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Araştırma Makalesi - Research Article

The Effects of Different Reinforcement Ratios on Wear Behaviors in EN AW 5754 (AlMg3)/SiCp Composite Materials Produced with the Squeeze Casting Method

Sıkıştırma Döküm Yöntemi İle ÜretilenEN AW 5754 (AlMg3)/SiCp Kompozit MalzemelerdeFarklı Takviye OranlarınınAşınma Davranışları Üzerine Etkisi

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ABSTRACT

In this study, SiCp particles were reinforced at volumetric ratios of 5%, 10%, 15% and 20% into the EN AW 5756 (AlMg3) metal matrix composite by using the squeeze casting method. The squeezing process was carried out for 10 seconds under a pressure of 80 MPa. The changes in the wear behaviors and friction coefficients of the EN AW 5754/SiCp composite samples were examined under1.0 N force, 5000 cycles and with a 0.04 m/s sliding speed. As a result of the experiments, it was found that the friction coefficient value increased from the non-reinforced alloy to the 10% SiCp-reinforced composite, while it then decreased in the 15% and 20% SiCp-reinforced composites. Moreover, the amount of wear in the composite material increased as the ratio of the reinforcement increased, and the highest wear occurred in the 10% SiCp-reinforced composite. This wear rate decreased in the 15% reinforced composite and then increased in the 20% reinforced composite. The deformation wear statuses of the composite materials that were used in the experiments were examined by conducting SEM (Scanning Electron Microscopy) and EDS (Energy-Dispersive Spectrometry) analyses. In these examinations, it was observed that the 5% and 10% SiCp reinforcements did not show a homogeneous distribution in the matrix, but the 15% and 20% SiCp reinforcements were homogeneously distributed in the matrix material.

Keywords- EN AW 5754 (AlMg3) Matrix Composites, SiCp, Squeeze Casting, Friction, Wear

ÖZ

Yapılan çalışmada, sıkıştırma döküm yöntemi kullanılarak hacimce %5, %10, %15 ve %20 hacim oranlarında SiCp parçacıkları EN AW 5754 (AlMg3) metal matrisli kompozit içine katılarak takviye edilmiştir. Sıkıştırma işlemi, 80 MPa basınç altında 10 saniye olacak şekilde uygulanmıştır. Üretimi yapılmış olan EN AW 5754/SiCp kompozit numunelerin aşınma davranışları ve sürtünme katsayısındaki değişimler 1.0 N kuvvet altında 5000 çevrimde 0,04 m/s kayma hızında incelenmiştir. Yapılan deneyler sonucunda sürtünme katsayısı incelendiğinde, takviyesiz alaşımdan %10 SiCp takviyeli kompozite kadar arttığı daha sonra %15 ve %20 SiCp takviyeli

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kompozitlerde ise düştüğü görülmüştür. Bunun dışında kompozit malzemenin aşınma miktarı, takviye oranı arttıkça artmış % 10 SiCp takviyeli kompozitte en yüksek aşınma durumu meydana gelmiştir. Daha sonra % 15 SiCp takviyeli kompozitte bu oran düşmüş, %20 takviyeli kompozitte ise bu oranın tekrar artışa geçtiği görülmüştür. Deneylerde kullanılan kompozit malzemelerin deformasyon aşınma durumları SEM (Taramalı elektron mikroskobu) ve EDS (Enerji Dağılım Spektrometresi) analizleri yapılarak incelenmiştir. Bu incelemelerde, %5 ve %10 SiCp takviyelerinin matris içerisinde homojen dağılım gösteremediği, fakat %15 ve %20 SiCp takviyelerinin matris malzemesi içerisinde homojen dağıldıkları görülmüştür.

Anahtar Kelimeler-EN AW 5754 (AlMg3) Matrisli Kompozitler, SiCp, Sıkıştırma Döküm, Sürtünme, Aşınma

I. INTRODUCTION

With technological developments today, the need for new-generation materials with superior properties is increasing constantly. Some of such materials are composite materials. The prominent properties of composites are generally dependent on the properties, size, and concentration of the reinforcement material, the characteristics of the matrix, the preparation method and the bond strength of the interface between the matrix and the fillings. Composite materials are used to obtain high strength, improved rigidity, lower density, and improved thermal and electrical properties in a composite structure [1-4]. Composite materials are formed by combining two or more materials, and this way, they meet product demands by improving the mechanical and thermal properties of materials. For composite production, various metals such as aluminum, steel alloys, magnesium, brass, bronze and cast irons can be used as matrix or reinforcement materials [5-6]. Composite materials, which gain a high strength/weight ratio, high tensile and compressive strength, good corrosion resistance and wear resistance, as well as the ductility and toughness of metals and high strength and high modulus of elasticity of ceramics, by combining the desired properties of different materials on a macro level, are advanced materials whose area of usage has increased today in almost all industrial fields, especially defense, automotive and aviation [7-13].

Mostly, aluminum alloys are used as the matrix in composite materials. These are among materials that are preferred in the production and manufacturing sector as they are light, easy to cast, have superior mechanical properties, low density and high thermal and electrical conductivity. However, the fact that the wear resistance of Al and its alloys is low limits their application areas. To improve the existing properties of aluminum and its alloys, metal matrix composite (MMC) materials are produced by using hard reinforcement components in the form of whiskers, fibers, or particles. The wear performance of MMC materials varies based on the properties of the matrix and the reinforcement material [14-16].

Adding reinforcing particles into aluminum which is used as the matrix material reduces its wear rate and friction coefficient. The particle size, volumetric ratio or compositions affect the friction coefficients of aluminum alloy composites [17].

In this study, SiCp particles that were used as the reinforcement material were added to the EN AW 5754 alloy that was used as the matrix material at volumetric ratios of 5%, 10%, 15%, and 20%. The stirring process continued during and after the addition of the reinforcement material into the matrix material. This way, it was ensured that the reinforcement material was homogeneously mixed into the matrix material. The homogeneous mixture was taken into a mold, the upper lid was closed, and the squeezing step was performed for 10 seconds under a pressure of 80 MPa. In the production of the composite material by using the squeeze casting method, it was expected that its porosity ratio would be lower, and as a result of this, there would be less mass loss during the wear test. For the EN AW 5754/SiCp composite materials that were produced homogeneously with different reinforcement ratios, changes in wear rates and friction coefficients were investigated in this study under certain conditions.

II. MATERIAL AND METHOD

A. Matrix Material

The EN AW 5754 (AlMg3) alloy was selected as the matrix material to produce SiCp particle-reinforced composite materials. The density of this alloy is 2.68 g/cm^3, and 5xxx series wrought aluminum alloys are those that cannot be thermally treated, and they can only be hardened by morphological changes. These alloys that cannot be heat-treated gain their highest mechanical properties by strain hardening, which is a method of increasing hardness and strength by cold forming. The properties of the EN AW 5754 alloy are given in Table 1 [14].

Table 1. Properties of EN AW 5754 aluminum alloy [18]

Chemical Composition (%)										
Al	Fe	Si	Cu	Mn	Mg	Zn	Cr	Ti	Mn+Cr	Other
Base	0.40	0.40	0.10	0.50	2.6-3.6	0.20	0.30	0.15	0.60	0.15

Physical Properties					
Density	Melting point	Thermal expansion	Modulus of elasticity	Thermal conductivity	Electrical resistivity
2.66 g/cm^3	600 °C	24x10^{-6}/ K	68 GPa	147 W/m.K	0.049x10^{-6} Ω.m

Mechanical Properties			
Yield Strength (Min-Max.)	Tensile Strength (Min-Max.)	Elongation (50%)	Brinell hardness
80-100 MPa	190-215 MPa	24	44 HB

B. Reinforcement Materials

The average particle size of the silicon carbide (SiCp) that was used in this study as the reinforcement material was 13 μm. SiCp particles have better wettability by liquid aluminum in comparison to other ceramic reinforcement components such as alumina (Al_2O_3) and aluminum nitride (AlN) due to their mechanical strength, high oxidation resistance and thermal shock resistance. As they are inexpensive, they are used in composite material applications, as well as wear-resistant nozzles, casting filters, casting ladles, and ceramic furnaces [19-22]. Some mechanical and physical properties of SiCp reinforcement materials are given in Table 2.

Table 2. Mechanical properties of SiCp particles [22]

Reinforcement Material	***SiCp***
Density (g/cm^3)	3.20
Thermal Expansion Coefficient (10^{-6}/K)	5
Melting Point (°C)	2500
Compressive Strength (MPa)	2000
Elasticity Modulus (10^3 MPa)	414
Hardness(HV)	3000

C. Production of Composite Materials with the Squeeze Casting Method

After putting the matrix material in a melting pot, the melting pot was put into the production furnace. The nitrogen gas supply was placed into the furnace so that the gas would contact the molten metal in a hot form. The matrix material inside the furnace was heated to the semi-solid temperature range (500-600 °C) in the nitrogen atmosphere by speed stirring at a low speed and wreaking using stirrers with ends that had a specialized profile. When the temperature inside the furnace reached the semi-solid temperature range, the reinforcement material started to be added into the matrix material.

The material was reinforced by stirring SiCp particles at ratios of 5%, 10%, 15% and 20% by volume into the EN AW 5754 aluminum alloy which was in a semi-solid state by using the modified squeeze casting method. When the reinforcement addition processes were completed, homogenization was carried out by applying short-lasting high-speed stirring to the mixture whose temperature increased fast, and the mixture in the semi-solid form after stirring and homogenization was taken into a steel mold. The upper lid was closed, the mold was put under the press, and the squeezing process was started within a few seconds. The squeezing process of the composite material inside the mold was carried out for 10 seconds under a pressure of80MPa. The mold was taken out after the squeezing step was completed. The squeezed composite material was left to cool inside the mold for a while, and the material was then removed from the mold and left to cool at the ambient temperature. This way, prismatic composite samples were created with dimensions of 110 mm x 140 mm x 25 mm.

For each reinforcement ratio, 3 samples were cast with the EN AW 5754/SiCp composite materials that were produced with the semi-solid stirring method. To compare the properties of the composites that were

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produced to those of the matrix alloy, unreinforced matrix alloy samples were produced under the same conditions to form the control samples [21].

D. Wear Experiment

In the wear experiment, the dry sliding wear behaviors of the EN AW 5754/SiCp composite samples produced at different reinforcement ratios were examined under a force of 1.0 N, with 5000 cycles and with a sliding speed of 0.04 m/s (Figure 1). The wear tests were conducted at an ambient temperature of 24 °C. The samples that were used for the test had dimensions of 20 mm x 20 mm x 10 mm. An alumina sphere with a diameter of 10 mm was used in the experiment.

Figure 1. Wear experiment setup

5XXX series aluminum alloys are alloys that cannot be subjected to thermal treatment and do not show precipitation hardening. They are known as relatively softer alloys. Despite this, their wear performance is very high [14].

III. RESULTS AND DISCUSSION

In this study, the EN AW 5754 aluminum alloy was especially selected as the matrix material due to its prevalent usage in the industrial field. Composites were obtained by stirring the SiCp material that was used as the reinforcement material into the aluminum alloy that was in a semi-solid state. Changes in the wear behaviors and friction coefficients of the sample materials that were produced at reinforcement ratios of 0%, 5%, 10%, 15% and 20% were examined under a force of 1.0 N.

A. Specific Weight and Porosity Measurement Results

The densities of the composite samples that were produced by SiCp particle reinforcement were measured based on the Archimedes principle. The changes in the theoretical and experimental specific weights and porosity values of the samples based on their reinforcement ratios are presented in Table 3.

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Table 3. Theoretical and experimental specific weights and porosities of samples

Material	*%SiCp (by volume)*	*Theoretical Specific Weight (g/cm³)*	*Experimental Specific Weight (g/cm³)*	*% Porosity*
100% AA5754	-	2.66	2.62	1.5
5% SiCp - 95% AA5754	5	2.69	2.65	1.2
10% SiCp - 90% AA5754	10	2.71	2.68	1.1
15% SiCp - 85% AA5754	15	2.74	2.72	0.8
20% SiCp - 80% AA5754	20	2.77	2.74	1.2

According to the porosity rates given in Table 3 obtained after the squeeze casting process based on the reinforcement ratios that were used; the highest porosity ratio was found as 1.5% in the unreinforced material (0% reinforcement). The porosity ratios of the 5%, 10% and 20% reinforced samples were close to each other.

B. Wear Experiment

Figure 2 displays the change in the friction coefficient of the EN AW 5754/SiCp composites based on their reinforcement ratios. A force of 1 N was applied onto the composite materials that were used in the experiments.

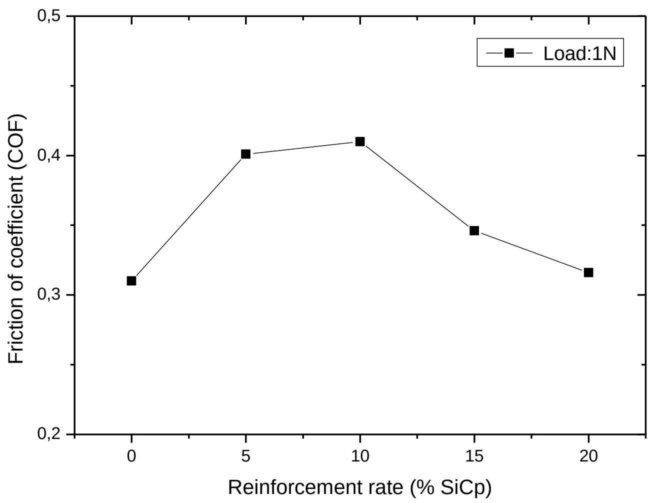

Figure 2. Change in the friction coefficient of the EN AW 5754/SiCp composite based on the reinforcement ratio.

As seen in Figure 2, there was an increase in the friction coefficient up to the reinforcement ratio of 10% SiCp, but this coefficient decreased at the reinforcement ratios of 15% and 20%. While it was expected that the highest friction coefficient would be seen in the unreinforced (0% reinforcement) material, it was found in the 5% and 10% SiCp-reinforced composite materials. As seen in the SEM images in Figure 4, this result may be explained by that the 5% and 10% SiCp reinforcements were not distributed homogeneously in the matrix, while the 15% and 20% reinforcements were homogeneously distributed. Moreover, the finding of the highest friction coefficient in the 5% and 10% SiCp-reinforced composite materials may have been caused by the damage forming on the sample surface during wear.

As seen in Figure 3, the amount of wear increased up to the reinforcement ratio of 10%, it decreased in the 15% reinforced samples and increased again in the 20% reinforced samples. Although the particle size is small, as the particle density increases, the amount of SiCp that the material contacts increases and wear becomes more difficult. Şimşek et al. produced samples by adding 5%, 10%, 15% and 20% SiCp reinforcement into the A356 matrix and subjected the samples to wear tests at 0.2 m/s, under a 15 N load and at a distance of 1500 m. As a result of the wear tests, as the reinforcement ratio increased, the number of particles that were lost from the surface of the sample decreased, and this way, weight loss decreased at higher reinforcement ratios. In the same study, under the same load and for the same sliding distance, the lowest friction coefficient was obtained in the 20% SiCp-reinforced sample [23]. Figure 3 displays the change in the wear amounts of the EN AW 5754/SiCp composites based on their reinforcement ratios.

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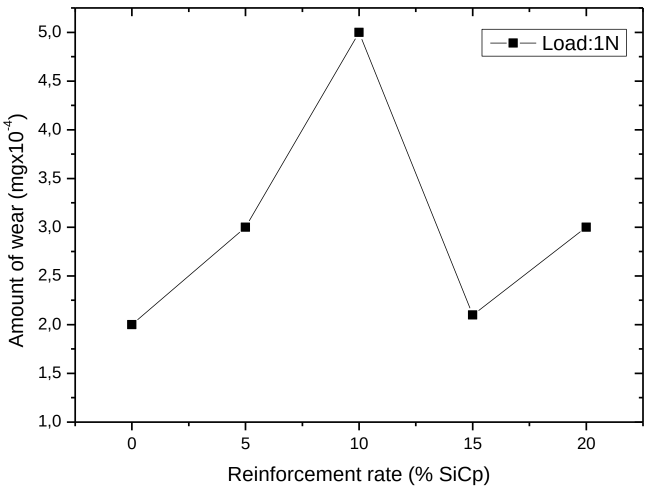
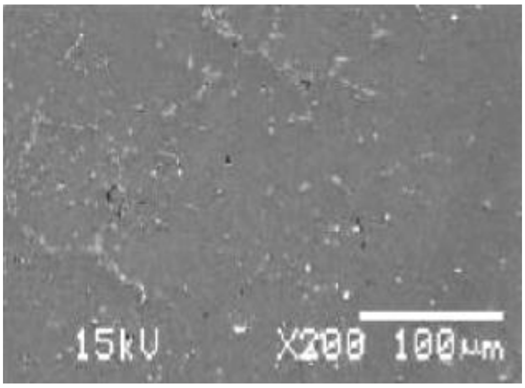


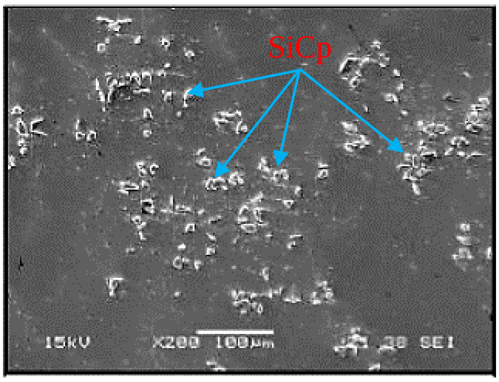
Figure 3. Change in the wear amounts of the EN AW 5754/SiCp composites based on their reinforcement ratios.

C. Microstructure examinations

The microstructural properties of the samples were examined using aJOEL brand JSM-6060 model SEM device. The SEM analysis results shown in Figure 4 demonstrate that the SiCp particles in the composite materials that were obtained in this experimental study were homogeneously distributed within the matrix. The fact that pressure was applied during the production of the samples allowed obtaining a lower porosity rate and close results to the theoretical density. The fact that the volumetric reinforcement ratio increased in the material that was produced with the squeeze casting method did not lead to an increase in porosity. This situation is clearly presented in Table 3. Whether or not homogeneous distribution was achieved in the prepared experimental samples and whether or not porosity and internal structure defects formed were checked by using an optical laboratory microscope and an SEM device with a semi-quantitative elemental analysis system. As a result of the examinations that were made, it was observed that the SiCp particles were homogeneously distributed inside the EN AW 5754 aluminum alloy.



a) AA5754/SiCp composite (vol 0%, x200)



b) AA5754/ SiCp composite (vol 5%, x200)

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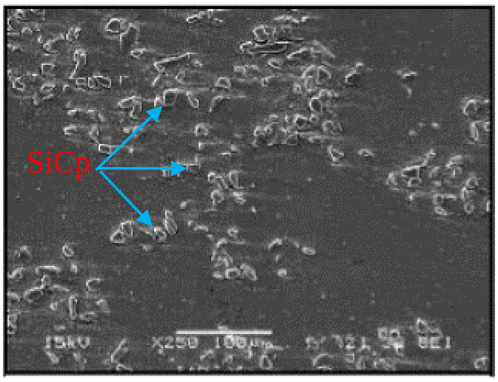
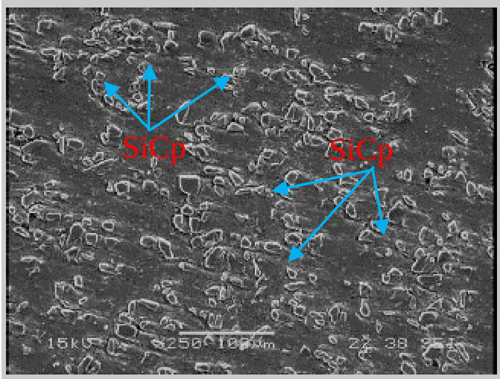
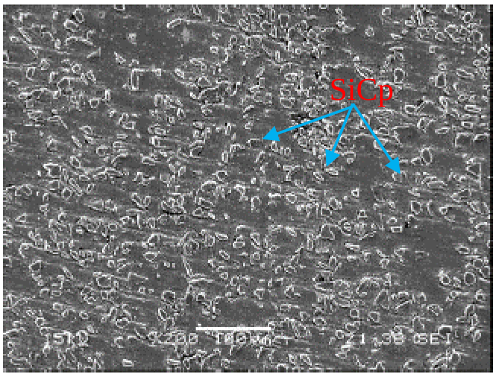


c) AA5754/SiCp composite (vol 10%, x250)

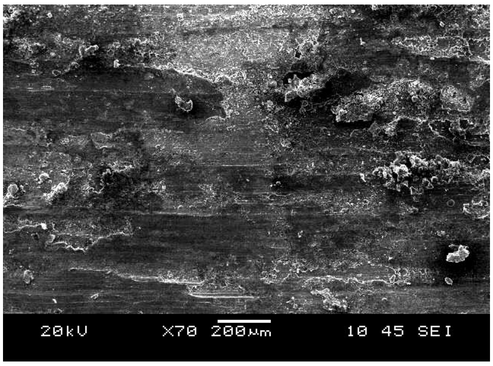


d) AA5754/SiCp composite (vol 15%, x250)

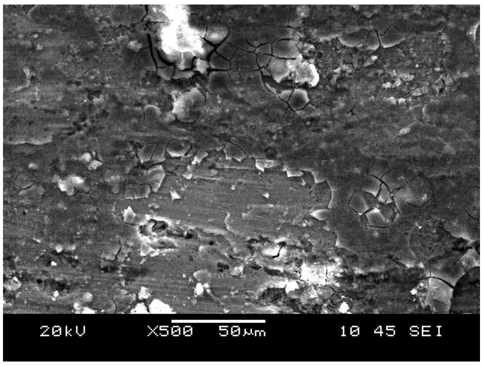


e) AA5754/SiCp composite (vol 20%, x200)

Figure 4. SEM images of EN AW 5754/SiCp composite surfaces before wear test.



a.



b.

Figure 5. SEM images of unreinforced EN AW 5754 alloy surfaces after wear test a, b.

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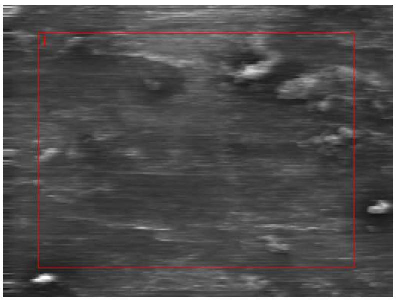
Elt	Line	İntensity (c/s)	Error (2-sig)	Conc		
C	Ka	2.12	0.291	10.199	Wt.%	
O	Ka	14.16	0.752	12.237	Wt.%	
Mg	Ka	16.85	0.821	2.366	Wt.%	
Al	Ka	509.94	4.516	75.100	Wt.%	
Si	Ka	0.28	0.105	0.097	Wt.%	
				100.000	Wt.%	Total

kV	20.0
Takeoff Angle	35.0º
Elapsed Livetime	100.0



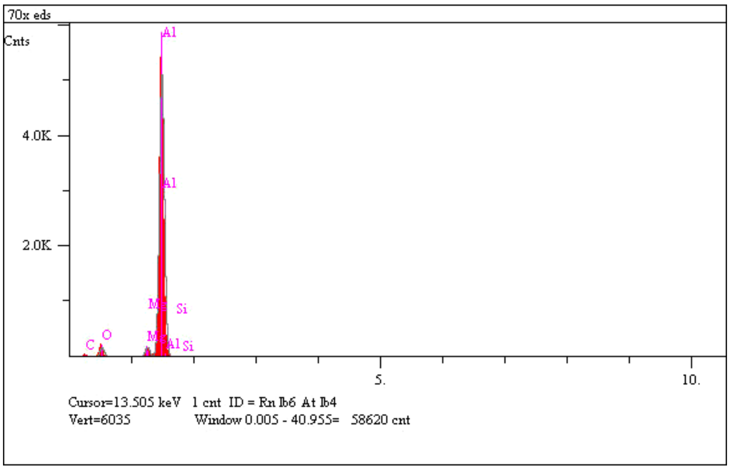
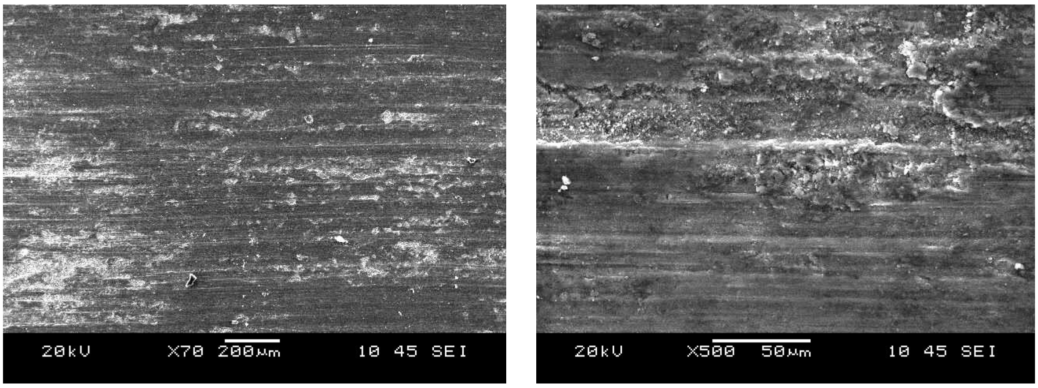


Figure 6. EDS analysis of unreinforced EN AW 5754 alloy after wear test.

The SEM images and EDS images of the surfaces of the unreinforced EN AW 5754 alloy after the wear test under 1 N of force are shown respectively in Figures 5 and 6.



a. b.

Figure 7. SEM images of 20% reinforced EN AW 5754/SiCp composites after wear test a, b.

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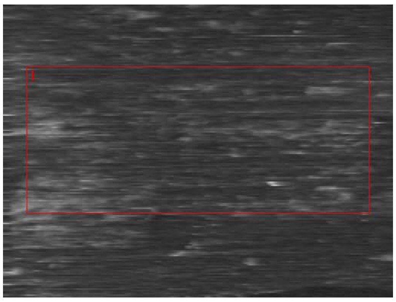
Elt	Line	İntensity (c/s)	Error (2-sig)	Conc		
C	Ka	1.27	0.225	6.995	Wt.%	
O	Ka	14.01	0.749	12.288	Wt.%	
Mg	Ka	12.32	0.702	1.728	Wt.%	
Al	Ka	386.66	3.933	54,970	Wt.%	
Si	Ka	85.84	1.853	24.019	Wt.%	
				100.000	Wt.%	Total

kV	20.0
Takeoff Angle	35.0º
Elapsed Livetime	100.0



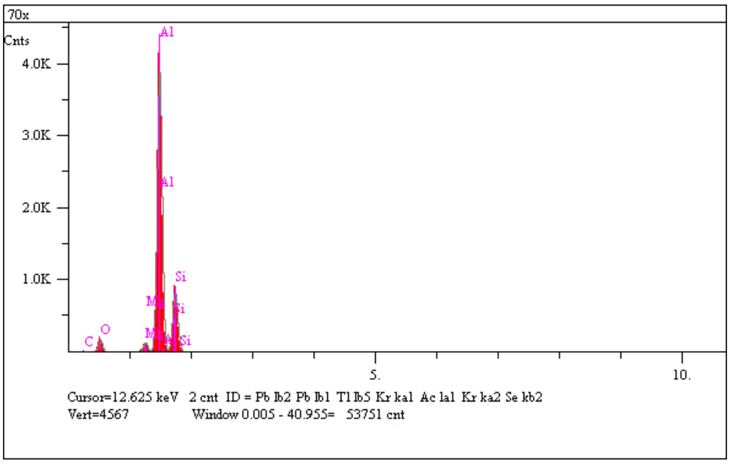


Figure 8. EDS analysis of 20% reinforced EN AW 5754/SiCp composites after wear test

The SEM images and EDS images of the surfaces of the 20% reinforced EN AW 5754/SiCp composites after the wear test under 1 N of force are shown respectively in Figures 7 and 8. The SEM images in Figure 7demonstrate that new surfaces formed with the effect of the force that was applied.

IV. CONCLUSION

In this experimental study, according to the SEM images, the SiCp particles used as the reinforcement material were surrounded well by the matrix material in the composites produced with different reinforcement ratios using the squeeze casting method, and a mechanical bond was formed between the matrix and the reinforcement. Moreover, the examinations showed that the 5% and 10% SiCp reinforcements did not show a homogeneous distribution inside the matrix, while the 15% and 20% SiCp reinforcements were homogeneously distributed in the matrix.

After the wear experiments, it was observed that the friction coefficient increased from the unreinforced alloy to the 10% reinforced composite, while it decreased in the 15% and 20% reinforced composites. Although it was expected that the highest friction coefficient would be found in the unreinforced (0% SiCp reinforcement) material, it was found in the 5% and 10% SiCp-reinforced composite materials.

The amount of wear increased as the reinforcement ratio increased up to 10%, the highest wear amounts were observed in the 10% SiCp-reinforced composite, these amounts decreased in the 15% SiCp-reinforced composite and increased again in the 20% reinforced composite.

In the examinations of the porosity ratios based on the reinforcement ratios, it was observed that both the porosity ratios and the wear amounts in the 5% and 20% reinforced composites were similar to each other. While the porosity ratios of the 5%, 10% and 20% reinforced composites were similar to each other, the 10% reinforced composite had the highest values of both wear and friction coefficient. It was seen that the 15% reinforced composite had the lowest porosity ratio, and in parallel with this, its wear amount was also low.

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