Edited by J.F. Nie, A.J. Morton and B.C. Muddle

Fracture Analysis of a Crack Propagating in Aluminium-7% Silicon Alloy Casting

S. Nishido[1,2], H. Toda[2], T. Kobayashi[2], J. Katano[2]

[1] Aisin Takaoka Co., Ltd, 1 Tennoh, Takaokashin-machi, Toyota, Aichi, 473-8501, Japan
[2] Department of Production Engineering, Toyohashi University of Technology, 1-1, Hibarigaoka, Tempaku, Toyohashi, 441-8580, Japan

Keywords: aluminium-7% silicon alloy, crack propagation, mechanical properties, eutectic silicon, damage, FEM analysis,.

Abstract

In this study the fracture behavior in an Al-Si alloy with different cooling rates was investigated. Under tensile and bending conditions, the differences of the damaging ratio of Si particles and theirs relaxation effect were estimated with the spatial distribution of Si particles. The distribution of Si particles has an effect on the crack path as well. The crack propagation paths were estimated by the FEM analysis supposed binary phase material at the crack tip. The closely microstructures were susceptible to microstructure factor such as primary α phase and eutectic region. The tortuous crack path in the case of closely material was related to microstructure closeness.

1. Introduction

Cast Al-Si alloys are conventional materials that have been used for structural members where great importance must be focused on mechanical property [1-3]. There are a great number of papers and reports in the literature in which the mechanical properties of Al-Si alloys have been experimentally investigated from various aspects. Tensile strength and elongation are related to its microstructures by changing cooling rate during solidification and heat treatment condition to achieve better mechanical properties.

In this study, Al-7%Si binary alloy has been produced as model materials which are cast at two different cooling rates in order to obtain different microstructure; especially primary α-phase and eutectic Si. In the case of commercial alloy, many factor such as casting defects, precipitate of aging, dispersion particles and Si particle morphology affect for fracture behavior. Therefore, it is very difficult to specify a contribution ratio for each factor.

That was why in this study the model alloy was applied and author was observed attended to Si particle damage. SEM In-situ observations of tensile and 3-point bending tests have been used to characterize crack propagation behaviours focusing on damage behaviors at Si particle [4-5].

A numerical model has been created based on real microstructures. In the FEM analysis, the model with the same size as a 3-D test piece shape is constructed to simulate observed crack propagation behaviours exactly. The input data of simulation are measured by tensile tests; those of pure aluminium and eutectic alloys are used for an α-phase and an eutectic phase, respectively. The differences in Si particle size and shape are considered by incorporating such microstructural affects into the input data by homogenization.

The FEM analysis technique seems to hold promise for cutting both time and cost as it reduces the need for endlessly repeating laborious experimental efforts as has been performed on the development processes of conventional materials.

2. Experimental Procedures

2.1 Materials for mechanical test

A pure Al-7%Si alloy was used in this study. 99.999% purity aluminium and 99.3% purity silicon were used to prepare the simple binary Al-Si alloy. The chemical composition is shown in Table 1. The melt surface was thoroughly skimmed and degassed with dry argon gas at 2 *l*/min for 1.8ks.

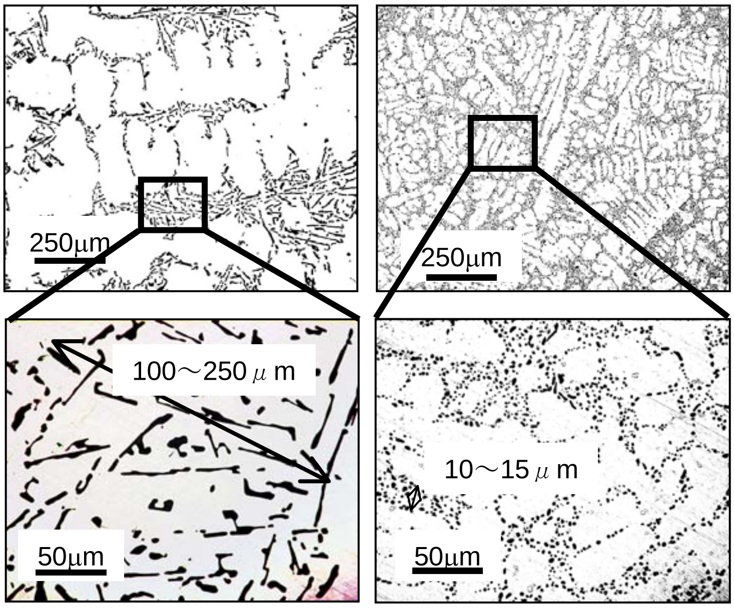
Table 1 Chemical composition of model alloy

Si	Cu	Mg	Zn	Fe	Mn	Ti	Pb	Sn	Ni	Cr	Al
7.05	<0.005	<0.005	<0.005	0.021	<0.005	<0.005	<0.005	0.008	<0.005	<0.005	Bal.

The alloy was poured into the two different types of mould to produce different microstructures by changing cooling rates. A cylindrical mould of 150mm in diameter and 300mm in height which was made from insulation material is utilized to obtain the lower cooling rate. This type of material is hereinafter called LC material. An 80X150X15mm ship shaped permanent mould was used for the higher cooling rate. This type is called HC material. Heat treatment was applied to all castings. The spheroidization treatment was applied at 808K for 14.4ks and lower temperature heat treatment was applied at 453K for 10.8ks. Microstructures for both materials are shown in Figure 1. The Secondary Dendrite Arm Spacing (DASII) and the width of the eutectic region were 130μm and 100~250μm for LC material, 20 μm and 10~15 μm for HC material, respectively.

2.2 SEM in-situ observation

Tensile tests inside the SEM were conducted on flat plate specimens of cross section 2X4 mm and gauge length 5 mm within the chamber of an SEM at a loading rate of 0.1 mm/min. Crack propagation tests were conducted on flat plate specimens of cross section 2X10 mm and span length 30 mm. Specimens were polished by conventional techniques using 0.1 μm diameter diamond slurry in the final process. A cross head was advanced incrementally during the tensile tests whilst observing the specimen surface without unloading the specimens. Sizes of both broken and intact particles as well as applied strain levels were recorded. In the crack propagation tests, the main cracks were observed with the features of microstructures.

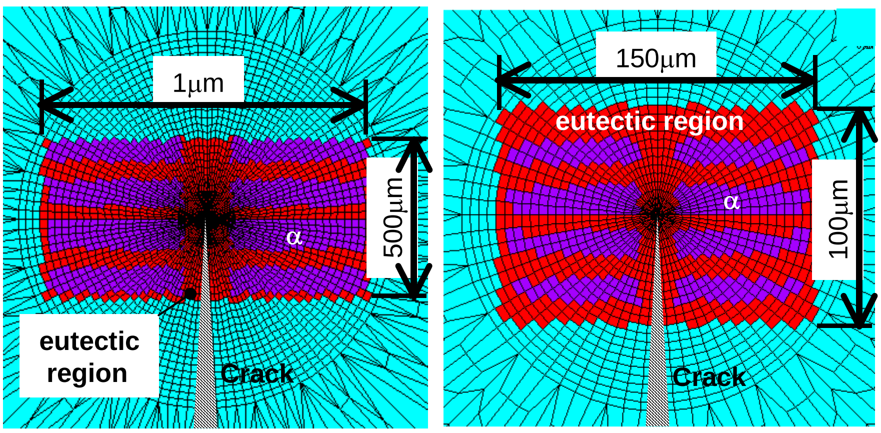


(a).LC Material (b).HC Material

Figure 1: Microstructures of LC and HC material

2.3 FEM analysis model

Two different types of materials with the feature same as the SEM in-situ tests were modeled by the FEM analysis shown in Figure 2-(a) and (b). This model material is an Al-7%Si alloy. Only a crack tip was modeled in details. The model was assumed to have two phases; α phase and eutectic region. The same element was applied to this calculation to ignore a difference in element shape. The 150 µm x 100 µm area for HC material and the 1mm x 500µm area for LC material, around the crack tip were divided into two phases that are α and eutectic region. These areas were assumed to have a eutectic region for each material. The α phase was supposed to be a rectangle shape to simplify calculation difficulties. The mechanical properties of pure Al and Al-12.6%Si alloy were applied to each α phase and eutectic region. The mechanical properties outside the above-mentioned area are assumed to be homogeneous and same as Al-7% Si alloys. All the input properties were measured by mechanical test.



(a). LC Material (b). HC Material

Figure 2: Numerical model (a).LC material (b).HC material

3. Results and Discussions

3.1 SEM in-situ tensile observation

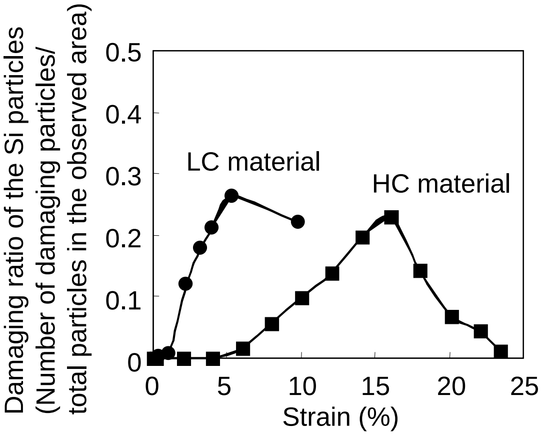


Figure 3: The relationships between damaging ratio of the Si particles and strain.

Figure 3 represents the damaging ratio of the Si particles as a function of strain in the in-situ tensile studies. The internal stress in the particle was increase with increasing the strain in the matrix, and then damaging ratio of Si particles was increased once. However, the damaging ratio was decreased by accumulative damage was restrained with decrease the strain in the matrix by relaxation effect of damaged Si.

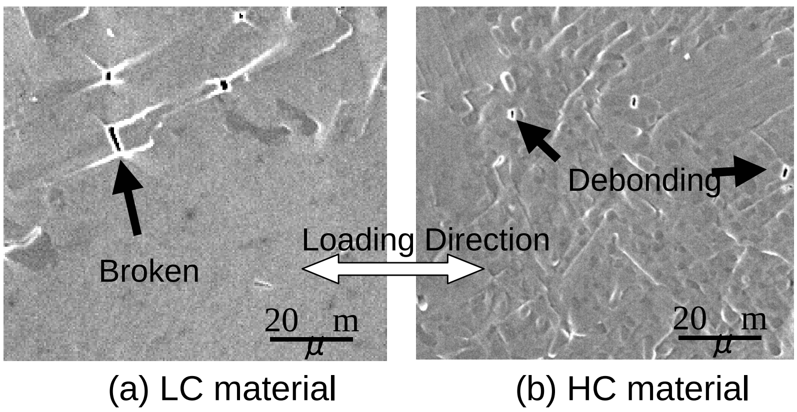
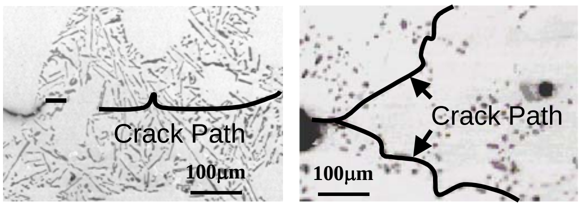


Figure 4: Damaged Si particles LC and HC materials

Figure 4 represents damaged Si particles in LC and HC materials. The shape of a Si particle in LC material is flat and thin, while that of HC material has a spheroidized shape. In the case of LC material the Si particles were mainly damaged by broken especially in the region where particles arranges in parallel to the loading direction. This behavior was caused by the differences of deformation ability of α phase and eutectic region. In the early stages the α phase was deformed in the direction perpendicular to the loading direction. The Si particles located in a parallel direction to the loading direction had lower resistance to deformation because the length of the Si particle in the direction of the stress was shorter than the particles located perpendicularly. On the other hand, debonding around Si was the main type of damage evident in the HC material.

The Si particles has size dependant of breaking strength as same as many dispersion particles. The debonding at the interface of Si particle and matrix was coursed by decreased grain size because of smaller particle has higher breaking strength.



(a) LC material (b) HC material

Figure 5: Crack path for LC and HC materials

3.2 Crack propagation observation

Figure 6 represents crack propagation behavior for both LC and HC materials. In the case of LC material a main crack was propagates almost straightly through the eutectic region detouring around the α phases. In the case of the HC material the main crack was propagated torturous through the eutectic region. The crack was not detouring the α phase, crack path was strongly effected microstructure morphology.

These phenomenons were same as fatigue crack propagation. Kobayashi et al dealing with crack path for Al-Si-Cu system alloy under the fatigue condition [6]. The behavior was similar inclination as this study. The crack was propagated straightly with larger Si particles and coursed distribution material.

The crack path and crack propagation were effect of the spatial distribution of Si particles considering the circumstances mentioned above.

3-3 FEM analysis

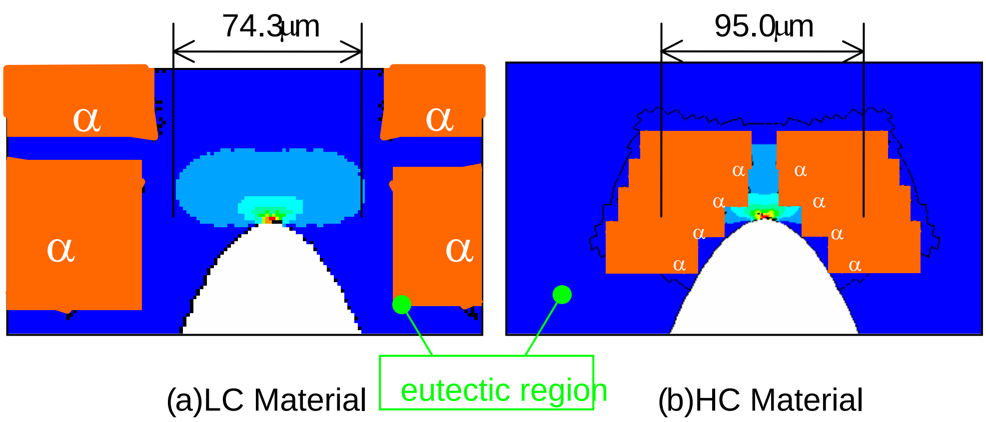


Figure 6: FEM results of each materials (a)LC material, (b)HC Material

The result of a two-phase model is shown in Figure 6. The stress was deserved as a gourd shape at the crack tip. The focused area which was divided into an α and an eutectic regions included the high stress distribution region. The High stress area in the case of the LC material was limited to the eutectic region, while the high stress area in the case of the HC material was extended to the α phase area. The High stress area of the HC material is higher than that of the LC material. The size of the high stress area was 74.3 μm for LC material and 95.0 μm for HC material.

In the case of HC material, the crack path will be tortuous because of the eutectic regions which toward various directions were sampled and the deformation at the crack tip was not uniformity by microstructure distribution. This phenomenon caused increasing crack propagation resistance.

As mentioned above, it was found that the condition of spatial distribution of Si particles was effect for the fracture toughness in the Al-Si alloys. It is need the quantitative analysis for the tortuous crack path using the large-scale 3D crack propagation analysis.

4. Conclusions

An evaluation of the relationship between microstructure and fracture mechanics in Al-Si model alloy has been carried out. From the SEM in-situ observation and FEM analysis, the following conclusions can be drawn:

1. Under the tensile condition, the internal stress in the particle was increase with increasing the strain in the matrix, and then damaging ratio of Si particles was increased once. However, the damaging ratio was decreased by accumulative damage was restrained with decrease the strain in the matrix by relaxation effect of damaged Si.
2. Under the bending condition, the crack was propagated straightly with large Si particles and coursed distribution material. Contrary, the crack was propagated torturous with the closely microstructure. The crack path and crack propagation were effect of the spatial distribution of Si particles.
3. The condition of spatial distribution of Si particles was effect for the fracture toughness in the Al-Si alloys. It is need the quantitative analysis for the tortuous crack path using the large-scale 3D crack propagation analysis.

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