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Influence of Shot Peening on the Fatigue and Corrosion Behavior of the Die Cast Magnesium Alloy AZ91 hp

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1 Abstract

The influence of shot peening and corrosion on the fatigue behaviour of the magnesium die cast alloy AZ91 hp is studied. Investigations on as-cast fatigue specimens show that the endurance limit is significantly reduced by the presence of pores in the near surface region. This effect can be drastically reduced by shot peening, improving the endurance limit of porous material by about 100%. The fatigue behavior of a dense material can also be improved by shot peening, but the effect is rather small (in the order of 20 %). Fatigue experiments under corrosive conditions underline one of the main disadvantages of magnesium alloys, i.e. their pronounced sensitivity to contact corrosion. Iron contamination from steel shot drastically accelerates corrosion. After 3 h in a 5% NaCl solution, corrosion attack is comparable to that observed for polished surfaces after one week. As a consequence of the accelerated corrosion, shot peening with steel shot leads to a strong deterioration of the fatigue behavior, showing clearly the need for nonferrous shot or a careful cleaning of the shot peened surface.

2 Introduction

Increasing demand of light materials in automotive applications focuses interest on magnesium alloys. In load-bearing parts, magnesium alloys are not used to any significant degree due to the lack of information on the fatigue behavior under corrosive conditions.

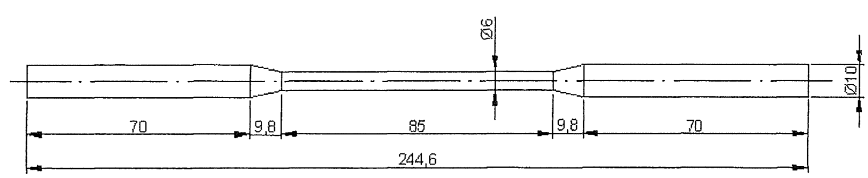
General information on corrosion and fatigue of magnesium and its alloys, is available in the open literature, see e.g. [1,2]. Mayer et al. [3] investigated the influence of salt-water on high-frequency fatigue tests of AZ91. In contrast to tests in ambient air, the high-pressure die cast alloy shows no fatigue limit in salt-water spray tests. Crack initiation takes place at porosity found on the surface. Pitting corrosion also reduces low cycle fatigue strength due to notch effects. The low-pressure die cast alloy shows a large scatter of fatigue strength due to crack initiation at casting defects. Fatigue strength values of pressureless die cast alloy are higher in ambient air than in sprayed saltwater. The same authors [4] investigated fatigue of AZ91 by ultrasonic testing. In salt water, pits are formed from which fatigue cracks initiate. No endurance limit was observed under these conditions. Ferguson et al. [5] used three-point bending tests to investigate fatigue of the alloy AM50 in air, in sprayed salt water and in laboratory water. Endurance fatigue limit values were similar (approx. 100 MPa) in the first two environments while low fatigue strength values and no fatigue limit were observed in water.

Schindelbacher and Rösch [6] investigated the mechanical properties of AZ91 as a function of wall thickness of die cast tubes. With increasing wall thickness, a linear decrease of tensile strength, yield strength and elongation to fracture was observed. Stephens et al. [7,8] studied corrosion fatigue of AZ91E-T6 in 3.5% sodium chloride. Fatigue lifetime is significantly decreased in comparison to tests in ambient air. Studying the growth of long cracks, corrosive environment is shown to clearly increase growth velocity. There is only little information available on the influence of shot peening on fatigue properties of magnesium alloys. Wagner [9] showed a considerable improvement of the endurance limit by shot peening of the alloy AZ 80, but the influence of an aggressive environment was not investigated in detail.

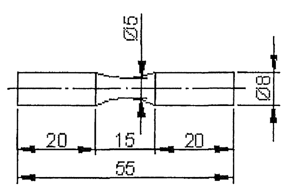
3 Experimental

Cylindrical specimens with dimensions shown in Fig.1a of the magnesium alloy AZ91 hp (nominal composition in wt %: 8.8 Al, 0.8 Zn, 0.22 Mn, and balance Mg), where produced by die casting at Norsk Hydro, Norway. After fatigue testing, the grip-section of the specimens was cut off and hourglass shaped specimens were machined with a gauge diameter of 5 mm and a length of 55 mm (Fig. 1b). Shot peening was performed with a ferritic shot SCCW 14 (diameter 0,35-0,4 mm) with an intensity of 0.41 mmN.

For optical microscopy samples were cut perpendicular to the axis of the fatigue specimens and mechanically polished. Fatigue tests were performed on a rotating beam testing machine (R = -1) under laboratory air at a frequency of 50 Hz. In order to investigate the influence of corrosion on fatigue lifetime, some specimens were precorroded in a 5% NaCl solution before fatigue testing.



a. As-cast fatigue specimen



b. Specimen machined from the grip-section of the cast specimen

Figure 1: Dimensions of fatigue specimens

4 Experimental Results and Discussion

Figure 2 shows typical micrographs of cross sections of the as-cast fatigue specimens taken from the gauge length (∅ 6 mm) and the gripping region (∅ 10 mm). In both samples a nearly pore free zone in the surface area is observed, while pores are present in the central area. With increasing diameter, the size of the pores increases too. This is a well-known problem in die cast magnesium alloys limiting good mechanical properties on thin components. In order to quantify the influence of pores on fatigue behavior, i.e. endurance limit, specimens were machined from the gripping area. The diameter of the specimens was chosen such as the surface of the fatigue specimens is in the highly porous zone.

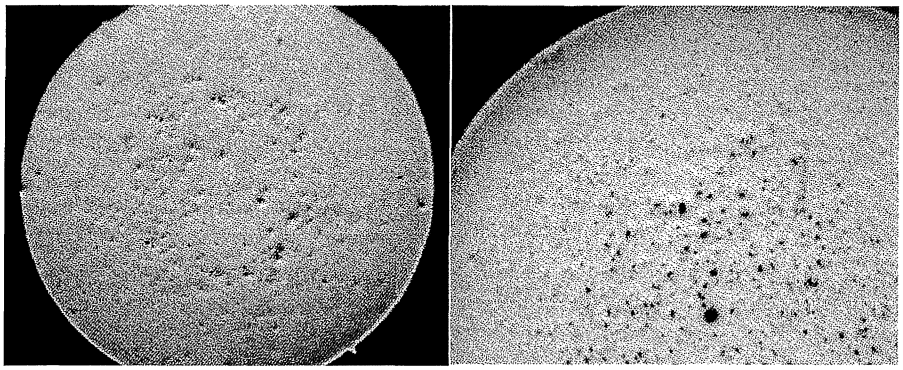


Figure 2: Micrographs of cross sections of the as-cast fatigue specimen: left from the gauge length of the specimen (Ø 6 mm), right from the grip-section (Ø 10 mm)

The die cast alloy AZ91 hp exhibits good fatigue properties (fig. 3), showing a stress amplitude endurance limit of 100 MPa (R = -1). As expected, pores have a detrimental influence on fatigue behavior. In rotating beam testing the presence of pores at the surface reduces the endurance limit by 50 % from a stress amplitude of 100 MPa to approximately 50 MPa (fig. 3). Shot peening can significantly reduce this detrimental effect. After the surface treatment the endurance limit of porous specimens rises from a stress amplitude of 50 to 90 MPa and reaches nearly the value of the pore-free material in the untreated condition (fig. 4). The improvement of fatigue behaviour of pore-free material by shot peening is rather small. The endurance limit rises only by about 20 % from 100 to 120 MPa (fig. 4). Experimental results by Wagner [9] on the magnesium alloy AZ 80 indicate that a more pronounced improvement of the endurance limit can be achieved by very low peening intensities in the order of 0.05 mm N. It remains doubtful, however, whether such low intensities would improve the fatigue behavior in the presence of pores.

While shot peening improves fatigue behavior of AZ91 hp under non- (or low) corrosive conditions, it reduces corrosion resistance in a drastic manner. Figure 5 shows photographs of the corrosive attack in a 5% NaCl solution on the polished surface of a fatigue specimen. After 3 hours (fig. 5b), the surface is partially attacked and after one week (fig. 5c) small pits can be observed on the surface. X-ray analysis revealed the presence of aluminium oxide on the surface. After shot peening large pits are present after 3 h exposure to NaCl solution (fig. 6b), and after one week the diameter of the specimen is significantly reduced (fig. 6c). The surface mainly consists of magnesium hydroxide $Mg(OH)_2$ without building up a protective layer. The dramatic acceleration of the corrosive attack is mainly caused by iron contamination of the surface due to the use of a steel shot. Quantitative element analysis by EDX revealed an iron concentration of about 1.6 wt% on the surface, while the concentration in the bulk material of the high purity alloy AZ91 hp is below 0.003 wt %. Disperse iron

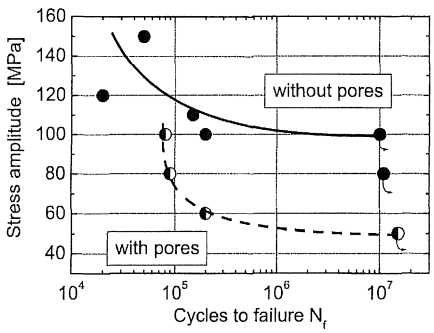


Figure 3: Influence of porosity on S-N curves

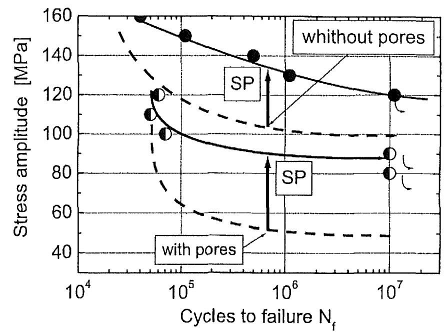
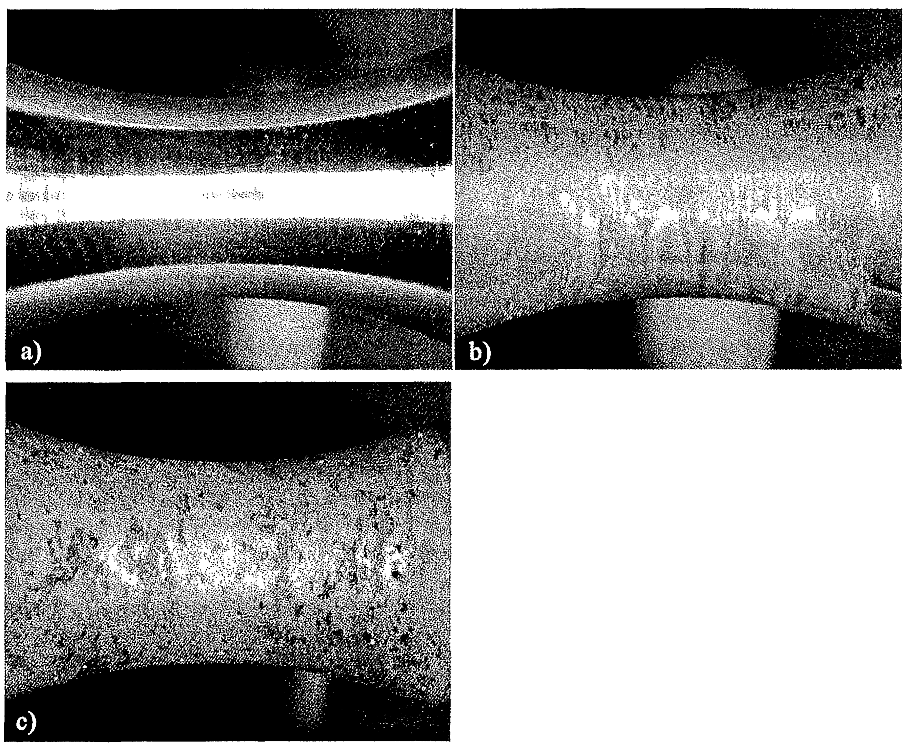


Figure 4: Influence of shot peening on S-N curves

particles are known to accelerate the corrosion process of magnesium alloys by a galvanic coupling [10,11]. In pure magnesium Polmcar [12] observed a strong increase of the corrosion rate for iron concentrations above 0.02 wt%, which is two orders of magnitude lower than the iron concentration observed here on the surface of shot peened fatigue specimens.



(**Figure 5:** Corrosion on the polished surface of a magnesium alloy AZ91 hp specimen a) polished, (b) 3 h 5 % NaCl, (c) 1 week 5 % NaCl

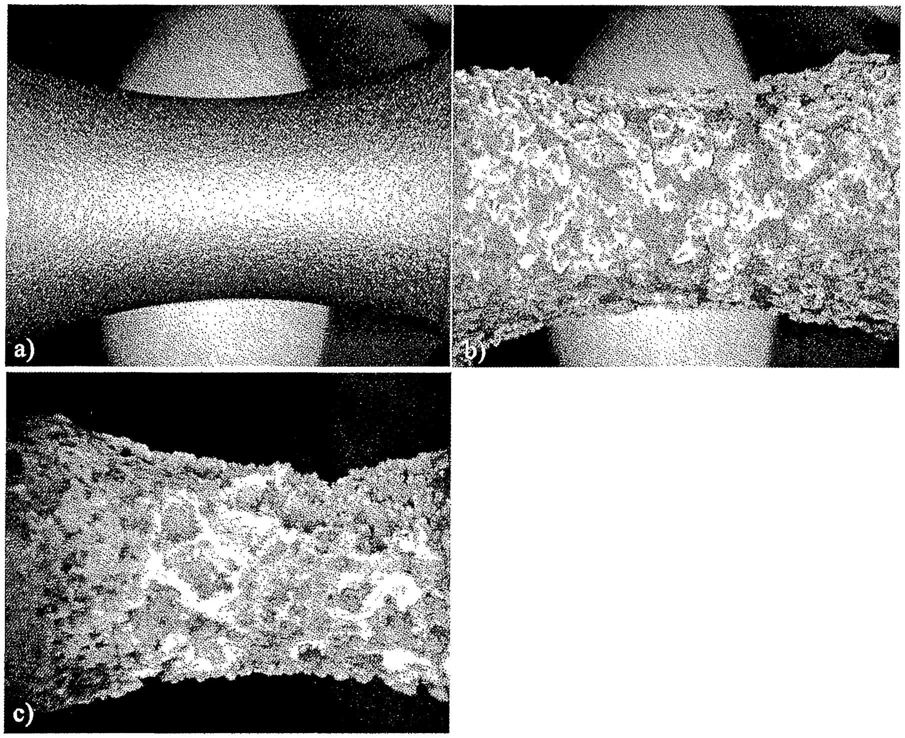


Figure 6: Corrosion on the shot–peened surface of a magnesium alloy AZ91 hp specimen (a) shot peened, (b) 3 h 5 % NaCl, (c) 1 week 5 % NaCl,

Pre-testing corrosion for one week reduces the endurance limit (10^7 cycles) of the as-cast specimen from a stress amplitude of 100 MPa to approximately 50 MPa (fig. 7). After shot peening a pre-testing corrosion of only 3 hours in a NaCl solution causes the endurance limit to drop from 120 MPa to 50 MPa (fig. 8). The fatigue behavior of specimens that were shot peenend and pre-testing corroded for one week was not tested, as a load amplitude of 50 MPa already leads to failure after a few cycles and the testing equipment did not allow lower loading. Determination of a 10^7 endurance limit would not make much sense, as its value will be well below 50 MPa and therefore out of interest for technical applications.

The question arises whether mechanical or chemical surface cleaning is an appropriate way to avoid the strong deterioration of the fatigue properties following corrosion. In order to utilize the benefit of shot peening on fatigue properties under corrosive conditions, iron concentration must be completely avoided as iron particles act as local elements for corrosion. Even if the overall surface concentration of iron may be low after cleaning, the local concentration must not exceed a very low value. If non-ferrous shot is used after the use of steel shot or after shot peening of ferrous targets, iron contamination will remain in the shot peening facilities, probably leading to accelerated corrosion. The questions of how much iron contamination is tolerable, and how the contaminated surfaces and shot peening facilities should be cleaned, will be addressed in forthcoming work.

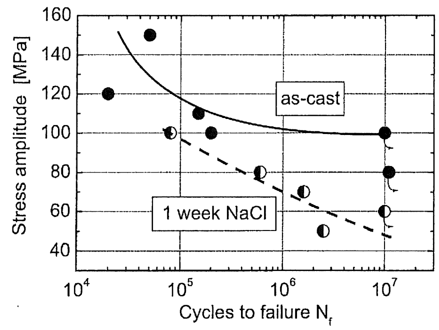


Figure 7: Influence of corrosion on S-N curves of as-cast specimens

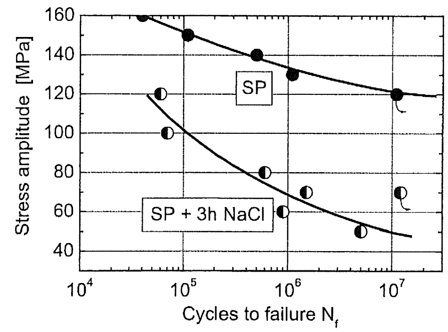


Figure 8: Influence of corrosion on S-N curves of shot-peened specimens

5 Summary and Conclusions

Shot peening is an appropriate method to improve the fatigue behavior of the magnesium die cast alloy AZ91. Especially the detrimental effect of casting pores on fatigue properties can be reduced.

Iron contamination of the surface drastically accelerates the corrosion process in salt water. This leads to a strong deterioration of the fatigue properties after shot peening with ferrous shot.

Even local iron-contamination will be sufficient to deteriorate fatigue properties by accelerating local corrosion (pitting). It remains therefore doubtful whether cleaning of the surface (mechanical or chemical) or the use on non-ferrous shot in an iron-contaminated shot peening equipment would be sufficiently effective to avoid the problem.

6 Acknowledgements

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