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Shot Peening of Cast Magnesium Alloys

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1 Abstract

The fatigue behavior of the high-pressure die cast magnesium alloys AM50 and AZ91 was investigated. In both alloys, cast defects led to marked scatter in fatigue performance.

To study potential improvements in fatigue behavior, shot peening was performed using various Almen intensities. Both alloys showed marked improvements in fatigue strength compared to an electropolished reference.

2 Introduction

The weight reduction of automobiles is one of the most effective ways for 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 candidates 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 of both cast and wrought magnesium alloys is of particular importance [3, 4]. The aim of this investigation was to outline potential improvements of the fatigue performance of the high-pressure die cast magnesium alloys AM50 and AZ91 through shot peening.

3 Experimental

The cast magnesium alloys AM50 (5Al, 0.5Mn, balance: Mg) and AZ91 (9Al, 1Zn, 0.2Mn, balance: Mg) were received from Audi AG, Ingolstadt, Germany as high-pressure test bar die castings (Fig. 1). From these castings, specimens were taken from the round bars with a diameter of 10 mm.

Crystallographic textures were determined by X-ray diffraction and are shown as (0002) pole figures. Tensile tests were performed on cylindrical specimens having gage lengths and gage diameters of 20 and 4 mm, respectively. The initial strain rate was $8.3 \times 10^{-4} s^{-1}$. For fatigue testing, hourglass shaped specimens (5mm gage diameter) were machined.

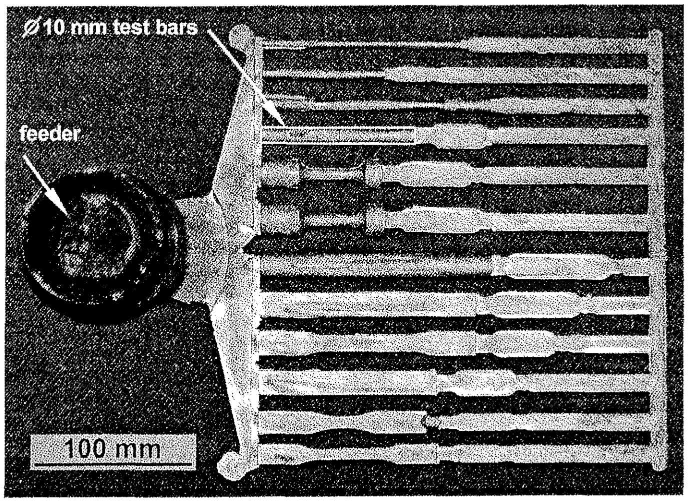


Figure 1: High-pressure die casting

After, machining, about 200 ìm 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.

Shot peening (SP) was performed with an injector type machine using spherically conditioned cut wire SCCW14 (0.36 mm average shot size). After shot peening, the change in surface layer properties was determined by profilometry and microhardness-depth profiles.

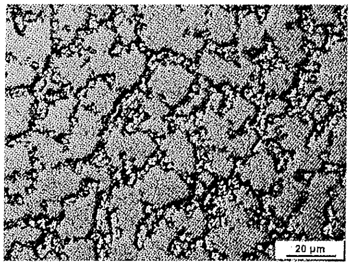
Fatigue tests were performed in rotating beam loading (R = -1) at frequencies of about 60 Hz in ambient air.

4 Results and Discussion

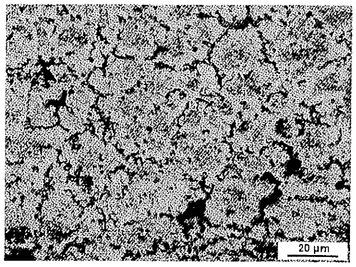
The microstructures of the high-pressure die cast magnesium alloys are shown in Figure 2. Both alloys AM50 (Fig. 2a) and AZ91 (Fig. 2b) are characterized by massive $Mg_{17}Al_{12}$ compound at the boundaries of small, cored grains. Presumably, the absence of precipitated discontinuous $Mg_{17}Al_{12}$ is the result of the rapid cooling during the high-pressure die casting process.

Typical pole figures of the cast alloys are illustrated in Figure 3. As expected, the basal planes are randomly oriented in AM50 (Fig. 3a) and AZ91 (Fig. 3b). As opposed to extruded alloys [5, 6] no directionality in properties is likely in cast alloys due to this random basal plane distribution.

Tensile properties of the alloys are illustrated in Table 1.

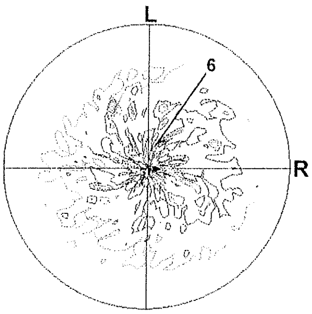


a) AM50

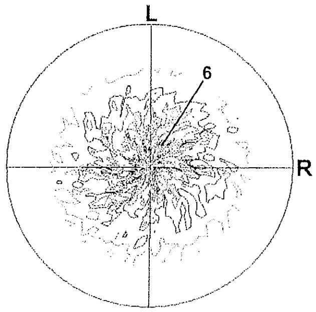


b) AZ91

Figure 2: Microstructure of the cast alloys



a) AM50



b) AZ91

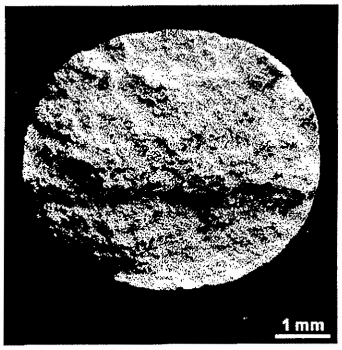
Figure 3: (0002) pole figure of the cast alloys

Table 1: Tensile properties of the high-pressure die cast magnesium alloys

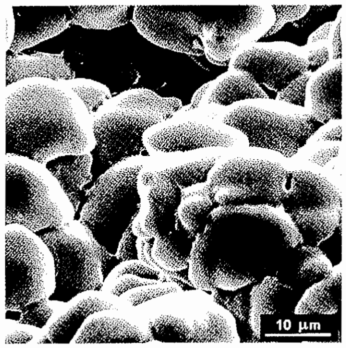
Material	$\sigma_{0.2}$ (MPa)	UTS (MPa)	El (%)	RA (%)
AM50	95	165	3	7.0
AZ91	125	170	2	3.5

Examples of typical fracture surfaces of the cast magnesium alloys are illustrated in Figure 4 and Figure 5. At high magnification, some degree of porosity was observed in both alloys AM50 (Fig. 4b) and AZ91 (Fig. 5b).

The amount of porosity markedly depended on the location from where the specimens were taken within the test bar [7] (Fig. 6). Close to the feeder, the amount of porosity was clearly higher than in regions far away from the feeder. Since two specimens were taken from each test bar, part of the specimens for mechanical tests had high amounts of porosity while others were fairly free of that (Fig. 6). Obviously, these cast defects are potential sites for fatigue crack nucleation during cyclic loading.

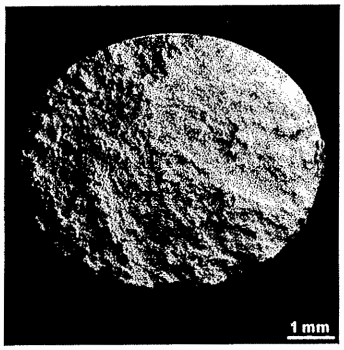


a) overview

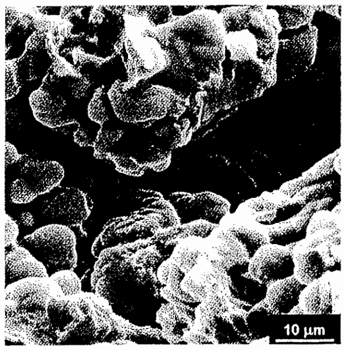


b) high magnification

Figure 4: Tensile fracture surfaces of the cast alloy AM50

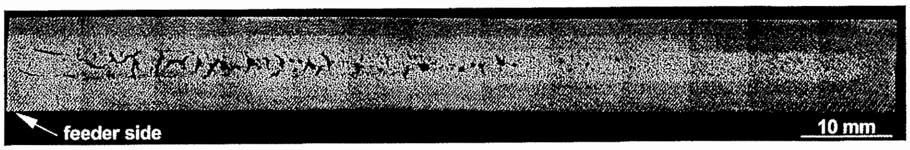


a) overview

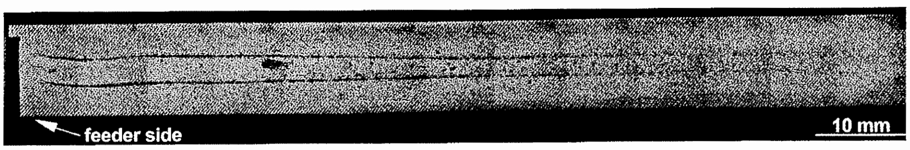


b) high magnification

Figure 5: Tensile fracture surfaces of the cast alloy AZ91



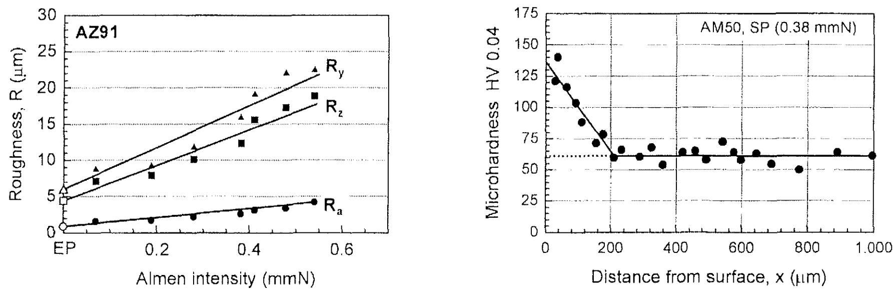
a) AM50



b) AZ91

Figure 6: Longitudinal cross sections of the Ø 10 mm test bars of the high-pressure die castings (compare with Fig. 1)

Typical changes in surface layer properties due to shot peening are shown in Figure 7. Shot peening (SP) drastically increases roughness. An example for the dependence of shot peening-induced roughness in AZ91 on Almen intensity is shown in Figure 7a.



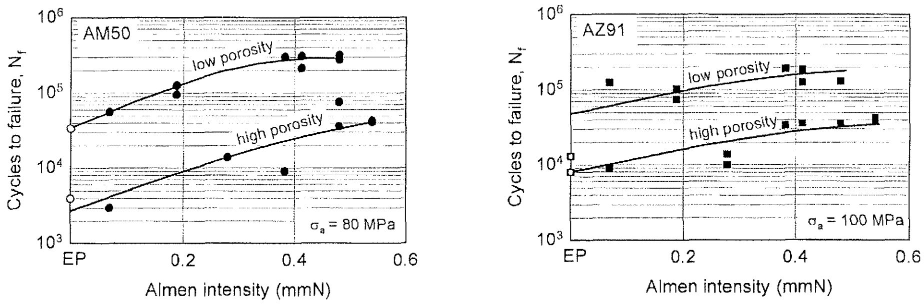
a) Roughness vs. Almen intensity

b) Microhardness-depth profile (SP, 0.38 mmN)

Figure 7: Surface layer properties after shot peening

Shot peening leads to marked increases in near-surface microhardness, particularly for AM50 (Fig. 7b), owing to pronounced work hardening (Table 1).

The effect of Almen intensity on fatigue life in rotating beam loading (R = –1) of both cast alloys is shown in Figure 8. For both alloys AM50 (Fig. 8a) and AZ91 (Fig. 8b), the data points can be assigned to two groups, i.e., specimens with low porosity and those with high porosity. On average, there is an order of magnitude difference in lifetime between these two groups (Fig. 8). For both groups, fatigue life steadily increases with an increase in Almen intensity.

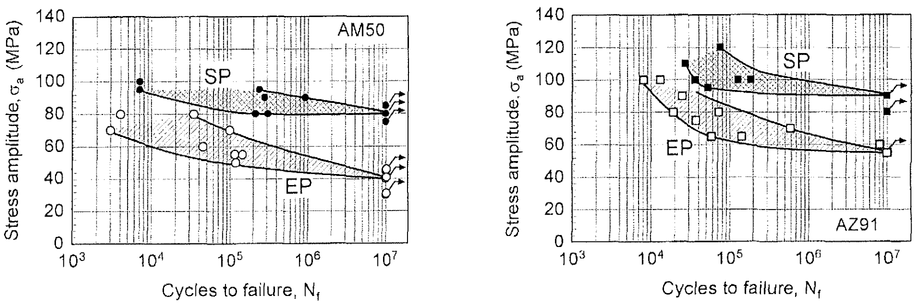


a) AM50

b) AZ91

Figure 8: Fatigue life (rotating beam loading, R = –1) vs. Almen intensity

The presented results can be summarized as follows: The change in fatigue performance of the high-pressure die cast magnesium alloys AM50 and AZ91 due to mechanical surface treatments depends on the process-induced surface topography, microhardness and residual stress profiles in near-surface regions. The process-induced residual compressive stresses can overcompensate the detrimental effect of surface roughness [8] since the fatigue life of shot peened specimens is higher than that of the electropolished reference (Fig. 9).



a) AM50

b) AZ91

Figure 9: S-N curves in rotating beam loading (R = −1)

Obviously, fatigue life extension by retardation of microcrack growth owing to the residual compressive stress field is greater than the reduction in fatigue life caused by earlier crack nucleation as a consequence of shot peening-induced higher surface roughness.

5 Acknowledgements

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6 References

[1] T.K. Aune and H. Westenhagen, Magnesium Alloys and their Applications, (Eds.: B. L. Mordike and F. Hehmann), DGM, 1992, 221.
[2] H. Friedrich and S. Schumann, Magnesium 2000, (Eds.: E. Aghion and D. Eliezer), MRI, 2000, 9.
[3] R. I. Stephens, C. D. Schrader and K. B. Lelase, J. Eng. Mater. Technol, 1995, 293.
[4] V. V. Ogarevic and R. I. Stephens, Ann. Rev., Mater. Sci., 1990, 141.
[5] M. Hilpert and L. Wagner, Journal of Materials Engineering and Performance, Vol.9, No. 4, 2000, 402.
[6] M. Hilpert, Dr.-Ing. thesis, Techn. Univ. of Brandenburg at Cottbus, Germany, 2001
[7] A. Wendt, Dipl.-Ing. thesis, Techn. Univ. of Brandenburg at Cottbus, Germany, 1998
[8] T. Dörr, M. Hilpert, P. Beckmerhagen, A. Kiefer and L. Wagner, Shot Peening, Present & Future, (Ed.: A. Nakonieczny), IMP, 1999, 153.