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INVESTIGATION OF MICROSTRUCTURE, HARDNESS AND WEAR BEHAVIOR OF POWDER METAL AL 7020 / SIC / NANO GRAPHENE DOPED HYBRID COMPOSITES

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ABSTRACT

Al 7020 aluminum alloy is mainly preferred in many engineering applications, especially in the aviation and space sectors. Nano graphene (Gr) particles were selected for the study due to their hybrid composite structure, microstructure, mechanical properties, lubrication properties, lightness, and small size compared to the matrix and reinforcement element. For this purpose, SiC and nanographene powder particles were added to the aluminum matrix as reinforcement phases in the study, and composite-hybrid test samples were produced. In the production of Al7020 powder metal matrix SiC/nanographene doped test samples, 10% SiC ceramic phase reinforcement by weight was applied to the matrix material at a fixed rate, and nanographene particle reinforcement was added at the rates of 0.25%, 0.50%, and 1.0%. The prepared matrix powder mixtures were mixed in a high-energy ball mill at 300 RPM and 240 minutes to ensure homogeneous distribution in terms of matrix/reinforcement. After mixing, the powder mixtures were compressed at room temperature using a pressing pressure of 650 MPa. The obtained raw density test samples were sintered at 600°C for 60 minutes under Argon gas flow. Thus, the effect of SiC-nano graphene reinforcement on density, microstructural, hardness, and wear (25N, 900m) results were evaluated. The pore amount increased in the samples containing reinforcement elements. The highest hardness value was 108.476 HBN in the sample containing Al-10%SiC-0.5%Gr.

Keywords: Al 7020, SiC, Nano graphene, Microstructure, Hardness, Wear.

1 INTRODUCTION

Aluminum matrix composites (AMC) are widely preferred in automotive, aviation, and defense industries due to their high strength/weight ratio, good wear resistance, and suitable mechanical properties [1–4]. In order to increase the performance of these composites, the formation of hybrid structures using different reinforcement elements has become quite interesting in recent years. In recent years, research on hybrid composite materials reinforced with ceramic particles has increased to improve the mechanical properties of aluminum alloys [5–9]. In this context, SiC particles are one of the most frequently preferred reinforcement materials due to their superior properties, such as high hardness, good wear resistance, and thermal stability [10,11].

However, nano-sized carbon-based reinforcements, especially graphene and graphene derivatives, are among the new-generation additive materials that are intensively studied to improve the mechanical and tribological properties of the material. Nanographene reinforcement improves the load transfer within the matrix material, thus significantly contributing to the increase in properties such as hardness, strength, and wear resistance [9]. Recent studies have reported that nanographene significantly increases aluminum matrix composites' mechanical and tribological performance, even in small amounts [12]. In addition, thanks to the low density and high specific surface area of nanographene, it is possible to ensure homogeneous distribution within the composite and to make the material performance more stable.

Al7020 aluminum alloy is an important alloy preferred in engineering applications due to its high strength, lightness, and workability [1,13]. However, the development of hybrid composites is critical to eliminate the weaknesses of pure alloys in some applications, such as insufficient wear resistance, limited hardness, and low performance at high temperatures [14,15]. In this direction, integrating SiC particles and nanographene additives into the Al7020 aluminum matrix can further improve the alloy's existing properties. These hybrid composites, which are expected to show more stable performance, especially under high-temperature conditions, are anticipated to provide significant advantages in advanced technology applications in the defence and aerospace sectors [16].

This study investigated the microstructure, hardness, and wear behavior of hybrid composites with reinforcements of 10% SiC and different ratios of nanographene particles in an Al7020 aluminum matrix. Studies were carried out on the production methods of the composites, ensuring a homogeneous distribution of reinforcement materials in the composite structure and increasing material performance. The material's phase formations and particle distribution were evaluated with the microstructure analysis of the composites, and the hardness obtained by mechanical tests and the wear resistance results determined by tribological tests were analyzed comparatively. The aim is to improve the mechanical and tribological properties of the Al7020 alloy and to ensure its more practical use in industrial applications. Thus, it aims to significantly contribute to the literature on developing aluminum-based hybrid composites.

2 MATERIAL AND METHOD

In this study, in order to examine the effectiveness of nanographene additives to Al 7020 matrix SiC/nanographene (Gr) particle additive hybrid composites, pre-alloyed 44 µm (325 mesh) and 99.9%+ purity Al 7020 metal matrix powders supplied by Nanografi Nanoteknoloji and produced by gas atomization method were used. The chemical composition of Al 7020 metal matrix alloy powders is given in Table 1.

Table 1. Chemical composition of Al 7020 material (%)

Element	Al	Zn	Mg	Ti	Cr	Mn	Fe	Si	Cu
Weight (%)	Bal.	4.67	1.34	0.3	0.29	0.48	0.09	0.02	0.01

Within the scope of composite-hybrid material production, SiC and Nano Graphene powder particles purchased from Nanografi Nanoteknoloji were used in experimental studies as reinforcement elements in the metal matrix. In the production of aluminum matrix composite-hybrid materials, 3 µm and 99.5%+ purity SiC powder and 3nm and 99.9%+ purity nano graphene powder were used in the study. The mixing ratios of matrix-reinforcement powder particles for the production of Al 7020 aluminum metal matrix test samples are given in Table 2. Matrix and reinforcement powder mixtures were prepared in proportions determined by precision scales and subjected to a mixing process focused on ensuring homogeneous distribution of matrix reinforcement with the help of a Thermnevo brand high-energy ball mill.

Table 2. Matrix and reinforcement starting powder mixing ratios (%)

Samples	Al 7020	Silicon Carbide	Nano grafen
A	100	-	-
AS	90	10	-
AS1	89.75	10	0.25
AS2	89.5	10	0.5
AS3	89	10	1

For this purpose, 300 rpm and 240 min. Mixing time was applied to the powder particles. The prepared powder mixtures were pressed under 650 MPa pressure using a Hidroliksan brand 60-ton single-axis press bench, and 12 mm diameter test samples were produced. Following the pressing process, the test samples were sintered for 60 minutes under argon gas flow at 600°C (Figure 1).

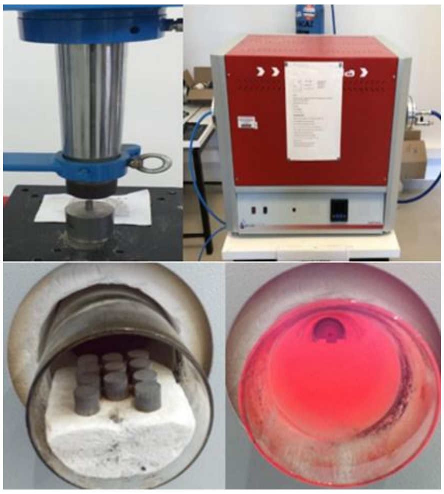

Figure 1. Pressing and sintering process.

The density measurement processes of composite-hybrid materials were carried out according to the Archimedes principle. A Hardway brand grinding and polishing device was used for microstructural characterization of the test samples after sintering and general metallographic studies. Then, 90% H_2O (Pure) and 10% HF solution were used for etching. As a result of the etching processes, microstructure examinations were obtained using the Hardway optical microscope and the Hitachi SEM device. Within the scope of hardness measurements, a 2.5 mm diameter ball tip was used under a 33.8 kgf load (10s) with the Brinell hardness (ASTM E10) measurement technique.

For the wear test (Figure 2), a Turkyus brand wear bench was used (block-on disk) application, AISI 4140 steel counter abrasive, 50 mm diameter and 65 HRC hardness value was included in the study. In the wear tests, weight loss was weighed on a scale with a precision of 1/10000 gr. Wear tests were conducted under a 25N load, a 0.5 ms-1 sliding speed, and a 0-900 m sliding distance.

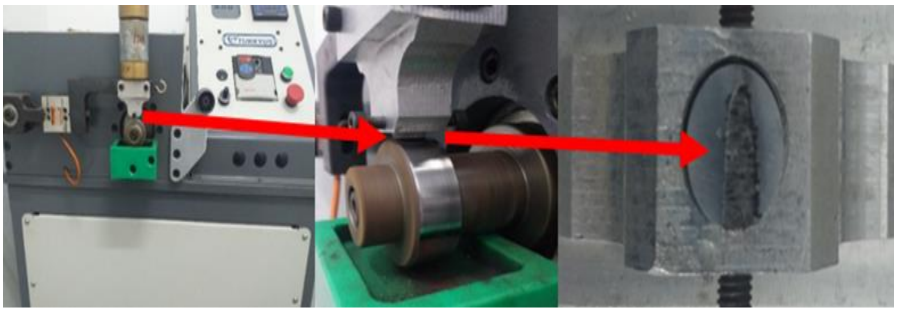

Figure 2. Block-on disc wear process.

3 RESULTS AND DISCUSSIONS

The initial matrix and reinforcement particles used to produce hybrid test samples reinforced with Al 7020 aluminum metal matrix SiC/Nano graphene particles are shown in Figure 3. When the SEM microstructure images are evaluated, it can be seen that the 7020 aluminum matrix powder particles are in spherical shape and morphology (Figure 3-a). Regarding powder distribution, satellite formation is more prevalent in small powder particles that come into contact with larger particles. In terms of reinforcement elements, it can be seen that the SiC ceramic phase particles are polygonal or mostly pointed and sharp-cornered in shape and morphology (Figure 3-b). It can be seen that the nanographene reinforcement powder particles have irregular shapes and morphology and exhibit flat flake morphology (Figure 3-c).

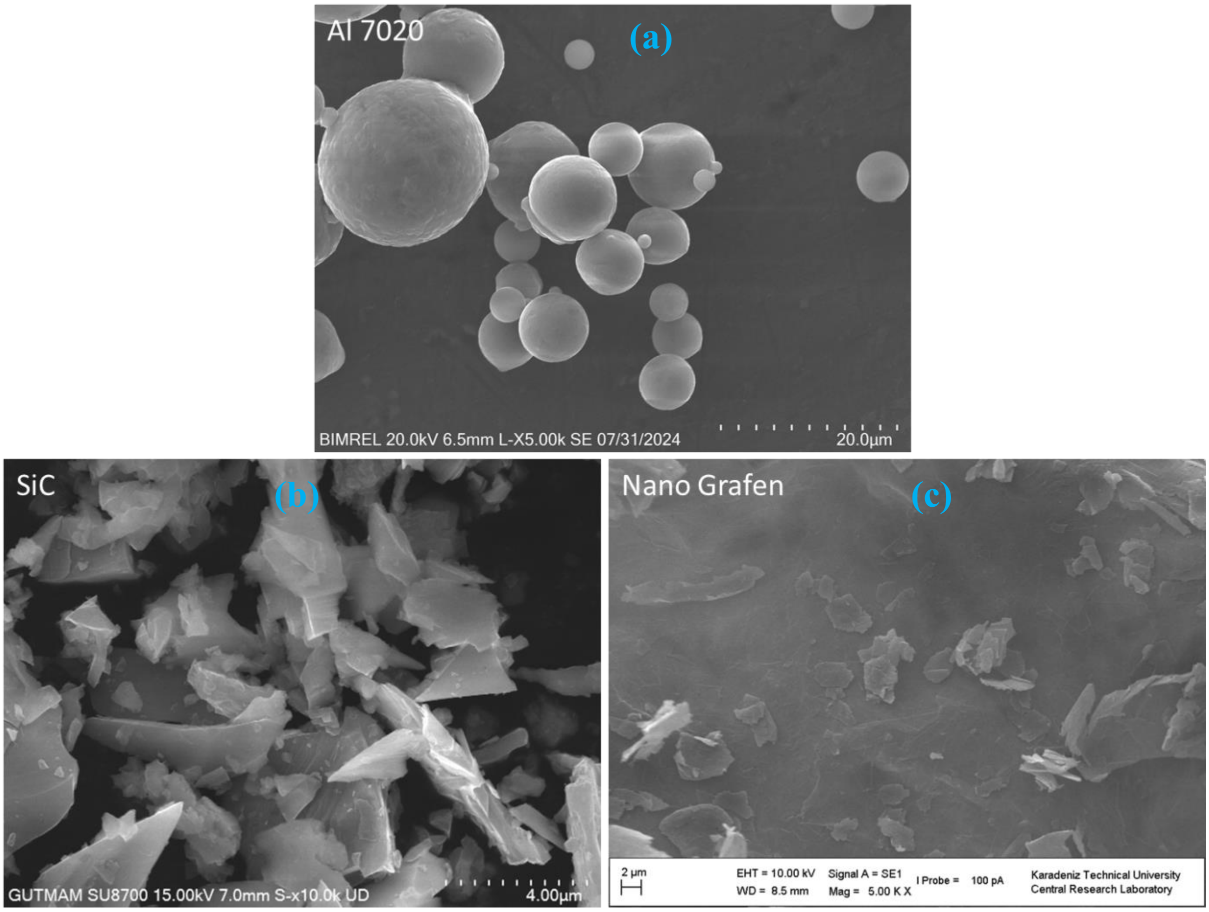

Figure 3. SEM images of matrix and reinforcement elements; a) Al 7020, b) SiC and c) Gr.

After sintering, the relative density values of the test samples were measured (Figure 4). When this density is considered primarily as a relative (%) density value, when the density results obtained due to the sintering process of the samples produced under reinforcement ratio differences of composite-hybrid materials are examined, it can be seen that there is a decrease in the density results after sintering. This situation can be stated as the clustering or agglomeration of the reinforcement element SiC/Nano graphene particles, especially along the grain boundaries. It can be seen that there are significant decreases in the density, especially after the increase in the amount of nanographene particles. In the literature, it is noteworthy that in the majority of the studies containing powder metal composites and especially hybrid materials produced with the powder metallurgy technique, there is a decrease in the density values of composite-hybrid materials due to the increase in the reinforcement phase ratios [15,17]. Again, it is known that there is a relationship between pressing pressure and pore structure in terms of materials produced using the powder metallurgy technique. Therefore, due to this situation, the cold pressing process can directly affect the grain structure-pore interaction [18].

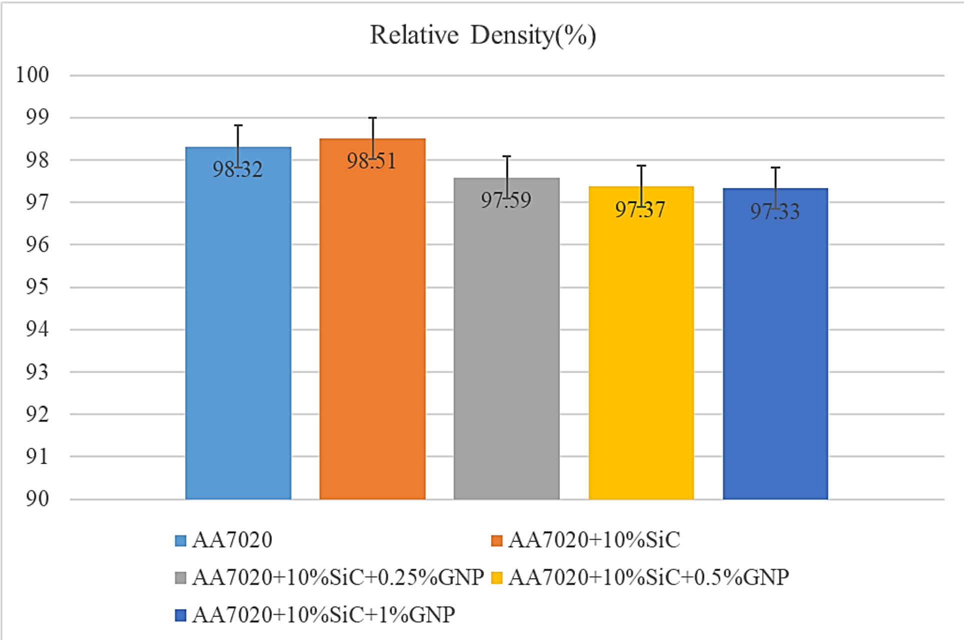

Figure 4. Density results of test samples.

The distribution of reinforcement particles SiC/Nano graphene and the amounts of reinforcement within the structure can directly trigger the decrease in the density value. The highest relative density value was obtained in the composite material with 10% SiC reinforcement with 98.51% compared to the Al7020 aluminum metal matrix structure. The lowest relative density value was obtained in the Al+10%SiC+1%Gr content test sample with 93.33%. The optical and SEM microstructure images of the Al7020 aluminum metal matrix SiC and Nano graphene particle reinforced composite-hybrid test samples following the pressing and sintering processes are shown in Figures 5 and 6, respectively. When the optical microstructure images given in Figure 5 are examined, it can be stated that the reinforcement particles tend to concentrate at the grain boundaries in the reinforced composite and hybrid test samples compared to the Al 7020 aluminum alloy metal matrix structure (Figure 5a) (Figure 5b-e). It can be stated that SiC ceramic phase particles especially exhibit a distribution in the grain boundaries and near the grain boundary regions and have a sharp-cornered and polygonal shape morphology (Figure 6b, e)

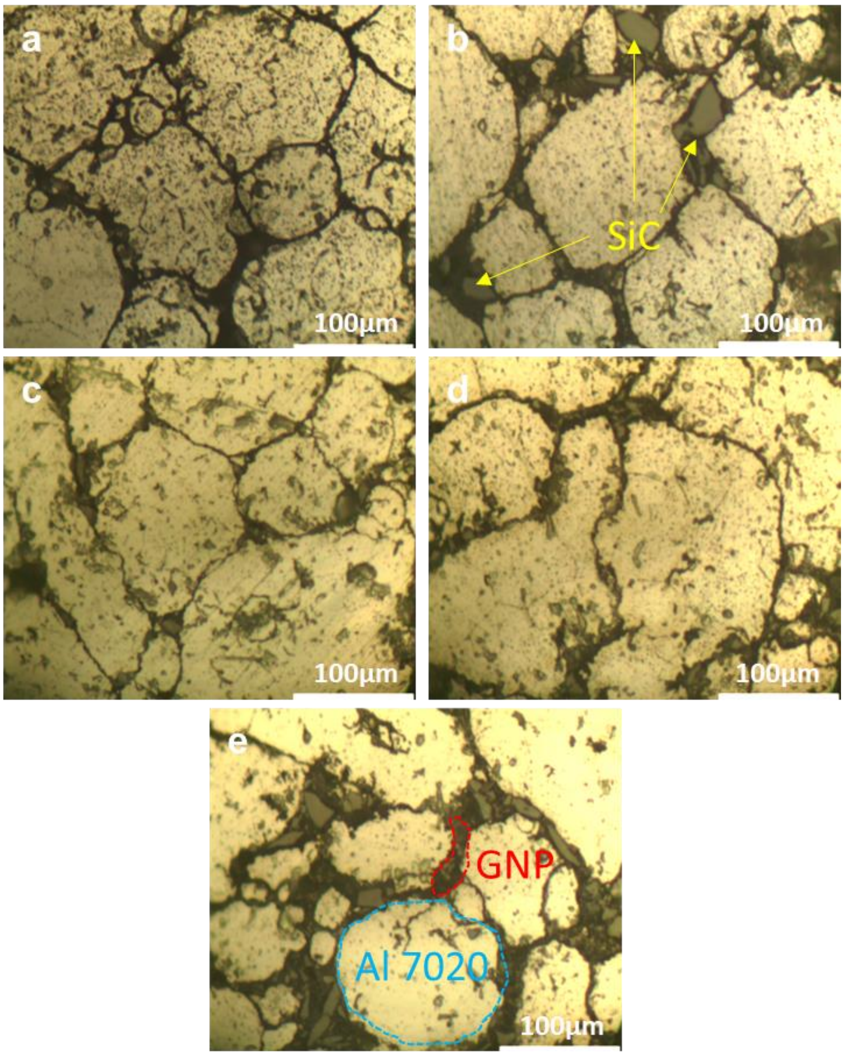

Figure 5. Optical microstructure images of test samples; a) A, b) AS, c) AS1, d) AS2 and e) AS3.

When the SEM microstructure images given in Figure 6 are examined, it can be said that the distribution and conditions of the SiC particles, which are primarily dark and grayish and also have sharp corners-polygonal shape morphology, are located in the grain boundary and areas close to the grain boundary, and the nanographene particles, which are dark black in appearance, are densely clustered in the neighborhood and at the ends of the SiC particles. Figure 7 shows the EDS analysis and elemental distribution mapping obtained from the SEM image of the experimental sample produced with Al7020+10%SiC+0.50% nanographene content.

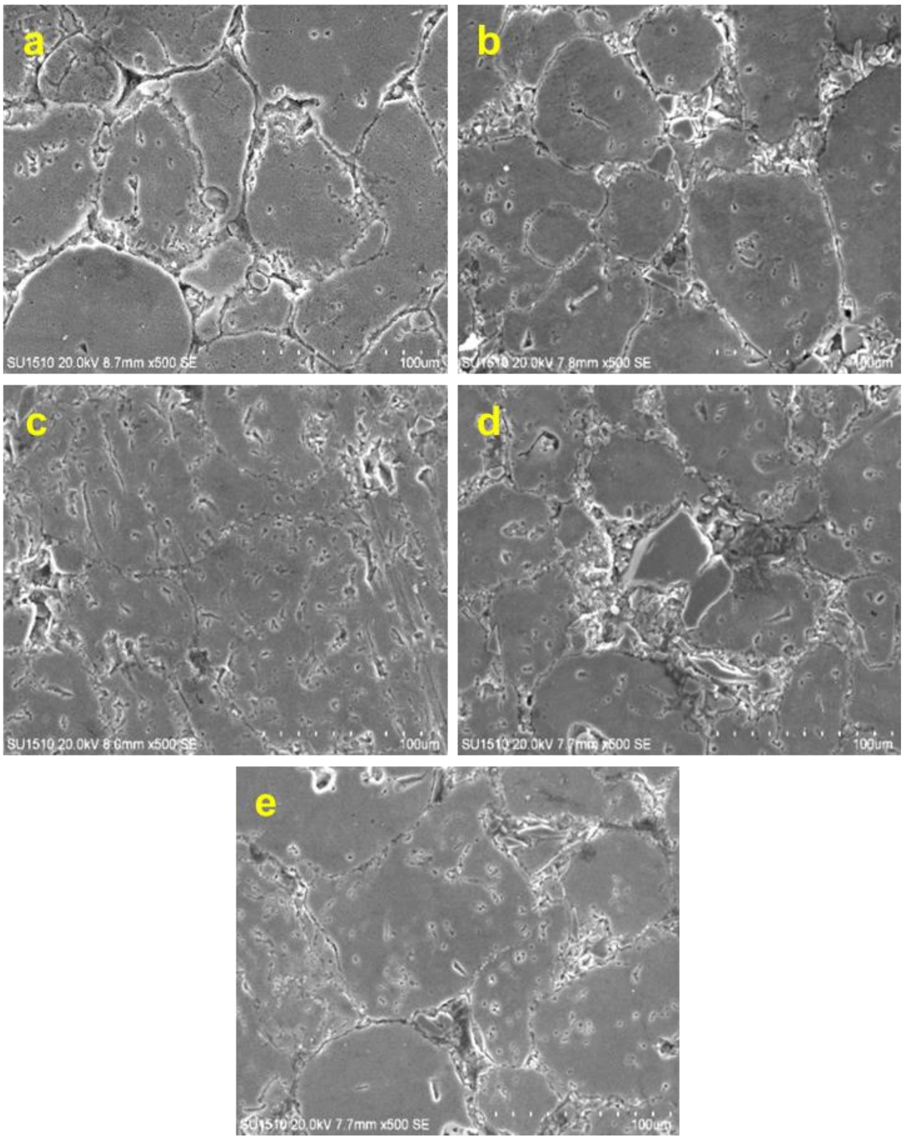

Figure 6. SEM images of test samples; a) A, b) AS, c) AS1, d) AS2 and e) AS3.

The general EDS analysis applied to the sample with Al7020-10% SiC-0.50% nanographene content was obtained depending on the alloy elements and reinforcement contents in the hybrid structure in Al7020 (Al, Zn, Cu, Mg, Si, C). According to the elemental mapping result, it is thought that the nanographene particles exhibit clustering with the agglomeration effect at the ends of the SiC powders.

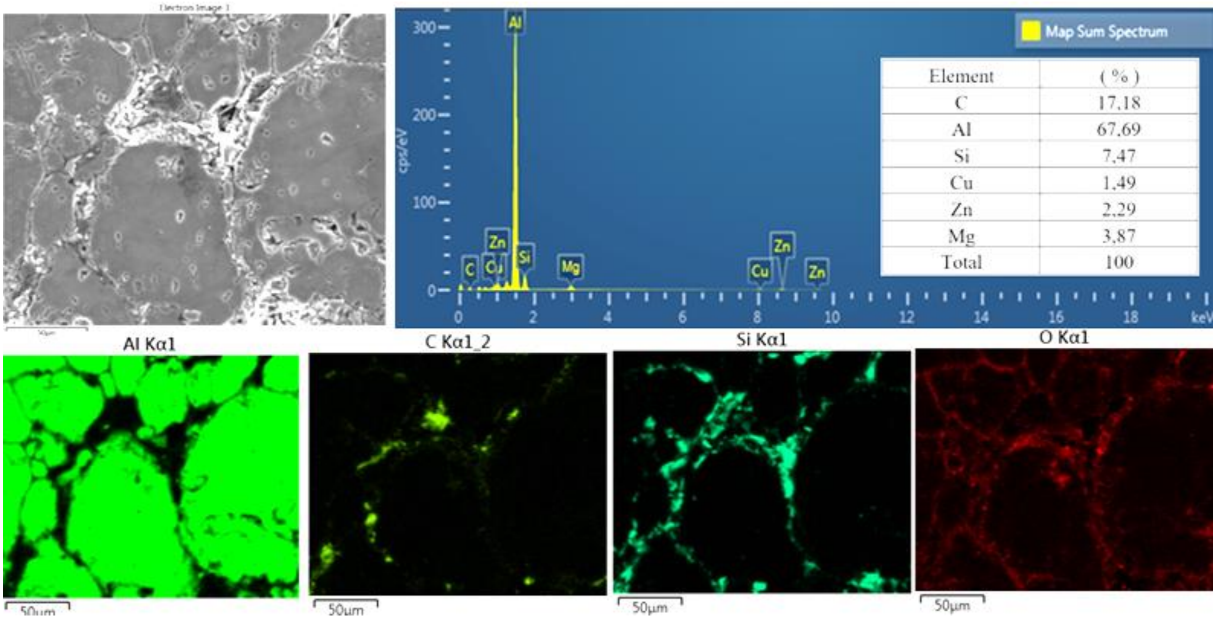

Figure 7. EDS analysis and elemental mapping of Al7020+10%SiC+0.5% nanographene.

The hardness results obtained from microstructure examinations of Al7020 aluminum metal matrix and reinforced hybrid test samples produced without using reinforcement elements are given in Figure 8. The hardness value of unreinforced Al7020 aluminum powder metal alloy was determined as 75.7 HBN. In addition, when 10% SiC was added as a reinforcement element, the hardness value was measured as 103.287 HBN, with an increase of 27.587%. This situation can be expressed as the higher hardness value of SiC ceramic particles in the reinforcement phase compared to the aluminum matrix and, therefore, the high hardness value. The hardness value of the reinforced sample containing 0.25% nanographene was observed as 108.476 HBN with an increase of 5.18% compared to the sample containing SiC as 10% reinforcement ceramic particle phase, and the highest hardness measurement result was observed as 108.476 HBN. According to these data, as the amount of SiC and nanographene reinforcement increases compared to Al7020 aluminum powder metal alloy, a significant increase in the hardness result was measured in the composite-hybrid material structure, and an improvement in mechanical properties was achieved. However, it was determined that the nanographene reinforcement particles added to the structure after a specific rate decreased the hardness result.

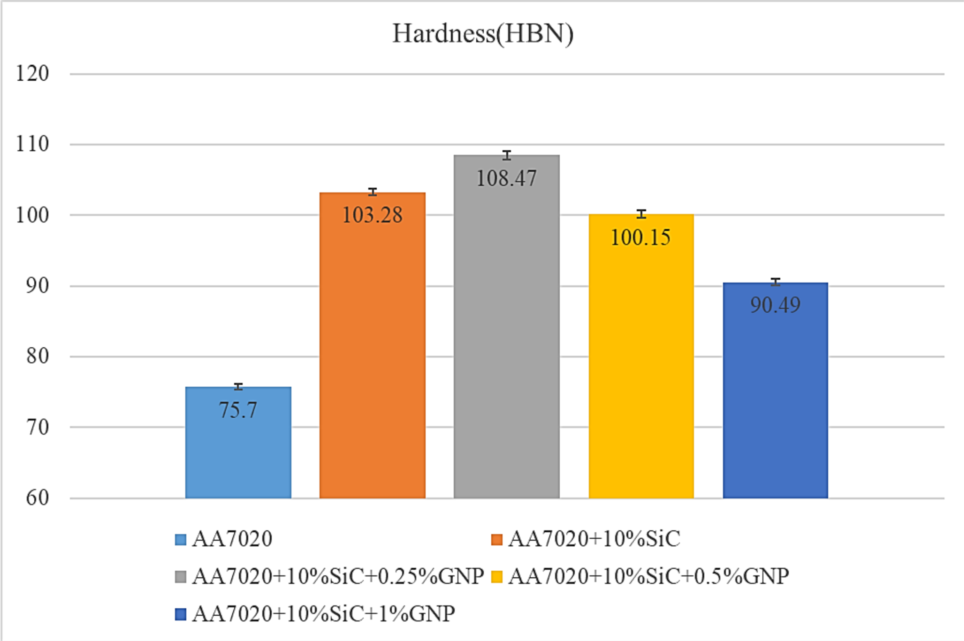

Figure 8. Hardness results of test samples.

The weight loss results of composite materials with different amounts of SiC and nanographene reinforcement added to Al7020 aluminum powder metal alloy are shown in Figure 9. When the wear weight loss results are examined, it is revealed that the highest weight loss occurs in Al7020 powder metal aluminum alloy. Wear tests have revealed that composite-hybrid materials exhibit consistently lower wear rates than the matrix alloy. In terms of wear weight loss results, it is generally understood that there is a decrease in weight loss values depending on the increasing amount of SiC and nanographene reinforcement. In terms of wear, this situation can be stated as an expected result: the weight loss value is low in the material with a high hardness result, and the weight loss is high in the material with a low hardness result [19,20]. The wear loss results of the test samples generally increase with increasing sliding distance. However, it is also noteworthy that there are sudden and high increases in the wear degrees of hybrid composites. This situation can be considered to occur because large particles break off from the material surface and areas close to the surface during the wear process, which causes the amount or degree of wear to increase after weight loss. Özyürek et al. [21] stated in their study that there was an increase in weight loss that occurred in the progressive wear distances in the composite materials they produced by using SiC reinforcement in the Al matrix. They emphasized that this result was due to the large particles breaking off from the sample during the wear process. In a study conducted on Al 6061/B4C/GNP hybrid composites, the highest value was obtained at 7% reinforcement instead of 10%. It was stated that there may be a decrease in hardness after a certain value. Similarly, with the increase in the nanographene ratio from 0.5% to 2.0%, a decrease in hardness values was explained. Since graphite, which shows a soft distribution, does not contribute positively to the hardness of the composite, a decrease in hardness value can be expected. Along with the lubricating effect of graphene, its softening feature on the composite structure can be considered [22]. When the studies conducted are evaluated in general, hardness and wear resistance increase depending on the increasing reinforcement ratio in composite structures. In addition to this situation, the use of solid lubricants and hybrid composites may also show lower performance, especially at increased wear distances.

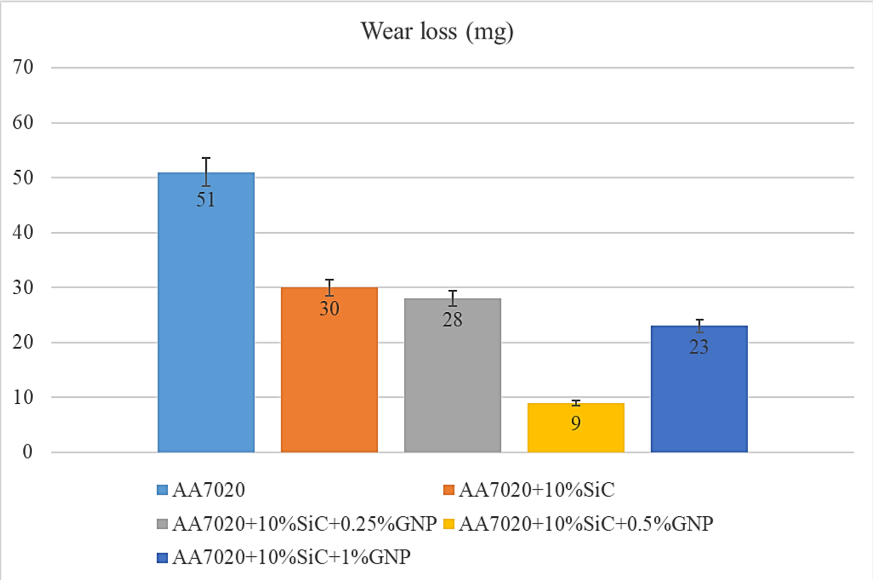

Figure 9. Wear loss results.

The friction coefficient results of the test samples, which completed the wear tests depending on the sliding distance of 900 meters, are shown in Figure 10. When the friction coefficient results are examined, the highest friction coefficient value was found in the Al 7020 powder metal alloy. In their study, Harichandran et al. stated that while the friction coefficient of the Al alloy without reinforcement was higher than the composite materials containing reinforcement, the friction coefficient decreased with the increase in the weight percentage of the reinforcement element [23].

It was determined that the SiC and nanographene additions to the Al 7020 powder metal matrix decreased the friction coefficient value. At the same time, it was observed that the resistance to friction increased in these test samples. It can be stated that the friction coefficient values obtained differ depending on the hardness values of the produced test samples. Özyürek et al. stated that the friction coefficient values decreased as the hardness results of aluminum and its alloys increased [24]. The resulting hardness result and friction coefficient values were also obtained in a way that confirms this situation.

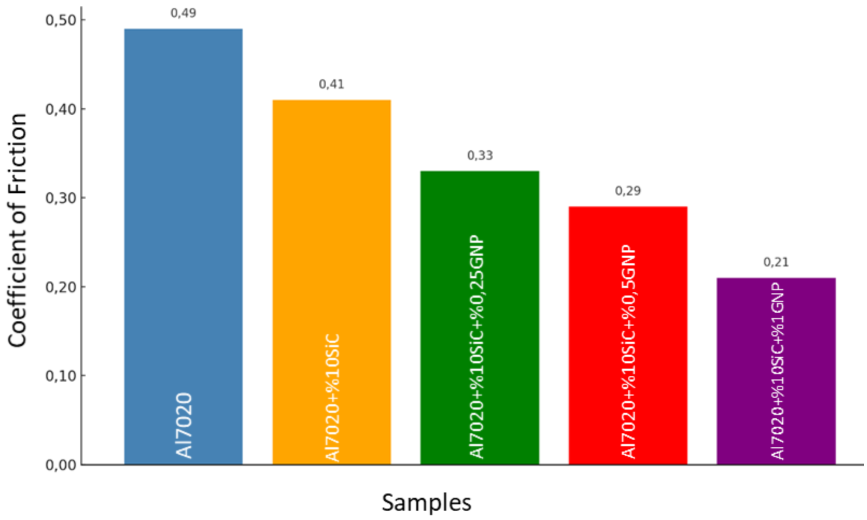

Figure 10. Friction coefficient results at 900 m sliding distance.

SEM analysis images of hybrid composites reinforced with Al 7020 matrix alloy and different ratios of SiC and nanographene particles are given in Figure 11. When the SEM microstructure images were examined, deep and distinct wear marks, grooves, wear particles, and plastic deformation-induced material accumulations were detected on the surface of the Al 7020 alloy without reinforcement. In composites reinforced with 10% SiC, it was observed that the depth and density of wear marks decreased slightly, but distinct scratches and rupture-induced particles still formed on the surface. On the other hand, it was determined that the wear marks on the surface were lighter in composites reinforced with SiC and low ratios of nanographene (0.25% and 0.5%), and plastic deformation and breakage from the material surface were significantly reduced [25]. Especially in the sample containing 1% nanographene reinforcement, the wear surface was smoother, more homogeneous, and consisted of relatively shallower marks, and the signs of material loss were at the lowest level. This situation reveals that nanographene particles reduce friction and distribute the load more effectively in the matrix [26]. As a result, it is clearly understood that the tribological performance of Al 7020/SiC composites is significantly improved by increasing the ratio of nanographene reinforcement, thus increasing the material's wear resistance.

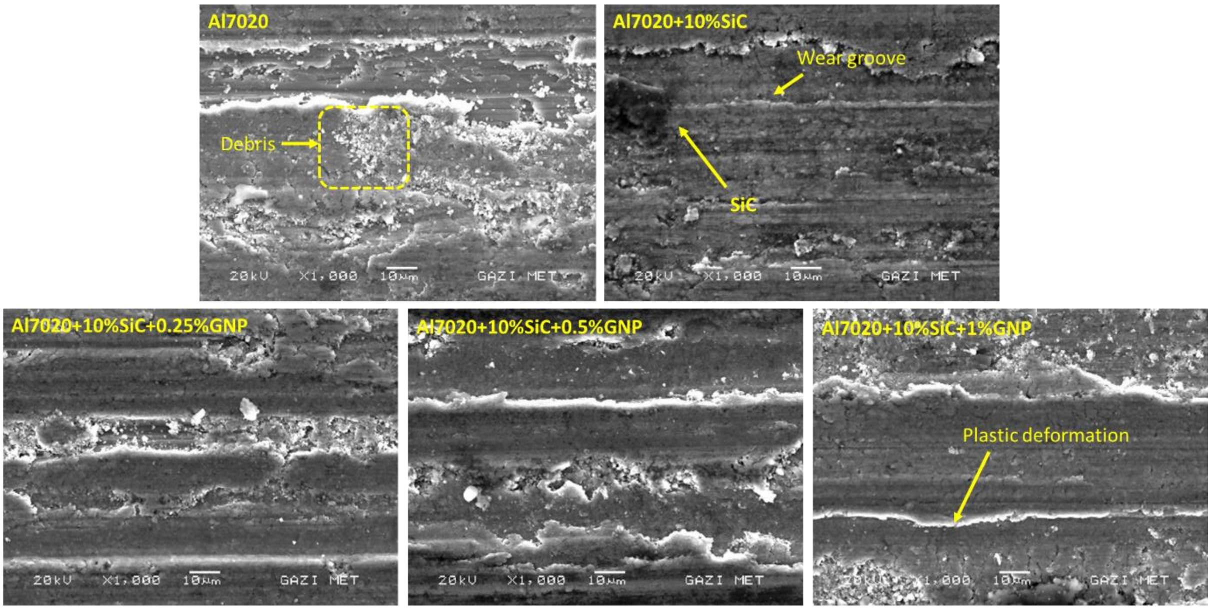

Figure 11. SEM images after wear test.

4 CONCLUSIONS

This study on the production processes of Al7020/SiC/nanographene hybrid composite materials yielded significant findings. The key results can be summarized as follows:

The novelty of these findings in the field of materials science and engineering (within the scope of new generation reinforcement materials such as nanographene and hybrid composite material applications) is intriguing and should pique the interest of the audience. In reinforced composite-hybrid samples, compared to Al7020 powder metal alloy, it was determined that SiC/nanographene exhibited a high tendency to cluster or agglomerate in the grain boundary regions in terms of pore-grain structure interaction and caused a decrease in the density value. The lowest relative density value was obtained as 93.33% in the Al-10%SiC-1%Gr content experimental sample. In terms of microstructural characterization, it was determined that dark black polygonal and sharp-cornered SiC powder particles and nanographene particles were clustered by agglomeration. The highest hardness value among the experimental samples was obtained as 108.476 HBN in the hybrid composite material containing Al+10%SiC+0.25%Gr. In terms of weight loss results with constant wear sliding distance, it was determined that there was a decrease in weight loss values depending on the increasing amount of SiC and nanographene reinforcement. It was determined that SiC and nanographene additions to the Al7020 powder metal matrix reduced the friction coefficient value. It was observed that wear marks on the surface were less frequent, plastic deformation and detachment from the material surface were less common in composites with nano graphene reinforcement. In hybrid composite materials, it has been observed that the reinforcement particles exhibit agglomeration after a certain value, and porous regions are formed accordingly. In fact, this agglomeration may be the reason why highest wear resistance does not occur in composites with 1% graphene added. It was determined that the tribological performance of Al7020/SiC composites improved significantly by increasing to a certain value ratio of nanographene reinforcement, thus increasing the material's wear resistance.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

Artificial Intelligence (AI) Contribution Statement

This manuscript was entirely written, edited, analyzed, and prepared without the assistance of any artificial intelligence (AI) tools. All content, including text, data analysis, and figures, was solely generated by the authors.

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