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Fatigue properties and microstructural analysis of diecast AlSi11Cu2(Fe) alloy: effect of surface finishing

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In the present work, a secondary AlSi11Cu2(Fe) alloy was diecast by means of a specifically designed die. Specimens with both the as-diecast surface quality and after sand-blasting were prepared and subjected to uniaxial fatigue tests in order to investigate the effect of surface finishing on S-N curves. The S-N curves for the two different surface finishing were estimated and compared in terms of inverse slope k and amplitude strength σ_A at 5×10^6 cycles. Experimental data for the two different surface finishing showed a similar statistical dispersion in fatigue life. Nevertheless, amplitude strength σ_A = 73 MPa and S-N slope k = 25.8 were obtained for sand-blasted samples, which are higher than the corresponding σ_A = 62 MPa and k = 11.4 showed by the as-diecast samples. After fatigue testing, both fracture profiles and surfaces were studied by optical and scanning electron microscopy to correlate crack initiation and propagation with fatigue strength. The crack initiation sites were localised mainly along the die separation-line in the as-diecast surface finishing condition, while, for the sand-blasted samples, an essential role in crack initiation was played by casting defects such as oxide films and porosities.

KEYWORDS: DIECAST ALUMINIUM ALLOY – FATIGUE TESTS – CASTING DEFECTS – SAND-BLASTING – MICROSTRUCTURE

INTRODUCTION

In the automotive industry, aluminium-silicon alloys are broadly used due to their high strength to density ratio and corrosion resistance. For the production of structural components with complex geometry and near net shape, high-pressure diecasting (HPDC) process is the most used. Despite in recent years a lot of work has been carried out to improve the quality of cast parts, the main drawback of components produced with HPDC remains the presence of defects. In particular, oxide films, gas and shrinkage porosity, cold shots, and micro or macro segregations are common defects usually affecting the mechanical properties of casting products to some extent. In literature, static and fatigue properties of high-pressure diecast specimens have been deeply studied. Avalle et al [1] showed that the porosity level of high-pressure diecast AlSi9Cu3(Fe) samples in the as-diecast condition controls the properties of the material and that tensile strength decreases linearly with the porosity content. The same authors dealt with the fatigue properties of the samples considering the effect of the as-diecast surface finishing. It is well known that the presen-

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ce of internal defects can surely affect the fatigue behaviour of diecast aluminium components, but they found that the resistance to fatigue loadings is mainly driven by external or subcortical defects as well as by roughness. The influence of porosity on the fatigue strength of an AlSi9Cu3 high-pressure diecast aluminium alloy was also studied by J. Linder et al. [2], with the aim to derive the influence of defect size with respect to the fatigue load.
A. Nourian-Avval et al. [3] evaluated the fatigue behaviour of A356 aluminium alloy specimens obtained by HPDC, in the as-diecast surface condition and considering the effect of the T6 heat treatment. They found that almost all the fatigue failures originated from pores at or near the surface, even though some fatal pores were randomly distributed in the entire cross section.
In light of these studies, the fatigue behaviour of diecast aluminum alloys in the as-diecast finishing condition has become of interest. In fact, fatigue tests are usually performed on machined samples, i.e. without taking into account the real finishing and the presence of sub-cortical defects typically of diecast components.

In this study, with the aim to improve the knowledge on how both the as-diecast and sand-blasted surface finishing as well as the microstructure interact with the fatigue crack initiation and propagation, diecast AlSi11Cu2(Fe) samples were fatigue tested under uniaxial constant amplitude loads at various stress levels. After fatigue testing, fractured samples were investigated by optical microscopy (OM) and scanning electron microscopy (SEM) in order to understand the role of surface finishing, microstructure and defects on fracture initiation and propagation.

MATERIAL AND METHODS

Sample preparation

Multi-specimen castings, composed of specimens for different mechanical tests, were performed using a specifically designed die in a cold-chamber diecasting machine [4]. The locking force of the diecasting machine together with the other process parameters are collected in Table 1. An AlSi11Cu2(Fe) (EN AC-46100) alloy according to standard chemical composition was used to produce the castings.

Tab.1 - HPDC process parameters.

Looking force	Regime die temperature	First phase plunger velocity	Second phase plunger velocity	Third phase pressure
2.9 Mn	~ 230 °C	0.2 m/s	2,7 m/s	40 Mpa

In this investigation, unnotched cylindrical specimens with a nominal diameter of 6 mm underwent fatigue tests. One half of specimens were maintained in the as-diecast surface condition, i.e. with surface details such as flashes. A three-cycle sand-blasting was performed on the other half of specimens. The standard procedure on this alloy is a one-cycle sand-blasting. Before fatigue testing, the arithmetic average surface roughness (Ra) of 0,62 ± 0,10 and 6,42 ± 1,13 was measured by a Handysurf E-35 (Zeiss, Oberkochen, Germany) stylus roughness tester on as-diecast and sand-blasted specimens, respectively.

FATIGUE TESTS

Uniaxial constant amplitude fatigue tests were performed by an Italsigma LM10 (Italsigma, Forlì, Italy) servo-hydraulic testing machine with a 20 kN load cell and at a load control with a frequency of 28 Hz. A stress ratio R = 0.1, which corresponds to a tension-tension cycle with $\sigma_{min}=0.1\cdot\sigma_{max}$, was chosen. In order to set up the different load levels, the average static properties in terms of yield strength (152 ± 5 MPa) and ultimate tensile strength (303 ± 4 MPa) were firstly evaluated. In light of this, and according to the load conditions collected in Table 2, all fatigue tests were carried out with stress amplitudes between 65 MPa and 82 MPa; a number of cycles equal to $1\cdot10^7$ was considered as the 'run-out' value.

Tab.2 - Fatigue tests set up.

σ_a [MPa]	$\Delta\sigma$ [MPa]	σ_{max} [MPa]	σ_{min} [MPa]	σ_m [MPa]
65	130	144	14	79
72	144	160	16	88
74	148	164	16	90
75	150	167	17	92
78	156	173	17	95
80	160	178	18	98
82	164	182	18	100

MICROSTRUCTURAL ANALYSIS

After fatigue testing, preliminary observations of the fracture surfaces of all the tested samples were carried out by a Leica MZ6 (Leica, Weztlar, Germany) stereomicroscope in order to identify at low magnifications the potential initiation sites and macro-defects which might have played a significant role in determining the mechanical behaviour of the material. Microstructural investigations were then performed by a Leica DMi8A (Leica, Wetzlar, Germany) optical microscope and a Zeiss EVO MA 15 (Zeiss, Oberkochen, Germany) scanning electron microscope to study the main microstructural features involved in both fracture initiation and propagation.

RESULTS AND DISCUSSION

Fatigue tests

Figure 1 displays the results of the fatigue tests for both the as-diecast and the sand-blasted samples. The S-N curves for the two different surface finishing were estimated in terms of the inverse slope k of the linear regressions. The amplitude strength σ_A at 5×10^6 cycles was assessed, as well as the scatter bands at 10% and 90% of survival probability. Regardless of the surface finishing, the results show a similar statistical dispersion in fatigue life. The values of amplitude strength σ_A = 73 MPa and S-N slope k = 25.8 obtained for sand-blasted samples are higher than the corresponding σ_A = 62 MPa and k = 11.4 shown by the as-diecast samples.

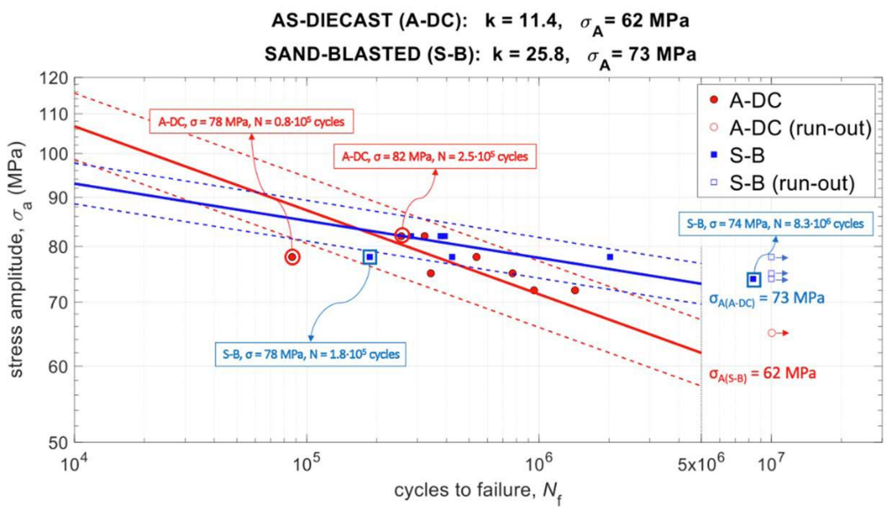

Fig.1 - S-N curves for as-diecast and sand-blasted specimens.

MICROSTRUCTURAL INVESTIGATIONS

The results of fatigue tests were subsequently analysed and interpreted on the basis of microstructural investigations conducted by stereomicroscopy, OM and SEM.

Before fatigue testing, the main microstructural features of the material were studied by OM on both longitudinal and transverse sections of the samples (Fig.2). Casting defects typically of high-pressure die-casting process were detected.

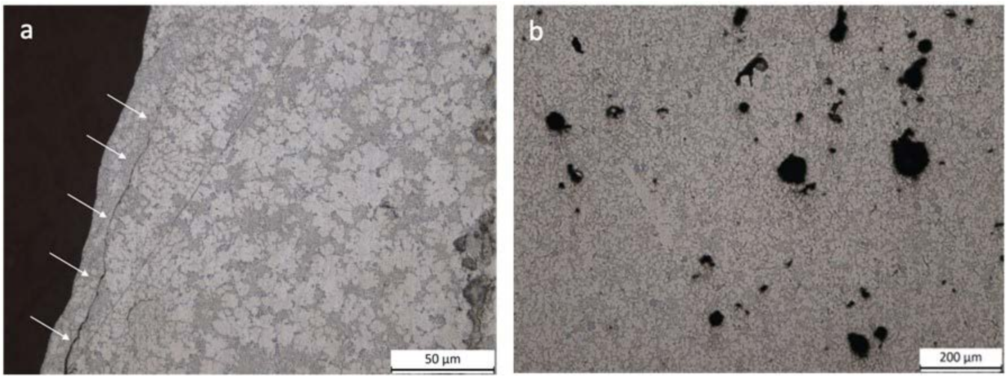

Fig.2 - OM micrographs of typical casting defects observed in the as-diecast samples: a) lamination and b) air/gas porosities.

In particular, the presence of lamination near to the casting surface (Fig.2a) as well as air/gas porosities close to the centre (Fig.2b) of the samples were observed; these defects can strongly affect the dynamic mechanical properties of the alloy.

The micrographs of the longitudinal sections of as-diecast and sand-blasted samples in Fig.3 show the different surface finishing induced by sand-blasting, in agreement with the measured roughness values. Moreover, the microstructure of the sand-blasted sample is clearly modified for the thickness of a few tens of microns below the surface. This may explain the improved fatigue behaviour of the alloy obtained in the fatigue tests (Fig.1).

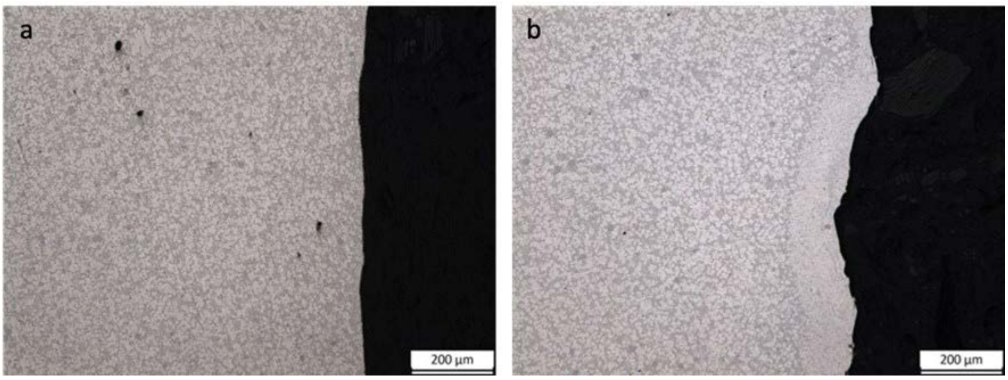

Fig.3 - OM microstructure and surface finishing of the longitudinal section of a) as-diecast and b) sand-blasted samples.

After fatigue testing, preliminary investigations of the fracture surfaces were carried out by stereomicroscopy in order to identify the fracture initiation sites and the macro-defects that played a significant role in the fracture mechanism. Figure 4 depicts the images of the fracture surfaces of four different tested samples with detail at higher magnification of the initiation site. The number of cycles at failure for each sample is also highlighted in Fig.2. Among all the tested samples, the sand-blasted sample in Fig.4c is characterised by the highest number of cycles at failure and the initiation site can be identified as an internal defect.

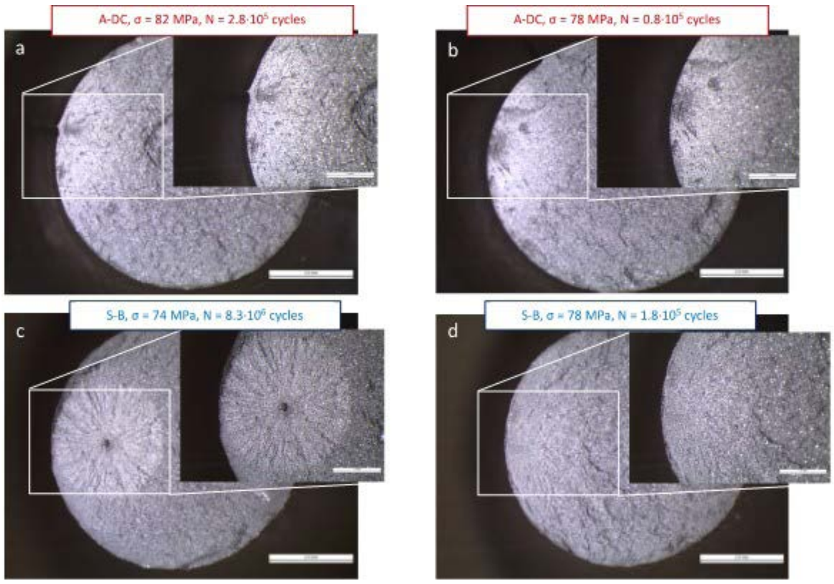

Fig.4 - Fracture surfaces of four different samples: a,b) as-diecast and c,d) sand-basted samples.

Fractographic analysis performed by SEM showed that, for as-diecast samples, the surface defects or sub-cortical pores provided sites for fatigue crack initiation. In Fig.5a it is possible to observe that the initiation of the fatigue fracture occurred at the flash generated by the parting line of the die (Fig.5b). In other samples, the initiation of the crack is promoted by the presence of sub-surface defects, such as porosities (Fig.5c and 5d).

Considering the sand-blasted samples (Fig.5e and 5g), the crack mainly initiated from internal defects such as porosities (Fig.5f) or cold joints (Fig.5d), generated by the die-casting process; overall, the samples that showed a longer fatigue life were those with the crack initiated from internal defects. This result is due to the compressive stress on the surface defects that is caused by sand-blasting.

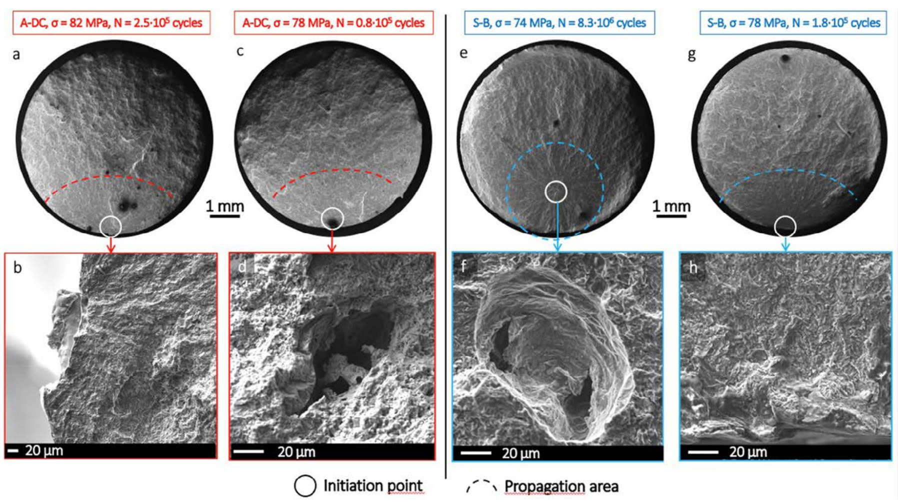

Fig.5- Fracture surfaces of four different samples: a,b) as-diecast and c,d) sand-basted samples.

CONCLUSIONS

In this work, uniaxial constant amplitude fatigue tests with stress ratio R = 0.1 were performed on AlSi11Cu2(Fe) diecast specimens and the effect of sand-blasting in improving the fatigue behaviour of the alloy was evaluated. Regardless of the surface finishing, the results show a similar statistical dispersion in fatigue life, even though the amplitude strength and S-N slope for sand-blasted specimens resulted higher than the corresponding ones for the as-diecast specimens. Microstructural investigations confirmed that crack initiation sites in as-diecast specimens are preferentially localised on the surface or on sub-cortical defects, while in sand-blasted ones also internal defects provide sites for fatigue crack initiation.

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