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The effect of reinforcement ratio on corrosion properties of Al_2O_3 reinforced AA2024 aluminum matrix composites produced by hot pressing

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Sıcak Presleme
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Korozyon
Alüminyum
Toz Metalurjisi

Graphical/Tabular Abstract (Grafik Özet)

In this study, corrosion properties of AA2024 aluminum alloy matrix composite materials reinforced with Al_2O_3 in three different ratios were investigated. / Bu çalışmada, üç farklı oranda Al_2O_3 takviyesi içeren AA2024 alüminyum alaşımı matrisli kompozit malzemelerin korozyon özellikleri incelenmiştir.

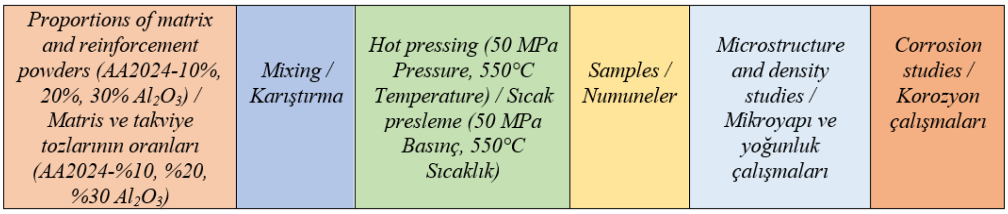

Figure A. *Experimental work steps /* ***Şekil A.*** *Deneysel çalışma aşamaları*

Highlights (Önemli noktalar)

- *Electrochemical Corrosion. / Elektrokimyasal korozyon*
- *Effect of Reinforcement. / Takviye etkisi*
- *Aluminum Alloy Composites. / Alüminyum alaşımlı kompozitler*

Aim (Amaç): *In this study, it is aimed to investigate the corrosion behavior, which is one of the most important surface properties, of 10%, 20% and 30% Al_2O_3 reinforced AA2024 aluminum matrix composite materials produced by powder metallurgy method and hot pressing method. / Bu çalışmada toz metalurjisi yöntemi ve sıcak presleme yöntemi ile üretilen %10, %20 ve %30 Al_2O_3 takviyeli AA2024 alüminyum matrisli kompozit malzemelerin en önemli yüzey özelliklerinden biri olan korozyon davranışının araştırılması amaçlanmıştır.*

Orginality (Özgünlük): *Regarding aluminum matrix composite materials, it is seen that studies in the literature are generally on mechanical properties and corrosion studies are limited. For this reason, in this study, the corrosion behavior of AA2024 based Al_2O_3 reinforced composites produced by hot pressing method were investigated. / Alüminyum matrisli kompozit malzemeler ile ilgili olarak literatürdeki çalışmaların genellikle mekanik özellikler üzerine olduğu ve korozyon çalışmalarının sınırlı kaldığı görülmektedir. Bu nedenle bu çalışmada, sıcak presleme yöntemi ile üretilen AA2024 esaslı Al_2O_3 takviyeli kompozitlerin korozyon davranışları incelenmiştir.*

Results (Bulgular): *Corrosion data of composite materials are given in Table 1 below. / Kompozit malzemelerin korozyon verileri aşağıda Tablo 1 de verilmiştir.*

Reinforcement Ratio / Takviye Oranı	Corrosion Potential (V) / Korozyon Potansiyeli	Corrosion Current Density (A/cm²) / Korozyon Akım Yoğunluğu	Corrosion Rate (mm/y) / Korozyon Hızı
AA2024 + 10% Al_2O_3	-1.277	$1.984.10^{-5}$	0.216
AA2024 + 20% Al_2O_3	-1.210	$7.438.10^{-6}$	0.081
AA2024 + 30% Al_2O_3	-1.219	$7.299.10^{-6}$	0.079

Table A. *Corrosion data of 10%, 20% and 30% Al_2O_3 reinforced AA2024 aluminum matrix composite materials /* ***Tablo A.*** *%10, %20 ve %30 Al_2O_3 takviyeli AA2024 alüminyum matrisli kompozit malzemelerin korozyon verileri*

Conclusion (Sonuç): *It is thought that Al_2O_3 reinforcement, which is more noble electrochemically to the aluminum matrix, is effective in decreasing the corrosion rate and improving corrosion resistance with the increase in the reinforcement ratio. / Alüminyum matrise elektrokimyasal olarak daha asil olan Al_2O_3 takviye oranının artmasıyla birlikte korozyon hızını düşürmede ve korozyon direncini iyileştirmede etkili olduğu düşünülmektedir.*

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Abstract

In this study, corrosion properties of AA2024 aluminum alloy matrix composite materials reinforced with Al_2O_3 in three different ratios were investigated. After mixing the aluminum alloy matrix material powders and the reinforcement material powders at 10%, 20% and 30% Al_2O_3 ratios homogeneously, composite materials were produced by keeping them in an axial mold under 50 MPa pressure and 550 °C temperature for 1 hour by hot pressing method. According to the corrosion test results, the corrosion resistance of the composite materials containing 20% and 30% Al_2O_3 reinforcement was very close to each other. The corrosion rates of these two samples were determined to be lower than the sample containing 10% Al_2O_3 reinforcement.

Sıcak Presleme ile Üretilen AA2024 Alüminyum Matrisli Al_2O_3 Takviyeli Kompozitlerde Takviye Oranının Korozyon Özelliklerine Etkisi

Makale Bilgisi

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Öz

Bu çalışmada üç farklı oranda Al_2O_3 ile takviye edilmiş AA2024 alüminyum alaşımı matrisli kompozit malzemelerin korozyon özellikleri araştırılmıştır. Alüminyum alaşımı matris malzemesi tozları ile %10, %20 ve %30 Al_2O_3 oranlarında takviye malzemesi tozları homojen şekilde karıştırıldıktan sonra sıcak presleme yöntemiyle tek yönlü olarak eksenel kalıp içerisinde 50 MPa basınç altında, 550 °C sıcaklıkta 1 saat süreyle bekletilerek kompozit malzemelerin üretimi yapılmıştır. Korozyon test sonuçlarına göre %20 ve %30 Al_2O_3 takviye içeren kompozit malzemelerin korozyon dayanımları birbirlerine çok yakın olmuştur. Bu iki numunenin korozyon hızları %10 Al_2O_3 takviye içeren numuneye göre daha düşük olarak belirlenmiştir.

1. INTRODUCTION (GİRİŞ)

In order to improve the mechanical properties of aluminum alloys such as hardness, yield-tensile strength, fatigue strength, and abrasion resistance, macro-size hard reinforcement elements are added to the aluminum matrix, and aluminum matrix composite materials with superior properties are produced and used in many areas. Generally, various ceramic compounds are preferred as reinforcement materials. Alumina (Al_2O_3) is one of the most used reinforcement elements among these reinforcement materials due to its superior properties such as high stability, inertness and high temperature resistance. Aluminum matrix composite materials are used in aviation, marine and land vehicles industry, mining industry and in many other fields [1-5]. Aluminum matrix composite materials can be produced by one of the liquid, liquid-solid and solid production methods. Powder metallurgy method is also one of the solid production methods used in production. Among the production methods, the method in which the reinforcement material can be distributed uniformly in the matrix material, the pore formation can be controlled, and good interfacial bonding between the matrix material and the reinforcement material should be preferred [6-8].

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The results of some studies on the corrosion behavior of alumina reinforced aluminum matrix composite materials are given below. Alanemea, K.K. and Olubambi, P.A [4], in their study where they examined the effect of the addition of rice husk ash on the corrosion behavior of Al_2O_3 reinforced aluminum matrix composite material in salty environment, reported that this addition increased the corrosion rate due to its accumulation at the interface of reinforcement and matrix. In a study investigating the effects of Al_2O_3 reinforcement ratio on corrosion, it was observed that corrosion resistance decreased with increasing reinforcement ratio in aluminum matrix composite material in seawater and industrial atmosphere [7]. In addition, it was observed that the corrosion resistance was less in seawater environment, especially pitting corrosion was effective in this environment, and it was noticed that grain boundary corrosion was more effective in the industrial environment. De Salazar, J.M.G. et al. [8] stated that the heat treatments applied to the material to improve the mechanical properties of Al_2O_3 reinforced aluminum matrix composite materials affect the corrosion behavior of the material. Dobrzanski, L.A. [9] reported that the corrosion rate of the composite material increased when the Al_2O_3 ratio was increased excessively in the Al_2O_3 particle reinforced aluminum matrix composites produced by the powder metallurgy method, and the addition of Al_2O_3 at lower rates was not effective on the corrosion properties. Durai, T. G. et al. [10] investigated the effects of Mn addition in Al_2O_3 reinforced aluminum matrix composite materials and determined that the addition of Mn at low rates improved corrosion resistance. Zhu, J. and Hihara, L. H. [11] reported that the corrosion resistance of metal matrix composites reinforced with alumina continuous fiber is lower than that of non-reinforced aluminum matrix material, and corrosion begins at the fiber-matrix interface. Hu, J. et al. [12] reported that the corrosion potential of heat-treated aluminaborate-reinforced aluminum composite in a salty environment changed negatively with solution heat treatment. It was evaluated that this negative change was caused by the interfacial reactions in the solution taking process. Lotto, R.T. and Babalola, P. [13] investigated the corrosion behavior of aluminum matrix composite materials containing nano-sized alumina, and determined that the corrosion resistance of the material is better when the alumina ratio is increased and the particle size is small. Saxena, M. et al. [14] reported that the deterioration of the continuity of the oxide film by breaking the oxide film is effective in the reduction of corrosion resistance in aluminum matrix composite materials compared to pure aluminum. Karabulut H. et al. [15] investigated the corrosion behavior of B_4C, SiC and Al_2O_3 reinforced aluminum matrix composites produced by mechanical alloying for 4 and 10 hours in salt water (3.5% NaCl). After mechanical alloying, the mixed powders were compressed under 700 MPa pressure and sintered at 600 °C. Electrochemical corrosion tests were applied to the samples in the salt water solution using potentiodynamic methods. According to the research results, the best corrosion resistance was obtained from aluminum/B_4C composites. Karacif K. [16] investigated the hardness and corrosion properties of functional graded AA5083/Al_2O_3 composites produced by powder metallurgy method. There was a small decrease in the corrosion rate of the materials with the increasing number of layers in functionally graded materials, and it was determined that the corrosion effect was higher in layers with high alumina reinforcement. On the other hand, Özay Ç. and Karlıdağ Ö.E. [17] coated the surface of the AA2024 alloy substrate with Al-B_4C reinforced composite using hot press sintering. Al and B_4C powders were synthesized by mechanical alloying. The microstructure of the Al/B_4C composite coating, the macrohardness of the coating layer, linear reciprocating motion and forward wear resistance were investigated. In addition, Karabulut H. [18] previously produced composite materials with two different Al_2O_3 reinforcements, 10% and 20%, by hot pressing at 550 °C and investigated the effect of reinforcement amount on properties such as density, hardness and wear. As a result of this study, it was found that the density value decreased slightly with the increase in the amount of reinforcement; it was determined that the hardness and wear resistance increased.

In this study, corrosion behavior, which is one of the most important surface properties, of AA2024 aluminum matrix composite materials reinforced with 10%, 20% and 30% Al_2O_3 produced by powder metallurgy method by hot pressing was investigated. In order to interpret the changes in these properties, the microstructure and density properties of the materials were also evaluated.

2.MATERIALS AND METHODS (MALZEME VE METOD)

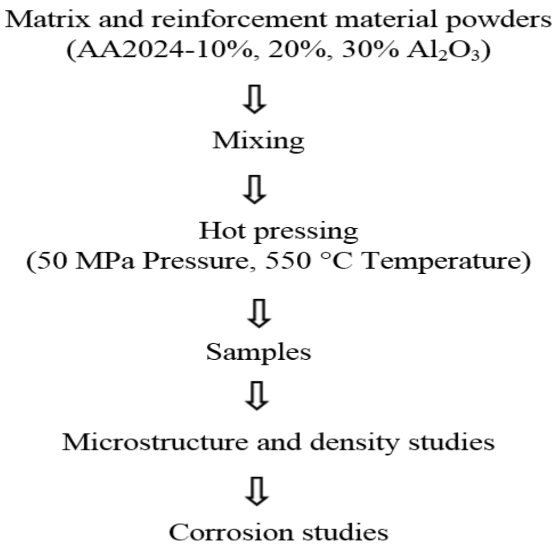
2.1. Material Production (Malzeme Üretimi)

The production of Al_2O_3 reinforced AA2024 aluminum matrix composite samples to be used in the study was made by powder metallurgy method. The average particle size of the reinforcement material Al_2O_3 powders is 10 µm. The chemical composition of the AA2024 aluminum alloy, which is the matrix material, is given in Table 1 [19].

Table 1. Chemical composition of AA2024 alloy *(AA2024 alaşımının kimyasal kompozisyonu)*

Alloy	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Other (Each)**	**Other (Total)**	**Al**
2024	0.50	0.50	3.8-4.9	0.30-0.9	1.2-1.8	0.10	0.25	0.15	0.05	0.15	Remainder

In the first stage of material production, the matrix and reinforcement material powders, which were weighed with a precision of 0.0001 g, with a RADWAG AS-60-220 C/2 precision balance containing 10%, 20% and 30% Al_2O_3 by weight, were made ready for mixing. The powders weighed according to the specified ratios were mixed with a Turbula brand triaxial mixer for one hour without a ball and became homogeneous. The obtained mixed powders were kept in an axial mold under 50 MPa pressure, at 550 °C temperature for 1 hour in a one-way axial mold, and they were turned into blocks by hot pressing method. Hot pressing of powders was done in MSE HP 1200 brand device. Experimental work steps are given on the side.



2.2. Microstructure and Density Studies
(Mikroyapı ve Yoğunluk Çalışmaları)

Nikon inverted metallurgical microscope was used for the microstructure images of the composite samples, for which metallographic preparation studies such as sanding and polishing were made. Density measurements of the samples were determined by Archimets principle. The relative densities of the samples were calculated by using the found density value and the theoretical density values.

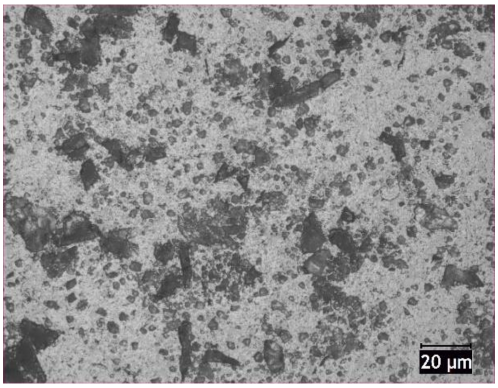
2.3. Corrosion Studies (Korozyon Çalışmaları)

Electrochemical corrosion tests were carried out in salt water environment to determine the corrosion properties of the samples. In corrosion studies, potentiostat/galvanostat device and 3.5% NaCl solution were used as salt water medium. In the corrosion tests, the general corrosion behavior was observed by obtaining the polarization curves by scanning the potential between -2 V and -0.5 V in the first stage, and the Tafel polarization curves were obtained by applying the potential between -1.6 V and -0.7 V in the second stage. A scanning rate of 1 mV/s was used for potential scanning. Corrosion potentials, corrosion current densities and corrosion rates of the samples were determined from the Tafel polarization curves. These data are calculated by the system with the software used with the potentiostat/galvanostat device.

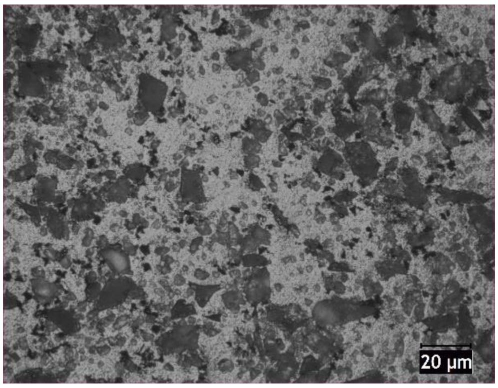
3. EXPERIMENTAL RESULTS AND DISCUSSION (DENEYSEL SONUÇLAR VE TARTIŞMA)

3.1.Microstructure and Density Results
(Mikroyapı ve Yoğunluk Sonuçları)

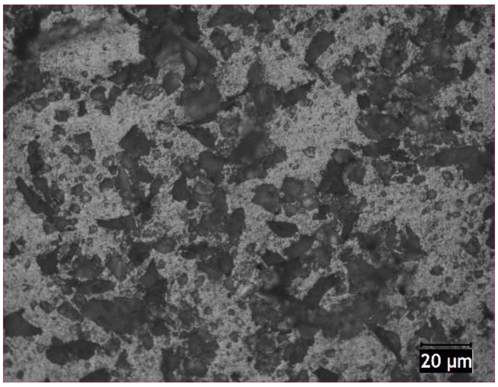
The microstructure images of AA2024 aluminum matrix composite materials containing three different ratios of Al_2O_3 reinforcement are given in Figure 1. From the microstructure images, it is seen that the Al_2O_3 reinforcement elements exhibit a homogeneous distribution in general. From the microstructure images, it can be said that the dark colored particles with an average size of 10 μm are Al_2O_3 reinforcement material, the smaller dark colored particles are copper and magnesium in AA 2024, and the light colored parts are aluminum. In addition, there is a homogeneous distribution in composites containing 30% reinforcement element, but some aggregation is observed. This may be due to the fact that the Al_2O_3 particles have a harder structure than the matrix due to the increase in the reinforcement ratio during pressing, although a homogeneous distribution is initially achieved with the triaxial mixer.



a) 10% Al_2O_3



b) 20% Al_2O_3



c) 30% Al_2O_3

Figure 1. Microstructure images of aluminum matrix composite samples containing (a) 10%, (b) 20% and (c) 30% Al_2O_3 *((a) %10, (b) %20 ve (c) %30 Al_2O_3 içeren alüminyum matrisli kompozit numunelerin mikroyapı görüntüleri*)

In Table 2, the density values of 10% and 20% Al_2O_3 reinforced composite materials taken from Karabulut's study [18] and the density values of 30% Al_2O_3 reinforced composite materials measured in this study are given together for comparison. As can be seen from this table, there is a decrease in the density of the composite material with the increase of the Al_2O_3 reinforcement ratio. While the relative density of the composite material containing 10% reinforcement is 98%, the relative density value decreases to 97% when the reinforcement ratio is 20%, and the relative density value decreases to 95% when the reinforcement ratio is increased to 30%. According to this table, it can be said that the pore ratio of the composite material increases with the increase in the reinforcement ratio, while the density values decrease. It is thought that the decrease in material density with increasing reinforcement ratio may be due to the fact that the hard Al_2O_3 reinforcement material adversely affects the compressibility of the powders during hot pressing. When the compaction property of the powders weakens, some more pores may remain in the composite material structure.

Table 2. Density values of AA2024 aluminum matrix composite materials reinforced with Al_2O_3 at different ratios *(Farklı oranlarda Al_2O_3 takviyeli AA2024 alüminyum matrisli kompozit malzemelerin yoğunluk değerleri)*

Al_2O_3 Reinforcement Ratio (wt.%)	Relative Density (%)
10	98 ±1
20	97 ±1
30	95 ±1

3.2. Corrosion Results (Korozyon Sonuçları)

The polarization curves of aluminum matrix composite materials reinforced with Al_2O_3 at different ratios are given in Figure 2. In order to obtain the polarization curves, a potential scan was made between -2.0 V and -0.5 V, and in this potential scanning, polarization curves were obtained with the change of current passing through the material. The potential application was started from the cathodic potential region, that is, the immunity potential without corrosion, was increased in the positive direction to the anodic region, the corrosion region, and returned to the initial cathodic potential. The potential scanning direction is indicated by the arrow on the polarization curves. In all three samples with different ratios of Al_2O_3 reinforcement, the current level passing through the material is low, up to a potential value of approximately -0.7 V. Although the potential application in this region is increased in the anodic direction, there is no increase in current. The passive oxide layer formed on the aluminum composite surface in this region, which is the post-immune passivity zone, stops the current increase, that is, corrosion. At a potential value of -0.7 V, the protective passive oxide film breaks down and the current increases rapidly. So the -0.7 V potential is the passivity decay potential. At this potential value, chloride ions in the salt water environment are very effective in the deterioration of the passive film on the material surface. Chloride ions are very aggressive and have the ability to disrupt the passive film. In polarization curves, the current values in the return potential are higher than the values in the going direction. Accordingly, corrosion continues in the material up to a slightly more negative potential, a potential value of -0.8 V, on the return.

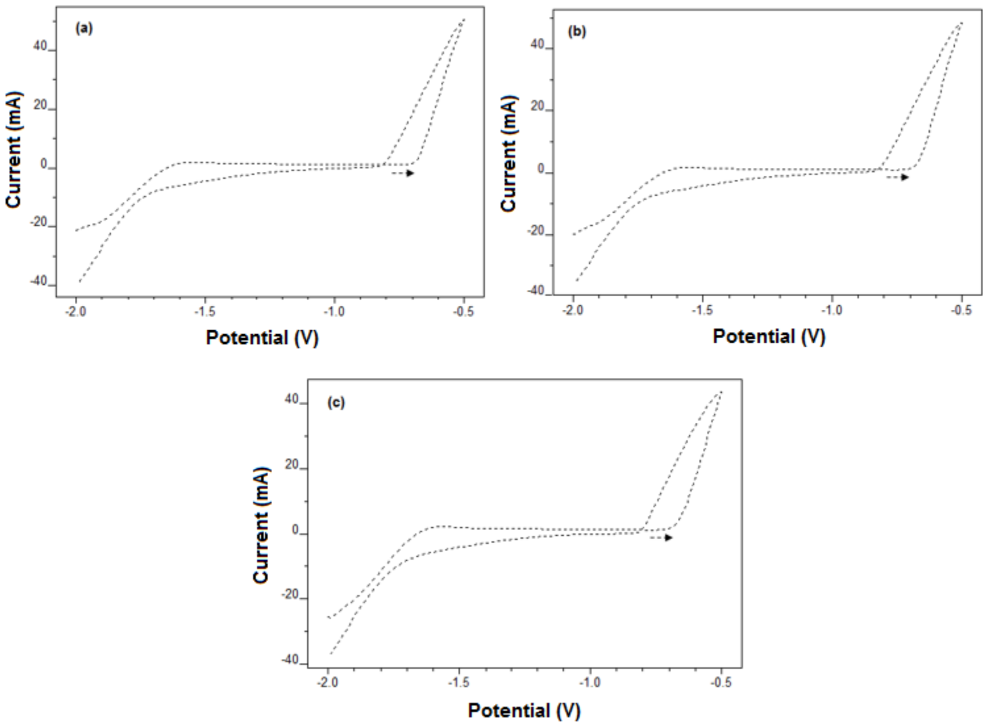


Figure 2. Polarization curves of (a) 10%, (b) 20% and (c) 30% Al_2O_3 reinforced AA2024 aluminum matrix composite materials *((a) %10, (b) %20 ve (c) %30 oranlarında Al_2O_3 takviyeli AA2024 alüminyum matrisli kompozit malzemelerin polarizasyon eğrileri)*

Tafel polarization curves of aluminum matrix composite materials reinforced with different ratios of Al_2O_3 are given in Figure 3 and the corrosion numerical results are given in Table 3. Corrosion potentials in the horizontal axis and corrosion currents in the vertical axis were determined by intersecting the linear lines drawn from the cathodic and anodic arms of the Tafel polarization curves. Corrosion current densities were determined by dividing the corrosion current values by the material surface area. The corrosion rate of the material was calculated based on the corrosion current with the computer aided corrosion test device software.

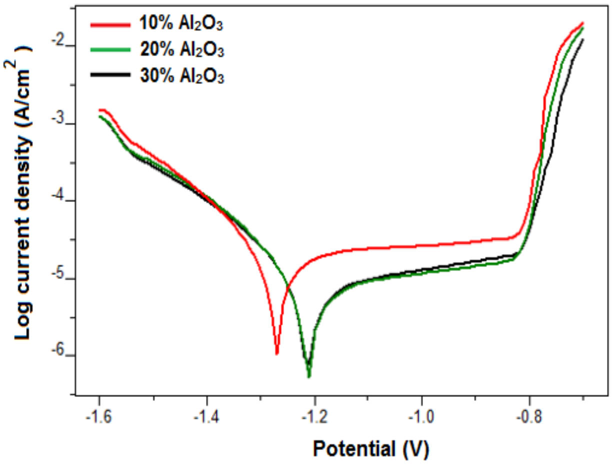


Figure 3. Tafel polarization curves of 10%, 20% and 30% Al_2O_3 reinforced AA2024 aluminum matrix composite materials (%10, %20 ve %30 oranlarında Al_2O_3 takviyeli AA2024 alüminyum matrisli kompozit malzemelerin Tafel polarizasyon eğrileri)

Table 3. Corrosion data of 10%, 20% and 30% Al_2O_3 reinforced AA2024 aluminum matrix composite materials (%10, %20 ve %30 oranlarında Al_2O_3 takviyeli AA2024 alüminyum matrisli kompozit malzemelerin korozyon verileri)

Reinforcement Ratio / Takviye Oranı	Corrosion Potential (V) / Korozyon Potansiyeli	Corrosion Current Density (A/cm^2) / Korozyon Akım Yoğunluğu	Corrosion Rate (mm/y) / Korozyon Hızı
AA2024 + 10% Al_2O_3	-1.277	$1.984.10^{-5}$	0.216
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AA2024 + 30% Al_2O_3	-1.219	$7.299.10^{-6}$	0.079

When the Tafel curves given in Figure 3 and the corrosion numerical results given in Table 3 are examined, it is seen that the Tafel curves and corrosion potential, corrosion current density and corrosion rate values of 20% and 30% Al_2O_3 reinforced composite materials are very close to each other. There is a difference of only 0.009 V between the corrosion potentials of these two composite samples, $0.139.10^{-6}$A/cm^2 between the corrosion current densities and only 0.002 mm/y between the corrosion rates. The corrosion potential value of the 10% Al_2O_3 reinforced composite material is more negative than the other two samples containing higher reinforcement, and the corrosion current density and corrosion rate values are approximately 2.5 times higher. The fact that the corrosion potential value of the 10% Al_2O_3 reinforced composite material is more negative than the others, the corrosion current density and corrosion rates are higher, show that the corrosion resistance of this sample is lower. In the case of corrosion of the Al_2O_3 reinforced AA2024 matrix composite material, the Al_2O_3 reinforcement material is more resistant to corrosion because it is in a ceramic structure. In other words, it shows a more noble behavior electrochemically in corrosion. As in composite materials, in materials consisting of structural components with different electrochemical properties, structural elements and zones with noble behavior form cathodic zones in corrosion. AA2024 aluminum alloy contains various alloying elements in its composition. Among these alloying elements, especially magnesium and zinc, they are very active electrochemically, that is, they are very sensitive to oxidation reaction. Metal dissolution and corrosion occurs as a result of the anodic reaction in very active building elements and areas. The matrix material in 10% Al_2O_3 reinforced composite material is 90% and the matrix ratio is higher than the other two materials. Although there is a slight increase in the pore ratio, which adversely affects corrosion, with the increase of the reinforcement element ratio, it is thought that the increase in the electrochemically more noble Al_2O_3 reinforcement is more effective in improving corrosion resistance. Lotto, R.T. and Babalola, P. [13] found similar results in a study on the corrosion properties of alumina-reinforced AA1070 aluminum alloy matrix composites. In the corrosion tests performed in acidic, salty and acidic/saline mixed environments, it has been reported that the corrosion rate decreases with the increase in the alumina reinforcement ratio.

4.CONCLUSIONS (SONUÇLAR)

In this study, the microstructure, density and corrosion properties of AA2024 aluminum alloy matrix composite materials produced by powder metallurgy method using hot pressing and reinforced with Al_2O_3 in three different ratios, 10%, 20% and 30%, were investigated, and the following results were obtained.

1. According to the microstructure images of the composite samples, it is seen that the Al_2O_3 reinforcement material is uniformly distributed in the structure, and accordingly, the powder metallurgy method is suitable for the production of this type of composite material.
2. In AA2024 aluminum composite samples reinforced with Al_2O_3, the composite material density decreased with the increase of Al_2O_3 reinforcement ratio to 30%. It is thought that the increase in the reinforcement ratio in the hard structure negatively affects the compressibility feature during pressing in production with powder metallurgy in this decrease in density.
3. The corrosion behavior of the composite materials at 20% and 30% Al_2O_3 reinforcement ratios are very close to each other, and their corrosion rates were lower than the composite materials with 10% Al_2O_3 reinforcement ratios. It is thought that Al_2O_3 reinforcement, which is more noble electrochemically to the aluminum matrix, is effective in decreasing the corrosion rate and improving corrosion resistance with the increase in the reinforcement ratio.

DECLARATION OF ETHICAL STANDARDS
(ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS’ CONTRIBUTIONS (YAZARLARIN KATKILARI)

***Hasan KARABULUT*:** He produced composite materials, measured the density, reviewed the results and contributed to the writing of the article.

Kompozit malzemeleri üretmiş, yoğunluğunu ölçmüş, sonuçları yorumlamış ve makalenin yazılmasına katkıda bulunmuştur.

***Kubilay KARACİF*:** He performed corrosion tests of composite materials, reviewed the results and contributed to the writing of the article.

Kompozit malzemelerin korozyon testlerini yapmış, sonuçları yorumlamış ve makalenin yazılmasına katkıda bulunmuştur.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

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