Effect of Sintering Temperature on the Room Temperature Properties of $Al_{90}Mn_8Ce_2$ Alloy

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Using a powder hot-pressing technique, a high-strength Al-8Mn-2Ce alloy (atomic percent (at.%)) in a size of ϕ20 × 10 mm has been made. The parameters used to obtain the highest strength of 895 MPa for the alloys are a pressing temperature of 803 K, a pressing time of 15 min, and a pressing stress of 1.2 GPa.

Keywords aluminum alloy, mechanical properties, sintering

1. Introduction

Al alloys have received considerable attention due to their high specific strength.[1-4] The specific strength of the Al alloys may further increase through grain size drop, supersaturation of α-Al, and the appearance of intermetallic compounds, which have been achieved by rapid solidification (RS) method and mechanical alloying (MA) method. Among Al alloys, AlLnTm (Ln = rare earth, Tm = V, Cr, Mn, Fe, and Mo) amorphous aluminum alloys possess high strength and good toughness.[4–7] The tensile strengths of the alloys are >1000 Mpa, while the alloys consist of amorphous matrix plus embedded nanostructured α-Al crystals or icosahedron quasi-crystals. A bulk high-strength AlLaNi alloy with a centimeter size has been made by a powder metallurgy method.[8] This is also the case for a ZrAlNiCuCo alloy.[9,10] In this study, the $Al_{90}Mn_8Ce_2$ alloy powders made by an ultrasonic atomization method were pressed under different temperatures. It was found that bulk samples with room temperature, high strength, and almost full density can be obtained through adjusting the pressing temperature.

2. Experimental Procedure

Al, Mn, and Ce elements with purities of 99.98% were melted in a vacuum induction furnace. The powders of the alloy with a composition of $Al_{90}Mn_8Ce_2$ (at.%) were obtained by ultrasonic atomization method under an argon atmosphere with a cooling rate of about 100 K/s. The size of the powders on average was 40 μm. The bulk alloy was produced by pressing under a hydraulic pressure machine at different temperatures between 553 K and ~853 K, with a high pressure of 1.2 GPa. The holding time was 15 min. The phase structure analysis of the bulk samples was made by a Rigaku (Tokyo, Japan) D/max x-ray instrument. The hardness measurements of the samples were carried out on a Vickers hardness instrument of HX-1000 type with a load of 50 g for 10 s. The compression strength of the alloys was measured on an Instron machine (Canton, MA). The fracture characteristic was observed by scanning electron microscope (SEM). The density was determined by use of Archimedes's principle by a balance with a precision of 0.01 mg. The porosity of the alloy δ was determined as follows:

$$\delta = (\rho_t - \rho_m)/\rho_t \quad \text{(Eq 1)}$$

where ρ_m and ρ_t are the measured density of the alloys and the theoretical density of the algebra sum of alloying elements, respectively. The relevant density data are cited from Ref. 11. The thermal analysis of the alloy was made by a differential scanning calorimeter (DSC-7 Perkin-Elmer, Norwalk, CT), with a heating rate of 0.667 K/s. The details of the measuring techniques have been described elsewhere.[9,10]

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3. Results and Discussions

Figure 1 shows the effect of pressing temperature *T* on the porosity of the sintered samples. The results indicate that bulk samples cannot be formed at temperatures <753 K where the powders remain in the original state, as shown in Fig. 2(a). Only when *T* > 753 K, the porosity of the sintered sample is

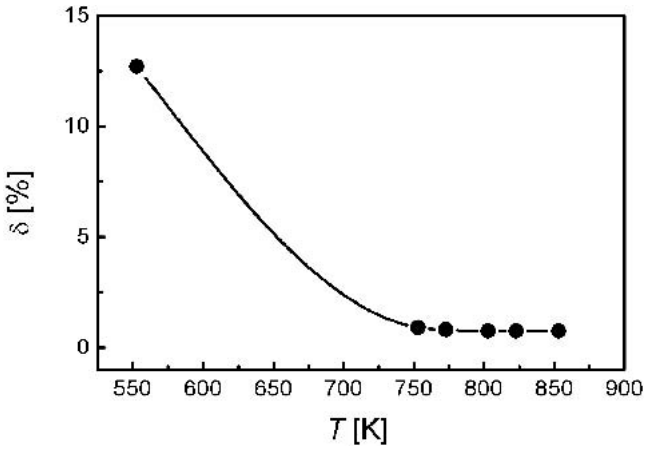
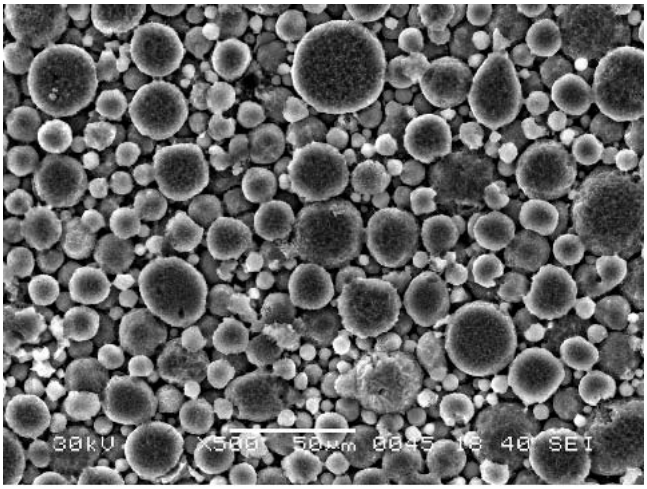
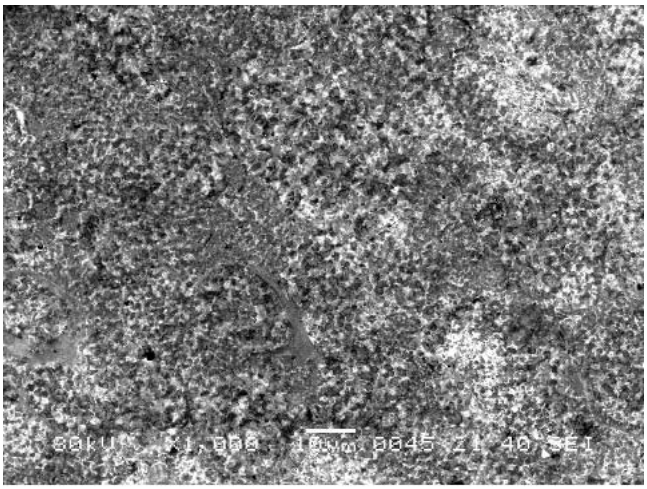


Fig. 1 Porosity of pressed samples at different pressing temperatures



(a)



(b)

Fig. 2 Micrographs of samples after mold pressing: **(a)** at 553 K; **(b)** at 803 K

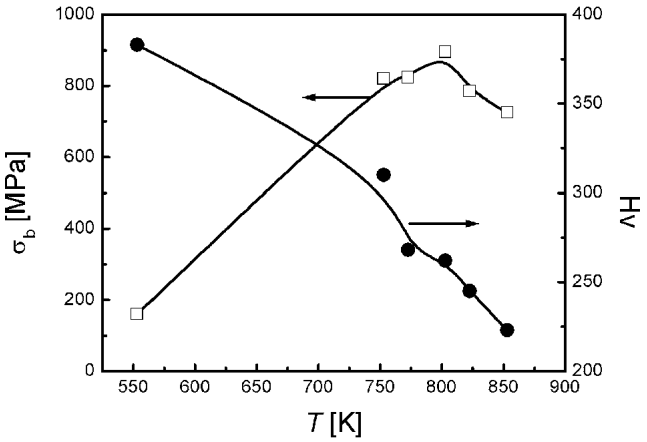


Fig. 3 Compression strength (σ_b) and HV pressed samples as functions of pressing temperatures (T)

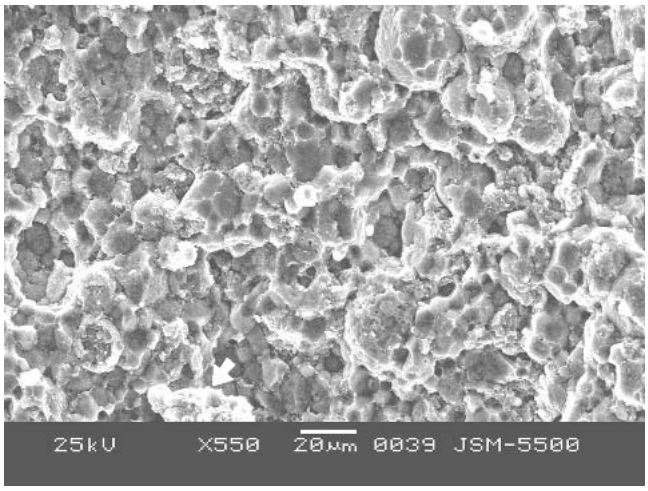


Fig. 4 SEM observation of the fracture of the sample pressed at 803 K

<1% with a fine grain structure (Fig. 2b). Note that if the pressure (P) is <1 GPa, δ cannot approach 0.[8]

The compression strength (σ_b) and Vickers hardness of samples (HV) at different T values are present in Fig. 3. It is interesting that σ_b and HV show different tendencies as T increases. When $T < 753$ K, the powders remain separate (Fig. 2a), and thus the σ_b value is very low. As $T > 753$ K, the powders are sintered and therefore have higher σ_b values. The highest value of 895 MPa is obtained at 803 K. Further higher temperatures do not increase σ_b value.

The sintered brittle sample cannot bear the tensile stress, which is identified by observing the tensile fracture of the sintered samples shown in Fig. 4. The percentage of the ductile fracture area (white area) is only 17%, as measured by the image analysis system of a microscope, which should be related to part of the α-Al, while intermetallic compounds consisting of alloys constitute the rest of the parts, leading to the residual brittle fracture.

X-ray analysis of the powders before the pressing shown in Fig. 5 indicates that the alloy consists of α-Al, Al_4Ce, $MnAl_6$, and Al_2O_3, while alumina could be produced on the surface of powders during both the manufacture and storage of the powders. The existence of large amounts of the oxide and the intermetallic compounds should strongly contribute to the hardness of the alloys.

Since the alumina that existed on the surface of the alloy powders has a higher melting temperature, a high pressure and a high pressing temperature are needed to deform and destroy it. Only when the fresh surfaces of the alloys are able to contact each other directly, and surface melting of the powder occurs, can sintering be realized. Since the ductile-fracture percentage shown in Fig. 4 is only 17%, alumina films can still exist after the sintering.

Figure 6 shows the result of thermal analysis of the alloy. An onset temperature with an exothermic peak at 726 K indicates the crystallization of the amorphous phase within the powders and an onset temperature with an endothermic peak at 922 K shows the melting. Below 922 K, the curve without an evident exothermic peak implies that the grain growth in this temperature range is negligible. Note that since the powders are

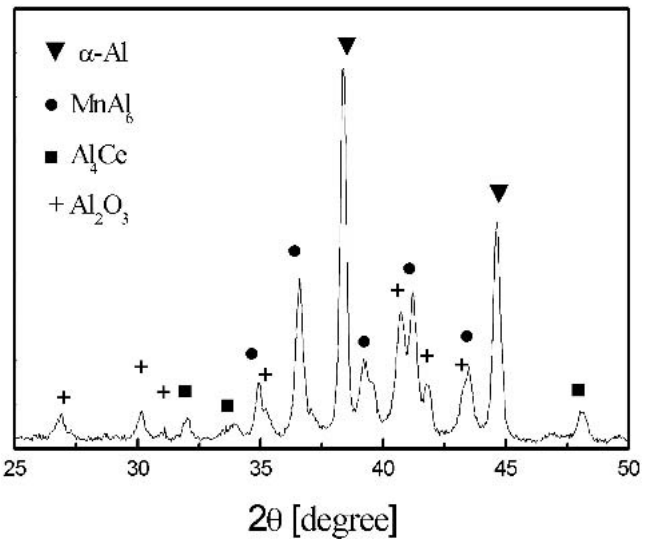


Fig. 5 X-ray structure analysis of a powder sample at room temperature

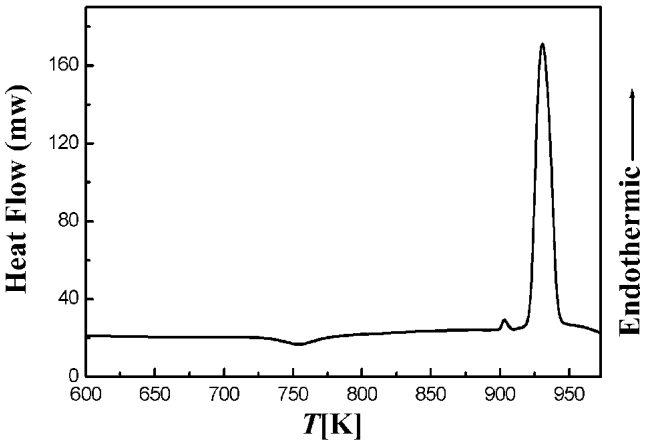


Fig. 6 DSC curve of powders before the pressing

obtained by quenching, although the quenching rate is only 100 K/s, a small amount of glass may be formed for this alloy,[2-4,8] which was identified by its exothermic peak at 726 K. However, no glass are detected in the alloy by x-ray analysis in Fig. 4, which indicates that the amount of undercooled liquid after the glass transition must be <2%. In addition, the surface melting of crystals arises at $T > 0.8T_m = 738$ K (T_m is the melting temperature),[12] which should occur between the surface alumina films and the alloy powders (substrates). Thus, the associative strength between them decreases due to the weakness of the substrate support for the films, which results in the easy destruction of the powder films. The existence of the undercooled liquid could have a similar effect on surface melting. Therefore, the pressing temperature must be >740 K where both effects work.

4. Summary

A high-strength $Al_{90}Mn_8Ce_2$ alloy that is $\phi 20 \times 10$ mm in size has been obtained by pressing powders under a temperature above the surface melting temperature (or $0.8T_m$). Above that temperature, the powders can be sintered with high density even if alumina exists on the surface of the powders. The highest strength (at 895 Mpa) are obtained when the sintering temperature is 803 K.

Acknowledgments

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