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Effects of Methanol and Stearic Acid as Processing Control Agents in AA6061 Aluminum Alloys Produced by Powder Metallurgy

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Abstract **–** Aluminum 6061 (AA 6061) alloy is an aluminum alloy with high strength and durability properties, widely used in modern engineering applications. Thanks to the advantages of powder metallurgy, the production of the alloy by powder metallurgy is increasing day by day. One of the parameters used in powder metallurgy production is particle control agents (PCA).

In this study, the microstructural and mechanical properties of AA 6061 alloy powders produced using different PCA types were investigated. Optical microstructure images show that the addition of PCA significantly affects the microstructure of the powders after sintering. Powders without PCA addition displayed randomly fractured, crushed, flaky, and spherical particles, whereas powders with stearic acid exhibited a more regular morphology with particles of varying sizes. Powders with methanol addition contained the smallest average particle sizes and spherical particles, and also had the lowest micro-void fraction among the powders.

Hardness and density analyses reveal that the types of PCA significantly affect the mechanical properties of the powders. Powders without PCA had the lowest hardness at 23.26 HV, while powders with stearic acid added had the highest hardness at 32.03 HV. The hardness of powders with methanol added was measured at 26.78 HV. The density values were found to be 2.197, 2.422, and 2.504 g/cm³ for powders without PCA, with stearic acid, and with methanol added, respectively. The lowest density was observed in the powders without PCA, while the highest density was observed in the powders with stearic acid added. The results indicate that the addition of PCA led to noticeable changes in the hardness and density values of the powders.

Keywords – AA6061, Powder Metallurgy, Particle Control Agent, Methanol, Stearic Acid.

I. INTRODUCTION

Aluminum 6061 (AA 6061) alloy is an aluminum alloy widely used in modern engineering applications due to its high strength and durability. Developed in 1935, this alloy is now utilized in various fields including automotive, aerospace, maritime, and construction sectors. The greatest advantages of AA 6061 are its excellent machinability and weldability. Additionally, its high resistance to corrosion makes it long-lasting under environmental conditions [1, 2].

AA 6061 primarily contains magnesium and silicon elements, which significantly enhance the alloy's mechanical properties such as strength and hardness [3]. The alloy also has high thermal and electrical conductivity, making it a preferred material in electronic and thermal applications. With the ability to undergo aging heat treatment, AA 6061 stands out for its high strength and hardness, making it ideal for load-bearing applications and high-performance engineering projects [1].

6061 aluminum alloys are generally produced by casting methods [4]. However, due to some limitations of casting and the advantages offered by powder metallurgy, the use of powder metallurgy for alloy production is becoming increasingly popular. Powder metallurgy allows for the creation of complex shapes and specific properties through the compression and sintering of metal powders. This method ensures a homogeneous microstructure, consistent mechanical properties, and improved material performance. It expands the performance and application areas of the alloy. Powder metallurgy optimizes the microstructural and mechanical properties of 6061 aluminum alloy, enabling it to better meet specific engineering requirements [5, 6, 21].

One of the main problems encountered in powder metallurgy production is the cold welding of ductile powders during mixing and the issue of powder breakage. A balance must be achieved between cold welding and breakage of the powders. To achieve this balance, a surface-active agent known as a processing control agent (PCA) is added to the powders before mixing. The effects of PCA vary depending on the type used. Some of the well-known effects include preventing powder agglomeration, controlling particle size, improving grinding efficiency, and enhancing powder flowability. Additives such as ethanol, methanol, stearic acid, hexane, polyethylene glycol, and benzoic acid are commonly used as PCAs. These additives can have lubricating, binding, and breaking effects on the powders. In addition to the type of PCA used, the quantity of these additives is also crucial for increasing or decreasing the effect of the PCA [7-11].

In this study, AA 6061 powders with an average size of 44 μm were mixed in a planetary mill for 1 hour with and without PCA, using methanol and stearic acid as separate PCAs, and then sintered at 550°C for 4 hours. The effects of the PCA used on the microstructure, density, and hardness of the AA 6061 powders after sintering were examined.

II. MATERIALS AND METHOD

In this study, AA 6061 powders with an average particle size of 44 μm, supplied by Nanokar, were used. The chemical composition of the AA 6061 powders is provided in Table 1, and the physical properties are given in Table 2.

Table 1. Chemical composition of AA 6061 by weight percentage

Element	Si	Mn	Cr	Zn	Mg	Cu	Ti	Fe	Al
wt %	0.4-0.8	≤0.150	0.04-0.35	≤0.25	0.8-1.2	0.15-0.40	≤0.15	≤0.7	Balance

Table 2. Physical properties of AA 6061 powders

Physical Properties	
Purity (%)	99.5
Average Particle Size (μm)	44
Particle Shape	Spherical
Melting point (°C)	482-660
Density (g/cm^3)	2.5-2.9

The AA 6061 powders to be used were each weighed at 2 grams. For the mixing process, 10 mm diameter tungsten balls, approximately 20 grams in weight (in a 1:10 ratio), were placed into the mixing chamber with the powders (Fig. 1). Finally, 3 different powder mixtures were prepared, with separate chambers using 3% methanol and stearic acid as PCAs. The PCA-containing and PCA-free mixtures were then mixed for 2 hours at 350 rpm (5 minutes of operation followed by 5 minutes of rest) using a Retsch PM 200 model planetary mill.

Fig. 1 Powder before mixing

The powders were cold-pressed using a hydraulic press into a 13 mm diameter mold with a thickness of 2 mm. A pressure of 100 bar was applied during the pressing. The image of the powders obtained after pressing is shown in Fig. 2a. The pressed powders were then sintered in a tube furnace at 550°C for 4 hours under an argon atmosphere. The image of the powder after sintering is shown in Fig. 2b.

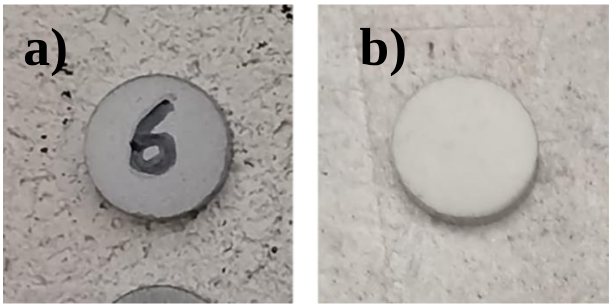

Fig. 2. a) Image of the powder after pressing, b) Image of the powder after sintering

The sintered powders were subjected to metallographic preparation processes. The samples were ground with sandpaper, starting from 600 mesh and progressing to 2000 mesh, and then polished with 0.05 µm alumina paste. A Metkon Forcipol 2V grinding machine was used for both sanding and polishing. After polishing, the samples were etched with a modified Keller solution. Optical microstructure images of the etched samples were captured using a Nikon Eclipse MA100 optical microscope. The hardness of the samples was measured with a Bulutmakina Microbul-N hardness tester using the micro-Vickers method, applying a 200 g load for 10 seconds. The densities of the samples were determined according to the Archimedes principle and in accordance with ASTM B595-11 standards. Hardness and density measurements were performed at room temperature, with at least five measurements taken for each sample.

III. RESULTS

Optical microstructure images of the sintered powders are presented in Fig. 3a-c. Examination of these images clearly indicates that PCA influences the microstructure of the powders after sintering. The powder without PCA shows randomly fractured, crushed, flaky, and spherical particles. In contrast, the powder with stearic acid as the PCA additive exhibits particles of various sizes, with flaky structures being notably absent. The powder with methanol additive has the smallest average particle size and displays a spherical particle shape. Additionally, microvoids are observed in the powder without PCA, while the powder with methanol additive shows the least amount of voids.

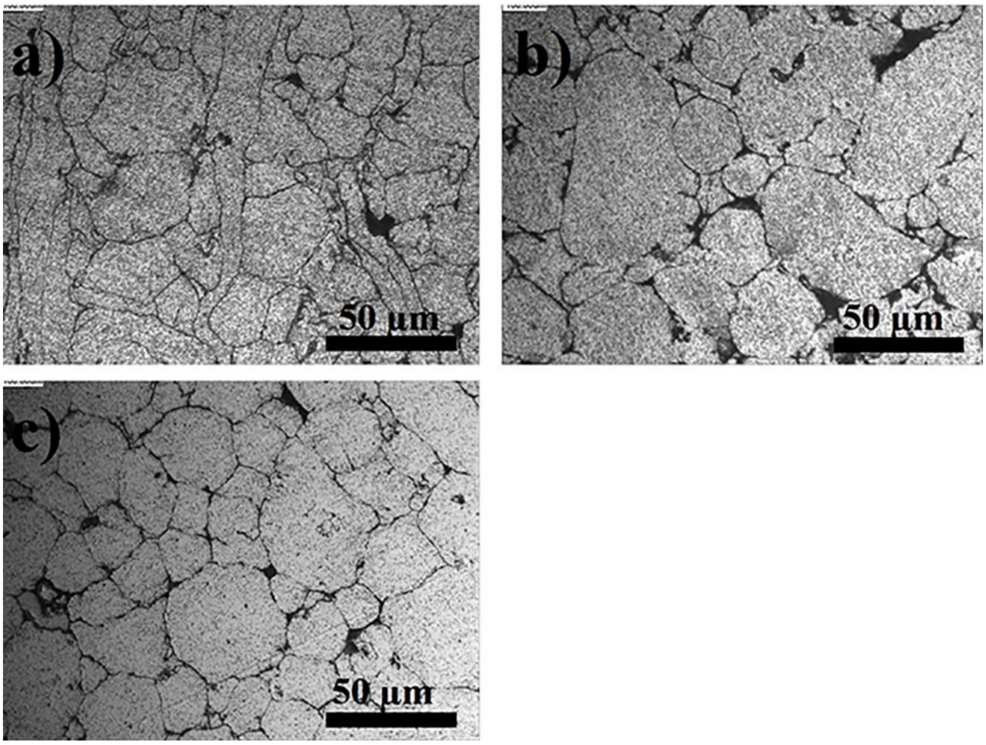

Fig. 3. Microstructure images of sintered powders: a) without PCA, b) stearic acid-added, c) methanol-added

The hardness and density values for powders with different types of PCA are presented in Fig. 4. The hardness results indicate that the lowest hardness of 23.26 HV is observed in the powder without PCA. The highest hardness is found in the powder with stearic acid, measuring 32.03 HV. The hardness of the powder with methanol is 26.78 HV. The densities of the powders without PCA, with stearic acid, and with methanol are determined to be 2.197, 2.422, and 2.504 g/cm³, respectively. The lowest density, similar to the hardness, is observed in the powder without PCA. The highest density is found in the powder with stearic acid as the PCA additive. Examination of the hardness and density results shows that the addition of PCA significantly alters both hardness and density.

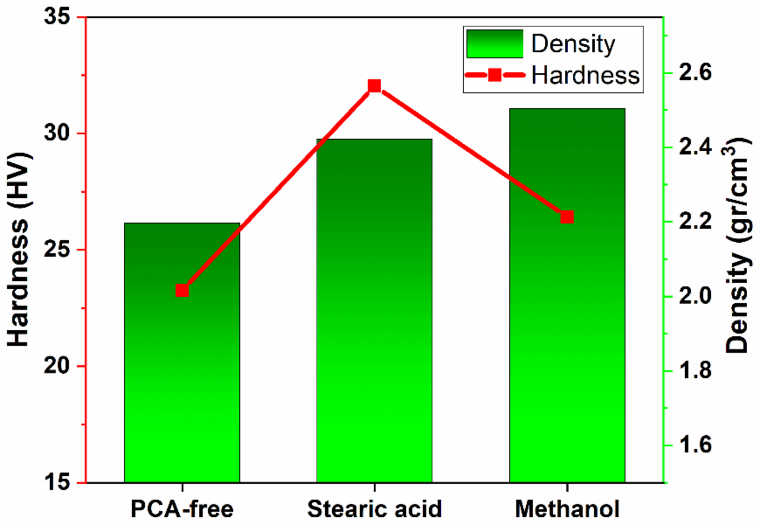

Fig. 4. Hardness and density of the powders: a) without PCA, b) stearic acid-added, c) methanol-added

IV. DISCUSSION

Examination of the microstructure images reveals that the addition of PCA significantly alters the microstructure of the powders. In powders without PCA, both spherical and flaky structures are observed intermittently. Some powders have adopted a flaky form due to being crushed between spheres. Ductile powders have deformed and broken, leading to an irregular microstructure. This observation is consistent with the literature. Stearic acid acts as a lubricant PCA. Powders with stearic acid show small and large particles reduced in size due to plastic deformation [11-13]. The short mixing time has prevented shrinkage from occurring in all the powders. The absence of flaky structures in powders with PCA compared to those without PCA is attributed to the presence of the lubricant PCA in the structure. Stearic acid adsorbs onto the surfaces of Al particles, creating a lubricating effect [13]. Methanol, used as PCA, has a fracturing effect on the structure [14]. This effect is clearly visible in the microstructure. Powders with methanol exhibit an average particle size that is smaller compared to other powders, due to the fracturing effect of methanol. Methanol spreads easily over metal surfaces, altering surface tension and making it difficult for powders to adhere to one another [15, 16]. The increased mechanical impact promotes fracture between the particles.

When examining the hardness of the powders, it is expected that the lowest hardness would be found in the powders without PCA. The irregular morphology of these powders and the inability to achieve a homogeneous distribution lead to excessive porosity. This is also clearly reflected in the density values. Since the desired bonding in the structure is not fully achieved, it is anticipated that the hardness will be lower compared to other powders. In powders with stearic acid, the presence of particles with a more homogeneous, spherical morphology contributes to a reduction in voids between the particles, thereby increasing the hardness. The use of stearic acid facilitates greater plastic deformation of the powders, supporting an increase in hardness. Thus, the highest hardness in this sample is expected [9, 17]. With the fracturing effect of methanol leading to even smaller particles, an increase in hardness compared to powders without PCA is anticipated. However, the lack of excessive plastic deformation and subsequent fracturing, as seen with stearic acid, prevents an increase in hardness due to plastic deformation. Therefore, hardness in powders with methanol is expected to be lower compared to those with stearic acid [13, 14, 18, 19].

Regarding density, irregular structures and non-homogeneous particle distributions are observed in powders without PCA. This leads to excessive void formation in the bulk material and consequently low density values. Powders with methanol, having smaller and more spherical particles, exhibit improved packability and increased density. This results in a reduction in void content and an increase in powder density. Powders containing stearic acid, being more regular and closer to spherical compared to those without PCA, exhibit higher density values [13, 19, 20].

V. CONCLUSION

Optical microstructure images reveal that the addition of PCA (Particle Control Agent) significantly affects the microstructure of the powders after sintering. Powders without PCA exhibited randomly fractured, crushed, flaky, and spherical particles. In contrast, powders with stearic acid displayed a more regular morphology with particles of various sizes. Powders with methanol, on the other hand, contained the smallest and most spherical particles on average and had the lowest porosity among the powders.

In the powders where stearic acid was used, a more homogeneous and spherical morphology, consisting of small and large grains, was observed due to the effect of plastic deformation. This contributed to the reduction of voids between the powders and, consequently, to an increase in hardness. The effect of stearic acid in enhancing the plastic deformation of the powders ensured higher hardness. On the other hand, the powders with added methanol contained smaller particles on average due to the breaking effect of methanol, which also increased the density of the powders.

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