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INFLUENCE OF SHOT PEENING ON FATIGUE PERFORMANCE OF HIGH-STRENGTH ALUMINUM- AND MAGNESIUM ALLOYS

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ABSTRACT

Shot peening was performed on 2024 Al and the magnesium alloy AZ 80 using various peening media (cast steel, spherically conditioned cut wire, ceramic and glass beads) and various Almen intensities. Fatigue performance of both alloys was found to depend mainly on Almen intensity, independent of the particular peening medium. While the fatigue life of 2024 Al strongly increased with Almen intensity and then reached a saturation value, the magnesium alloy showed a pronounced overpeening effect, i.e., a marked fatigue life improvement at low Almen intensities followed by a severe drop in fatigue life as Almen intensity increased. The results are explained in terms of the sensitivity of the different materials to surface damage affecting both fatigue crack nucleation and microcrack propagation.

KEY WORDS

aluminum alloys, magnesium alloys, fatigue crack nucleation, overpeening effect

INTRODUCTION

Magnesium alloys possess the lowest density of all structural metallic materials having about one quarter of the density of steel and roughly two thirds that of aluminum alloys. By substituting magnesium alloys for these metals, many structural parts can be substantially reduced in weight [1]. Particularly the automotive industry is highly interested in using magnesium alloys either as castings, e.g., for engine or transmission housings or as wrought alloys for body sheets. For these applications, stiffness and fatigue performance are of primary interest. Although the beneficial effect of mechanical surface treatments on fatigue performance of steels and aluminum alloys [2, 3] is well documented, there is little information on the influence of mechanical surface treatments on fatigue performance of magnesium alloys [4, 5]. Therefore, the present investigation is aimed at optimizing fatigue behavior of the magnesium alloy AZ 80 by suitable shot peening treatments. Since previous work [5 - 7] has indicated that magnesium by suitable shot peening treatments. Since previous work [5 - 7] has indicated that magnesium alloys can respond critically to a shot peening treatment, in the present investigation typical process parameters, namely peening medium and Almen intensity, are varied over a wide range. For comparison, similar tests were performed on the high-strength 2024 aluminum alloy.

EXPERIMENTAL

Both the magnesium alloy AZ 80 (nominal composition: 8.5 Al, 0.5 Zn, 0.2 Mn, balance: Mg) and 2024 Al (4.6 Cu, 1.3 Mg, 0.6 Mn, balance: Al) were received as extrusions. The magnesium alloy was tested in the as received condition. Specimens were taken in extrusion direction.

From the aluminum alloy blanks were taken perpendicular to the extrusion direction (TD). The material was solution treated at 495°C for 1h, water quenched and naturally aged at room temperature for at least 5 days (T4). Tensile properties of the two alloys are listed in Table 1.

Table 1: Tensile properties of 2024 Al and AZ 80

	$\sigma_{0.2}$ [MPa]	UTS [MPa]	El [%]	RA [%]
2024 Al (T4)	290	455	15.8	26
AZ 80, as rec.	225	350	9.3	12

For fatigue testing, hour-glass shaped cylindrical specimens (5 mm gage diameter) were prepared. After machining, about 100µm was removed from the surface of the specimens by electrolytical polishing to ensure that any machining effect that could mask the results was absent. This electrolytically polished condition (**EP**) is taken as the reference.

Shot peening (**SP**) was performed with an injector type machine using spherically conditioned cut wire **SCCW 14** (carbon steel), **SCCWS 23** (stainless steel), cast steel shot **S 330**, ceramic shot **Z 600** (zirconia fused beads) and **glass beads** (MGL).

The properties of the various peening media are given in Table 2.

The Almen intensity was varied between 0.03 and 0.90 mmN. Some shot peened specimens were polished afterwards to reduce the process-induced roughness. Surface roughness was measured by a profilometer.

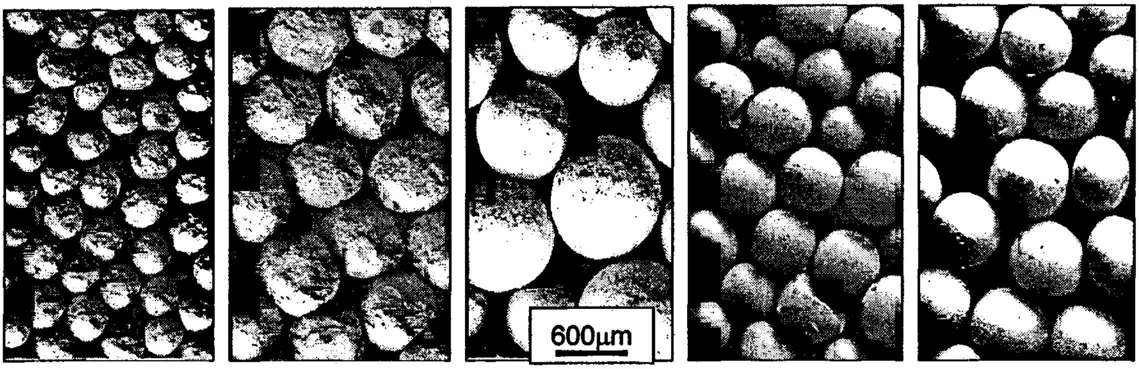
Fatigue tests were performed under ambient conditions under rotating beam loading (R=-1) at a frequency of about 60 Hz. Fracture surfaces were studied by SEM.

Table 2: Properties of the various peening media

peening medium	composition (wt%)	Average diameter (mm)	hardness HV 1	density (g·cm^{-3})
SCCW 14, spherically conditioned cut wire, carbon steel	0.57 C, 0.22 Si, 0.67 Mn; P, S ≤ 0,25	0.36	610	7.6
SCCWS 23, spherically conditioned cut wire, stainless steel	17.8 Cr, 8.6 Ni, 0.33 Si, 1.2 Mn	0.60	640	7.6
S 330, cast steel	0.90 C, 0.1 Si, 0.4 Mn; P, S ≤ 0,05	0.80	460	7.4
Z600, zirconia fused beads	67% ZrO_2, 30% SiO_2, 3% others	0.60	710	3.9
Glass beads, Ballotini MGL	70% SiO_2, 10% CaO, 15%Na_2O+K_2O, 5% MgO	0.66	47 (HRC)	2.5

RESULTS AND DISCUSSION

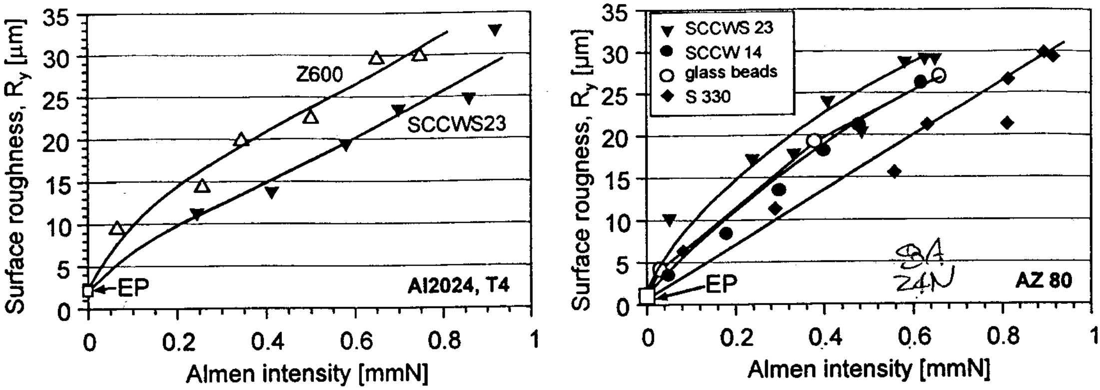
SEM micrographs of the various shot peening media are shown in Fig. 1. Both kinds of spherically conditioned cut wire SCCW 14 (Fig. 1a) and SCCWS 23 (Fig. 1b) exhibit the typical slight deviations from a perfect circular shape owing to the manufacturing process. In comparison, S 330 (Fig. 1c), Z600 (Fig. 1d) and glass beads (Fig. 1e) exhibit a perfect circular shape.



a) SCCW 14 b) SCCWS 23 c) S 330 d) Z600 e) Glass beads

Fig. 1: SEM micrographs of the various shot peening media

The effect of Almen intensity on maximum surface roughness R_y is shown in Fig. 2. For both 2024 Al (Fig. 2a) and AZ 80 (Fig. 2b), the surface roughness clearly increases with Almen intensitiy. For a given Almen intensity, peening 2024 Al with Z 600 leads to roughness values significantly higher than after peening with SCCWS 23 (Fig. 2a), presumably caused by the greater hardness of the ceramic medium. Peening AZ 80 with S 330 resulted in the lowest roughness (Fig. 2b) which may be the result of both largest shot size and lowest hardness. For a given shot peening treatment, the induced surface roughness in AZ 80 is higher than in 2024 Al (compare Fig. 2b with Fig. 2a) owing to the lower strength of the magnesium alloy (Table 1).



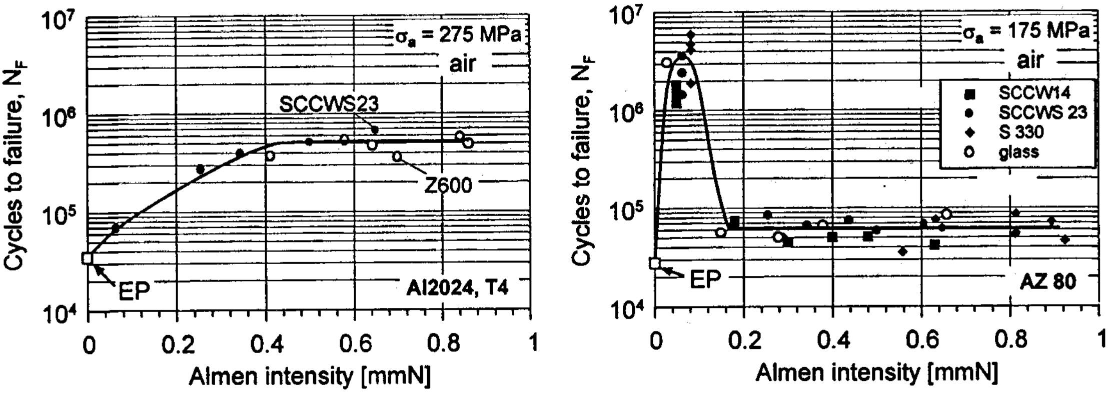
a) 2024 Al

b) AZ 80

Fig. 2: Effect of Almen intensity on surface roughness for various peening media

The effect of peening medium and Almen intensity on fatigue life is shown in Fig. 3. Starting with the electropolished reference, the fatigue life in 2024 Al at a constant stress amplitude of σ_a = 275 MPa gradually increases with increasing Almen intensity and reaches saturation at about 0.5 mmN Almen intensity (Fig. 3a). For the stress amplitude chosen, the fatigue life increases by roughly one order of magnitude. Despite differences in surface roughness, no significant difference in fatigue performance was found between SCCWS 23 and Z 600 (compare Fig. 3a with Fig. 2a).

As seen in Fig. 3b, the magnesium alloy AZ 80 responds differently to shot peening. Starting with the reference EP, the fatigue life at a stress amplitude of σ_a = 175 MPa first dramatically increases by roughly two orders of magnitude, then drops drastically as peening intensity increases. Similarly to 2024 Al, fatigue life depends on Almen intensity, irrespective of the particular peening medium (compare Fig. 3b with Fig. 3a)

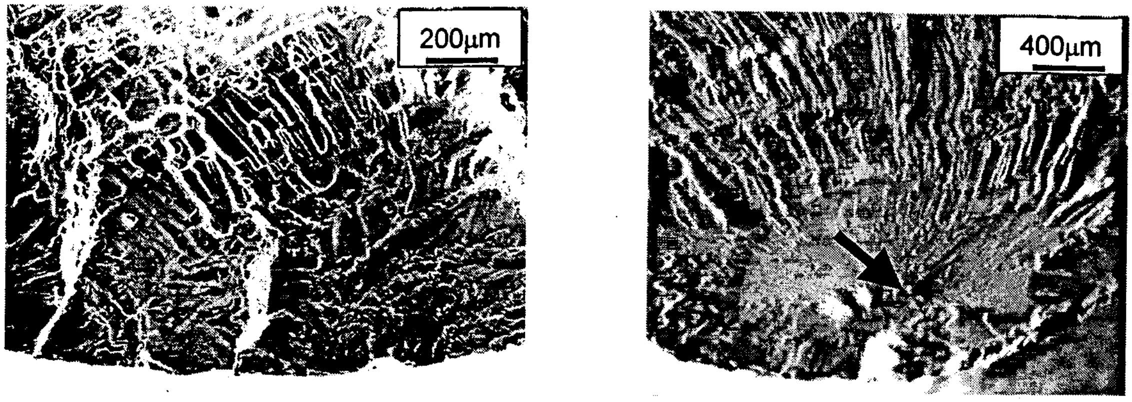


a) 2024 Al

b) AZ 80

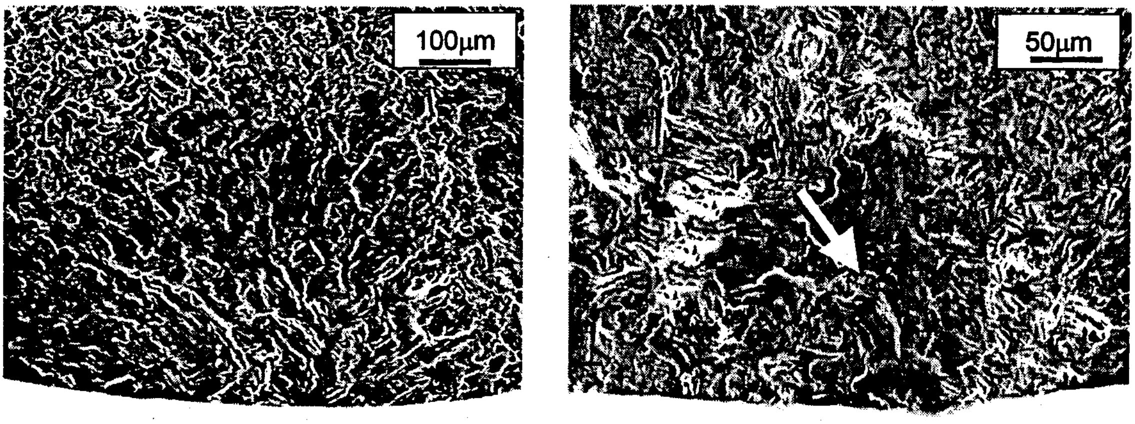
Fig. 3: Fatigue life in rotating beam loading, effect of Almen intensity

Fracture surfaces of the fatigue tested specimens of 2024 Al are shown in Fig. 4. Fatigue crack nucleation occured at the surface for the electropolished reference (Fig. 4a) as well as for specimens peened at low intensity. The crack nucleation site in shot peened specimens shifted to subsurface regions as fatigue life reached saturation (Fig. 4b). Therefore, differences in surface roughness had no effect on fatigue performance in shot peened (> 0.5 mmN) 2024 Al.



a) at surface (EP) b) subsurface (SP, 0.65 mmN)

Fig. 4: Fatigue crack nucleation sites in 2024 Al (SEM)



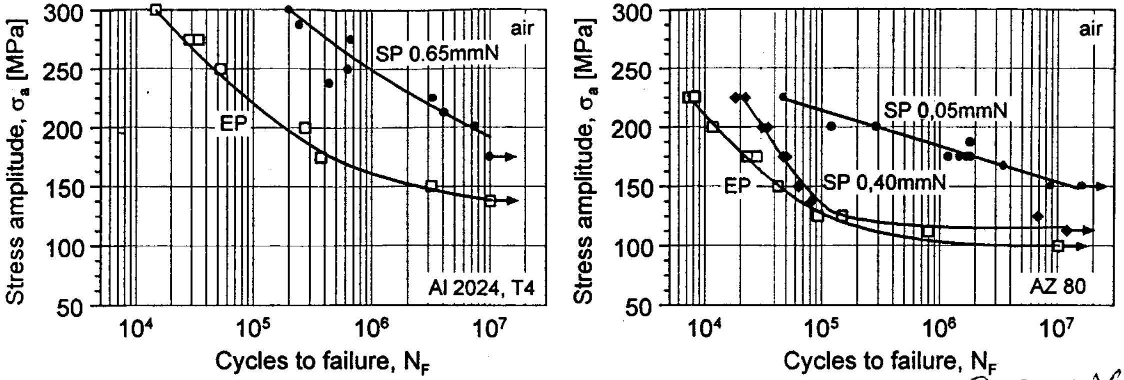
a) at surface (EP) b) subsurface (SP, 0.05 mmN)

Fig. 5: Fatigue crack nucleation sites in AZ 80 (SEM)

As seen in Fig. 5b, subsurface fatigue crack nucleation was also found in shot peened specimens of the magnesium alloy AZ 80 under optimum peening conditions (0.05 mmN), resulting in the highest fatigue life (Fig. 3b), while crack nucleation at the surface was observed for the reference EP (Fig. 5a) as well as on all specimens peened to higher intensities resulting in a severe drop of fatigue life (Fig. 3b).

Despite the absence of an aggressive environment in the material interior, fatigue cracks under optimum peening conditions nucleate for both 2024 Al and AZ 80 below the surface, where residual tensile stresses are present which balance the outer compressive stress field [8].

S-N curves for 2024 Al and AZ 80 are shown in Fig. 6 comparing the electropolished reference with optimum peened conditions. For 2024 Al (Fig. 6a), optimum shot peening increases the fatigue life for all stress amplitudes tested by rougly one order of magnitude. For AZ 80 (Fig. 6b), optimum shot peening (0.05 mmN) increases the fatigue life by roughly two orders of magnitude in the HCF-regime. However, heavier (0.40 mmN) shot peening leads to a marked detereoration of the fatigue performance as compared to optimum shot peening (Fig. 6b). As described above, this increase in Almen intensity from 0.05 to 0.40 mmN shifted the fatigue crack nucleation site in AZ 80 from subsurface regions to the surface. Presumably, the limited deformability of the hexagonal crystal structure of the magnesium alloy leads to the development of critical microcracks during heavier shot peenning and thus, to crack growth from the surface into the interior. No such sensitivity to Almen intensity was observed on 2024 Al owing to the much greater deformability by slip of the fcc crystal structure.



a) 2024 Al

b) AZ 80

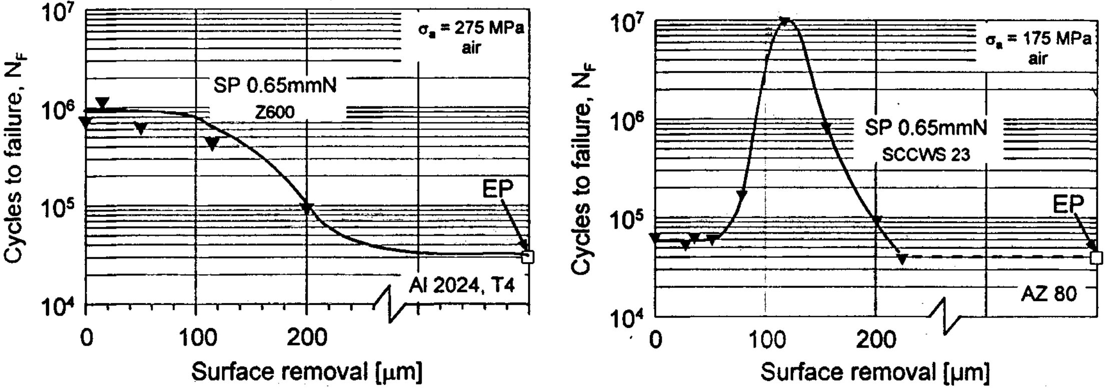
OVERPEENING

Fig. 6: S-N curves in rotating beam loading, effect of shot peening

The effect of polishing heavily shot peened specimens on the fatigue performance is shown in Fig. 7. To remove all peening-induced microcracks, dents and overlaps, a surface removal of 50 µm and 100 µm was found to be sufficient for 2024 Al and AZ 80, respectively. While the fatigue performance of shot peened 2024 Al was not improved by polishing (Fig. 7a), the magnesium alloy AZ 80 showed a dramatic lifetime improvement after removing roughly 100 µm from the as-peened surface (Fig. 7b). As shown in Fig. 8, polishing heavily shot peened specimens of AZ 80 shifted the fatigue crack nucleation site from the surface (Fig. 8a) back to subsurface regions (Fig. 8b).

NO IMPROVEMENT

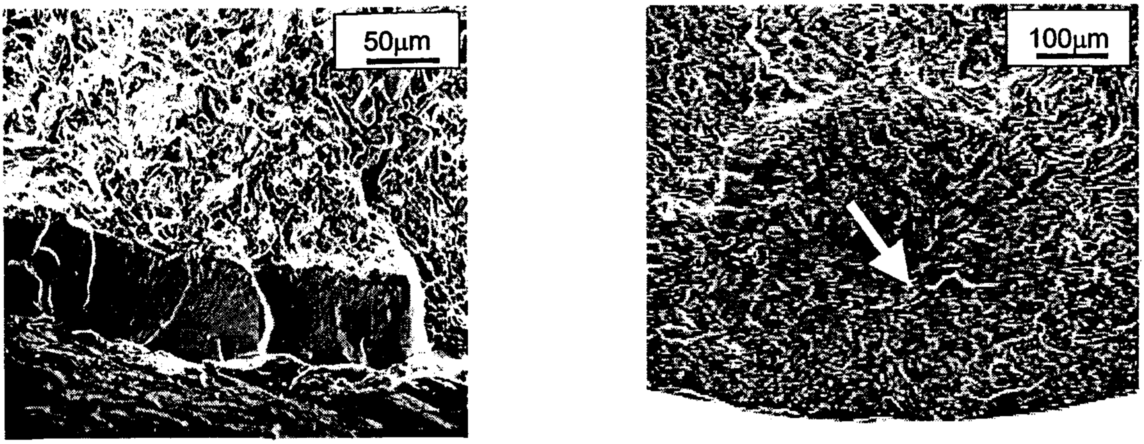
OPTIMAL REMOVAL



a) 2024 Al

b) AZ 80

Fig. 7: Fatigue life after heavy shot peening, effect of surface removal

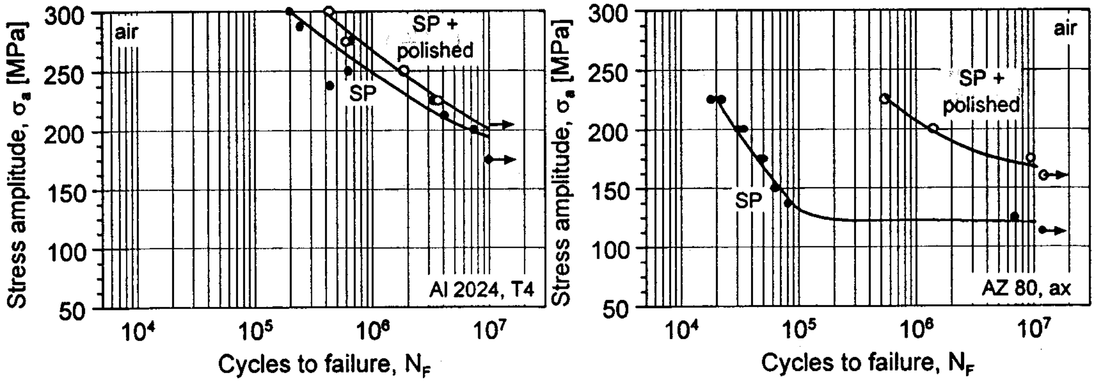


a) as peened

b) after additional polishing

Fig. 8: Fatigue crack nucleation sites in AZ 80 after heavy shot peening, effect of surface removal

S-N curves for 2024 Al and AZ 80 are shown in Fig. 9 illustrating the effect of polishing after heavy shot peening. While the fatigue performance of 2024 Al (Fig. 9a) was hardly changed, polishing heavily shot peened AZ 80 markedly increased fatigue performance (Fig. 9b). The fatigue performance of polished heavily shot peened AZ 80 is even superior over that of the optimum lightly (0.05 mmN) peened condition (compare Fig. 9b with Fig.6b)



a) 2024 Al

b) AZ 80

Fig. 9: S-N curves in rotating beam loading, effect of polishing after heavy shot peening (0.65mmN)

SUMMARY

Unlike aluminum alloys, magnesium alloys respond quite critically to a shot peening treatment presumably owing to their hexagonal crystal structure, which allows only very limited room temperature deformability by slip.

Provided that very low Almen intensities are used, shot peening can markedly improve the fatigue performance of magnesium alloys under ambient conditions, irrespective of the peening medium. Heavy peening results in significant life improvements only if the process-induced microcracks are removed by additional polishing.

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REFERENCES

[1] Aune, T.K., Westengen, H., Mechanical Properties of Pressure Die Cast Mg-Alloys, Magnesium Alloys and their Applications (B.L. Mordike, and F. Hehmann, eds.), DGM, 221-228, 1992.

[2] T. Dörr and L. Wagner: S-N Behavior of Prefatigued 2024 Al: Effects of Surface Crack Length and Shot Peening, Fatigue '96, (G. Lütjering and H. Nowack, eds.) Pergamon Press (1996) 1391.

[3] T. Dörr and L. Wagner: Effect of Shot Peening on Residual Life of Fatigue Pre-damaged 2024 Al, 6th Int. Conf. on Shot Peening (J. Champaigne, ed.) (1996) 174.

[4] Deiseroth, D., Zinn, W., Scholtes, B., Consequences of Mechanical Surface Treatments on Near-Surface Properties of Mg-Alloy AZ 31, Magnesium Alloys and Their Applications (B. L. Mordike and K. U. Kainer, eds.) DGM, 409-414, 1998.

[5] Hilpert, M., Wagner, L., Effect of Mechanical Surface Treatments on The Fatigue Behavior of the High-Strength Magnesium Alloy AZ 80, Magnesium Alloys and Their Applications (B.L. Mordike and K.U. Kainer, eds.), DGM, 271-276, 1998.

[6] Hilpert, M., Wagner, L., Corrosion Fatigue Behavior of the High-Strength Magnesium Alloy AZ 80, Light-Weight Alloys for Aerospace Applications V (E.W. Lee, W. Frazier, K. Jata and N.J. Kim, eds.), TMS, 1999.

[7] Hilpert, M., Wagner, L., Mechanical Surface Treatments on High-Strength Magnesium Alloys for Fatigue Life Improvements, Automotive Alloys III (S.K. Das, ed.), TMS, 1999.

[8] Wagner, L., Fatigue Life Behavior of Titanium Alloys, ASM Handbook Vol. 19, Fatigue and Fracture, 839, 1996.