Science of Sintering, **54** (2022) 177-187

https://doi.org/10.2298/SOS2202177O

UDK: 539.375; 692.533.1; 539.53

Investigation of the Microstructure-Hardness and Wear Performances of Hybrid/Composite Materials Al_2O_3/SiC Particle Reinforced in AA 7075 Matrix

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Abstract:

As a result of advances in science and technology, the importance of metal matrix composite materials is increasing gradually today. However, in many studies, composite production is carried out with monotype ceramic particle reinforcement. In this study, the production, microstructure-hardness, and wear performance of composite-hybrid materials that had AA 7075 aluminum powder metal matrix and were reinforced by SiC and Al_2O_3 ceramic particles at different ratios were examined. The prepared Matrix and reinforcement powder mixtures were mixed for half an hour in the three-axis Turbula T2F type mixer and then, pressed unidirectionally and cylindrically under the pressure of 700 MPa. The pressed samples were sintered for 1 h at a temperature of 600^oC in the argon atmosphere. Microstructure examinations were carried out using SEM (Scanning Electron Microscope) and optical microscope devices, while hardness measurements were obtained as a result of Brinell measurement. Wear performance of the test samples were tested in the Pin-on-disk type device at 10 N load and 500 rpm rotation speed by depending on the wear distances at 1000, 1500 and 2000 m. It was observed that hardness increased as the amount of ceramic particle in composite-hybrid samples increased. As a result of wear tests, in hybrid composites, compared to single-phase ceramic particle reinforced composites, weight losses increased depending on the increase in the reinforcement amount.

Keywords*: AA7075; Al_2O_3; SiC; Composite; Hybrid.*

1. Introduction

Recently, in order to meet special product requirements, the production of advanced materials has become widespread worldwide. This is due to the fact that a single material often does not meet the requirements of all engineering fields. For this reason, researchers are making efforts to use composite materials with unique properties. Therefore, in recent years there has been a tremendous increase in the production of metal matrix composites and these materials. The most important of these are Aluminum (Al) Metal Matrix Composites (MMC). Apart from manufacturing methods such as casting, extrusion, and rolling, which are the production methods of MMCs, the use of different production methods such as powder

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metallurgy (PM) has been increasing in recent years [1-2]. Due to their superior properties such as density, high strength, corrosion resistance, and electrical conductivity, aluminum and its alloys are widely used in industry, especially in the automotive sector. The alloy series with the highest strength among aluminum alloys is the 7XXX series. In the aviation industry, it is used in the production of fuselage and wings of aircraft. AA7075 aluminum alloy is the most commonly used alloy group in the 7XXX series [3]. Besides these superior properties, aluminum alloys have some negative properties. These are high temperature performance and wear resistance. To improve these poor properties, aluminum alloy metal matrix composites reinforced with ceramic particles have been developed [4]. Internal combustion engines, pistons, liners, pulleys, and pivots are subjected to wear very much. During the production of these parts, by reinforcing SiC and Al_2O_3 ceramic particles with high wear resistance, a decrease in density and thermal expansion coefficient and an improvement in hardness are ensured, and commercial products, such as materials whose ambient-temperature mechanical properties are wear-resistant, can be produced [5-6]. Some of the most important parameters that affect the mechanical properties and wear resistance of aluminum alloys are grain size and structure, inclusions, sediments, intermetallic phases, and the amount of pores occurring in the structure [7]. Al-Kady and Fathy noted that increasing the amount of SiC reinforcement in the Al matrix and decreasing the particle size reduced grain size and thermal conductivity, while it increased hardness and compressive strength [8]. Singh investigated several aspects related to the production and wear properties of Al/SiC/Gr hybrid composites, and he found that the wear resistance of Al/SiC/Gr composites increased by the addition of Gr [9].

In this study conducted on the production of ceramic particle reinforced composite/hybrid materials in Al metal matrix structure, the effects of Al_2O_3 and SiC reinforcements were investigated. In this way, studies were carried out on the determination of microstructure, hardness, and wear behaviors of composite-hybrid materials.

2. Materials and Experimental Procedures

In this study, test samples were produced using powder metallurgy method. For this purpose, Al_2O_3 and SiC ceramic particles with different percentages by weight (5, 10, 15 %) were used as reinforcement materials. As a matrix material, spherical AA7075 aluminum metal powders produced by the gas atomization method were used. The chemical composition of the initial matrix material used in the production of the powder metal test samples is given in Table I.

Tab. I The chemical composition of AA7075 alloy and powder size.

Al	**Mg**	**Zn**	**Cr**	**Zr**	**Si**	**Fe**	**Mn**	**Cu**	**Powder size (μm)**
89.6	2.596	5.480	0.012	0.030	0.403	0.549	0.014	1.568	74

The chemical and mechanical properties of the used reinforcement Al_2O_3 and SiC particles are shown in Table II.

Tab. II $Al_2O_3$and SiC powder properties.

Density (g/cm^3)	**Melting Temperature (^{o}C)**	**Powder size (μm)**
3.97	2040	<32
3.21	2545	<44

AA7075-aluminum-metal matrix powder mixtures prepared in different Al_2O_3 and SiC reinforcement rates (5, 10, 15 %) were mixed for 30 min in a 3-axis Turbula T2F type device in order to ensure homogeneous powder distributions. After the mixing process, composite-hybrid powder metal test samples with a diameter of 10 mm and 12 mm height were produced by pressing process performed at a pressure of 700MPa in a single-axis double-acting cold press device (sample mass: 3 g). After the pressing process, 0.0001 g precision scales were used to determine the raw densities of the samples. The sintering process of the test samples was carried out for 60 minutes at a temperature of 600^{o}C by using an atmosphere-controlled heat treatment furnace. To be able to prevent oxidation that might occur, the sintering process on the samples was carried out under a flow of high purity argon gas. In order to determine the density changes of the sintered samples, the density measurements of the samples were carried out using the Archimedes principle given in Equation 1 [10]. After the density measurements, for general metallography studies, the samples were subjected to grinding-polishing and etching, respectively. Keller solution (1 ml HF, 1.5 ml HCl, 2.5 ml HNO_3, 95 ml H_2O) was used in the etching process of the test samples.

$$d = \frac{\mathrm{m}}{\mathrm{Vy} - \mathrm{Vs}} \qquad (1)$$

where is *d*-density (g/cm^3); *m*-weight (g); *Vy*-wet weight (g); *Vs*-weight (g) in water refers to values.

After the etching process, Brinell hardness measurements were done to determine the hardness of the test samples. An average hardness value was determined by taking the hardness values from five different points of the sample surfaces. For wear experiments of the samples, the pin-on-disk type wear device was used in experimental studies under adhesive wear conditions (UST Tribometer T10/20 device). A steel disc prepared from Hardox 500 steel and had a hardness of 52 HRc was used as an abrasive in the adhesive wear mechanism. Wear tests were applied at 10 N force, 500 rpm rotation speed and wear distances of 1000, 1500 and 2000 m. Equation 2 was used in the wear rate calculations:

$$Wa = \Delta Gd \times P \times S \qquad (2)$$

where is *Wa*-wear rate (mm^3/Nm); *ΔG*-weight loss (g); *d*-density (g/cm^3); *P*-the port load (N) and *S* are the wear distance in the wear test [7].

In experimental studies, the optical microscope and the scanning electron microscope (SEM) were used to evaluate microstructure characterization of initial powder materials and test samples before and after wear.

3. Results and Discussion

SEM images of the initial matrix and reinforcement elements used for the production of Al_2O_3-SiC reinforced composite/hybrid materials with powder metal AA7075 matrix are given in Fig. 1. When the SEM images were examined, it was observed that the AA7075 aluminum alloy Matrix element had a powder shape and morphology that was mostly spherical, rod-like, and called teardrop (Fig. 1a). On the other hand, it was determined that Al_2O_3 and SiC ceramic phase structures used as reinforcement elements were in irregular, mostly rod-like and polygonal powder shapes and morphologies, respectively (Fig. 1b and c). Density measurement results (after sintering) of composite/hybrid test samples, which produced using Al_2O_3 and SiC ceramic particle reinforcement and were in AA7075 metal matrix structure, are given in Fig. 2.

It is known that the density values obtained after the sintering process are important especially in terms of comparing them with the values before the sintering process. In this regard, the density values of the test samples before the sintering process were determined to be approximately 2.60 g/cm^3. Moreover, when the density values of the test samples were examined after sintering (Fig. 2), it was seen that there was a decrease in the density values. It can be stated that the demand, which is effective on the decrease in the density values of the powder metal experiments, is from the gaps in the bonding/interfaces of the ceramic particles with AA 7075 aluminum alloy matrix material. It can be stated that due to the increase in the amount of particles, the amount of voids observed at the interface increases and the density decreases in parallel. In addition, the basic alloying elements in the aluminum alloy matrix structure, zinc, copper, etc. [11].

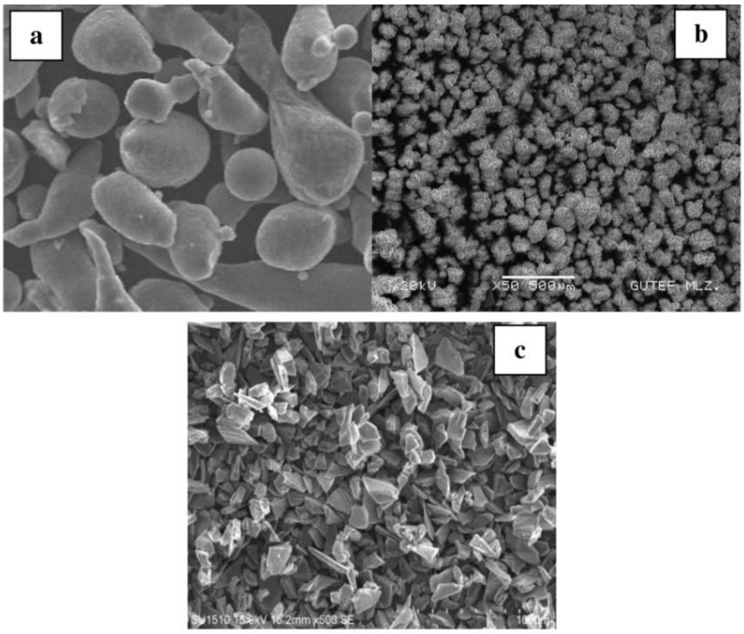

Fig. 1. SEM images of starting powder materials; a) AA7075, b) Al_2O_3, c) SiC.

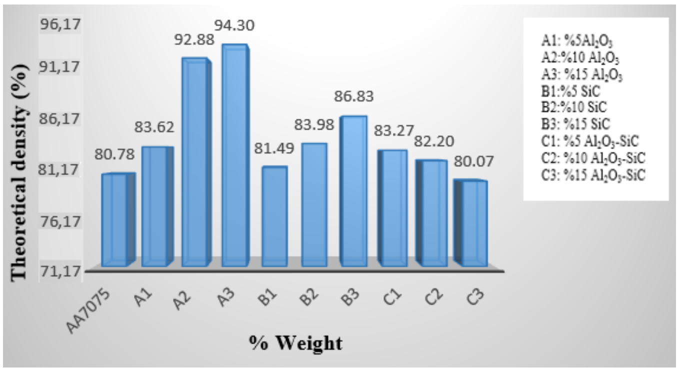

Fig. 2. Density values of hybrid/composite samples according to % particle rate of samples after sintering.

In a similar research in which production of powder metal parts was performed, a study was conducted on the production of composite-hybrid materials reinforced by B_4C/Al_2O_3 with different percentages. In that study, depending on an increase in ceramic particles, a decrease in density values was determined in the metal matrix structure. The reason for this situation was stated as that there were surface spaces between the Matrix and the reinforcement particles [12]. Kumar and Rajadurаı conducted a similar study by using TiO_2 with different percentages by weight (4, 8, 12 %) as a second reinforcement in Al + 15 % SiC. They found that as the reinforcement rate increased in hybrid composites produced by powder metallurgy, an increase in density occurred in them [13]. It is known that ceramic material density values are higher than aluminum matrix. In metal matrix ceramic particle reinforced composite materials, an increase in density occurs due to the increase in single-phase ceramic particle reinforcement. However, after the use of double ceramic phase reinforcement in hybrid composite materials, the ceramic particles dispersed in the grain boundaries in the sintering process resist the shrinkage of the pores. In this case it can be considered that there is a decreasing trend for hybrid composites as opposed to the increase in density.

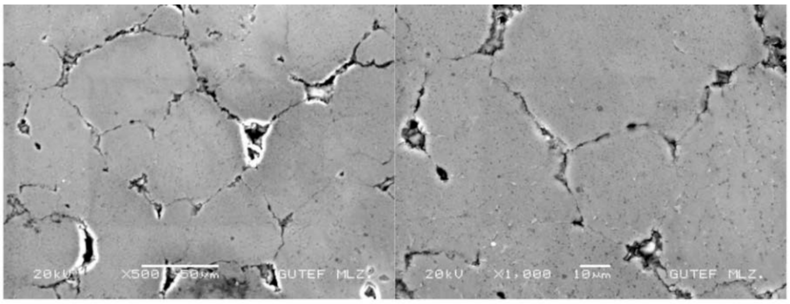

Fig. 3. After sintering AA7075 aluminum material SEM images.

When the density results of composite/hybrid test samples given in Fig. 2 were examined, the highest density values were determined in 15 % SiC and Al_2O_3 reinforcement rate and in 5 % Al_2O_3-SiC hybrid sample. On the other hand, when hybrid samples were evaluated within themselves, it was found that depending on the increase in particle reinforcement rate, there was a decrease in density value after sintering. It is thought that this was due to the lack of adequate formation of the interface caused by the dimensions of the matrix and reinforcement materials. In general, it was found that depending on sintering, a decrease in the density value of powdered metal composite/hybrid materials occurred. Especially considering the AA 7075 aluminum metal material, the effectiveness of the sintering process is very important in terms of the pore-grain structure relationship. In this regard, AA 7075 aluminum material's SEM images obtained after sintering are shown in Fig. 3. In terms of microstructural pore-material grain structure and high-temperature resistance, it can be stated that the sintering process has been completed or its appropriateness is sufficient.

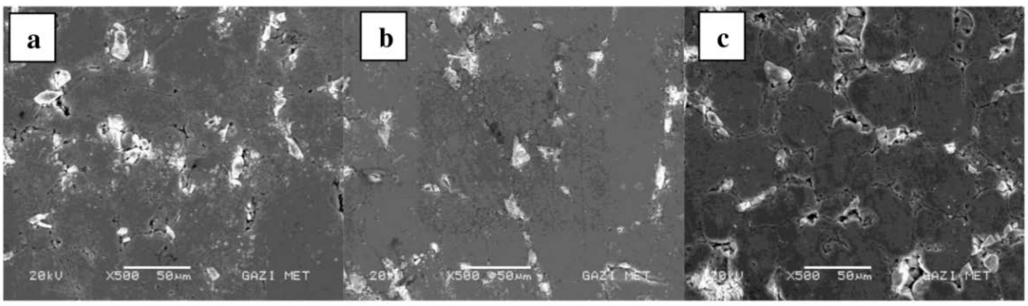

Fig. 4. SEM images of composite samples after sintering: a) %5Al_2O_3, b) %10Al_2O_3, c) %15Al_2O_3.

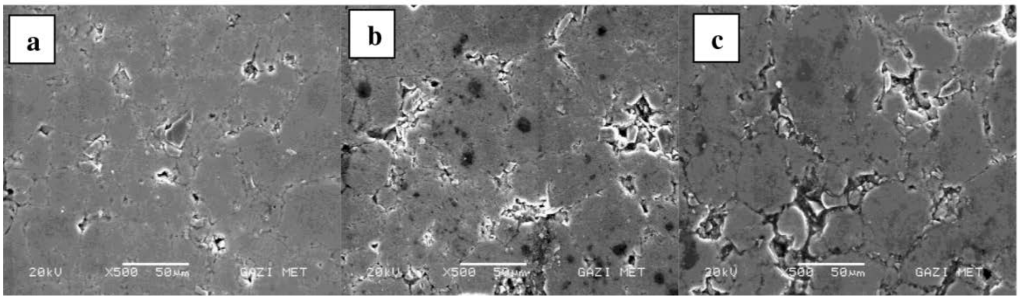

Fig. 5. SEM images of composite samples after sintering: a) %5SiC, b) %10SiC, c) %15SiC.

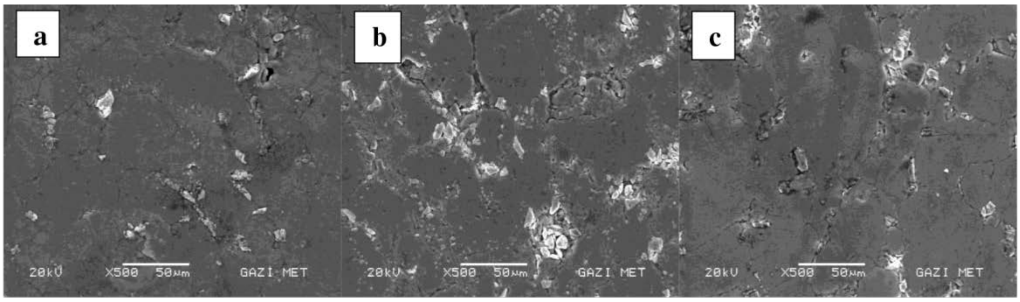

Fig. 6. SEM images of hybrid composite samples after sintering: a) %5 Al_2O_3-SiC, b) %10 Al_2O_3-SiC, c) %15 Al_2O_3-SiC.

SEM images obtained from composite/hybrid samples after sintering processes are given in Figs. 4-5-6. When the SEM images shown in Figs. 4-5 are examined, it can be obviously seen that depending on the increase in the ceramic particle reinforcement phase, the pore distributions increase in the aluminum metal matrix structure. In composites produced by SiC ceramic particle reinforcement, the amount of pore was found to be greater than composites produced by Al_2O_3 reinforcement. In their study conducted on B_4C and MoS_2 reinforced hybrid composite materials, Liu and colleagues [14] found that reinforcement materials exhibit a homogeneous distribution in the matrix material. In this study, related to the production of hybrid composite materials (Al_2O_3-SiC), it can be said that the amount of porosity at grain boundaries increased in terms of the reinforcement phase increase. Especially when an evaluation is made from a microstructural point of view, it can be said that the Al_2O_3 ceramic particle reinforcement distributes in irregular shapes, while the SiC ceramic particle reinforcement distributes in polygonal shape morphologies, mostly at grain boundaries.

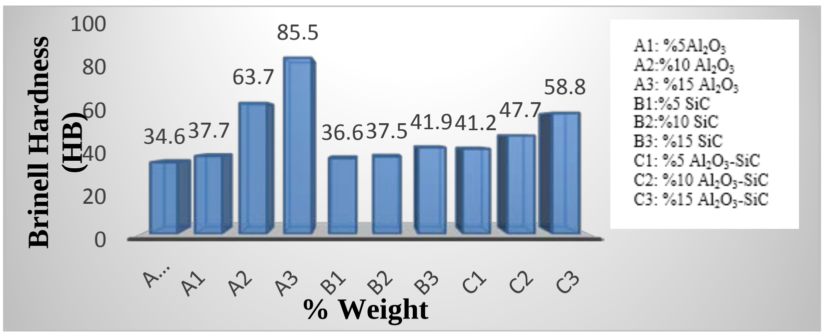

Fig. 7. Hardness results of test samples after sintering.

In Fig. 7, the average results of Brinell hardness values taken from 5 different points of composite/hybrid samples were given. According to the hardness results obtained, hardness values increased depending on the increased reinforcement amount of ceramic particles in both composite and hybrid samples compared to the matrix AA 7075 aluminum material. In a study of Pul [15], he found that depending on the increase in reinforcement, there were decreases in the hardness values of the B_4C+TiB_2 reinforced Al 2024 material samples produced by the powder metallurgy. He also attributed this to an increase in the pore amount microstructurally. In a study conducted by Rao and colleagues [16], they found that in samples produced with TiC ceramic particles by depending on various percentage amounts by weight (2, 4, 6, 8, 10 %), an increase in the hardness value occurred depending on an increase in the reinforcing ceramic material. In this study, on the other hand, in parallel with the study done by Rao and his colleagues, it was found that an increase in hardness value occurred with the increase of the reinforcement material. In a study conducted by Davodi and colleagues [17], Ag/Al_2O_3 metal matrix composites were fabricated by mechanical milling. They showed that the hardness value (HV) increased with the Al_2O_3 content.

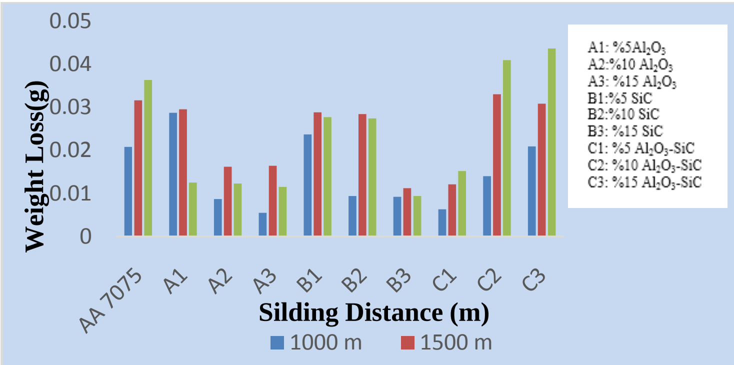

Fig. 8. Weight loss of test samples after wear.

The weight loss results obtained as a result of pin-on-disc wear applications on the test samples at the end of sintering processes are shown in Fig. 8. When the weight loss results obtained as a result of the wear test were examined, it was determined that the highest weight loss occurred in AA7075 aluminum material. It was determined that compared to AA7075 aluminum material; there was a decrease in weight losses of composites produced by single-phase ceramic particle reinforcement depending on an increase in the reinforcement amount. In hybrid composite materials, on the other hand, this situation is the opposite. Compared to single-phase ceramic reinforced composite test samples, weight losses increased depending on an increase in the amount of reinforcement. It can be stated that this result occurs as a result of the differentiation that emerges in the grain structure-pore interaction due to the increased rate of reinforcement. It can also be noted that an increase in weight loss occurs depending on increased wear distance. It has also been found that this situation parallels the coefficient of friction and material losses in hybrid composite samples. In a similar study conducted by Haq and Anand, they produced hybrid composite test samples by using AA7075 + 8% Si_3N_4 and Gr reinforcement at various rates by weight (0, 2, 4, 6 %). Based on the results of the wear test, they found that an increase in material loss occurred due to an increase in load and an increase in speed. They were unable to determine any link between material loss and the increase in ceramic phase particles by weight [18]. Şimşek and colleagues concentrated on composite material production by reinforcing 10, 20, 30, and 40 % SiO_2 into AA7075 alloy by using the depressurized infiltration method. Based on the obtained wear test data, they determined that the weight loss and friction coefficients of aluminum composites also decreased depending on the increase in the reinforcement volume amount

[19]. In a similar study, Matic and Tanattı found that wear resistance increased depending on the increased reinforcement rate in AA7075 composites reinforced with SiC particles at different rates [20]. As a result of studies conducted on the mechanical and tribological performance of the hybrid composites they produced, Devaganesh and colleagues noted that the wear rate in the material produced as Al7075 + 5 % SiC+5 % hBN was the lowest [21].

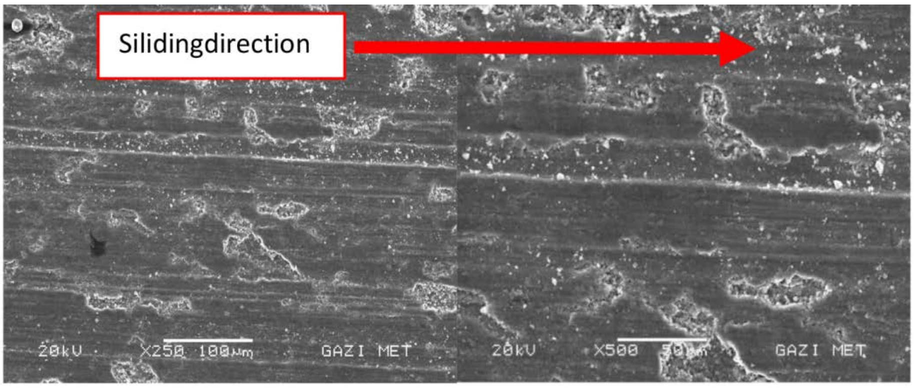

Fig. 9. SEM images of AA 7075 aluminum after wear.

A SEM investigation was used to determine wear mechanism of experiment samples in especially most wear articles [22]. As a result of sintering and wear testing applications, the obtained SEM images of the wear surface of AA 7075 aluminum material are shown in Fig. 9. In their study investigating the effect of the friction mixing process on the microstructure and properties of AA7075/TiB2 in situ composites, Rajan et al. [23] found parallel grooves along the surface as a result of wear as in this study (Fig. 9).

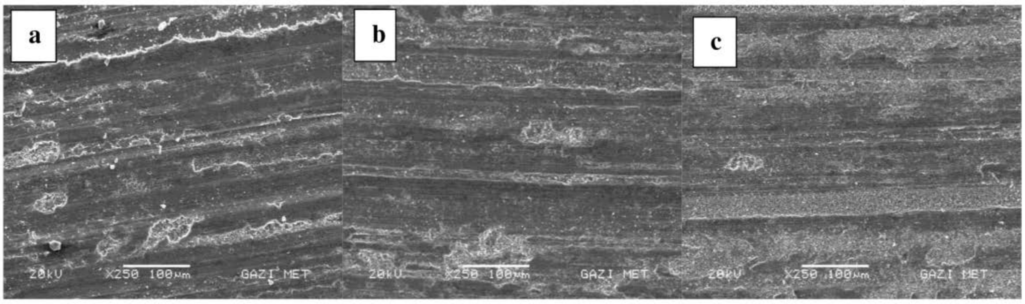

Fig. 10. SEM images of AA7075 + Al_2O_3wear surface: a) %5 b) %10, c) %15.

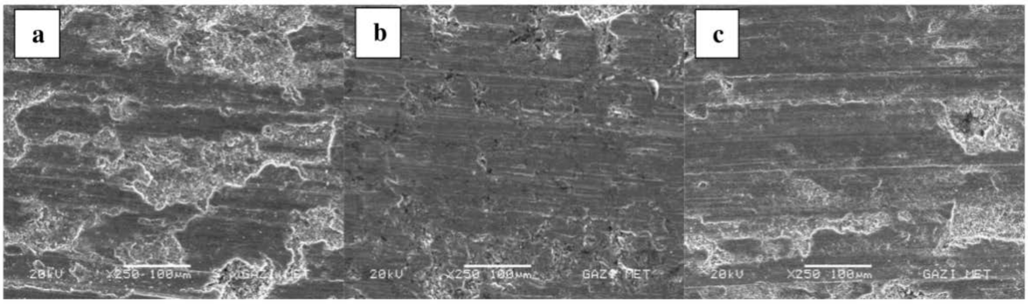

Fig. 11. SEM images of AA7075 + SiC wear surface: a) %5 b) %10, c) %15.

Depending on the sliding distance, some ductile particles broke off from the soft and ductile metal matrix structure due to the friction; then, as a result of the adhesion of ductile particles to the surface again, weight losses also occurred in AA7075 aluminum material. SEM images obtained after wear of composite-hybrid test samples produced by Al_2O_3 and SiC ceramic particle reinforcements are given in Figs. 10, 11, and 12, respectively, compared to AA 7075 aluminum matrix material. In Fig. 10, it is understood that particles that broke off from the Al_2O_3 reinforced surface caused damages such as plaster layers, scratches, tears, and spills on the wear surfaces by adhering to the surface again.

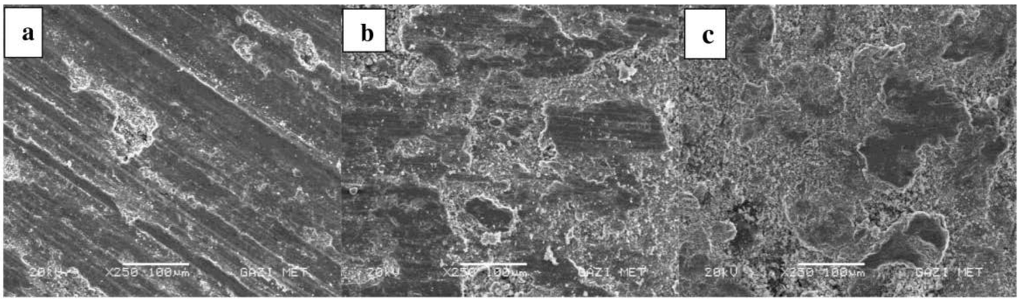

Fig. 12. SEM images of AA7075 + Al_2O_3-SiC wear surface: a) %5 b) %10, c) %15.

When the wear surface images of the SiC reinforced composite in Fig. 11 are examined, adhesive craters and many flakes are seen on the surface. It was found that the deformation occurring in the samples decreased as the reinforcement amount of single ceramic phase Al_2O_3 and SiC inside the samples increased. A. Kumar and M. Kumar found that depending on the increase in the reinforcement rate, shallow grooves emerged as a result of wear in hybrid composite samples reinforced with B_4C and rice husk ash at different percentages [24]. As can be seen in Fig. 12, it was determined that especially at the Al_2O_3-SiC reinforcement rates of 5 and 10 %, micro-pits and micro-chip particles occurring on wear surfaces caused serious deformation on the surface. It can be said that these hard particles breaking off from the surface accelerate wear, thus occurring material deformation increases the deformation of double ceramic reinforcement in this type of hybrid composite materials.

4. Conclusion

In this study, the wear behaviors of aluminum composite-hybrid materials produced by adding Al_2O_3 and SiC ceramic particle reinforcements to AA7075 alloy, which is commonly used in the aerospace sector, by powder metallurgy method were examined. The obtained results are summarized below;

Compared to AA 7075 powder metal material, in single-phase ceramic particle (Al_2O_3 and SiC) reinforced composites, their composite densities increased as the amount of reinforcement increased, while in double-ceramic particle reinforced hybrid composites, their composite densities decreased. In SEM images of the hybrid composite material, it was determined that ceramic phase particle reinforcements were found to be located on grain boundaries and in areas near the grain boundaries and especially those they increased the amount of porosity. It can be noted that the increased amount of reinforcement and particle size differences affect the pore-grain structure of the hybrid composite material, and thus, this negatively affects the shrinkage of the pores. Compared to AA 7075 aluminum, the hardness value in composite-hybrid materials showed an increase. The highest hardness value was determined to be 85.5 HB in 15 % Al_2O_3 reinforced composite material. As a result of wear tests, it was determined that the highest weight loss was in AA7075 aluminum material. In

SEM images of the wear surface of AA7075 alloy, it was observed that depending on an increase in sliding distance, there was the formation of excessive plastic deformation on the sample surfaces. Continuous scratches on wear surfaces and micro-cracks caused by fatigue also indicate that adhesive wear mechanisms have been formed.

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Сажетак: *Као резултат напретка науке и технологије, важност материјала на бази металних композита и данас расте. У овом раду, испитивано је добијање, микроструктура-тврдоћа, и перформансе хабања композитног хибридног материјала који је имао AA 7075 алуминијумски метални матрикс и био је ојачан са честицама керамика SiC и Al_2O_3 са различитим односима. Припремљени матрикс и ојачана смеша су млевени пола сата у млину типа Turbula T2F а затим пресовани на 700 MPa. Пресовани узорци су синтеровани 1 сат на 600^oC у аргону. Микроструктурна испитивања су рађена на SEM-у и оптичком микроскопу, док је тврдоћа добијена мерењем по Brinell-у. Перформансе хабања су добијене на уређају типа Игла-на-диску при 10 N оптерећењу и 500 обртаја у минути на дистанцама хабања од 1000, 1500 и 2000 метара. Уочено је да тврдоћа расте са порастом количине керамичких честица. Као резултат хабања, у хибридно композиту, у поређењу са једнофазним композитом, пад масе расте са порастом количине ојачања.*
Кључне речи*: AA7075, Al_2O_3, композити, хибрид, хабање.*