CRYSTALLIZATION BEHAVIOR OF RAPIDLY SOLIDIFIED Al-Sm ALLOYS

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Abstract

Crystallization processes of rapidly solidified $Al_{100-x}Sm_x$ (X=6-16at%) alloys were investigated. The alloys were rapidly solidified into ribbons by a single roller method. The rapidly solidified $Al_{100-x}Sm_x$ (X=8-14) ribbons are composed of an amorphous phase containing a small amount of crystalline phase, while the $Al_{94}Sm_6$ and $Al_{84}Sm_{16}$ ribbons are composed of only an α-Al phase and of α-Al and Al_4Sm phases, respectively. Subsequent decomposition behavior of the melt spun ribbons was examined by XRD, TEM and DSC. Three kinds of new phases which are defined as M1, M2 and S3 were found to appear in the decomposition process of the rapidly solidified ribbons. M1, M2 and S3 are a metastable hexagonal phase with a=0.4597nm and c=0.6358nm, a metastable cubic phase with a=1.9154nm and an orthorhombic phase with a=1.3781nm, b=1.1019nm and c=0.7303nm, respectively.

Introduction

Al-based amorphous alloys, particularly those containing rare earth elements [1-4], have attracted much attention to theoretical research and practical application. After the amorphous alloys are annealed, the rare earth elements in these alloys precipitate as intermetallic compounds from the amorphous phase. The microstructure has a dominant influence on the mechanical properties of the alloys. Consequently it is necessary to investigate the

decomposition process of the amorphous alloys. Al-based amorphous alloys were chosen because of the ease of the study on their decomposition processes. Among binary Al-rare earth element alloys, Al-Sm system has a wider amorphous formation composition range and a complicated decomposition process[5]. There are a few unknown phases which appear in the decomposition process of Al-Sm amorphous alloys. Little is known about the structures of the phases. This paper is intended to investigate crystallization processes of rapidly solidified Al-Sm alloys.

Experimental Methods

$Al_{100-x}Sm_x$ (X=6-16at%) alloys were prepared from pure elements by arc melting in an argon atmosphere. The purity was 99.99wt% for Al and 99.9wt% for Sm. By using a single roller melt spinning apparatus, the prealloyed ingots were rapidly solidified into a ribbon form at a circumferential speed of 40m/s in an argon atmosphere. The thickness of these ribbons is in the range of 20-30 μm. As-quenched and annealed structures of these ribbons were examined by X-ray diffractometry and transmission electron microscopy (TEM). The annealing time was fixed to be 1h. The thermal stability of these rapidly solidified ribbons was also evaluated by DSC. The structural change with increasing temperature was examined in situ by using a transmission electron microscope with a heating stage.

Results and Discussion

Phase structures of rapidly solidified $Al_{100-x}Sm_x$ (X=6-16) alloys

According to the results obtained by X-ray diffraction analysis, the rapidly solidified $Al_{100-x}Sm_x$ (X=8-14) ribbons with a thickness of 20-30μm are composed of an amorphous phase containing a small amount of crystalline phase. The $Al_{94}Sm_6$ ribbon consists of only an α-Al phase, while the $Al_{84}Sm_{16}$ ribbon is composed of α-Al and Al_4Sm phases.

Crystallization of rapidly solidified $Al_{94}Sm_6$ alloy

Thermal stability of the $Al_{94}Sm_6$ ribbon was examined by DSC. There are two exothermic peaks in the DSC curve and the temperature at each peak is 560K and 600K, respectively. In order to investigate the precipitates corresponding to their exothermic peaks, the rapidly solidified ribbon was annealed for 1h at 573K and 873K. The X-ray diffraction results show that the annealing-induced phase at 573K is Al_4Sm tetragonal phase with

a=0.428nm and c=0.990nm. The increase in annealing temperature to 873K causes the disappearance of the Al_4Sm phase and the appearance of a hexagonal Al_3Sm phase with a=0.638nm and c=0.4597nm. This result proves that the first exothermic peak is due to the transformation of supersaturated α-Al → α-Al + Al_4Sm and the second is caused by the transformation of α-Al + Al_4Sm → α-Al + Al_3Sm.

Crystallization of rapidly solidified $Al_{92}Sm_8$ alloy

The X-ray diffraction results shown in Fig.1 show that the $Al_{92}Sm_8$ ribbon with a thickness of 20-30μm is composed only of an amorphous phase. It is seen that there are three peaks in the DSC curve shown in Fig.2. The X-ray diffraction results show that α-Al phase precipitates from the amorphous phase at 473K. At 541K an Al_4Sm phase appears, accompanying the precipitation of a new orthorhombic phase. The lattice parameter of the new orthorhombic phase was determined as a=1.3781nm, b=1.1019nm and c=0.7303nm. Here, the new orthorhombic phase is named as S3.

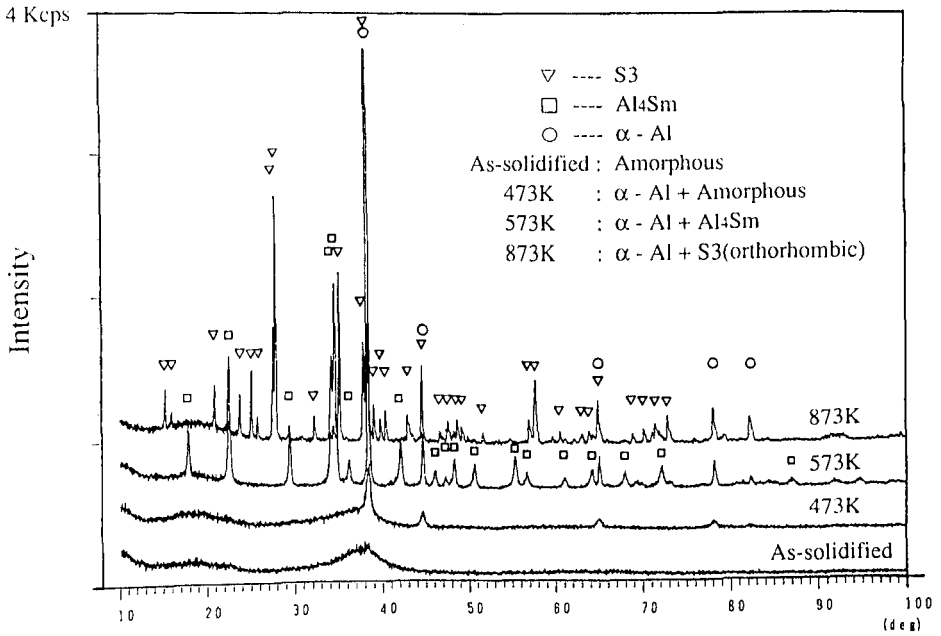


Fig.1 X-ray diffraction patterns of an $Al_{92}Sm_8$ alloy

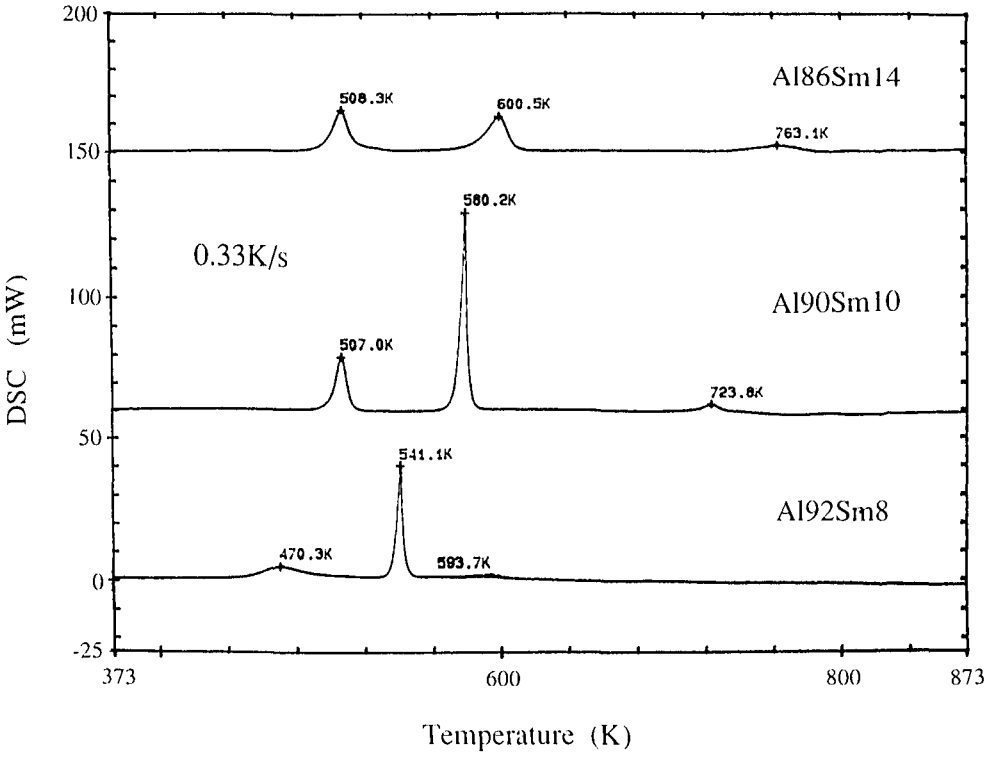


Fig.2 DSC curves of rapidly solidified Al-Sm alloys

Crystallization of rapidly solidified $Al_{90}Sm_{10}$ and $Al_{88}Sm_{12}$ alloys

No appreciable difference in the crystallization process is seen between rapidly solidified $Al_{90}Sm_{10}$ and $Al_{88}Sm_{12}$ alloys. Three exothermic peaks are observed in the DSC curve. The X-ray diffraction results on the $Al_{90}Sm_{10}$ ribbons shown in Fig.3 show that the first DSC peak is due to the precipitation of α-Al, Al_4Sm and a new hexagonal phase. At the second DSC peak, no new phase appears. This means that at temperature of the second DSC peak, the phase transformation occurred at the first DSC peak continues going on. When the alloy is annealed at 873K above the third DSC peak, both the new hexagonal phase and Al_4Sm disappear and the S3 phase forms. On the basis of the X-ray analytical data, the lattice parameter of the new hexagonal phase is determined as a=0.4597nm and c=0.6358nm and the space group is presumed to be P6. Here, the hexagonal phase is defined as M1. The rapidly

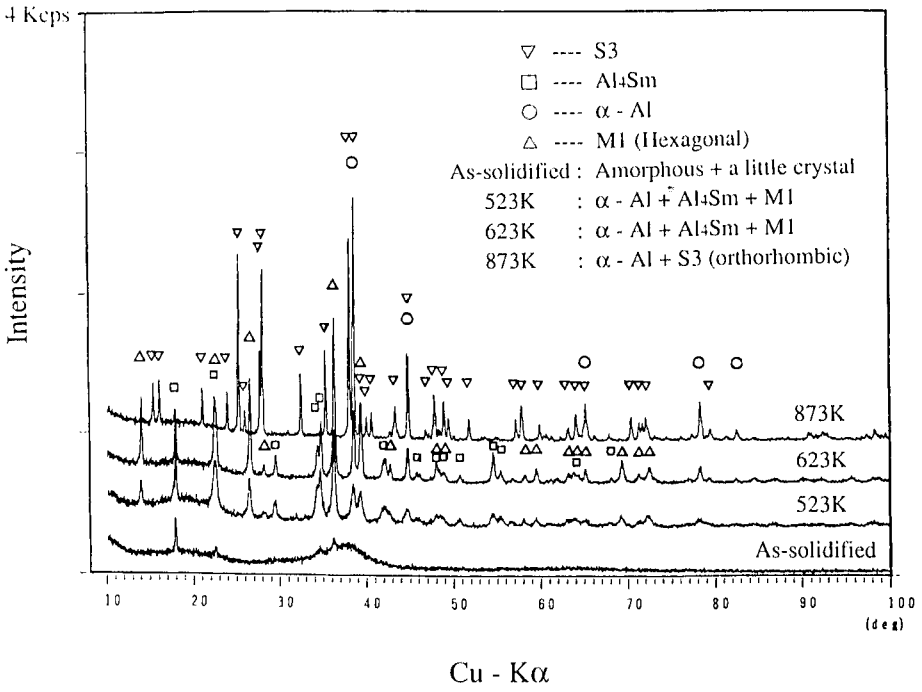
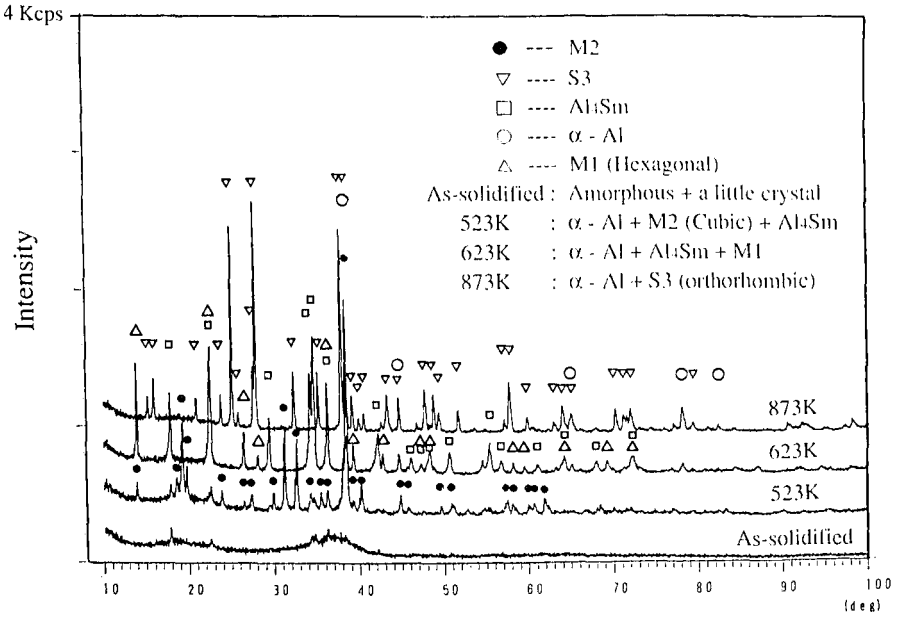


Fig.3 X-ray diffraction patterns of an $Al_{90}Sm_{10}$ alloy

solidified $Al_{90}Sm_{10}$ ribbon was observed in situ by using a transmission electron microscope with a heating stage. From the selected area diffraction patterns on the new phases, the two new phases M1 and S3 were confirmed to exist in the decomposition processes of the alloy.

Crystallization of rapidly solidified $Al_{86}Sm_{14}$ and $Al_{84}Sm_{16}$ alloys

On the basis of XRD, DSC and TEM data, the crystallization process of the $Al_{86}Sm_{14}$ alloy is determined as Amorphous → α-Al + M2 + Al_4Sm → α-Al + Al_4Sm + M1 → α-Al + S3, as shown in Fig.4. Here, M2 is referred as a new metastable cubic phase with a=1.9154nm. The existence of the new cubic phase is also confirmed by selected area electron diffraction analyses. According to the XRD results, the crystallization process of the $Al_{84}Sm_{16}$ alloy is determined as α-Al + Al_4Sm → α-Al + Al_4Sm + S3→ α-Al + S3.



Cu - Kα

Fig.4 X-ray diffraction patterns of an $Al_{86}Sm_{14}$ alloy

Conclusions

The crystallization process of the rapidly solidified $Al_{100-x}SmX$ (X=6-16) alloys depends sensitively on alloy composition. Three kinds of new phases were found to appear in the crystallization process of these alloys. They are named as M1, M2 and S3, respectively. The M1 is a metastable hexagonal phase with a=0.4597nm and c=0.6358nm. The M2 is a metastable cubic phase with a=1.9154nm and the S3 is an orthorhombic phase with a=1.3781nm, b=1.1019nm and c=0.7303nm. The crystallization processes of the $Al_{100-x}Sm_x$ (X=6-16) alloys are summarized as follows.

$Al_{94}Sm_6$ α-Al → α-Al + Al_4Sm → α-Al + Al_3Sm

$Al_{92}Sm_8$ Am → α-Al + Am → α-Al + Al_4Sm → α-Al + S3

$Al_{90}Sm_{10}$ Am → α-Al + Al_4Sm + M1 → α-Al + S3

$Al_{88}Sm_{12}$ Am → α-Al + Al_4Sm + M1 → α-Al + S3

$Al_{86}Sm_{14}$ Am → α-Al + Al_4Sm + M2 → α-Al + Al_4Sm + M1 → α-Al + S3

$Al_{84}Sm_{16}$ α-Al + Al_4Sm → α-Al + Al_4Sm + S3 → α-Al + S3

Here, Am is referred to amorphous, Al_4Sm is a tetragonal phase with a=0.428nm and c=0.990nm, and Al_3Sm is a hexagonal phase with a=0.638nm and c=0.4597nm.

Acknowledgment

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MECHANICAL PROPERTIES OF RAPIDLY SOLIDIFIED ALUMINUM ALLOY EXTRUDED FROM NANOCRYSTALLINE POWDERS

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INTRODUCTION

Recently, aluminum alloys with superior properties such as high tensile strength and high elevated temperature strength have been developed by rapid solidification technique or mechanical alloying. These aluminum alloys are strengthened by homogeneous dispersion of carbides, oxides or fine intermetallic compounds consisting of transition elements having low diffusion rates in aluminum.

The present authors have found that bulky Al-Ni-Mm (Mm=misch metal) and Al-Ni-Zr crystalline alloys have high tensile strength, high elevated temperature strength and good wear resistance [1] [2] [3]. These bulks were prepared by extruding powders produced by a high-pressure gas atomization technique. Very recently, we have found that an ultra-high tensile strength of 1000 MPa is obtained for an as-extruded $Al_{89.5}Ni_8Mm_{0.75}Zr_{1.75}$ (compositions in at.%) alloy because of the ultra-fine-grained structure and the homogeneous dispersion of a large amount of fine intermetallic compounds [4]. The objective of this paper is to demonstrate that the warm extrusion of rapidly solidified $Al_{89.7}Ni_8Mm_{1.5}Zr_{0.8}$ powders causes simultaneous achievement of high tensile strength, high fatigue strength and good wear resistance.