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# Fatigue Resistance of Self-hardening Aluminium Cast Alloy

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## Abstract

Cast aluminium alloys are widely used in fatigue critical structural applications, such as engine blocks, cylinder heads, chassis and suspension components, to improve automotive fuel economy. However, it may be difficult to use these alloys for parts that require a high fatigue strength and high reliability because of a large number of casting defects as porosity and microshrinkages exist in them. Fatigue properties of cast aluminium components are controlled by maximum defect size in the material. The larger maximum defect size, the lower the fatigue strength and life.

Self-hardening Al-alloys (Al-Zn-Si-Mg alloys) introduce an innovative class of light Al-alloys. Fatigue properties of AlZn10Si8Mg cast alloy in the high cycle region were tested by rotating bending fatigue loading in a high cycle region with the used of parameters - frequency f = 40 Hz, temperature T = 20 ± 5 ℃ and stress ratio R = -1. Because of that large pores are near or at specimen´ s surface and its dominant reason of fatigue crack initiation and propagation.

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*Keywords:* AlZn10Si8Mg cast aluminium alloy; fatigue lifetime; casting defects.

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## 1. Introduction

Cast Al-alloys are seeing increasing uses in the automotive industry due to their excellent castability, corrosion resistance, and especially their high strength to weigh ratio. The increasing use of high integrity shaped cast

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aluminium components under repeated cyclic loading has focused considerable interest on the fatigue properties of cast Al-Si alloys. Numerous studies shown that cast aluminium alloys are very sensitive to casting defects and whenever large pore is present at or near the specimen's surface, it will be the dominant cause of fatigue crack initiation. The maximum defect size has been recognized as the most important parameter in determining the fatigue properties of aluminium castings. In the presence of casting defects, crack initiation can be ignored and fatigue life is mainly spent in crack propagation [1-3]. Methods to accurately predict fatigue properties of these castings early in the component and manufacturing process design cycle are needed [4].

Self-hardening Al-alloys (e.g. Al-Zn-Si-Mg alloys) introduce an innovative class of light Al-alloys. The important benefit represents possibility to avoid the heat treatment, contributing the considerably reduce cost of some components and also the amount of energy [5-9].

The present study is a part of larger research project, which was conducted to investigate and to provide a better understanding self-hardening AlZn10Si8Mg cast alloy. In this paper authors publish their own results of experimental examination of fatigue properties during rotating bending fatigue loading for this alloy.

## 2. Experimental material

As an experimental material was used recycled - secondary (scrap-based) AlZn10Si8Mg cast alloy with chemical composition given in Table 1 and with very good casting properties, good wear resistance, low thermal expansion, very good machining and mechanical properties which are presented in Table 2. This alloy is a selfhardening and good strength values are reached without the need for heat treatment, e.g. casting obtained after first day approximately 50 %, after second and third day approximately 80 % final value of mechanical properties [9,10]. Test bars (ø 20 mm with length 300 mm) were produced by process sand casting in foundry UNEKO, s.r.o., Zátor, Ltd. Czech Republic. The melt was not modified or refined.

Table 1. Chemical composition of AlZn10Si8Mg aluminium 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. |

Table 2. Mechanical properties of AlZn10Si8Mg aluminium alloy

| Yield strength [MPa] | UTS [MPa] | Ductility [%] | Hardness HBW5/250/30 |
|---|---|---|---|
| 190-230 | 220-250 | 1-2 | 80-100 |

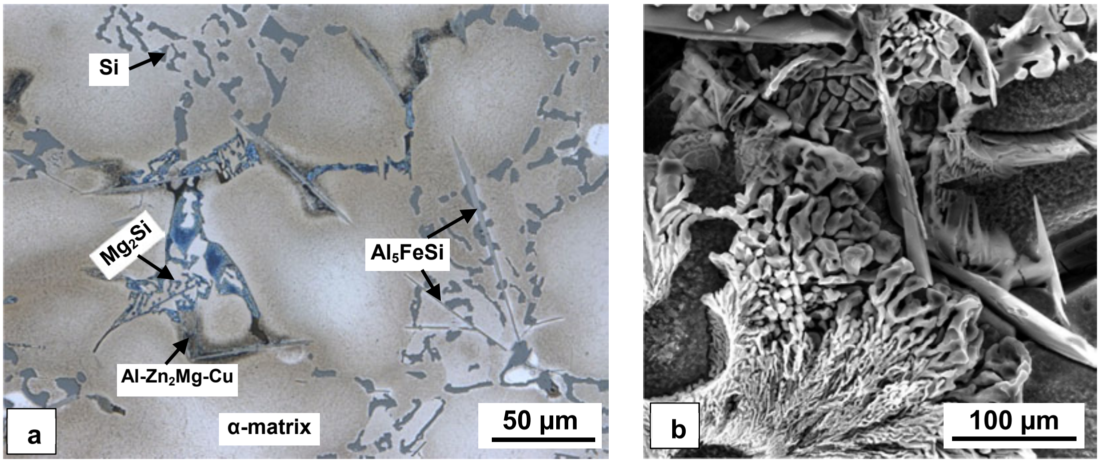

Fig. 1. Microstructure of AlZn10Si8Mg cast alloy: (a) etch. 0.5 % HF; (b) morphology of phases, deep etch. HCl.

The samples for microscopic analysis were prepared by standards metallographic procedures (i.e. mounting in bakelite, wet ground, DP polished with diamond pastes and etched by 0.5 % HF). Microstructural details were analyzed using optical microscopy (Neophot 32). After fatigue testing, the fracture surfaces of the tested specimens were examined in a TESCAN Vega scanning electron microscope.

The microstructure of AlZn10Si8Mg cast alloy (Fig. 1) consist of α-phase, eutectic (crystals Si in α- phase) and various type of Fe-, Cu- or Mg-rich intermetallic phases [6-7]. Silicon crystals shown in the metallographic plane cut as poorly rounded grains of smaller to larger sizes (Fig. 1a, b). Fe as one of the most undesirable impurities, led to the formation plate/needle like $Al_5FeSi$ phase. These phases are formed between the α-dendrites, primarily in the immediate vicinity of casting defects such as cavities and bubbles.

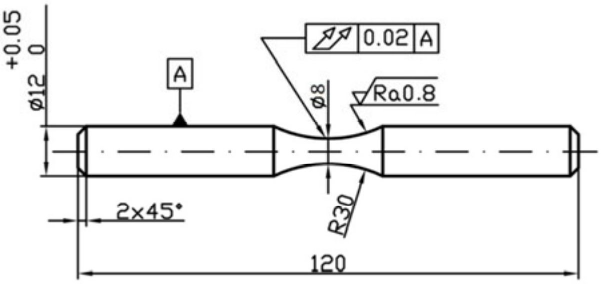

Fig. 2. The shape and the dimension of smooth specimens.

Set of smooth specimens was used as an experimental material (11PCS) (Fig. 2) with geometry in accordance ISO 1143 [11], were tested with the aim to determine the fatigue limit $\sigma_c$ at $N = 3\times10^6$ cycles. The gauge diameter of length was $d_0$ = 8 mm and total length of specimen 120 mm. Fatigue tests were performed on a rotating bending fatigue device in Politecnico di Milano in Italy, with the use of parameters (temperature T = 20 ± 5 °C, frequency 40 Hz, stress ratio R = -1). The set of smooth specimens (11PCS) have been carried out at a different cyclic stresses based on Wöhler´s curve [12]. The samples were fatigue tested at different stress levels, ranging from 100 MPa to 90MPa, 80 MPa, 70 MPa and 60 MPa.

## 3. Results and Discussion

The obtained results of fatigue tests are shown in the Fig. 3.

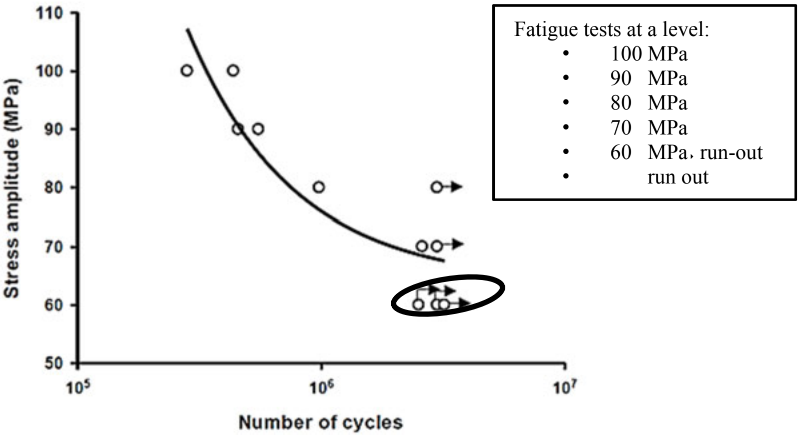

Fig. 3. Wöhler curve of AlZn10Si8Mg cast alloy.

The fatigue lifetime is increasing with decreasing total strain of amplitudes. The fatigue strength of the cast alloy was defined as the highest applied stress under which a specimen can withstand N = 3 x $10^6$ cycles. From an analysis of the results could be obtained that fatigue limit at 3 x $10^6$ cycles was stated for $\sigma_c$ = 60 MPa. Filled markers indicate specimens that did not fail before the maximum number of cycles (run-out).

The fatigue properties of cast aluminium alloy are strongly influenced by the presence of casting defects. In the presence of imperfections, fatigue strength is little affected by chemical composition, heat treatment, or solidification time, as reflected by dendrite arm spacing and the sizes of eutectic silicon and intermetallic particles. Several studies have stated that when porosity is current the fatigue cracks are initiated in the Al-Si casting alloys. They are significantly reducing the fatigue strength [13].

Porosity may be defined as the voids or cavities, which form within a casting during solidification; it is considered to be the most frequently occurring defect in Al-Si casting alloys. The fatigue performance of the casting alloys is increasing with the elimination of porosity [14]. These defects are often as a result of poor mechanical properties including limited strength and ductility, irregular crack initiation, variable fracture toughness and crack propagation characteristics, potentially accompanied by a lack of pressure tightness and subsequently porosity is considered the major cause of rejection of the casting under discussion [15].

Porosity reduces the time to crack initiation by creating a high stress concentration region adjacent to this microstructural defect. There are two factors to the formation of porosity in Al-Si cast alloy, the first one of these is the microshrinkage (Fig. 4) resulting from the volume contraction accompanying solidification, while the second one is the entrapment of gas (in the most cases hydrogen) resulting from a decrease in a gas solubility in the solid metal compared to the liquid [16].

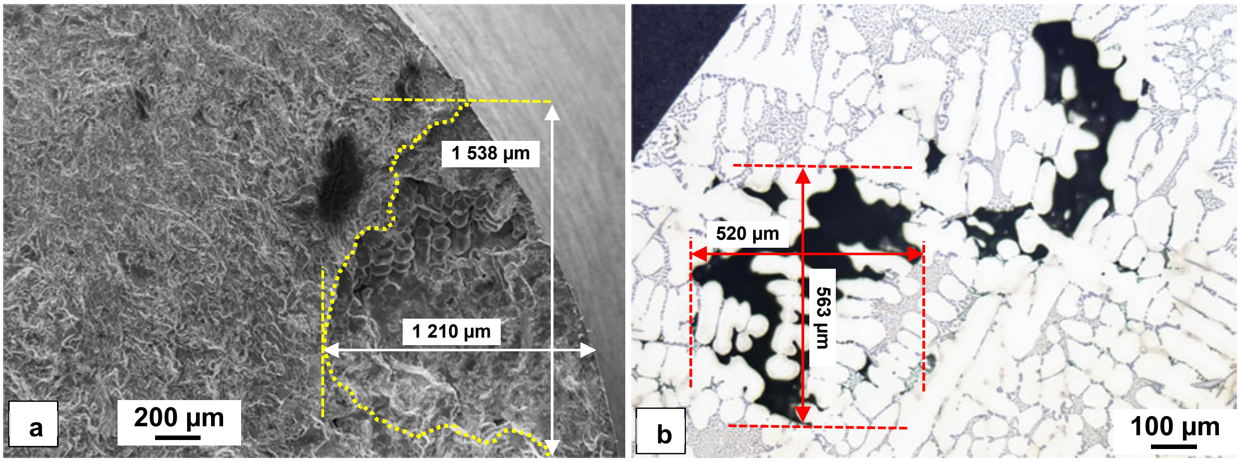

Fig. 4. Porosity of the material: (a) fracture surface - detail of crack initiation, specimen $\sigma_a$ = 100 MPa, $N_f$ = 282 000 cycles; (b) etch. 0.5 % HF.

Fatigue fracture surface were investigated with the use of scanning electron microscopy (SEM) for identity the crack initiation sites. The results show that fatigue cracks in most cases initiated from the pores, which were located near or at the surface on the specimen (Fig. 4) and this is due to rotating bending conditions that develops the highest stress on the surface. It is generally accepted [10, 13] that an interior pore is less detrimental than a surface pore in affecting fatigue performance.

Metallographic measurement of porosity is a common practice in industry and is often used as input to fatigue life prediction models, or to compare casting processes. It is unlikely that a random section through a pore will expose the maximum pore dimension, but under loading, the largest pores will be most favoured to start cracks. As illustrated in Fig. 4, pores observed on the fracture surfaces (Fig. 4a) are larger than those observed on the metallographic planes (Fig. 4b) regardless of the alloy and casting process.

Porosity of all samples was therefore quantified in terms of their lengths, areas and the depth from the SEM specimen free surface (Fig. 5).

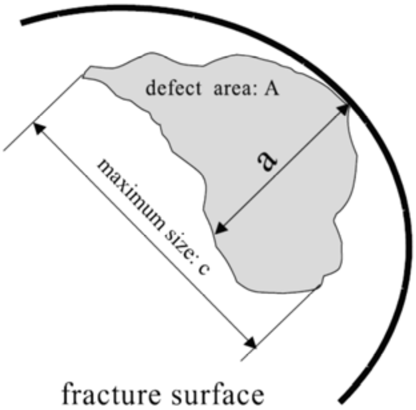

Fig. 5. Illustration of a casting defect and the dimensions on the fracture surface [13].

The fatigue results are corresponding with size of pores and also with morphology of the pores. The diameters of initiating pores were measured in a range of 100 µm to cca 1300 µm. Fig. 6 shows examples from the fatigue fracture surface of AlZn10Si8Mg alloy with different pores size. The effect of surface pores area is immediately evident, as the surface pores size increases; there is significant decrease in the duration of the fatigue life itself. When surface of pores size increases, fatigue life decreases (Fig. 6a) at each stress level and also at the same time, fatigue life also decreases with an increasing the stress amplitudes. When surface of pores size decreases, fatigue life increases (Fig. 6b) at each stress level. The results correspond with authors [17-18].

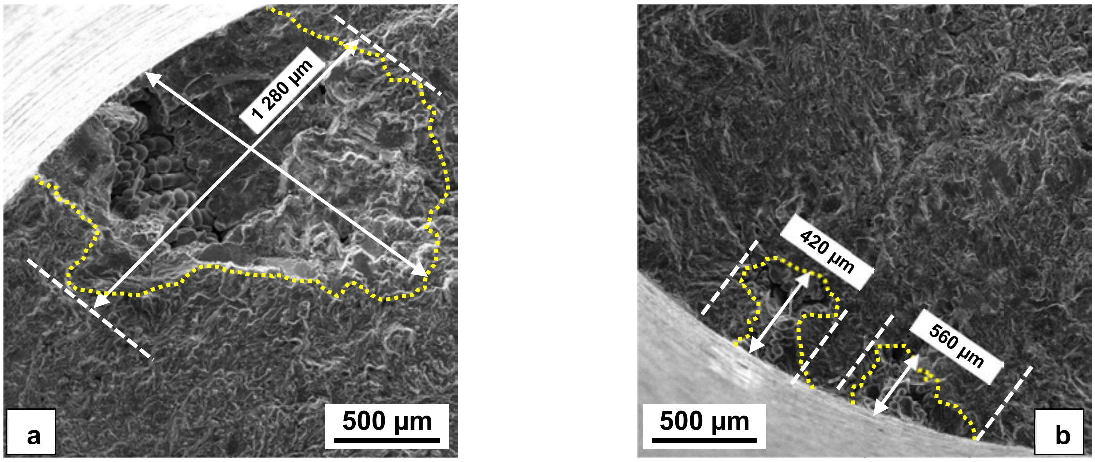

Fig. 6. SEM images of the fatigue fracture surface of AlZn10Si8Mg cast alloy: (a) detail of crack initiation, specimen $\sigma_a$ = 90 MPa, $N_f$ = 553 000 cycles (b) detail of crack initiation, specimen $\sigma_a$ = 60 MPa, $N_f$ = 3 211 000 cycles.

In the cast aluminium alloy are also other microstructural features such as hard, brittle plate or needles Fe-rich phases ($Al_5FeSi$ phase) and can act as the main crack initiation site. Different scientists have reported that iron may have a strong influence on porosity of Al-Si cast alloy, most notably, a change in pore morphology from discrete isolated pores to spongy interdendritic pores can occur even with a small deliberate additions of iron [19]. Taylor [19] proposed also that the defect porosity occurred because Al-Si eutectic grains nucleated on these prior $Al_5FeSi$ platelets and it was this that led to the rapid break down in permeability and hence feeding. But compared with porosity, the eutectic structure and Fe-rich intermetallic phases play a minor role in crack initiation. Detail of pores initiation on brittle and thin plate like $Al_5FeSi$ phase is documented in Fig. 7.

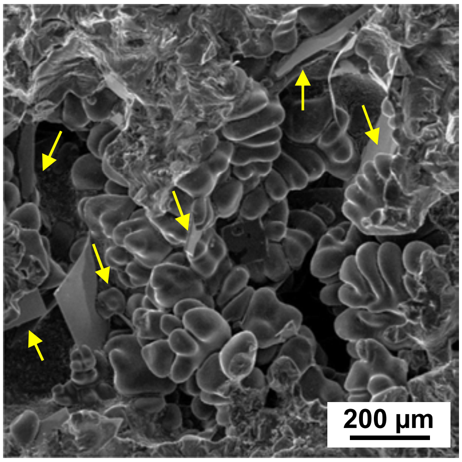

Fig. 7. SEM images of the fatigue fracture surface - detail of pores initiation on brittle and thin plate like $Al_5FeSi$ phase.

## 4. Conclusions

In the present study, the fatigue resistance of self-hardening AlZn10Si8Mg cast alloy was investigated. From an analysis of the results obtained, the following may be concluded:

- The fatigue limit at $N = 3 \times 10^6$ cycles was determined for $\sigma_c = 60$ MPa.
- Surface porosity is the most important casting defect which affects fatigue life. The diameters of initiating pores were measured in a range of 100 µm to cca 1300 µm. As the surface pores size increases the fatigue life decreases.
- Effective sizes of pores increases brittle particles as plate/needle like Fe-rich phases.

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## References

[1] K. Masaki, Y. Ochi, T. Matsumara, Y. Sano, Materials Science and Engineering. (2007) 171-175.
[2] Q.G. Wang, D. Apelian, D.A. Lados, Journal of Light Metals. Vol.1 (2001) 73-84.
[3] I. Peter, Material Science Forum. Vol. 794-796 1221-1226.
[4] Q.G. Wang, P.E. Jones, Metallurgical and Materials Transaction B. (2007) 615-621.
[5] M. Rosso, I. Peter, Ch. Castella, R. Molina, Materials Today: Proceedings 2. (2015) 4949-4956.
[6] E. Tillová, E. Ďuriníková, M. Chalupová, Acta Metallurgica Slovaca. Vol. 17 (2011) 4-10.
[7] E. Ďuriníková, E. Tillová, Manufacturing Technology. Vol. 11 (2011) 11-17.
[8] S.K. Shaha, F.Czerwinski, D.L. Chen, W. Kasprzak, Mater.Sci.Technol. 31 (2015) 63-72.
[9] J. Pezda, Archiwes of Foundry Engineering. 13, (2013) 143-146.
[10] H.R. Ammar, A.M. Samuel, F.H. Samuel, Materials Science and Engineering A. 473 (2008) 65-75.
[11] ISO 1143, Metals - Rotating Bar Bending Fatigue Testing, 1975.
[12] P. Kopas, M, Sága, Manufacturing Technology. 1 (2013) 59-64.
[13] H.R. Ammar, A.M. Samuel, F.H. Samuel, Materials Science and Engineering A. 473 (2008) 58-64.
[14] C.M. Sonsino, J. Ziese, International Journal Fat. 15 (1993) 75-84.
[15] N. Roy, A.M. Samuel, F.H. Samuel, Metal Mater Trans A. (1996) 415-429.
[16] Y.J. Huang, S.Z. Lu, in: Proceedings of the 2nd international aluminum casting technology symposium, A measurement of the porosity in aluminum cast alloys using fractal analysis, 2002.
[17] K.S. Chan, Q.G. Wang, Materials Science and Engineering A. (2003) 18-34.
[18] G. Nicoletto, R. Konečná, S. Fintová, International Journal of Fatigue. Vol. 41 (2012) 39-46.
[19] J.A. Taylor, G.B. Schaffer, D.H. StJohn, Metal Mater Trans A. (1999) 1643-1650.