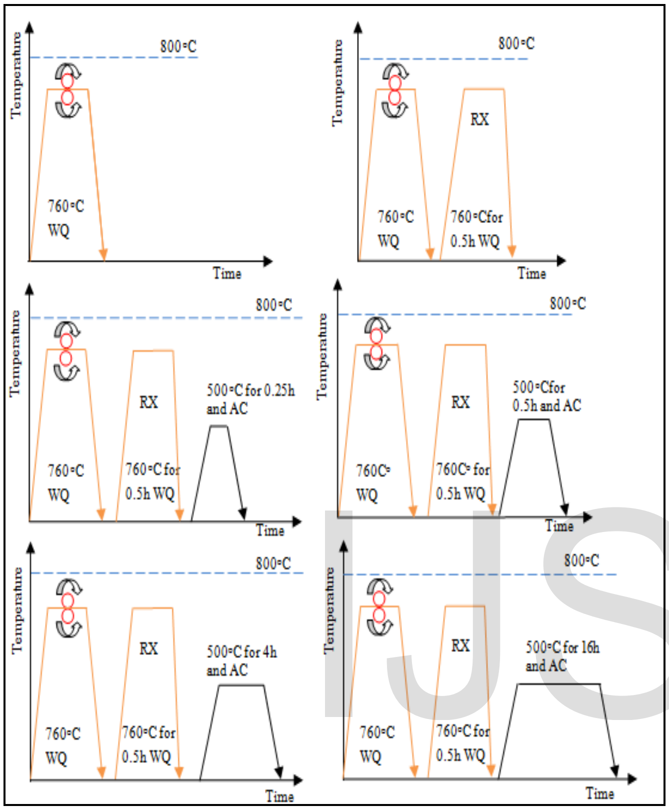

Fig.1 Thermomechanical process for producing LCB titanium samples: WQ—Water quenching; AC—Air cooling; RX— Solution treatment.

3 Results and Discussion

3.1. microstructure

The microstructure of the tested samples of the LCB Ti alloy under different heat treatment conditions are shown in Fig. 2. Because the swaging process was carried out at a temperature below the beta-transus or in the α+β zone (760 °C) the swaged samples obtained a structure consisting of primary α-phase imbedded in a β-matrix [12] (Fig. 3(a)). It is also recommended to apply solution treatment process below the β-transus, as mentioned in this study, to maintain fine grain structure that resulted in a acceptable combination of strength and ductility as well as fatigue property [8]. Therefore the solution treated samples showed fine equiaxed β-grain structure with nearly complete spheroidization of 15% primary α-phase (Fig. 2(b)).The primary α-phase locates at boundaries of β-grains and located also at the triple points of the β-grains.

The β-grain size ranging from 3 to 5 μm. The microstructure of the aged samples showed a different feature from the solution treated one. As shown in Figs. 3(c)−(f), the microstructure of the aged samples consists mainly of primary α-phase and fine secondary α-phase precipitated at/or inside the β-grains.

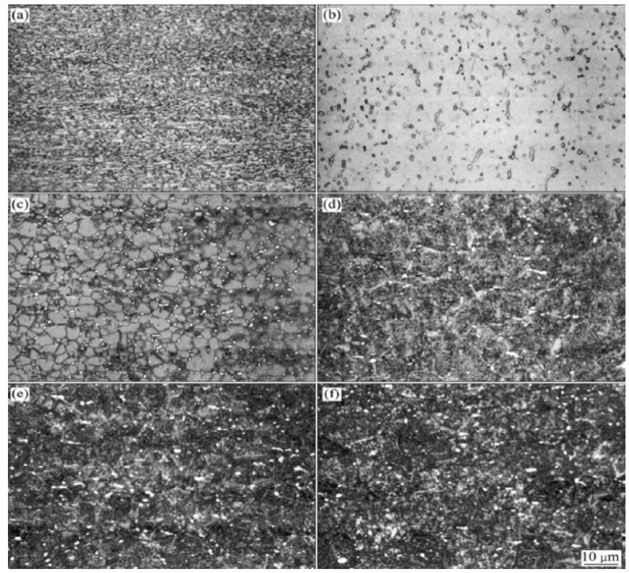

Fig.2 Microstructures of investigated LCB Ti-alloy in different conditions: (a) Swaged; (b) Solution treated; (c) RX+aging for 0.25 h; (d) RX+aging for 0.5 h; (e) RX+aging for 4 h; (f) RX+aging for 16 h.

The amount of precipitated fine secondary α-phase increased with increasing ageing time [13],[14]. It is also observed that increasing ageing time had a minor effect on the volume fraction of primary α-phase and grain size of the β-matrix [15].For example the aged samples at 500 °C for 0.25 h showed a structure consisting of primary α-phase (globular white shape) distributed at the β-grain boundaries and fine secondary α-precipitates (black shape) distributed at/inside the grain boundaries (Fig. 3(c)). However a longer ageing time resulted in growth thickening and thickening of the primary α-phase that distributed heterogeneously at the β-grain boundaries [13,16]. In addition a larger number of fine secondary α-precipitates were found inside the β-matrix (Figs. 3(d)−(f)).

3.2. Mechanical properties

In our study five selected conditions (up to 16 h ageing time) were chosen to evaluate the mechanical properties. These selected conditions were solution treatment (RX),ageing for 0.25 h (RX+A) , ageing for 0.5 h (RX+B) , ageing for 4h (RX+C) and ageing for 16h (RX+D) . The effect of β strengthening with the precipitations of the secondary α-phase is clearly shown in the aged conditions where the modules of elasticity increased from 81 GPa to 106 GPa with increasing ageing time up to 0.5h and reduced with increasing time Figs.3.

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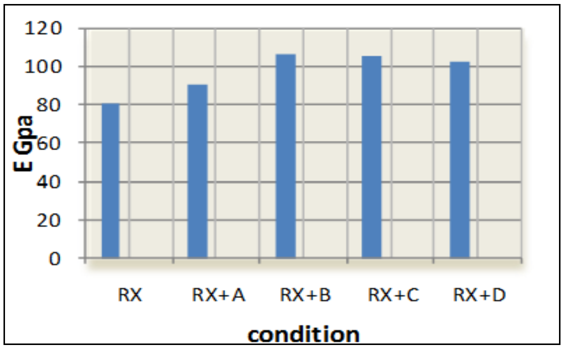

Fig.3 The modules of elasticity variation with conditions.

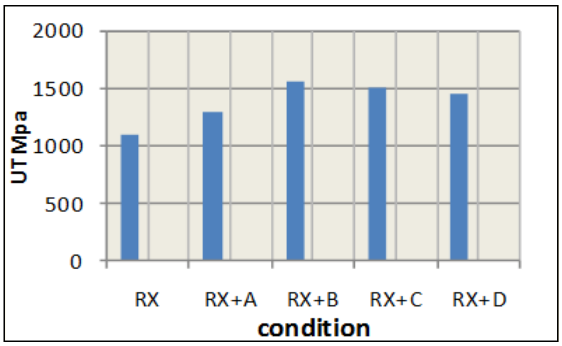

Fig.4 The ultimate tensile strength variation with conditions.

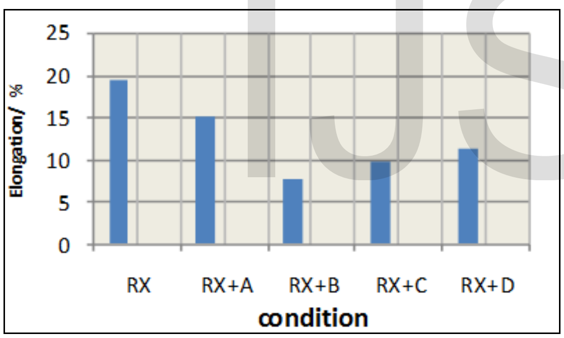

Fig.5 The ductility variation with conditions.

The ductility decreases with increasing ageing time(Figs.5) . The maximum ultimate strength of 1565 MPa was obtained for the ageing condition of 500 °C for 0.5 h, while with increasing the aging time to 16 h, the ultimate strength decreases to 1460 MPa(see Figs.4). It is suggest that ageing at 500 °C for 0.5 h gave the most uniform distribution of secondary α-phase inside or/at the β-grain boundaries. with increasing ageing time to 16 h, the structure showed massive quantities of secondary α-phase distributed heterogeneously inside the β-grain boundaries which will in opposite weaken these boundaries [13],[14],[15],[16],[17]. Therefore it could be said that the decrease in strength by increasing the ageing time to 16 h is returned to the coarsening of structure and existing of massive number of secondary α particles at β-grain boundaries.

4 Conclusions

1-The swaging operation refines the grain size in the as-cast structure from 200 to 3-5 µm.
2-The swaged samples obtained a structure consisting of primary α-phase imbedded in a β-matrix .
3-The microstructure of the Solution treated LCB Ti-samples showed fine equiaxed β-grains with about 15% primary α.
4-The volume fraction of secondary α-precipitates increased with increasing the ageing time.
5-The aged samples for 0.5h gives the maximum tensile strength.

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