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MECHANICAL PROPERTIES OF Al-14Si-2.5Cu-0.5Mg ALUMINUM-SILICON P/M ALLOY

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Abstract. The present research is focused on the evaluation of the sintering and mechanical properties of Al-14Si-2.5Cu-0.5Mg powder alloy by using conventional powder metallurgy techniques. The sintering of the alloy was conducted up to the temperature of 570 °C under nitrogen atmosphere with different sintering variables. Sintered specimens were subsequently T6 heat treated to improve mechanical properties. The sintered and heat treated specimens were evaluated by analyzing density, hardness, microstructure and tensile properties. Sintered density could reach up to 97% of true density in the optimum sintering condition. After T6 treatment, the alloy showed the UTS of 280 MPa and the hardness of 80 HRB.

1. INTRODUCTION

Aluminum-Silicon P/M alloys have attracted attention for automotive and aerospace applications because of their good mechanical properties with high thermal properties [1-3]. However, aluminum particles always covered with thin Al_2O_3 layers and the oxide cannot be reduced by the sintering atmosphere. This is a barrier to get good sintering properties of the Al powders. Some researchers have shown that successful sintering of Al alloys can be carried out through the formation of a liquid phase that disrupts the stable aluminum oxide in nitrogen atmosphere [2-5]. The papers also have been analyzed the interactions between Al powder compacts and nitrogen gas, but the reaction mechanism with nitrogen gas and Al powder to form AlN still remains unclear [6,7]. The mechanical properties of the Al alloys can be improved by precipitation hardening. For example AA2014 alloy, possible precipitates are $CuAl_2$ (θ-type), Mg_2Si (β-type), and Al_2CuMg (S-type) after T6 heat treatment [8]. In this study, we investigate the sintering behavior of a hypereutectic Al-Si alloy including the effect of compaction pressure, sintering temperature and time, also evaluated the effect of heat treatment on the sintered specimens

2. EXPERIMENTAL PROCEDURE

The raw powder used was the commercial Alumix 231 powder(Al-14Si-2.5Cu-0.5Mg-1.5Amidwax, density=2.67 g/cm^3, Ecka Granules, Germany). Where, amidwax is used as a binder. The powder was uniaxially pressed in the rigid steel die at the pressure range of 300 – 700 MPa. The compacts were sintered in a tube furnace under flowing ultra high purity nitrogen gas (>99.999%) with the temperature range of 520 – 570 °C for 1hr. During sintering, the debinding process was performed at 400 °C for 20 min to improve the sinterability. The sintered specimens were subsequently T6 heat treated to improve mechanical properties by precipitation hardening. For T6 treatment, the sintered specimens were solution treated at 512 °C for 50 min, then quenched

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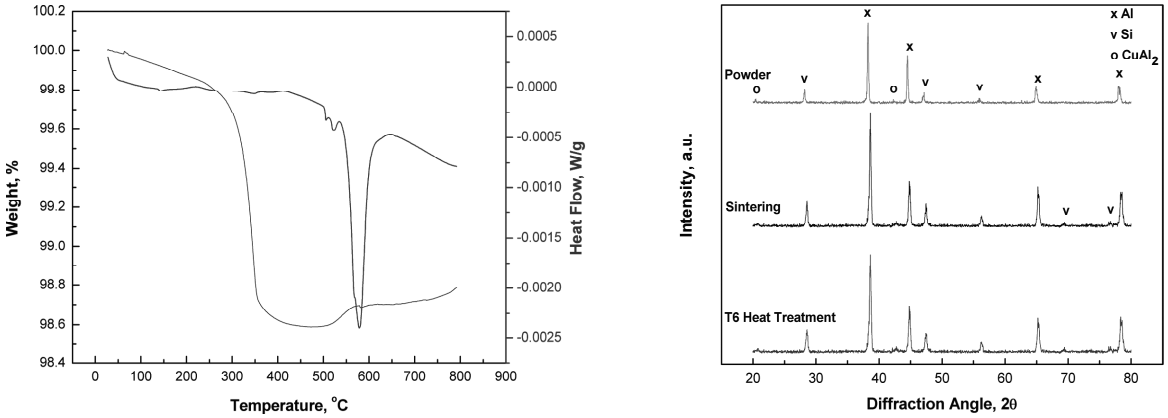

Fig. 1. (a) TG-DSC analysis of alloy powders(Al-14Si-2.5Cu-0.5Mg), (b) X-ray diffraction patterns of the alloy powder, sintered and T6 treated specimen.

in water, followed by aging at 173 °C for 5-50 hrs. Differential scanning calorimetriy (DSC) and thermogravimetry analysis (TGA) were carried out to characterize thermal properties of the powder. OM, XRD, SEM, and EDS were used to characterize the properties of the specimens. Hardness was measured using a Rockwell hardness testing machine on B scale (Wolpert Amsler, Germany) and tensile strength were measured by using Instron tensile tester. The density of the compact and sintered specimens was determined using the Archimedes method.

3. RESULTS AND DISCUSSION

Fig. 1a shows the TG-DSC analysis result of the Al-14Si-2.5Cu-0.5Mg powder. As shown in Fig. 1a, there are several peaks related to endothermic reactions around the temperature range of 505 – 580 °C. The first endothermic peak is related to an Al-Mg eutectic reaction. The second peak comes from the Al-Cu eutectic reaction. The third one should be related to the Al-Si eutectic reaction [2,9]. Those reactions were closely related to the liquid formation of the powder and concomitantly the onset of a liquid phase sintering (LPS). These DSC results give the useful information to determine the optimum sintering temperature range. Mg element in the aluminum matrix is very reactive and has the capability to react with the surface oxide layer of the Al powder and possible reaction is,

$$3Mg + 4Al_2O_3 \leftrightarrow 3MgAl_2O_4 + 2Al.$$

Pieckzonka *et al.* reported that Mg atoms in the Al particles migrate to the surface oxide region and form a ternary oxide. Surface aluminum oxide layer is possible to be broken by formation of ternary oxide [3-5,10,11]. That was the possible reason to improve the sinterability of Al compacts. Fig. 1b shows the X-ray diffraction patterns measured from the raw Alumix 231 powder, sintered specimen and T6 heat treated specimen. The figure showed the presence of aluminum, silicon, and θ ($CuAl_2$) phases in the all processing steps. Fig. 2a shows that the green densities increased with an increasing the compaction pressure until the upper safety limit of the compacting die (700 MPa). The formation of a liquid phase is also important to obtain a high sintering density [12]. As shown in Fig. 2b, the density was increased with increasing the sintering temperature since a large amount of liquid was produced at the high sintering temperature. The highest sintered density, a relative density of ~97%, was obtained at the sintering temperature of 560 °C. However, the density rapidly decreased at the sintering temperature of 570 °C because the liquid phase accumulated to one side and eventually large pores were formed and grown as shown in optical microscope images (Fig. 3b). Sintering time also influences the sintering density. Fig. 2c shows that the highest sintered density was obtained when the sintering time of 120 min. with the relative density of 99%. The hardness dependent on the sintering temperature was measured to know the relations with density. As shown in Fig. 2d, the highest hardness was obtained at the sintering temperature of 560 °C with the hardness value of 63 HRB. The figure also shows the hardness values are nearly proportional to the sintered density. The question still remains about the role of nitrogen atmosphere gas. Some researchers reported that there is a possible reaction between aluminum and nitrogen gas to form AlN,

$$2Al + N_2 \rightarrow 2AlN.$$

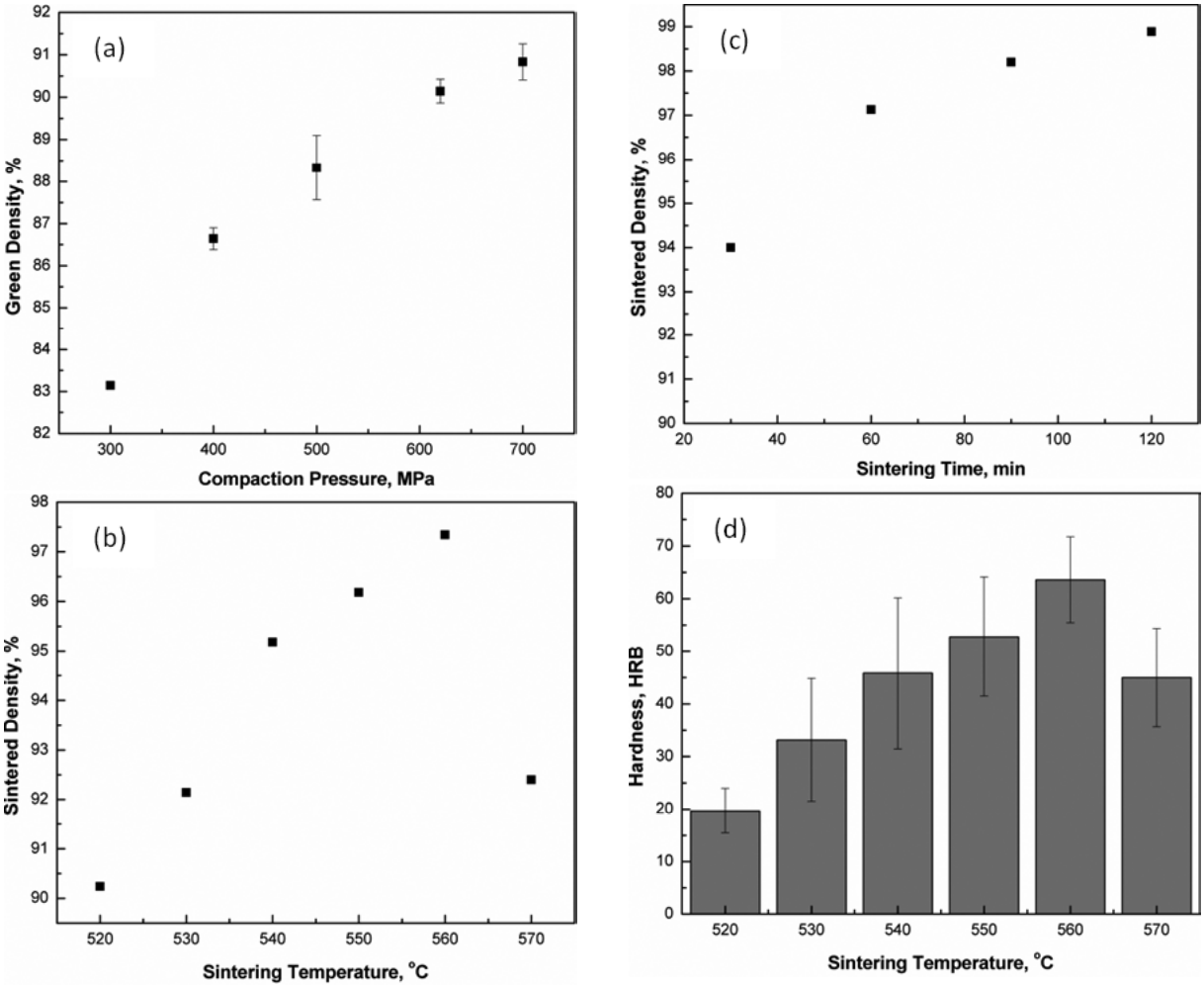

Fig. 2. Mechanical properties of Al-14Si-2.5Cu-0.5Mg alloys. (a) Green density versus compaction pressure, (b) Sintered density versus sintering temperature, (c) Sintered density versus sintering time at 560 °C, (d) Hardness versus sintering temperature. Alloy powders were compacted with the compaction pressure of 620 MPa and sintering and heat treatment was conducted with the heating rate of 10 °C/min for 1 hour.

Yan *et al.* shows that there were AlN at the Al-Mg_2Si interface and inside Mg_2Si grains in Al-2Mg-2Si-0.25Cu alloy [7]. They also reported that the mass of AlN increased after sintering [3,6,7]. However, Formation of AlN was not detected by x-ray diffraction in this study (Fig. 1b). Considering the chemical composition of the Al-14Si-2.5Cu-0.5Mg alloy powder, it is possible to form several strengthening precipitates including θ (Al_2Cu) and β (Mg_2Si) phase. Through XRD data, a strong evidence of θ phase was confirmed in the all samples (Fig. 1b), but β phase was not detected. It was postulated that the θ phase is the dominant precipitate when aging in the state of super saturated solid solution (SSSS) [9]:

$$SSSS \rightarrow GPZones \rightarrow \theta'' \rightarrow \theta' \rightarrow \theta.$$

To improve the mechanical properties of Al-14Si-2.5Cu-0.5Mg powders, artificial aging treatment (T6) was introduced. Fig. 4a shows there is an increase of hardness up to 24 hour aging time. The highest mechanical properties were obtained with the hardness of 80 HRB and UTS of 280 MPa as well. However, the hardness decreased caused by overaging after long aging time of 50 hrs. As shown in the strain curve of Fig. 4b, T6 treated specimens were more brittle and higher tensile strength than that of specimen without T6 heat treatment. Figs. 4c and 4d show the fractured surface appearance of the T6 treated specimen. The figures show the large and small dimple structure and broken or cracked primary Si particles. This indicates that the fracture occur ductile fracture in the Al matrix and also brittle fracture in the primary Si particles. Thus, it may be

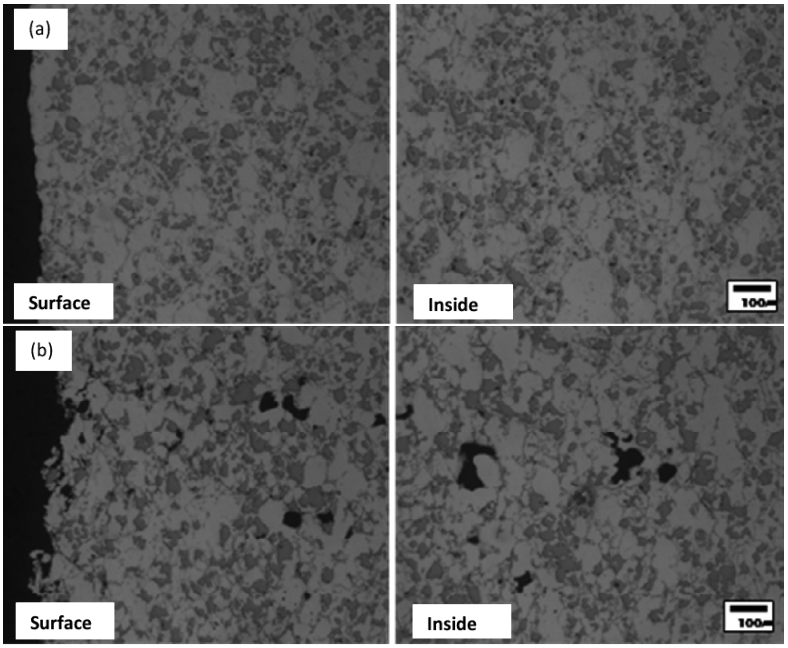

Fig. 3. Optical microscope images of sintered alloys. (a) sintered at 560 °C, (b) sintered at 570 °C after compacting with 620 MPa.

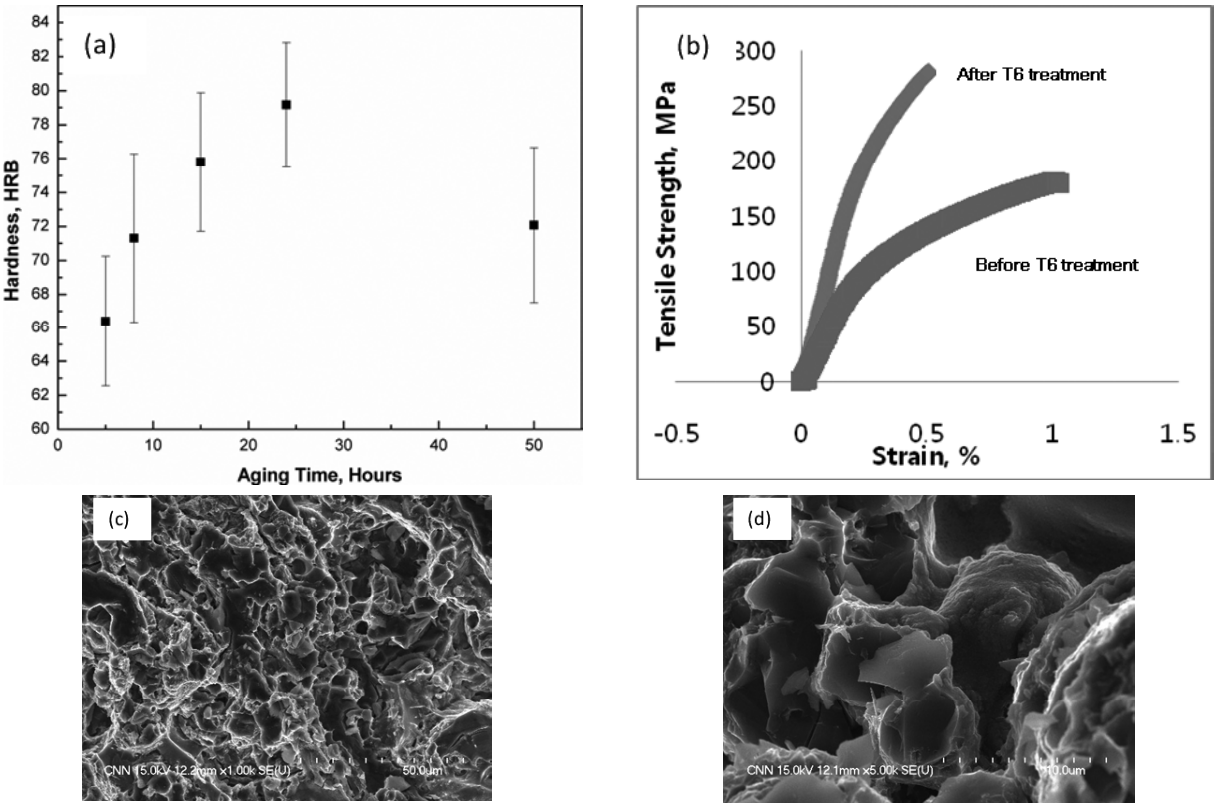

Fig. 4. (a) Hardness versus artificial aging time, (b) Tensile strength of alloys with and without T6 heat treatment. (c) and (d) SEM images of tensile fracture surface of T6 heat treated Al-14Si-2.5Cu-0.5Mg alloys.

assumed that the fracture of the primary Si particles is responsible for the relatively low ductility of the T6 treated specimens [13,14]. The figure also shows the most of the primary Si particles contain cracks and the cracks run through their center. This means that the void nuclei was formed and grew at the interfaces between the Si particles and Al matrix. Al_2Cu and Mg_2Si will also contribute to improving the me-

chanical properties by increasing the bonding of the matrix though they reduce the ductility.

4. CONCLUSION

Al-14Si-2.5Cu-0.5Mg alloy powder was successfully sintered under flowing nitrogen gas at the sintering temperature of 560 °C and with the compaction pressure of 620 MPa. The sintering density of the alloy was 97% of T.D. and hardness was 63 HRB at an optimum sintering condition. Optimal T6 treatment condition was that solutionizing at 512 °C for 50 minutes and water quenching, then artificially aging for 24 hour at 173 °C. It was confirmed that dominant strengthening precipitates were θ type phase by T6 heat treatment. The specimens after sintering and heat treatment have hardness of 80 HRB with UTS of 280 MPa.

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