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Production and Investigation of Properties of Nickel Particle Reinforced AA5083 Matrix Metal-Metal Composites

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ABSTRACT

The aim of this study is to develop metal-metal composites reinforced with nickel powder using an AA5083 aluminium alloy matrix by powder metallurgy methods and to investigate their properties. In order to analyse the influence of different amounts of nickel particles on the AA5083-Ni composite, specimens were prepared by incorporating nickel at 5%, 10% and 15% by weight. To achieve a uniform distribution of nickel particles, the matrix and composite powders were mixed in ball mills for five hours. These powders were then hot pressed at 500°C under a pressure of 500 MPa for two hours in an argon gas atmosphere to produce the samples. These samples were then tested for microstructure, hardness, density, tensile properties and corrosion behaviour to assess the effect of varying nickel content on the AA5083-Ni metal-metal composites.

Keywords: Powder metallurgy, Metal matrix composite, Mechanical alloying, AA5083, Nickel

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Nikel Parçacık Takviyeli AA5083 Matrisli Metal-Metal Kompozitlerinin Üretimi ve Özelliklerinin Araştırılması

ÖZ

Bu çalışmanın amacı, AA5083 alüminyum alaşım matrisi kullanılarak toz metalurjisi yöntemleriyle nikel tozu takviyeli metal-metal kompozitler geliştirmek ve özelliklerini incelemektir. Farklı miktarlardaki nikel partiküllerinin AA5083-Ni kompoziti üzerindeki etkisini analiz etmek için, %5, %10 ve %15 ağırlık yüzdelerinde nikel eklenerek numuneler üretilmiştir. Nikel partiküllerinin homojen bir dağılımını elde etmek için matris ve kompozit tozlar bilyalı değirmenlerde beş saat boyunca karıştırılmıştır. Daha sonra, bu tozlar argon gazı atmosferinde iki saat boyunca 500 MPa basınç altında 500°C'de sıcak preslenmiş ve numuneler oluşturulmuştur. Bu numuneler daha sonra değişen nikel içeriğinin AA5083-Ni metal-metal kompozitler üzerindeki etkisini değerlendirmek için mikroyapı, sertlik, yoğunluk, çekme özellikleri ve korozyon davranışları açısından test edilmiştir.

Anahtar Kelimeler: Toz metalurjisi, metal matrisli kompozitler, mekanik alaşımlama, AA5083, Nikel

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1. Introduction

Aluminium Metal Matrix Composites (AMMCs) have attracted considerable attention in engineering and technology due to their remarkable properties such as light weight, high strength, exceptional wear resistance and excellent thermal conductivity. [1–4]. The production of AMMCs is aimed at obtaining a material with enhanced properties by combining the properties of the base alloy with those of the reinforcing particles. The AA5083 alloy, known as the lowest density series of aluminium alloys, has been identified as a suitable material for use in the aerospace and automotive industries due to its outstanding properties such as high strength, rigidity and wear resistance [1,2,5]. With an approximate magnesium content of 4%, AA5083 also exhibits high corrosion resistance, making it a preferred material in areas such as shipbuilding and pressure vessels. To date, research studies have reinforced AA5083 alloy with ceramic particles by casting, powder metallurgy and other conventional methods to further enhance its desired properties [2]. Leading these ceramic reinforcements are SiC, Al_2O3, B_4C, Graphene, and TiB_2[6–10]. However, due to some weaknesses caused by ceramic reinforcing particles, this strategy has been limited in improving the mechanical properties of aluminium alloys. The main drawback of such ceramic reinforcements is the low wettability between the reinforcement and matrix phases. In particular, due to the low wettability between the matrix and reinforcement phases, many studies aimed at developing ceramic particle reinforced metal matrix materials have reported interfacial bonding problems [6,11,12]. This low interfacial bonding prevents the material from achieving the desired strength values [3]. In addition, delamination and agglomeration of ceramic reinforcing particles are common problems. To overcome these problems, the idea of metal-metal composites has emerged in recent years and research has begun in this area. In metal-metal composites, since both the matrix and reinforcement phases are metals, strong bonding is expected due to intermetallic formation at the interfaces and the expected reactions between the matrix and reinforcement phases. In this context, previous studies have used Cu, Ni, Cr and 316L SS powders as reinforcing materials in metal-metal composites [3]. Among the materials under consideration, nickel stands out as one that has a positive impact on mechanical properties, corrosion resistance, and wear behaviour. The effect of nickel addition on the hardness and strength properties of metal matrix composites manifests through two different mechanisms. Firstly, nickel hinders dislocation movement, and secondly, it influences the grain size of the matrix phase. Furthermore, previous studies have shown that nickel passivates the material surface, protecting it against corrosion. These effects are just a few examples of the beneficial impacts of nickel addition in metal matrix composites. Nevertheless, it has been observed in certain studies that nickel reinforcement can result in the formation of nickel carbide, a brittle phase, which has a detrimental impact on the strength and ductility properties of the material. Consequently, nickel has both beneficial and detrimental effects on composite materials. The extent to which these effects prevail depends on the quantity of nickel present and the interactions between nickel and the matrix material. A review of the literature reveals numerous studies on the mechanical, corrosive, and tribological properties of AA5083 matrix ceramic particle-reinforced materials [13–15]. However, no studies have been found on metal particle-reinforced metal-metal composites with an AA5083 matrix. In this study, AA5083/Ni metal-metal composites were produced using the mechanical alloying method, and the effect of varying nickel content on the mechanical properties and corrosion behavior of AA5083/Ni composites was investigated.

2. Experimental Study

In this study, AA5083-Ni metal-metal composites were produced using the mechanical alloying method, an advanced stage of the powder metallurgy technique, and the effect of nickel reinforcement amount on the mechanical and corrosive properties of the composite was examined. AA5083 powders were used as the matrix phase, with their chemical composition shown in Table 1.

Table 1. Chemical Composition of AA5083

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
Composition wt. (%)	0.4	0.4	0.1	0.4-1.0	4.0-4.9	0.25	0.15	0.05-0.25	Balance

Firstly, composite powders containing 5%, 10%, and 15% by weight of Ni were prepared, and these powders were mechanically alloyed in high-energy mills for 5 hours. Subsequently, these samples were coded as A0 (unreinforced), A5, A10, and A15 respectively. After the mechanical alloying process, these powders were hot-pressed under a pressure of 500 MPa at 500°C for 2 hours in a protective argon gas atmosphere. After metallographic processing, the samples were examined for density/porosity, microstructure, hardness, and tensile strength from a mechanical perspective. The Brinell hardness values of the metallographically prepared samples were measured using an Innovatest-Nemesis 9000 model testing device according to ASTM E10-18 standards, applying a load of 31.25 kg with a 2.5 mm diameter indenter. Tensile strength tests of the samples were conducted using an MTS Criterion Universal testing machine at a tensile speed of 1 mm/min in accordance with ASTM E8 standards. Additionally, to examine the effect of Ni reinforcement on corrosive properties, potentiodynamic polarization tests were performed using a Gamry Reference 3000 corrosion test device following the guidelines specified in ASTM G59-97 standards. The corrosion tests were conducted in an aqueous solution of 3.5% by weight NaCl at room temperature. The corrosion potential (Ecorr) and corrosion current density (Icorr) values of each sample were determined to evaluate their corrosion performance. The flow chart of the experiments performed in this study is shown in Figure 1.

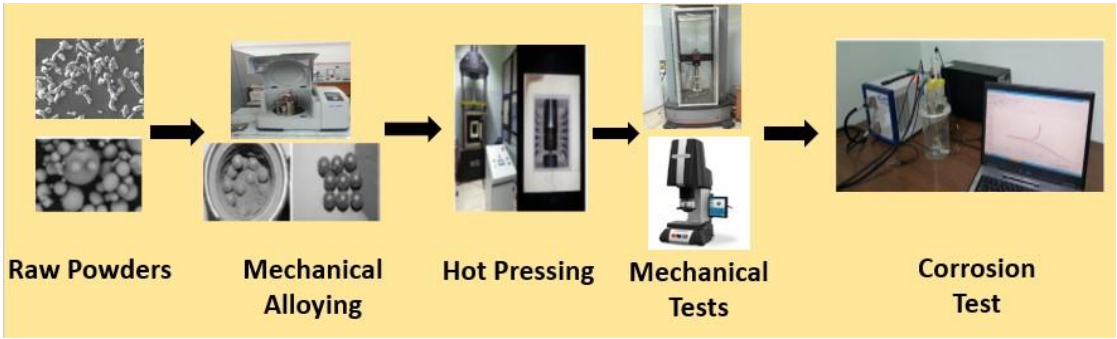

Figure 1. Flow chart of experimental study

3. Results And Discussions

3.1. Microstructural investigation

Microstructure images of samples containing nickel particles in different proportions are seen in Figure 2. In the microstructure images, white, light gray, and gray regions represent nickel, AA5083, and intermetallic phases, respectively. As seen from the images, nickel particles are homogeneously distributed within the structure, and an intermetallic phase surrounding the nickel particles is observed (Figure 2-d). An elemental mapping photograph is also available in Figure 2-e. In the photograph, the green coloured regions represent the Nickel phase and the red coloured regions represent the AA5083 phase. As seen in the photo, green areas are also seen around the pure nickel particles. These green areas are due to the intermetallic phase formed between Ni and AA5083. In other words, it is understood from the elemental map pictures that an intermetallic phase is formed around the nickel particles by dissolving the nickel phase in the AA5083 matrix. The formation of this phase is the most significant result expected in this study, as it is anticipated to improve the strength values through the formation of this interphase. Indeed, in the literature review related to composite materials, it is observed that the formation of an intermetallic phase, where two phases dissolve into each other as a result of the bond formation between reinforcement and matrix phases, is the most desired bonding structure. In previous studies on metal matrix composites, it has been stated that in composites consisting of metal matrix and ceramic reinforcement compositions, there is no good wetting and bonding at the metal/ceramic interface. Moreover, ceramic particles cannot improve the strength values to the desired extent by separating from the structure. In microstructure examinations, the formation of intermetallic at the interface is considered a positive result for the development and use of a new type of reinforcement in metal matrix composites, opening the way for further studies in this regard.

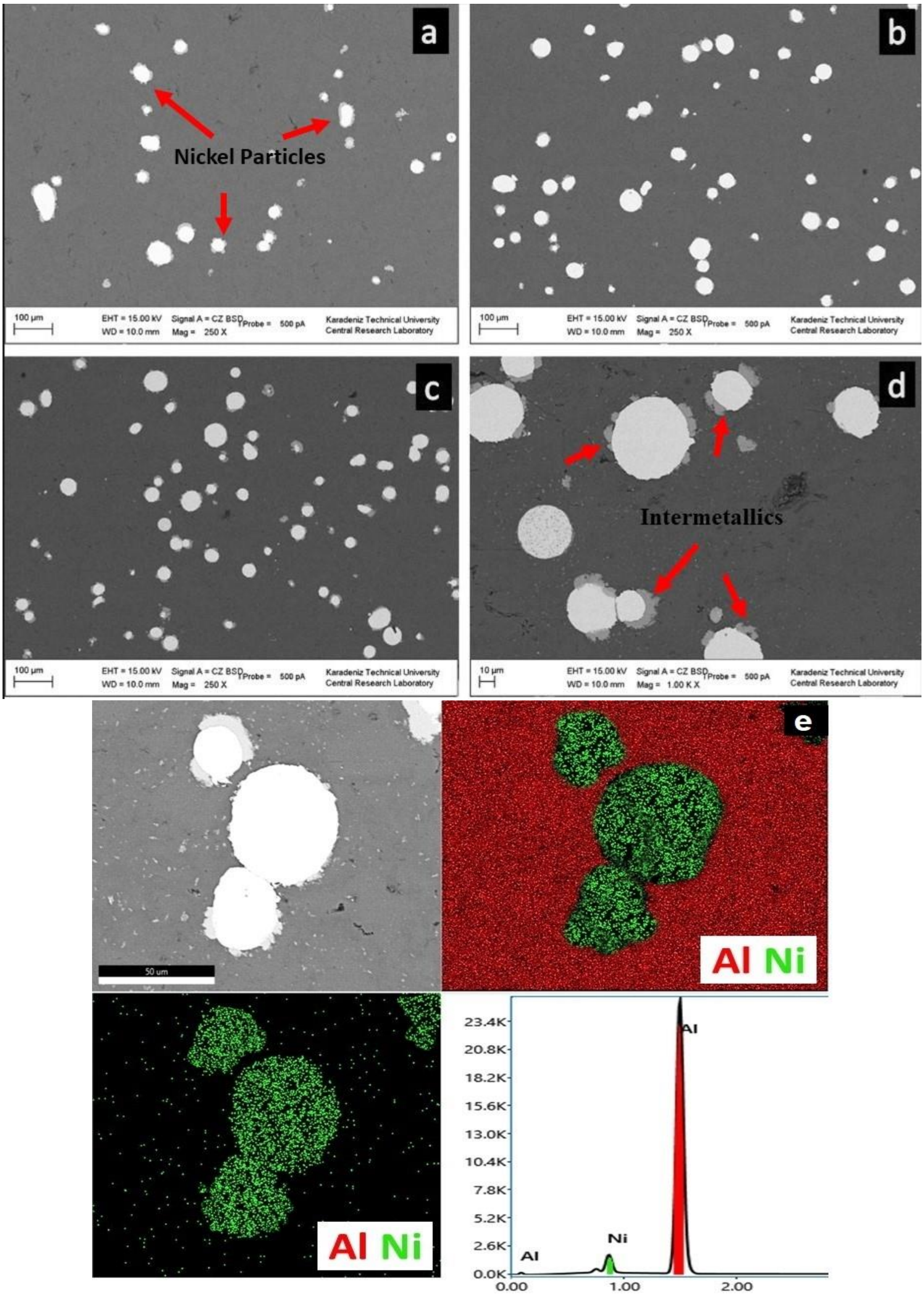

Figure 2. Microstructures of a) A5 b) A10 c) A15 samples (250x) d) high magnified microstructure of A15 (1000x) e)Elemental mapping of A15

3.2. Investigation of porosity and hardness

In Figure 3, graphs showing the changes in hardness and relative density of the samples depending on the increasing Ni content are presented. Firstly, examining the relative density curve, it is observed that the highest relative density value of 98% is obtained in the A0 sample, and this value decreases with the increasing Ni content, reaching the lowest value of 83% in the A15 sample. The relative density value is the inverse of porosity. In other words, a decrease in the relative density value indicates an increase in the porosity of the sample. In this study, the decrease in relative density with the increasing Ni content can be explained by the fact that nickel particles are harder than the AA5083 phase [3,10]. To explain comparatively, in the A0 sample, only AA5083 powders were pressed, achieving the highest relative density values. However, when Ni particles, which are harder than AA5083, were added to the structure, they resisted pressing and packing. As a result, the formation of micro-scale pores between the powders negatively affected the packing of the powders. Therefore, with the increasing Ni content, approximately 17% porosity was observed in the A15 sample. When examining the macro hardness of the samples, it was found that the lowest hardness value was obtained in the unreinforced A0 sample, while the highest hardness value was obtained in the A15 sample containing 15% nickel by weight. The primary reason for this change in hardness can be directly explained by the rule of mixtures, where the added nickel particles are harder than the AA5083 phase. To elaborate, the hardness of the AA5083 phase is approximately 85 Brinell in the literature, while nickel alloy hardness ranges from 125 to 250 Brinell. Thus, the high hardness of the nickel phase added as a reinforcement phase directly increased the hardness of the composite structure. However, it might seem contradictory that the nickel phase increases both hardness and porosity simultaneously since the general expectation is that increased porosity would decrease hardness. To explain this apparent contradiction in terms of hardness and porosity, it can be stated that the contribution of the nickel particles to hardness outweighs the negative impact caused by the increase in porosity.

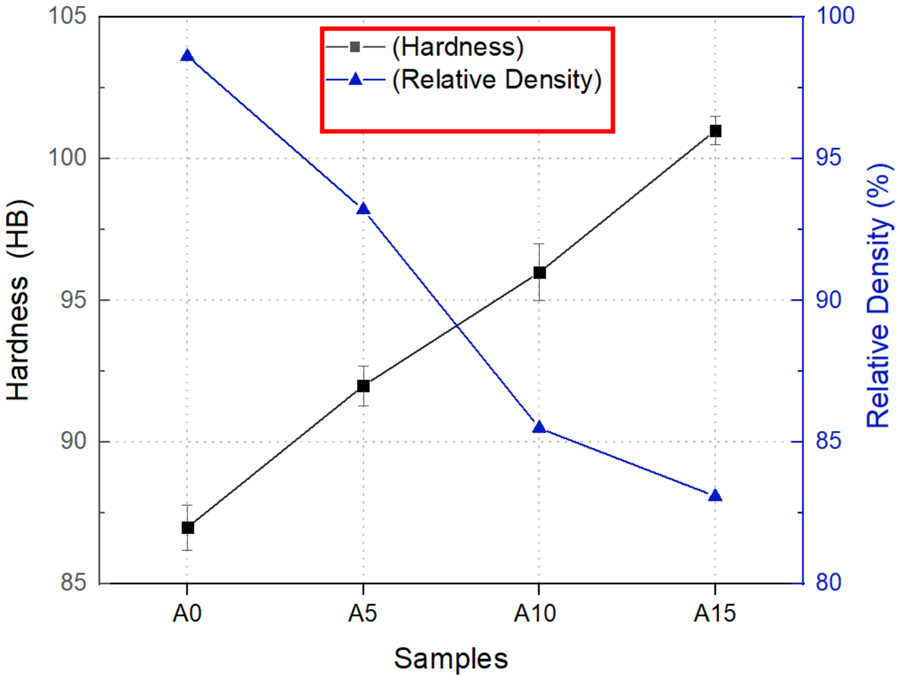

Figure 3. Graphs of the hardness and relative density of the samples

3.3. Tensile strength

Figure 4 shows the tensile stress-strain curves of the composite samples. Upon examination of Figure 4, it is observed that the highest tensile strength value is obtained in sample A15, while the lowest value is obtained in sample A0. However, it is noted that the elongation values decrease with increasing reinforcement content, indicating a decrease in ductility values. The increase in tensile strength with increasing Ni content can be attributed to the high elastic modulus of nickel, which is significantly higher than that of the AA5083 alloy, and its transfer of this property to the matrix material. In other words, the nickel particles added to the structure directly contribute to an increase in strength. However, porosity examinations have indicated that the increase in Ni content also increases porosity. It has been observed in literature studies that an increase in porosity leads to a decrease in strength values; hence, there appears to be a contradiction between porosity and strength values in this study. This phenomenon can be explained by the strength property of nickel, which is transferred to the composite structure and compensates for the loss due to porosity. Similar examples can be found in the literature. Another result obtained from tensile tests is the decrease in elongation with increasing nickel content. While the AA5083 alloy exhibits good ductility, the nickel particles added to the structure hinder dislocation movement, creating resistance to plastic deformation. Additionally, nickel particles can cause stress concentrations at matrix-matrix and matrix-reinforcement interfaces, further impeding plastic deformation and adversely affecting the ductility properties of the composite material.

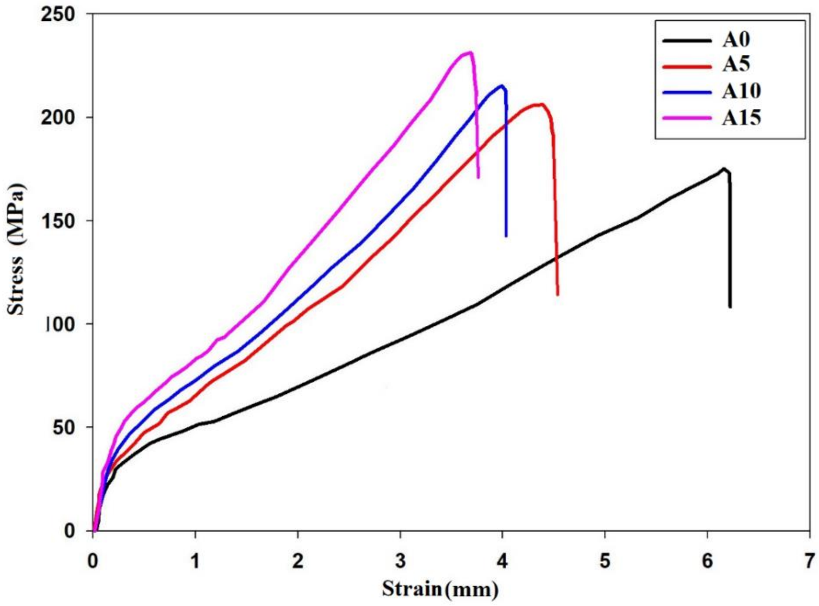

Figure 4. Stress-strain plots of samples

3.3. Investigation of corrosion

The Tafel plots and the numerical results obtained from these plots are given in Figure 5 and Table 2 respectively. Firstly, when we evaluate the samples in terms of corrosion potential, we see that the A10 sample has the highest Ecorr value (-695 mV). This indicates that it is in a more passive state compared to the other samples and has a lower tendency to corrode. When we examine the values for the A15 sample, we observe that it has the lowest Ecorr value, meaning that the A15 sample has the highest tendency to corrode. In terms of corrosion current density, the A5 sample has the highest Icorr value (9.00 µA/cm²), and therefore, the highest corrosion rate. The A15 sample, on the other hand, has the lowest Icorr value, indicating that it has the lowest corrosion rate. There is a contradiction between the Ecorr and Icorr values; while the A15 sample has the highest corrosion potential when evaluated in terms of Ecorr, it also has the lowest corrosion rate when evaluated in terms of Icorr. This situation is due to the high potential of the A15 sample to transition from a passive to an active state due to the influence of intermetallics in the structure, despite its low corrosion rate. The A0 sample has a moderate corrosion potential, and its corrosion resistance is better than that of the A5 and A10 samples but lower than that of the A15 sample. The A10 sample, with an Ecorr of -695 mV, has the most positive corrosion potential, meaning it has the lowest tendency to corrode. However, with a corrosion current density of 7.59 µA/cm², the A10 sample has a moderate corrosion rate, indicating that its corrosion resistance is lower than that of the A15 sample but better than that of the A5 and A0 samples. In conclusion, the A15 sample, despite having the lowest corrosion rate, should be examined carefully in the long term due to its highly negative corrosion potential. The A10 sample has the most positive corrosion potential, indicating the lowest tendency to corrode, but it has a moderate corrosion rate. The A5 sample has the highest corrosion rate and the lowest corrosion resistance. The A0 sample, in general, has moderate corrosion resistance and rate. These analyses provide important insights into the corrosion resistance and behavior of each sample in a given environment.

Table 2. Corrosion potential (Ecorr) and corrosion current of the samples obtained from Tafel plots

Sample Code	**Ecorr (mV)**	**Icorr (μA)**
A0	-746	5.33
A5	-723	9.00
A10	-695	7.59
A15	-749	3.35

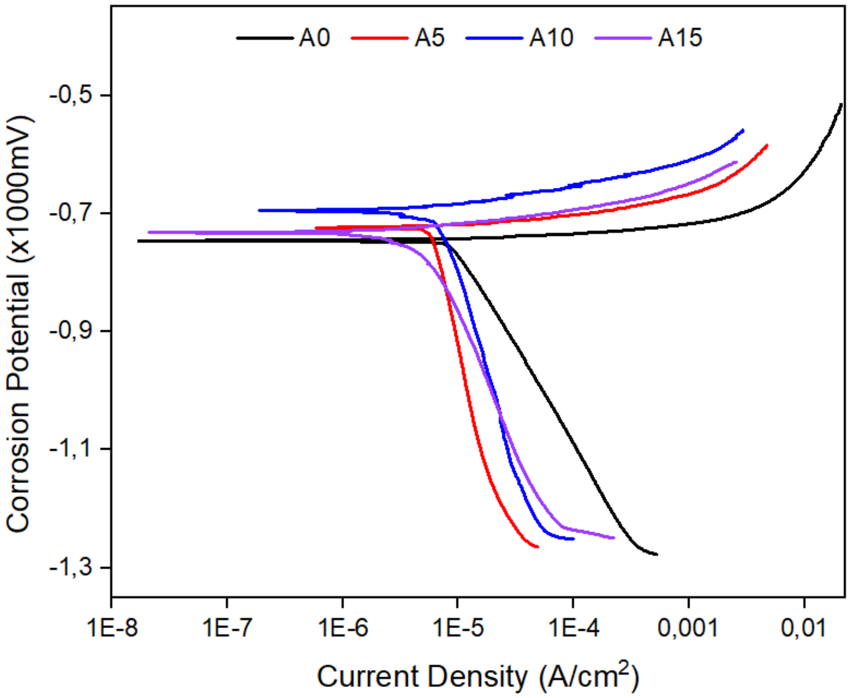

Figure 5. Tafel plot of the A0, A5, A10 and A15 samples in 3.5 wt.% NaCl solution

4. Conclusions

AA5083-Ni matrix metal-metal composites were successfully produced using the powder metallurgy method, which involves compacting and sintering metal powders to create a solid material. This method proved effective in achieving a uniform distribution of nickel particles within the AA5083 matrix. The homogeneous dispersion of nickel particles was evident in the microstructure, where an intermetallic phase formed between the nickel particles and the AA5083 matrix, indicating a strong bond and interaction between the two components. The study revealed that increasing the nickel content in the composites had a significant impact on their mechanical properties. Specifically, higher nickel concentrations resulted in increased hardness values. This enhancement in hardness can be attributed to the presence of the hard intermetallic phases and the reinforcement effect of the nickel particles. However, a trade-off was observed, as the relative density values of the composites decreased with higher nickel content. This decrease in density might be due to the introduction of porosity or voids during the powder metallurgy process, which could not be entirely eliminated. Furthermore, the tensile strength of the composites improved with the addition of more nickel. This increase in tensile strength suggests that the nickel particles effectively reinforced the AA5083 matrix, enhancing its ability to withstand tensile loads. On the other hand, the elongation values of the composites decreased as the nickel content increased. This reduction in ductility is likely a consequence of the brittleness introduced by the intermetallic phases and the reduced capacity of the composite to undergo plastic deformation. Corrosion resistance was another critical aspect evaluated in the study. The A15 sample, with the highest nickel content, exhibited the highest corrosion potential when assessed in terms of the corrosion potential (Ecorr). This indicates that the A15 sample was more resistant to corrosion compared to the other samples. Conversely, the A10 sample showed the lowest tendency to corrode, suggesting that its corrosion resistance was the least effective among the samples tested. These findings highlight the complex interplay between nickel content and the various properties of AA5083-Ni composites, providing valuable insights for optimizing their composition for specific applications.

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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