Shot Peening and Ball-Burnishing Effects in cp-Ti

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Abstract

The purpose of this work was to study the effect of surface treatment on fatigue properties of coarse and fine grained conditions in cp-Ti grade 1. The shot peening (SP) and ball burnishing (BB) induced changes in the surface and near-surface properties were evaluated by measurements of surface topography and micro-hardness-depth profile. The fatigue life of the coarse grained condition was markedly enhanced by shot peening and ball-burnishing. The 10^7 cycles fatigue strength of the EP condition serving as reference was increased from 125 MPa to 260 and 300 MPa after SP and BB, respectively. In contrast, the fine grained condition exhibited a loss in fatigue strength after shot peening and ball-burnishing. Possible explanation for such differences in the response between the coarse and fine grained counterparts to shot peening and ball-burnishing are outlined in terms of differences in work-hardening capabilities.

Keywords cp-Ti, shot peening, ball-burnishing, fatigue performance

Introduction

Mechanical surface treatments such as shot peening and ball-burnishing are often applied to light alloys based on aluminum and titanium mostly to improve their HCF strengths in aircraft applications. The unique high strength-to-weight ratio, excellent corrosion resistance and good fatigue resistance led to the introduction of titanium in aerospace application such as rocket engine parts and fuel tank. The next important area of application of titanium alloys is chemical and general engineering. For low-stress application, commercially pure (CP) titanium is generally used [1-3]. The surface treatment of structural parts has a strong influence on the fatigue life because in fatigue, the cracks usually nucleate at the surface. It is well known that especially shot peening can lead to a marked increase in fatigue life. In general, mechanical surface treatments raise the dislocation density in the surface layer and because of localized plastic deformation, residual macrostresses are developed and further the surface topography is changed [4, 5]. It is often believed that the residual compressive stresses in the surface layer are the main reason for the improvement in fatigue life due to mechanical surface treatments [6-8]. The beneficial effect of residual compressive stresses on the retardation of microcrack propagation was experimentally directly observed [9]. On an austenitic precipitation hardened steel it could be shown that the homogenization of the slip distribution in the surface layer due to a shot peening process has a marked influence on the fatigue crack nucleation [10]. In contrast to shot peening, ball-burnishing usually results in very smooth surfaces [11]. SP and BB induced-compressive residual stresses have been found to retard pitting corrosion and corrosion fatigue in Al alloys [12, 13].

The present work aims at studying the effects of shot peening and ball-burnishing on the surface layer properties and fatigue performance of coarse and fine grained cp-Ti grade 1.

Experimental Procedure

The chemical composition of the investigated cp-Ti is given in table 1. Round bars were severe plastically deformed (SPD) by rotary swaging (SW) at ambient temperature from Ø = 32 mm down to Ø = 9 mm in multiple steps. The SPD material was then either recrystallization annealed at 850°C for 24 hours to result in a coarse grained microstructure and annealed at only 450°C for 1hour to produce a fine grained counterpart. Tensile tests were performed using threaded cylindrical specimens having gage lengths and gage diameters of 25 and 5 mm, respectively.

Shot peening (SP) was performed using a direct air pressure system (Gravi 2000, OSK Kiefer, Oppurg) and spherically conditioned cut wire (SCCW14) having an average shot size of 0.36

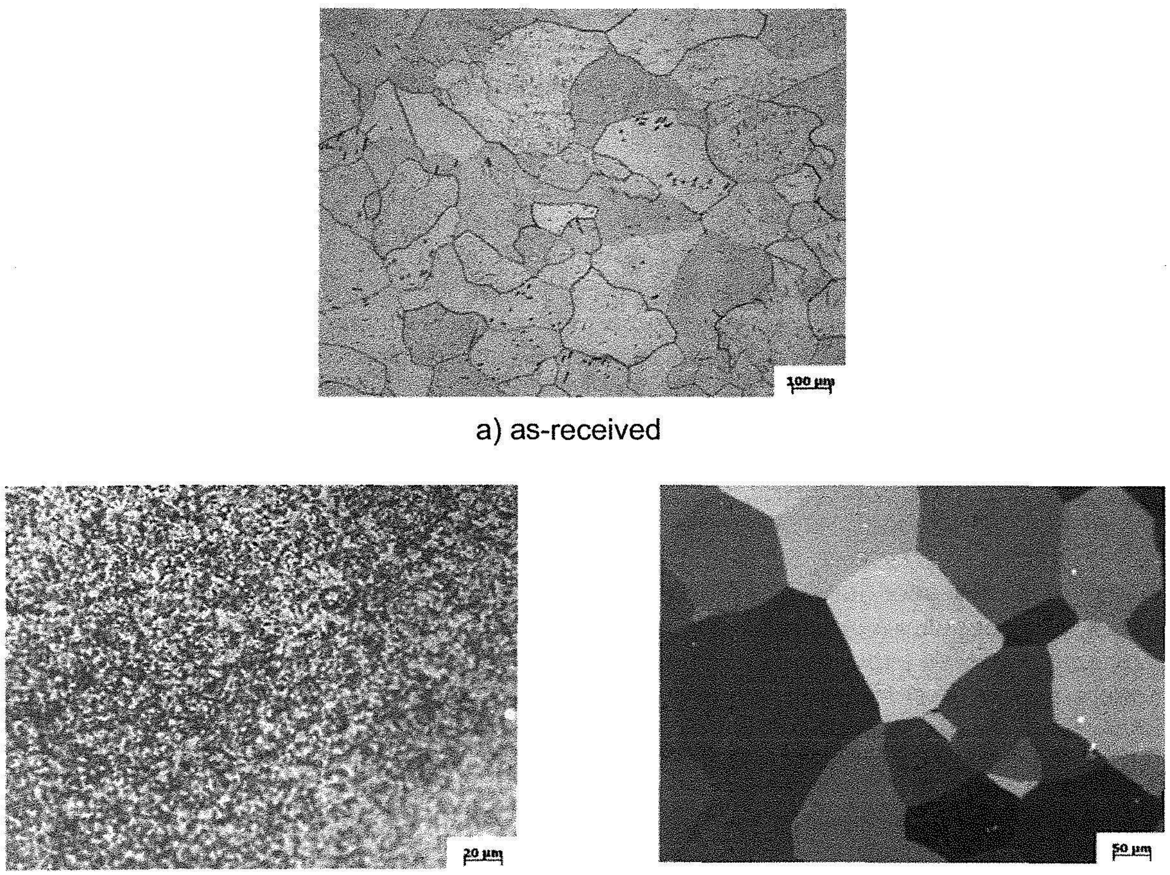
mm. Peening was done to full coverage at an Almen intensity of 0.20 mmA. Ball-burnishing (BB) was performed using a conventional lathe and a hydrostatically driven tool with a hard metal ball of 6 mm in diameter (ECOROLL, Celle). The burnishing pressure was kept constant at 200 bar. Electrolytically 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 (HV 0.1) and a loading time of 10 seconds was used to determine micro-hardness.

Table 1: Chemical composition of cp-Ti grade 1 (wt. %)

N	C	H	Fe	O	Ti
0.015	0.009	0.0018	0.04	0.0163	bal

Results and discussion

The optical microstructures of as-received, fine and coarse grained conditions are illustrated in figure 1. The fine grained material reveals grain sizes of less than 5 μm (Fig.1b) while the coarse grained material exhibits grain sizes of about 270 μm (Fig.1c).



a) as-received

b) fine grained

c) coarse grained

Figure 1: Microstructures of cp-Ti

The tensile properties of the coarse and fine grained conditions are given in table 2.

Table 2: Tensile properties of cp-Ti.

Conditions	YS (MPa)	UTS (MPa)	UTS-YS (MPa)	$\varepsilon_F = \ln(A_0/A_F)$
CG	155	370	215	1.60
FG	585	745	160	0.90

Obviously, the fine grained condition has yield stress und tensile strength values much higher than the coarse grained condition. The tensile ductility of the fine grained material being lower than that of its coarse grained counterpart is explained by residual cold work effects from the SW process (table 2).
The S–N curves in rotating beam loading (R = -1) of FG and CG materials are illustrated in figure 2. Obviously, the 10^7 cycles fatigue strength of FG material is significantly higher than that of CG material. This can be attributed to the yield stress in FG being much higher than in CG material (table 2).

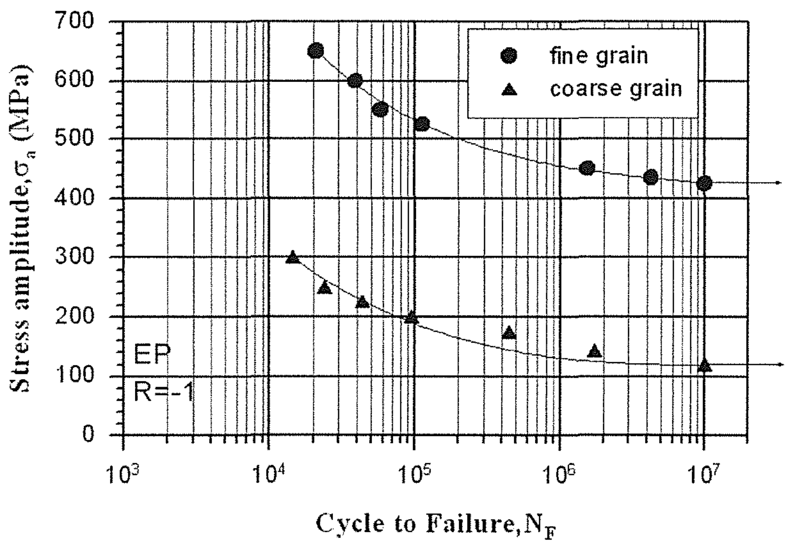
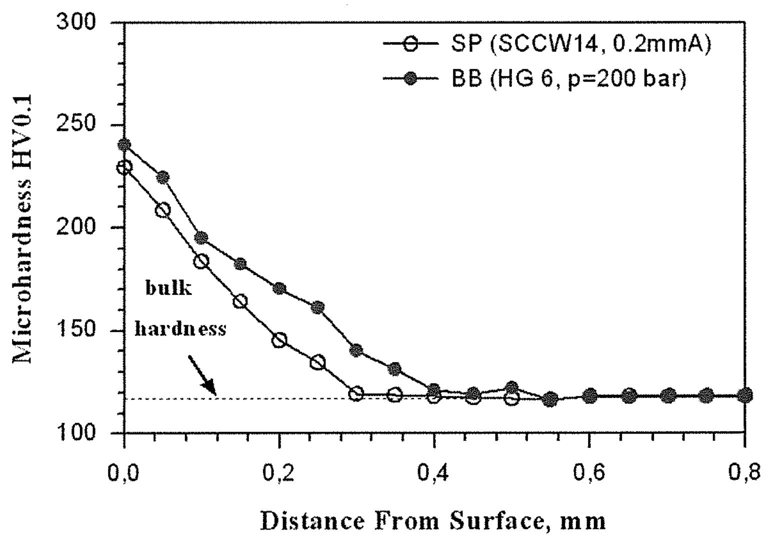
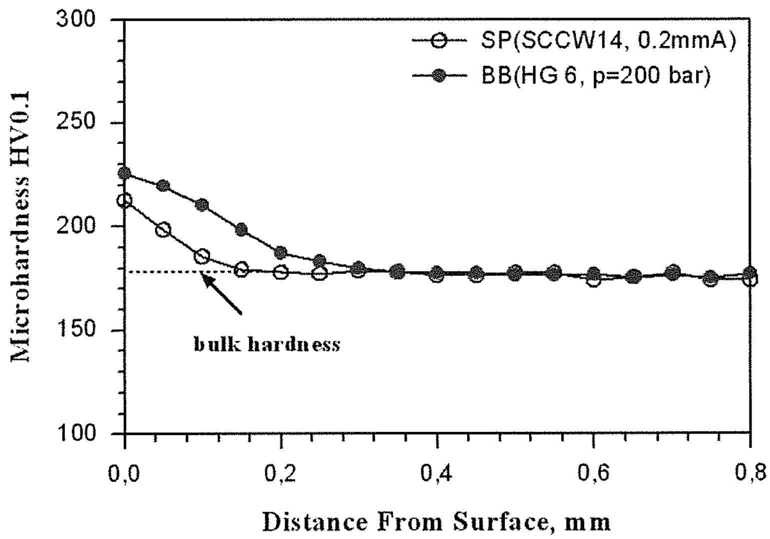


Figure 2: S–N curves of cp-T in rotating beam loading (R = -1)

Figure 3 illustrates the micro-hardness-depth profiles of fine and coarse grained cp-Ti grade 1 after SP and BB. While not much of a difference in the maximum hardness value close to the surface is found between BB and SP, BB results in significantly greater depths of plastic deformation in both coarse and fine grained materials (Fig. 3). The bulk hardness values for the coarse and fine grained materials were about 120 HV 0.1 and 180 HV 0.1, respectively while the hardness values after SP and BB treatments at the surface in the coarse grained material were about 230 and 240 HV 0.1, respectively. The surface hardness values in the fine grained material of the conditions SP and BB were 210 and 225 HV 0.1, respectively. Obviously, BB led to greater depths of plastic deformation. The depth of induced plastic deformation was about 0.28 and 0.40 mm after SP and BB for the coarse grained material. These results can be correlated to work hardening capabilities (UTS-YS) of cp-Ti amounting to 215MPa in coarse grained and only 160 MPa in the fine grained material (Table 2). The penetration depths for the SP and BB in the fine grained material were about 0.18 and 0.24 mm, respectively (Figure 3b).
The effect of mechanical surface treatments on fatigue performance in rotating beam loading is shown in figure 4 comparing the effects of SP and BB on both coarse and fine grained. The SP improves the HCF strength value of the coarse grained condition. The highest fatigue strength is observed in BB condition. Comparing the fatigue behavior after mechanical surface treatment between coarse and fine grained conditions, it is apparent that the coarse grained condition shows HCF behavior superior to that of fined grained condition. The BB and SP treatments significantly improve the fatigue strength at 10^7 cycles of coarse grained condition from 125 MPa (EP) to 225 MPa and 300 MPa after SP and BB, respectively (Fig 4a). This result may be related to the marked work hardening capabilities (UTS-YS) of cp-Ti to 215 MPa in the coarse grained condition (Table 2). Obviously, the BB and SP-induced strengthening and residual compressive stresses play an important role to improve the fatigue performance.

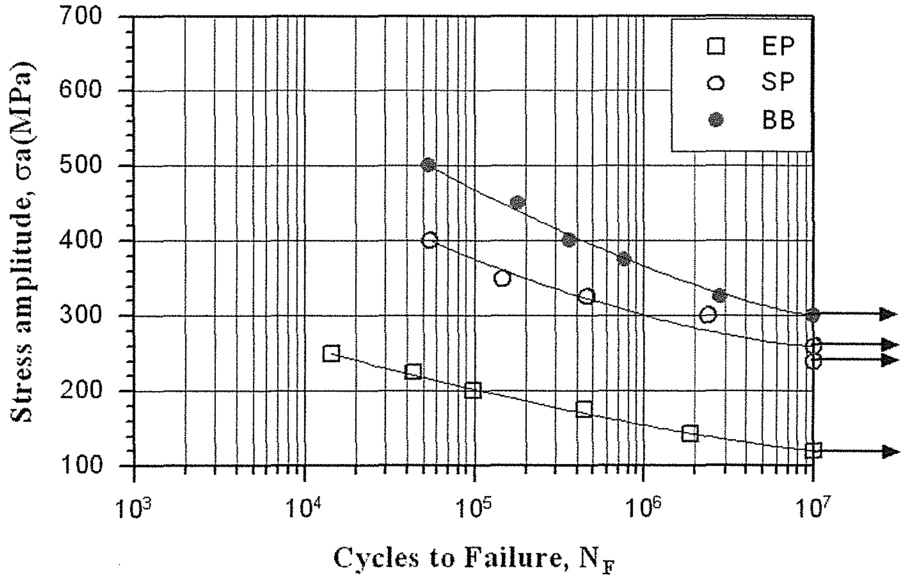


a) coarse grained

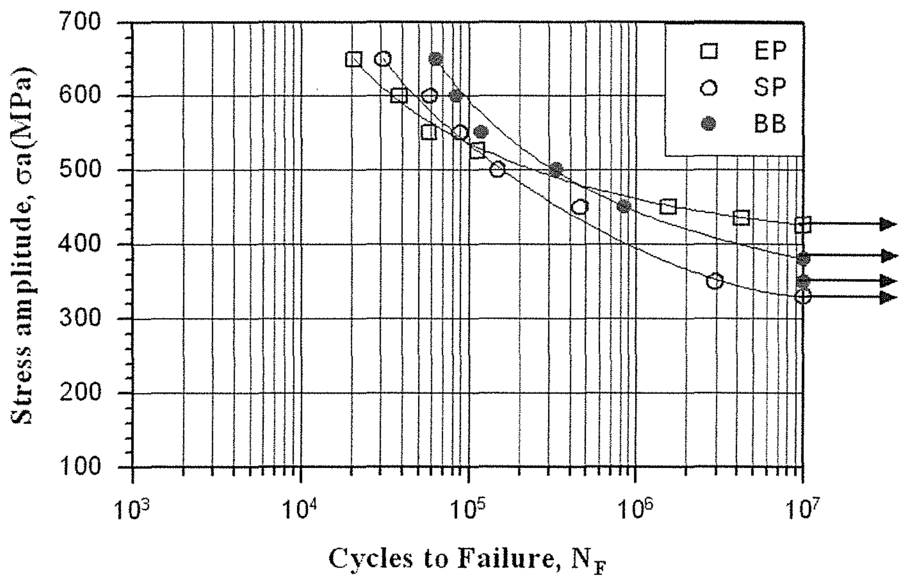


b) fine grained

Figure 3: Micro-hardness-depth profiles in cp-Ti after mechanical surface treating



a) coarse grained



b) fine grained

Figure 4: Effects of SP and BB on S-N curves

In contrast to the result of coarse condition, the HCF strength of fine condition is lowered by SP and BB as well (Fig 4b). The 10^7 cycles fatigue strength of EP significantly decreases after SP from 425 MPa to 330 MPa while the change in fatigue strength after BB is rather moderate (Fig. 4b). Presumably, the drop in HCF strength after SP is related to the increase in surface roughness and development of residual tensile stresses [14].

Conclusions

The present results indicate that the differences in fatigue response of fine and coarse grained conditions of cp-Ti to mechanical surface treatments can be interpreted by differences in the degree of work-hardening being very marked in the coarse grained material and less pronounced in the fine grained material. The reason for the worse performance of the fine grained material could be derived from the low recrystallization degree due to annealing the SPD material at comparatively low temperature. Presumably, the drop in HCF strength is related to residual tensile stresses after SP and BB in the fine grained condition.

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