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Effect of Silicon Particles on the Tensile Properties of Heat Resistant Al-Si-Cu-Ni-Mg Alloy Pertaining to Different Tensile Temperature

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Abstract

The deformation behavior of Al-1Si and Al-11Si aluminum alloy in hot tensile procedure from 200 °C to 450 °C was investigated in this study. The results indicated that the flow stress was strongly dependent on second phase particles of δ (Al_3CuNi), Q ($Al_5Cu_2Mg_8Si_6$), τ_1 (Al_9FeNi) and Si particles. At 200 °C to 300 °C, the yield and ultimate tensile strength of Al-11Si were higher than Al-1Si. It can be found that the mount of intermetallic δ particles increasing will increase the deformation resistance whereas Si particle is detrimental. However, at elevated temperatures, Al-1Si would exhibit a higher elongation at 450°C but Al-11Si was higher than Al-1Si after 400°C. Microstructural observations showed Si particles would restrain the failure of matrix and increase the ductility.

Keyword: Al-1Si and Al-11Si aluminum, second phase particles, elevated temperatures, elongation

1. Introduction

Thermo-expansion ability of Al-Si-Cu-Ni-Mg alloy could be advanced by adding Si to form primary Si [1]. It can be used in the production of piston for automobile and high Cu and Ni additives increasing the alloy's hardness and strength after natural or artificial aging. The alloy performance is less satisfactory owing to the excessive Si content (over 12.5wt %) and Cu & Ni elements [2]. However, the alloy shows excellent cutting, high temperature tensile properties and the high hardness of the alloy itself due to the extra Si, Cu and Ni. Because of various alloy element additives, it could be defined as a new composite material.

However, eutectic phases consisting of Cu, Ni and Mg elements reinforce the tensile strength whereas the elongation would not be improved if the phases become thicker or clusters are formed [3-5]. But to increase particles or grain refinement will raise the ductility a lot at high working temperature [6-8]. In this study, the different Si content aluminum alloy (with hypoeutectic and eutectic Si) of Al-Si-Cu-Ni-Mg alloy will be discussed in terms of plastic deformation ability at high temperature, especially in ductility.

2. Experimental procedure

In this study, the adopted alloy of Si content was hypoeutectic (about 1%) and near eutectic point (Si amount: 11.3wt %) for the best cutting property [1]. And for the working property at high temperature, the copper and nickel contents were raised from 1% to 3.4% and 2.3% respectively. The chemical composition is listed in Table 1. The materials were prepared from extruded plates. All samples were heated at 430 °C and remained at the temperature for 3 hours to eliminate residual stress. For easy identification throughout the experimental procedures, these specimens are labeled as Al-1Si and Al-11Si alloys. The microstructure of the samples was observed with OM and SEM. Optical microscopy was employed to examine the grain structure and grain size. The samples for optical observation were etched in Keller's reagent for 5 seconds. The dimension of tensile specimen is illustrated in Fig. 1 and the tensile test temperature was 200 °C to 450 °C under 3.3×10^{-3} s^{-1} initial strain.

3. Results and discussion

3.1 Tensile

Fig. 2 (a) exhibited the results of strength at elevated temperature. The 0.2% proof strength of Al-1Si and Al-11Si samples were approached. Some researches [9] indicated that second phase particles didn't dissolved in low-heat input whereas would cause the heterogeneity of particles dissolution at higher temperature and contributed to the formation of extra large grains. At the condition that copper, nickel and magnesium contents are so close in Al-11Si and Al-1Si alloy, the model of tensile behavior at high temperature were also the same that second phase particles including copper and nickel elements, or other precipitation phases enhance the tensile strength at high temperature [10].

As Fig. 2(b) demonstrated, the performance of elongation evolved with elevated temperature. The difference between 1Si and 11Si was apparently especially from 300 to 450 °C. The deformation behavior of Al-1Si alloy was still depended on matrix deformation at 450℃ [11]. Below 400 °C, Si particles were still the main factor in failure behavior [10], especially even increasing to 300 °C. In tensile curve (Fig. 3), it shows the total elongation will increase after 400 °C in Al-11Si samples but Al-1Si won't. Obviously, if number of particles increase in alloy, then elongation increases above 400 °C working temperature because the failure delays by particles holding.

3.2 Microstructural

Microstructural and EDS observation of the Al-1Si and Al-11Si alloy detected the following microconstituents: such as Si, Al_7Cu_4Ni, τ_1, θ, δ and Q [12] as shown in Fig. 4 found by EDS. Table 2 demonstrates the composition. The grain size in the as extruded was non-uniform and Si particles were the origin of crack propagation in tensile behavior at normal temperature, Al-11Si was either. It should be noted that specimens exhibit intergranular fracture patterns as increased the testing temperature from 300 to 450°C.

But in general, Al-1Si alloy has better ductility than Al-11Si at 300 °C because the Fig. 5(a) shows the intergranular and dimples fracture patterns whereas the Al-11Si is just dimple fracture surface. At 450 °C, the performance of fracture exhibits intergranular fracture surface in Al-1Si sample. However, elongation is smaller than Al-11Si because big size of dimples occurs grain growth. Al-11Si sample has smaller size (Fig. 5(d)) and it indicates that second phase particles impede the grain growth behavior, and then postpone failure in tensile test. In research figured out that particles can refine the elongated subgrains by particle joining, or by pinning the slip of long parallel dislocations to form ladderlike subgrains [13]. By the way, joining small particles, it can postpone the time of failure and elongation will increase at high temperature work.

4. Conclusion

This investigation demonstrates that the number of Si or second phase particles increase will improve the high temperature ductility:

(1) Below 400 ^{o}C, matrix deformation leads the failure behavior and elongation will decrease by crack propagation because of stress concentration in hard-brittle particles.

(2) By the particles joining, ductility is improved after 400 ^{o}C working temperature because the ability of delayed fracture increases.

5. Acknowledgment

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6. Reference

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Table 1. Chemical composition of experimental alloy.

Component (mass %)	Al	Si	Cu	Ni	Mg	Mn	Zn
Al-1Si	Bal.	**1.3**	3.8	1.3	1.1	0.5	0.23
Al-11Si	Bal.	**11.4**	3.4	2.3	0.9	0.6	0.12

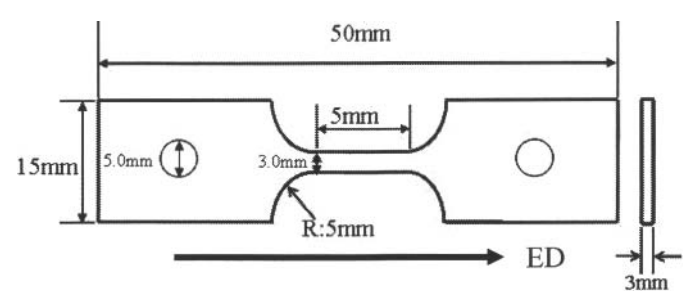


Fig. 1 The illustration of friction stirring process and the dimension of specimens for tensile test

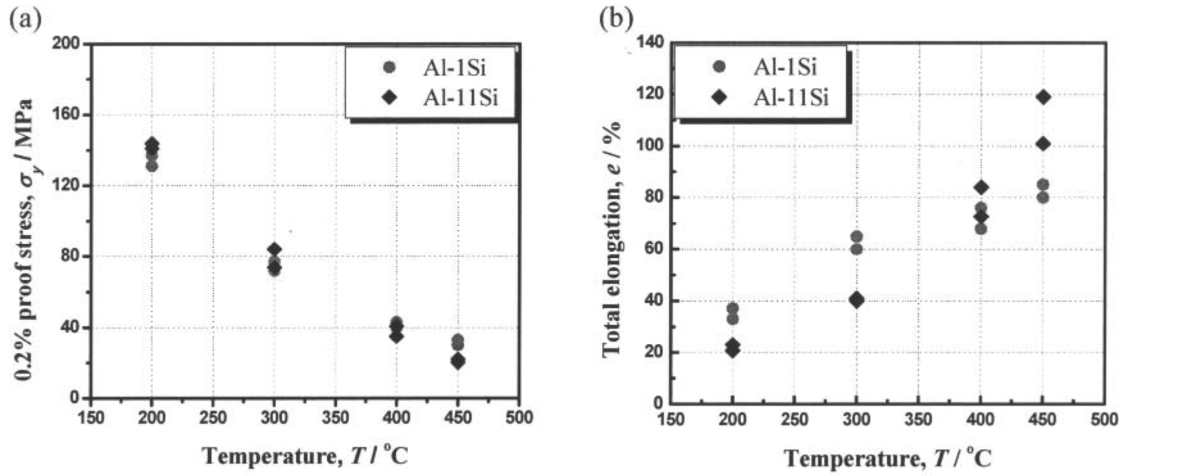


Fig. 2 Tensile properties exhibit the trend of (a) 0.2 pct proof strength and (b) total elongation of samples at elevated temperature.

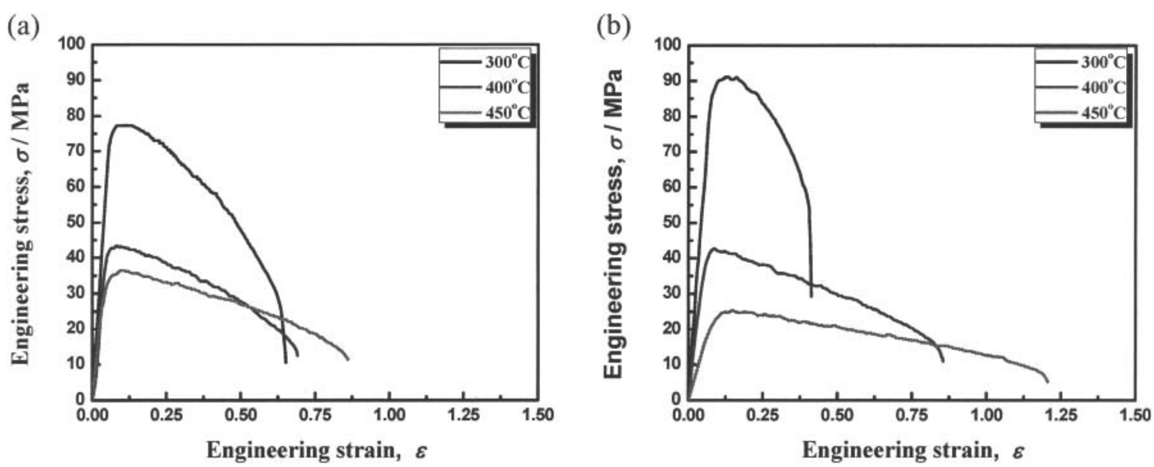
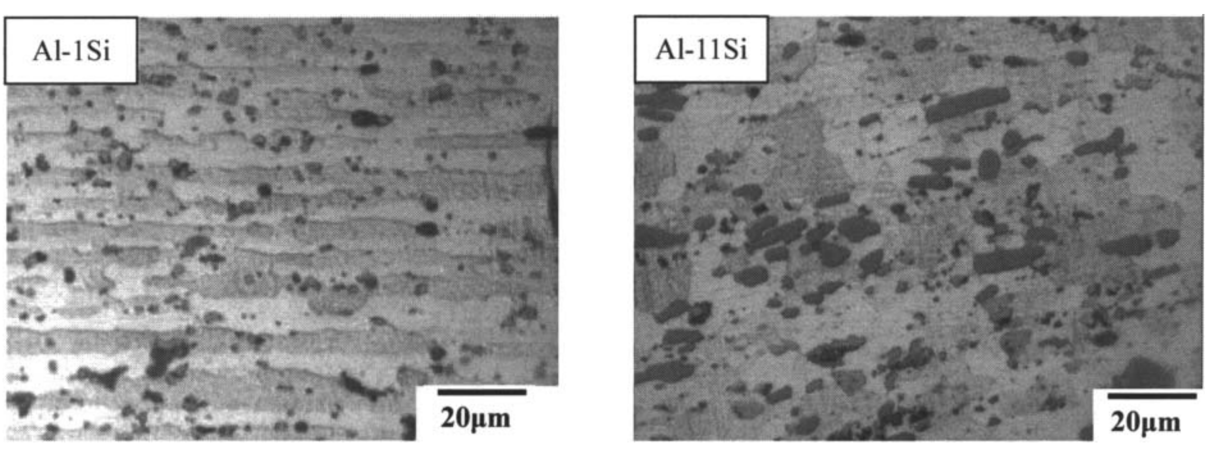


Fig. 3 Tensile curves were shown at different temperature from 300 to 450 ℃ (a) Al-1Si (b) Al-11Si



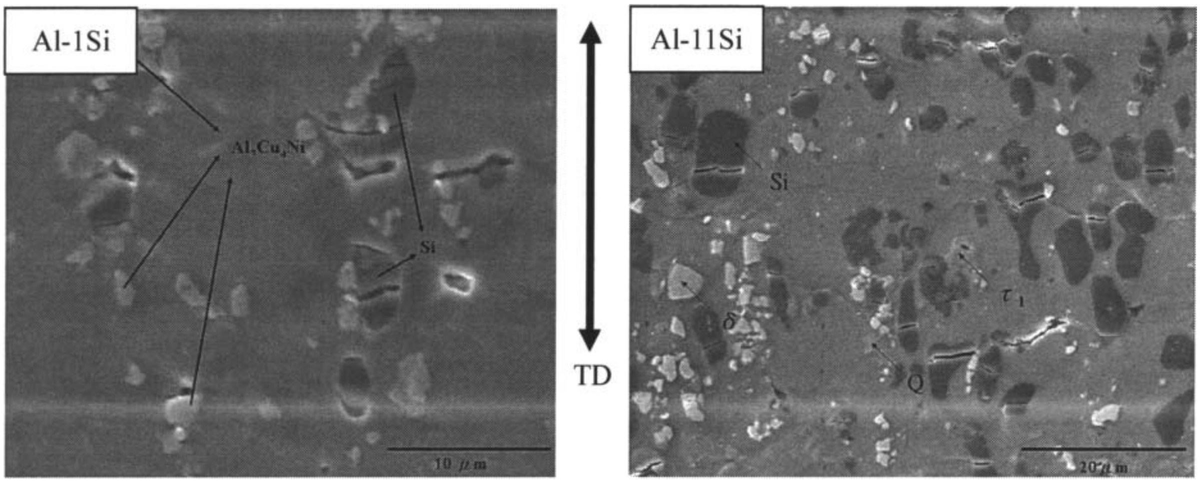


Fig. 4 Optical and scanning electron microscopy shows the particle's morphology after extruding, and in tensile condition. Composition of second phase particles were indentified by EDS (Table. 2).

Table 2. The consist of second phase particle

at%	Al	Si	Ni	Cu	Mg	Fe
Q ($Al_5Cu_2Mg_8Si_6$)	65.81	17.26	---	4.16	12.77	---
δ (Al_3CuNi)	66.97	---	15.30	17.72	---	---
τ_1 (Al_9FeNi)	83.3	---	3.02	---	---	13.67

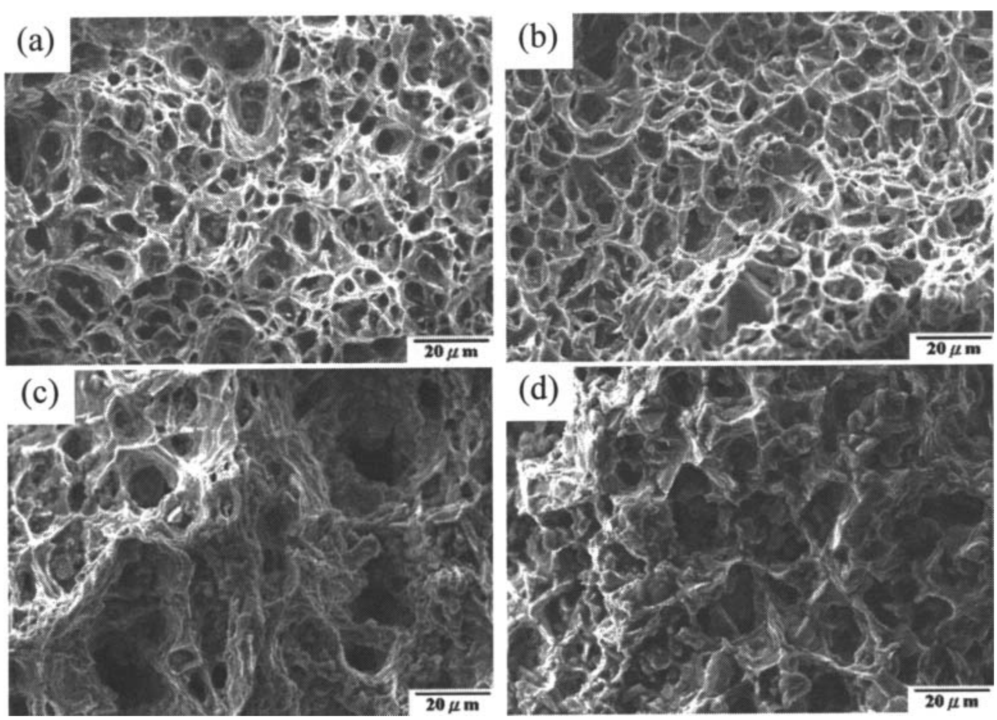


Fig. 5 Fracture surface observed at elevated temperature by Scanning electron micrograph of samples: (a) Al-1Si at 300 °C, (b) Al-11Si at 300 °C, (c) Al-1Si at 450 °C and (d) Al-11Si at 450 °C