Effects of Shot peening and Ball-burnishing on the Fatigue Performance of Al 6082

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Abstract

In this study, the effects of shot peening (SP) and ball-burnishing (BB) on the fatigue performance of the aluminum alloy Al 6082 in naturally aged (T4) and artificially aged conditions (T6) were investigated. SP was conducted using spherically conditioned cut wire (SCCW14) with an Almen intensity of 0.20 mmA. BB was performed using a hard metal ball (HG6) and a burnishing pressure of 100 bar. Surface property (roughness) and near-surface properties (microhardness and residual stresses) were evaluated. SP and BB markedly enhanced the fatigue performance of the electropolished reference condition. The fatigue enhancement due to mechanical surface treating in T4 is more pronounced than in T6. This is explained by the differences in work-hardening capability of the two temper conditions.

Keywords: Al 6082, shot peening, ball-burnishing, fatigue, work-hardening capability.

Introduction

The Al 6XXX- series contains magnesium and silicon as major alloying elements. These multiphase alloys belong to the group of commercial alloys in which relative volume, chemical composition and morphology of structural constituents exert significant influences on their useful properties [1-3]. Al-Si-Mg-Cu alloy is of considerable interest for aerospace and automobile applications because of its low cost, high strength-to-weight ratio, and good wear-resistance characteristics [4]. The increasing use of this alloy creates the need for enhancing the quasi-static and cyclic strength. Mechanical surface treatments such as shot peening (SP) and ball-burnishing (BB) are efficient techniques to improve the fatigue and corrosion fatigue performance of structural materials [5-8]. This improvement can be derived from two contributing factors; namely surface strengthening by the induced high dislocation densities and residual compressive stresses. As opposed to shot peening, ball-burnishing results in very smooth surfaces [9]. SP and BB induced-compressive residual stresses have been found to retard pitting corrosion and corrosion fatigue in Al alloys [10, 11].

The present work aims at studying the effects of shot peening and ball-burnishing on the surface and near-surface layer properties. In addition the effects on fatigue performance in naturally aged condition T4 and artificially aged condition T6 are investigated.

Experimental procedure

Al 6082 was received as cylindrical extrusions (∅ 70 mm) with chemical composition given in Table 1.

Table 1: Chemical composition of AA 6082 (wt. %).

Si	Mg	Mn	Fe	Al
1.18	0.88	0.77	0.40	Bal.

Sample blanks were taken parallel to the extrusion direction and solution heat treated at 520°C for 0.5 h followed by water quenching. Finally, the blanks were either naturally aged at room temperature for at least 5 days (T4 temper) or artificially aged at 175°C for 12 h to obtain T6 peak-aged condition.

Tensile tests were performed using threaded cylindrical specimens having gage lengths and diameters of 25 and 5 mm, respectively.

Hour-glass shaped fatigue samples with a minimum diameter of 6 mm were shot peened (SP) using a direct air pressure system (Gravi 2000, OSK Kiefer, Oppurg) and spherically conditioned cut wire (SCCW14) having a hardness of 580 HV and an average shot size of 0.36 mm. Peening was performed to full coverage using Almen intensity of 0.20 mmA. Other samples were ball-burnished (BB) using a conventional lathe and a hydrostatic tool by which a hard metal ball (Ø 6 mm) is pressed with a pressure of 100 bar onto the specimen surface. Electrolytically polished (EP) samples were taken as the baseline to which the SP and BB conditions are compared.
The surface roughness of the various conditions was determined by means of an electronic contact (stylus) profilometer instrument (Perthometer). Microhardness was determined by using a Struers Duramin tester with a force of 50 ponds (HV0.05) and a loading time of 10 seconds. Residual stresses were evaluated with the incremental hole drilling technique using an oscillating drill with a 1.9 mm diameter driven by an air turbine with a rotational speed of 200,000 rpm.
Fatigue tests were performed with rotating beam loading (R = -1) in air at a frequency of 50 Hz.

Results and discussion
The optical microstructure of the age-hardening condition T4 is illustrated in Figure 1. Compared to this T4 conditions, no difference in optical appearance was found for the peak aged T6 condition. However, the precipitate morphology which is not visible by optical microscopy is known to be quite different. In T6, the precipitates are characterized by semi-coherent needles and rods whereas in T4 only GP zones will be present [12].

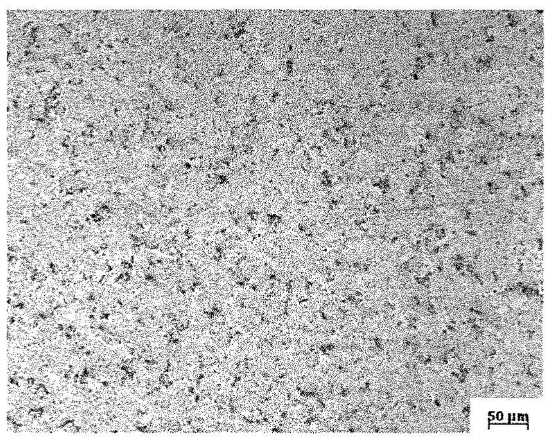


Figure 1: Microstructure of Al 6082 in T4 condition

Table 2 summarizes the tensile and hardness properties of the T4 and T6 conditions. The work-hardening capability which can be roughly estimated by (UTS – YS) in T4 condition is higher than in T6.

Table 2: Tensile properties of Al 6082 in T4 and T6 conditions

Condition	YS (MPa)	UTS (MPa)	UTS–YS (MPa)	El (%)	HV10
T4	290	325	35	15.2	85
T6	350	365	15	12.3	108

The surface roughness values after SP and BB treatments on both T4 and T6 conditions are given in Figure 2. The surface roughness after SP is significantly increased relative to EP, whereas the roughness after BB is almost as low as in the EP reference condition. On average, the roughness values in T4 are somewhat higher than those of T6, probably due to the lower yield stress of the naturally aged condition.

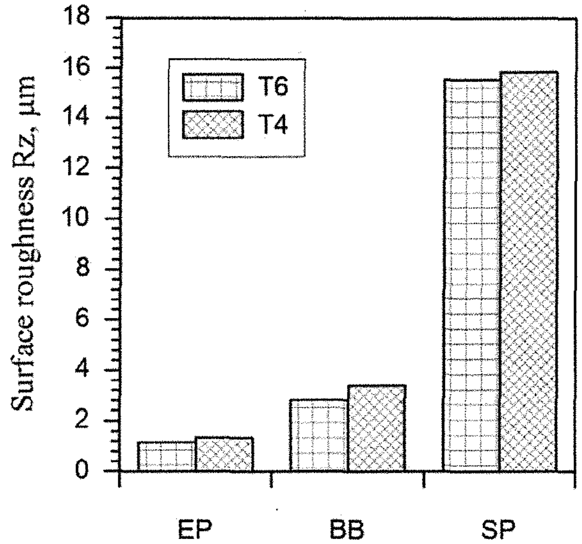
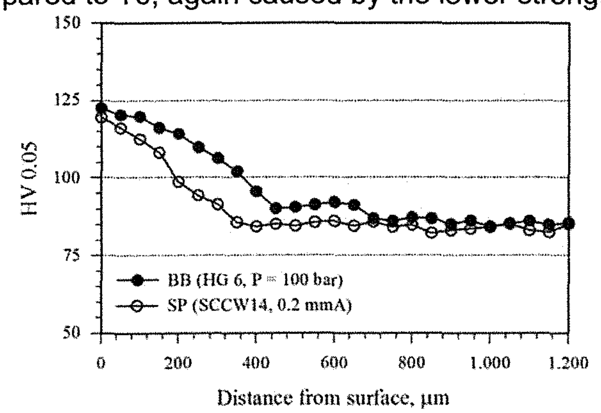
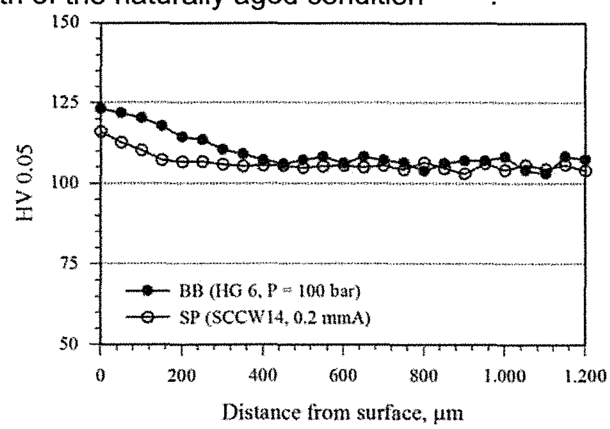


Figure 2: Roughness values of the various surface treated conditions.

The micro-hardness-depth distributions after SP and BB are given in Figure 3. Obviously, the most pronounced difference in the hardness-depth distributions between the two aging conditions is the degree of hardness increase relative to the bulk hardness. The micro-hardness at the surface of Al 6082 in T4 condition increases by 37 HV after BB and by 33 HV after SP. In T6, the micro-hardness at the surface increases by only 15 HV after BB and by 10 HV after SP, these results being related to differences in work-hardening capability of the two conditions. Additionally, the depth of SP and BB-induced plastic deformation in T4 was higher compared to T6, again caused by the lower strength of the naturally aged condition .



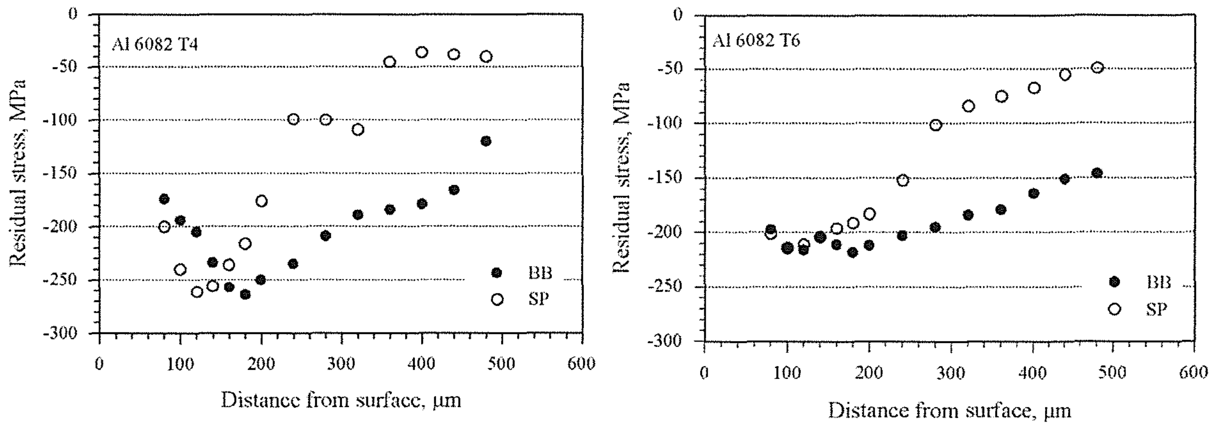
(a) T4



(b) T6

Figure 3: Microhardness-depth profiles after mechanical surface treating

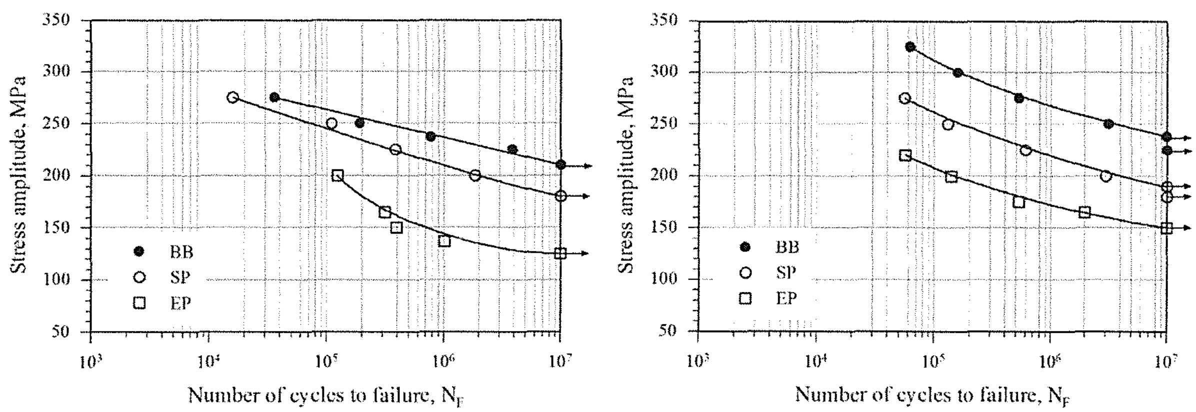
Figure 4 shows the residual stress-depth profiles of Al 6082, in T6 and T4 aging condition. It is apparent that after ball-burnishing, the measured maximum compressive stresses amount to as much as 220 and 265 MPa in T6 and T4 conditions, respectively. The higher residual compressive stress in T4 are explained by its work-hardening capability being higher than in T6 (Table 2). Average residual compressive stress levels are slightly lower in SP in comparison to BB. Maximum values in SP conditions are 215 and 255 MPa in T6 and T4, respectively. However in both conditions ball-burnishing revealed deeper depths of induced residual stresses.



(a) T4 (b) T6

Figure 4: Residual stress-depth profiles after SP and BB

The effects of BB and SP on the S-N curves T6 and T4 conditions are shown in Figure 5. Both ball-burnishing and shot peening lead to marked improvements in fatigue performance. The 10^7 cycles fatigue strength of EP condition in T6 increased from 150 MPa to 190 and 240 MPa after SP and BB, respectively. In T4, the fatigue strength increased to 125 MPa to 180 and 210 MPa after SP and BB, respectively. The more marked improvement in HCF strengths in T4 can be explained by its higher work-hardening capability. However, the absolut value of the fatigue strength in T6 after surface treating is still higher than in T4.



(a) T4 (b) T6

Figure 5: Effects of SP and BB on S-N curves

The significant fatigue life enhancement after BB compared to SP is attributed to deeper penetration depths and lower surface roughness.

Conclusions

The fatigue life of both T4 and T6 conditions was markedly enhanced after applying BB and SP in comparison to the reference EP condition. Presumably, this is a result of the induced residual compressive stresses which retard fatigue micro-crack propagation.
The superior improvement of the fatigue performance due to BB is explained by the deeper depth of plastic deformation and lower surface roughness.
The Fatigue response to surface treatments was more marked in T4 compared to T6 due to the higher work-hardening capability of the natural temper. However, the fatigue life in T6 after applying SP and BB is still slightly higher than in T4.

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References

[1] S. Spigarelli, E. Evangelista, H.J. McQueen, *Study of hot workability of a heat treated AA6082 aluminum alloy*, Scripta Materialia, Vol. 49 (2003), pp 179–183.
[2] B. Rønning, K. Nord- Varhaung, T. Furu, E. Nes, *The effect of chemical composition and microstructure on the flow stress during hot deformation of aluminium alloys*, Materials Science Forum, Vol. 331–337 (2000), pp 571–576.
[3] M. De Giorgi, A. Scialpi, F. W. Panella, L. A. C. De Filippis, *Effect of shoulder geometry on residual stress and fatigue properties of AA6082 FSW joints*, Journal of Mechanical Science and Technology, Vol. 23 (2009), pp 26–35.
[4] O.P. Modi, M. Saxena, B.K. Prasad, A.H. Yegneswaran, M. L. Vaidya, *Corrosion behaviour of squeeze cast aluminium alloy–silicon carbide composites*, Journal of Materials Science, Vol. 27 (1992), pp 3897–3902.
[5] A. Zammit, M. Mhaede, M. Grech, S. Abela, L. Wagner, *Influence of shot peening on the fatigue life of Cu-Ni austempered ductile iron*, Materials Science and Engineering A, Vol. 545 (2012), pp 78–85.
[6] L. Wagner, M. Mhaede, M. Wollmann, I Altenberger, Y. Sano, *Fatigue performance of Al 7075-T73 and Ti-6Al-V: comparing results after shot peening, laser shock peening and ball-burnishing*, International Journal Structure Integrity, Vol. 2 (2011), pp185–199.
[7] M. Mhaede, L. Wagner, Kh. Ibrahim, *Thermomechanical treatments and surface treatments to enhance the mechanical properties and fatigue performance of recycled cp-Ti*, International Journal of Materials Research, Vol. 104 (2013), pp 713-720.
[8] M. Abdulstaar, M. Mhaede, M. Wollmann, L. Wagner, *Pre-Corrosion and surface treatments effects on the fatigue life of AA6082 T6*, Advanced Engineering Materials, Vol. 15 (2013), pp 1002-1006.
[9] T. Ludian, L. Wagner, *Effect of age-hardening conditions on high-cycle fatigue performance of mechanically surface treated Al 2024*, Materials Science and Engineering A, Vol. 468-470 (2007), pp 210–213.
[10] S. Mall, V.K. Jain, H.A. Fadag, *Effects of shot-peening on fretting fatigue crack growth behavior in Ti-6Al-4V*, Strain, Vol. 47 (2011), pp e305–e318.
[11] P.S. Prevey, J. Cammett, *Low cost corrosion damage mitigation and improved fatigue performance of low plasticity burnished 7075-T6*, Journal of Materials Engineering and Performance, Vol. 10 (2001), pp 548–555.
[12] O. Grong, *Recent Advances in Solid-State Joining Of Aluminum*, Journal of Welding, Vol. 91 (2012), pp 26–33.