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EFFECTS OF NI ADDITIVE ON FATIGUE AND MECHANICAL PROPERTIES OF AL-CU ALLOY MANUFACTURED USING POWDER METALLURGY

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Abstract

As it is known, aluminium-coper alloys are used for many applications of our life, such as within the aeronautic industry, which only further emphasises the necessity of improving and better understanding alloys' mechanical properties. This can be seen when adding nickel changes the alloy's mechanical characteristics significantly for copper alloys used in the aromatic industry to improve the mechanical characteristics. In this study, the effect of the nickel additive is studied experimentally and numerically. Al-Cu Ally was made of Al-Cu-2 per cent alloy and Al-Cu-3 per cent Ni composites based on powder metallurgy technology. For mixing powders, 4 hours of ball friction, cold compression and sintering are used at 550°C for 1 hour. Argon gas was used as a frying or sintering environment. In this paper, the microstructure research involves an optical microscope (O.M.), an electron-scanning microscope (M.E.) and X-ray diffraction (XRD). Also, mechanical features, including hardness, compression and fatigue strength testing of Rockwell, determined the Ni additive effect on the al-Cu alloy. The results show that the Al-Cu composite's hardness and compressive strength is improved compared with the base Al-Cu alloy. The XRD results supported this increase in mechanical properties due to intermetallic compounds (new phases) during sintering processes such as Al7Cu4Ni and Al4Ni3, which are solid phases. The numerical analysis was performed using the F.E.M. technique (ANSYS software) to estimate the alloy's fatigue life understudy. It was concluded that the overall difference in fatigue life between numerical and experimental results did not exceed 11.3%.

Keywords: Al-Cu composite, Mechanical properties, Microstructure, Powder metallurgy.

1. Introduction

Aluminium alloys are primarily used to enhance properties such as strength, durability, corrosion resistance and density in the aeronautical sectors. Improving aluminium alloys' properties can be accomplished by changing the chemical composition and strictly regulating procedures, and developing new manufacturing methods, such as rapid solidification and mechanical alloys [1]. Particulate dispersion can be achieved by traditional ingot metallurgy, by mixing dispersion with the cast matrix alloy or by situ formations of the intermetallic phase by suitable addition of alloys [2]. However, problems such as the construction of segregation and coarse intermetallic particles typically occur during the ingot solidification process. More precisely, powder metallurgy as a treatment method helps mechanical alloys solve these problems [3].

Mechanical alloys effectively reduce the particle volume of bulk material, as they rely on mechanical forces, including compressive force or sheer impact [4]. At least two physically and chemically distinct steps are distributed to ensure proper properties that cannot be accomplished in any two individual phases - the Metal Matrix Composites (M.M.C.s). MMC has been developed to satisfy the demand for lightweight and high-precise materials, strength and wear durability [5]. For example, aluminium is favoured in the M.M.C.s because of its low density and ease of production with useful engineering features [6]. A mixture of high ductility, resilience, superior strength and hardness ceramic enhancement that have been used in some significant engineering applications as in cars and aerospace was developed for MMC. [7].

Metal enhancement may have several different objectives. The reinforcement of light metals permits applying these materials in priority areas for reduced weight when necessary to enhance the component's properties [8]. In a simple, cheap production process, other conventional smelting or casting techniques cannot fulfil the requirement for conducting powder metallurgy (M.A.). The M A, which was then used extensively in the manufacture of powders with an accurate microstructure, was originally invented by John Benjamin6. This M.A, the process's primary mechanism is the powder ball collision which occurs in the M.A. Procedure, and the powder particles were continuously maintained between the container and the colliding balls. This powerful influence has led frequently to deformation, cold welding and powder particulate fracture, and its physical and mechanical properties have been improved [9].

The effects of the nickel additive on the mechanical characteristics and production of aluminium, zinc, magnesium and copper alloys were studied by Naeem et al. [10]. At variance temperature conditions, aluminium-alloys with additive Ni have been homogenised. The results demonstrated that the yield strength (Y.S.), ultimate tensile strength (U.T.S.) and Vickers alloy hardness dramatically improved [10]. Ni additive on corrosion-resistant to Al-Zn-Mg-Cu alloy produced using mechanical alloy was studied by Mohammed et al. [11]. The results showed that the PM molten alloy's corrosion resistance is improved by adding nickel to produce intermetallic dispersion and precipitation particles [11].

The results show the combination of the Ni (0.9%) and Cu (2,60%) add-ons for Alloy Basis 413.0 formed various intermetallic formations, as well as Al11(MnFeNiCu)4Si and Al12(CrMnfeNiCu)3Si_2 compared with base 413.0, impurity and traction properties. Abdelaziz et al. [12] examined the effect of additives on Al-Si micro-structure tensile resistance, with the results showing that

Adding alloy elements (Mg, Cu, Ag, Ni, Zn, Ce, and La) increases the strength of alloys, which decreases the ductility of alloys. Furthermore, the fatigue behaviour of materials is improved with various techniques, such as fibre-reinforcement materials, reinforcement of the base material by incorporating nanomaterials [13-16], temperature treatment [17-18] or other technique [19-21].

The goal of the research is to investigate the mechanical properties and microstructure of Ni-reinforced alloy aluminium 2024. The Al matrix was strengthened with the mechanical alloy process, thus increasing mechanical features such as compressive force, stiffness and fatigue strength of A.M.C.s.

2. Experimental work

The tests include the measurement of mechanical and fatigue properties for the aluminium alloy with various nickel additives. The aluminium alloy microstructural change will also be experimentally tested. Using mechanical alloying techniques, thin grains and homogeneous structure can be produced, which have enhanced mechanical properties. The experimental work required first developing samples needed, then the testing of the necessary mechanical features and other behaviours were performed by using appropriate tools [22-25]. Since the test results are verified, the error rate is reasonable, so the material's mechanical behaviour and fatigue behaviour with different effects can be considered for testing [26-28]. The experimental work presented included two elements: first, the manufacturing of nickel additive alloy and the measurement of mechanical and weariness characteristics for studied alloys.

2.1. Preparation of alloys

Three different kinds of material have been picked - Aluminum (Al), Copper (Cu), Nickel (Ni). Table 1 indicates the pureness and diameter of the metal powders. The particles shape of received powders was determined by SEM, Al, Cu, and Ni particles have mainly spherical shapes as shown in Figs. 1-3 of S.E.M. of 3 powder types. Al and Cu pullers are combined with an Al-Cu alloy (alloy A) manufacturing base with a specific weight ratio of 95% Al and 5% Cu. In addition to the previous alloy, the Ni powder was applied to the previous alloy by the sum of 2% and 3%, respectively, to render the Al-Cu-Ni composite described in Table 2.

Table 1. Particle size and purity of powders.

Material	Average particle size (μm)	Purity (%)
Al	35	**99.9**5
Cu	45	**99.89**
Ni	40	99.80

Table 2. Weight percentages of alloys.

Alloy	Weight percentages of materials %		
	Al	Cu	Ni
A	95	5	0
B	93	5	2
C	92	5	3

Powders were blended in a sealing stainless steel container with 10:1 ball/powder ratio verifications, moulded in a planetary mill at 200 rpm, argon protective mode and mixing for four hours, and were mixed with steel balls with a 10 mm diameter. Following the milling, a hydraulic hot-cold powder was coated to create a billet with circular cross-sections (13 mm in diameter and 15 mm in highness) at 400 MPs in the mechanical engineering departments/college of engineering. Following compaction, tickets were sintered in a tube oven with Argon Protective at (550 °C) 1-hour soaking time [29]. The circular billets are shown in Fig. 4. Figures 5 to 9 show facilities and billet steps.

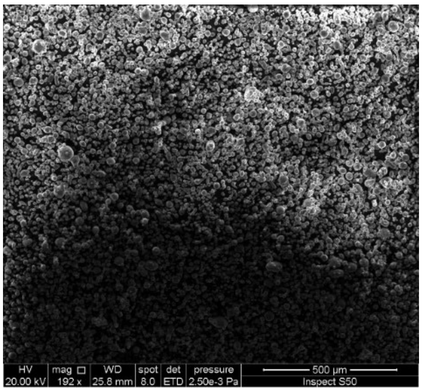


Fig. 1. S.E.M. image of Al powder.

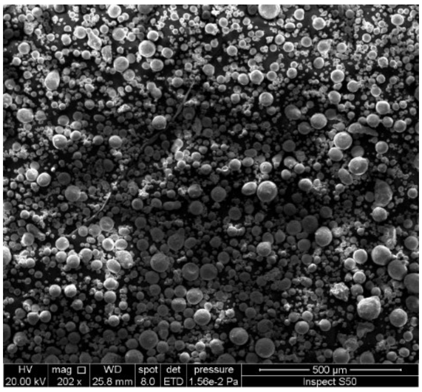


Fig. 2. S.E.M. image of Cu powder.

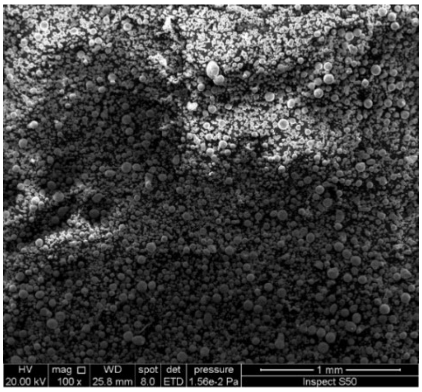


Fig. 3. S.E.M. image of Ni powder.

Fig. 4. Circular billets.

Fig. 5. Digital balance.

Fig. 6. Planetary ball milling.

Fig. 7. Steel balls.

Fig. 8. Parts of die.

Fig. 9. Tube furnace.

2.2. Mechanical properties and fatigue behavior

The Rockwell hardness test, compressive strength test, tensile test and fatigue testing were performed on the prepared specimens, with optical microscopy, S.E.M. and X-Ray propagation characterised specimens. Therefore, the fatigue test for the fabricated sample was conducted with dimensions indicated in Fig. 10, using the fatigue test machine shown in Fig. 11, by testing eight samples for each additive nickel samples.

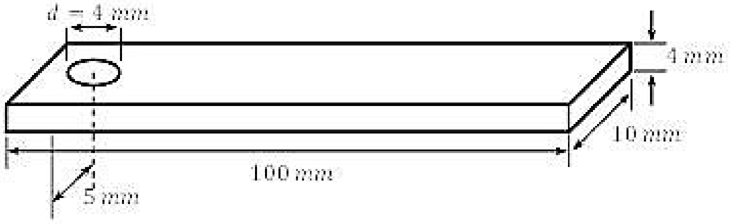


Fig. 10. Fatigue sample dimensions.

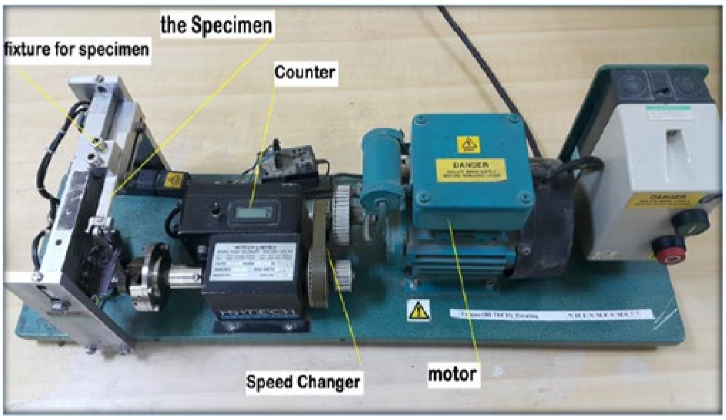


Fig. 11. Fatigue machine test.

3. Numerical Technique

Numerical work is an approximate technique that can be used by accepting an error compared to other experimental or theoretical works to solve engineering problems [30-32]. Therefore, the mechanical behaviour of various materials with different effects and applications can be measured using a numerical technique [33-35]. In this work, the finite element approach, with ANSYS software's aid, is used to generate fatigue behaviour. To obtain the best performance for ally fatigue activity, this technique required first selecting [36-38] the best element number and calculating the right percentage for alloy fatigue behaviour [39]. In this work, the finite element approach, with ANSYS software's aid, is used to generate fatigue behaviour. Therefore, as illustrated in Fig 12, the best element form to be selected for fatigue is (Solid 187) [18].

The meshed fatigue test sample and the figure's convergence test are shown in Figs.13 and 14. The best number of elements was chosen with different nickel additives to achieve aluminium alloy's fatigue behaviour [40-41]. 187 is a three-dimensional high-orders element with ten nodes for every node of three degrees of freedom. The modelling behaviour of Solid 187 is a quadratic displacement with an irregular mesh, which is ideal for general materials. This factor can also be used for fatigue, creep, stress, plasticity, high strain, hyperelasticity, large deflection, etc.

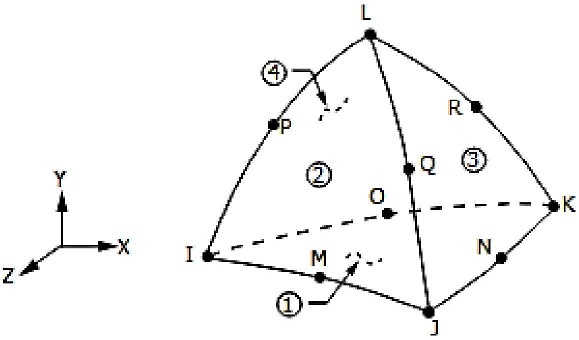


Fig. 12. Solid 187 element type.

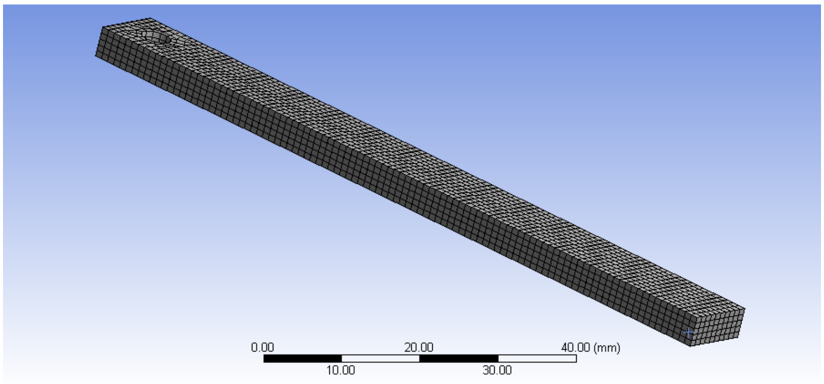


Fig. 13. Meshed sample (ANSYS software)

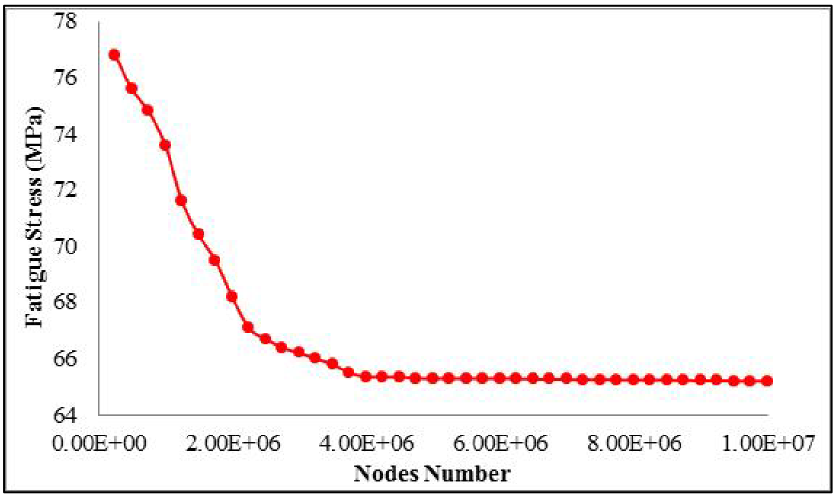


Fig. 14. Convergence test to select the best nodes number.

4. Results and Discussion

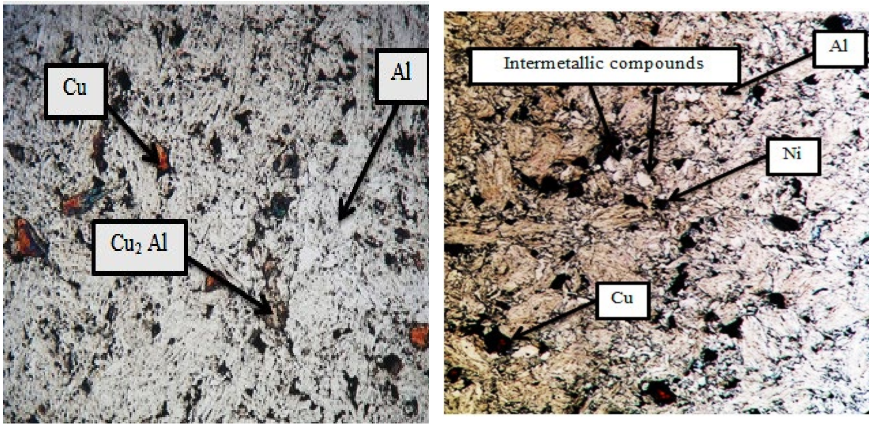
The current work results show the impact of Nickel additive on the mechanical properties and microstructure of Al-Cu Alloy materials manufactured using Powder Metallurgy. These results are divided into the microstructure results (the micrographs for samples with Nickel effect). Second, the tested samples' mechanical properties (hardness, strength and fatigue behaviour of the alloy materials with the nickel additive effect are presented).

4.1. Microstructural results

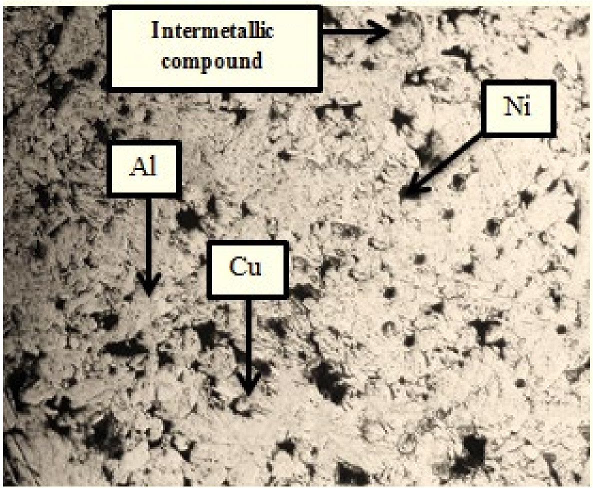
As demonstrated in the optical micrographs of prepared alloys A, B and C, Figs. 15(a), (b), and (c) respectively. Within the reliable aluminium-rich solution, the sample structure comprises transparent grains of an equal axis. The efficacy of the mechanical frying process and the effect of nickel additives are the cause of the interdendritic mesh of intermetallic composites that form during the sintering stage this balanced.

As shown in Figs. 15(a), (b) and (c), the grain size of A, B and C alloys are reduced, with nickel added to the base alloy. Generally, the theory behind the decrease of the grain size is the grain refining system, which is the development of the heterogeneous nucleus in the primary aluminium process as the number of solidification sites. The nickel particles act in the matrix base alloy as substrates. Grain size and morphology lead the efficiency of grain refining to a more specific structure, which provides the advantages of improving grain as an enhanced mechanical property if grain morphology is matched.

Figures 16(a), (b) and (c) show the S.E.M. images for alloys A, B, and C, respectively, which the intermetallic is compound appeared clearly in images (b) and (c) after added Ni powder for the base alloy. The same behaviour has resulted in [10].

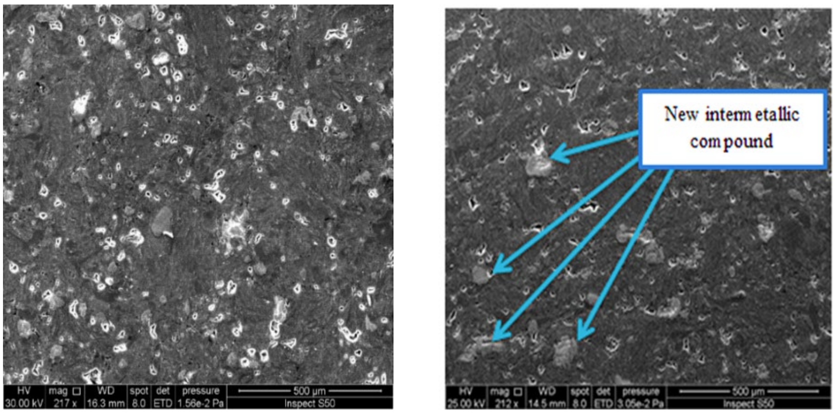


(a) Alloy A. **(b) Alloy B.**

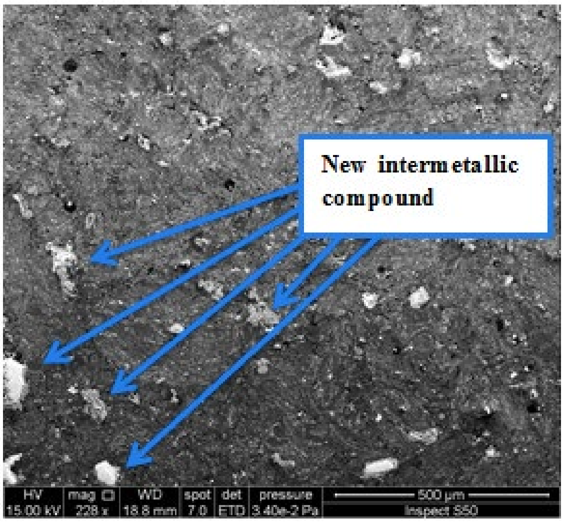


(c) Alloy C

Fig. 15. Microstructure image for Al-Cu alloy, 10x.



(a) Alloy A. **(b) Alloy B.**

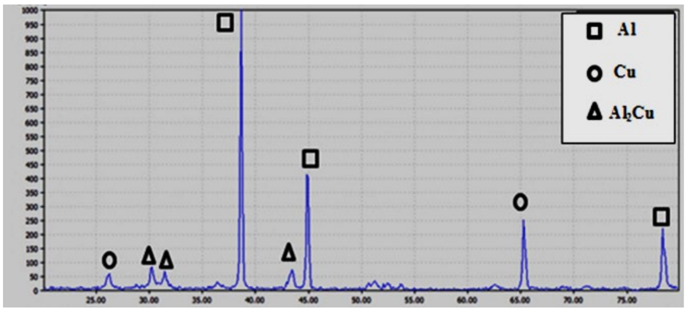


(c) Alloy C

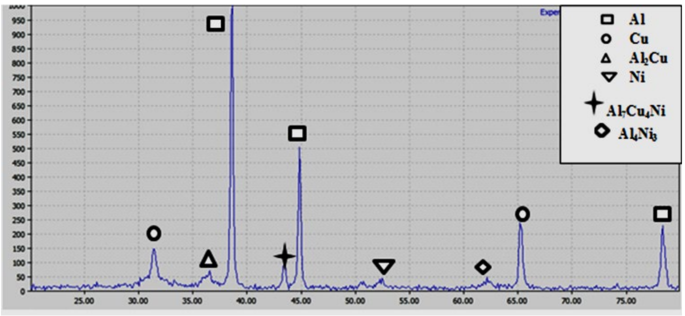
Fig. 16. S.E.M. image for Al-Cu-Ni composite.

Figure 17(a) displays the X-Ray Diffraction in preparing alloy A, Fig. 17(b) shows the XRD for alloys B and Fig. 17(c) shows the XRD for alloy C.

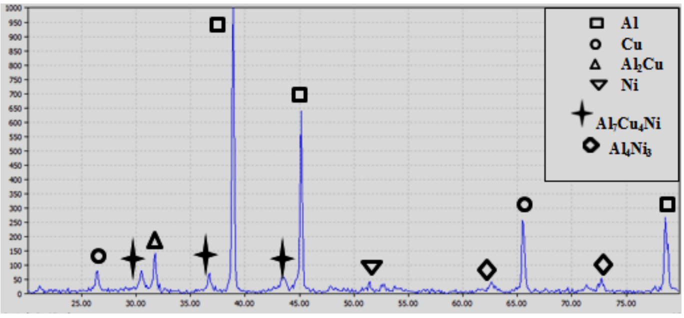
From XRD analyses new intermetallic compounds were formed during the sintering process in alloys B and C, such as Al7Cu4Ni and Al4Ni3, which appears through this test XRD test was confirmed the microstructure examination results in Figs. 15 and 16, which appear new intermetallic compounds after the addition of Ni particles for alloy A, these results confirmed the enhancement of the mechanical properties of alloys B and C because of the significant intermetallic compounds. The results of the new phases are agreed with the results of reference [10].



(a) Alloy A



(b) Alloy B



(c) Alloy C

Fig. 17. XRD for alloys

4.2. Mechanical properties and fatigue results

Table 3 shows the mechanical characteristics of the prepared alloys (Rockwell hardness and compressive strength). Table 3 showed that after Ni powder's addition, the mechanical properties of alloy A were increased and improved. The results of S.E.M. and XRD confirmed the improvement compared with references [1, 10] due to new intermetallic components that impact the hardness and the compression strength of the alloys made. Image. Figure 18 indicates alloy B's numerical fatigue behaviour. Finally, Fig. 19 to 21 present the fatigue behaviour for these alloys with different Nickel materials. The comparison of the test results to numerical fatigue is shown in Fig. 19. It is noticed that the experimental work was a perfect technique used to estimate the fatigue behaviour of alloys with

Nickel additive since the maximum discrepancy for the presented results obtained the two techniques did not exceed about (11.3%). Then, in Fig. 20, it can be seen that Alloy C's fatigue strength and life were more than that of Alloys B and A. It was enhanced by about 50% of the base alloy regarding fatigue strength at 106 cycles, as shown in Figs. 19, 20 and 21. The same behaviour was concluded by references [14, 21].

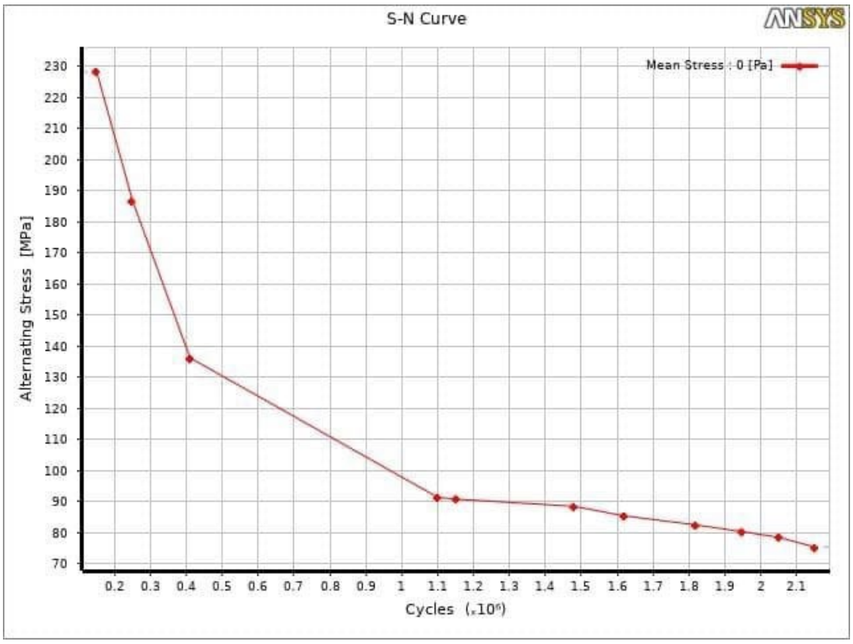
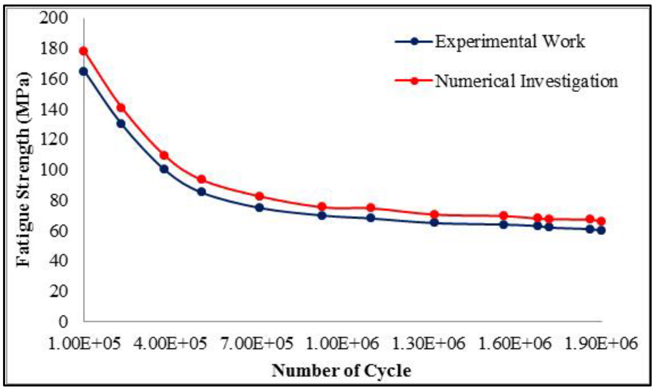


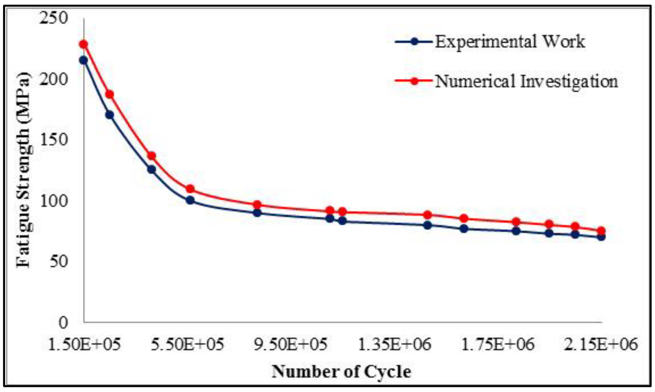
Fig. 18. Numerical result of fatigue behaviour of alloy B.

Table 3. The mechanical properties of alloys A and B.

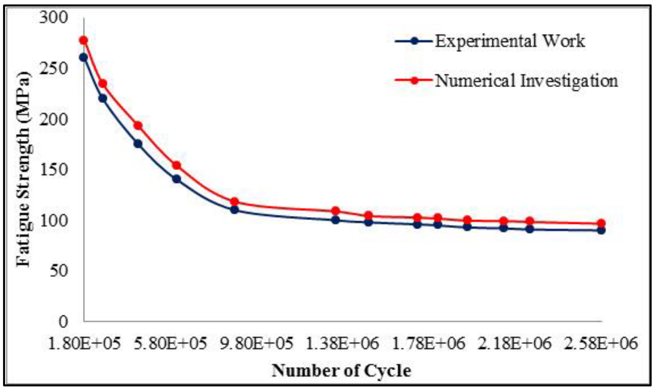
Mechanical Properties	Alloy (A)	Alloy (B)	Alloy (C)
Rockwell Hardness (R.H.N.)	71	77	84
Compressive strength (MPa)	168	211	243



(a) Alloy A



(b) Alloy B



(c) Alloy C

Fig. 19. Comparison between experimental and numerical fatigue results.

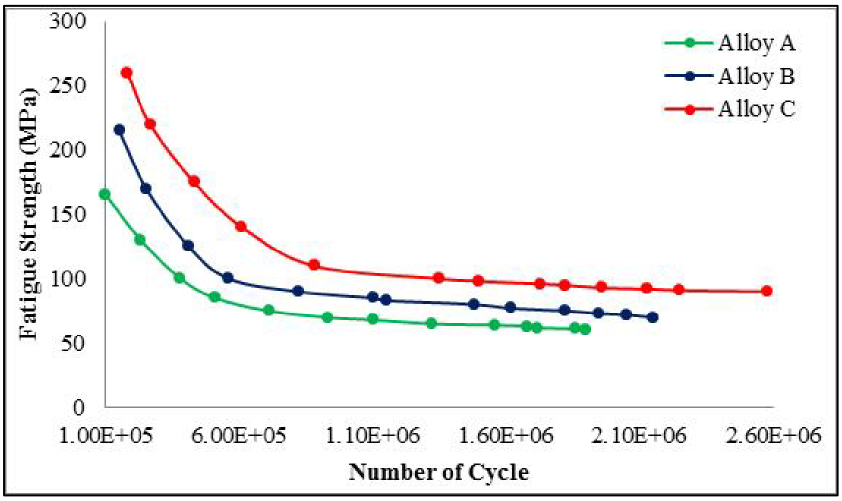
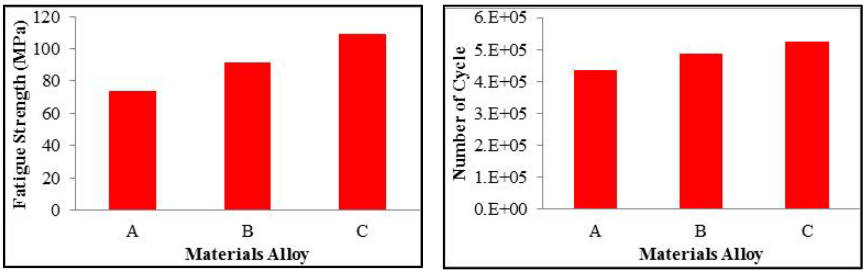


Fig. 20. Fatigue behaviour for different alloy materials.



(a) Fatigue strength. **(b) Fatigue life.**

Fig. 21. Fatigue strength and life for various alloy materials.

5. Conclusions

The present work and observations have concluded with exciting results and are summarised as follows:

- The Al-Cu alloy's compressive strength is enhanced by 44.6% by adding 3% of Ni powder to the base alloy.
- Observations of alloys' microstructures revealed phases such as Al7Cu4Ni and Al4Ni$_3$, which are standing behind to improve the mechanical properties.
- Ni powder additive leads to form new intermetallic compounds, which affect mechanical properties as a positive effect.
- The Al-Cu alloy's fatigue life is enhanced by adding 3% Ni by increasing its fatigue strength by about 50% of the base alloy strength at 10^6 cycles.
- With increasing Ni additive by 3%, the Rockwell surface hardness is increased by 18.3% regarding the base alloy.

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