Shot Peening and Ball-Burnishing effect in TIMETAL (Ti-54M)

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Abstract

The purpose of this work was aimed to study the effects of mechanical surface treatment (shot peening SP and ball burnishing BB) on fatigue performance of TIMETAL Ti-54M alloy. The shot peening (SP) and ball burnishing (BB) was conducted using spherically shot (SCCW14) with Almen intensity of 0.22 mmA. Hard ball steel (HG6) with burnishing pressure of 300 bar was used for ball-burnishing. Surface layer properties (surface roughness) and near surface layer properties (micro-hardness and residual stress) were calculated. The fatigue life of electrolytically polished condition (EP), which served as a reference, was markedly enhanced in comparison to shot peened and ball-burnished conditions.

Keyword: Ti-54M, Shot peening (SP), ball-burnishing (BB) and hot swaged.

Introduction

TIMETAL-54M (Ti-54M) is a new (α+β) titanium alloy which was developed by TIMET, Henderson, NV (USA) to provide a cost benefit for parts that require extensive machining compared to the well-known Ti-6Al-4V alloy. Ti-54M has lower Al content and contains slight addition of Mo and Fe that reduce the β-transus temperature [1- 3]. Therefore, the working temperature necessary in (α+β) thermo mechanical processing is also reduced. Mechanical surface treatments such as shot peening (SP) or ball-burnishing (BB) can improve the HCF performance of Ti-54M. In general, all mechanical surface treatments lead to surface strengthening by the induced high dislocation densities and residual compressive stresses [4, 5]. Residual compressive stresses are well known to enhance the fatigue performance and corrosion resistance by retarding or even suppressing micro-crack growth from the surface into the interior. Rotary swaging (RS) , swaging is forming of reducing cross section area of solids, bars, tubes and wires using two or more dies which surround the outside of the workpiece completely or partially, to a round predetermined diameter (Fig. 1) [4]. Some of the advantages of rotary swaging include short cycle times, good surface finishes and tight size tolerances [5].

Experimental procedure

The investigation was performed on (α+β) phase Ti-54M. The material was received as hot extruded bar in duplex microstructure (Fig 2) with chemical composition as given in Table 1. In hot rotary swaging (RS), various deformation degree (true strain calculated from cross sectional area reduction) $\varphi = \ln (A_0/A)$ with (A_0) initial cross-section and (A) final cross-section were applied at 850°C temperature. From the swaged bar, specimen were taken in transverse direction (TD) and were heat treated to obtain a fully and coarse grained equiaxed microstructure by annealing at 800°C and 940°C for 1h followed by air cooling (AC) and furnace cooling (FC), respectively. All material was given a final heat treatment at 500°C for 24h to age-hardening the phase α by Ti_3Al precipitates and the β phase by fine secondary α precipitates. Shot peen (SP) was performed using spherically conditioned cut wire (SCCW14) having an average shot size of 0.36 mm. Peening was done to full coverage at an Almen intensity of 0.20 mmA. Ball-burnishing (BB) was done using a conventional lathe and a hydrostatically driven tool with a hard metal ball of 6 mm in diameter. The burnishing pressure was kept constant at 300 bars. Electrolytically polished (EP) samples were taken as the baseline to which the SP and BB conditions are compared. A Struers Duramin tester with a force of 100 ponds (HV1.0) and a loading time of 10 seconds was used to determine micro-hardness.

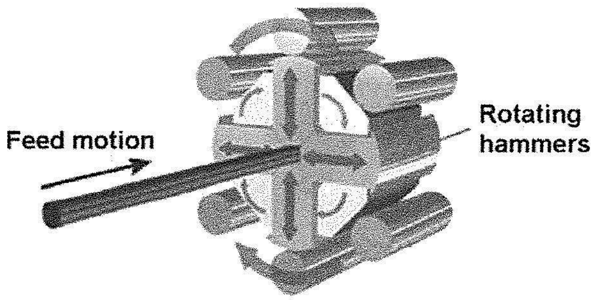

Table 1: Chemical composition of CP-Ti wt%.

Element	AL	V	Mo	Zr	Si	Fe	N	O	C	Ti
Ti-54M	5.03	3.95	0.57	0.005	0.11	0.506	0.05	0.06	0.10	Rest

Tensile tests were performed on both conditions using threaded cylindrical specimens having gauge lengths and diameters of 25 and 5 mm, respectively. Young's moduli were measured with strain gauges attached to the gauge length of the specimens. Initial strain rates were $6.7x10^{-4}$ S^{-1}). In addition, Vickers hardness measurements tests were performed on the material after each steps of swaging.

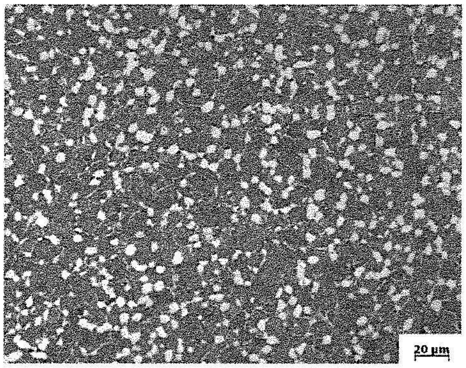

Fig. 2: Duplex microstructure as-received condition

3. Results and discussion

3.1. Microstructure evolution

The EQ/AC and FC microstructure of both Ti-54M conditions are shown in Figure 3. Both microstructures are fully equiaxed with the equilibrium volume fraction β phase located at triple-points of the α- grain boundaries. This marked difference in grain size is caused by the difference TMT used. The volume fraction of the α and β are 90% and 10% respectively [6].

It can be seen (Table 2) that a fine grain size condition exhibits a UTS and yield stress value are nearly the same, because of the very low work- hardening capability ($UTS/\sigma_{0.2}=1.002$) in this condition. On the other hand the coarse grain size condition shows the UTS is significantly higher than yield stress due to very high work- hardening capability ($UTS/\sigma_{0.2}=1.224$) in this condition, while tensile ductility value are highly superior to those in fine grain size.

The HCF performance of Ti-54M in fine grain equiaxed microstructure, EQ/WQ is significantly higher than in coarse grain equiaxed (Fig 4) results show an improvement in the fatigue strength from 400 MPa to 600 MPa.

Tensile properties of the fine and coarse grained is illustrated in Table 2. The modus of elasticity varied between 113 and 117 GPa.

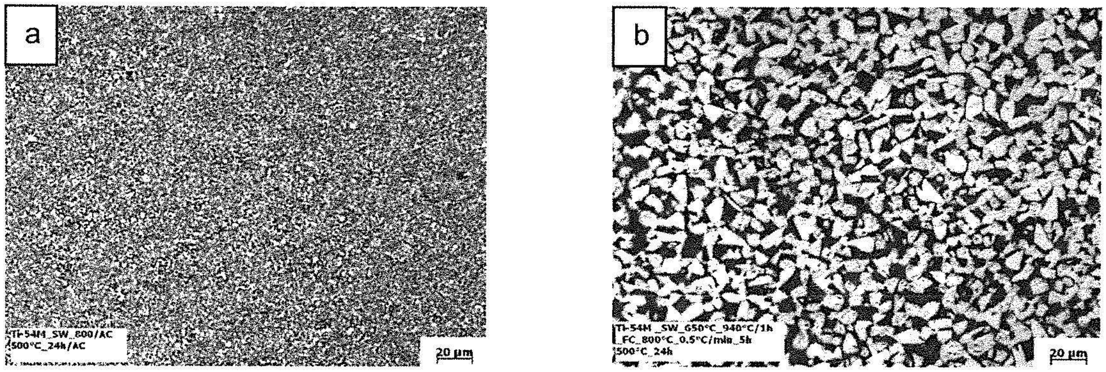

Fig. 3: Equiaxed microstructure of Ti-54M EQ/AC in (a) and EQ/FC in (b).

Table 2: Tensile and hardness properties of Ti-54M.

condition	YS (MPa)	UTS (MPa)	UTS-YS (MPa)	$\varepsilon_F = \ln(A_0/A_F)$
Fine grain	1135	1145	10	0.70
Coarse grain	931	1140	209	1.20

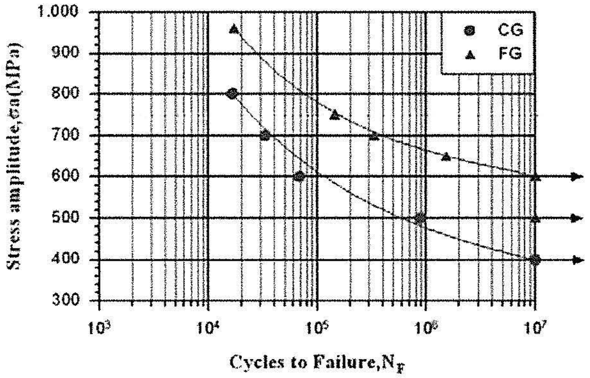

Fig. 4: S–N curves(R=-1) of Ti-54M EP condition

Figure 5 (a, b) shows the microhardness-depth profiles in coarse and fine grained of Ti-54M alloys after SP and BB, respectively. Both SP and BB-induced plastic deformation increase the surface layer hardness in Ti-54M. The bulk hardness value was about 331 and 360 HV0.1, while the hardness values at the surface were about 437, and 440, 420 and 430 HV0.1 after SP and BB for both coarse and fine grained, respectively. Obviously, BB led to greater depths of plastic deformation. The depth of induced plastic deformation was about 0.30, 0.50, 0.25 and 0.35mm after SP and BB for coarse and fine grained, respectively. The coarse grained exhibits hardness increases after SP and BB more marked than fine grained (Fig 5 a, b). These results can be correlated to work hardening capabilities (UTS-YS) of Ti-54M to 209 MPa in coarse grained and only 10 MPa in fine grained (Table 2). Figure 6 represent the fatigue performance in rotating beam load of coarse and fine grained of Ti-54M after SP and BB are compared with the electropolished references. The SP improves the HCF strength values of these electropolished conditions, while the BB is generally superior to SP. Changing the cooling rate from AC to FC in EQ not only markedly the HCF strength from 400 to 650 MPa but also the degree of further improvements by mechanical surface treatments. These values are 600 to 680 MPa in SP for coarse and fine grained in EQ microstructure, respectively. In case BB the values are 700 to 780 MPa for coarse and fine grained, respectively.

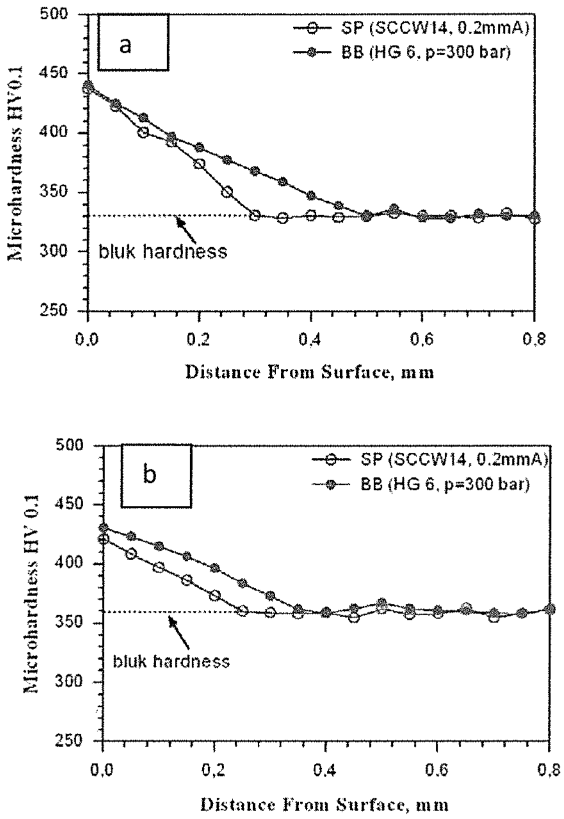

Fig. 5: Micro-hardness-depth Profiles after mechanical Surface treatment of Ti-54M (a) coarse grained and (b) fine grained condition.

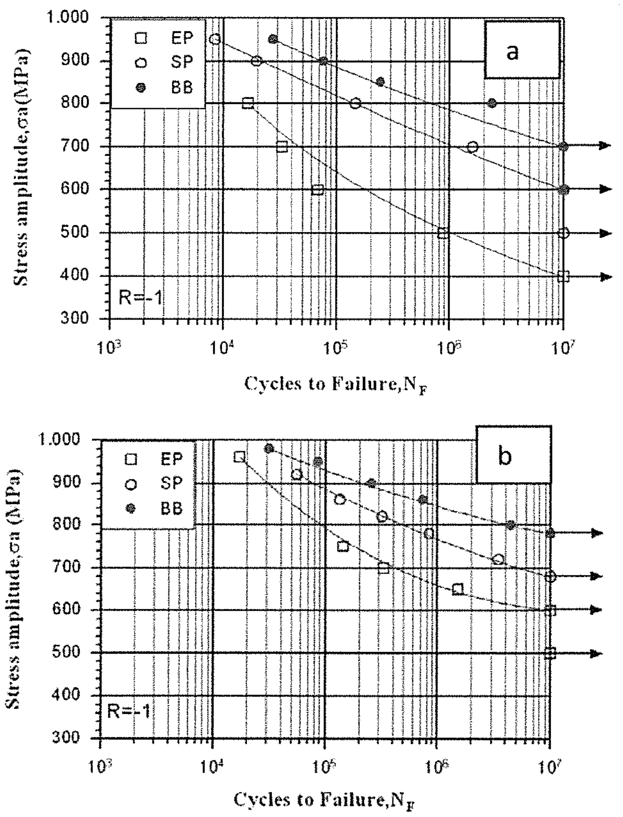

Fig. 6: S-N curves of Ti-54M in rotating beam loading (R=-1) in air after SP and BB in (a) coarse and in (b) fine grained.

Conclusions

The present results indicate:

- The depth of induced plastic deformation was about 0.30, 0.50, 0.25 and 0.35 mm after SP and BB for coarse and fine grained, respectively.
- The hardness value has improved at the surface after SP and BB about 16%, 19%, 33% and 33% in fine and coarse-grained onditions, respectively.
- The SP improves the HCF strength values of the electropolished conditions, while the BB is generally superior to SP.
- Changing the cooling rate from FC to AC in EQ not only markedly the HCF strength from 400 to 650 MPa but also the degree of further improvements by mechanical surface treatments.
- These results can be correlated to work hardening capabilities (UTS-YS) of Ti-54M to 209 MPa in coarse grained and only 10 MPa in fine-grained conditions.

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