MICROSTRUCTURE AND MECHANICAL PROPERTIES OF Al-2.5%Cu-0.23%Sc ALLOY

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ABSTRACT Microstructure and mechanical properties of Al-2.5mass%Cu-0.23mass%Sc ternary alloy and Al-2.8mass%Cu binary alloy aged 423 and 573K were investigated by TEM observation and tension test. The maximun tensile strength(σ_{max}) and the 0.2% yield stress($\sigma_{0.2}$) of the ternary alloy are higher than those of the binary alloy. Elongations(ε) at the peak-aging stage are approximately 20% in both the alloys. When σ_{max} is compared by ε of 20%, σ_{max} of the ternary alloy, 300MPa, is much higher than that of the binary alloy, 200MPa. High strength and ductility of the ternary alloy aged at 573K is mainly caused by the fine distribution of Al_3Sc and θ'-Al_2Cu pricipitates in the matrix.

Keywords: *Al-Cu-Sc alloy, age-hardening, Al_3Sc, θ'-Al_2Cu, mechanical properties*

1. INTRODUCTION

Aluminum with the addition of small amount of scandium is strengthened by the precipitation of coherent spherical $L1_2$ type of Al_3Sc intermetallic phase[1,2]. Effects of scandium addition on the age-hardening behavior have been reported for the Al-Mg alloy[3] and the Al-Li alloys[4]. Yield stress and hardeness are remarkably increased with the additon of about 0.2mass%Sc. The addition of scandium to Al-Cu alloy may lead to higher strength by the synergistic age-hardening effects of copper and scandium. Authors reported in the previous paper[5] that Al-2.5mass%Cu alloy, which scandium of 0.23mass% was added to and aged at the temperature from 423K to 673K, showed the most remarkable age-hardening at 573K aging. The precipitates which occur during aging at 573K were spherical $L1_2$ Al_3Sc and semi-coherent plate-like θ'-Al_2Cu. The Al_3Sc precipitates are dispersed finely and coherent with the matrix even after a prolonged aging. On the other hand, the θ'-Al_2Cu precipitates are relatively coarse. GP zones and θ''-Al_2Cu precipitates, which occur at low aging temperatures mainly contribute to the increase in strength of the Al-Cu alloys. The aging temperature of 573K is too high for aging of the conventional Al-Cu alloys. However, a marked effect of Al_3Sc cannot be expected from the aging at temperatures lower than 473K. In this study, age-hardening behavior and mechanical properties of Al-2.5mass%Cu-0.23mass%Sc ternary alloy and Al-2.8 mass%Cu binary alloy were investigated by hardness test, TEM observation and tension test.

2. EXPERIMENTAL PROCEDURE

Two kinds of aluminum alloys, Al-2.8mass%Cu and Al-2.5mass%Cu-0.23mass%Sc were prepared using pure aluminum(99.99%), pure scandium(99.9%) and commercial Al-40mass%Cu. In addition to these alloys, an Al-0.23mass%Sc alloy was also prepared for comparison. These alloy ingots were hot-rolled at 733K and cold-rolled at 673K to a plate of 2mm thick. Specimens for tension test were cut from the rolled plates. The specimens for tension test are in the form of plate 2mm in thickness and 40mm in length. The gage length and the width of the reduced section are 8mm and 3mm, respectively. Holes 4mm in diameter were drilled at both ends of specimen for pin chuck. After surface-finished and encapsuled in glass tube with Ar gas, the specimens were solution treated at 873K for 21.6ks, and aged at the temperature of 423 to 623K for the time up to 600ks. Surface of the reduced portion of the specimen was electro-polished in order to avoid notch effect. Specimens were stretched at the tension speed of 1mm/min (initial strain rate was $1.4x10^{3}s^{-1}$) using Shimadzu Autograph AG-5000D. The tensile strength, 0.2%yield sress and elongation were measured on stress-strain charts. TEM observation was made for the as-aged specimens using Hitachi 600AB TEM, operating at 100kV.

3. RESULTS AND DISCUSSION

3.2 TEM microstructure

It has been clarified from the TEM observation in the previous study[5] that the precipitates which occurred during aging at 573K in the Al-Cu-Sc ternary alloy were θ' and Al_3Sc. Figure 1 shows bright field TEM images at the stages of peak-aging(aging time is 6ks) and over-aging(60ks and 600ks) of the ternary alloy aged at 573K. The incident electron beam is parallel to the [100] direction of the matrix in all TEM images. θ' precipitates are observed at early aging stage. But, Al_3Sc precipitates cannot be observed even at the peak-aging stage in spite of the high hardness of the alloy(Fig. 1(a)). Isotropic elastic strain field constrasts, which show the presence of spherical coherent Al_3Sc, are observed between θ' precipitates at the aging time of 60ks in the over-aging stage

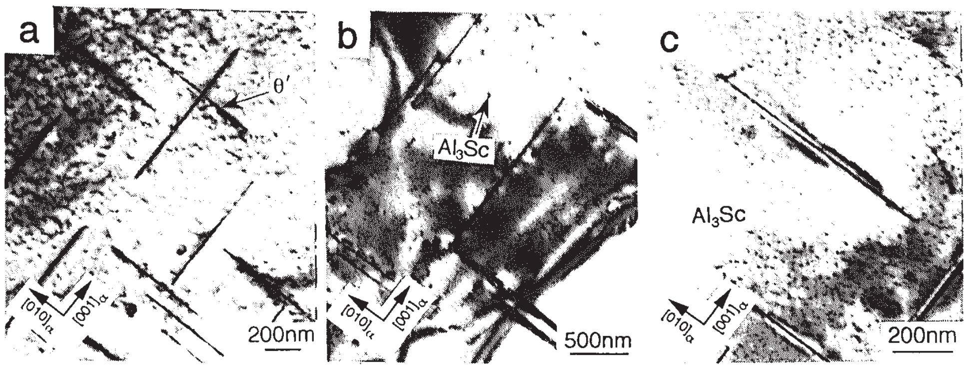

Fig.1 TEM images of the Al-Cu-Sc alloy aged at 573K. Aging time is: (a) 6ks, (b) 60ks and (c) 600ks. The incident electron beam is parallel to the [100] direction of the matrix.

(Fig. 1(b), arrowed). At the very long aging time of 600ks a number of elastic strain contrasts can be seen around θ' precipitates(Fig. 1(c)). It is recognized from the bright field TEM images and the selected area diffraction patterns that a number of grown-up Al_3Sc precipitates are present and they are coherent with the matrix even after a very long aging time. Nevertheless, the Al_3Sc precipitates are too small and their sizes are hardly measured on the TEM dark field images, until they grow large enough after the aging time of 300s at 623K aging[6]. Their sizes are approximately 10nm in diameter at the aging time of 10^3ks. Therefore, the sizes of Al_3Sc precipitates may be fairly less than 10nm in diameter at 573K aging.

3.2 Mechanical properties of Al-Cu-Sc alloy

θ' and Al_3Sc precipitates occur during aging at 573K. A number of very fine Al_3Sc precipitates distribute uniformly in the matrix, while θ' precipitates distribute relatively coarsely. Therefore, it is considered that Al_3Sc precipitates mainly contribute to strengthening of the alloy and coarse θ' precipitates have significant effect on ductility rather than strengthening. So mechanical properties such as tensile strength and elongation for the Al-Cu-Sc and the Al-Cu alloys aged at 423 and 573K for the periods up to 10^3ks were investigated in this section.

Changes of tensile strength(σ_{max}), 0.2% yield stress($\sigma_{0.2}$) and elongation(ε) of the Al-Cu-Sc and the Al-Cu alloys during aging at 423 and 573K are shown in Fig.2. In both alloys the values of σ_{max} and $\sigma_{0.2}$ are low at the early stage of aging and then they increase gradually up to the aging time of 1.2ks at 423K and 0.6ks at 573K. At the aging time of 1200ks in the aging at 423K, σ_{max} and $\sigma_{0.2}$ of the

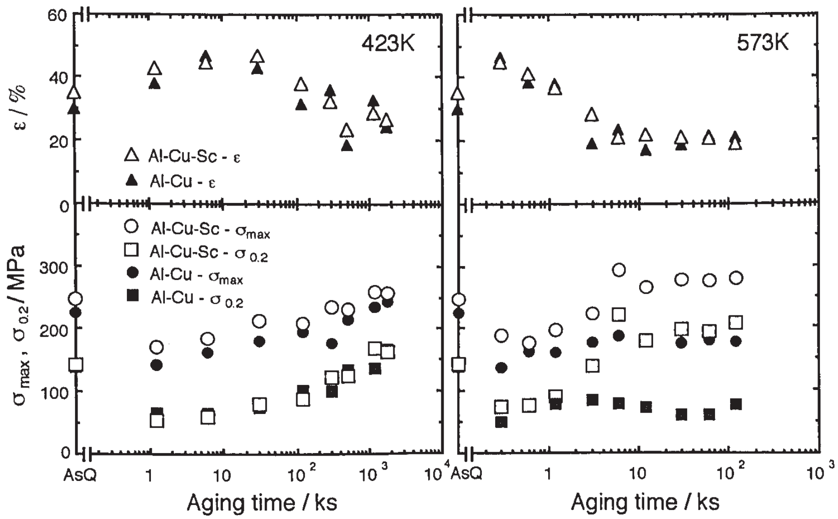

Fig.2 Changes of tensile strength(σ_{max}), 0.2% yield stress($\sigma_{0.2}$) and elongation(ε) during aging at 423 and 573K in the Al-Cu-Sc and the Al-Cu alloys.

Al-Cu-Sc alloy are 260 and 170MPa, respectively, while those of the Al-Cu alloy are 243 and 166MPa, respectively. σ_{max} of the Al-Cu-Sc alloy is higher than that of the Al-Cu alloy. $\sigma_{0.2}$ of the Al-Cu-Sc alloy is almost equal to that of the Al-Cu alloy. ε increases with aging time and it reaches to the maximum at the aging time of 6ks in both of the Al-Cu-Sc alloy and the Al-Cu alloy. The maximum of $\varepsilon(\varepsilon_{max})$ are approximately 45%. In 573K aging, σ_{max} and $\sigma_{0.2}$ of the Al-Cu-Sc alloy and the Al-Cu alloy reach to the maximum at the aging time of 6ks. The maximum values of σ_{max} and $\sigma_{0.2}$ of the Al-Cu-Sc alloy are 300MPa and 220MPa, respectively. On the other hand, their maximum values of the Al-Cu alloy are 190MPa and 80MPa, respectively. Both of σ_{max} and $\sigma_{0.2}$ in the Al-Cu-Sc alloy are much higher than those in the Al-Cu alloy after peak-aging and they decrease gradually at over-aging stage. The maximum values of ε of both two alloys are approximately 45% at the aging time of 0.3ks.

Plots of σ_{max} aginst ε were made on the basis of results from tension test, as shown in Fig.3. There is a good linear relationship between σ_{max} and ε both in the Al-Cu-Sc alloy and the Al-Cu alloy. The slope of linear relational expression between σ_{max} and ε obtained by the method of least squares in the Al-Cu-Sc alloy is larger than that in the Al-Cu alloy. Therefore, the value of σ_{max} of the Al-Cu-Sc alloy is larger than that of the Al-Cu alloy against the same value of ε. Difference between σ_{max} of two alloys against the same value of ε is larger as ε is small. ε is approximately 20% at the maximum values of σ_{max} in Fig.2. Thus when σ_{max} is compared at ε of 20%, σ_{max} of the Al-Cu-Sc alloy, 300MPa is much larger than that of the Al-Cu alloy, 200MPa. Consequently the result of Fig.3 suggests that scandium is a very effective alloying element for the strengthening of aluminum alloys.

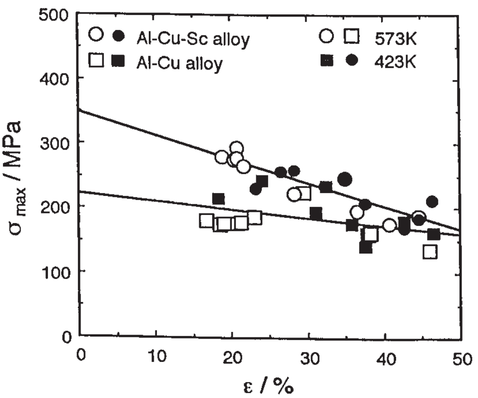

Fig.3 Relationship between σ_{max} and ε of the Al-Cu-Sc and the Al-Cu alloys aged at 423 and 573K.

Figure 4 shows TEM images of the Al-Cu-Sc alloy and the Al-Cu alloy aged at 573K. Figure 4(a) and (b) correspond to TEM images at the aging time of 6ks(peak-aging) and 120ks(over-aging) respectively, in the Al-Cu-Sc alloy. Figure 4(c) and (d) correspond to TEM images at the aging time

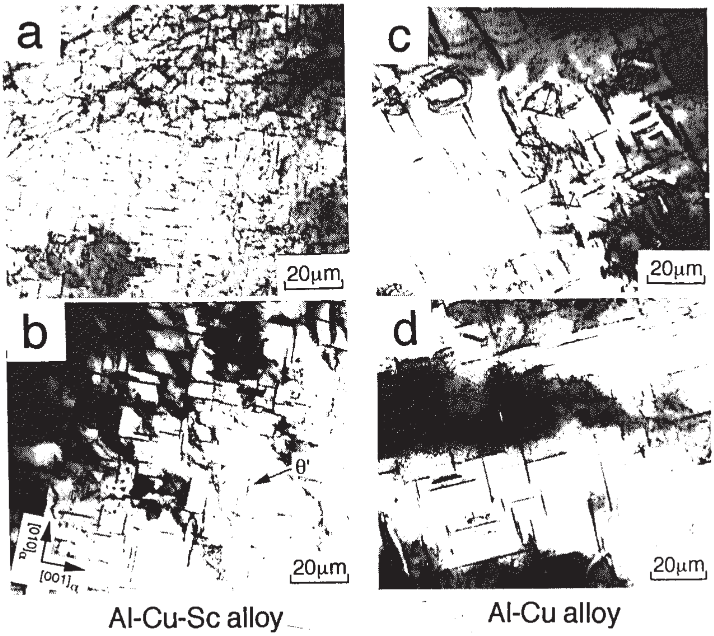

Fig.4 TEM images of the Al-Cu-Sc and the Al-Cu alloys aged at 573K. Aging times is: (a), (c) - 6ks(peak-aging), (b), (d) - 120ks(over-aging). The incident electron beam is parallel to the [100] direction of the matrix.

of 6ks(peak-aging) and 120ks(over-aging) respectively, in the Al-Cu alloy. The size of the Al_3Sc precipitates are too small to be measured. The size of coherent broad planes of plate-like θ' precipitates can be measured. They seem to be larger in the ternary alloy than in the binary alloy at each aging stage. The measured mean sizes of θ' at under-aging, peak-aging and over-aging stages in the Al-Cu-Sc alloy are 0.2, 0.6 and 1.0μm respectively, while those in the Al-Cu alloy are 0.4, 1.2 and 1.5μm respectively. The results manifest that the sizes of θ' in the Al-Cu-Sc alloy are smaller than those in the Al-Cu alloy at all the aging stages. The slow growth rate of θ' in the Al-Cu-Sc alloy may be because that scandium atoms retard migration of copper in the matrix due to high binding energy between scandium atoms and vacancies[7]. Therefore, high strength and ductility of the Al-Cu-Sc alloy aged at 573K are mainly caused by the fine distribution of Al_3Sc and θ' precipitates in the matrix.

4. CONCLUSIONS

Effect of scandium on microstructure and mechanical properties of Al-Cu alloys were investigated by tension test and TEM observation using Al-2.5mass%Cu-0.23mass%Sc ternary alloy, Al-2.8 mass%Cu and Al-0.23mass%Sc binary alloys aged at the temperatue from 423 and 573K for various periods. Precipitates which occur during aging at 573K were spherical Al_3Sc with order structure of $L1_2$ and semi-coherent plate-like θ'. The maximum values of σ_{max} and $\sigma_{0.2}$ of the Al-Cu-Sc ternary alloy aged at 573K were 300 and 220MPa respectively(at the aging time of 6ks), while those of the Al-Cu binary alloy aged at 423K were 243 and 166MPa(at the aging time of 1800ks). Change of ε during aging was almost same in both of the ternary and the binary alloys. The maximum elongation, ε_{max} was approximately 45% in aging at 423K for 10ks and at 573K for 0.3ks in the ternary and binary alloys. ε at the maximum value of σ_{max} is approximately 20% in both alloys. Thus when σ_{max} is compared at ε of 20%, σ_{max} of the ternary alloy, 300MPa is much higher than that of the binary alloy, 200MPa. θ' precipitates are smaller in size in the ternary alloy than in the binary alloy. The observed slow growth rate of θ' in the Al-Cu-Sc alloy may be because that scandium atoms retard migration of copper in the matrix due to high binding energy between scandium atoms and vacancies. High strength and ductility of the ternary alloy aged at 573K is mainly caused by the fine distribution of Al_3Sc and θ' precipitates in the matrix.

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