INFLUENCE OF BALL-BURNISHING ON STRESS CORROSION CRACKING, FATIGUE AND CORROSION FATIGUE OF Al 2024 AND Al 6082

M. Mhaede, M. Wollmann and L. Wagner

Institute of Materials Science and Engineering
Clausthal University of Technology
Agricolastraße 6, D-38678 Clausthal, Germany

ABSTRACT

Ball-burnishing (BB) was done on the age-hardenable alloys Al 2024 and Al 6082. The main process parameter rolling force was varied to a wide extent. The process-induced changes in near-surface properties were determined by microhardness-depth profiles and residual stress-depth profiles measured by the incremental hole drilling method. The influences of these surface layer properties on stress corrosion cracking (SCC) and corrosion fatigue (CF) in aqueous 3.5% NaCl solutions were studied. Results were compared with electrolytically polished references.

Stress corrosion cracking (SCC) tests were performed on standard tensile specimens under stress control using stress levels ranging from 60 to 100% of the yield stress. The time to failure was recorded. Corrosion fatigue (CF) tests were performed on hour-glass shaped specimens in rotating beam loading (R = -1) at frequencies of 50 s^{-1}. Results of these corrosion fatigue (CF) tests were compared with results obtained in fatigue tests in air. It was found that the time to failure (TTF) in the SCC tests as well as the fatigue life in the CF tests were markedly improved by ball-burnishing.

KEY WORDS

Ball-burnishing, stress corrosion, fatigue, corrosion fatigue

INTRODUCTION

Because of their good specific strengths, Al 2024 and Al 6082 are widely used as materials for structural components in transport engineering such as in aircraft and automotive. Such structures are often subject to high static or cyclic loading in chloride containing aggressive environments.

In general, fatigue cracks nucleate at the surface of a component even in the absence of stress gradients and in inert environments while surface cracking in static loading is usually associated with aggressive environments. Under both loading conditions, mechanical surface treatments such as shot peening and ball-burnishing which induce high dislocation densities and residual compressive stresses can be helpful in increasing lifetime. The beneficial effect of ball-burnishing on fatigue life has been shown on a number of metallic materials, e.g. steels [L.N. López de Lacalle et al. 2007], titanium [L. Wagner 1999], aluminum [L. Wagner 1999; U. Noster and B. Scholtes 2001; P. Juijerm et al. 2004] and magnesium alloys [L. Wagner 1999; U. Noster and B. Scholtes 2001]. The corrosion fatigue performance and resistance to SCC of metallic materials could also be improved by introducing ball-burnishing as a mechanical surface treatment [P. Prevey and J. Cammett, 2004] [N. Jayaraman et al, 2005] The purpose of this work was to investigate the effects of ball-burnishing on stress corrosion cracking, fatigue and corrosion fatigue on Al 2024 and Al 6082.

EXPERIMENTAL

The age-hardenable alloys Al 2024 and Al 6082 were received as Ø 63 mm extrusions from Otto Fuchs Metallwerke, Meinerzhagen, Germany. The chemical compositions are listed in Table 1.

Table 1: Chemical composition (wt.%)

	Cu	Mg	Si	Mn	Cr	Zn	Fe	Ti	Al
Al 2024	4.54	1.36	0.06	0.81	0.01	0.01	0.01	0.04	Bal.
Al 6082	0.04	0.79	0.98	0.65	0.15	0.02	0.26	0.03	Bal.

Specimen blanks (10x10x60 mm) were taken with the load axis perpendicular to the extrusion direction (R). Al 2024 was given both natural (T4) and artificial (T6) tempers while Al 6082 was given a T4 temper only.
Tensile specimens according to ASTM G 47-9 having gage lengths and gage diameters of 20 mm and 5 mm, respectively were prepared for tensile as well as for SCC tests. Tensile test results (initial strain rate 10-3 s-1) are illustrated in Table 2.

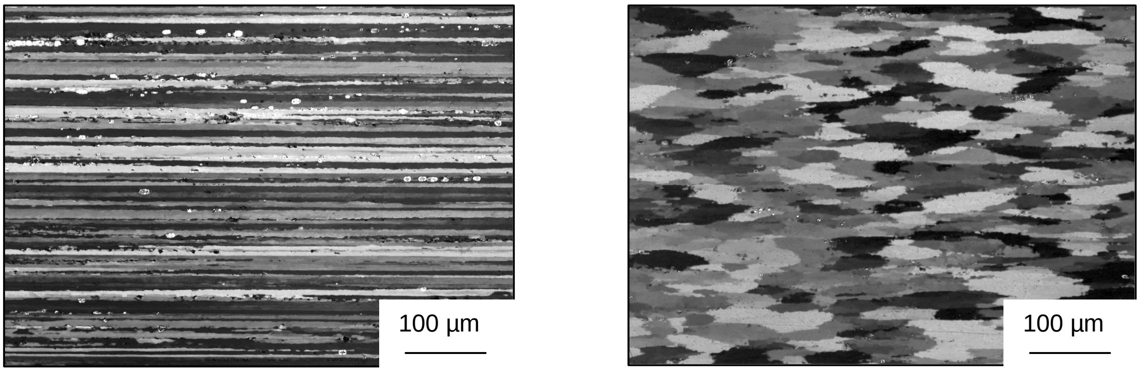
Table 2: Tensile properties

	condition	YS (MPa)	UTS (MPa)	El (%)	$\varepsilon_F = \ln (A_0/A_F)$
Al 2024	T4	315	470	13.0	0.22
	T6	360	435	6.0	0.20
Al 6082	T4	165	295	23.5	0.42

For the fatigue and CF-tests, hour-glass shaped specimens with a minimum diameter of Ø 3.8 mm were prepared. After machining, the specimens to be used for the SCC tests and the fatigue specimens were either electropolished or ball-burnished. During electropolishing, 100 μm were removed from the as-machined surface to ensure that any machining effect that could mask the results was absent. Ball-burnishing was performed by means of a conventional lathe using a device from the company ECOROLL, by which a hard metal ball of Ø3 mm (HG3) is hydrostatically pressed onto the rotating specimen surface. The change in surface layer properties was evaluated by surface roughness measurements, microhardness-depth profiles as well as by residual stress-depth profiles. The residual stresses were calculated from residual strains as measured by strain gage rosettes using the incremental hole drilling method. A drill with Ø1.9 mm being driven by an air-turbine was used which operated at 200000 rpm.
SCC tests on Al 2024 in both T4 and T6 tempers were performed under constant tensile stresses corresponding to 60, 75, 90 and 100% of the particular yield stress of the materials. During testing, the specimens were permanently immersed in an aqueous 3.5% NaCl solution. The CF tests for both Al 2024 (T4 and T6) and Al 6082 T4 were performed in rotating beam loading (R = -1) using a frequency of 50 s^{-1}. The same 3.5% NaCl solution was used as in the SCC tests.

RESULTS AND DISCUSSION

The microstructure of the extruded Al 2024 is illustrated in Figure 1. Grains are highly elongated in extrusion direction (Fig. 1a) while they are much less elongated perpendicular to the extrusion direction (Fig. 1b). Similar elongated grains were also found in the extrusion of Al 6082.



a) Extrusion direction ⇨ b) Extrusion direction ⊙

Figure 1: Microstructure in Al 2024 (T4)

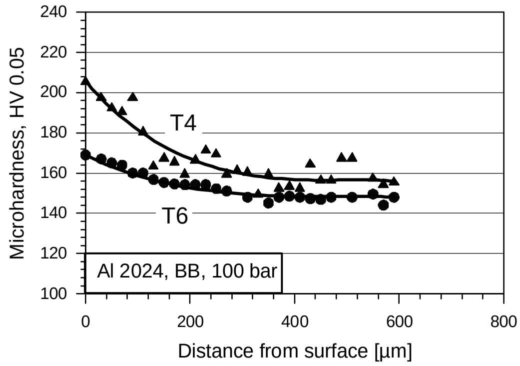
As seen in Table 2, the lowest yield stress was observed in Al 6082 T4 and the highest in Al 2024 T6 followed by Al 2024 T6. As expected, Al 6082 T4 has the highest ductility followed by Al 2024 T4 and Al 2024 T6. The work-hardening capability which can be roughly estimated by (UTS-YS) is highest in Al 2024 T4 (155 MPa) followed by Al 6082 T4 (130 MPa). The lowest value was observed in Al 2024 T6 (75 MPa) which also exhibits the lowest tensile elongation (Table 2).

From parallel work [M. Mhaede et al. 2007] it is known that the maximum surface roughness in BB of these alloys is as low as that of the electropolished reference (R_z = 1.4 µm).

The BB-induced plastic deformation significantly increases the surface layer hardness over the bulk hardness as illustrated in Figure 2. The more marked hardness increase in T4 as compared to T6 can be explained by the higher work-hardening capability in T4 as opposed to T6 (Table 2).

Residual compressive stresses with pronounced maximum values at some distances below the surface were measured in BB conditions on both T4 and T6 tempers of Al 2024 (Fig. 3). However, the measured residual compressive stresses in T4 were higher than in T6, this being explained by its work-hardening capability being markedly higher than in T6 (Fig. 2 and Table 2).

The SCC test results of Al 2024 are shown in Figure 4 where the S-t curves in 3.5% NaCl solution are illustrated for both EP (Fig. 4a) and BB conditions (Fig. 4b). For reasons of comparison, the applied tensile stresses are normalized by yield stress. For the reference EP (Fig. 4a), the time to failure at all tested stress levels in condition T4 is markedly higher than in T6. This indicates that T6 is much more susceptible to SCC than T4.



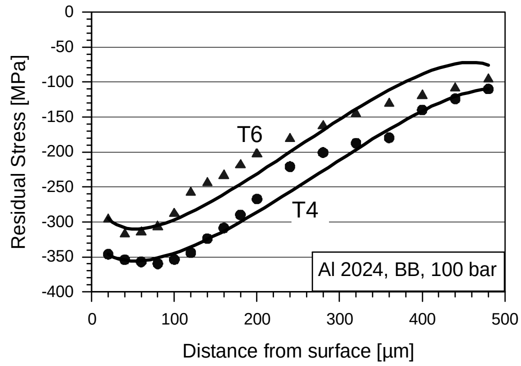
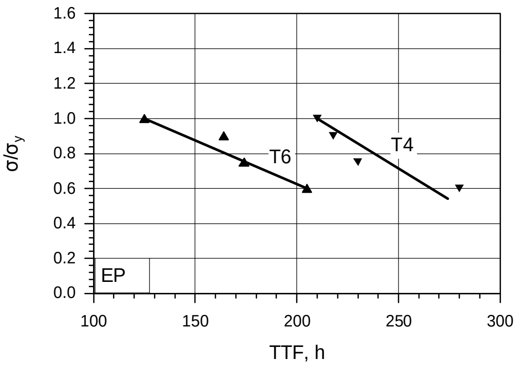
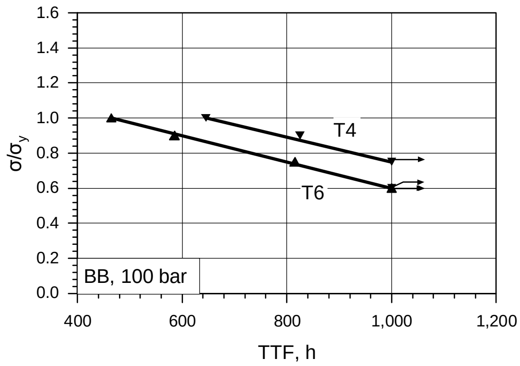


Fig. 2: Microhardness-depth profiles

Fig. 3: Residual stress-depth profiles

Comparing Figure 4b with Figure 4a, it is seen that ball burnishing (100 bar pressure) increases the SCC lifetimes of both T4 and T6 tempers. Again, best performance is observed in condition T4.





a) Condition EP

b) Condition BB

Fig. 4: S-t performance in SCC of Al 2024

Metallographic observation of the samples after SCC tests (Figure 5) revealed that the cracks initiate from pits and then grow along grain boundaries. This behaviour is typical for extrusions of high strength aluminum alloys [A.F. Oliveira et al. 2004] [K.S. Ghosh et al. 2003].

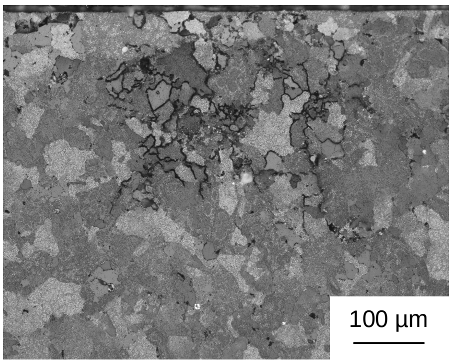
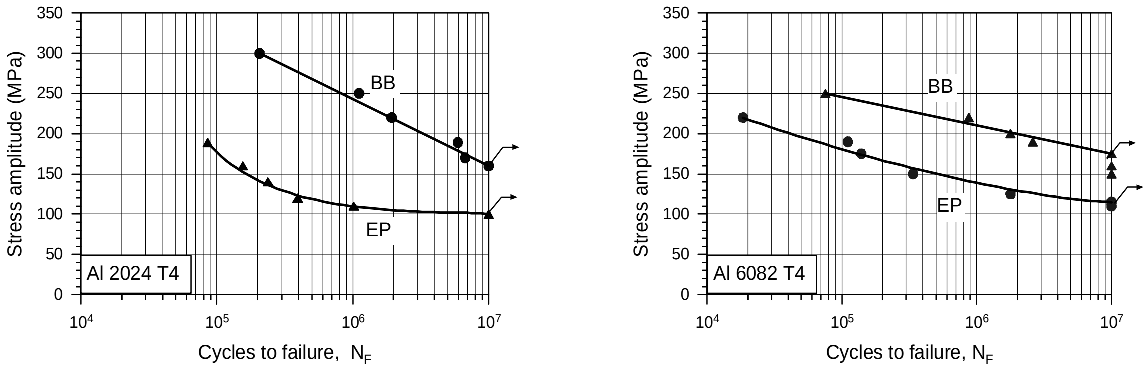


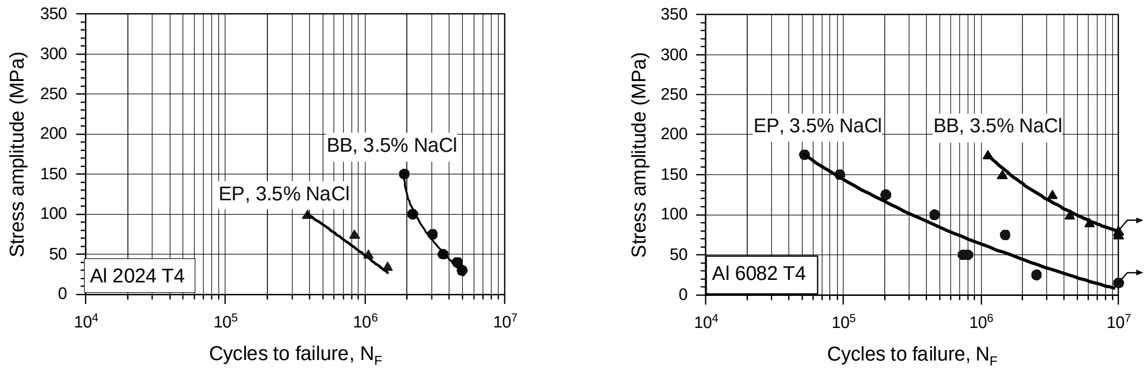
Figure 5: Cross sectioned sample of Al 2024 T4, EP, σ/σ_y=1, TTF=210 h

The effects of ball-burnishing on the S-N curves in air of Al 2024 T4 and Al 6082 T4 are shown in Figure 6. Ball-burnishing leads to an increase in fatigue life at high stress amplitudes by roughly two orders of magnitude. Even at a stress amplitude close to the yield stress of the material (compare Fig. 6a with Table 2), ball-burnished specimens can survive 10^5 cycles. Obviously, this is caused by the burnishing-induced high local yield stress at the surface which increases the resistance to fatigue crack nucleation. For both Al 2024 T4 and Al 6082 T4, the 10^7 cycles fatigue strengths of conditions EP are improved by BB by as much as 60% (Fig. 6).



a) Al 2024 T4 b) Al 6082-T4

Fig. 6: S-N curves in rotating beam loading (R = -1) in air, BB vs. EP



a) Al 2024 T4 b) Al 6082-T4

Fig. 7: S-N curves in rotating beam loading (R = -1) in 3.5% NaCl solution, BB vs. EP

The corrosive environment markedly reduces the fatigue life for a given stress amplitude of both Al 2024 T4 and Al 6082 T4 (compare Figures 7 and 6). The detrimental influence of the environment is relatively small for the high-stress regime but becomes more significant in the low-stress HCF regime. This behavior can be explained by time effects since the aggressive environment can act over much longer times in the HCF regime [M.L. Du et al. 1998]. For Al 2024 T4, no fatigue limit was apparent in the CF tests even at stress amplitudes as low as 20 MPa. In contrast, the lower strength Al 6082 T4 has a much higher resistance to corrosion fatigue than Al 2024, particularly in condition BB.

ACKNOWLEDGEMENTS
The authors would like to thank Dr.-Ing. M. Hilpert of Otto Fuchs Metallwerke, Meinerzhagen for providing the extrusions of Al 2024 and Al 6082. Thanks are also due to U. Koerner for performing the ball-burnishing treatments. One of the authors (M. M.) would like to thank the Egyptian Government for financial support during his study towards a PhD degree at TU Clausthal.

REFERENCES

A. F. Oliveira, M. C. de Barros, K. R. Cardos, Mater. Sci. Eng, A379 (2004) 321.
K. S. Ghosh, K. Das and U. K. Chatterjee, JCSE, 6 (2003) C014.
L. N. López de Lacalle, A. Lamikiz and J. A. Sánchez, Int. J. Adv. Manuf. Technol. 32 (2007) 958.
L. Wagner, Mater. Sci. Eng. A 263 (1999) 210.
M. L. Du, F. P. Chiang, S. V. Kagwade and C. R. Clayton, Int. J. Fatigue Vol. 20(1998) 743.
M. Mhaede, M. Wollmann and L. Wagner, Metals Processing and Manufacturing Conference, Cairo (2007) 144.
N. Jayaraman, P. Prevery, N. Ontko, M. Shepard, R. Ware and J. Coate, ICSP9, Paris 2005. 247.
P. Juijerm, U. Noster, I. Altenberger and B. Scholtes, Mater. Sci. Eng. A379 (2004) 286.
P. Prevey and J. Cammett, Int. J. Fatigue Vol. 26/9 (2004) 975-982.
U. Noster, B. Scholtes, Z. Metallkd. 92 (2001) 260.