Materials Research Proceedings **32** (2023) 303-308 https://doi.org/10.21741/9781644902615-35

Improvement in strength and ductility of flame-retardant magnesium alloy through uniaxial hot pressing

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Keywords: Magnesium Alloy, Heat Treatment, Tensile Test, Dynamic Recrystallization

Abstract. Flame-retardant magnesium alloys containing calcium element are attracting attention from aircraft and automotive industries because of their low density and high ignition temperature. Though thermomechanical treatments such as hot extrusion are effective to increase their mechanical properties, they cause an increase in cost. Present study focusses on commercial Mg-6Al-0.4Mn-2Ca and Mg-9Al-1Zn-2Ca alloys. Simple uniaxial hot pressing process is performed in these magnesium alloy plates. Tensile tests at room temperature revealed that the hot pressed Mg-6Al-0.4Mn-2Ca and Mg-9Al-1Zn-2Ca alloys have high tensile strength and elongation. Microstructural observation clarified that the improved mechanical properties were mainly due to dynamic recrystallization during the hot pressing. The present uniaxial hot pressing process has a potential as a simple thermomechanical treatment process for flame-retardant magnesium alloys.

Introduction

Many experimental studies have focused on the mechanical properties of lightweight magnesium alloys. For example, low temperature superplasticity in commercial Mg-Al-Zn alloys was induced by grain refinement through severe plastic deformation processes [1,2]. Recently, flame-retardant magnesium alloys have been developed by addition of calcium. Calcium element causes high strength and high heat resistance in Mg-Al alloys because of precipitation hardening by hard second phase (Al_2Ca) [3]. However, the low formability of Mg-Al-Ca alloys prevents the structural applications. Several thermomechanical treatment processes have been proposed in Mg-Al-Ca alloys. Hot extrusion is one of the effective process to increase both the strength and the ductility of Mg-Al-Ca alloys [4,5]. On the other hand, the hot extrusion process requires a large-scale equipment which increases the production cost.

The authors have proposed the simple uniaxial hot pressing process for enhanced formability of commercial magnesium alloys. The uniaxially hot pressed Mg-9Al-1Zn alloy showed high tensile strength as well as high elongation at room temperature [6]. In the present study, the hot pressing process is applied on Mg-Al-Ca alloys. The mechanical properties after the hot pressing process are evaluated by microstructural observation and tensile tests at room temperature.

Experimental Procedure

Hot extruded Mg-6Al-0.4Mn-2Ca alloy and cast Mg-9Al-1Zn-2Ca alloy were supplied by Fuji light metal Co., Ltd., Japan. Chemical compositions are shown in Table 1. Rectangular plates were cut from the starting materials. Uniaxial hot pressing was carried out using a Shimadzu CONCRETO 2000X compression testing machine. Specimens were compressed at 573 K, 623 K and 673 K in atmosphere. Boron nitride powder was used as a lubricant.

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Table 1 Chemical compositions of as-extruded Mg-6Al-0.4Mn-2Ca alloy and as-cast Mg-9Al-1Zn-2Ca alloy (mass%).

Element	Al	Zn	Mn	Fe, Ni	Si	Cu	Ca	Mg
Mg-6Al-0.4Mn-2Ca	6.17	0.01	0.35	<0.001	0.03	0.001	2.04	Bal.
Mg-9Al-1Zn-2Ca	9.42	0.62	0.20	<0.001	0.04	0.001	2.16	Bal.

Microstructural observation was carried out using a JEOL JSM-IT800 field emission scanning electron microscope (FE-SEM). Crystal grains were evaluated by orientation imaging microscopy (OIM) analysis based on the electron back scattered diffraction (EBSD) patterns.

Tensile test specimens with different thicknesses were cut by electrical discharge machining. Tensile tests were performed using a Shimadzu Autograph AGX-50kVD universal testing machine at room temperature. Crosshead separation rate was fixed at 1 mm/min.

Results and Discussion

Inverse pole figure (IPF) maps of as-extruded Mg-6Al-0.4Mn-2Ca alloy and as-cast Mg-9Al-1Zn-2Ca alloy are shown in Fig. 1. Average crystal grain diameters of Mg-6Al-0.4Mn-2Ca alloy and Mg-9Al-1Zn-2Ca alloy were 8.3 μm and 1098 μm, respectively. In addition, the casting defects were observed in Mg-9Al-1Zn-2Ca alloy.

IPF maps of Mg-6Al-0.4Mn-2Ca alloy after the hot pressing at 573 K, 623 K and 673 K are shown in Fig. 2. Vertical directions are parallel to the compression direction. A part of area consisting of fine crystal grains were observed. This is due to the dynamic recrystallization during the hot pressing. However, the crystal grain sizes did not change significantly.

IPF maps of Mg-9Al-1Zn-2Ca alloy after the hot pressing at 573 K, 623 K and 673 K are shown in Fig. 3. Vertical directions are parallel to the compression direction. Area of dynamic recrystallization increased with increasing the temperature and the compressive strain. As a result, fine equiaxial grains were formed in specimens more than 50% compressive strain. In addition, the area of initial casting defects decreased after the hot pressing process.

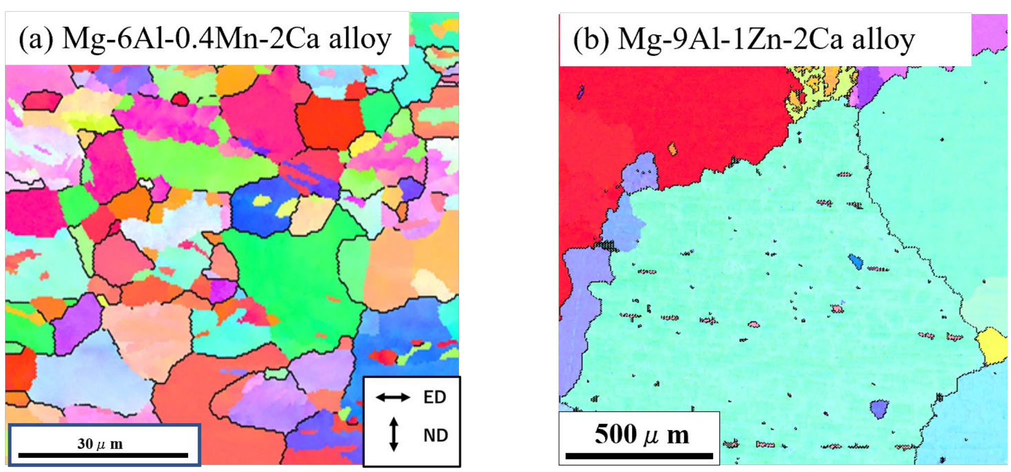

Fig. 1 IPF maps of (a) as-extruded Mg-6Al-0.4Mn-2Ca alloy and (b) as-cast Mg-9Al-1Zn-2Ca alloy.

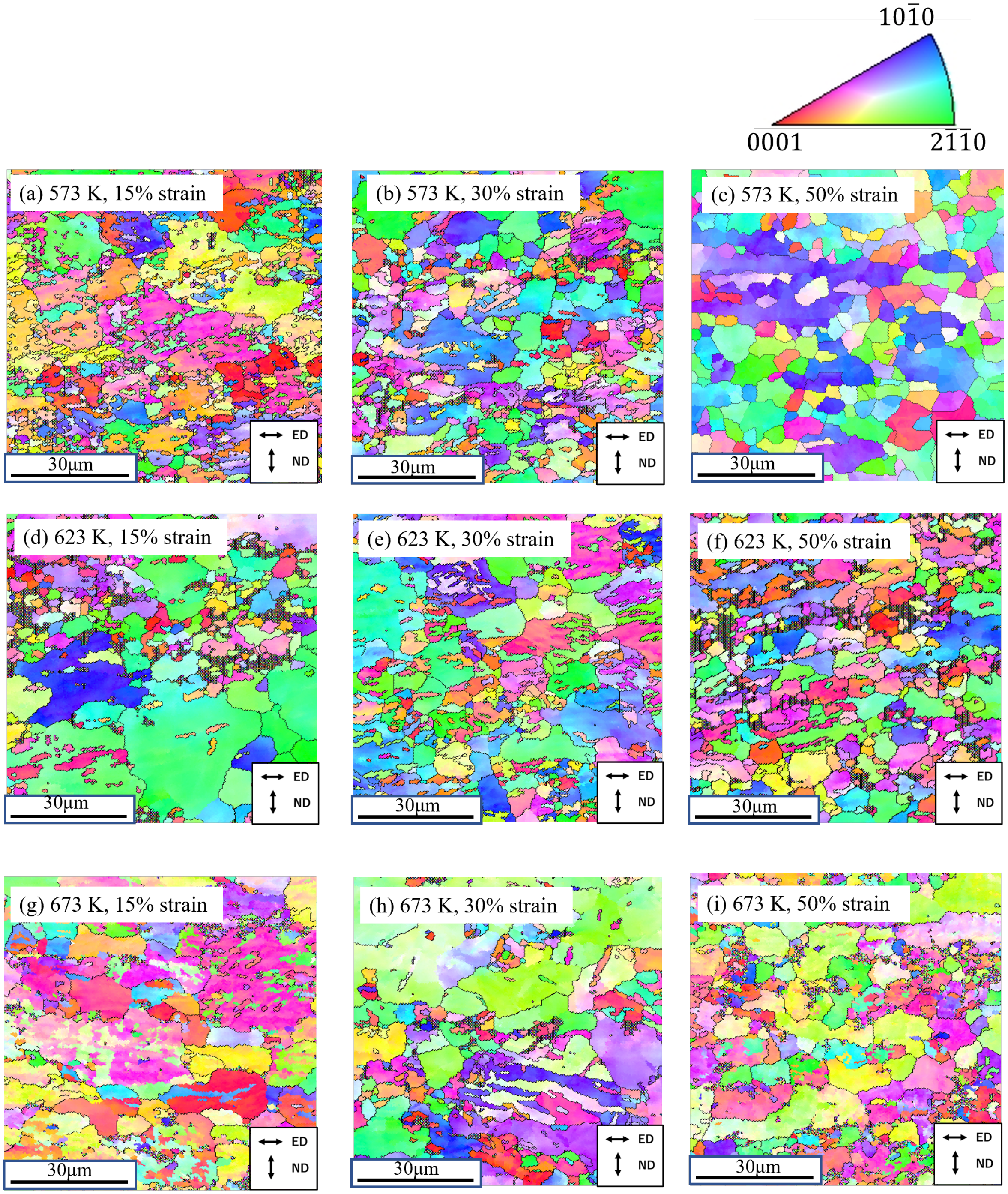

Fig. 2 IPF maps of Mg-6Al-0.4Mn-2Ca alloy. The specimens were hot pressed at 573 K to (a) 15%, (b) 30%, (c) 50% strains, at 623 K to (d) 15%, (e) 30%, (f) 50% strains, at 673 K to (g) 15%, (h) 30%, (i) 50% strains.

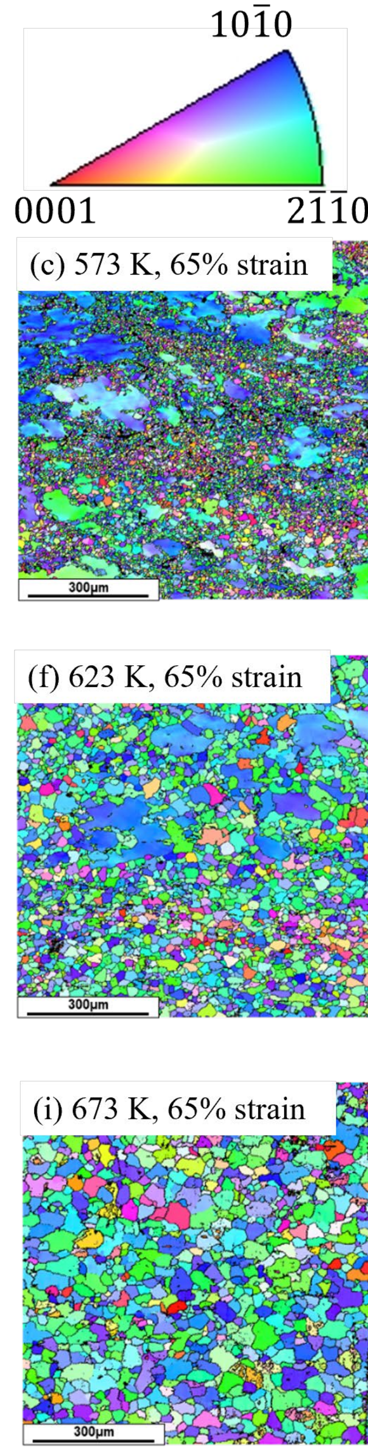

Fig. 3 IPF maps of Mg-9Al-1Zn-2Ca alloy. The specimens were hot pressed at 573 K to (a) 30%, (b) 50%, (c) 65% strains, at 623 K to (d) 30%, (e) 50%, (f) 65% strains, at 673 K to (g) 30%, (h) 50%, (i) 65% strains.

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Results of tensile tests in Mg-6Al-0.4Mn-2Ca alloy are shown in Fig. 4. The 0.2% proof stress and the tensile strength were slightly increased after the hot pressing. The specimen compressed at 623 K to 15% strain showed the highest elongation of 16.4%. The enhancement of the mechanical properties was relatively low because of the initial fine equiaxial grains in as-extruded Mg-6Al-0.4Mn-2Ca alloy.

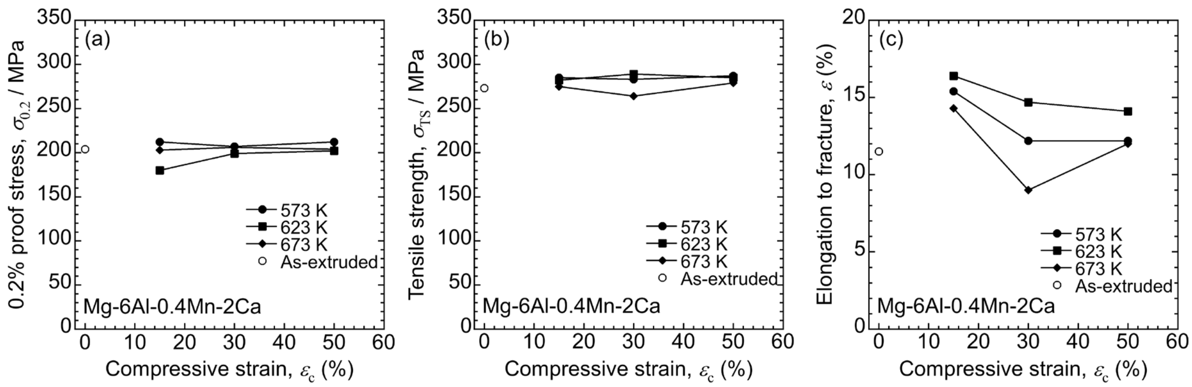

Fig. 4 (a) 0.2% proof stress, (b) tensile strength and (c) elongation to fracture in Mg-6Al-0.4Mn-2Ca alloys were plotted as a function of compressive strain.

Results of tensile tests in Mg-9Al-1Zn alloy are shown in Fig. 5. The 0.2% proof stress, the tensile strength and the elongation to fracture increased with increasing the compressive strain. The specimen compressed at 673 K to 65% strain showed the highest elongation of 8.1%. These results are due to the grain refinement induced by the dynamic recrystallization. Large crystal grains in as-cast Mg-9Al-1Zn-2Ca alloy were refined during the hot pressing process. In addition, casting defects decreased by the plastic deformation at high temperature. This is effective to increase the ductility.

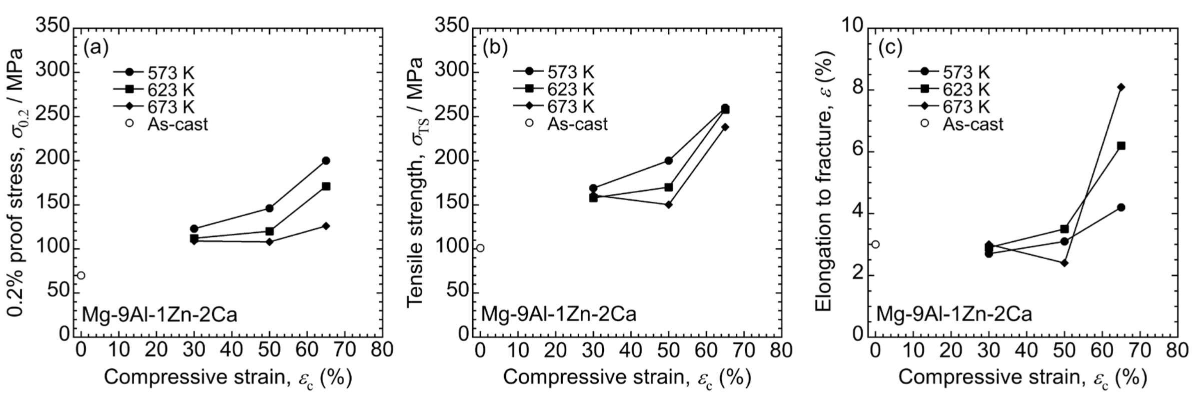

Fig. 5 (a) 0.2% proof stress, (b) tensile strength and (c) elongation to fracture in Mg-9Al-1Zn-2Ca alloys were plotted as a function of compressive strain.

Summary

Uniaxial hot pressing treatment was carried out to as-extruded Mg-6Al-0.4Mn-2Ca alloy and as-cast Mg-9Al-1Zn-2Ca alloys. During the high compression process, initial coarse grains were refined due to the dynamic recrystallization. Tensile tests revealed that the improvement in tensile strength and ductility of flame-retardant magnesium alloys. Especially, the mechanical properties of as-cast Mg-9Al-1Zn-2Ca alloy were significantly improved after the hot pressing process. Reduced casting defects is one reason of the improvements.

Acknowledgement
This work was supported in part by Light Metal Educational Foundation, Japan.

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