FRACTURE BEHAVIOR OF DEPOSITED AlSiFe ALLOY①

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ABSTRACT The fracture behavior of a spray deposited AlSiFe alloy during tensile deformation has been studied. The results showed that the microcracks initiated both inside Si phases and at the boundaries of Si phases with the matrix during the tension. Some microcracks inside Si phases existed before tensile deformation, while the others generated due to the brittle fracture of Si phase during tension deformation. Microcracks at the boundaries of Si phase with matrix were caused by microporosity and bad mechanical connecting between them. The failure of the materials occurred through joining of these microcracks.

Key words spray deposition Al-Si alloy fracture

1 INTRODUCTION

Fracture behavior has been studied as an important subject for composite materials and rapidly solidified alloys, especially for brittle particles embedded in a ductile matrix. Fracture behavior is very complex because the materials usually bear different kinds of load and possess various microstructure characteristics. In recent years studies in this area have gained great progress in the development of new composite materials and rapidly solidified alloys[1-4].

The relatively low coefficient of thermal expansion and high wear resistance, modulus and strength characteristics of rapidly solidified Al-SiFe alloys have gained great interests as new materials for automotive engine, but studies on the fracture of the alloys are still few so far. Reference [5] investigated the fracture mechanism of spray Al-15Si-3Fe alloy with small amount of other alloying elements.

The purpose of this work is to study the fracture mechanism of the spray deposited Al-20.8Si-5.4Fe alloy.

2 EXPERIMENTAL PROCEDURE

AlSiFe alloys with 20.8% Si, 5.4% Fe and small amount of other alloying elements were prepared from 99.99% Al, 99.7% Si and 99% Fe. The parameters of spray deposition are listed in Table 1.

Consolidation was made through hot extrusion at temperature of 450 ℃, with a section reduction rate of 12∶1. Semi-finished product was shaped into rods with a diameter of 15 mm.

The specimens for optical metallographic observation were prepared using normal techniques and etched by 0.5% HF.

Microstructure and fracture morphology observations were performed with an Olympas BH-2 microscope (OM) and an S-570 SEM. The process of fracture was identified using an in situ SEM tensile tester.

Table 1 The technological parameters of spray deposition

Atomization gas	Atomization pressure/MPa	Atomizer structure	Spray angle/(°)	Deposition distance/mm	Melt temperature/℃	Delivery tube diameter/mm
N_2	3.0	ring cranny	75	400	870	3.0

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3 RESULTS AND DISCUSSION

3.1 Microstructure and process of fracture

Fig. 1 is the microstructure of as-extruded AlSiFe alloy. In these micrometallographs, α-Al, particle-like Si phases and intermetallics can be seen. Si phases and intermetallics are less than 4 μm in size and homogeneously distributed in α-Al matrix. The size of intermetallics is smaller than that of Si phase. Therefore, both Si phases and intermetallics are dispersion strengthening phases. This is the reason why the as-spray deposited alloys possess much higher mechanical properties than do the ingot metallurgy alloys with the same chemical composition[6].

Fig. 2(a) and (b) show the crack formation in the alloys during SEM tensile test. Before tensile deformation, some microcracks have existed inside Si phases and many microporosities have appeared at the boundaries of Si phase with matrix (see Fig. 1(b)). While tensile deformation proceeds to a certain extent, a plenty of microcracks form in the matrix, going through the Si phases or along the boundaries of the Si phases with matrix (see Fig. 2(a)). These microcracks are all perpendicular to the tensile direction. While tensile deformation proceeds further,

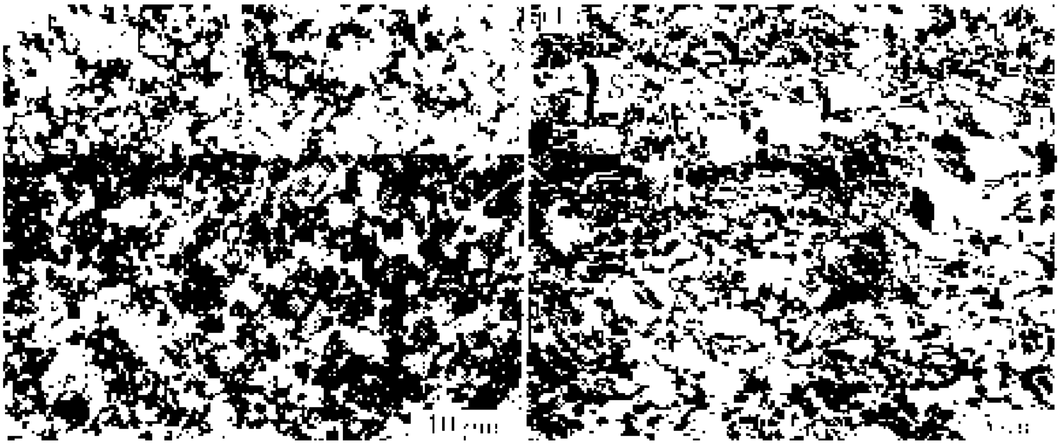

Fig. 1 Microstructure of as-extruded AlSiFe alloy
(a) —OM; (b) —SEM

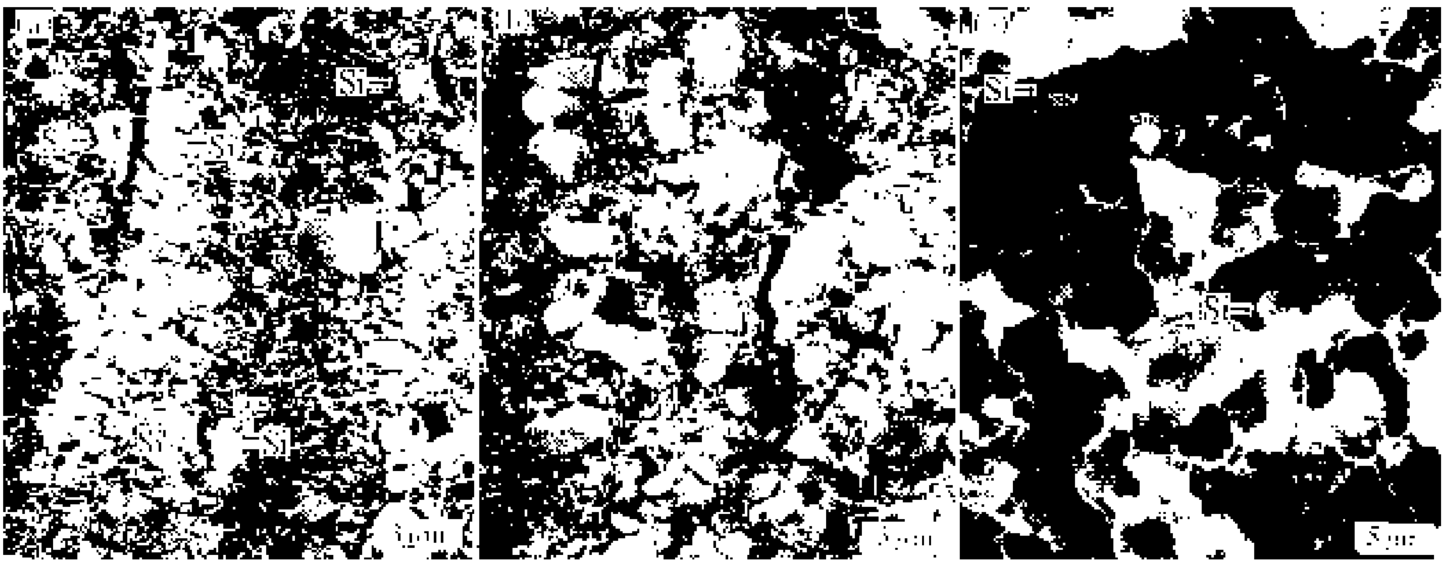

Fig. 2 Microcracks and microfractography of AlSiFe alloy during tensile deformation

more and more new microcracks appear and the existing microcracks widen continuously. Then, some microcracks join into large macroscopic cracks by shearing matrix, leading fracture of the alloy (see Fig. 2(b)). Therefore, the fracture process of spray deposited AlSiFe alloy includes three steps. The first is crack nucleation, the second is microcrack widening and increasing in number, and the third microcrack connecting.

The schematic representation of fracture process is shown in Fig. 3.

3.2 Formation of microcracks

Two possible reasons are considered for formation of microcrack inside Si phases. One is the preexisting microcracks enlarging during tensile deformation. The other is Si phases brittle fracture. Suppose the microcracks are caused by brittle fracture of Si phase, fracture criterion can be calculated by the classical Eshelby problem of the inclusion, considering Si phases as spherical inclusion in the matrix. The total elastic energy W available inside a Si particle of radius R is:

$$W = (4/3) \cdot \pi \cdot R^3 \cdot \omega \qquad (1)$$

where ω is density of elastic energy inside a Si particle[7].

The required energy to cleave the particle of radius R is $2\pi R^2 \sigma_s$, where σ_s is the surface energy of Si. Writing in this way we assume that the fracture of Si particle is perfectly brittle. And the failure of Si particle of size R will occur when the stored elastic energy exceeds the needed surface energy. The fracture criterion is as follows:

$$W > 2\pi R^2 \sigma_s \quad \text{or} \quad \omega > (3/2)(\sigma_s / R) \qquad (2)$$

This formula states clearly that the larger size a Si particle has, the lower the density of elastic energy is required for fracture, and the more easily the fracture occurs. The stress when the density of elastic energy attains critical value of fracture can be calculated. Here σ_s is selected as $3\ J/m^2$[8], and the critical stress of fracture of Si particle with radius of $4\ \mu m$ is about 360 MPa. Therefore, if fracture of a Si particle takes place, the additional stress will be 360 MPa at least.

During tensile deformation the microcracks inside Si phases can be observed when the tensile stress only attains 300 MPa. Therefore, these microcracks are likely to preexist because the stress does not attain the critical fracture stress of Si phase with $4\ \mu m$ in radius. These microcracks are considered to be formed during extrusion. Because the extrusion made the as-spray deposited Si phases break into smaller ones and redistribute in the matrix, some internal microcracks inside Si particles can not be avoided due to the high brittle especially at the edge angle in Si particles. Before tensile deformation, the majority of internal microcracks can not be observed for they are under press stress, only a few in the entirely cracked Si phases can be seen (see Fig. 1 (b)). While tensile deformation proceeding, stress of Si particle changed from press to tension, and the internal microcracks perpendicular to the tensile direction could be observed easily to enlarge. The brittle fracture of Si particle mainly occurs at the later stage of tensile deformation. Because fracture stress of the alloy is about 401

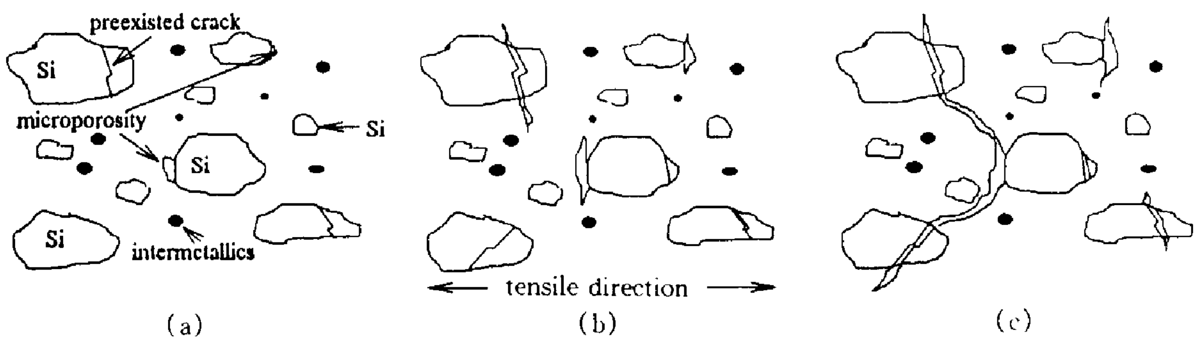

Fig. 3 Schematic representation for fracture process of a deposited AlSiFe alloy
(a) —before tensile deformation; (b) —microcracks initiation; (c) —microcracks linking

MPa in SEM tensile test, which attains to or above critical fracture stress of Si particle with a radius of 4 μm. The brittle fracture of Si particles can take place before fracture of the alloy. Thus the brittle fracture of Si phases can be as microcrack source also. The microcrack formation at the boundaries of Si phases with the matrix is related to the connecting of them. During extrusion, some boundaries of Si phases with matrix are generated by reconnection of new surface of Si phases with plastic flowed matrix due to extrusion. This mechanical connection of many existing small cracks is loose, moreover, most defects like microporosity appear at the boundaries would cause local stress concentration. Therefore, these boundaries can be as microcracks directly or indirectly.

Intermetallics have less tendency to cause local stress concentration due to their smaller size and spherical shape, and fracture would not occur through them[9].

Fracture morphology shows (see Fig. 2(c)) that the size of dimples is near to that of Si phases, and some Si particles and cleavage planes of Si phase can be seen. These mean that brittle fracture in Si phases occurs or Si phases divorce from the matrix along their boundaries.

4 CONCLUSIONS

(1) The failure in tension of an AlSiFe alloy can be divided into three main stages: crack nucleation in some Si phases and at the boundaries of Si phases with matrix, development of fracture by increasing the number of microcracks and final fracture by connecting the microcracks through shearing matrix.

(2) The microcracks inside Si phases include preexisting microcracks caused by extrusion and brittle fracture microcracks by tensile deformation. The microcracks at the boundaries are caused by loose mechanical connection and defects.

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