Investigation on the Sintering Behavior of P/M Al-Zn-Mg-Cu Alloy

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Abstract

In the present work, the sintering behavior of high strength Al-5.6Zn-2.5Mg-1.6Cu (in wt.%) alloy compacts prepared from elemental powders was investigated. Microstructural evaluation was accompanied by XRD and DSC methods in order to determine the temperature and chemical composition of the liquid phases formed during sintering. It was found that three transient liquid phases are formed at 420, 439 and 450 °C. Microstructural study revealed the progressive formation of sintered contacts due to the presence of the liquid phases, although the green compact expands as a result of the melt penetration along the grain boundaries. While Zn melts at ~420 °C, the intermetallic phases formed between Al and Mg were found to be responsible for the formation of liquid phase and the dimensional change at higher temperatures.

Keywords : Sintering; 7075 Al Alloys; Liquid phase, Microstructure

1. Introduction

The production of lightweight aluminum powder metallurgy (P/M) parts has traditionally attracted much attention because of their unique combination of properties [1]. However, as compared to P/M ferrous materials, Al alloys are more difficult to produce due to very stable oxide layers covering the powder particles [2,3]. Besides the technical problems in sintering of aluminum, the currently commercialized P/M processed alloys made by pressing and sintering of elemental mixes have insufficient strength to be used in the drive train of modern automobiles [4]. Therefore, manufacturing of high strength Al alloys such as those containing Zn, Mg and Cu as the alloying elements is attractive. In the present work, the sintering behavior of Al-Zn-Mg-Cu powder mixtures is studied.

2. Experimental and Results

Gas atomized Al powder supplied by Khorasan Powder Metallurgy Co. (KPM, Mashhad, Iran) was used as the starting material. The particle size distribution of the powder was determined by a laser particle size analyzer (Mastersizer 2000, Malvern, UK) and was found to have an average size of 75 μm. Gas atomized zinc (<100 μm), electrolytic copper (<63 μm), and milled magnesium (<100 μm) powders were also obtained from KPM. The elemental powders were mixed in a Turbula mixer for 30 min to prepare the Al-5.6Zn-2.5Mg-1.6Cu (in wt.%) alloy.

Green parts were produced by pressing 3 g of the blended powder at 350 MPa in a cylindrical die with a diameter of 15 mm. Die wall lubrication was afforded by a Teflon spray. The green density of the compacts was determined by the volumetric method. The specimens were then sintered in a dry nitrogen atmosphere (dew point<-50 °C) at 400, 450, 500, 550 and 600 °C. The heating rate was 10 K min^{-1} and the sintering time was 30 min. The specimens were quenched in water from the sintering temperatures in order to assess the liquid phases formed during processing.

The sintered density was measured according to the water displacement (Archimedes) method. Both optical and scanning electron microscopy (SEM TESCAN VEGA\\XMU, Czech Republic) coupled with energy dispersive spectroscopy (EDS) were used for microstructural study. In order to determine the phase transformations occurring during sintering, differential scanning calorimetry (DSC) was employed. X-ray diffraction (XRD) analysis was also performed by a Philips X'Pert instrument with Cu-Kα radiation.

The green and sintered densities of the Al-Zn-Mg-Cu compacts are reported in Table 1. A decrease in the sintered density compared to the green state is noticed when sintering was applied at <550 °C for 30 min. Processing at higher temperatures, however, resulted in a slight increase of the density. It seems that if the temperature is relatively low, swelling of the compacts during heating occurs. The results of DSC analysis indicated the formation of three liquid phases upon sintering (Fig. 1). The earliest event, marked by the peak starting at about 419.4 °C, is related to the formation of a liquid by melting of the Zn particles. Since the solubility of zinc in the aluminum lattice is significant (~83 wt. % [3]), the diffusion of certain atomic species in the matrix is likely to occur. As the temperature increases during heating, a small peak at 438.7 °C is noticed. Martin et al. [1] have reported the formation of a eutectic liquid between $Mg_{17}Al_{12}$ and Mg at about 437 °C).

Therefore, at low temperatures the penetration of the melt along the particle boundaries and the effect of capillary flow caused expansion [5].

Table 1. Green and sintered densities of the Al-Zn-Mg-Cu Alloy

Temperature (°C)	Green density (g/cm^3)	Sintered density (g/cm^3)
400	2.5934	2.5921
450	2.5886	2.5167
500	2.5893	2.5253
550	2.5965	2.6316
600	2.5977	2.6625

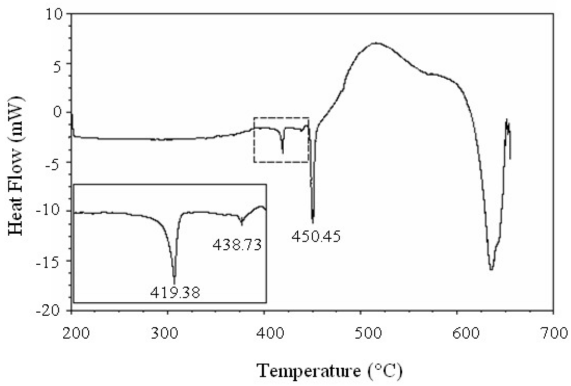

Fig. 1. DSC graph of the Al-Zn-Mg-Cu powder compact.

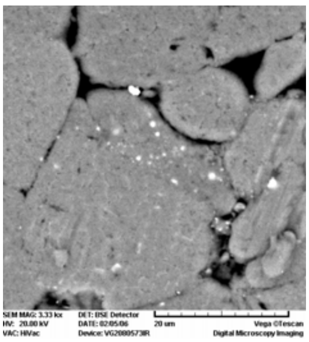

Fig. 2. Backscattered SEM micrograph of the Al alloy specimen sintered at 450 °C for 30 min.

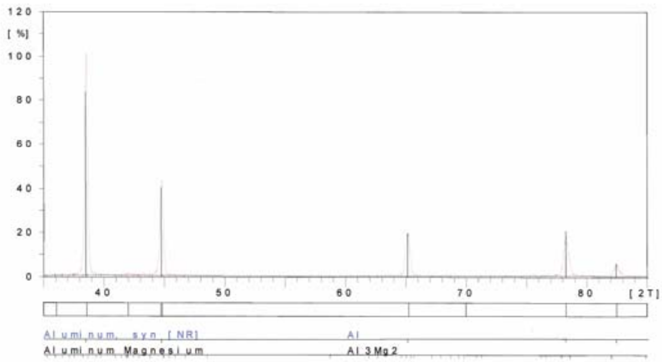

Fig. 3. XRD pattern of the sample sintered at 500 °C for 30 min. Intense peaks are related to Al and weak peaks are related to Al_3Mg_2.

Fig. 2 shows a back-scattered SEM micrograph of the specimen sintered at 450 °C. Note that Zinc-rich phases in the back scattered SEM mode are revealed as white regions [6]. The results of EDS analysis showed that these regions are Al-base (≈89 at. %) with almost equal ratio of Mg: Zn in at. %. The results of XRD study also indicated the formation of Al_3Mg_2 intermetallic when sintering was performed at 500 °C (Fig. 3). Apparently, the reaction between Mg and Al neighboring particles occurred and the eutectic reaction led to formation of a low-temperature liquid phase which contributes in densification by particle rearrangement and grain shape accommodation [1].

3. Summary

The sintering behavior of Al-5.6Zn-2.5Mg-1.6Cu specimens prepared from elemental powdwers was studied. It was found that during heating the powder compact to sintering temperature, three liquid phases are formed. The earliest event is related to the zinc melting at ~420 °C. Another liquid formed at 438 °C is due to the reaction between Mg and Al neighboring particles and formation of a eutectic liquid phase. At higher temperatures, an intermetallic phase between Al, Mg, and Zn is formed which significantly influences the densification of the compacts. It was found that the addition of Mg is more important than that of Zn. The formation of liquid phases is accompanied by compact swelling at low temperatures (<550 °C) and thus loss of dimensional accuracy.

4. References

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