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Preparation and Investigation Mechanical Properties of Functionally Graded Materials of Aluminum-Nickel Alloys

Saad Hameed Al-Shafaie[†], Nabaa S. Radhi[†], Massoud Aziz Hussein[‡]

[†]University of Babylon/ Collage of Materials Engineering

[‡]Iraqi Ministry of Interior

Author Email: saadalshafaie8@gmail.com; dr.nabbaa@gmail.com; massoud.aziz85@gmail.com

ABSTRACT: Functionally graded material (FGM) is new generations of composite materials where the properties are changed linearly according to the change in composition. This research presents the design, fabrication and characterization of multi AlNi alloys incorporated into single functionally graded materials. By using powder metallurgy method, FGM (Al-Ni) have been successfully fabricated. FGMs samples consist of 5 layers where these layers start with Al on one side and end with Ni on the other side. In this study, the samples of FGM (Al-Ni) were produced consist of as follows with percent: (100 Al, 25 Ni-75Al, 50Ni-50Al, 75Ni-25Al and 100Ni) wt%. The samples were pressed with a load of 800 MPa and sintered at temperature 600°C for 3 hours. The hardness and compression test were performed to study the mechanical properties of FGM (Al-Ni) sample. Finally, FE-SEM images, has been taken for the sample to discuss the morphological aspects to validate the developed material.

KEYWORDS: Functionally graded materials, aluminum-nickel alloy, powder metallurgy, FE-SEM images, hardness and compression test.

INTRODUCTION

Functionally graded materials (FGMs) are materials whose properties are graded from one side to other, depending on the development of chemical composition and /or microstructure. FGMs are composite of multi-phase microstructure. Nature is always a source of inspiration for solving many problems by researchers and scientists. FGMs are produced in several ways, the most important of which is powder metallurgy and it is one of the simplest technique out of them [1].

Aluminum-based alloys are of scientific as well as technical value, like Al-Ni. They combine low weight with high temperature resistance and high strength. The creation of intermetallic phases is caused by nickel addition to aluminum or aluminum addition to nickel. The chemical composition and morphologies of these intermetallic phases depend on material's thermal history and added content [2,3]. In the AlNi system, there are five distinct intermetallic compounds that may exist, namely Al_3Ni, Al_3Ni_2, AlNi, Al_3Ni_5 as well as $AlNi_3$ [4,5]. The intermetallic crystals have distinct properties than the surrounding metallic matrix because it have chemical bond between it's atoms. The high hardness of Ni-Al intermetallic has the ability to enhance the hardness, wear resistance and strength of pure aluminum [6,7]. Such intermetallic phases are also stable at elevated temperatures and can the applications of aluminum alloy at high temperatures[8,9]. As the yield strength of the compound $AlNi_3$ increases anomalously when the temperature increases, the nickel-rich portion of the Al-Ni phase diagram is of fundamental interest to nickel-based super alloys [10]. Nickel - Aluminum system is of particular interest due to their use in the manufacture of aviation and space equipment units and parts, such as aircraft fuselage covers, fuel injectors, screw components, rocket engine nozzle components, etc.[11] .There are some studies concerned with the aluminum-nickel system and explained the influence of mechanical properties. Cintas J. et al., 2005 studied the fracture behavior and microstructure of aluminum with addition 1 % Ni where it was prepared by the Powder Metallurgy [12]. Funda G. K. et al., 2014 conducted a study about Al-Ni alloys with different nickel contents (1 - 5 In this study, the effects of nickel on the hardness, tensile strength and wear resistance of aluminum were studied [13].

EXPERIMENTAL DETAILS

In this work, FGMs compact samples were manufactured from aluminum and nickel materials using the powder metallurgy method. The particle size for nickel powder was(9.922 µm) and for aluminum was (18.3µm). The FGMs samples consist of five layers, the first layer 3mm thickness is made from pure aluminum. The second layer of 2.5 mm thickness is made from (25 Ni-75Al) %, the third layer of 2 mm thickness is made from (50 Ni-50 Al) % and the fourth layer of 1.5 mm thickness is (75 Ni-25Al) % and fifth layer of 1mm is made from pure nickel. The materials used to prepare each layer are mixed with the pre-defined weight percentages. The time of mixing was set constant for all samples (30 minutes). The constituents of powders were arranged according to the volume fraction of layers starting from aluminum to nickel as shown in figure (1). Functionally graded material samples were made 10 mm in length and 10 mm in diameter. After weighing the powder and mixing, the samples were pressed with a force of 800 MPa with a Spanish-made press device. Then the all samples were sintered at temperature 600 °C and using the vacuum furnace. The samples sintered by heating them to 400°C at rate 10ºC/min and are held for 1 hours then it heated to 600° C for 3 hours. In order to avoid the possible SHS procedure and preserve the original shape, the heating rate was less than 10 °C/min during the whole process**.**

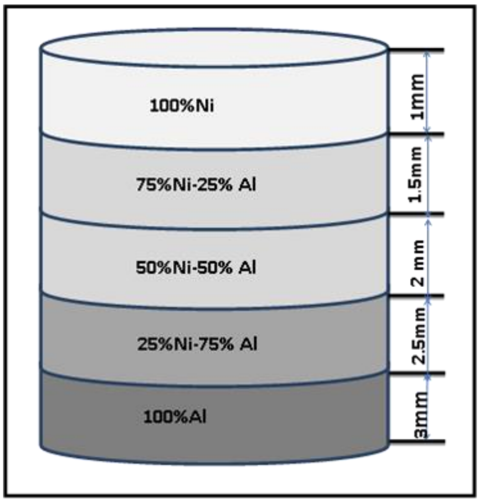


Figure 1. Schematic diagram shows the dimensions of each layer of FGM sample.

After sintering process the samples was take to produce mechanical tests such as micro Vickers hardness and compression. The indentation load in microhardness test was 2.94 N a 60-second period. To study the mechanical properties and their effect by adding nickel to aluminum or vice versa, the compression test was performed. The samples have been prepared with (10 mm) diameter and (20 mm) high. For the purpose of preparing the FGM sample for hardness testing and FE-SEM inspection was cut in half as shown in the figure (2).

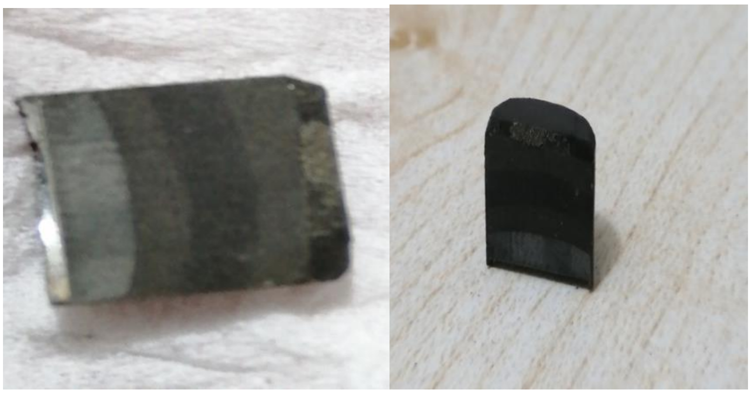


Figure 2. shown the cutting of FGM sample

RESULTS

Measurements of the hardness

Micro Vickers hardness tester was used to measure the hardness of the samples. The indentation load was 2.94 N for period time 60 Sec. Hardness tests were carried out to understand the effect of nickel on the hardness of pure aluminum or vice versa, as well as to know the hardness of each layer. As seen in figure (3) the hardness value of the sample goes up with the increase in the nickel content. The reason for the increased hardness is due to the formation of intermetallic compounds in samples. Moreover, the hardness of nickel is too much higher than the hardness of aluminum.

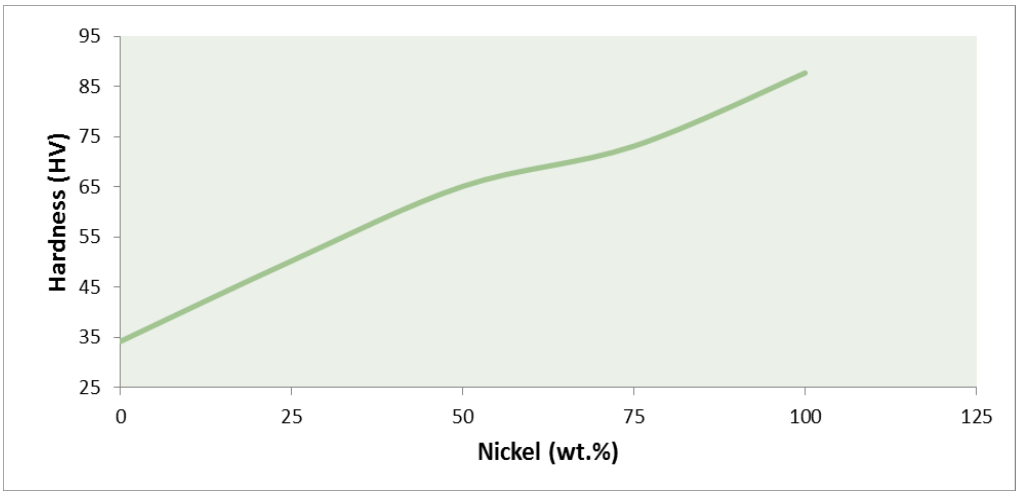


Figure 3. Effect of nickel content on hardness

The micro-hardness distribution at the interfaces of Al/Ni functionally graded materials (FGM) and across the layers is illustrated in figure 4. An increase in hardness is observed, as expected, with the rise in nickel content. Where we notice the presence of a gradient in the hardness of the aluminum side to the side of the nickel. The reason for this increase in hardness is due to the intermediate phases that have developed.

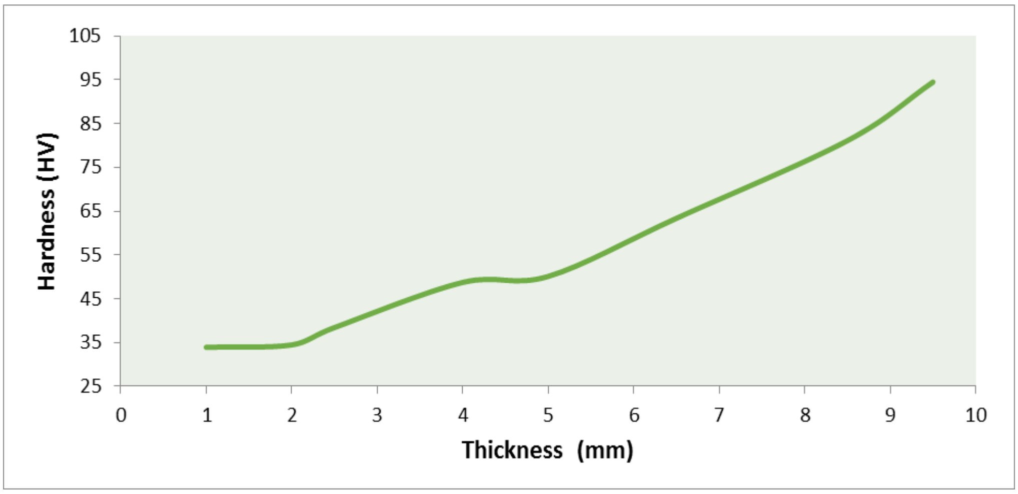


Figure 4. Micro-hardness along the thickness of FGMs

Compression test

The results of compression test of stepwise Al/Ni FGM compact specimen and each layer is shown in figures. Figure (5) illustrates the yield stress of Al/Ni FGM compact specimen compared to each layer. The highest yield stress value was the fifth layer that it consists of (100% Ni), the yield stress value of Al/Ni FGM compact specimen approaches the value of the fifth layer and this is considered a major advance in mechanical properties compared to those of the first layer that consists of (100% Al).

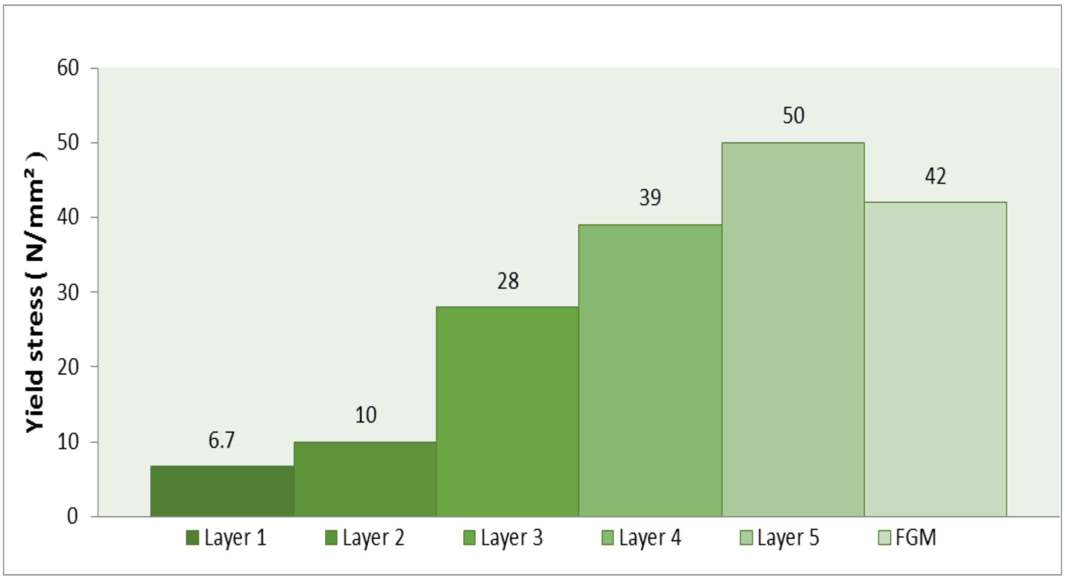


Figure 5. shown the yield stress of layers and FGM sample

Figure (6) illustrates the ultimate stress of each layer compared to Al/Ni FGM where it appears that the highest value in ultimate stress was recorded for layer 5 . The ultimate stress value of Al/Ni FGM closes to the value of the ultimate stress of the fifth layer. Figure (7) shows Young's modulus of layers and FGM sample. Where the value of Young's modulus of nickel was (211 Gpa), while that of aluminum was (73 Gpa) the rest of the values for other percentages of nickel-aluminum compact fall between these two values.

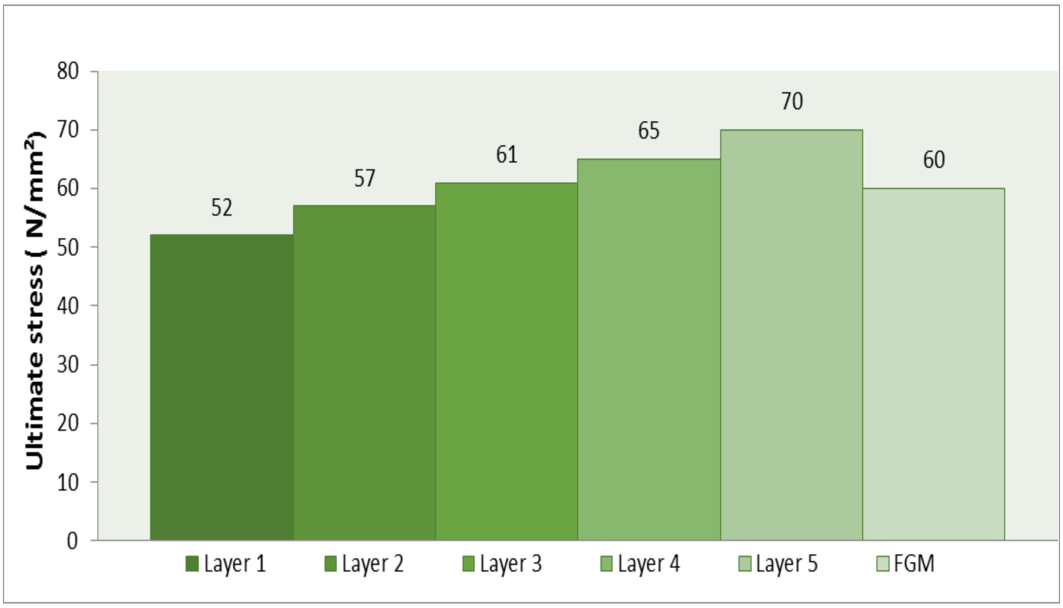


Figure 6. shown the ultimate stress of layers and FGM sample

Chemical composition and microstructure examination

By using energy - dispersive spectrometer (EDS), scan of elements was conducted on the sintered specimen (for each layer alloys and FGM). The results are illustrated in the figures (8(a to e)). As can be noted, the outcomes of EDS analysis were relatively close from the percentage of addition, because the values gained from EDS analysis do not cover the whole area , just the place where the electron stroke [14].

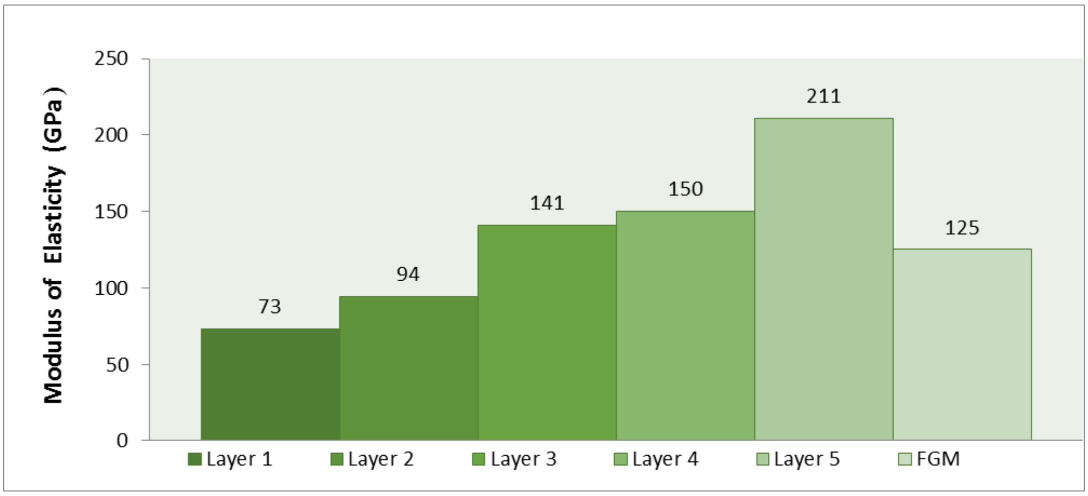
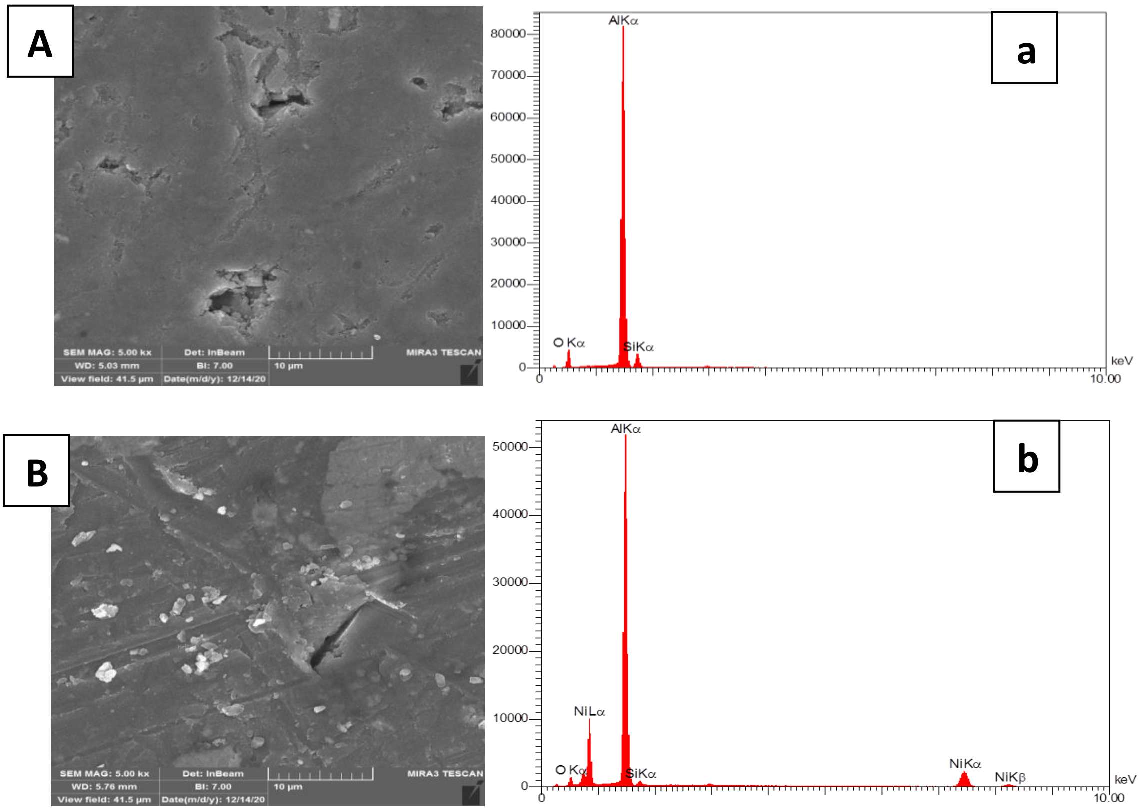


Figure 7. shown the Young's modulus of layers and FGM sample

The EDS also provides no proof of elements other than Ni and Al. Furthermore, the EDS results aid in verifying the purity of the initial elemental powders as well as the prevention of contamination of the powders during mixing and the production of sintering samples..



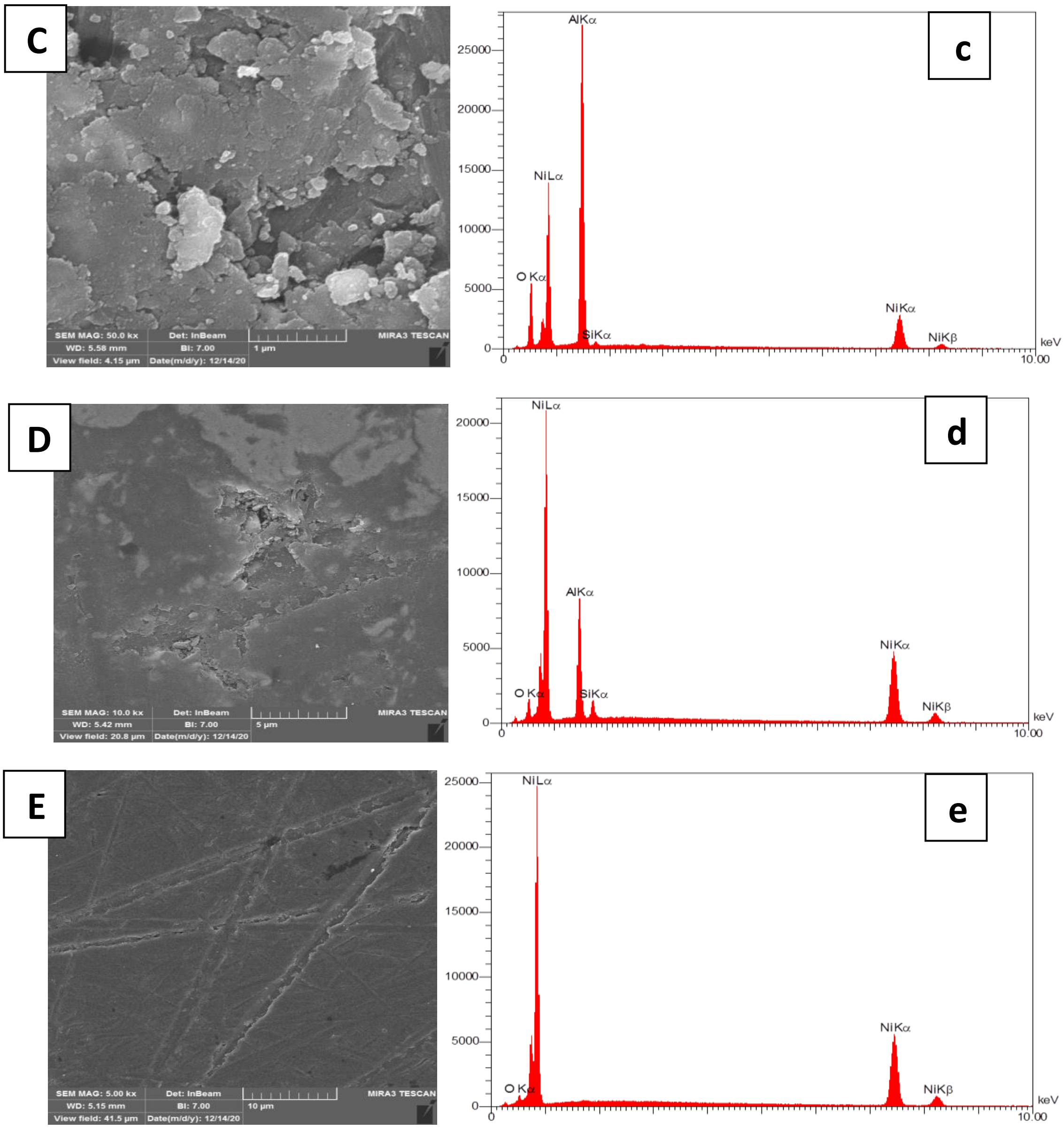


Figure 8. FE-SEM micrographs and EDS analysis of the intermetallic phases in each layer: (a) layer 1, (b) layer 2, (c) layer 3, (d) layer 4 , (e) layer 5.

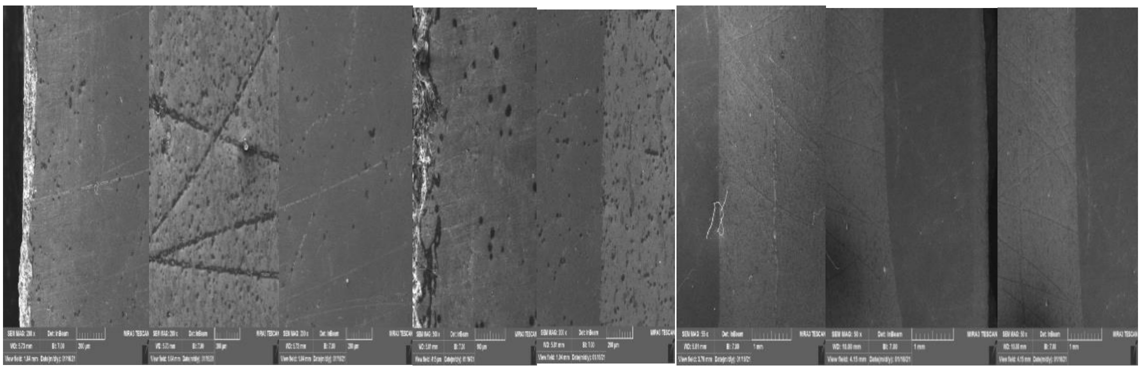


Figure 9. FE-SEM micrographs of the interface btween layers in FGM sample

In scanning electron microscope, beam of electrons have relatively high-energy is scanned through the sample's surface. The primary electrons transfer energy to the material through its penetration the surface similar to how X rays and ions work in SIMS and XPS, respectively. The incident electrons transfer enough energy for electrons (secondary electrons) to be emitted from the specimen (figures 8 and 9). The secondary electrons intensity primarily depends on the surface topography. The electron beam scans the samples and determines the current generated from secondary electrons, surface images are obtained (figures 8 and 9). In contrast to the methods mentioned previously, providing chemical information on the surface, scanning electron microscope generally provides images reflecting topography of the surface. The microstructure image by (SEM) for sintering layer and functionally graded samples (3 hr at 600 °C) have been shown in figures (8(a to e) and 9)). Pores of different size are no longer cusp-shaped and are irregular but have become rounded. The transition in microstructure form that of green compacts to that of sintered compacts is a function of sintering time and temperature.

CONCLUSION

The following conclusions have been drawn, according to the current study:

- Al-Ni (FGMs) successfully fabricated by powder metallurgy and sintered at 600°C.
- Hardness of Al-Ni alloys increases with increasing nickel content.
- Young's modulus of the fifth layer (100% nickel) was (211 Gpa), while that of first layer (100% aluminum) was (73 Gpa) and the rest of the values for other layers fall between these two values so with increase nickel content increase Young's modulus of the alloy.
- The yield stress and ultimate stress value of Al/Ni FGM compact specimen approaches the value of the fifth layer and this is considered a major advance in mechanical properties.

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