SHOT PEENING OF EXTRUDED MAGNESIUM AND ALUMINUM ALLOYS FOR TRANSPORTATION

Lothar Wagner and Matthias Hilpert
Chair of Physical Metallurgy and Materials Technology
Technical University of Brandenburg at Cottbus, 03013 Cottbus, Germany

ABSTRACT

The fatigue behaviour of the extruded magnesium alloys AZ31 and AZ80 as well as aluminum alloys Al 6005 and Al 6082 was investigated. Owing to the anisotropy of the hcp crystal structure of magnesium, the marked crystallographic textures in the extrusions of AZ31 and AZ80 lead to pronounced directional mechanical properties in tensile and cyclic loading with strength values in extrusion direction being significantly superior to those perpendicular to the extrusion direction. As a result of the more isotropic properties of the fcc crystal structure, no marked directionality in mechanical peoperties was found in the Al 6005 and Al 6082 extrusions. Shot peening was found to improve the fatigue performance of both magnesium and aluminum alloys. unlike the aluminum alloys, the magnesium alloys showed a marked overpeening effect.

INTRODUCTION

The weight reduction of automobile is one of the most effective ways in improving fuel consumption since the resistances of a vehicle to rolling, climbing and acceleration are directly dependent on vehicle mass. Therefore, the application of magnesium alloys which density is only roughly 25% that of steel and 66% that of aluminum is expected to substantially increase in this decade. While for a limited number of vehicle components cast magnesium alloys are already in production such as materials for transmission gearbox housings, seat frames and steering wheels, both cast and wrought magnesium alloys are potential condidates for many further applications, e.g., as materials for body and suspension components where they can largely substitute steels and even aluminum alloys [1,2].

For these automotive applications, the fatigue performance is of particular importance [3-7]. The aim of this investigation was to outline potential improvements of the fatigue performance of wrought magnesium alloys by shot peening. Results on shot peened magnesium alloys AZ31 and AZ80 are compared and contrasted with those of the aluminum alloys A1 6005 and A1 6082.

EXPERIMENTAL

The wrought magnesium alloys AZ31 (nominal composition in weight percent: 3Al. 0.8Zn, 0.2Mn, balance: Mg) and Az80 (8Al, 0.5Zn, 0.2Mn, balance Mg) were received as extrusions from Otto Fuchs Metallwerke, Meinerzhagen, Germany. The rectangular bars had cross sections of 100 x 20 mm (extrusion ratio, ER:13) and 110 x 70 mm (ER:9) for AZ31 and AZ80, respectively. Both magnesium extrusions were tested in the as-fabricated conditions. The extruded aluminum alloy Al 6082 (1Mg, 1Si, 0.6Mn, balance Al) with the dimension 85x25mm (ER: 12) was also received from Otto Fuchs Metallwerke while the aluminum alloy Al 6005 (0.5Mg, 0.7Si, balance Al) with the dimension 105 x 8 mm was received from TULE, Ludwigsfelde, Germany. Both aluminum extrusions were tested in the peak-aged (T6) conditions. Specimens of the various extrusions were machined with the load axis parallel to the extrusion (L) direction as well as in the long transverse (T) direction (Fig.1). Tensile test results on the various alloys are listed in Table 1.

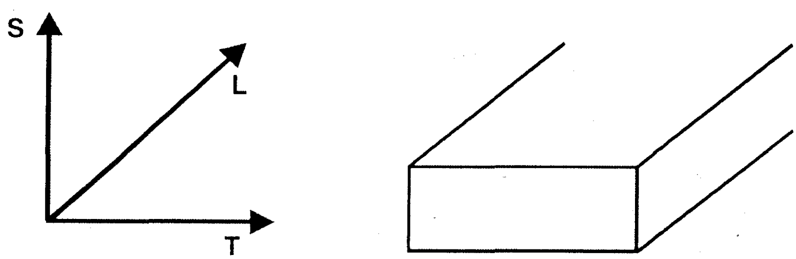


Fig.1. As-received extrusions (L: longitudinal, T: long transverse, S: short transverse directions, schematic)

Table 1. Tensile test results on the various extrusions

Material	Testing direction	$\sigma_{0.2}$(MPa)	UTS (MPa)	El (%)	RA (%)
AZ31	L	210	280	15	26
	T	140	255	11	12
AZ80	L	245	340	12	14
	T	140	200	3	6
Al 6005 T6	L	280	325	18	55
	T	265	305	13	54
Al 6082 T6	L	340	365	12	42
	T	320	340	10	38

Crystallographic textures were determined by X-ray diffraction using Ni-filtered Cu-K_α radiation and are shown as (0002) and (111) pole figures for the magnesium and aluminum alloys, respectively. Tensile tests were performed on threaded cylindrical specimens having gage lengths of 20mm. The initial strain rate was $8.3 \times 10^{-4}s^{-1}$. For fatigue testing, hourglass shaped round specimens (5mm gage diameter) were machined. After machining, about 200 μm were removed from the surface of the specimens by electrolytical polishing(EP) to ensure that any machining effect that could mask the results was absent. This electropolished condition was taken to serve as reference.

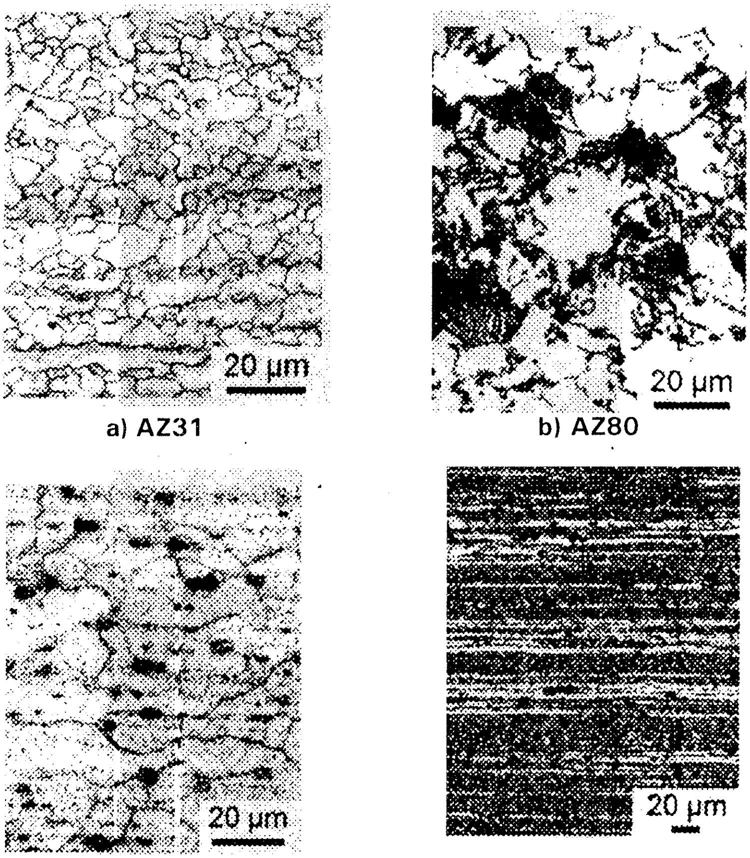
Shot peening(SP) was performed with an injector type machine using spherically conditioned cut wire SCCW14 (0.36 mm average shot size). During the peening treatment, the specimens rotated at 1/s. The distance between nozzle tip and specimen surface was 45 mm.

After shot peening, the change in surface layer properties was determined by profilometry, microhardness measurements and X-ray measurements and was evaluated by surface roughness profiles, depth profiles of microhardness, half width breadths, and residual macrostresses.

Fatigue tests were performed in rotating beam loading($R = -1$) at frequencies of about 60 Hz in ambient air.

RESULTS AND DISCUSSION.

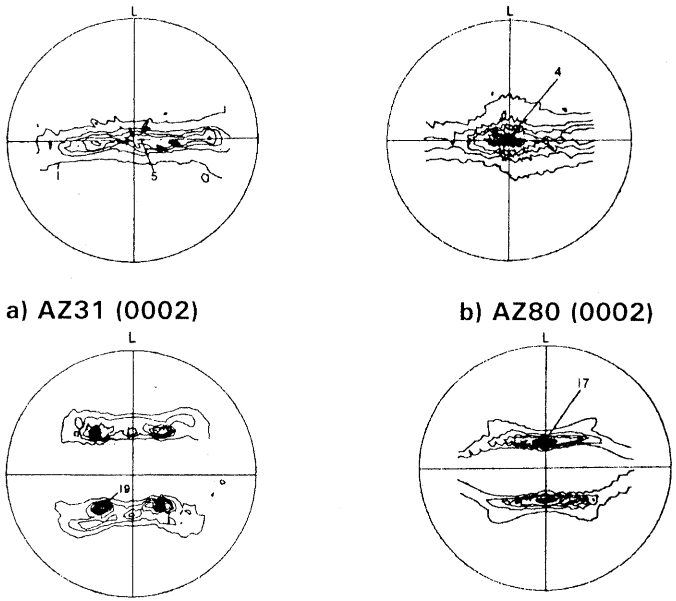
The microstructures of the various alloys are shown in Fig.2. The average α-grain size is roughly 10μm in AZ31 (Fig.2a) and about 30μm in AZ80 (Fig.2b). For AZ80, a discontinuous precipitation of $Mg_{17}AL_{12}$ is clearly seen by optical microscopy (Fig.2b). The average grain size is about 25μm in Al 6005 (Fig.2c) and roughly 10μm in Al 6082 (Fig.2d)



c) Al6005 d) Al6082

Fig.2. Microstructures of the various extrusions

The pole figures of the various magnesium and aluminum alloys are illustrated in Fig.3. Most of the hexagonal magnesium grains in the as-fabricated extrusion of AZ80 (Fig.3a) are oriented with the basal planes parallel to the extrusion direction and normal to te surface of the extrusion. No significant difference was found for the pole figure of AZ31 (Fig.3b). Most grains in the Al 6005 are oriented with the (111) planes in the L-T plane tilted by 25^0 to 30^0 in L-direction (Fig.3c). No significant difference was found for the pole figure of Al 6082 (Fig.3d). For both magnesium alloys AZ31 and AZ80, the yield stresses $\sigma_{0.2}$ perpendicular to the L-direction are only 60% of the corresponding values in L-direction (Table 1). Plastic deformation in T-direction occurs more readily than in L-direction since basal planes experience large shear stresses by loading in T-direction, while hardly any shear stresses act on basal planes for loading in L-direction (Fig.3a). For both aluminum alloys Al6005 and Al6082, much smaller differences in tensile properties between L- and T-directions were found (Table 1) since the mechanical properties in a fcc crystal structure are much less directional than in a hcp crystal structure.

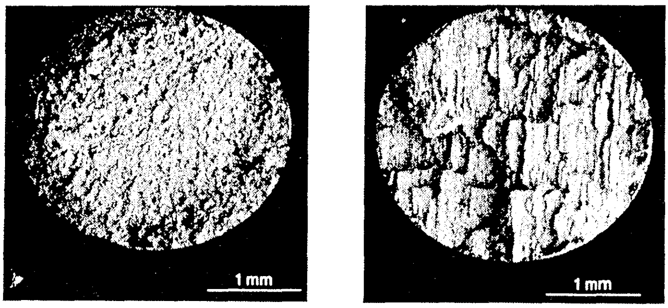


a) AZ31 (0002) b) AZ80 (0002)

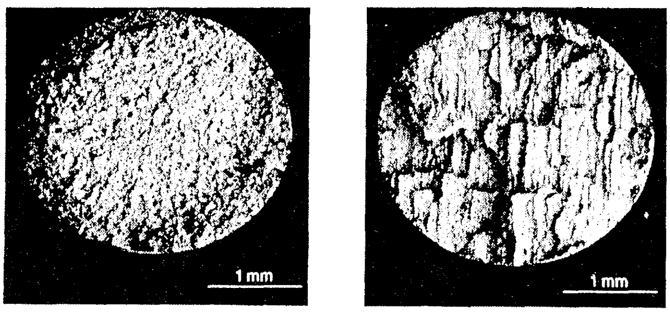
c) Al 6005 (111) d) Al 6082 (111)

Fig.3 Pole figures of the various extrusions

Examples of typical fracture surfaces of the magnesium and aluminum alloys are illustrated in Fig.4. By loading in L-direction, the tensile fracture surface of AZ80 appears fairly homogeneous (Fig.4a) while the fracture surface is rough and terraced by loading T-direction (Fig. 4b). The latter is caused by tension perpendicular to the second phase stringers in the extrusion which also leads to lower ductility values (Table 1). Similar differences in fracture appearance between L- and T- directions were observed in AZ31. Typical tensile fracture surfaces of the aluminum extrusions are shown in Figs. 4c and 4d. No marked differences in fracture appearance were found in Al 6082 between L-direction(Fig.4c) and T-direction (Fig.4d). Similar results were also found on Al 6005.



a) AZ80, load axis: L   b) AZ80, load axis: T



c) Al 6082, Load axis: L   d) Al 6082, Load axis: T

Fig.4. Fracture surfaces of the various extrusions

The S-N curves of the various alloys inthe electropolished reference conditions are given in Fig.5. As expected, the 10^7 cycles fatigue strength of both extruded magnesium alloys AZ31 (Fig.5a) and AZ80 (Fig.5b) in L-direction are markedly higher than in T-direction. In comparison differences in S-N curves between L-direction and T-direction were much smaller in the aluminum extrusions of Al 6005(Fig.5c) and Al 6082 (Fig.5d)

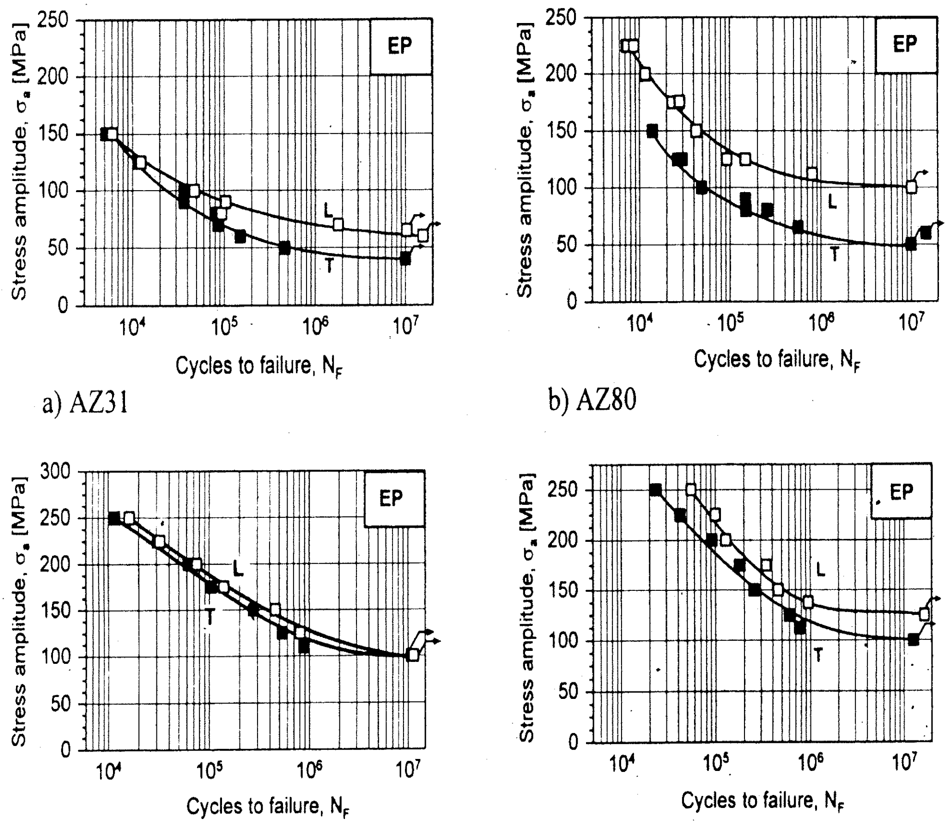
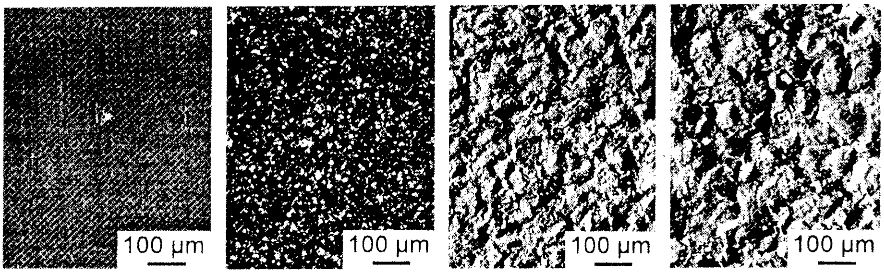


Fig.5. S-N curves (R = -1) of the various extrusions (electrolytically polished reference)

In order to improve the fatigue performance of the various alloys, shot peening was utilized. Typical changes in surface topography of AZ80 due to shot peening are shown in Fig.6.

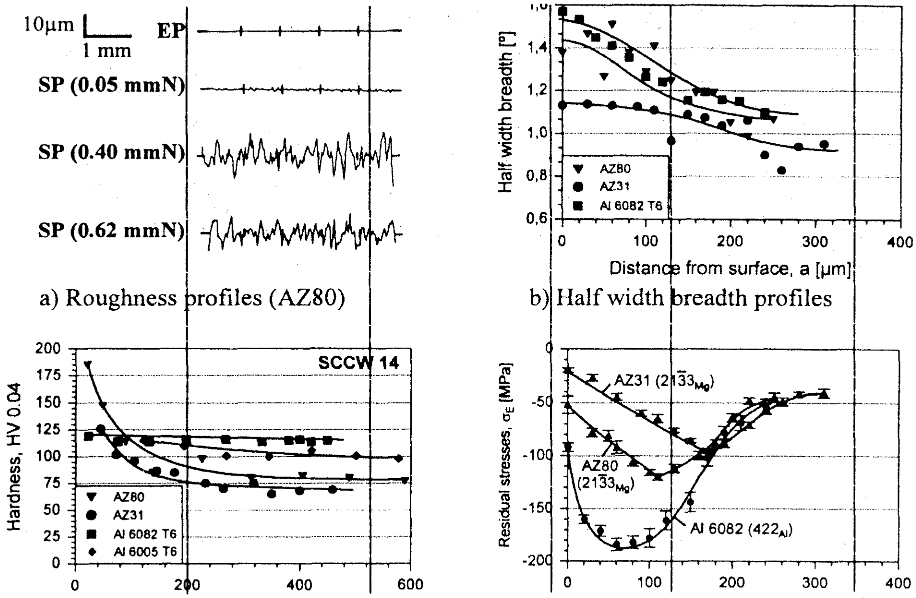


a) EP b) SP (0.05 mmN) c) SP (0.40 mmN). d) SP (0.62) mmN)

Fig.6. Surface topographies after shot peening (AZ80)

Depending on Almen intensity the surface topography is more or less drastically changed. This is also seen in Fig.7a where the roughness profile of the electropolished reference is compared with profiles after shot peening to various intensities. The half width breadth or x-ray interference lines taken as a measure of the total dislocation density shows maximum values at the surface with gradual decrease to the inferior of the materials (Fig.7b). The microhardness profiles after shot peening (Fig. 7c) illustrate workhardening in the surface layer with maximum values again at the surface. Compared to the magnesium alloys, the hardness increase is much less pronounced in the aluminum alloys presumably owing to the T6 heat treatment resulting in low work-hardening capacity. The residual stress profiles of the various alloys (Fig.7d) are characterized by residual compressive stresses in the surface layer with marked maximum values below the surface.

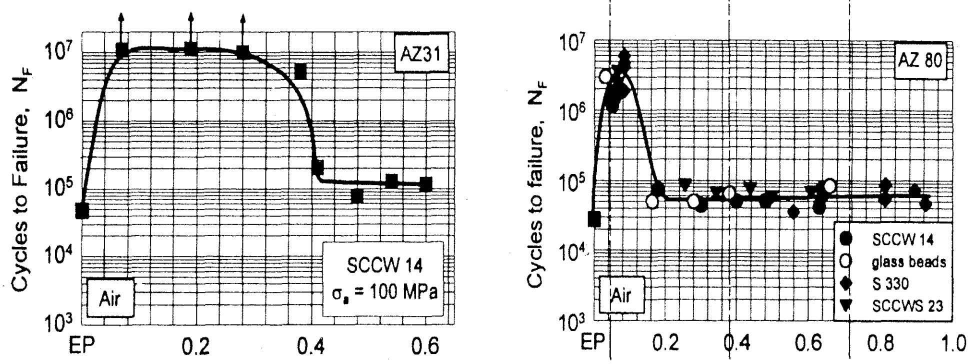
The effect of Almen intensity in shot peening on fatigue life of the magnesium alloys is given in Fig.8. The fatigue life at a stress amplitude of 100 MPa as function of Almen intensity is shown in Fig.8a for AZ31. Starting with the electropolished condition the fatigue life first dramatically increases and then drops drastically after peening with higher intensities. This strong overpeening effect was more pronounced in AZ80 tested at a stress amplitude of 175 MPa(Fig.8b)



a) Roughness profiles (AZ80) b) Half width breadth profiles

c) microhardness profiles d) Residual stress profiles

Fig.7. Surface layer poperties after shot peening.

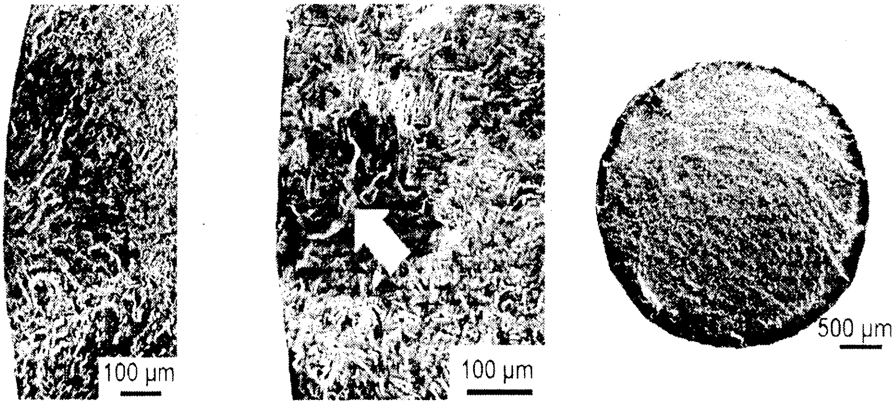


Almen intensity [mmN] Almen intensity [mmN]

a) AZ31 b) AZ80(*a = 175 MPa)

Fif.8. Fatigue life of the magnesium alloys vs. Almen intensity(L-direction)

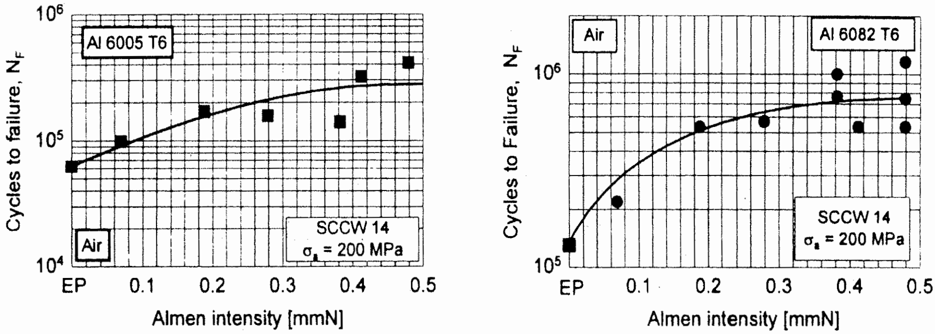
As seen in Fig.9, subsurface fatigue crack nucleation in AZ80 was found under optimum peening conditions(Fig.9b), while fatigue crack nucleated at the surface not only in the reference (Fig.9a) but also after peening with higher Almem intensities (Fig.9c).



a) at surface (EP) b) subsurface (SP, 0.05 mmN) c) at surface(SP,0.62 mmN)

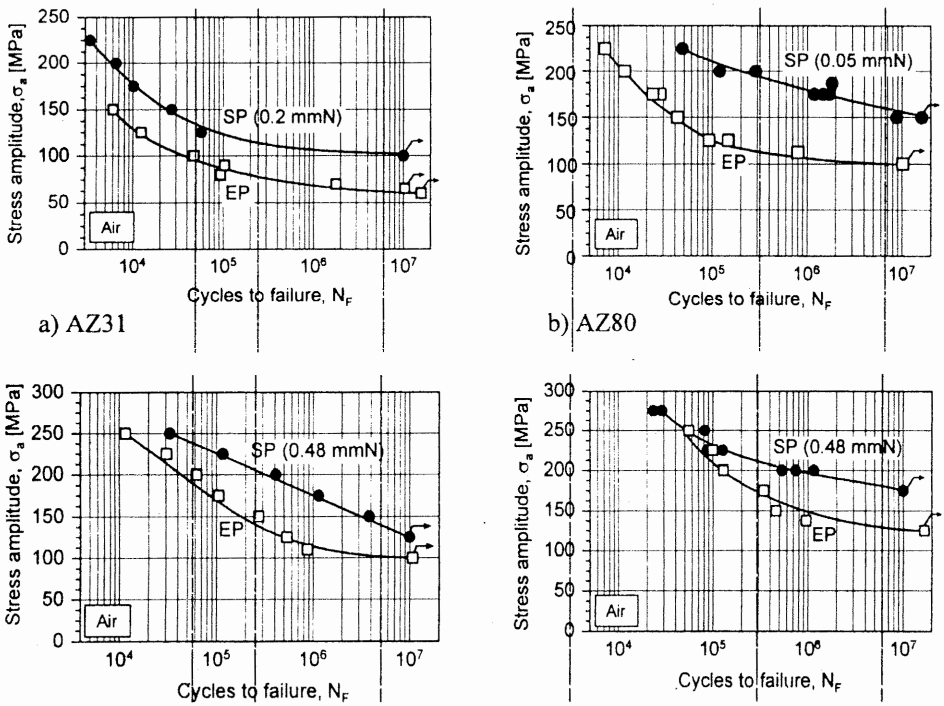
Fig. 9 Fatigue crack nucleation sites (SEM) in AZ80

Fig.9. Fatigue crack nucleation sites (SEM) in AZ80 The maximum in fatigue life is characterized by a shift in fatigue crack nucleation site from the surface to the interior [8-10]. Note that when fatigue cracks nucleates subsurface, crack nucleation as well as early crack propagation occur under vacuum conditions. Again this shift in crack nucleation site was independent of the particular peening medium used. Similar results were reported in earlier work[8]. With an increase in Almen intensity, a significantly higher number of fatigue cracks nucleation sites at the surface of magnesium alloys was found. In addition, numerous secondary cracks which were hindered to propagate were seen, particularly on specimens shot peened to higher intensities (Fig.9c), indicating a pronounced effect of surface roughness on the resistance to fatigue crack nucleation. Unlike the situation in the magnesium alloys no overpeening effect was found in aluminum alloys Fig.10. For both Al 6005 (Fig.10a) and Al 6082 (Fig.10b), there is a gradual increase in fatigue life with Almen intensity until saturation occurs (Fig.10b). No subsurface fatigue crack nucleation sites were observed in shot peened Al 6005 or Al 6082, irrespective of Almen intensity used[11-14].



a) Al 6005 b) Al 6082

Fig.10. Fatigue life of aluminum alloys vs Almen intensity (L-direction.



a) AZ31 b) AZ80

c) Al 6005 d) Al 6082

Fig.11. S-N curves (R = -1) of the varicus extrusions (L-direction). Effect of optimum shot peening

The S-N curves of the various alloys as tested in L-direction are shown in Fig.11 comparing the electropolished reference with optimum shot peened conditions. Both magnesium alloys AZ31 (Fig.11a) and AZ80 (Fig. 11b) respond to optimum shot peening with a pronounced improvement of the 10^7 cycles fatigue strength, particularly the higher strength alloy AZ80. In comparison, the fatigue life improvement in both aluminium alloys Al 6005 (Fig.11c) and Al 6082 (Fig.11d) was less marked. This is prresumably caused by the T6 heat treatment leading to cyclic softening and less stable residual compressive stresses[11].

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