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Preparation and investigation of microstructure and wear properties of functionally graded materials of Aluminum-Nickel alloys

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Abstract A functionally graded material is a high-performance engineering material that can withstand extreme working conditions without losing its properties or failing during operation. The design, fabrication, and characterization of Al-Ni integrated into single functionally graded materials are presented in this study. FGM (Al-Ni) have been successfully fabricated using the powder metallurgy process. FGMs samples are made up of five layers, starting with Al on one side and ending with Ni on the other. The FGM (Al-Ni) samples used in this research were made up of the following percentages: (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. In this research we applied the wear test and X-ray analysis of FGM (Al-Ni) samples where the intermetallic phases that formed were ($AlNi_3$, $Al_{0.9}Ni_{1.1}$, Ni_5Al_3, Al_3Ni_2, Al_4Ni_3, $AlNi$,), in addition to optical microscopy images.

1. Introduction

There are many problems that have been solved by researchers by extrapolating ideas from nature. Functionally graded materials have been extracted from nature, bamboo for example consists of several layers, where through these layers the properties are graduated, as well as teeth, wood and bones [1]. Pure metals are always less used because most engineering applications and designs require conflicting properties, for example hardness and ductility are two conflicting properties, therefore, when the design is intended with the presence of these two properties, pure materials are outside the designer's thinking, and the role of composite materials comes, which functionally graduated materials are part of. Development in functionally graduated materials began in Japan in the 1980 to reuse rocket engines to increase adhesion and reduce thermal stresses by coordinating materials (metal-ceramic) functionally graduated.

These materials (Al/Ni alloys) have an important and vital role in the field of aircraft, space shuttle and automobiles [2-6]. The preparation and design of these materials is carried out in several ways, and one of these methods is powder metallurgy [7,8]. Many researchers have important and valuable research in this aspect. Elisa Fracchia et al, 2019, fabricated FGM samples based on Al–Si alloys. In this paper, it is discussed in terms of microstructure and mechanical testing, with a special emphasis on the characterization of the joint between the two alloys using impact testing [9]. Shaodong Hu et al, 2018, studied Fabrication of aluminum alloy functionally graded material using directional solidification under an axial static magnetic field. Al-Zn, Al-Ni and Al-Cu alloys with a hypereutectic composition were selected to produce FGMs [10]. Saad Hameed Al-Shafaie et al, 2021, prepared (Al/Ni) functional graded materials where the effect of nickel percentage was studied, as well as a hardness and compression test of each layer of the sample [11]. In this paper, attempts have been made to fabricate Al-Ni FGMs, which will expand the application of the technology. Also, the X-ray diffraction (XRD) analysis, microstructure characterization, and wear-resistance along the graded direction are investigated.

2. Experimental details

Aluminum powder with a mean particles size of 18.3 µm and density (2.7 g/cm³), and nickel powder with a mean particles size of 9,922 µm and density (8.9 g/cm³), were used for the preparation of the suspensions. The purity of both powders was 99.98%. The compositions of the powder mixtures and high of each layers are listed in Table 1. Each layer's powders were weighed and mixed in a ceramic cup. Electro–mechanical mixer, this was used for wet mixing the metal powders. After testing for homogeneity by hand, place them in the mold in an orderly fashion and press the mixed powder into a green compact. The green compact was pressed in a cylinder die, with diameter of 10 mm and high of 10 mm. Samples were sintered in a vacuum furnace at 600 °C for 3 hours, and then the furnace was turned off.

Table (1): shows weight composition distributions of Al–Ni for FGM samples.

Layer number	Thickness layer (mm)	Layer weight percentage	
	-	Al%	Ni%
1	3	100	0
2	2.5	75	25
3	2	50	50
4	1.5	25	75
5	1	0	100

After the sintering process, FGM sample was cut to prepare it for any inspection or test. The samples are backed by epoxy to prepare them for testing. These samples were examined after grinding of up to 3000 grit. Wear test is done using (Pin-on-disc) apparatus. This apparatus contains a disc of steel turning with a speed of (950) r.p.m. It contains horizontal balance lever with rectangular section, has a special part to fix the sample and balance load. X-ray spectroscopy was used to analyze the elemental distribution of nickel and aluminum in the sample cross section. After the wear test, each layer of a sample was imaged by light optical microscopy to study the damaged surface of each layer.

3. Results and Discussion

3.1 Microstructure

Figure (1) shows the cut section of a fabricated Al/Ni FGM. It has five layers: a pure Al layer and three Al/Ni composite layers containing, respectively (25, 50, 75) wt.% of Ni content and a pure Ni layer. Since the contents of FGMs vary in each layer, the layers must be made up of a variety of phases. The X-ray diffraction patterns (XRD) from the surface of the cross-section for the layers of (Al/Ni) FGM after the presureless sintering under vacuum at 600 °C for 3 hours are shown in figure (2).

Figure 1. shown the section of a fabricated Al/Ni FGM sample.

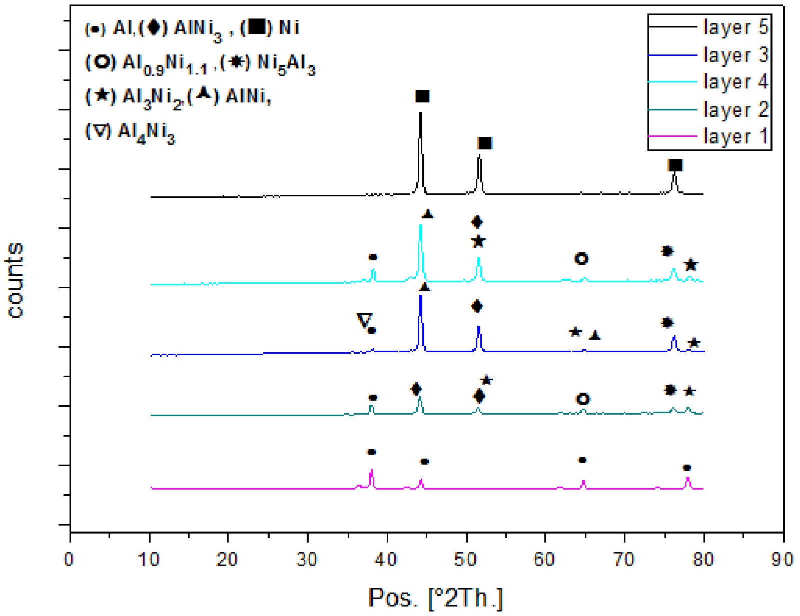

Figure 2. Comparative XRD pattern of each layer in (Al/Ni) FGM.

The diffracted peaks were recorded from 20 to 80°. Figure (2) represents an X-ray analysis of the first layer, which is made of pure aluminum and the second layer, where we notice the formation of the intermetallic phases ($AlNi_3$, $Al_{0.9}Ni_{1.1}$, Ni_5Al_3, Al_3Ni_2). The intermetallic phases that are formed in the third layer are (Al_4Ni_3, AlNi, $AlNi_3$, Al_3Ni_2, Ni_5Al_3). As for the fourth layer, we notice the intermetallic phases (AlNi, $Al_{0.9}Ni_{1.1}$, $AlNi_3$, Al_3Ni_2, Ni_5Al_3). The fifth and final layer, which consists of pure nickel.

3.2 Wear test

The microstructural constituents have a great effect on the tribological properties of alloys. The amount, size, morphology and type of the phases in the microstructure greatly control the sliding wear properties of materials. The sample of FGM and Al-Ni alloys subjected to wear test for different times (5, 10 and 15) min and under various loads (5, 10 and 15) N at room temperature. The wear test results are shown in the following figures (3,4 and 5). From these figures it is clear that the rate of wear increases with the increase in the applied load. The reason is with increasing the load, the friction increases between the sample surface and rotating disc. Also, the wear rate increases with increasing time due to the continuous loss of sample particles with increasing friction time. From the figures, it is clear, that the wear rate of second layer at (5 min) load time and under (5 N) applied load was (5.9 mm^3) and it is the highest compared to the other layers which the lowest value in fifth layer (1.2 mm^3). With increase applied load and/or time, the wear rate of fourth layer increases significantly which it is (415.9 mm^3) at 15 min and under 15 N. Figure (3) shows the wear test under a load of 5, 10 and 15 N and for a period of 5 minutes for FGM sample and for all layers.

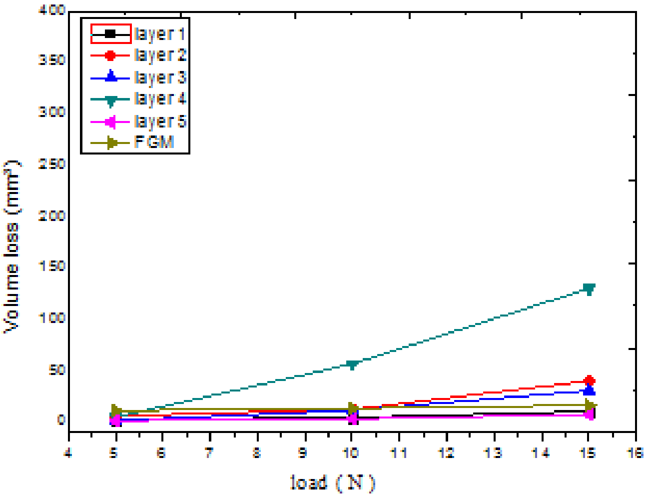

Figure 3. wear rate for FGMs sample and each layer for 5 minutes.

Figure (4) shows the wear test under a load of 5, 10 and 15 N and for a period of 10 minutes for FGM sample and for all layers.

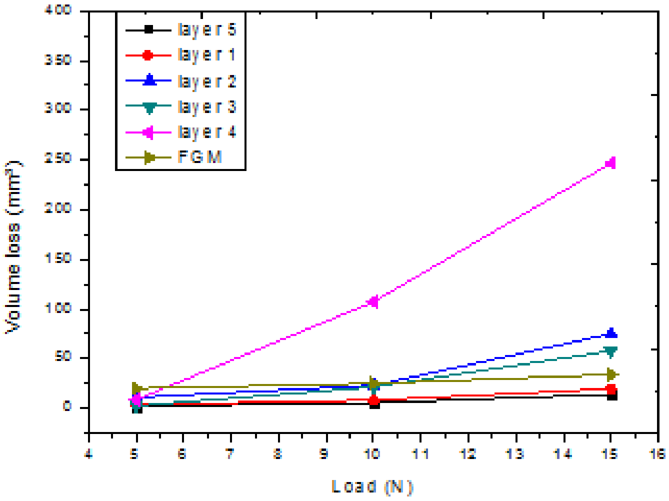

Figure 4. wear rate for FGMs sample and each layer for 10 minutes.

Figure (5) shows the wear test under a load of 5, 10 and 15 N and for a period of 15 minutes for FGM sample and for all layers.

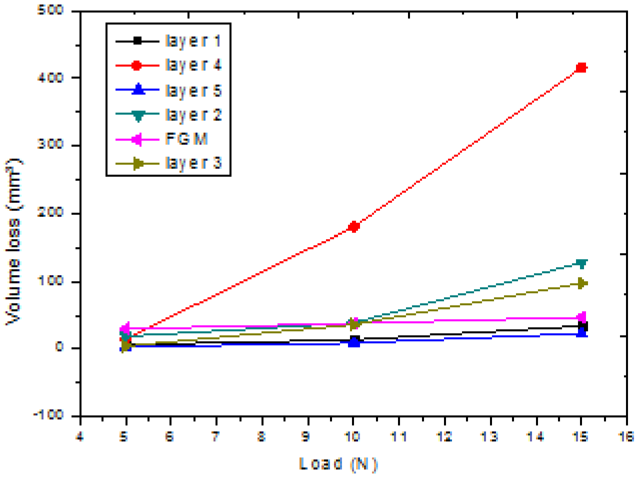

Figure 5. wear rate for FGMs sample and each layer for 15 minutes.

The figures indicate the wear rate of (Al/Ni) FGM sample. The wear rate at (5 min) test time and under (5 N) applied load was (11.24 mm³) while at (15 min) and under (15 N), the wear rate was (47.15 mm³). This result is good indicator where with increasing of test time and applied load, the wear rate does not significantly increase with compared to other layers.

Figures (6) shown the optical microscope images for the first layer, second layer, third layer, fourth layer and fifth layer respectively.

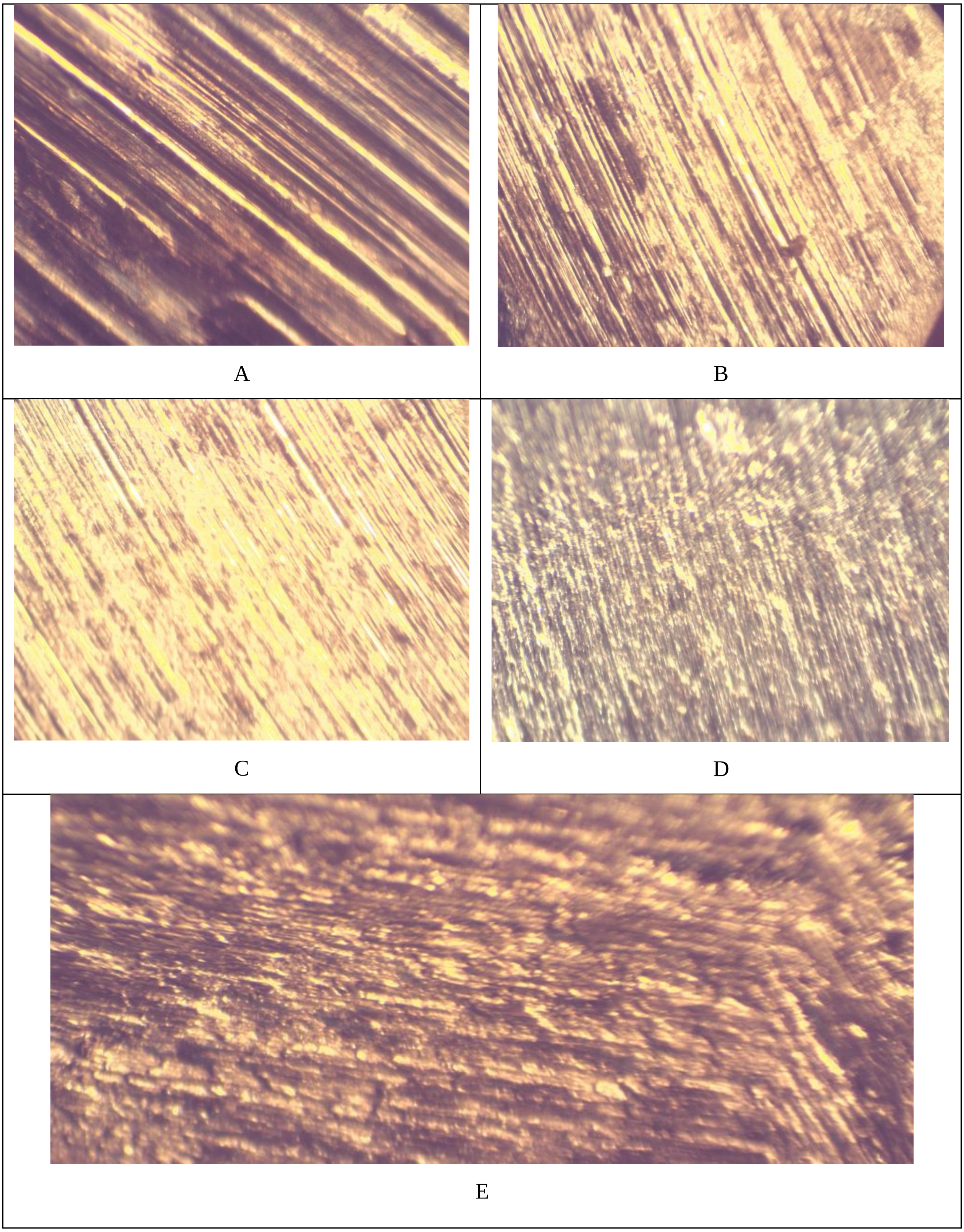

Figure 6. Optical microscope images for each layer in FGM sample, (A) for the first layer, (B) for the second layer, (C) for the third layer, (D) for the fourth layer and (E) for the fifth layer.

4. Conclusion

- Functionally graded materials (FGMs) of aluminum-nickel has been successfully fabricated by powder metallurgy technology and sintered at 600°C for 3 hours.
- Investigations of the microstructure showed that most of the particles of Al and Ni were not melted but bound to each other.
- Although the sintering temperature that was used is low (600 °C) compared to the melting point of nickel, we find that the nickel powder is well sintered.
- We notice the formation of the intermetallic phases ($AlNi_3$, $Al_{0.9}Ni_{1.1}$, Ni_5Al_3, $Al_3Ni_{2,}$ Al_4Ni_3, AlNi,),) as wll as Al and Ni.
- The wear rate of second layer at low load time and under low applied load is the highest compared to the other layers which the lowest value in fifth layer but with increase applied load and/or time, the wear rate of fourth layer increases significantly.
- The wear resistance of (Al/Ni) Functionally graded materials is the best compared to Al/Ni system alloys.

References

[1] Matthew T. Tilbrook, Robert J. Moon, Mark Hoffman, Finite element simulations of crack propagation in functionally graded materials under flexural loading, Eng. Fract. Mech. 72 (2005) 2444–2467.

[2] T. Hirai, L. Chen, Recent and prospective development of functionally graded materials in Japan, Mater. Sci. Forum 308–311 (1999) 509–514.

[3] Michael M. Gasik, Functionally graded materials: bulk processing techniques, Int. J. Mater. Product Technol. 39 (1/2) (2010) 20–29.

[4] Ankit Gupta, Mohammad Talha, Recent development in modeling and analysis of functionally graded materials and structures, Prog. Aerosp. Sci. 79 (2015) 1–14.

[5] Minoo Naebe, Kamyar Shirvanimoghaddam, Functionally graded materials: A review of fabrication and properties, Appl. Mater. Today 5 (2016) 223–245.

[6] Rityuj Singh Parihar, Srinivasu Gangi Setti, Raj Kumar Sahu, Recent advances in the manufacturing processes of functionally graded materials: a review, Sci. Eng. Compos. Mater. (2015) 0395.

[7] Emilio Carlos Nelli Silva, C. Matthew, Walters, H. Glaucio, Paulino, Modeling bamboo as a functionally graded material: lessons for the analysis of affordable materials, J. Mater. Sci. 41 (2006) 6991–7004.

[8] T. Sadowski, M. Boniecki, Z. Librant, K. Nakonieczny, Theoretical prediction and experimental verification of temperature distribution in FGM cylindrical plates subjected to thermal shock, Int. J. Heat Mass Transf. 50 (2007) 4461–4467.

[9] Elisa Fracchia, Federico Simone Gobber, Mario Rosso, Marco Actis Grande, Jana Bidulsk, Róbert Bidulsk, Junction Characterization in a Functionally Graded Aluminum Part, Materials 2019, 12(21), 3475; https://doi.org/10.3390/ma12213475.

[10] Shaodong Hu, Annie Gagnoud ,Yves Fautrelle ,Rene Moreau, Xi Li, Fabrication of aluminum alloy functionally graded material using directional solidification under an axial static magnetic field, 7945 (2018).

[11] Saad Hameed Al-Shafaie ,Nabaa S. Radhi ,Massoud Aziz Hussein , "Preparation and investigation mechanical properties of functionally graded materials of Aluminum-Nickel alloys" , ISSN :1024-1752 ,VoL 44 ,No. 4 ,PP. 102-109.