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Optimizing the Processing Parameters for Al-20Si-6Cu Aluminum-Silicon P/M Alloy

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Abstract: **-- The compaction, sintering and heat treatment processing conditions for the Al-20Si-6Cu (wt%) P/M alloyhave been optimized in this study.The alloy powder was uniaxiallypressed in the rigid steel die at the pressure range of 400-900 MPa.The green density increased with an increasing the compaction pressure until 800 MPa.The sintering of the compacts was conducted under flowing nitrogen gas with the temperature range of 530-570C and different sintering times (40-120 minutes). The highest hardness was obtained at the sintering temperature of 550 C and 1 hour sintering time. The sintered specimens were subsequently T6 heat treated to improve mechanical properties. After determining optimum heat treatment time of 10 hours, the alloy showed the hardness of 93.7 HV.**

Key words: **Powder Metallurgy, Gaz Atomization, Al-Si Alloy, Sintering**

1. INTRODUCTION

In recent years, researches on emissions reduction are among the most important research topics in the automotive industry. Therefore, one of the focused points in the studies is reducing fuel consumption and increasing efficiency by reducing the weight [1, 2]. Because of the reduction of vehicle weight and the required power, less fuel consumption could be achieved P/M aluminum alloys have the potential to reduce the vehicle weight for application in automotive components instead of P/M steel parts due to the low density of aluminum alloys. In recent years there has been a resurgence of interest in development of P/M Al alloys and components, especially for automotive applications [3, 4, 5].

Hypereutectic Al-Si alloys are very promising material for aluminum alloys due to their excellent properties, including low coefficient of thermal expansion, low density, good corrosion resistance and high wear resistance. Therefore, conventional P/M technology come to the fore to provide expected technological properties with relatively low manufacturing cost for the structural parts by cold pressing and sintering approach [3, 6].

This paper studied several P/M processing parameters of concern and outlines the influences of these parameters on the properties of aluminum-silicon based P/M alloys. Sintering is the key process in P/M fabrication route responsible for the development of mechanical properties for final P/M parts.The effects of the processing variables on microstructural developments and mechanical properties of this alloy system are discussed in details in this study.

Moreover, controls of the aging time and temperature are important to obtain uniform distribution of the precipitates within the matrix since the size and distribution of precipitates will determine the strength of the alloy.

2. EXPERIMENTAL PROCEDURE

The powder was produced by using gas atomization unit in the mechanical engineering department of Dumlupınaruniversity of Kütahya. The actual composition, determined on a sample sintered at 560 ^{0}C for 1 hr in N2 using a spark emission spectrometer, was Al-20Si-6Cu-0.2Mg-1.4Fe-2.8Zn-0.1Mn (wt%). The characterization of the produced powder were done to determine the powder apparent density, flow rate, powder shape, microstructure and existent phases.Differential scanning calorimetry (DSC) and thermogravimetryanalysis (TGA) were carried out to characterize thermal properties of the powder.Prepared powder mixture was pressed with a pressure between 400-900 MPa. The sintering process was applied using nitrogen gas in a tube furnace with the temperature range of 530-570 ^{0}C for 40-120 minutes.A HWMMT-X3B Vickers Hardness testing machine was used to measure the hardness of the polished samples. At least 20 measurements were taken for each sample. A fixed load of 1000 gf with the load time of 15 second was set constant throughout the measurements. Later, T6 heat treatment was applied and the change on the hardness and microstructure was determined. For T6 treatment the sintered specimens were solution treated at 520 ^{0}C for 1 hr, then quenched in water, followed by aging at 190 ^{0}C for 5-48 hours.

3. RESULTS AND DISCUSSIONS

The most important phases that are present in the powder are FCC Al-rich phase, Si andθ-phase (CuAl2), according to the XRD trace displayed in Fig. 1.Furthermore, Fig. 2 shows the DSC analysis result of the Al-20Si-6Cu powder. As shown in Fig. 2, there are several peaks related to endothermic reactions around the temperature range of 526-577^{0}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, 8]. These DSC results give the useful information to determine the optimum sintering temperature range.

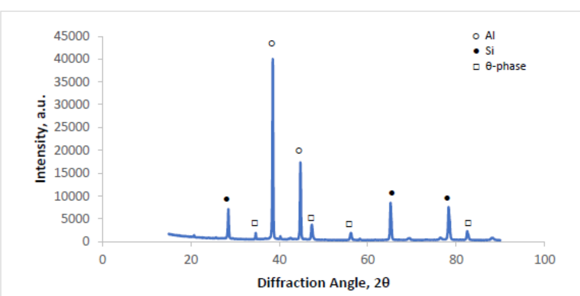

Fig. 1. XRD pattern corresponding to Al-20Si-6Cu

Diffraction Angle, Diffraction Angle, Diffraction Angle, Diffraction Angle, Diffraction Angle, Diffraction Angle, Diffraction Angle, Diffraction Angle, Diffraction Angle, Diffraction Angle, Diffraction Angle, Diffraction Angle, Diffraction Angle, Diffraction Angle, Diffraction Angle, 2θ

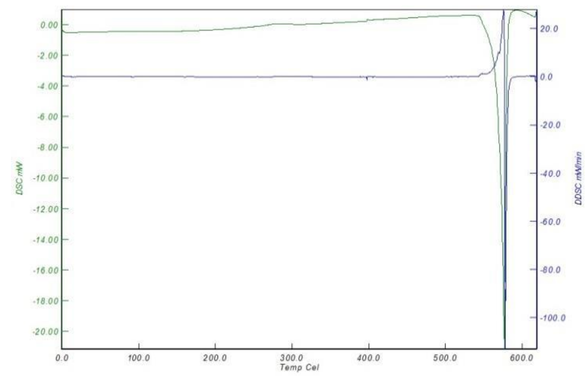

Fig. 2. DSC analysis of Al-20Si-6Cu alloy powder.

Fig. 3 displays the green density of the compacts as a function of compaction pressure. It can be noted that the green density of the compacts increased with the increase of the compaction pressure. At the compaction pressure of 400 MPa, the green body achieved the green density of 2.40 g/cm3, which was corresponding to 85.2 % of the theoretical value(2.82g/cm3). Further increase of the compaction pressure to 800 MPa markeda substantial increase of green density to 2.62 g/cm3 or 93 % of theoreticalvalue. While the green density of the compacts continued to increase with theincrease of compaction pressure, the rate of densification decreased at the sametime. The compacts pressed at 900 MPa did not has very remarkable increase in green density, with only approximately 0.3 % increase indensification. Thus, compaction pressure at 800 MPa can be considered as amodest pressing pressure to be used in the subsequent works. High compactionpressure is not generally used in the industry due to the excessive wear of tooling.With this in mind, the upper compaction pressure limit was maintained to be900 MPa.

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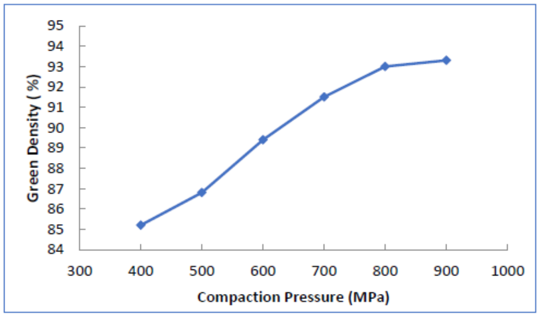

Fig. 3.Green density versus compaction pressure of Al-20Si-6Cu alloy.

The sintering temperatures was determined using high temperature Netzsch 404 Differential Scanning Calorimetry (DSC) to be within the range of 530°C to 570°C. The compacts were subjected to desired sintering temperatures for 60 min at the heating rate of 10 K/min. As shown in Fig. 4, the highest hardness was obtained at the sintering temperature of 550 °C with the hardness value of 64.6 Vickers. When the compact was sintered up to 550 ^{0}C, a well sintered microstructure can be obtained as shown in Fig. 5a. According to the Figs. 5b and 5c, the notable difference is mean grain size increased as a result of grain growth due to grain coalescence and grain coarsening. Thus, it can be summarized that 550 ^{0}C will be the optimum sintering temperature to obtain compact with highest hardness value and lowest porosity value.

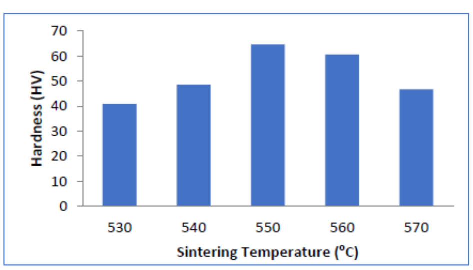

Fig. 4. Hardness of the Al-20Si-6Cu alloy versus sintering temperatures for 1 hour.

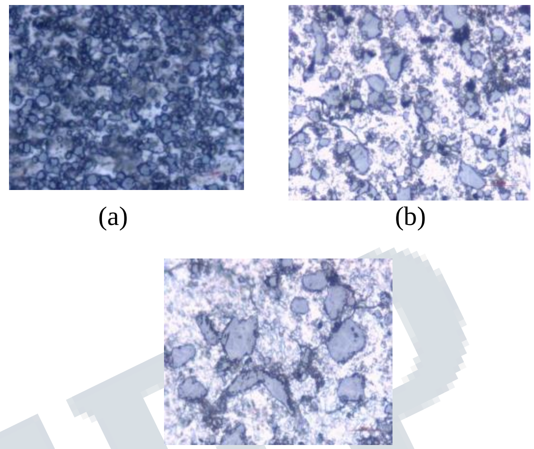

Fig. 5. Optical micrographs corresponding to the sintered alloys. (a) sintered at 550 ℃, (b) sintered at 560 ℃, (c) sintered at 570 ℃ after compacting with 800 MPa.

Fig. 6 showed the effect of sintering time on hardness. Sintering time of 40 minutes was clearly not sufficient for complete sintering of compacts. The sintered hardness of the compact only achieved 58.3 Vickers. It can be seen that solid state sintering, had not initiated yet at 40 minutes of sintering time. The microstructure of the compact again proved that sintering of compact at 40 minutes is not sufficient since particle boundary can still be observed possibly due to incomplete diffusion [10]. A significant increase in hardness can be noted at 60 minutes. Longer sintering times, however, did not bring significant increase in hardness. In terms of microstructural development, extended time is beneficial for continued pore elimination [7, 8, 9]. By comparing the microstructures of the compacts sintered at 40 and 60 minutes, compact sintered at 60 minutes showed better pore closure with less large pores being observed. Prolonged sintering time is not desirable since it will lead to microstructural coarsening. It is, thus, determined that sintering time of 60 minutes is preferable to attain compacts with satisfactory hardness and better pore closure.

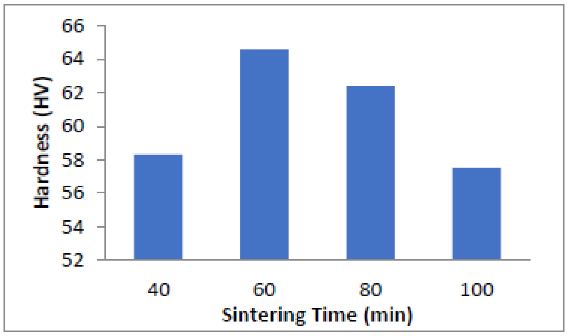

Fig. 6. Hardness of the Al-20Si-6Cu alloy versus sintering times at 550 ℃.

The conventional T6 heattreatment used in this study involved solution heat treatment, quenching and artificially aging to enhance the mechanical properties of the compacts [11, 12]. After sintering, the compacts were remained in the furnace for the subsequent solution heat treatment to be carried out.Compacts was subjected tosolutionizing temperature of 520°C for 1 hour before quenching in cold water. The compacts were later subjected to artificial ageing in aconventional air furnace for the time interval between 5 and 48 hours at 190°C. The changes in Vickers hardness were plottedas function of ageing time. All the alloys showed similar trend, whereby the hardness value increased until a maximum and subsequently decreased with the prolonged ageing time. The maximum hardness value of 93.7 HV was achieved by compacts solutionized at 520 °C after aging 10 hours at 190 °C as shown in figs. 7 and 8.

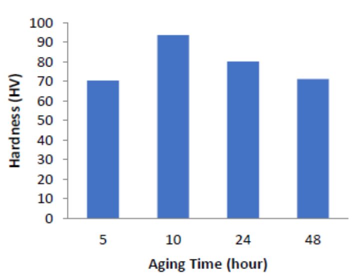

Fig. 7. Hardness of the Al-20Si-6Cu alloy versus aging times at 190 ℃. The alloy solutionized at 520 ℃ for 1 hour.

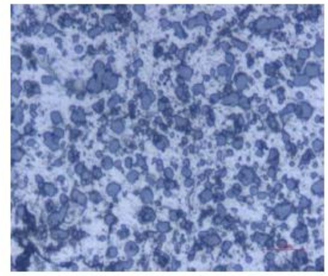

Fig. 8. Optical micrograph corresponding to the sampleaged at 190 ℃ for 10 hours.

4. CONCLUSION

Green density of the compact increased with increasing compaction pressure. At 800MPa, the green density of theAl-20Si-6Cu P/M alloy achieved 2.62 g/cm3 or 93 % of theoretical density. As result of the study, the process conditions for the better mechanical properties was determined for the alloy.Characterization techniques was applied to define the structural and mechanical properties of the samples after sintering.According to the microstructure and hardness results after sintering, the most suitable sintering temperature and sintering time for the alloy was determined as subsequently 550^{0}C and 1 hour.Later, T6 heat treatment was applied and the change on the hardness and microstructure was determined. After determining optimum heat treatment time of 10 hours, the alloy showed the hardness of 93.7 HV.

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