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Endurance limit of die-cast magnesium alloys AM50hp and AZ91hp depending on type and size of internal cavities

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ABSTRACT

The aim of this work was to investigate the influence of internal cavities on the fatigue properties of two of the technical most common die-cast magnesium alloys, AM50hp and AZ91hp. For this purpose the endurance limits of altogether three batches of *S–N* specimens, two conventional cast and one vacural cast, with varying internal defects have been measured. After fatigue failure the fracture surface of each sample has been analysed with respect to the site of crack initiation and, where appropriate, the size of the crack initiating cavity or pore. Moreover, on both alloys crack growth tests have been carried out and the thresholds ΔK_{th} of the stress intensity factor have been measured.

Finally, the experimental data from both, the *S–N* tests and the crack propagation measurements, were depicted in a modified Kitagawa–Takahashi diagram. Using El Haddad's and Topper's approach the distribution function of the endurance limit has been proposed, whose parameters could be determined by fitting them to the experimental results. The knowledge of these parameters allows the calculation of the fracture probability as a function of an equivalent crack length and the stress amplitude.

1. Introduction

The alloy AZ91 is the most common die-cast magnesium alloy being characterised by high strength, good castability, and high corrosion resistance. In fact, the high strength, investigated at separately cast specimens is often not reached in real components. The reasons for this are an inhomogeneous microstructure, gas inclusions or microvoids. Possible causes for such kinds of inner defects are

- air pockets from the casting set or the die-casting form,
- gases as decomposition products of auxiliary materials,
- shrinkage cavities from the phase transition liquid/solid,
- segregations and
- non-metallic inclusions.

Frequently, porous zones arise during the die-casting process, especially at transitions of wall thickness and areas where force lines are deflected as well. One explanation for this phenomenon given by Dahle and St. John is based on the interaction between externally solidified crystals (ESCs) and newly nucleation at the mould [1]. Investigations by Kinzler et al. indicate shrinkage-induced porosity having an influence on the mechanical behaviour of AM50hp and AZ91hp at high strain rate [2]. The authors visualise the three-dimensional inhomogeneity distribution and describe its effect on mechanical strength values. A quantitative description of spatial arrangement of shrinkage cavities and gas pores in cast Mg alloys of the AM series is given by Balasundaram and Gokhale [3]. Liu et al. also describe the influence of porosities on mechanical characteristic values of the alloys AZ91hp, AM50hp, AS41, and AE42 [4]. Whereas the yield strength has been found to be practically uninfluenced by porosity, a correlation between tensile strength and ultimate elongation was observed, both depending on the porosity, a fact that also holds for other die-cast alloys [5].

Moreover, for a broad application of die-cast Mg-alloys it is necessary to obtain knowledge about their fatigue behaviour. Investigations on the alloys AZ91hp, AM50hp, and AM20hp were carried out by Sonsino et al. and compared to corresponding data of several steels and Al-alloys [6]. Eisenmeier et al. studied the cyclic deformation and fatigue behaviour of the alloy AZ91 at constant strain amplitudes between 1.4×10^{-3} and 2×10^{-2} at room temperature and at 130 °C [7]. They verified that crack propagation occurs mainly by the coalescence of smaller cracks. Höppel et al. carried out fatigue experiments at AZ91 and point out that for crack initiation cavities at or beneath the surface play an important role [8]. Badini et al. establish a connection between mechanical properties and cast defects in Al and Mg die-cast alloys [9]. The latter emphasise the particular importance of the distribution and morphology of defects as well as their location within casting for

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Table 1
Chemical composition of the magnesium die-casting alloys AM50hp and AZ91hp.

Alloy	Alloying element (mass%)						
AM50hp	Al	Mn	Zn	Si	Cu	Ni	Fe
	4.5–5.3	0.28–0.5	<0.2	<0.05	<0.008	<0.001	<0.004
AZ91hp	Al	Mn	Zn	Si	Cu	Ni	Others
	8.5–9.5	0.15–0.4	0.45–0.9	<0.02	<0.08	<0.01	<0.30

fatigue properties. Zenner and Renner show, that the results from fatigue examinations at the alloys AZ91 and AM60 are strongly affected by inner defects as microporosity for example [10]. The Mg alloys AZ91, AM60, AE21 and AS21 as well as the Al-alloy AlSi9Cu3 were compared by Mayer et al. with respect to their fatigue behaviour [11]. The experiments have been performed up to 10^9 cycles using an ultrasonic fatigue testing method. At this, the Mg alloys reached endurance limits of 34–55 MPa while the Al alloy showed a mean endurance limit of 75 MPa. In 98.5% of the specimens crack initiation at porosity was observed.

Examinations on die-cast aluminium of Linder et al. focused on the fatigue strength assessments of differently sized defects in terms of a Kitagawa diagram, which can be used to prescribe the largest allowable defect at a given load situation [12]. Similar investigations on die-cast aluminium were carried out by Oberwinkler et al. who derive the sustainable local load by combining the results of a statistical porosity model and the Kitagawa diagram [13].

In this investigation two of the most commonly used magnesium die-casting alloys, AZ91hp with main alloying elements aluminium and zinc and AM50hp with main alloying elements aluminium and manganese have been studied. For reasons deriving from corrosion protection today's alloys are of high purity (hp), having very low contents of iron, nickel and copper. In order to study the influence of typical die-casting caused microporosity on fatigue behaviour three sample batches have been investigated. Therefore different types of pores have been inserted by variation of the die-cast parameters within the same batch. In contrast to most other studies the fatigue behaviour of the specimens has been tested directly without removing the casting skin, so equalling a real component's surface. Finally, the fracture surfaces have been analysed. Thereby defect induced failure could be interpreted by a Kitagawa analysis to derive the influence of defect size and stress amplitude on the number of cycles to failure [14].

2. Material

In the present investigation the most frequently used die-cast magnesium alloys AM50hp and AZ91hp were chosen as materials of study. While AZ91hp excels in its high strength and good corrosion resistance, AM50hp is attractive for its ductility. The chemical composition of both materials is shown in Table 1.

3. Experimental procedure

3.1. Die-casting

For the manufacturing of the specimens a specially constructed die-casting mould was built, which included two fatigue specimens and two plate-like samples (250 mm × 60 mm) for fracture mechanics experiments with each of them having 2 and 6 mm wall thickness. It had been optimised performing simulations of the solidification in the run-up (Fig. 1) resulting in a mould that is well suited for conventional die-casting as well as for vacural die-casting (Fig. 2). The latter is characterised by evacuating the mould before it is entered by the melt, so that entrapped air as well as an oxidation of the melt is suppressed widely.

The casting was carried out at a 7.5 MN die-casting machine in conventional and vacural process. In order to generate specimens including different configurations of inner defects with respect to size, type and distribution, the process parameters prefilling velocity v_1, plunger velocity v_2 and casting pressure p have been varied within the same batch in certain limits:

- v_1 = 0.4–0.8 m/s,
- v_2 = 2.0–3.5 m/s and
- $p = 5 \times 10^7 – 1 \times 10^8$ Pa.

To avoid results being influenced negatively by run-up conditions at least the first five castings of every specimen series with the same set of parameters have been rejected.

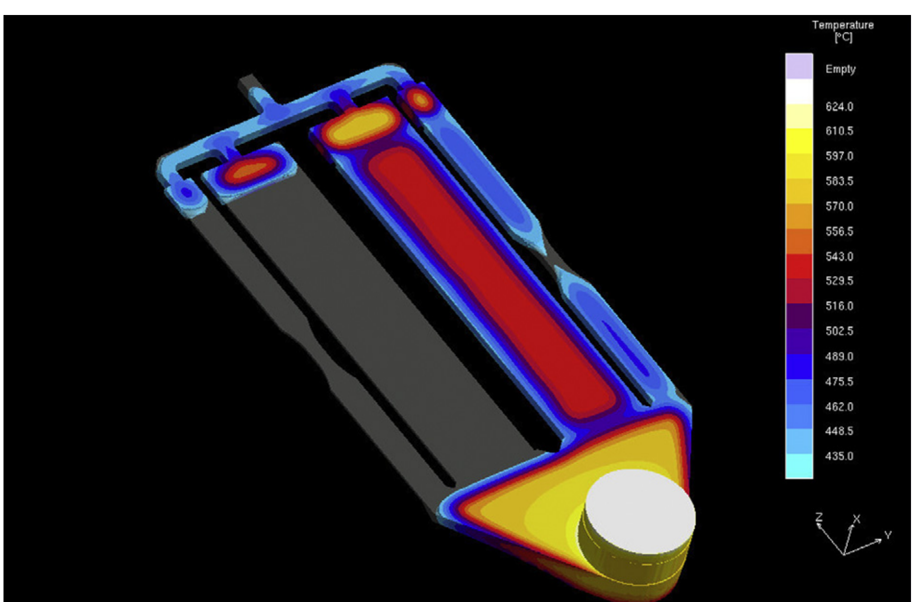

Fig. 1. Simulation of temperature during the solidification of the cast: In contrast to the completely solidified two specimens on the left hand with 2 mm wall thickness, the two specimens on the right with 6 mm wall thickness contain liquid parts. This means that the right hand side cannot be fed sufficiently and shrinkage porosity arises.