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Mechanical Properties and Microstructure of Aluminum Alloys with Dispersed Nanoscale Quasicrystalline Particles

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Abstract

New Al-based alloys with very high ultimate tensile strength were developed in high Al concentration range of 91-95 at.% for Al-Fe-Cr-Ti-M (M: Co and Mo) systems and Al-Fe-Cr-Mo-Ti-Co system by the dispersion of nanoscale quasicrystalline particles in Al phase. The effect of adding elements, M was discussed in the viewpoint of stability of super-cooled liquid state and formation ability of quasicrystalline phase. The P/M Al-Fe-Cr-Ti-M alloys with dispersed nanoscale quasicrystalline particles exhibited ultimate tensile strength of 350MPa at 573K and 200MPa at 673K.

Keywords: **aluminum-based alloy, quasicrystalline phase, powder metallurgy, high elevated-temperature strength**

1. Introduction

It is known that quasicrystalline (Q.C.) alloys with stoichiometric compositions have high Vickers hardness (*Hv*) and extremely brittle nature. For example, Hv is 1010 for the rapidly solidified (RS) Q.C. $Al_{77.5}Mn_{22.5}$ alloy[1)], 710 for the RS Q.C. $Al_{85.6}Cr_{15.4}$ alloy[1)] and 735 for the RS Q.C. $Al_{86}V_{14}$ alloy[2)]. These alloys also have high thermal stability. The volume fraction of the Q.C. particles decreases in order of Cr＞Mn＞V in the powder metallurgy (P/M) $Al_{93}Fe_3M_2Ti_2$ (M: V, Cr, Mn) alloys[3)]. There is a possibility of synthesizing a new material with high specific strength, high elevated-temperature strength and high wear resistance by dispersing Q.C. particles into fcc-Al phase. The P/M $Al_{94}V_4Fe_2$ and $Al_{93}Fe_3Cr_2Ti_2$ alloys containing quasicrystalline phase have high strength exceeding 580MPa[4)], high-elevated temperature strength exceeding 300MPa at 573K, and much better wear resistance than commercial A390 aluminum alloy[4)]. This paper presents the microstructure and mechanical properties for Al-Fe-Cr-Ti-M (M: Co and Mo) alloys and Al-Fe-Cr-Mo-Ti-Co alloy produced by melt spinning technique and powder metallurgy technique.

2. Experimental procedures

The alloy ingots were prepared by arc melting pure metals where there purity is better than 99.85% in an argon atmosphere. From the ingots, RS alloys with a cross section of $0.02\times1mm^2$ were produced by a melt spinning technique. The ingots of powder metallurgy (P/M) alloys were prepared by induction melting in an argon atmosphere. Rapid solidified (RS) powders were produced by high pressur gas and water atomization process[5)], followed by sieving into the sizes smaller than 150 m. By using the conventional powder metallurgy technique, P/M Al-Fe-Cr-Ti-M alloys with a diameter of 10 mm and a length of 600 mm were produced by extrusion of the atomization powders. The structure of RS and P/M alloys were examined by X-ray diffraction and transmission electron microscopy (TEM). Tensile strength was measured at a strain rate of 4.0×10^{-4} s^{-1} in the temperature range from room temperature to 673 K with an Instron testing machine.

3. Results and Discussion

3-1. Microstructure of RS $(Al_{0.93}Fe_{0.03}Cr_{0.02}Ti_{0.02})_{100-x}M_x$ (M: Co and Mo, x=0, 2 and 3) alloy ribbons

Figure 1 shows X-ray diffraction patterns of the RS $(Al_{0.93}Fe_{0.03}Cr_{0.02}Ti_{0.02})_{100-x}Co_x$ (x=0, 2 and 3) alloy ribbons produced by a melt spinning technique at the copper roller circumferential velocity (*Vc*) of 40m/s. The X-ray diffraction peaks broaden by adding cobalt element compared with $Al_{93}Fe_3Cr_2Ti_2$ alloy. The X-ray diffraction pattern shows an amorphous single phase when Co is added to 3at%. This means that addition of cobalt stabilizes the super-cooled liquid state of Al-Fe-Cr-Ti alloy.

Figure 2 shows X-ray diffraction patterns of the RS $(Al_{0.93}Fe_{0.03}Cr_{0.02}Ti_{0.02})_{98}M_2$ (M=None, Mo) alloy ribbons produced by a melt spinning technique at the copper roller of *Vc*=20m/s. The X-ray diffraction peaks of the $Al_{93}Fe_3Cr_2Ti_2$ alloy consist of fcc-Al, quasicrystalline (Q.C.) and $Al_{23}Ti_9$ phases. On the other hand, by addition of 2 at% Mo, the intermetallic compound peaks disappear and the quasicrystalline peaks becomes very clear. This means that molybdenum imparts a better formation ability of quasicrystalline phase to Al-Fe-Cr-Ti alloy.

In alloy design to disperse nanoscale Q.C. particles into fcc-Al phase, it is definitely important to consider the balance between the stability of super-cooled liquid state and the formation ability of quasicrystalline phase. In this study, Co and Mo are added to Al-Fe-Cr-Ti alloy to balance those two issues.

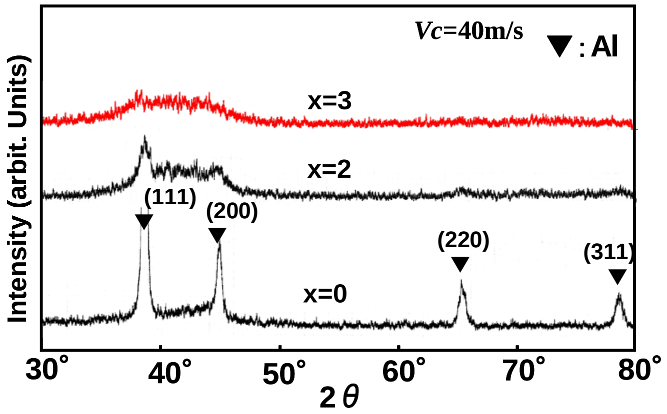

Fig. 1. X-ray diffraction patterns of the RS $(Al_{0.93}Fe_{0.03}Cr_{0.02}Ti_{0.02})_{100-x}Co_x$ alloys.

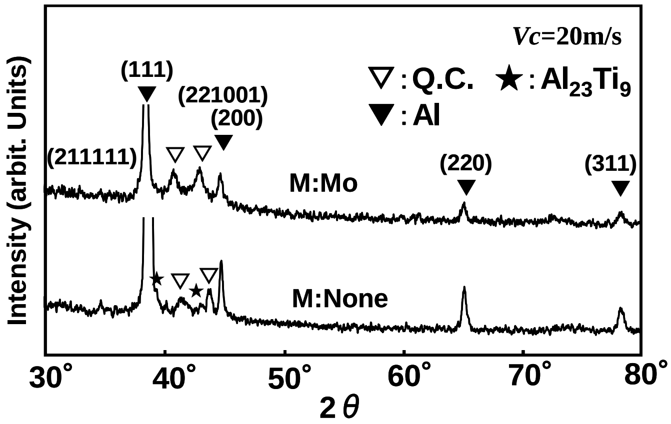

Fig. 2. X-ray diffraction patterns of the RS $(Al_{0.93}Fe_{0.03}Cr_{0.02}Ti_{0.02})_{98}M_2$ alloys

3-2. Microstructure and mechanical properties of P/M $Al_{93}Fe_{2.45}Cr_{2.45}Mo_{0.5}Ti_{0.8}Co_{0.8}$ alloy

Figure 3 shows the temperature dependence of the ultimate tensile strength (σ_{uts}) for the P/M $Al_{93}Fe_{2.45}Cr_{2.45}Mo_{0.5}Ti_{0.8}Co_{0.8}$ alloy at each testing temperature, together with the data of $Al_{93}Fe_3Cr_2Ti_2$ alloy and the conventional Al-based alloy. The σ_{uts} show much higher ones over the whole temperature range up to 673 K as compared with those of conventional Al alloys with high elevated-temperature strength.

Figure 4 shows bright field electron micrograph and selected-area electron diffraction pattern of the P/M $Al_{93}Fe_{2.45}Cr_{2.45}Mo_{0.5}Ti_{0.8}Co_{0.8}$ alloy. One can see the spherical Q.C. particles with a grain size of about 100 nm dispersed uniformly into fcc-Al matrix.

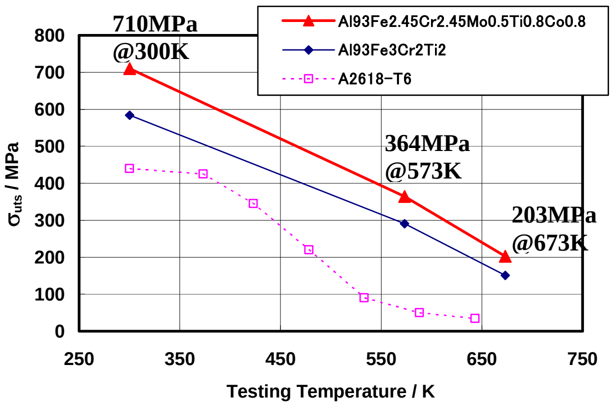

Fig. 3. Temperature dependence of ultimate tensile strength (σ_{UTS}) as a function of testing temperature for the P/M $Al_{93}Fe_{2.45}Cr_{2.45}Mo_{0.5}Ti_{0.8}Co_{0.8}$ alloy.

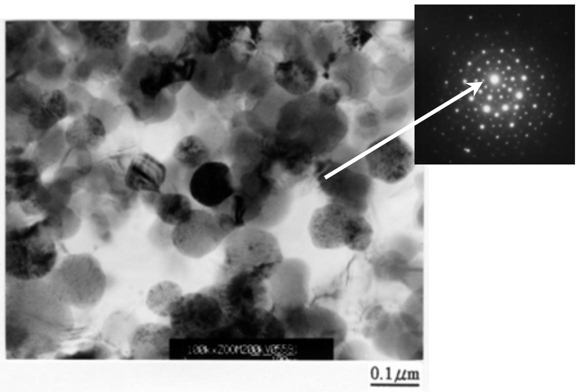

Fig. 4. Bright field electron micrograph and selected-area diffraction pattern of the P/M $Al_{93}Fe_{2.45}Cr_{2.45}Mo_{0.5}Ti_{0.8}Co_{0.8}$ alloy.

3. Summary

By addition of Co and Mo to Al-Fe-Cr-Ti alloy the good balance between the stability of super-cooled liquid state and the formation ability of quasicrystalline phase was obtained. The P/M Al-Fe-Cr-Ti-Co-Mo alloy with dispersed nanoscale quasicrystalline particles exhibited ultimate tensile strength of more than 350 MPa at 573 K and 200 MPa at 673 K.

4. References

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