STATIC AND FATIGUE STRENGTH OF A DIE CAST ALUMINIUM ALLOY UNDER DIFFERENT FEEDING CONDITIONS

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Abstract

The paper investigates the influence of porosity and casting defects on the static and constant-amplitude fatigue strength of a die cast aluminium alloy. Three batches of specimens, differing for the sprue-runner design and consequently for content and type of defects, are tested in "as cast" conditions. Defects consist in gas and shrinkage pores as well as cold fills, dross and alumina skins. Casting defects are observed to significantly lower the static and fatigue properties of the material. While for the static characteristics the decrease is progressive with the porosity range, for the fatigue strength the decrease is most significant from the lowest to the middle porosity range. The batches are classified with regards to the porosity level, as the metallurgical defects are not detectable a priori through X-ray examination. However, content and size of metallurgical defects are observed to increase together with the porosity level. SEM observation of the fracture surfaces proved the important role played by dross, alumina skins and, above all, cold fills on the fatigue fracture.

Riassunto

INTRODUCTION

Casting is the most economical way to transfer raw materials into readily usable components. However, one of the major drawbacks for conventional and even more advanced casting techniques is the formation of shrinkage and gas cavities, often coupled with other defects: cold fills, alumina skins, dross [1].

The literature on the influence of casting defects on the material properties of cast aluminium alloys is quite broad [2-9]. It is generally acknowledged that the static and fatigue strength of materials containing defects is lower than that of a defect free material. In the case of fatigue strength, defect distance from a free surface needs to be taken into account. Recent data also showed the importance of the distribution and morphology of phases in the microstructure. In [9], fatigue strength is observed to vary with solidification parameters and hence location in the casting.

In general, literature data are almost exclusively concerned with the effect of porosity, as investigations are carried out on samples obtained by sand or permanent mould casting. Moreover, often the difference between the samples consist in the adjustment of the melt gas content which is likely to influence the porosity level alone. On the other hand, the aforementioned metallurgical defects, more commonly encountered in die casting components, are known to adversely affect the mechanical properties [1], but quantitative data are still lacking. Understanding the influence of these defects can be quite important, considering that, contrary to shrinkage and gas porosity, they are usually not detected by the foundry on-line radioscopic quality control.

The paper investigates the influence of casting defects on the static and constant amplitude fatigue strength of a die cast aluminium alloy. Three batches of standard specimens are tested which are characterised by a different sprue-runner design and consequently different feeding conditions. Defects consist in gas and shrinkage pores as well as cold fills, dross and alumina skins. The material is EN AC-46000 - UNI EN 1706 (ex GD – Al Si8.5 Cu 3.5 Fe - UNI 50759). Hypo-eutectic aluminium-silicon alloys are widely used in industrial applications due to the favourable strength/weight ratio and good manufacturability.

EXPERIMENTAL

The chemical composition (wt%) and mechanical properties of the alloy used in this study are given in Table 1 and 2, respectively (UNI EN 1706).
The geometry and dimensions of static and fatigue specimens are depicted in Figure 1. Specimens were obtained directly from die casting and were tested in "as cast" conditions (i.e. with as cast surface). The only modification to the cast surface was the trimming of the overpress of the half mould. Three different batches of specimens were tested. In the attempt of studying the influence of casting defects and not of porosity alone, the batches were characterised by a different sprue-runner design, i.e. different feeding conditions.
Figure 2 depicts the sprue-runner design for the high porosity range: the feeding occurred at the level of the two fillets with a vertical inflow and no feeder. For the middle porosity range, one feeding channel was closed and two small feeders added at the specimen extremities. For the low porosity range, the sprue runner was completely changed. A single large feeding channel was used to feed one extremity of the specimen. The inflow was therefore coaxial with the specimen. A large feeder was added on the other extremity of the specimen.
Prior to testing, each specimen was examined through X-ray in order to assess the specimen porosity level. The three batches were classified as ranges 0, 2, 4 (category A) according to ASTM E505 standard [10]. Density measurements of the three batches were also taken in support of the X-ray classification (Table 3). Regarding porosity, it should be noted that even specimens classified as having a porosity range A0 are not free from pores. They have scattered/isolated micropores up to 0.1 mm in size. These micropores are also found adjacent to larger pores in specimens with a higher range of porosity. With porosity range A2, pore diameters up to 0.2 mm were found and with porosity range A4, pore diameters up to 0.5 mm.
SEM pictures taken on the fracture surfaces proved that the cavities are rounded and more concentrated in the core of the castings (Figure 3). The pore shape and limited size of the samples indicate that porosity arises mainly by entrapped air bubbles during the feeding of the die and eventually by hydrogen development during solidification. However, shrinkage is also present at the centre of the samples for high porosity ranges.

TABLE 1. CHEMICAL COMPOSITION OF THE ALUMINIUM ALLOY USED IN THE STUDY (% BY WEIGHT)

Si	Cu	Fe	Zn	Mn	Mg	Ni	Ti	Pb
9.83	2.99	0.98	1.11	0.19	0.04	0.064	0.052	0.19

TABLE 2. MECHANICAL PROPERTIES OF THE ALUMINIUM ALLOY USED IN THE STUDY

E (GPa)	r (kg/m^3)	$R_{p0.2}$ (MPa)	R_m (MPa)	A%
70	2730	140	240	1

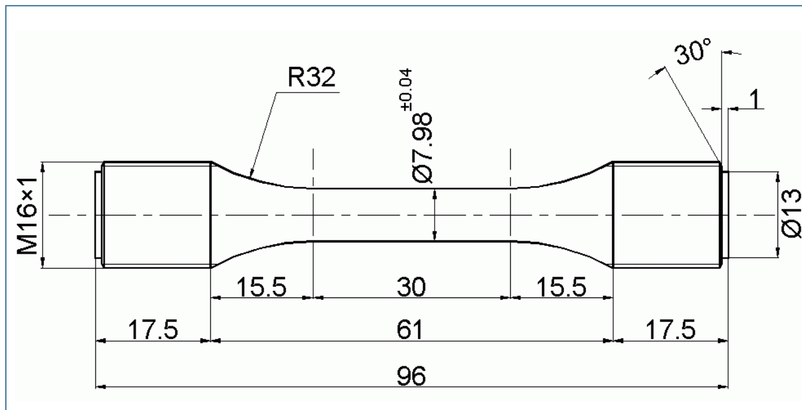

Fig. 1: Static and rotating bending fatigue specimen

Fig. 2: Sprue-runner design for high porosity range (A4)

TABLE 3. DENSITY MEASUREMENTS ON THE SPECIMEN BATCHES

	A0	A2	A4
ρ (kg/m^3)	2730	2570	2230

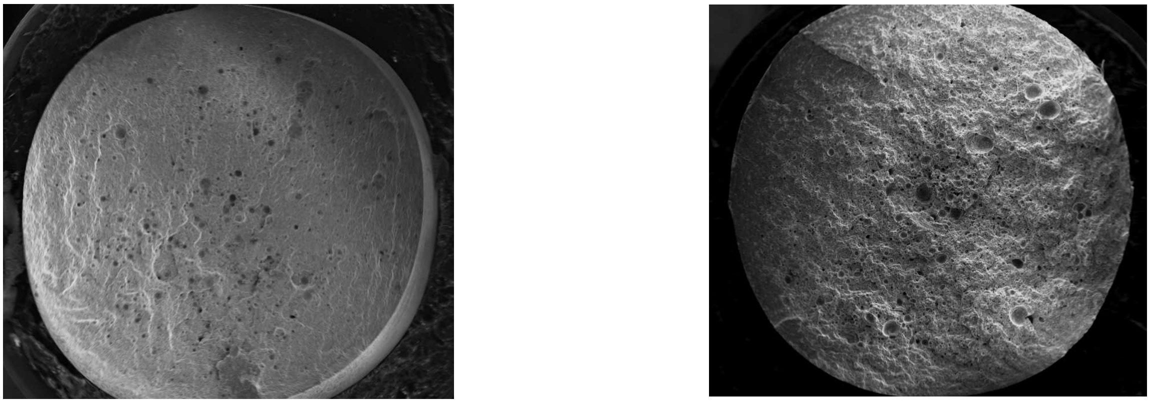

Fig. 3: Representative fracture surfaces for the A2 (left) and A4 batch (right). 30X

As mentioned above, the changes in the sprue-runner design introduced by the foundry are likely to increase the porosity level as well as the presence of other casting defects due to a non-optimisation of the feeding channel. However, casting defects as dross, cold fills and alumina skins are not detectable a priori through X-ray examination. An initial classification for the three batches was therefore made with regards to the porosity level alone.

RESULTS AND DISCUSSION

Figure 4 shows static stress-strain characteristics for the three batches. Owing to important variations in density (Table 3), a notable decrease in the yield and ultimate strength with the degree of porosity is observed. As expected, the elongation at rupture also decreased for increasing levels of porosity.

Fatigue testing was carried out by means of a cantilever bending machine at 100 Hz. Cantilever rotating bending tests were run against tensile fatigue tests, considering that specimens are tested in "as cast" conditions and die casting is known to enhance material properties at the surface. One first series of tests was run on the A0 batch with the purpose of investigating the material under study.

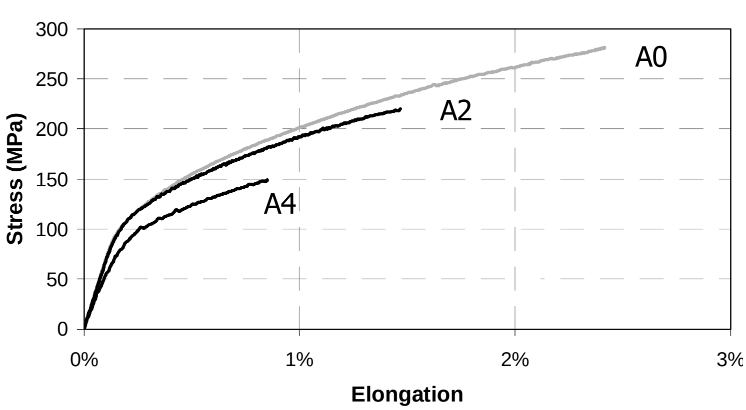

Fig. 4: Static stress-strain curves for the three batches

S-N curves were taken up to 10^7 cycles and the fatigue crack initiation sites were characterised by using SEM.

The fatigue strength at 10^7 cycles was determined by means of a stair-case procedure. A median value for the fatigue strength of 143 MPa was found, with a standard deviation of 3.9 MPa. Therefore, the fatigue strength falls very close to the yield strength of the material. It is generally acknowledged [4] that, for materials for which there is little difference between the endurance limit and the yield strength, the S-N curves are quite flat. To verify the hypothesis, a second stair-case was run to estimate the fatigue strength at $2\cdot10^6$ cycles. A median value for the fatigue strength of 152 MPa was found, with a standard deviation of 4.9 MPa. The difference between the fatigue strength at $2\cdot10^6$ and 10^7 cycles is indeed limited, as expected.

Figure 5 shows S-N curves for the A0 specimens. A series of fatigue tests was run to failure at different peak stress levels, from 150 to 190 MPa. The stress range was limited considering that the stress levels are above the yield strength of the material.

For comparison of the three batches, the fatigue strength at $2\cdot10^6$ cycles was evaluated by means of a stair-case procedure. Figure 6 shows results obtained for the different batches as for fatigue strength median value and standard deviation. The decrease in fatigue strength appears to be most significant when the degree of porosity is increased from A0 to A2, while it is distinctly lower from A2 to A4. This trend of results is in agreement with literature data published by Sonsino and Ziese on silicon-magnesium aluminium cast alloys [4].

SEM pictures taken on the fracture surfaces proved that for the A0 batch the fatigue fractures originate from an area with no visible defects. For the A2 and A4 batches, the fatigue cracks initiate from gas cavities (Fig. 7a) as well as dross (Fig. 7b), cold fills (Fig. 7c) and alumina skins (Fig. 7d). Indeed, the changes in the sprue-runner design made by the foundry caused an increase in the porosity level as well as in the content of other casting defects due to a non-optimisation of the feeding channel. It is the combination of pores and other metallurgical defects to cause the decrease in material properties observed among the three batches. This combination of casting defects might well be the reason for the observed large decrease in material characteristics as compared to literature sources [2-5].

In the authors' opinion, a change in the sprue-runner design may be more representative of real work conditions, i.e. different design of the die, than the simple addition of gas content in the melt as often done in literature works. In this respect, it is worthwhile underlining that cavities tend to concentrate in the middle of thick sections while cold fills represent a discontinuity in the material at the edge of the specimen, where fatigue cracks tend to nucleate.

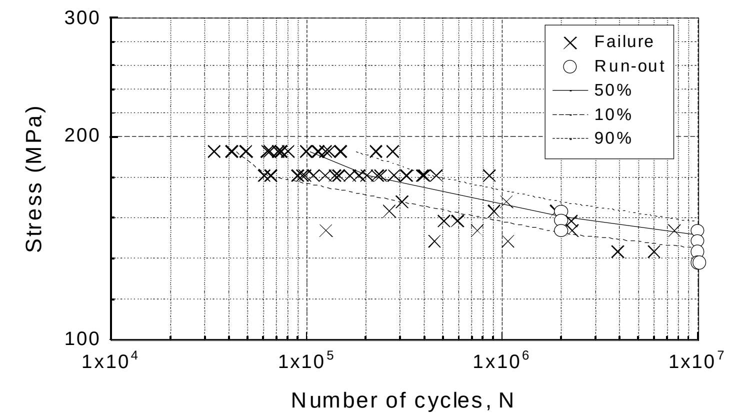

Fig. 5: S-N fatigue curve for the A0 batch. Percentages refer to probability of survival

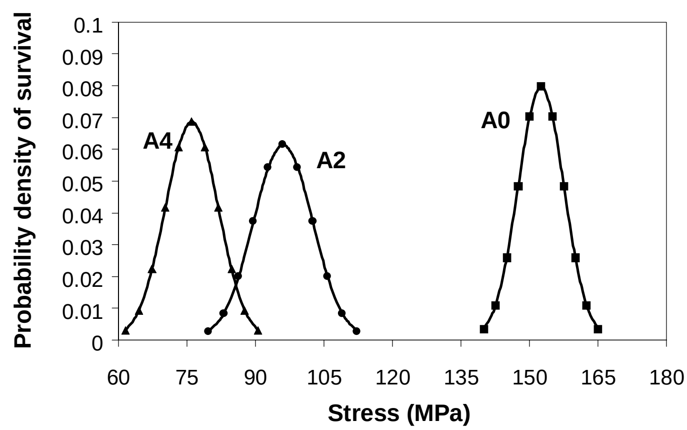

Fig. 6: Comparison for the fatigue strength at 2·10^6 cycles for the three batches

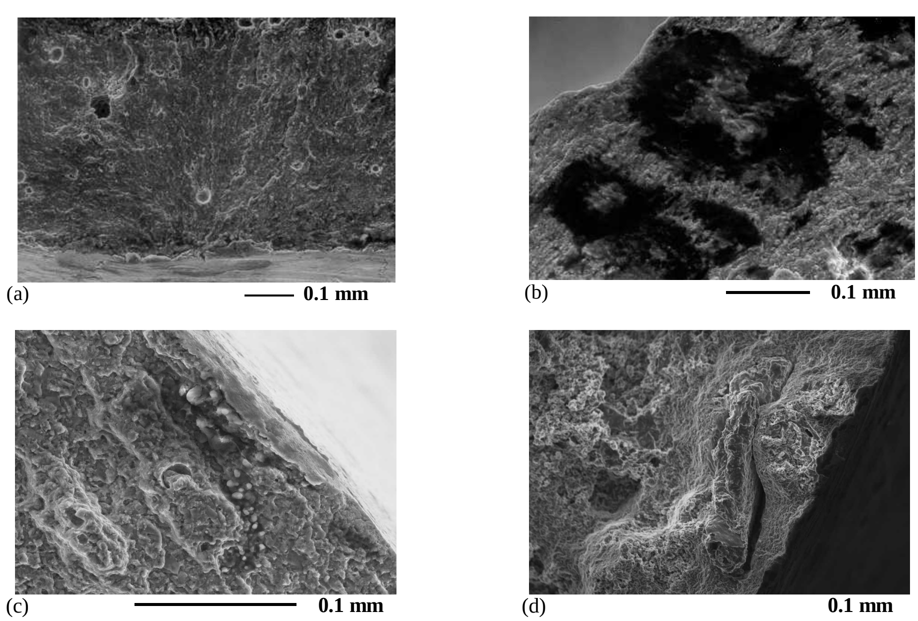

Fig. 7: Fatigue cracks originating from casting defects. Gas cavities (150 X), dross (250 X), cold fills (500 X), alumina skins (140 X)

CONCLUSIONS

Changes in the sprue-runner design have been observed to affect the porosity level of the casting as well as the content of other casting defects as dross, alumina skins and cold fills. Casting defects are observed to lower the static and fatigue strength of the material. While for the static characteristics the decrease is progressive with the defect content; for the fatigue strength the decrease is most significant at first. The observed decrease in material characteristics is greater as compared to literature data since the combined effect of porosity and metallurgical defects is considered, whereas in most experimental studies batches differ for the melt gas content, i.e. for the porosity level alone.

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