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Effect of Overloads on Fatigue of Shot Peened 2024 Al

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1 Introduction

Numerous investigations in the past have shown that shot peening can improve the fatigue performance of structural materials such as steels and aluminum alloys [1-4]. However, this beneficial effect of shot peening is usually demonstrated in constant amplitude tests although components in service hardly see simple constant load amplitudes [5]. Only a limited number of studies on shot peened components has been performed under variable amplitude loading [6]. Since shot peening-induced residual compressive stresses which are known to be the main reason for the improvement of the fatigue performance may not be cyclically stable if overloads of sufficient magnitude occur in service, it is interesting to know to what extent shot peening is still beneficial if variable amplitudes are applied.

2 Experimental

The investigation was performed on the well known AlCuMg-based aircraft alloy 2024 Al. The material was delivered as ∅ 12 mm extruded bar. The material was cut into blanks with a length of 50 mm. After solutionizing at 495 °C for 1 hour and water-quenching, part of the blanks was naturally age-hardened at room temperature for at least 5 days (T4 temper) while the other part was given an artificial aging by annealing at 190 °C for 12 hours (T6 temper). Tensile tests were performed on threaded cylindrical specimens having gage lengths of 20 mm. The initial strain rate was $8.3 \times 10^{-4}s^{-1}$. Tensile test results are listed in Table 1.

Table 1: Tensile tests results on 2024 Al

	E (GPa)	$\sigma_{0,2}$ (MPa)	UTS (MPa)	σ_F (MPa)	El (%)
T4	74	350	500	650	18
T6	75	380	450	550	11

To determine the cyclic deformation characteristics of the two tempers, stress controlled low cycle fatigue (LCF) tests were performed on cylindrical specimens having gage lengths and gage diameters of 20 and 6 mm, respectively [7]. These tests were done in axial loading at a stress ratio of $R = -1$ by means of a servohydraulic testing machine. The test frequency was 1 Hz. During testing, the axial strain was recorded by strain gages. From the hysteresis loops, the plastic strain was measured and plotted versus number of cycles.

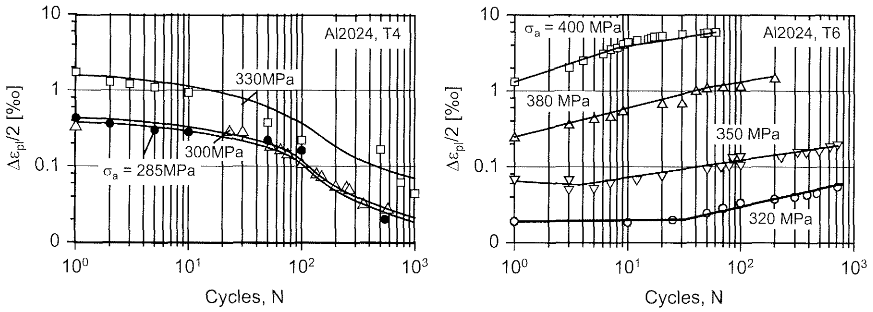
For high cycle fatigue (HCF) testing, hour glass shaped specimens with a gage diameter of 3.6 mm were machined. For both tempers, part of the specimens was electropolished (EP) to serve as reference. 100 µm were removed from the as-machined surface to ensure that any machining effect that could mask the results was absent. The other part was shot peened (SP) by means of an injector type machine using spherically conditioned cut wire SCCW14 (0.36 mm average shot size). During the peening treatment, the specimens rotated at $1s^{-1}$. The distance between nozzle tip and specimen surface was 45 mm. Peening was done to an Almen intensity of 0.28 mmA at full coverage.

The change in surface layer properties was characterized by measurements of surface roughness through profilometry and by microhardness-depth profiles.

Fatigue tests were performed in rotating beam loading ($R = -1$) at frequencies of about 60 Hz. During constant amplitude testing, 1000 overload cycles were applied every 10.000 cycles. The fraction overload/baseline stress amplitude was kept constant at 1.3.

3 Results and Discussion

The cyclic deformation behavior of 2024 Al is illustrated in Fig. 1 comparing the results of the T4 (Fig. 1a) and T6 (Fig. 1b) tempers [6]. For the utilized stress amplitudes, the cyclic plastic strain decreases with number of cycles in T4 indicating cyclic hardening (Fig. 1a) while cyclic softening was observed in T6 (Fig. 1b).

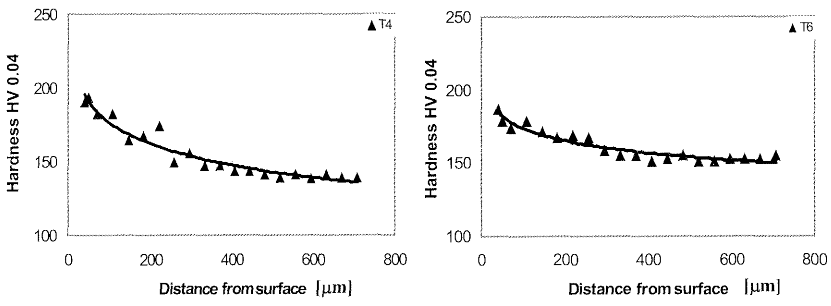


a) T4 (cyclic hardening) b) T6 (cyclic softening)

Figure 1: Cyclic deformation characteristics in 2024 Al ($R = -1$)

The microhardness-depth profiles after shot peening are plotted in Fig. 2 comparing again results of the naturally aged T4 (Fig. 2a) and artificially aged T6 (Fig. 2b) tempers. While the penetration depth of plastic deformation in the two tempers is very similar, the near-surface hardness values in T4 are somewhat higher than in T6 whereas the bulk hardness of T6 is slightly higher than T4 (Fig. 2, compare Figs. 2a and 2b). These results can be correlated with the tensile properties (table 1) indicating lower yield stress but higher work-hardening capacity in T4 as opposed to T6.

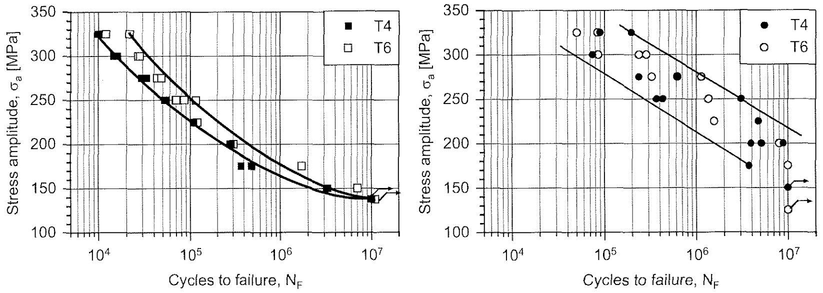
The fatigue performance of the T4 and T6 tempers is shown in Fig. 3 comparing the results of the electropolished reference (Fig. 3a) and shot peened (Fig. 3b) conditions in constant amplitude rotating beam loading. In the electropolished reference, T6 is somewhat superior to T4 presumably caused by the higher yield stress in T6 as opposed to T4 (compare Fig. 2 with Table 1). After shot peening, the fatigue performance of both tempers is markedly improved. Since



a) T4 b) T6

Figure 2: Microhardness depth profiles after shot peening (0.28 mmA)

both tempers show roughly the same S-N scatter band after shot peening, the fatigue response of T4 to shot peening is more beneficial than that of T6.



a) Electrolytically polished (EP) b) Shot peened (SP, 0.28 mmA)

Figure 3: S-N curves (constant amplitude loading) in 2024 Al, rotating beam ($R = -1$), effect of aging

This result confirms earlier work and can be correlated with the shot peening-induced residual compressive stresses in T4 being markedly higher than in T6 owing to the more pronounced work-hardening capacity after natural aging [3, 8]. Furthermore, the residual stresses in T4 are likely to be cyclically more stable than in T6 since T4 exhibits cyclic hardening while T6 cyclically softens as seen in Fig.1.

The load-time sequence in the fatigue tests with periodic overload cycles are shown schematically in Fig. 4. After 10000 baseline cycles, 1000 overload cycles were periodically applied. The magnitude of the overload was 1.3 times the baseline load. For example, a baseline stress amplitude of 250 MPa was periodically followed by overload cycles of 325 MPa.

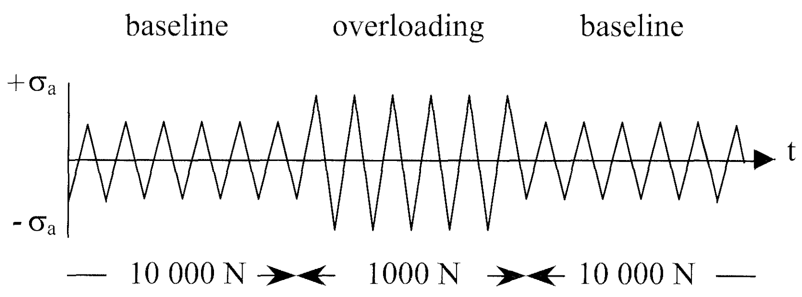


Figure 4: Load-time sequence in fatigue testing with periodic overload blocks (schematic)

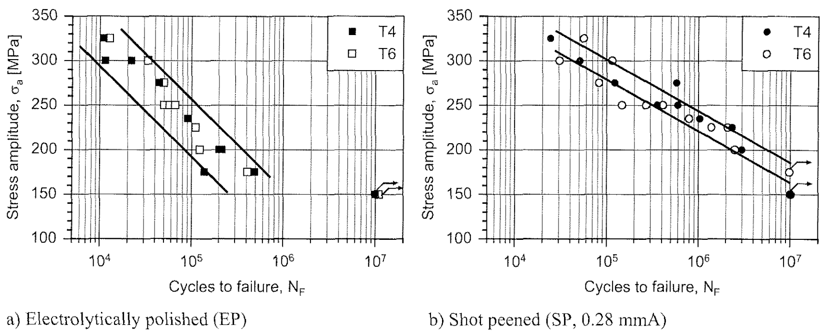


Figure 5: S-N curves (variable amplitude loading) in 2024 Al, rotating beam (R = -1), effect of aging

The fatigue response of the T4 and T6 tempers to the periodic overloads is illustrated in Fig. 5 comparing the fatigue performance of the electropolished reference (Fig. 5a) and shot peened (Fig. 5b) conditions. As in the constant amplitude tests, the baseline stress amplitude is plotted. In the electropolished reference, no significant differences in fatigue life between the two tempers T4 and T6 are seen (Fig. 5a). Thus, the constant amplitude fatigue performance of T6 is somewhat more affected by the periodic overloads than T4 (compare Fig. 5a with Fig. 3a). This less inferior response of the fatigue performance of T4 to periodic overloads is somewhat more pronounced in the shot peened condition (Fig. 5b, compare Fig. 5b with Fig. 3b). It is argued that the higher cyclic stability of the shot peening-induced residual compressive stresses in T4 owing to the materials cyclic hardening characteristics is still useful if periodic overloads occur. Cyclically stable residual compressive stresses will lead to reduced growth rates of microcracks thus, improving fatigue life [9].

4 References

[1] H. Wohlfahrt, Shot Peening (Eds.: H. Wohlfahrt, R. Kopp and O. Vöhringer) DGM (1987) 563.

[2] R. Schreiber, H. Wohlfahrt and E. Macherauch, Arch. Eisenhüttenwes. 48 (1977) 653.

[3] T. Hirsch, O. Vöhringer and E. Macherauch, Shot Peening (H. O. Fuchs, ed.) American Shot Peening Society (1984) 90.

[4] T. Dörr, M. Hilpert, P. Beckmerhagen, A. Kiefer and L. Wagner, Shot Peening (A. Nakonieczny, ed.) IMP (1999) 153.

[5] P. Skočovský, P. Palček, R. Konečná, L. Várkoly, Konštrukčné materiály, ŽU v Žiline, EDIS (2000) 167.

[6] W. Schütz, Shot Peening (H. O. Fuchs, ed.) American Shot Peening Society (1984) 166.

[7] T. Dörr, Dr.-Ing. dissertation, BTU Cottbus (2000)

[8] L. Wagner and C. Müller, J. Materials Manufacturing & Processing (1992) 423.

[9] J. K. Gregory and L. Wagner, LCF 3, Elsevier Applied Science (1992) 588.