Microstructure and Mechanical Properties of Rapidly Solidified Powder Metallurgy Al-Fe-V-Si-X Alloys

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Abstract

High heat-resistant Al-Fe-V-Si and Al-Fe-V-Si-X rapidly solidified powder metallurgy (RS P/M) alloys have been developed under well-controlled high purity argon gas atmosphere. The $Al_{90.49}Fe_{6.45}V_{0.68}Si_{2.38}$ (at. %) RS P/M alloy exhibited high elevated-temperature strength exceeding 300 MPa and good ductility with elongation of 6 % at 573 K. Reduction of H_2O partical pressure in P/M processing atmosphere led to improvement in mechanical properties of the powder-consolidated alloys under elevated-temperature service conditions. Ti addition to the Al-Fe-V-Si conduced to enhancement of the strength at room temperature. The tensile yeild strength and ultimate strenght were 545 MPa and 722 MPa, respectively.

Keywords : aluminum alloy, powder metallurgy, rapid solidification, closed process, mechachanical property

1. Introduction

The rapidly solidification technique makes structural modification such as reduction of segregation, refinement of grain size, and increase in solid solubility. As a result, mechanical properties of aluminum P/M alloys have been improved [1].

In the P/M processing, the extrusion processing is applicable to consolidation of rapidly solidified powder. Extrusion technique realizes densification and bonding of powder particles simultaneously at low temperature. Shearing force of extrusion brings about breaking oxide layer on the powder surface, and then formation of metal-to-metal bonding between the powder particles. Therefore, it is important to keep the powder surface clean without adsorption gas during all processing.

In previous study, we have established the closed P/M processing system with well-controlled high pure argon gas atmosphere. In the closed P/M processing, all the processes, that is, powder preparation, collecting and sieving of atomized powders, packing of them into the copper billets, degassing and extrusion, were performed in a closed chamber and glove box, in which oxygen and moisture contents in the argon atmosphere were maintained less than 0.5 ppm by a gas-purifier [2]. This paper aims to prepare the high heat-resistant Al-Fe-V-Si [3] and Al-Fe-V-Si-X (X = Ti, Cr) RS P/M alloys from the clean powder by the closed P/M processing system. Furthermore, in order to clarify the influence of processing atmosphere on the mechanical properties of the final RS P/M products, we compared the clean powder-consolidated alloy (CPC-Alloy) and open powder-consolidated alloy (OPC-Alloy). Hereafter, the clean powder and open powder mean the powder exposed to high purity argon gas and to humid air, respectively.

2. Experimental Procedure

Master alloy ingots of $Al_{90.49}Fe_{6.45}V_{0.68}Si_{2.38}$ (at. %), $Al_{90.49}Fe_{4.30}V_{0.68}Si_{2.38}Ti_{2.15}$, and $Al_{90.49}Fe_{4.30}V_{0.68}Si_{2.38}Cr_{2.15}$ were prepared by arc melting. RS powders were produced by a high pressure argon-gas atomization. The powders, which were sieved to less than 38 m, were first cold-pressed into a copper can, and then degassed for 900 s at 623 K. The consolidation was conducted by means of extrusion. The extrusion was performed at an extrusion ratio of 5, an extrusion temperature of 623 K, and a ram speed of 2.5 mm/s. Powder production and its consolidation were conducted through the closed or open P/M processing. Vacuum degassing behavior of the powder was investigated by the Temperature-programmed desorption (TPD) measurement. The TPD measurement using quadrupole mass spectrometer is useful to monitor the gas species given off the powder surface during degassing [4]. The structure of the atomized powders and the consolidated alloys was investigated using X-ray diffractometer (XRD), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Tensile strength and elongation were investigated at a strain rate of 5 x 10^{-4} s^{-1} using an Instron-type tensile testing machine.

3. Results and Discussion

Figure 1 shows mechanical properties of the CPC- and OPC-alloys at room temperature and at 573 K. In the case of the $Al_{90.49}Fe_{6.45}V_{0.68}Si_{2.38}$ alloy, the CPC alloy exhibited higher strength than the OPC alloy. Furthermore, the elongation of the CPC-alloy showed much larger than that of the OPC-alloy. Clean powder consolication through the closed P/M processing brings about improvement of ductility. Mechanical properties of Ti and Cr containing Al-Fe-V-Si-X alloys are also shown in Fig. 1. The Ti addition to the Al-Fe-V-Si-X alloy improved tensile yeild strength and ultimate strength at room temperature, although elongation decreased. On the other hand, the Cr addition to the Al-Fe-V-Si-X alloy lowered the strength at room and elevated temperatures.

Although XRD patterns are not shown in this paper, the results suggest that the Al-Fe-V-Si alloy consists of -Al, $Al_{13}(Fe,V)_3Si$. The Ti addition leads to formation of the $L1_2$-Al_3Ti and $D0_{22}$-Al_3Ti; the Cr addition promotes formation of quasicrystal. Icosahedral phase in the Cr-conataining alloy may bring about decrease in tensile strength of the alloys.

Figure 2 shows the tensile fracture surface of the CPC- and the OPC-alloys with a composition of $Al_{90.49}Fe_{6.45}V_{0.68}Si_{2.38}$. The fracture pattern of the CPC alloy indicates a typical ductile fracture. On the other hand, many brittle spherical-shaped fracture surfaces, possibly associated with the original powder particles, were observed in the OPC-alloy. There is a significant difference in fracture surfaces between the CPC- and the OPC-alloys.

In conclusion, the closed P/M processing, that is, process-atmosphere controlling, is effective in achivement of the sound bonding between powder particles during extrusion, resulting in improvement of mechanical properties. Fuethermore, Ti addition to the Al-Fe-V-Si-X alloy improved mechanical properties of the alloys because of formation of Ti-containing intermetallic compounds.

4. Acknowledgement

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5. References

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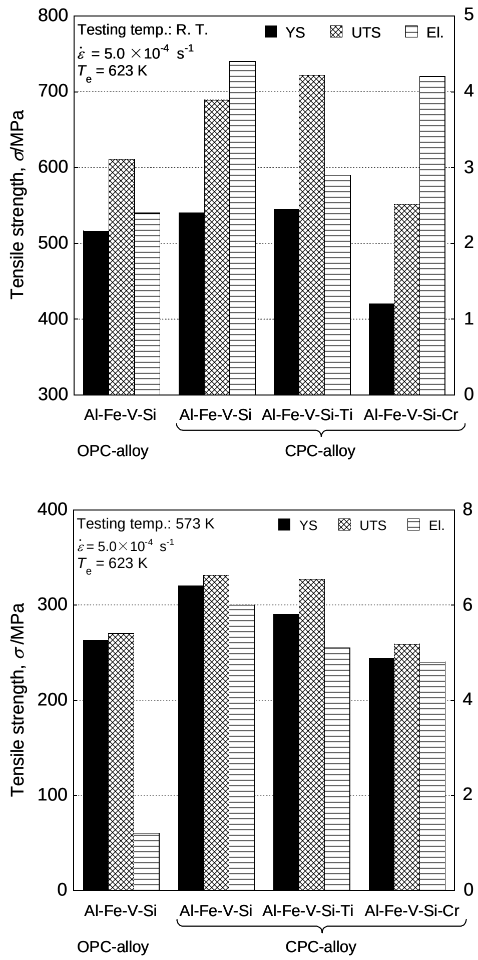

Fig. 1. Mechanical properties of the CPC- and the OPC-alloys at room temperature and 573 K. Alloy compositions are $Al_{90.49}Fe_{6.45}V_{0.68}Si_{2.38}$ and $Al_{90.49}Fe_{4.30}V_{0.68}Si_{2.38}(Ti, Cr)_{2.15}$.

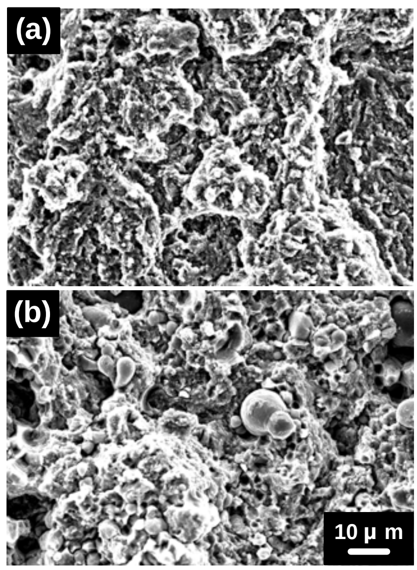

Fig. 2. SEM micrographs revealing tensile fracture surfaces of (a) the CPC-alloy and (b) the OPC-alloy of the $Al_{90.49}Fe_{6.45}V_{0.68}Si_{2.38}$.