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Research Article

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The Effect of Aging Process on Wear Properties of Al6061/GNP Metal Matrix Composite

Yaşlandırma Prosesinin GNP Takviyeli Al6061 Metal Matris Kompozitinin Aşınma Özelliklerine Etkisi

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ABSTRACT

In this study, the effect of aging on wear characteristics of the nano GNP reinforced Al6061 metal matrix was investigated. In this scope, the samples were produced by hot press at 500 °C temperature under 50 MPa pressure for 30 minutes. The wear characteristics of the composites were determined using the ball-on disc wear test method. The effect of aging on the friction coefficient and wear ratio was investigated. Graphene reinforcement significantly increased the friction coefficient between the stainless-steel ball and specimen but the aging process lowered the coefficient of friction to a better level. Also, artificially aged specimens showed significant increase in hardness values. Key factors affecting the mechanical performance of the Al based alloy is reinforcement and aging process.

Key Words

Powder metallurgy, metal matrix composites, aging, wear properties.

ÖZ

Bu çalışmada; nano GNP takviyeli Al6061 takviyeli metal matris kompozitlerin aşınma karakteristiği incelenmiştir. Bu ölçekte, numuneler 500 °C sıcaklıkta 50 MPa basınçta 30 dakika boyunca sıcaklıkta preslenmiştir. Yaşlandırmanın sürtünme katsayısı ve aşınma üzerine etkisi incelenmiştir. Grafen takviye, paslanmaz çelik bilya ve numune arasındaki sürtünme katsayısını artırsa da yaşlandırma prosesi sürtünme katsayısını azaltarak daha iyi seviyelere getirmiştir. Aynı zamanda yapay yaşlandırılan numuneler sertlik değerlerinde de belirgin bir artış göstermiştir. Mekanik performansı artıran ana faktörler takviye ve yaşlandırma prosesidir.

Anahtar Kelimeler

Toz metalurjisi, metal matris kompozitler, yaşlandırma, aşınma özellikleri.

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INTRODUCTION

Aluminum is light in weight, two thirds of steel and it has leading requirements in most of the industrial areas like automobile and aerospace. Also, Al is the most economical solution in case of lightweight metals. Powder Metallurgy (PM) with mechanical alloying (MA) is a solid state production method, which provides a near design shape with low cost and high efficiency. MA makes it possible to achieve a more homogeneous metallic matrix with reinforcing particles [1]. It is known that conventional metals and alloys are unsatisfactory under extreme conditions that require high hardness and strength, while metal matrix composites (MMC) have the lightness and high specific strength values due to containing the reinforcement groups. Thanks to these exceptional features, MMCs have become an important part of the automotive and aerospace industries. PM is among the most used methods to achieve nano particle reinforced MMCs. Compaction pressure, sintering time and temperature, weight fraction of reinforcement are key factors on hardness values of Al composites which influences wear properties of the composite [2]

In a recent paper, Rathod and Menghani, inspected the influence of precipitation hardening in aluminum based systems. They stated aging is a cost-efficient and simple method to achieve mechanical and wear improvements on Al based alloys [3]. Also, some previous studies indicate that ceramic and carbon reinforcements affect the precipitation hardening mechanism and result in different aging behavior [4], [5]. Graphene reinforced metal matrix composites are getting more and more attention over the past few decades due to the excellent mechanical, thermal and electrical properties of the graphene. Most of the studies are about pure metal matrix composites but metal alloy matrices are mostly evaded due to complexity of the analysis compared to the pure metal matrix composites [6].

The aging process, which consists of solutionizing, quenching, and aging processes, provides a significant increase in strength. The precipitate particles formed with the aging heat treatment restrict the dislocation movement and thus the alloy gains strength. In this study, the focus is on increasing the mechanical properties of the matrix material (Al6061) by both secondary reinforcement (GNPs) and aging heat treatment. The limited

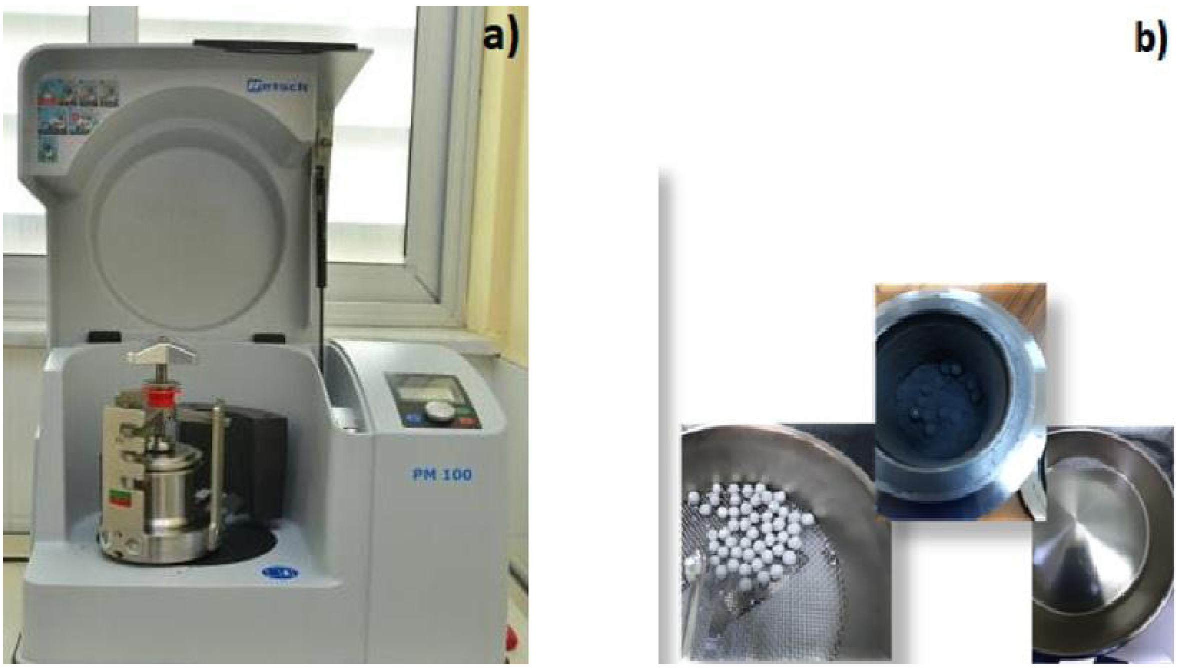

Figure 1. a. Ball milling machine b. Stainless Steel jars and zirconia balls with 10 mm diameter

Table 1. Figure-of-merit (FOM) calculation of the sensor at different glycerol concentrations (FWHM represents full width at half maximum of the curves).

Elemental Analysis	Si	Mn	Cr	Zn	Cu	Ti	Mg	Al
	0.4-0.8	≤0.15	0.04-0.35	≤0.25	0.15-0.40	≤0.15	0.8-1.2	Bal

number of heat treatments studied applied to MMCs in the literature has revealed the motivation of this issue. Moreover, in this study the effects of reinforcement and aging on the friction coefficient are investigated.

MATERIALS and METHODS

Fabrication of GNPs/Al6061 composite powders

Ball milling strategy was used for the fabrication of GNPs/Al6061 composite powders. Gas atomized 99% pure 40 µm Al6061 powders and 5 nm GNPs were placed in a steel jar with 1/10 powder to ball weight ratio. Al6061 and GNPs mixture consisted of 8 wt% GNPs. Steel jars are placed in a Retsch Ball Milling machine with 250 rpm rotational speed for 1 hour duration and left for 10 hours of cooling. Retsch Ball Milling Machine and stainless steel jars can be seen in Fig 1. Elemental analysis of Al6061 is given in Table 1.

Production of composite samples with hot pressing

Fabricated composites powders are hot pressed at 500 °C under 50 MPa compaction pressure for 30 minutes within argon (Ar) atmosphere. The Hot Pressing Machine, dies and samples can be seen in Fig 2.

Aging process of composite samples

Samples produced by hot pressing are artificially aged. Parameters for aging; 560 °C 10 h solutioning and aging for 8 h at 165 °C. Total time spent for aging is 18 hours. Furnace used for artificial aging can be seen in Fig 3.

Ball on disk wear testing

All samples produced by hot pressing whether they are aged or reinforced are tested on CSM Tribometer which can be seen at Fig 4. SS 316 Stainless-Steel balls with 6mm of diameter are used for the ball on disk method. The Contact surface of the ball changed after every test carried out.

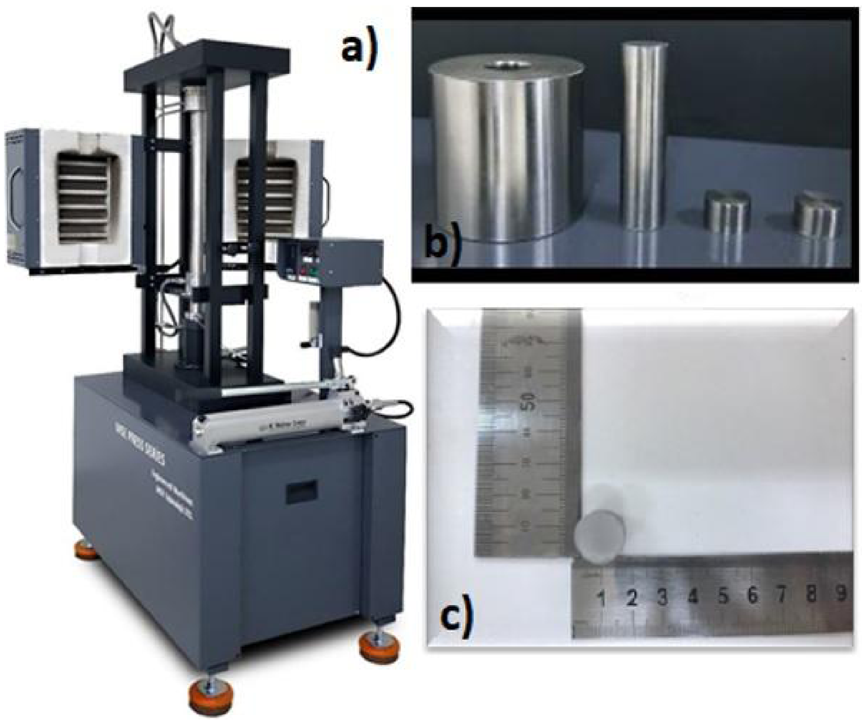

Figure 2. a. Hot pressing machine b. Die and punches made of hot work tool steel c. an example of produced samples

Figure 3. Protherm metal furnace.

Figure 4. CSM Tribometer.

RESULTS and DISCUSSION

Adding GNP to Al6061 resulted in increased Brinell Hardness values as shown in Table 2. But also in coefficient of friction (Fig. 5.) and ended up with increase in material loss as can be seen in the widened and darker wear trail (Figure 6. c.) due to the added GNP amount. However as can be seen in Fig. 5. aging the specimen ended up with lower friction of coefficient than the untreated one. Also the slided surface of the aged specimen is brighter than the untreated specimen (Fig 6.). After the aging process grains of the Al and GNP are mostly interbedded (Fig 7. d.), due to the interbedding it is unlikely to tear off GNP nanoparticles. With the lubricating and wear reducing properties of GNP and interbedding effect of aging specimens shown increase on wear resistance.

Table 2. Hardness values of produced samples

Hardness Values	Al	Al6061	Al6061 wt 8% GNP	Al6061 wt 8% GNP (Artifically Aged)
	21 HB	25 HB	35 HB	66 HB

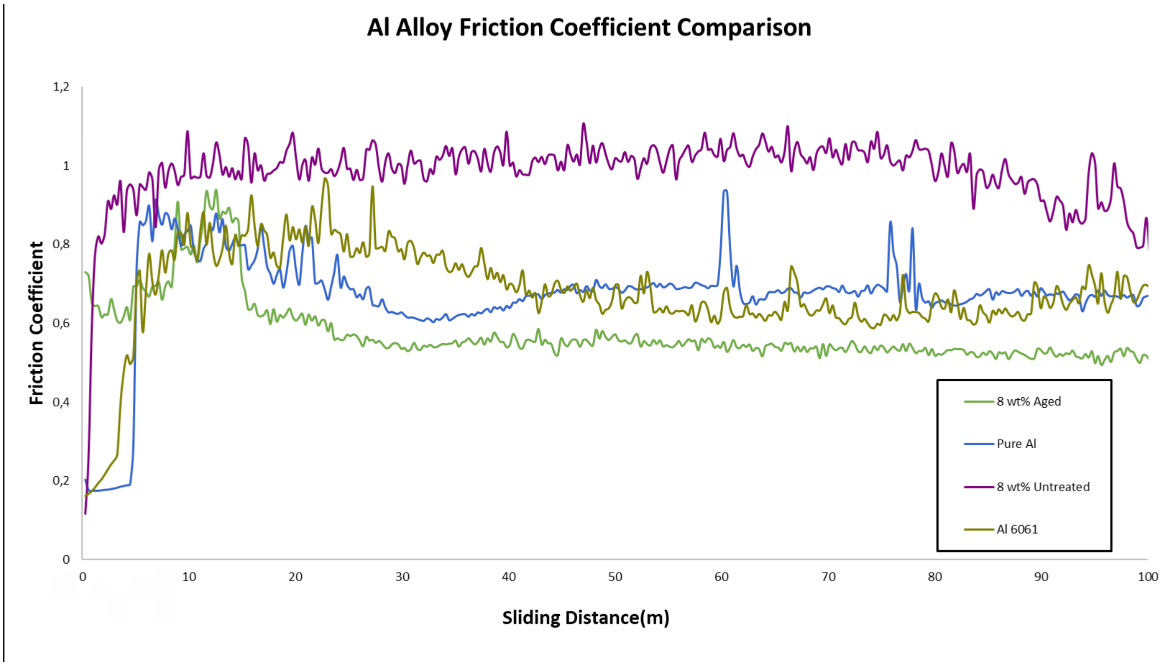

Figure 5. Friction coefficients change with sliding distance.

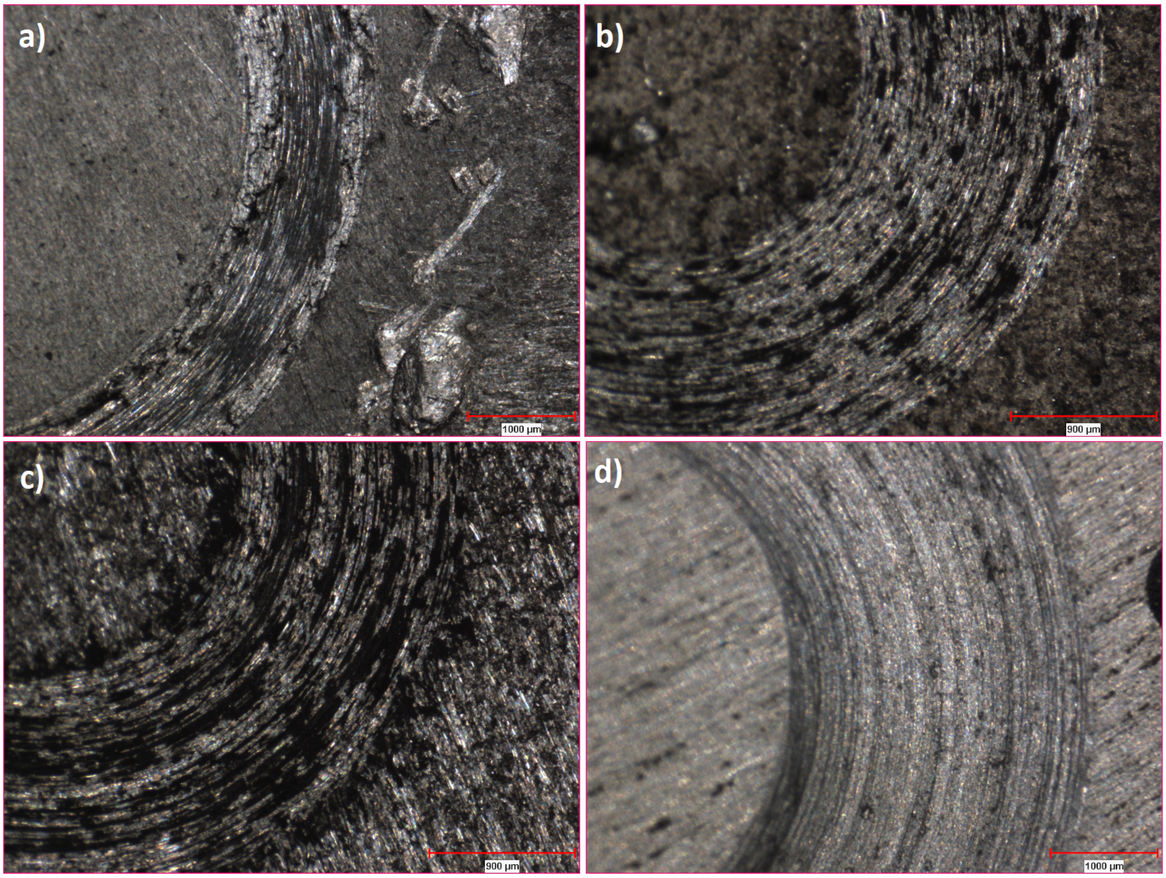

Figure 6. Wear surfaces of the specimens a. Pure Al untreated b. Al6061 without reinforcement and heat treatment c. Al6061 8 wt% GNP untreated d. Al6061 8 wt% GNP and artificially aged

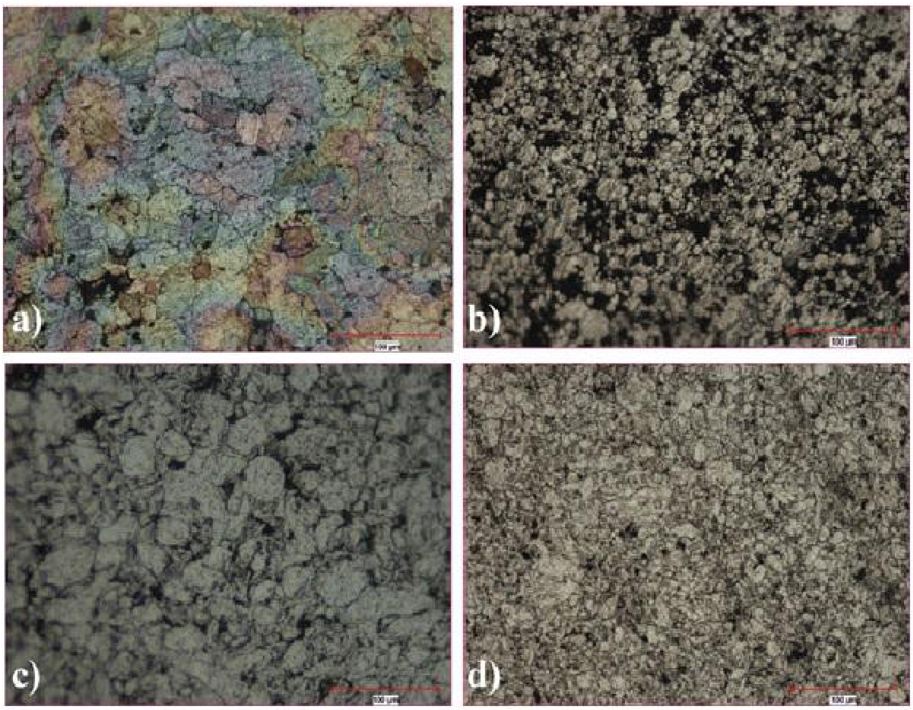

Figure 7. Microstructures of the specimens. a. Pure Al untreated b. Al6061 without reinforcement and heat treatment c. Al6061 8 wt% GNP untreated d. Al6061 8 wt% GNP and artificially aged.

In this study, the effects of GNP reinforcement and precipitation hardening effect on mechanical properties were investigated. As a result of the examination of the wear test data and wear microstructures, it was determined that the reinforcement and aging process reduced the wear rate, compared to the untreated samples. While the specific wear rate was 0.009 mm^3/Nm in the Al6061/GNPs aged composite, it was 0.0020 mm^3/Nm and 0.0019 mm^3/Nm in the unreinforced Al and Al6061 materials, respectively. In the microstructure images (Fig. 7), it was determined that the grain size of the Al/GNPs composites decreased after the precipitation hardening, consequentially the wear resistance increased. It has been stated in the literature that long aging times cause grain coarsening, and such an undesirable situation was not encountered in the study. It was determined that the wear resistance and hardness (66 HB) of Al/GNPs composites increased approximately two times compared to unreinforced Al (25 HB). This important contribution is attributed to refinement of grains and participation hardening effects on Al6061/GNPs composites. In addition, the reduction in coefficient of friction (COF) is thought to be due to the solid lubricant property of the graphene nanoplate material.

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