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Effects of porosity on the fatigue behaviour of AlZn10Si8Mg casting alloys in a high cycle region

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Abstract

The fatigue behaviour of AlZn10Si8Mg cast alloy used in an automotive industry and consequently effect of porosity was investigated for present study. The study was exploring for a lifetimes as long as 106 cycles using rotating bending fatigue device operating at 30 Hz, at a room temperature 20±5 °C. The tested specimen´s fracture surfaces and fracture profiles were observed with the use of a scanning electron microscope (SEM) and optical microscope to determine the fatigue crack initiation sites and porosity. A correlation was made between the sample fatigue life and the distribution of the pores and Fe-rich needle-like phases which initiated the fatigue crack. It was shown that fatigue life decreases as the surface pore size increases and that the crack initiation site contains multiple pores or consists of a spongy structure. Main factor for decreasing the fatigue life are these castings defects since 90 % of the samples examined tended to fracture as a result of the casting defects.

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Keywords: AlZn10Si8Mg cast aluminium alloy; fatigue behaviour; surface porosity

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1. Introduction

Using the cast aluminium alloys in competition with wrought products offers interesting advantages in reduce of production steps and the ability to produce complex - shaped parts in the automotive industry [1]. The casting process unfortunately imperative produces a wide range of variations microstructure and also defects occurrence like porosity, trapped oxide films and intermetallic particles, which are all detrimental to the mechanical properties, but in particular the fatigue behaviour [2]. Further crack initiation from oxides, particles of Si, or other defects reported, although various studies demonstrated that fatigue cracks initiation is mainly caused by porosity of the material Al-Si cast alloy [3-5]. Fractography with the use of the scanning electron microscope was revealed that surface or near the surface pores are the mainly cause for the fatigue cracks initiation [6]. Fatigue properties of Al-Si cast alloy are sensitive to the defect size [6]. In the previous years, the maximum defects (pores) size has been recognized as the most important parameter which determined fatigue behaviour of cast aluminium alloy. As the larger is the defect size as the lower is the fatigue strength. In the presence of imperfections, fatigue strength is also affected by chemical composition, heat treatment, or solidification time, as reflected by dendrite arm spacing and the sizes of eutectic silicon and intermetallic particles [7-9].

The present study is a part of larger research project, which was conducted to investigate and to provide a better understanding of properties of Al-Zn-Si cast alloys. The main objective of this work was to study the effects of porosity on the fatigue behaviour in AlZn10Si8MgMn cast alloy.

2. Experimental material

The AlZn10Si8Mg (Table 1) unmodified cast alloy was used as an experimental material. In this alloy is no - need any additional heat treatment, because it is self-hardening alloy with good strength and there was observed after first day around 50 % of final value of mechanical properties and after second, third day around 80 % of those values [10-12]. The test bars were made in foundry UNEKO Zátor, Ltd. Czech Republic by sand casting process with diameter ø 20 mm and total length 300 mm and made for fatigue testing as smooth specimens.

Table 1. Chemical composition of AlZn10Si8Mg cast alloy in wt. %

Zn	Si	Cu	Fe	Mn	Mg	Ti	Ni	Cr	Ca	Cd	Bi	Sb	Al
9.6	8.64	0.005	0.1143	0.181	0.452	0.0624	0.0022	0.0014	0.0002	0.0001	0.0003	0.0007	bal.

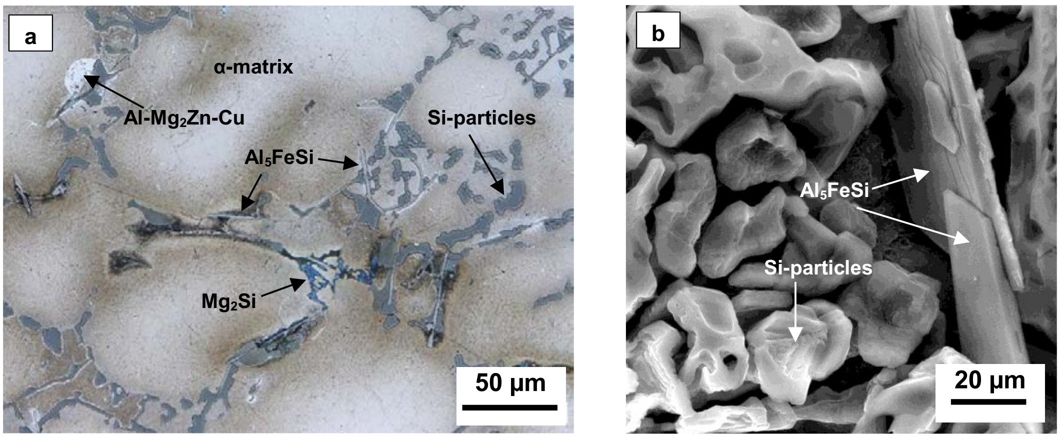

Fig. 1. Microstructures of AlZn10Si8Mg cast alloy: a) etch. 0.5 % HF; b) morphology of phases - detail, deep etch. HCl

AlZn10Si8Mg samples were prepared by standard metallographic procedures [10, 11] and used for microscopic analysis. The microstructures were immediately studied using an optical (Neophot 32) and scanning electron microscope (SEM) VEGA LMU II. Chemical composition of phases were analysed by the energy dispersive X-ray spectroscopy (EDX analyser Brucker Quantax).

The fatigue test specimens (14 PCS) were machined with geometry according to ISO 1143 from casted bars, the gauge diameter was d_0=8 mm and total length of the specimen 150 mm [11]. Fatigue behaviour of the specimens on rotating bending fatigue device were carried under rotating bending loading at temperature 20 ± 5 °C, frequency 30 Hz and stress ratio R = -1 [11]. Specimens were tested to determine the fatigue limit σ_c at $N_c = 3 \times 10^6$ cycles. Specimens that did not fail before the maximum number of cycles were considered to be run-outs. After fatigue tests were the fracture profile observed using optical microscope and the fracture surfaces SEM. The distribution of pores was observed at metallographic prepared cross-sections (etch. 0.5 % HF) of using the broken specimen.

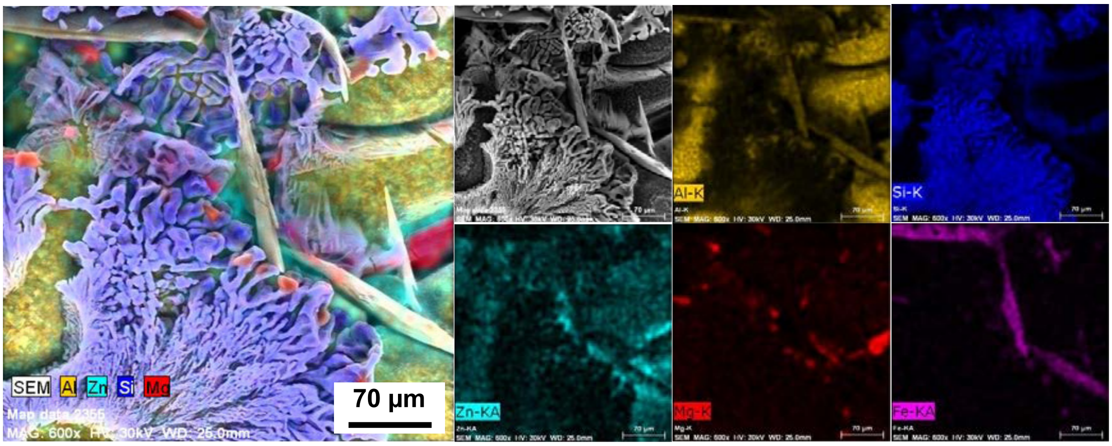

Fig. 2. X-ray mapping of phases in AlZn10Si8Mg cast alloy, deep. etch. HCl; SEM

Al-Si alloys contains relatively high content of Si [13]. The microstructure of experimental cast alloy consists of α-phase, eutectic (Si crystals in α- phase) and variously type of Cu-, Fe- and Mg-rich phases (Fig. 1 and Fig, 2). There are observed different morphologies of intermetallic particles such as needles/plates, script-like or Chinese script [10, 11]. Iron led to the formation of thin needle-like Al_5FeSi phases (Fig. 1b and Fig. 2). These phases are formed between the α-dendrites, mainly near the casting defects such as cavities or bubbles. Brittle Al_5FeSi phases with plate-like morphology significantly affect the mechanical properties, decrease the strength and ductility of the cast alloys and are observed as initiation place for crack initiation [14, 15].

3. Results and discussion

In a high cycle region were carried out rotating bending fatigue tests of cast aluminium alloy AlZn10Si8Mg. There was used testing device Italsigma at the Department of Mechanics, Politecnico di Milano, Italy. Determination of fatigue limit σ_c was performed with the use the classic Wöhler's curve.

The relationship between the stress amplitude and the fatigue life in the form of the number of cycles N of loading (S-N curve) is given in Fig. 3. Filled markers indicate specimens that did not fail before the maximum number of cycles (run-out). The fatigue lifetime increased with decreasing total stress amplitude. Fatigue tests for specimens were carried out in the range of stress amplitudes from σ_a = 60 MPa to σ_a = 100 MPa. Fatigue tests result shown that the fatigue limit is σ_c = 60 MPa at $N_c = 3x10^6$ cycles [11, 15].

The correlation of fatigue fracture surfaces (fracture profile) was made between the samples of fatigue life and the sizes of microstructural defects/pores, and the result is that the formation of fatigue cracks is caused by pores respectively defects.

Porosity may be defined as the voids or cavities, which form within a casting during solidification; it is considered to be the most frequently observed defect in Al-Si casting alloys [16, 17]. This defect often results in poor mechanical properties including limited strength and ductility, variable fracture toughness, irregular crack initiation and crack propagation characteristics. Iron resulted in a solidification sequence that saw the formation of Al_5FeSi-phase platelets prior to the solidification of the Al-Si eutectic. Taylor [17] proposed that the defect porosity occurred because Al-Si eutectic grains nucleated on these prior this Al5FeSi-phase platelets.

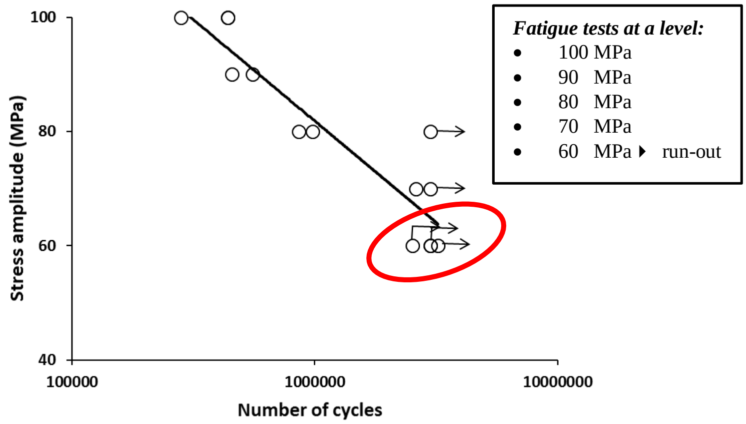

Fig. 3. Wöhler's curve of AlZn10Si8Mg cast alloy for as-machined state

In order to compare the fatigue fracture surface were analysed samples fatigued at the same maximum stress (σ_a = 100 MPa) but with different fatigue lives (N = 282 000 and 437 000 cycles).

Typical macrofractographic surfaces are shown in Fig. 4. The global view of the fatigue fracture surfaces are similar one other. Within the bounds of fatigue tests was established that, high stress amplitude caused small fatigue region and large region of final static rupture. The process of fatigue consists of crack initiation stage, stable crack growth region with flat and smooth surface, with the typical "beach marks" and the unstable final static rupture with rough or granular aspect (Fig. 4a, b).

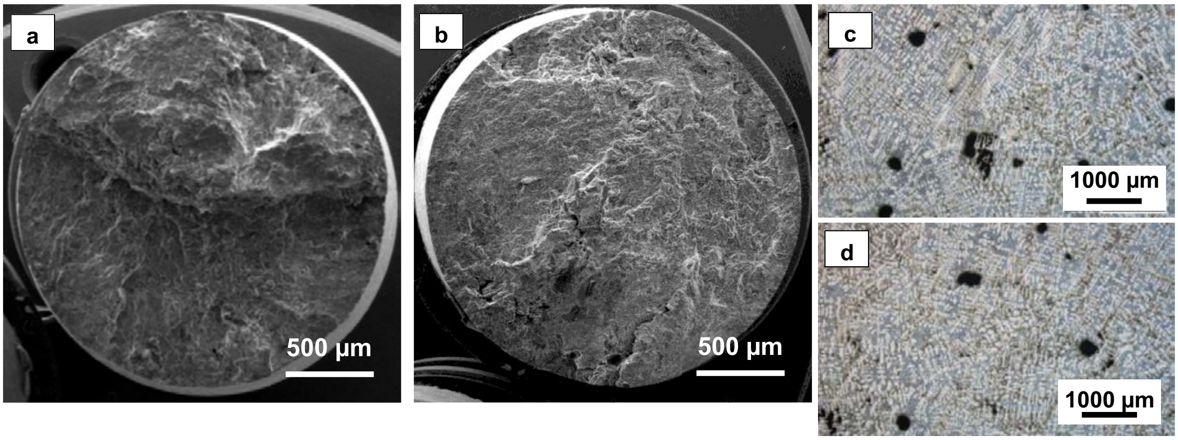

Fig. 4. Macroscopic view of fracture surfaces at the stress σ_a = 100 MPa (SEM): a) N = 282 000 cycles; b) N = 437 000 cycles; and distribution of the porosity at the stress σ_a = 100 MPa (etch. 0.5 % HF): c) N = 282 000 cycles d) N = 437 000 cycles

The porosity distribution for sand cast specimens at the same maximum stress (σ_a = 100 MPa) but with different fatigue lives (N = 282 000 and 437 000 cycles) at metallographic prepared cross-sections (etch. 0.5 % HF) are documented in Fig. 4c, d. The porosity is homogenously distributed in the matrix. This is not very surprising since the porosity probable was formed during solidification when the solubility of hydrogen is reduced drastically. Furthermore, since specimens are solidified from the outside and inwards most shrinkage pores could be treated as interior. In Fig. 4c, d it can be observed, that a number of pores is higher in sample, broken at N = 282 000 cycles.

Iron resulted in a solidification sequence that saw the formation of Al_5FeSi-phase platelets prior to the solidification of the Al-Si eutectic, and when this occurred there was an increased tendency to form extensive and damaging shrinkage porosity defects.

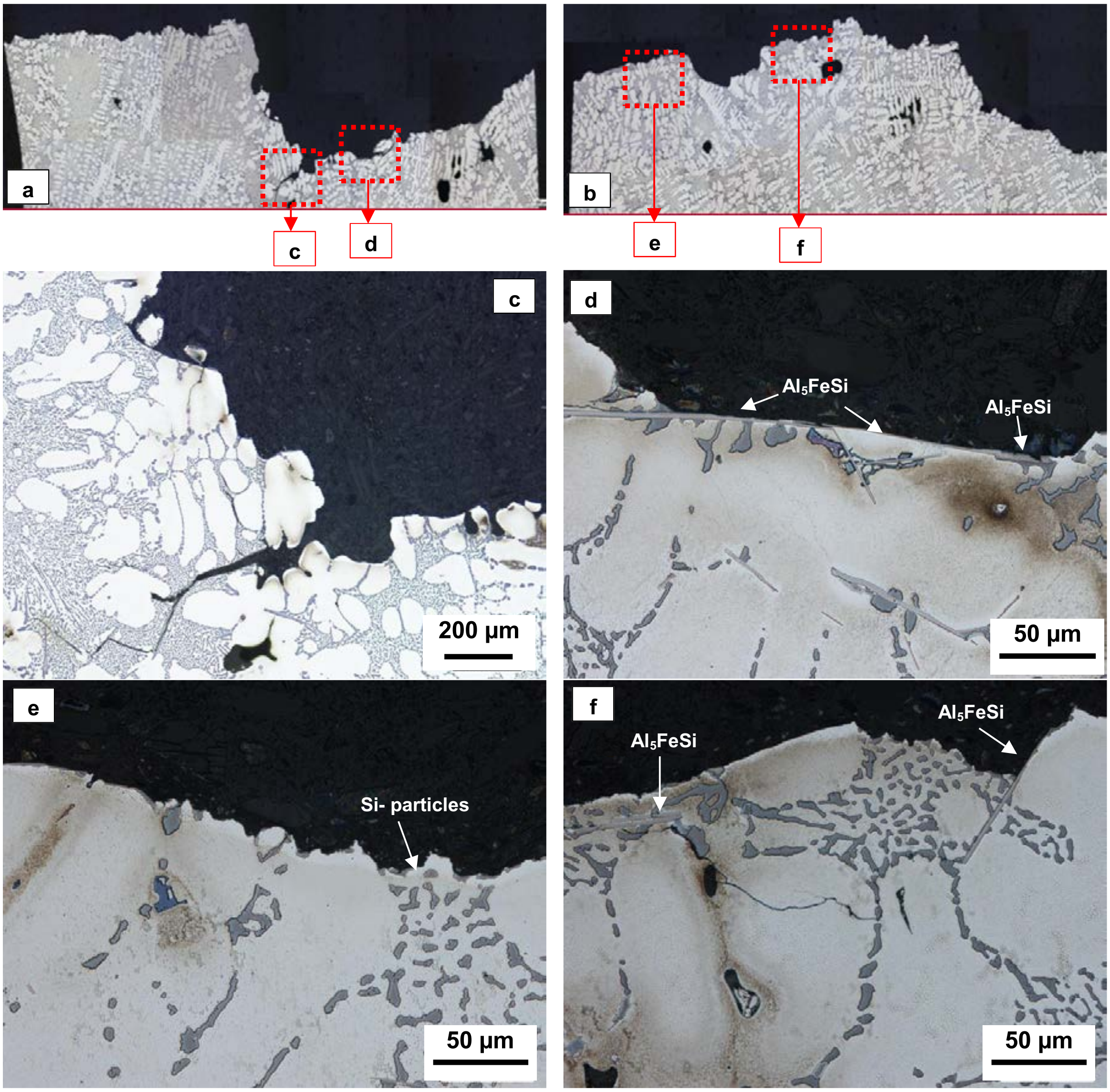

Fig. 5. Optical micrographs of the fracture profile, etch. 0.5 % HF: a) specimen σ_a = 100 MPa, N = 282 000 cycles b) specimen σ_a = 100 MPa, N = 437 000 cycles c) porosity and Fe-needles as crack initiation, d) detail of decohesion and damage of brittle needle-like Fe-particles (Al_5FeSi) e) damage and decohesion of eutectic Si particles on the fracture surface; f) decohesion of brittle needle-like phase Al_5FeSi with secondary cracks;

In Fig. 5 is documented fatigue fracture profile. It can be observed, that the actual pore size that initiated the fatigue crack in the specimen with fatigue lifetime broken at N = 437 000 cycles is smaller (Fig. 5b) as was initiated in fatigue lifetime broken at N = 282 000 cycles (Fig. 5a). In Figures 5c and 5d it is visible that pores are at the surface and also subsurface and the initiation pores were obtained to be generally larger, accordingly brittle Al_5FeSi (Fig. 5d). The decohesion and damage of brittle needle-like Fe-particles (Al_5FeSi) at the fracture surface, as shown in the areas (Fig. 5d, Fig. 5f), may clearly be seen, indicating that these particles contribute to the fatigue cracking, to increasing the fatigue crack propagation rate, and to shortening the fatigue life.

4. Conclusions

After fatigue tests of AlZn10Si8Mg selfhardening cast alloy was investigated the fractography of fracture surfaces with following conclusions:

- the fatigue strength was determined for σ_c = 60 MPa for a run-out number of cycles $N_c = 3\times10^6$ cycles
- the most casting defects affecting the fatigue lifetime is surface porosity
- when the pores, microshinkage, brittle phases (such as thin brittle needle-like Fe-phases - Al_5FeSi) are besides the casting defects than the fatigue lifetime is decreasing
- the samples with more pores and Fe-needles withstand less number of loading cycles

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