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TENSILE PROPERTY OF Al-20 MASS.% Si ALLOYS PRODUCED BY A GAS ATOMIZATION PROCESS

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Abstract. High temperature tensile property of the extruded Al-20 mass.% Si alloys was investigated to obtain the optimal plastic deformation condition. Al-Si alloys including some amount of Cu, Fe, Mg, Mn were produced by a gas atomization process and hot extrusion at 500 °C was simply applied to the compacted powders without degassing to pursue industrial advantages. The maximum stresses in stress-strain curves of tensile tests at 500 °C increased with increasing strain rate. The highest strain rate sensitivity exponents (*m*-values) for tensile tests at 500 °C were about 0.3 between strain rates of 10^{-2} and 10^{-1} s^{-1}. The fracture surfaces of test pieces showed very fine microstructure and the average grain size was estimated to be about 1 μm. Real elongations, however, were not high (about 30%), though these alloys have fine-grained microstructure and high *m*-value. The reason will be that uniform deformation was interrupted by voids included in the materials.

1. INTRODUCTION

Aluminum alloys are widely used as structural materials for automobile, machine parts, train, and so on, to reduce weight for attaining high efficiency of machines and to save energy. The application, however, is limited, because of low wear resistance, high thermal expansion, low stiffness, and relatively low strength. To improve the weakness of aluminum alloys, hypereutectic Al-Si alloys including some other alloying elements such as Fe, Mn, and Ni are promising and being developed by rapid solidification processes, because it is very difficult to produce hypereutectic Al-Si alloys with fine primary Si crystals through conventional casting processes. By rapid solidification, hypereutectic Al-Si alloys with fine microstructure and high content of alloying elements can be produced, because these alloying elements have higher solubility in the liquid state of aluminum and grain growth can be suppressed by rapid solidification [1-3]. Atomizing processes and spray forming are being used as the rapid solidification processes. The properties and formability of rapidly solidified hypereutectic Al-Si alloys depend on consolidation and sintering conditions of rapidly solidified powders. Several papers have been reported on the properties of the hypereutectic Al-Si alloys [4,5]. Authors also reported on fundamental atomizing conditions of Al-20 mass.% Si alloys [6]. If the hypereutectic Al-Si alloys are consolidated after degassing, followed by hot extrusion, high elongation, sometimes superplasticity, could be obtained [7]. However, simpler processes will be desirable for industrial application. For such purpose, in this work, Al-20 mass.% Si alloys including some amount of Cu, Fe, Mg, Mn were produced by a gas atomization process and hot extrusion was applied directly to the compacted powders without degassing to pursue industrial advantages. High temperature tensile property of the extruded Al-20 mass.% Si alloys was compared and discussed to obtain the

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Table 1. Chemical composition of Al-20mass.% Si alloys.

Alloys	Elements [mass.%]					
	Si	Cu	Fe	Mg	Mn	Al
VN-1	20	3.5	5.5	1.2	0.5	Bal.
VN-4	20		5.5	1.2	0.5	Bal.

optimal plastic deformation condition of these alloys at high temperatures.

2. EXPERIMENTAL PROCEDURES

Al chips (99.5 mass.% purity) with average size of 5 mm and Si powders (99.7 mass.% purity) with average size of 2 – 3 mm were used for alloying elements. High purity Cu, Fe, Mg, and Mn were mixed as alloying elements. All elements for each alloy were melted by a high frequency induction furnace to prepare master alloy ingots. Two kinds of Al-20 mass.% Si alloys (designated as VN-1 and VN-4) were prepared and chemical compositions are listed in Table 1.

From these ingots, the Al-Si alloy powders were produced by a gas atomizer in a mixed gas of 80% N_2 and 20% O_2 under the dynamic pressure of 2 MPa. Atomization was performed at 950 °C, which is 290° higher than aluminum melting point. These aluminum alloy powders were mechanically sieved and their sizes were analyzed by the laser particle size analyzer (Micromeritecs, ASAP2000). The microstructure of the produced powders was examined using an optical microscope (OM) and a scanning electron microscope (SEM, JEOL, JEM 5800). Powders were compacted and extruded to a rod with 20 mm in diameter at 500 °C in the air. Extrusion ration was 10:1. The extruded materials were T6 heat treated (holding at 515 °C for 30 min, water quenched, then held at 172 °C for 20 hr). The extruded materials were machined along their axis to make tensile test pieces having the gage length of 14 mm with 2.4 mm in diameter. Tensile tests were performed at 400 °C, 450 °C, 500 °C, 520 °C at initial strain rates of $1\text{x}10^{-4}$, $1\text{x }10^{-3}$, $1\text{x }10^{-2}$, $1\text{x }10^{-1}$ s^{-1}.

3. EXPERIMENTAL RESULTS

3.1. Microstructure

Microstructures of the extruded VN-4 alloy powders sieved under 75 μm in particle size are shown in Fig. 1. Figs. 1a and 1b are perpendicular and parallel to the extrusion direction (extrusion direction is shown in the photo). In both pictures, complex shape of δ-AlFeSi (Al_4FeSi_2) and fine Si primary crystals are observed.

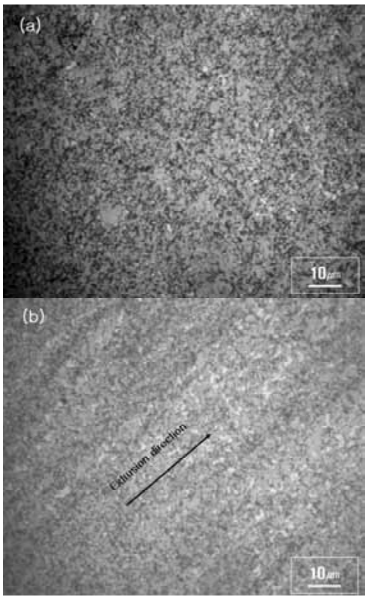

Fig. 1. Microstructures of the extruded VN-4 (75 μm) alloy, (a) perpendicular and (b) parallel to the extrusion direction.

3.2. Tensile properties

Typical examples of stress-strain curves of tensile tests are shown in Fig. 2. Figs. 2a and 2b are extruded materials of VN-1 alloy powders under 75 μm in size and VN-4 alloy powders under 150 μm in size. The maximum stress decreased with increasing test temperature and, on the contrary, elongation increased. The maximum stresses of VN-1 alloy decreased more quickly with increasing temperature than those of VN-4 alloy, because the melting start point of VN-1 alloy was 524 °C and lower than 552 °C of VN-4 alloy, which were obtained by DSC analysis, and tests of VN-1 alloy above 520 °C was difficult [6]. The elongation is roughly between 30% and 40% at 500 °C. The suitable temperature for plastic deformation of these alloys will be 500 °C, because flow stress is low and elongation is relatively high.

The dependences of stress on strain rate are shown in Fig. 3 for VN-4 alloy produced from powders (a) under 150 μm and (b) under 75 μm in size. The dependence of the maximum stress on strain rate appeared clearly. The maximum stress increased with increasing strain rate. When strain rate was low, elongation was low. When strain rate was

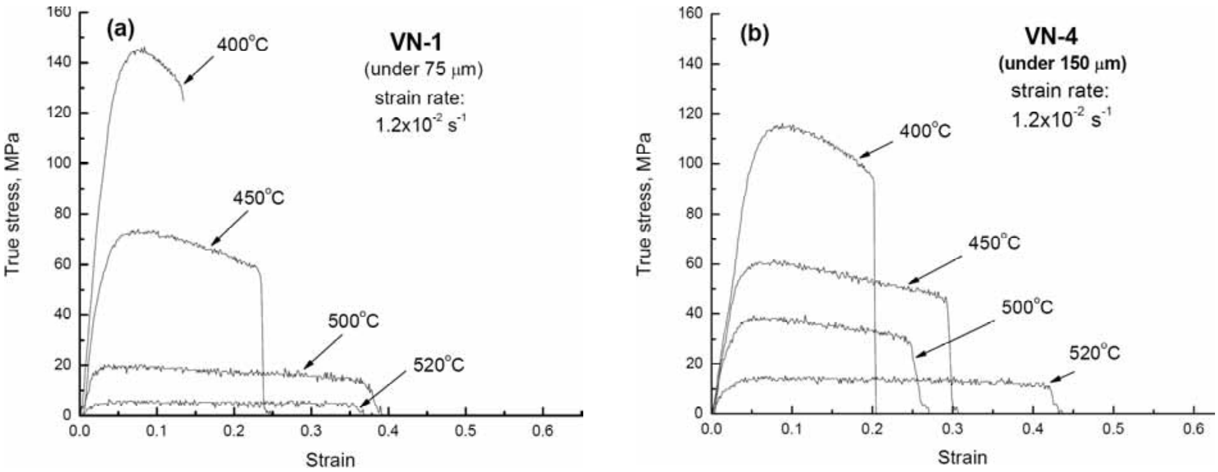

Fig. 2. Temperature change of stress-strain curves of VN-1 and VN-4 alloys. (a) VN-1 alloy produced from the powder under 75 μm in size, (b) VN-4 alloy from the powder under 150 μm.

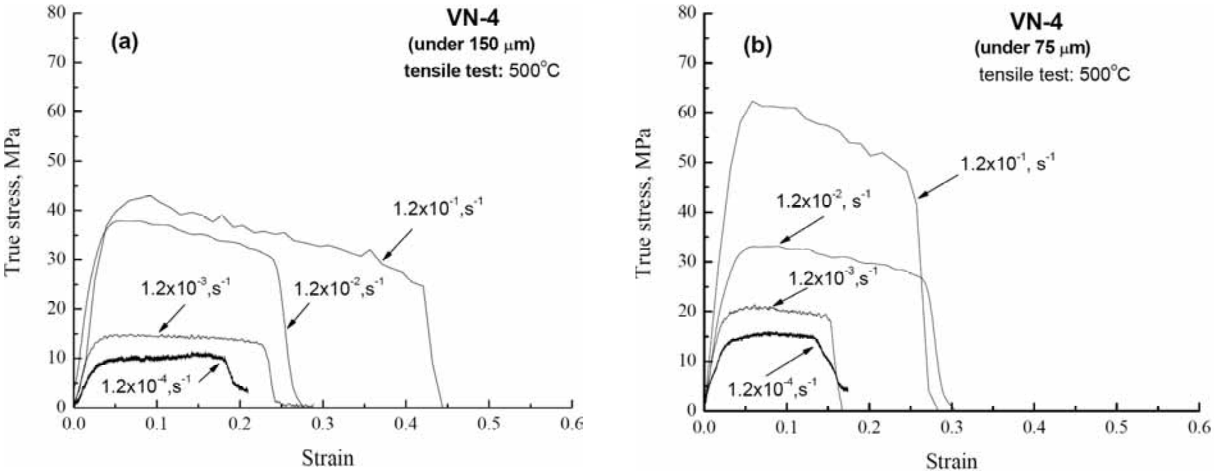

Fig. 3. Change of stress-strain curves of VN-4 alloy by strain rate. (a) for powders under 150 μm in size, (b) for powder under 75 μm.

higher than 10^{-2} s^{-1}, elongation increased up to about 30%. The suitable strain rate of these alloys for plastic deformation will be 10^{-2} s^{-1}. The maximum stress of (b) (under 75 μm) was slightly higher than that of (a) (under 150 μm).

Stress-strain curves of VN-1 alloy are shown in Fig. 4. The dependence of the maximum stress on strain rate was also very clear in this alloy, though the maximum stresses of the material of (b) (under 75 μm) were much higher than those of (a) (under 150 μm).

The fracture surface of a test piece is shown in Fig. 5, which was tested at 500 °C at the strain rate of 10^{-2} s^{-1}. This fracture surface is very characteristic. The fracture surface is neither typical brittle surface, nor ductile surface. The fracture surface seems to show that the breakage occurred at the grain boundaries. In the picture, Fig. 5b, the surface material looks agglomerates of very fine grains remained even after deformation at 500 °C. If those are the agglomerates of fine grains, the grain size will be estimated to be about 1 μm. When metallic materials exhibit superplasticity, the materials usually show ductile fracture surfaces [8] and sometime fine filaments (whiskers) appear on the fracture surfaces [9-12].

These experimental results show that the total elongation increases with increasing strain rate and with increasing temperature. The total elongation values, however, were scattered. These extruded materials involve some voids in them, because these materials were extruded in the air. These voids should have acted as a crack initiation point. However, as these extruded materials have very fine grain size as shown in Fig. 5, these alloys might be superplastic.

The constitutive equation in tensile deformation is given by:

$$\sigma = k\left(\mathrm{d}\varepsilon/\mathrm{d}t\right)^{m}, \qquad (1)$$

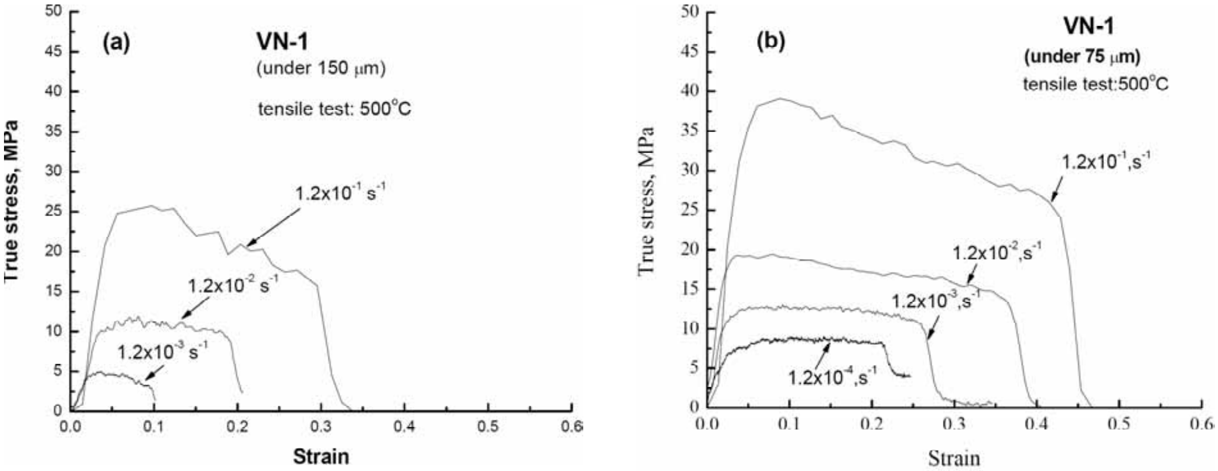

Fig. 4. Change of stress-strain curves of VN-1 alloy by strain rate. (a) for powder under 150 μm in size, (b) for under 50 μm.

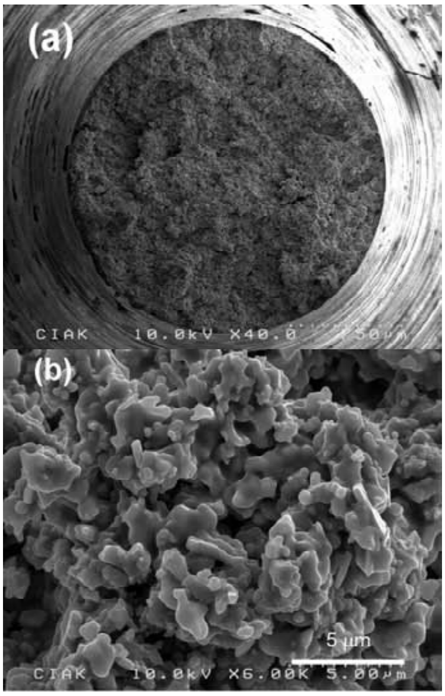

Fig. 5. Fracture surface of VN-1 alloy (under 150 mm) tested at 500 °C at the strain rate of 10^{-2} s^{-1}. (a) fracture surface, (b) magnified picture of the fracture surface.

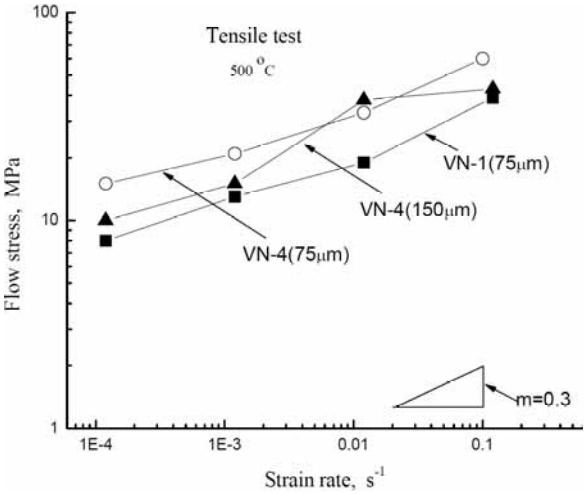

Fig. 6. Relationship between flow stress and strain rate of VN-1 and VN-4 alloys.

where σ is the true flow stress, *t* is time, *k* is a constant, and *dε/dt* is the strain rate. *m* is the strain rate sensitivity exponent. When $m > 0.3$, the alloy usually exhibits superplasticity. The relationships between the flow stress and the strain rate of the VN-1 and VN-4 alloys are plotted in Fig. 6. The maximum stress in a stress-strain curve was taken as the flow stress. The flow stresses of each alloy increased with increasing strain rate and the gradients, which are the strain rate sensitivity exponents, *m*-values, were about 0.3 for these extruded materials between strain rates of 10^{-2} and 10^{-1} s^{-1} at 500 °C. These *m*-values will be an important material parameter to get uniform elongation without necking. Therefore, these extruded materials have two important factors: fine-grained microstructure and high *m*-value, to exhibit superplasticity. Real elongation, however, was not high, because uniform deformation should have been interrupted by voids included in the materials. This discussion is supported by the fact that the shapes of stress-strain curves shown in Figs. 2 – 4 at the strain rate of 10^{-2} and 10^{-1} s^{-1} look typical ones of superplastic deformation and a breakage occurred suddenly. These results suggest that if these materials are deformed under some hydrostatic pressure like forging, higher elongation might be obtained without fracture.

5. CONCLUSION

High temperature tensile and compressive properties of the extruded Al-20mass.% Si alloys were investigated to obtain the optimal plastic deformation condition.

(1) The highest values of the strain rate sensitivity exponents (*m*-values) in tensile tests were about 0.3 between 10^{-2} and 10^{-1} s^{-1} at 500 °C.

(2) The fracture surfaces of test pieces showed very fine microstructure and the average grain size was estimated to be about 1 mm.

(3) Real elongations were not high (about 30%), though these alloys have fine-grained microstructure and high *m*-value. The reason will be that uniform deformation was interrupted by voids included in the materials.

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