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Powder Metal Composite-Hybrid Material: A Study on Microstructure and Hardness Property

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ABSTRACT : *The demand for light engineering materials in industrial applications is constantly increasing. Among metallic materials used as construction materials, aluminum alloys are preferred materials in industrial applications due to their low density. In this context, besides aluminum matrix composite materials, hybrid composites are a type of engineering materials in which two or more different reinforcement elements are combined to take advantage of their good properties. In material design, hybrid structures offer many possibilities in a wide range of fields. In this study, AA7075 aluminum alloy matrix structure was reinforced with SiC and Al2O3 ceramic phase materials and composite-hybrid test samples were produced by powder metallurgy method. After pressing and sintering processes, composite-hybrid test samples were examined in terms of density, microstructure characterization, and hardness properties.*

KEYWORDS *AA7075, SiC, Al2O3, Hybrid, Composites, Microstructure, Hardness*

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I. INTRODUCTION

Simply, powder metallurgy (P/M) is the process of converting metal, alloy, or ceramic, which are in solid and powder form and whose average grain size is less than 150 µm, to a form whose shape and properties are predetermined [1]. In order to meet the changing needs of the developing world, different methods have been introduced by many scientists. The powder metallurgy method is the most important of these. Starting from prehistoric times, it has undergone many changes and developments to the present day. In many parts of the world, metal powders began to be used in prehistoric times. In 3000 BC, the Egyptians made iron tools by using the powder metallurgy method [2]. Powder metallurgy entered our modern era with Edison making a lamp filament from tungsten powders. In 1930s, cemented carbides, porous bronze, and copper-graphite were produced as electric conductors.

After the Second World War, the use of the powder metallurgy method gained momentum. Today, powder metallurgy is applied in many fields such as nuclear, aircraft, aerospace industry, electric, and magnetic [3]. 70% of the products produced by the powder metallurgy method are used in the automotive sector, 12% in machines, 5% in agricultural tools, and 13% in the production of other modern tools [4]. It is also used in the production of electronic parts, cutting tools, implants used in the health field, and high-tech composites used in the aircraft industry, etc.

Developing technology has brought a different perspective to modern engineering problems. Traditional materials and manufacturing methods have been replaced by new materials and unconventional manufacturing methods. In addition to reviewing material selection according to the working environment, attempts are performed to make these materials more favorable in production methods. Therefore, composite materials continue to take the place of conventional materials in many industrial areas due to their superior properties [5, 6]. As a term, composite can be called a material created by combining multiple natural or synthetic components. Composite materials are new materials produced by combining two or more materials in macro size in order to produce a convenient new material that can provide the desired properties in design. Composite materials consist of a main component called matrix and components called reinforcement.

The matrix ensures that the load applied to the material is evenly and uniformly distributed to the fibers, and also protects the fibers from environmental effects by holding them together. Fiber components, on the other hand, carry the load applied to the material and increase the strength of the material [7-9].

With the production of hybrid composites, composite material production activities have gained another dimension. Hybrid composites are a type of composite obtained by using more than one fiber and ceramic phase varieties in the same composite. Thanks to hybrid composites, optimal material production can be achieved by combining the good aspects of ceramic materials that have different properties [10].
In this study, composite and hybrid composite test samples were produced by adding 5-10-15 wt% Al2O3, SiC and 10 wt% Al2O3-SiC reinforcement materials to the AA7075 matrix. Density, microstructure, and hardness properties of the produced samples were examined.

II. EXPERIMENTAL

In experimental studies, the production of composite-hybrid test samples with a metal matrix was carried out through the powder metallurgy technique by using AA 7075 aluminum powders (90.66 µm) as a matrix material. The chemical composition of AA 7075 aluminum Matrix powder material is given in Table 1. In terms of composite-hybrid material production, SiC and Al2O3 ceramic powder materials were used as reinforcement phases. Physical properties and powder sizes of the reinforcement-powder ceramic phases are shown in Table 2. In the production of composite and hybrid composite test samples with AA 7075 aluminum metal matrix structure, 5-10-15 wt% SiC, Al2O3 and 10 wt% SiC-Al2O3 ceramic phase reinforcements were used (Table 3).

Table 1.Chemical composition of AA7075 matrix material

Al	Mg	Zn	Cr	Zr	Si	Fe	Mn	Cu
89.6	2.596	5.480	0.012	0.030	0.403	0.549	0.014	1.568

Table 2.Properties of reinforcement powders

	Yoğunluk (g/cm^3)	Ergime sıcaklığı (°C)	Toz boyutu (µm)
SiC	3.16	1800	5
Al_2O_3	3.97	2040	<32

In order to prepare matrix-reinforcement powder mixtures and to ensure they had a homogeneous distribution, 1-hour powder mixing process was carried out using a planetary type mechanical mixing device. Following the mixing process, the prepared matrix-reinforcement powder mixtures were pressed under room temperature conditions and under a pressure of 700MPa using the powder pressing mold shown in Figure 1. 1-hour sintering process was applied in a quartz glass tube under Argon gas flow by using an atmosphere-controlled heat treatment furnace at 560 °C to give high-temperature strength to the test samples that obtained raw density after the pressing processes (Figure 2).

Table 3.Contents and composition of test samples

AA7075 (%)	SiC (%)	Al_2O_3(%)	Weight (gram)
100	---	---	2
95	5	---	1.9+0.1
90	10	---	1.8+0.2
85	15	---	1.7+0.3
95	---	5	1.9+0.1
90	---	10	1.8+0.2
85	---	15	1.7+0.3
80	10	10	1.6+0.2+0.2

To be able to measure the density values of the test samples during and after the sintering process, a Micromeritics–Accupyc2 1340 brand helium Pycnometer was used. Average density results were obtained by making at least 5 measurements in each test sample. In terms of microstructural characterization of test samples, after the sintering and density processes, general metallographic studies, including grinding (600-800-1200 grinding), polishing (1 um diamond solution) and etching (95 ml H2O and 5 ml HC1), were conducted respectively. As a result of general metallography studies, microstructural examination of the single and double ceramic phase reinforced composite-hybrid test samples having AA 7075 Al metal matrix were conducted. To be able to determine microstructure differences and particle distributions of the SiC-Al2O3 ceramic phase, optical microscope (Hardway), SEM (Scanning Electron Microscope) (Hitachi SU 1510 model), and associated EDS (Energy Dispersion Spectrometer) analyses were used in experimental studies. Finally, the hardness measurements of the produced composite-hybrid test samples were made using the Hardway micro-hardness device (HV0.1).

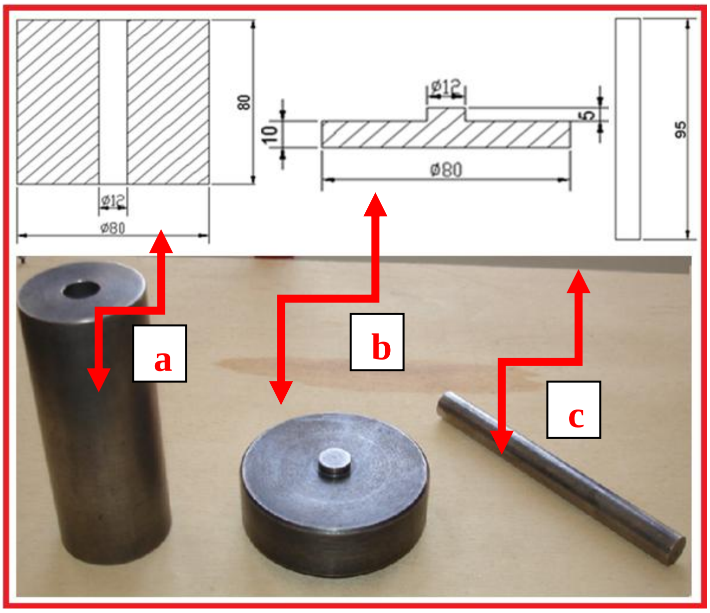


Figure 1.The pressing of samples; (a) Female mold, (b) Base, (c) Punch

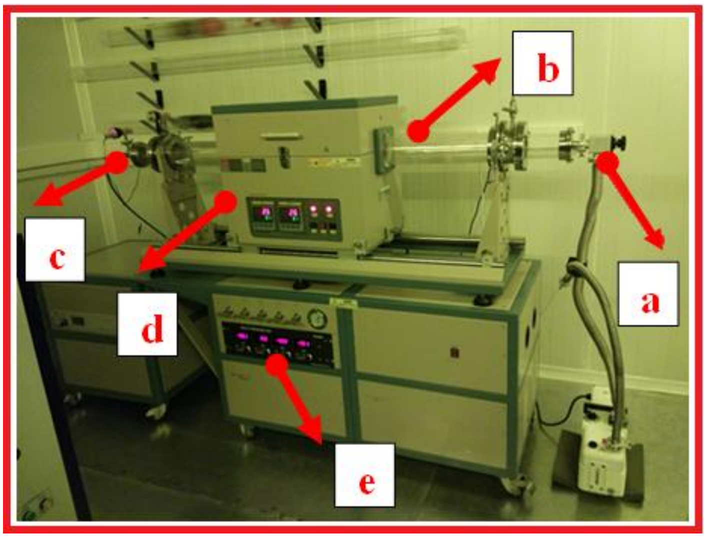


Figure 2.Sintering process of samples; a) Vacuum connection, b) Quartz glass tube, c) Gas flange, d) Furnace and temperature panel, e) Vacuum and gas gauge

III. RESULTS AND DISCUSSION

Initial powder-material SEM images of AA7075 metal matrix, SiC and Al2O3 ceramic phase reinforcements used in the production of composite-hybrid test samples are given in Figure 3. When these initial powder-material SEM images are examined, it is understood that the powders used as the AA 7075 Al metal matrix are gas-atomized and in the spherical shape morphology (Figure 3a). It is seen that Al2O3 and SiC ceramic phase powder reinforcements, which are used as ceramic phase reinforcements in composite and hybrid material production, are in the powder-shape morphologies that have an appearance of irregular-spongy and various polygonal-sharp corner forms, respectively (Figure 3b-c). Both AA 7075 Al matrix and ceramic phase reinforced composite and hybrid test samples' density results obtained as a result of pressing and sintering operations are shown in Figure 4. In terms of raw density values, with pressing operations, it was attempted to approach the density value of Al matrix material, which is about 2.70 g/cm3 [11].

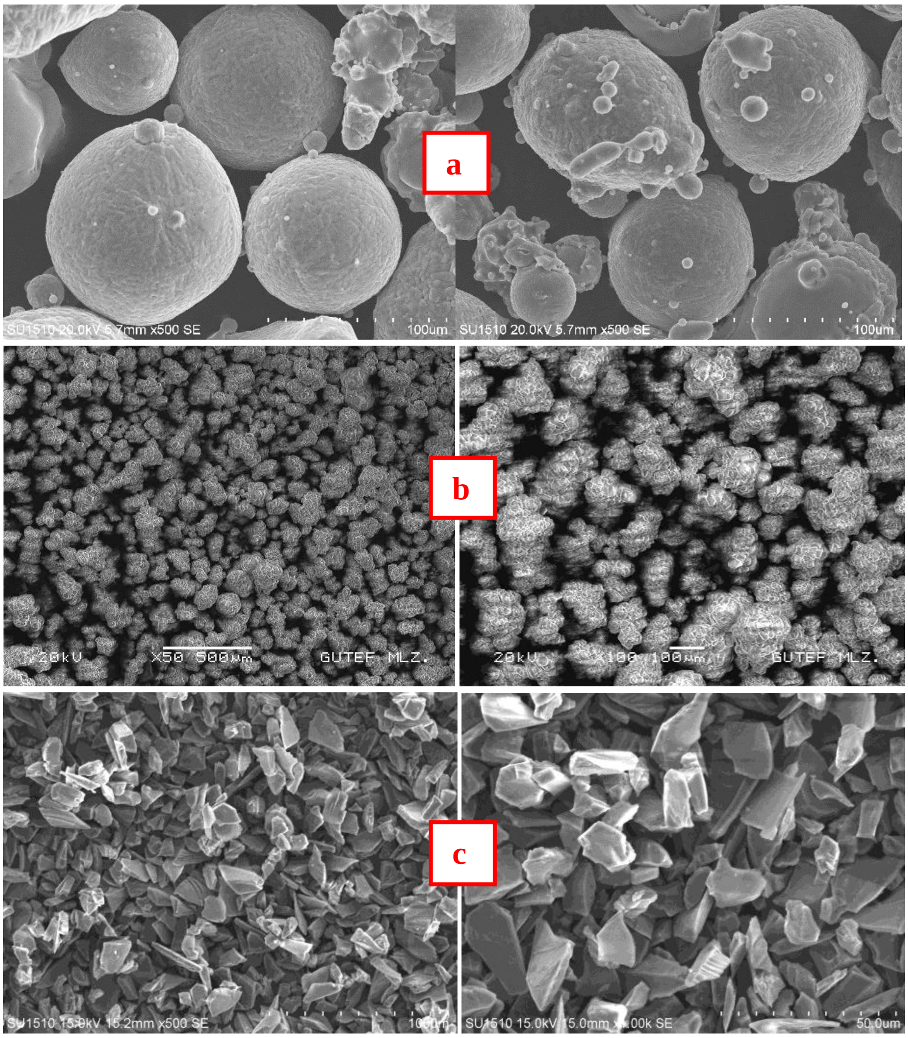


Figure 3.SEM images of matrix and reinforcing powders;(a) AA 7075, (b) Al_2O_3 and (c) SiC

For this purpose, in a similar study, Hakan et al. focused on the optimal pressing pressure in the Al powder metal material [2]. In this regard, when the density values of ceramic reinforced composite-hybrid materials were examined in the Al matrix pressed under a pressure of 700MPa in the study, it was found that the density values, especially after sintering, tend to decrease in all samples. After both pressing and sintering, the highest density value was determined in AA7075 Al material without reinforcement. By the sintering process, decreasing density values were determined. In composite and hybrid materials, this condition can be stated as the specific weights of ceramic phase particles, condensation at grain boundaries during sintering, and shrinkage of pores. Considering AA 7075 aluminum alloy without reinforcement, another effect on reducing density and shrinking pores can be stated as the presence of other alloying elements in the microstructure.

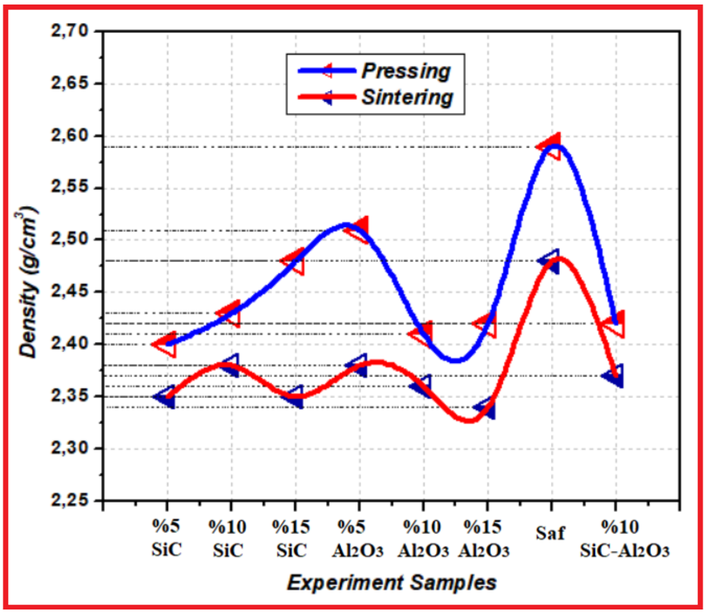


Figure 4.Density changes of samples

As a result of sintering processes, optical microscope microstructure images of the AA 7075 Al matrix material without reinforcement are shown in Figure 5. When the microstructure images given in Figures 5a and b are examined, it can be understood that the sintering mechanism (temperature-duration) is sufficient in terms of grain structure-pore morphology. When the pore formations located at grain boundaries are considered (Figure 5b), this condition can be explained as in sintering theory especially by taking into account the spherical or triangular formation located at the triple grain junction point [12]. Thus, the appropriateness of sintering in terms of grain structure-pore interaction can be specified. Figures 6 and 7 show optical microscope microstructure images of AA 7075 Al metal matrix composite material with 5-10-15 wt% SiC and Al2O3 single ceramic phase reinforcement, respectively. When the microstructure images were examined, it was found that single-phase ceramic distributions densified based on the increased reinforcement rates. Examining the microstructure images in Figure 6, it is understood that SiC ceramic phase particles with particularly sharp corners and polygonal morphology on a light white matrix increase at the increasing reinforcement rate and tend to cluster especially in some regions of grain boundary. A similar situation can also be seen in the composite material created by Al2O3 ceramic phase reinforcement (Figure 7). However, besides the increase of the reinforcement amount, it can be noted that the tendency to distribute (mostly) over the matrix and to cluster in some regions is more intense compared to SiC reinforcement. This difference can be considered to occur under the lead of both powder grain size and reinforcement-ceramic-phase powder shapes and morphologies. In addition to single ceramic phase reinforcement, optical and SEM microstructure images of the AA 7075 Al metal matrix hybrid composite material having 10 wt% SiC-Al2O3 reinforcement are shown in Figure 8.

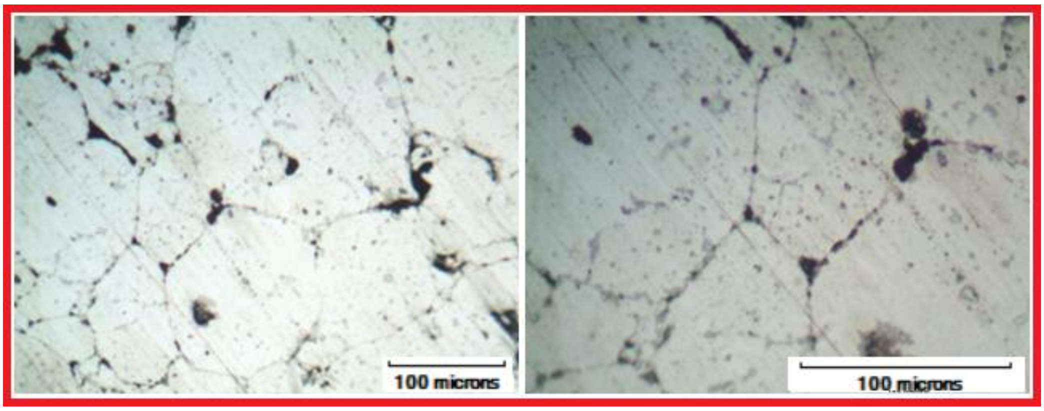


Figure 5.Sintered AA 7075 microstructure images

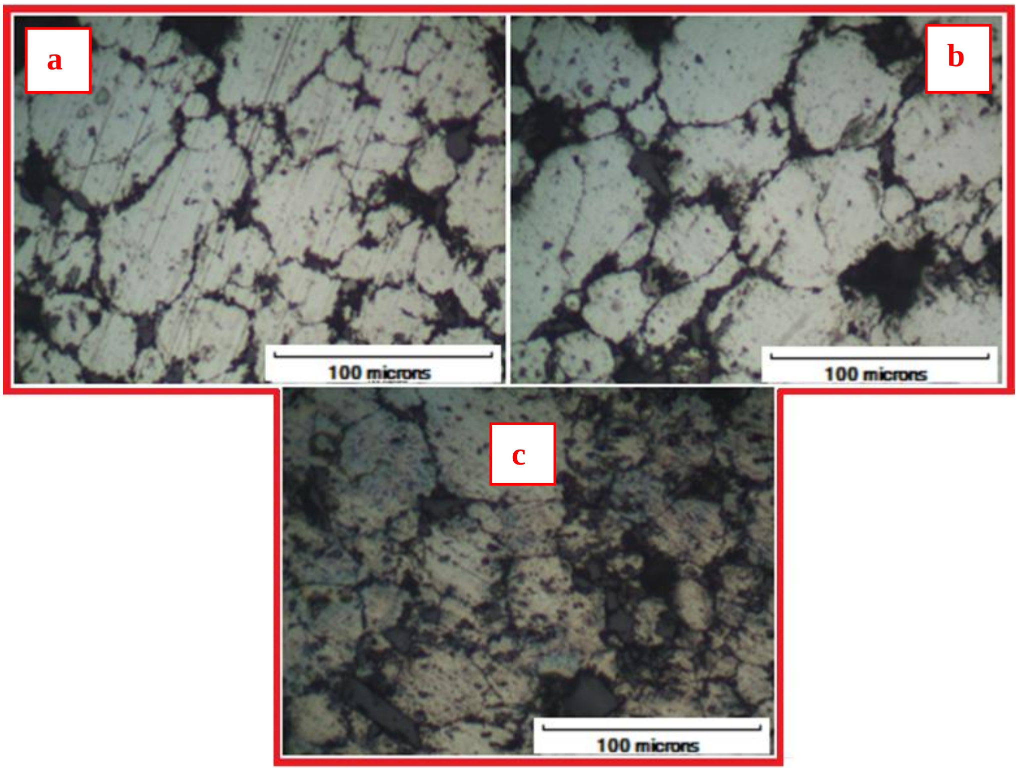


Figure 6.Microstructure of particle reinforced composites;(a) 5% SiC, (b) 10% SiC, (c) 15% SiC

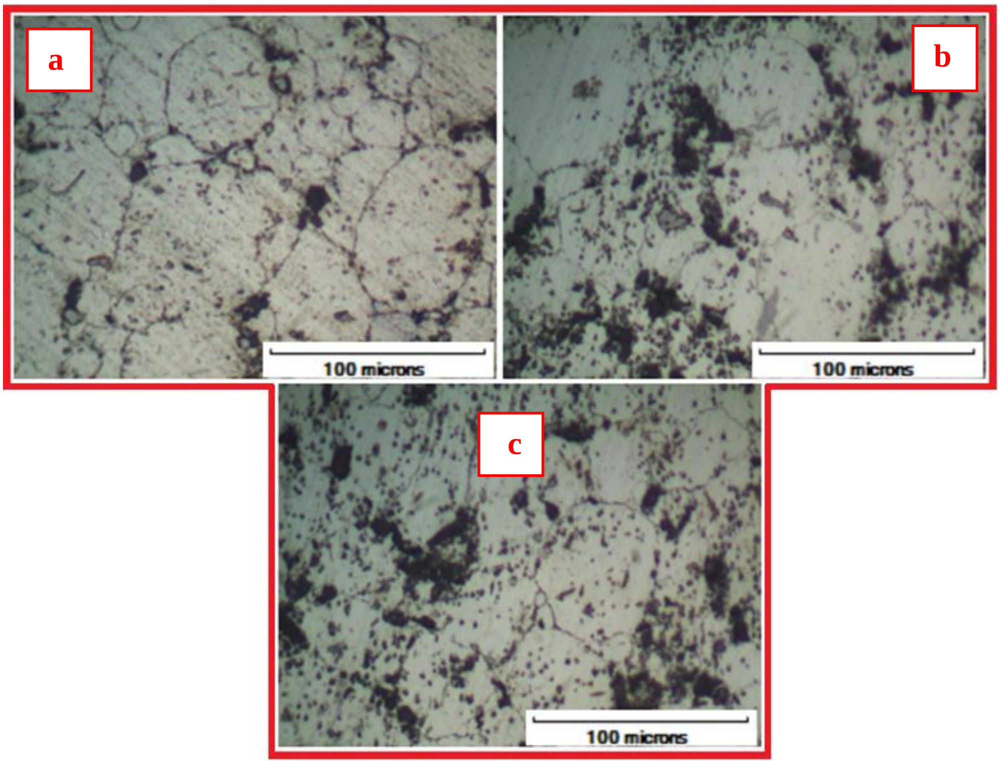


Figure 7. Microstructure of particle reinforced composites; (a) 5% Al_2O_3, (b) 10% Al_2O_3, (c) 15% Al_2O_3

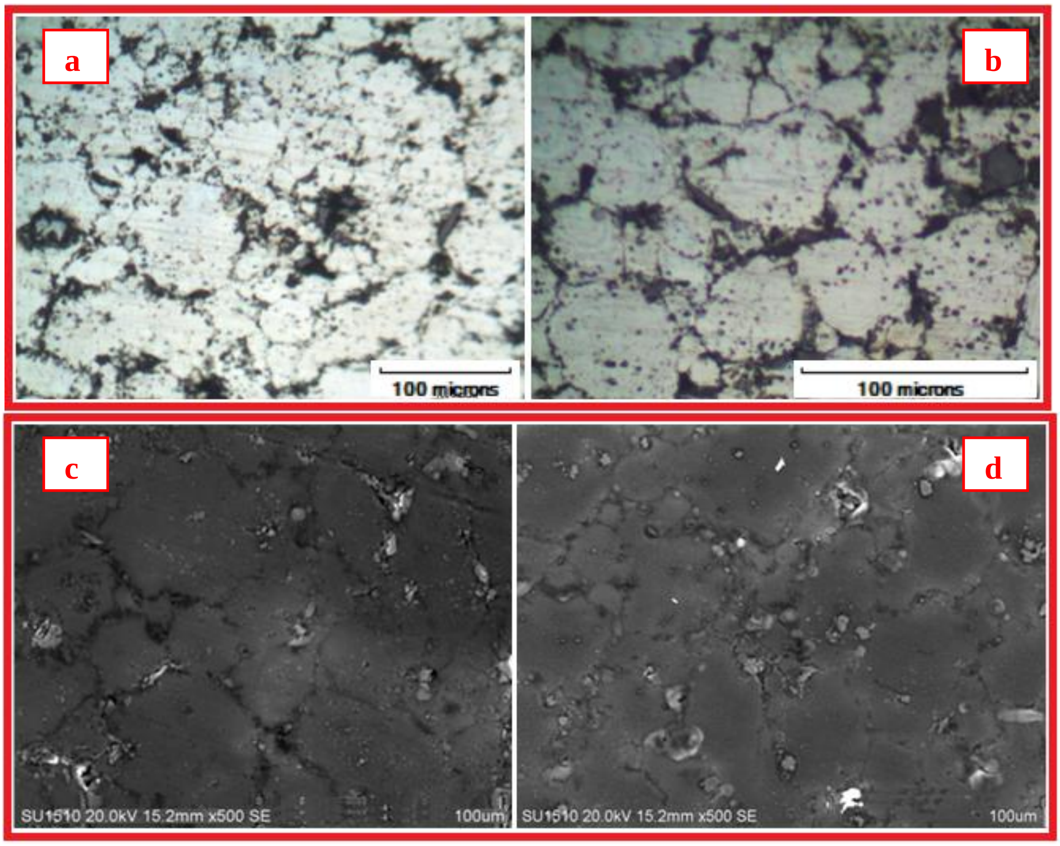


Figure 8.Optical and SEM images of 10% SiC-Al_2O_3 hybrid composite

When the optical microstructure images given in Figures 8a and b are examined, it is understood that the AA 7075 Al metal matrix, which is seen in light and white color, and the reinforcing ceramic phases are mostly located at the grain boundaries. The distribution of the SiC ceramic phase in dark greyish sharp angular and polygonal shape morphologies can be seen. On the other hand, it can be said that the Al2O3 ceramic phase reinforcement exhibits a combination of condensation in smaller sizes and together by the effect of clustering. As can be seen in the initial powder SEM images, while the SIC ceramic phase reinforcement is clearly determined, the exact determination of the Al2O3 ceramic phase is not understood. In this case, the EDS analysis and general and point analyses were decisive. In Figure 8c and d, SEM images and matrix-reinforcement distributions are able to be observed more clearly compared to optical microstructure images. Similarly, ceramic phase reinforcements distributed on the matrix structure, especially at grain boundaries, can be seen prominently. It can be said that the reinforcement ceramic phases exhibit a homogeneous distribution that is relatively compatible with the AA 7075 Al matrix structure. In order to more clearly reveal this situation, especially the distributions from an elemental point of view, EDS mapping images are given in Figure 9.

When examining the elemental mapping result given in Figure 9, the prominent alloying elements such as Cu and Fe as well as the basic alloying element Zn can be seen in the AA 7075 Al matrix; moreover, in terms of ceramic phase distributions, chemicals such as Si and O can also be seen. In the hybrid composite material produced with 10 wt% SiC-Al2O3 reinforcement, the results of the point EDS analysis carried out to determine the reinforcement ceramic phases are shown respectively in Figure 10. Based on the 1st point analysis result, the presence of the Al2O3 ceramic phase was determined. Based on the 2nd and 3rd point analysis results, AA 7075 aluminum alloy matrix structure and SiC ceramic phase were determined. In this case, it can be noted that beyond the distributions of sharp-angular and polygonal shapes, the distribution morphologies in the form of a more irregular-whitish and shining appearance refer to the Al2O3 ceramic phases.

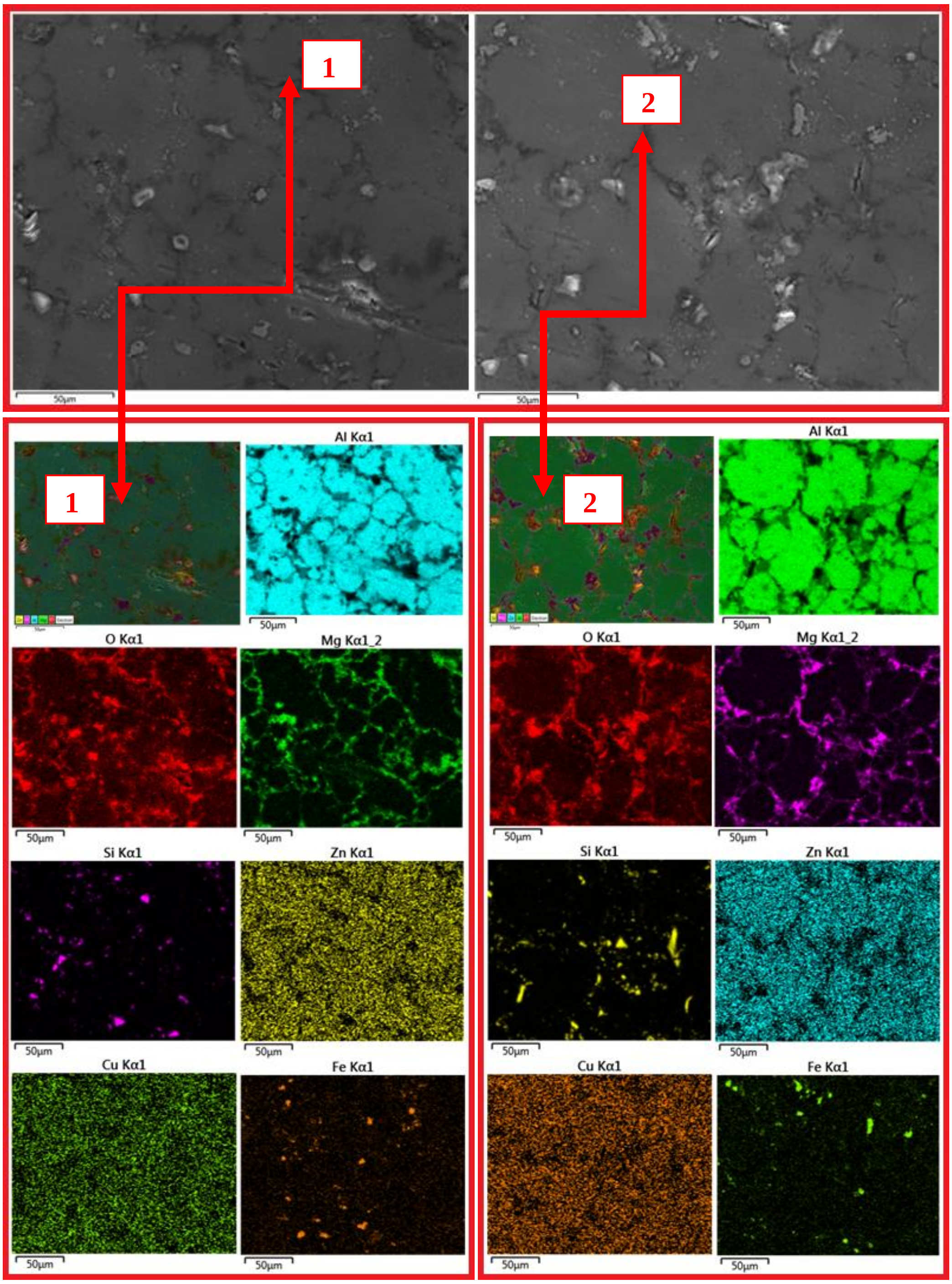


Figure 9.10% SiC-Al_2O_3 hybrid composite mapping

The change in hardness values of the ceramic phase reinforced test samples obtained as a result ofmicrostructural studies conducted on the produced composite and hybrid composite materials is shown in Figure 11 compared to the Al matrix structure. In this figure, hardness measurements and average values can be seen. When the average results of hardness measurements were examined, it was observed that hardness results increased as the percentage by weight (wt%) increase in all single ceramic reinforced composite materials compared to Al matrix structure. The highest rate of increase occurred in SiC reinforced composite materials. In the hybrid composite material produced with 10 wt% SiC-Al2O3 ceramic phase reinforcement, the hardness value was at a moderate level compared to SiC and Al2O3 reinforced composite materials.

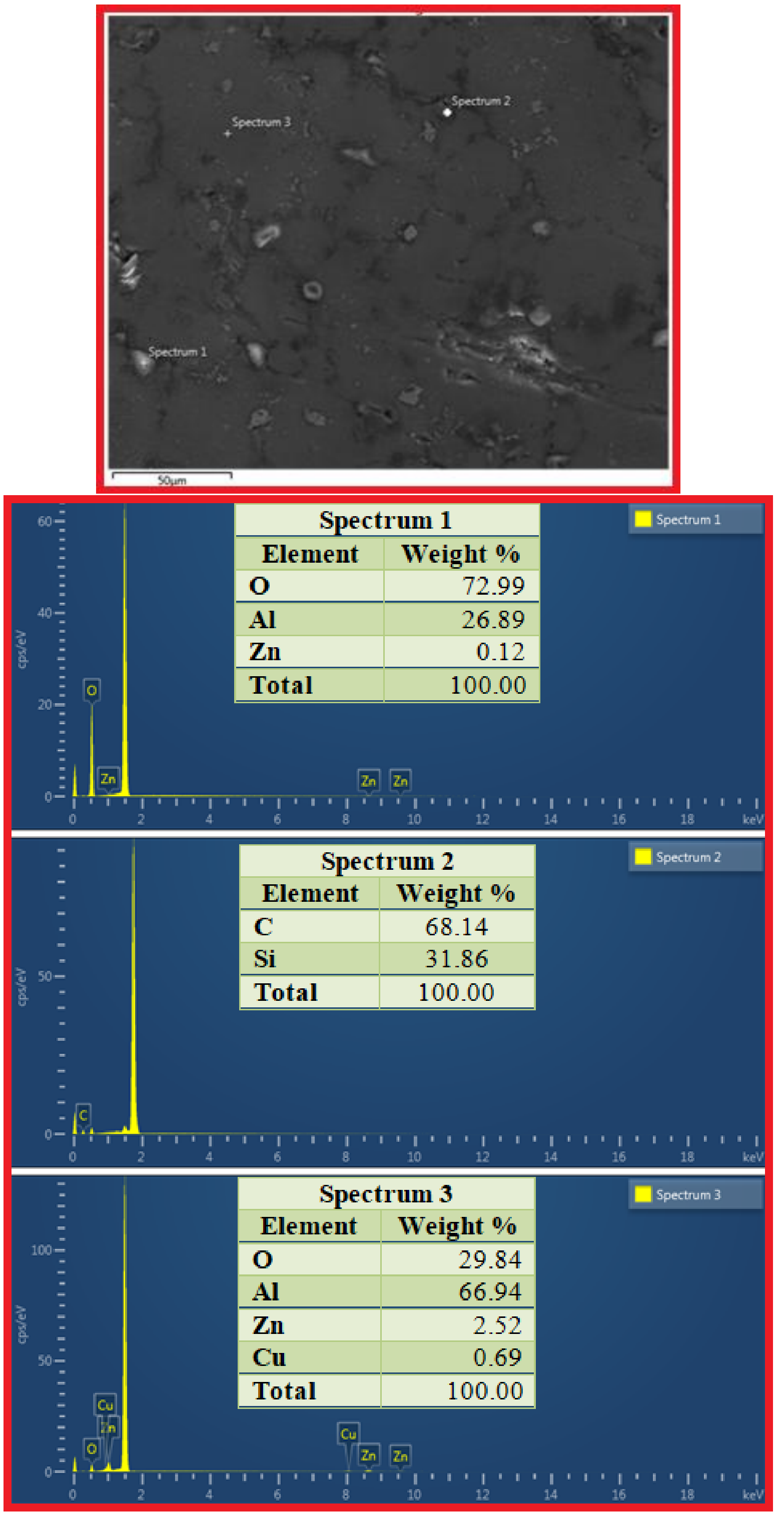
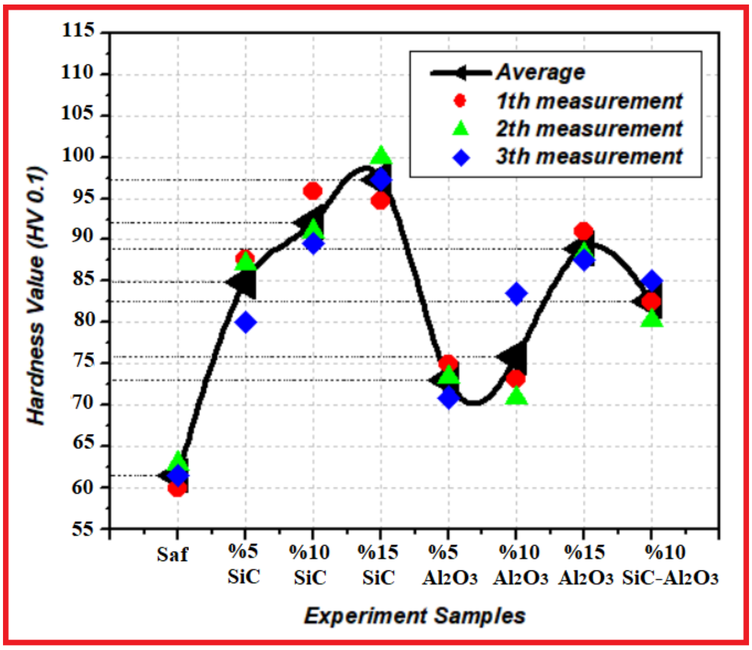


Figure10.EDS analysis of 10% SiC-Al_2O_3 hybrid composite



Şekil 11.Hardness values of test samples

IV. CONCLUSION

In the study, the hybrid/composite samples with metal matrix were produced by the conventional powder metallurgy method. The results obtained at the end of the pressing and sintering processes are presented below;

It was observed that compared to AA 7075 aluminum alloy, there was a decrease in density in composite-hybrid test samples produced by adding ceramic particles. Besides the AA 7075 Al metal matrix, reinforcement ceramic phases were also seen to position mostly at grain boundaries. Distributions of the SiC ceramic phase in dark greyish sharp-angular and polygonal shape morphologies were determined. Al2O3 ceramic phase reinforcement, on the other hand, was found to exhibit condensations in smaller sizes and together by the effect of clustering. This condition and in particular EDS elemental analysis demonstrated distributions clearly in the hybrid composite material. While hardness values increased with particle reinforcement in AA 7075 matrix composites, the highest hardness value was obtained in the sample containing 15 wt% SiC. In the hybrid composite sample, on the other hand, a higher hardness value than composites containing Al2O3 and a hardness value close to the hardness of SiC reinforced composite material were obtained at a similar reinforcement rate.

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