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EFFECT OF NICKEL CONTENT AND HEAT TREATMENT ON THE ELECTRO-MECHANICAL PROPERTIES AND MICROSTRUCTURAL EVOLUTION OF ALUMINIUM

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ABSTRACT
Aluminium is a very important metal among the engineering materials. Owing to its importance, several researches are being conducted on its characteristics and the effects of other materials on its characteristics. This paper investigated the effects of various composition of nickel on the characteristics of aluminium. The characters of interest were strength, hardness, electrical conductivity and microstructural evolutions. Alloys were developed with variation of nickel from 2%, 4%, 6%, 8%, to 10%, these included the tensile specimens, hardness specimens, electrical conductivity specimens, and the microscopic specimens. Each set were produced in threes: one annealed, one age-hardened and the other left untreated. The results of the various test show that CN5 has the highest hardness, with hardness value of 435, followed by HN4, with the value of 416 and then AN4 with 403. All the rest are below these three values. The cast samples produced more elongations than the annealed and hardened samples, while there is more strength in the case of the hardened samples compared to annealed and as cast samples. As for electrical conductivity AN3 has the highest conductivity value of 6.1 x 10^7 S/m.

Keywords: *Aluminium, nickel, alloy, strength, resistivity, conductivity, hardness*

INTRODUCTION

Aluminium is being applied in many areas (space, aircraft, vehicle, electricity, building, packaging, electronics, and kitchen utensil) mainly because of its light weight, corrosion resistance, and good mechanical and electrical properties. Aluminium is a light metal and can be given great strength by alloying and heat treatment thereby improving the mechanical properties (Abdulwahab, Madugu, Yaro & Popoola, 2011 and Abifarin & Adeyemi, 2003). Aluminium is used extensively in our daily lives because it has low density and can resist corrosion through what is well known as passivation. The metal is used for building, such as in doors, windows, and roof and in aerospace manufacturing, also in rail and road transport facilities and machineries. (Degarmo; Black and Kohser, 2003).

Aluminium and its alloys have being in use for some many application, it is better used in alloy state for structural and engineering application. When other elements are added to aluminium to improve its properties, such as tensile strength, hardness, toughness and fatigue strength, it is then referred to as aluminium alloy. Some most often use alloying elements for the production of aluminium alloys are copper, zinc, magnesium, manganese and silicon. Aluminium alloys are of

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two categories, which are cast alloy and wrought alloy and further subdivided into cast heat treatable and cast non-heat treatable, wrought heat treatable and wrought non-heat treatable alloys. Silicon is used mostly for cast alloys, with composition ranging from 4-13% by weight of silicon, though substantial number of aluminium alloys are in wrought form, given roughly 85% in usage (Degarmo *et al,* 2003).

Problem Statement

Aluminium is seldom used in pure form in engineering application, except in a situation where good conductivity and good corrosion resistance is paramount. In some situations, it is required that the metal is alloyed in such a way that it does not lose much of its conductivity. Therefore it is required that a careful choice of alloying element may solve the problem of reducing conductivity at the expense of strength. It is a fact that face centred cubic (FCC) - a crystal structure with an atom on each corner and each face of a cube totally 14 atoms - metals is more ductile and highly conductive compare to hexagonal close packed (HCP) and body centered cubic (BCC). This study is intended to add some quantities of zinc in varied form to study the effects on some properties of aluminium.

Aim and Objectives

The aim of the study is to locally develop alloys of aluminium with Nickel in order to analyze their electrical, mechanical and microstructure properties.
The objectives of this study are:

- To develop aluminium alloy with Nickel having the following range of compositions: 2%, 4%, 6%, 8% and 10%.
- To determine the tensile and hardness strength on each of the specimens in the composition groups.
- To find the electrical conductivity of each of the specimens in each composition group using the relationship that connect resistivity with conductivity.
- To identify the arrangement of the various phases/structures in each alloy.

REVIEW PROPERTIES ALUMINIUM ALLOYS

According to Chen; Lin; Zeng and Chen (2008), an alloy is a mixture of metallic elements or metallic and nonmetallic elements forming solid solution completely or partially. Matula; Jardiel; Jimenez; Levenfeld and Várez, (2008), states that alloy is a mixture of atoms in which the primary constituent is a metal in order to produce a new metal with unique characteristics. Complete solid solutions give rise to a single phase microstructure, while partial solutions produce two or more phases that may be homogeneous in distribution (Chen *et al.,* 2008). The main purpose of alloying is to improve mechanical properties, though reducing some other properties like conductivity and corrosion resistance occurs at the end of process (Matula *et al.,* 2008).
Isomorphous systems contain metals which are completely soluble in each other and have a single type of crystal structure (Phanikumar, Dutta, Galun, & Chattopadhyay, 2004). Alloy constituents are usually measured by mass. Alloys are usually classified as substitutional or interstitial alloys. They can be further classified as homogeneous, consisting of a single phase; heterogeneous,

consisting of two or more phases, or intermetallic, where there is no distinct boundary between phases (Chen *et al*., 2008).

Mixing a metal with another is carried out when one or more other metals or nonmetals are combined to it to enhance its properties. Steel is stronger than iron, its primary element for instance (Figueiredo and Langdon, 2009). The physical properties, such as density, melting points, boiling points, reactivity, Young's modulus, and electrical and thermal conductivity, of an alloy may not differ greatly from those of its elements, but engineering properties such as tensile, torsion , fatigue, creep and shear strengths may be remarkably different from those of the constituent metals in the alloy (Zhang, Butch & Greene, 2012).

A mixture of two different atoms, excluding impurities, such as copper-nickel alloy is called a binary alloy. Three atoms mix to form a ternary alloy, such as iron, nickel and chromium, while four constituents alloy is a quaternary alloy, and a quinary alloys contain five different atoms (Phanikumar *et al.,* 2004).

Aluminium alloys are those alloys that are made by adding other metals into aluminium, such that aluminium is acting as the base metal, while other metals are acting as alloying elements. The distinctive alloying elements for the development of common aluminium alloys are copper, magnesium, manganese, silicon and zinc (Dobrzanski, Maniara & Sokolowski, 2006).

Aluminium alloy exteriors will preserve their superficial luster in a dry surroundings due to the formation of a clear, protective film of aluminium oxide, but, galvanic corrosion can take place when an aluminium alloy is placed in electrical contact with other metals with more negative corrosion potentials than aluminium in wet environment (Wierzbinska & Sieniawski, 2006).

For the production of alloys and master alloys, as well as for the formation of protective coating on metal surfaces, brazing, welding, fabrication of composites and super conductive materials, the knowledge of how solid and liquid metals interact is important (Kiril, Blagoj and Ratko, 1999):

- The complexity of solid metal-liquid aluminium interaction
- Simultaneous formation and dissolution of intermetallic phases
- Large amounts of alloying elements
- Large difference in physical and chemical properties between aluminium and transition metals
- Large number of variables which is difficult to control

Aluminium alloys with a wide range of properties are used in engineering structures. Selecting the right alloy for a given application entails considerations of its tensile strength, density, ductility, formability, workability, weldability, and corrosion resistance, to name a few (Zander & Sandstrom, 2008). Aluminium alloys are used extensively in aircraft due to their high strength-to-weight ratio. On the other hand, pure aluminium metal is much too soft for such uses, and it does not have the high tensile strength that is needed for airplanes and helicopters (Jiang *et al.,* 2008).

The proliferation application of cast aluminium alloys in automobile for engine blocks and cylinder heads generates the necessity for bottomless understanding of fatigue performance and the stimulus of dispensation factors (Mrowka-Nowotnik; Sieniawski and Wierzbinska, 2007).

RESEARCH METHODOLOGY

The chapter explains the research design adopted for this research, the coding designation for the various alloys and charge calculation for the various sets of alloys.

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Materials used

The materials used for the experiments are; Aluminium metal, Nickel metal, hacksaw, melting furnace, ladle, sand mould, lathe machine, shaping machine, file, emery cloth, abrasive paper, polishing machine, etching reagent (Hydrofluoric acid, Nitric acid and water), metallurgical microscope, tensile testing machine, Brinell hardness testing machine, voltmeter, and ammeter, etc.

The specimens from annealed, age-hardened and normal cast from all the compositions will be selected and shaped for tensile tests, hardness tests, electrical properties test and microscopic examinations.

Table 1: number of specimens for each of the categories of the alloys

Alloy Composition	Tensile specimens	Hardness specimens	Electrical specimens	Microscopic specimens
2%	3	3	3	3
4%	3	3	3	3
6%	3	3	3	3
8%	3	3	3	3
10%	3	3	3	3
Total	15	15	15	15

Designation of the Alloys

The alloys from each of the three groups of alloy categories are given some unique designated codes for easy identifications and classifications as shown on the tables 2

Table 2: Al-Ni Alloys specimens' designations

Compositions of alloying elements	Annealed	Age-Hardened	Normal cast
2%	ANX1	HNX1	CNX1
4%	ANX2	HNX2	CNX2
6%	ANX3	HNX3	CNX3
8%	ANX4	HNX4	CNX4
10%	ANX5	HNX5	CNX5

According to tables 2, the first letters A referred to Annealed specimen, H for Age-Hardened specimen and C is referred to normal cast specimen. The second letters, N is the initials of the alloying elements involved, that is, Nickel. The figures 1, 2, 3, 4, 5 stand for the series of the alloys with compositions 2%, 4%, 6%, 8%, and 10% respectively. X stands for the types of test to be carried out on the specimen. As for tensile specimens T will be added after the second letter in place of X follow by the figure (1, 2, 3, 4, or 5), while for Hardness specimens H will replace the X, E will replace X for electrical specimens. So that ANT1 is referring to Annealed Aluminium-2%Nickel alloy specimen for tensile test.

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Table 3: Al-Ni alloys samples

Composition	Mechanical test		Electrical test	Microscopic examination	Total samples
	Tensile	Hardness			
2%Ni	3	3	3	3	12
4%Ni	3	3	3	3	12
6%Ni	3	3	3	3	12
8%Ni	3	3	3	3	12
10%Ni	3	3	3	3	12
Total	15	15	15	15	60

Testing of Prepared Work Pieces

The types of tests to be conducted on various specimens are tensile test, hardness test, electrical conductivity test, and microscopic examination.

Tensile test was done using universal tensile/compressive testing machine using varied loads till the specimen failed. The hardness test was conducted to identify the extent of indentation done on the surface of the specimen. Electrical conductivity test was done using voltmeter, ammeter connected to the wire obtained from the specimen and the amount of current and voltage across was measured. The specimens for microscopic examination were mounted on a Metallurgical microscope and the structures were revealed.

RESULTS AND DISCUSSION

The results of the various tests are displayed below followed by analysis and discussion on the data displayed.

Hardness Test Result

Below are the results of the hardness tests conducted on the various alloys.

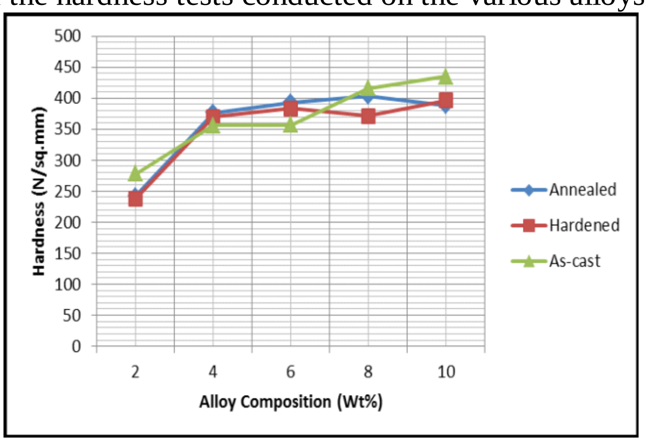

Fig 1: Hardness of Al-Ni Alloys Specimens at Various Conditions

Graph on figure 1 show the Brinell hardness number of the various sets of Al-Ni alloys, ranging from 2% to 10% Ni contents. It can be observed from the graph that CN5 has the highest HBN, which is 435, followed by HN4 with HBN of 416 and then AN4 with HBN of 403. The smallest value of the HBN is for 238, which is that of HN1, follow by that of AN1 with HBN of 243 and

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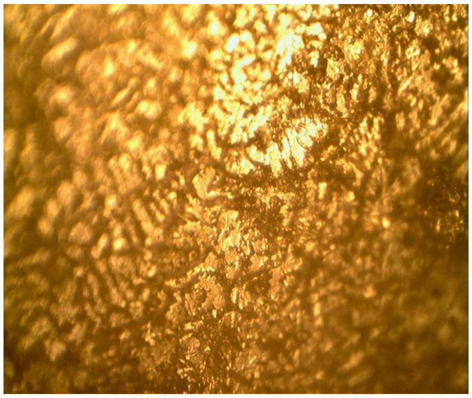
then that of CN1, with HBN of 278.5. The trend of the HBN shows that as cast alloy set have higher HBN than the annealed and hardened alloy sets, with the exception of CN2 and CN3 with HBN of 356 and 356.7 respectively.


(a) HN1

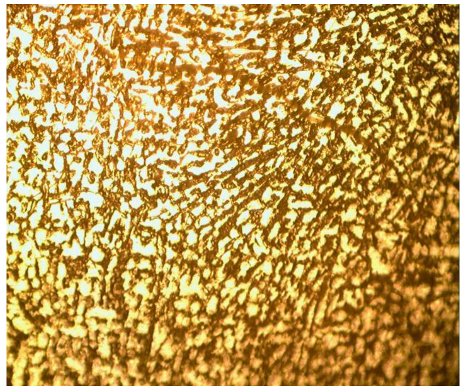

(b) CN5

Plate 1: Optical Micrograph of the Al-Ni alloy with the highest and the least HBN.

From plate 1, HN1 has the lowest HBN of 238, while CN5 has the highest of 435, the structures show that HN1 spheroidisation of precipitates of Ni can be seen throughout the matrix of Al, with slight white patches of primary Al around the top center of the matrix with little patch of white patch of primary Al around the top center of the graph. In CN5 there are coarse dendrites of dark patches of precipitates distributed over the micrograph, having some whitish portion of primary phases at the top left corner, fibrous and acicular structures, with the white primary phases more widely spread, a continuous-precipitates with a mixture of acicular and small nodular structures can be noticed.

Tensile Test Results

The results of the tensile tests carried out on various alloys are as displayed below.

Table 4: Geometric Parameters of Al-Ni Alloy Tensile Specimens

Specimens	Do (mm)	Df (mm)	Go (mm)	Gf (mm)	ΔA (mm)	ΔL (mm)	%ΔA (mm)	%ΔL (mm)
AN1	5.50	5.00	26.00	24.00	0.50	2.00	9.09	7.69
AN2	5.70	5.30	25.50	23.90	0.40	1.60	7.02	6.27
AN3	5.40	5.00	26.50	24.50	0.40	2.00	7.41	7.55
AN4	5.50	4.90	26.00	24.00	0.60	2.00	10.91	7.69
AN5	5.50	4.80	25.50	24.00	0.70	1.50	12.73	5.88
HN1	5.80	5.20	25.50	23.50	0.60	2.60	10.34	6.00
HN2	6.00	5.50	25.00	23.50	0.50	1.50	8.33	7.06
HN3	5.50	5.30	25.80	24.00	0.20	1.80	3.64	5.77
HN4	5.70	5.00	26.00	24.50	0.70	1.50	12.28	5.88
HN5	5.50	5.00	25.50	24.00	0.50	1.50	9.09	9.62

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CN1	6.00	5.40	25.50	23.00	0.60	2.50	10.00	7.69
CN2	5.80	5.30	26.00	24.00	0.50	2.00	8.62	7.84
CN3	5.30	5.00	25.50	23.00	0.30	2.00	5.66	7.84
CN4	5.40	5.00	25.00	23.00	0.40	2.00	7.41	8.00
CN5	5.50	5.00	25.50	23.00	0.50	2.50	9.09	9.80

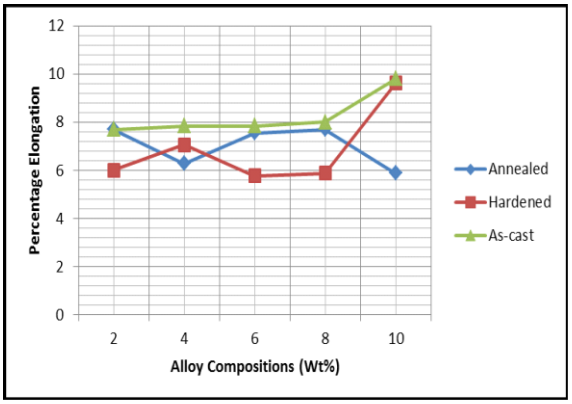

Fig 2: Percentage Elongation of Al-Ni Alloy Specimens at Various Conditions

As can be seen on the graph on figure 2, the percentage elongate is unusual, as as-cast alloys is having the highest percentage elongation throughout the composition. At 2%wt composition as-cast and annealed alloys have almost the same percentage elongation, while hardened alloy is lower. At 4%wt composition as-cast is the highest followed by hardened and annealed alloy is the lowest, while at 6%wt composition as-cast is the highest closely followed by annealed and hardened is the lowest, the same is the case of 8%wt composition, while at 10%wt composition as-cast alloy and hardened alloy have almost the same percentage elongation, with annealed been the lowest.

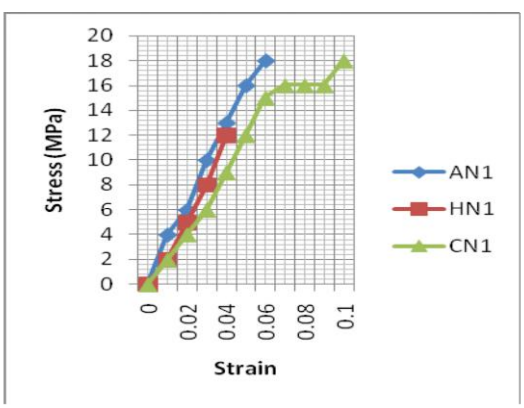

Fig 3: Stress-Strain Curve for Al-2%Ni Alloys Set

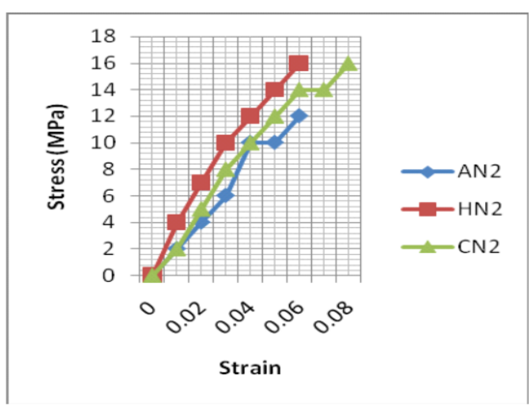

Fig 4: Stress-Strain Curve for Al-4%Ni Alloys Set

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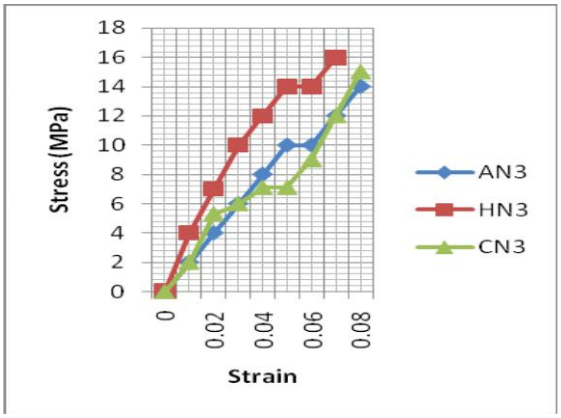

Fig 5: Stress-Strain Curve for Al-6%Ni Alloys Set

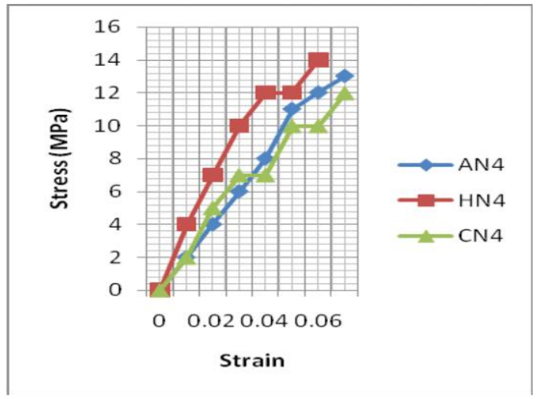

Fig 6: Stress-Strain Curve for Al-8%Ni Alloys Set

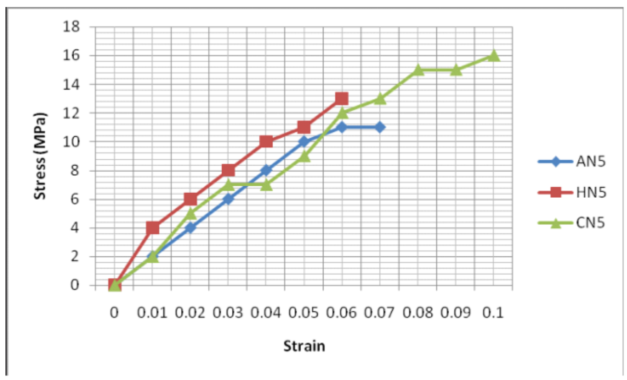

Fig 7: Stress-Strain Curve for Al-10%Ni Alloys Set

Figure 3, indicate that annealed alloy is stronger as it has to be given more stress to extend it like others. The most ductile of all of the three is the as cast alloy, which extend up to a strain value of 0.10. The most brittle of them is the hardened alloy, which just extend to a strain value of about 0.03. Annealed alloy has a strain value of 0.06. In figure 4, the annealed alloy extends to the same strain value with the hardened alloy (0.06), with the as cast alloy extend to a strain value of 0.08, which is the highest of them all. In figure 5, hardened alloy is the strongest as it has to receive more stress to extend it up to a strain value of 0.07, with a stress of 16MPa, while the most ductile being the as cast alloy, though they are closely related to each other with the annealed alloy, which breaks at a strain value of 0.08. Hardened alloy in figure 6 is stronger than the other two, though it breaks at a strain value of 0.06. The most ductile of them all is the as cast alloy, but annealed alloy and as cast alloy break at the same strain value of 0.07. Figure 7 shows that annealed alloy proved to obey hooks' law, but it breaks at a strain value of 0.07, which is more than the hardened alloy, which break at 0.06, though at a higher stress value of above 12MPa, while the as cast alloy extend more than the two with maximum strain value of 0.10.

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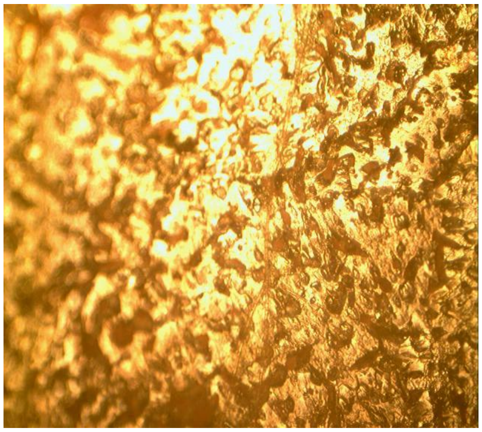
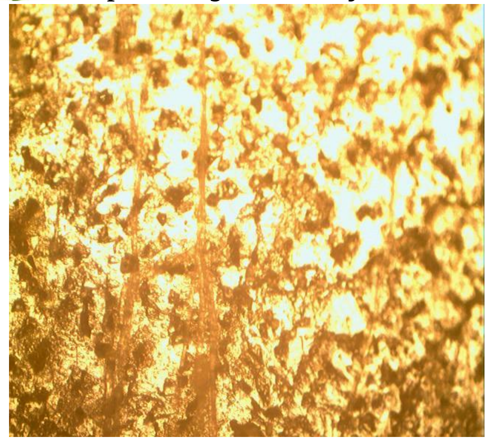


(a) AN1



(b) AN5

Plate 2: Optical Micrograph of the Al-Ni Alloy with the highest and lowest UTS.

Plate 2 shows AN1 of UTS of 321.34MPa, the structure shows spheroidisation of precipitates of Ni can be seen throughout the matrix of Al, with slight white patches of primary Al around the top center of the matrix down midway, botryoidal structures intermixed with few of twinned grain and widmanstatten side plate can be seen on the graph, while AN5 with UTS of 611.44MPa, the highest, has cloud-like patches of white primary phases of Al can be seen around the upper side of the micrograph, fibrous lines can be seen, with spread of nodular and botryoidal structures can be observed.

Electrical Properties Test Results

The tables of readings are presented in table 5, while the graphs are shown on figure 8.

Table 5: Electrical properties of Al-Ni Alloys Samples

Specimens	L (m)	D (m)	A (m^2)	Lx (m)	Rx (Ω)	ρ ($X10^{-8}$Ω-m)	σ ($X10^7$ S/m)
AN1	0.090	0.00015	1.77 X 10^{-8}	4.3	0.09	1.77	5.65
AN2	0.091	0.00014	1.54 X 10^{-8}	4.8	0.10	1.69	5.91
AN3	0.090	0.00013	1.33 X 10^{-8}	5.1	0.11	1.63	6.15
AN4	0.092	0.00013	1.33 X 10^{-8}	5.7	0.12	1.74	5.76
AN5	0.091	0.00012	1.13 X 10^{-8}	6.4	0.14	1.74	5.76
HN1	0.090	0.00013	1.33 X 10^{-8}	7.0	0.15	2.22	4.51
HN2	0.092	0.00014	1.54 X 10^{-8}	7.5	0.16	2.68	3.73
HN3	0.090	0.00013	1.33 X 10^{-8}	7.7	0.17	2.51	3.98
HN4	0.090	0.00015	1.77 X 10^{-8}	8.3	0.18	3.54	2.82
HN5	0.091	0.00014	1.54 X 10^{-}	8.7	0.19	3.22	3.11
CN1	0.091	0.00013	1.33 X 10^{-}	5.7	0.12	1.75	5.70
CN2	0.090	0.00012	1.13 X 10^{-}	6.3	0.14	1.76	5.69
CN3	0.089	0.00013	1.33 X 10^{-}	6.5	0.14	2.09	4.78
CN4	0.091	0.00014	1.54 X 10^{-}	7.1	0.15	2.54	3.94
CN5	0.090	0.00014	1.54 X 10^{-}	7.0	0.15	2.57	3.90

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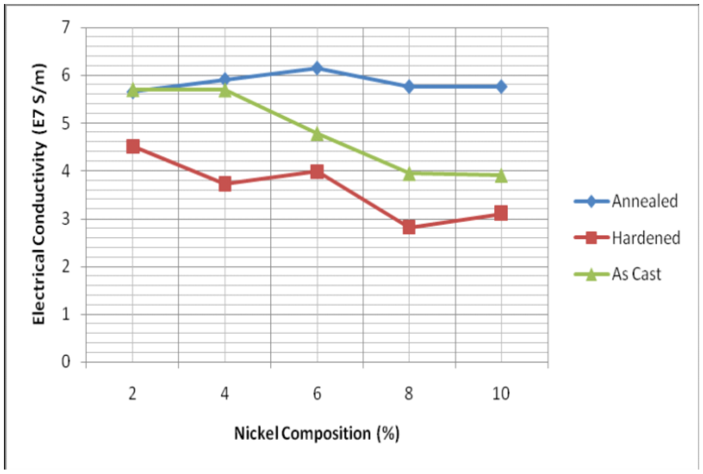
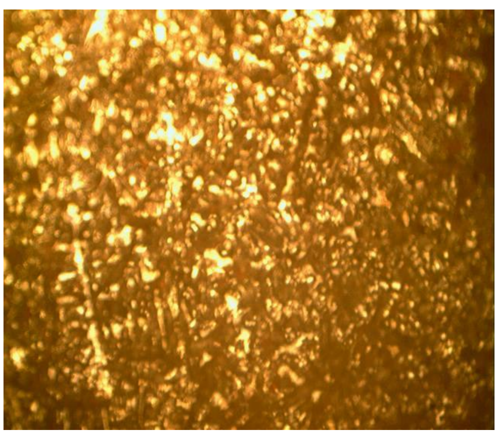
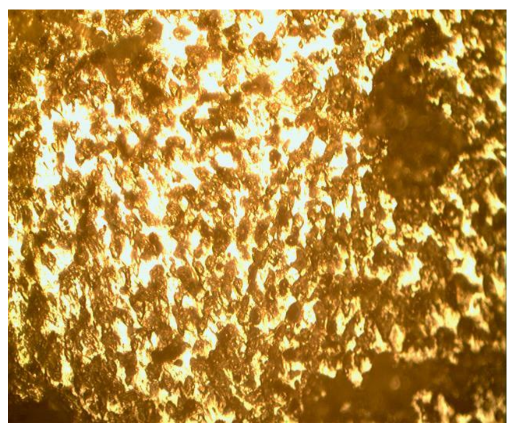


Fig. 8: Electrical Conductivity of Al-Ni Alloy Samples

From fig 8, it can be observed that throughout the compositions, annealed alloy samples have the highest electrical conductivity, while as-cast follow and hardened alloy samples have the lowest electrical conductivity. Though at 2%wt composition, as-cast alloy and annealed alloy almost the same in value, while at 4% they are close to each other in electrical conductivity.



(a)HN4



(b) AN3

Plate 3: Optical Micrograph of the Al-Ni Alloy with the highest and lowest σ.

Plate 3 has HN4, the lowest σ in all Al-Ni alloys with value of 2.88E7 S/m and AN3, the highest in all, value of 6.15E7 S/m. Micrograph of HN4 shows distributed dark secondary phases with dots of primary phases concentrated mostly at the top and narrow down to the bottom, continuous precipitates of Ni, which diffused from the right to the left, with primary phases can be observed, while AN3 is with spread precipitate of Ni spheroidised all over the matrix of Al with some few dark portion seen by top right, bottom right and left, nodular, acicular, and dendritic structures with dark segregates of Ni precipitates concentrated at the bottom right, left and near top right.

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CONCLUSION

There is an interwoven trend in the effects of the alloying elements on the measured properties of aluminium; as such no one out of the element used is the highest in all the tests conducted. From the results obtained and the analysis the following conclusion can be made:

- Al-10%Ni as-cast alloy has the highest HBN of 435, which indicate that in as cast state high nickel contents in aluminium is better for application in area that require high hardness, such as in rubbing parts. Al-6%Ni alloy has the highest conductivity of 6.15 x 10^7S/m, at annealed condition showing that nickel is good for better conductivity of aluminium at annealed condition. Annealing promote better conductivity than hardening and untreated alloy of aluminium, which show that for Al-Ni alloy to be used for electrical purposes it should be annealed. As cast Al-10%Ni alloy (CN5) has the highest hardness of 435. Nickel has high influence on electrical conductivity of aluminium. Al-6%Ni and Al-10%Ni are the only alloys that combine the highest values of HBN, UTS and electrical conductivity in their series, in all cases the two are annealed. Virtually all the as cast alloys micrographs show dendritic structures, while the hardened alloy show slight modification of the micrographs of as cast alloy, annealed alloys micrographs are generally made up of spheroidised precipitates of the secondary phases. Nickel is the best alloying element that can give aluminium high strength and good conductivity of electricity at any condition.
- As cast alloy and the annealed alloys has higher elongation compared the hardened alloys. For the 2%Ni content, as cast look more ductile, while the annealed sample was stronger. Also, for the 4%Ni content, the as cast was more ductile, but the hardened sample was stronger. For 6% and 8% the same scenario followed, such that as cast and annealed samples are more ductile than the hardened sample, which in turn is stronger. 10% Ni show as cast being the highest in ductility followed by annealed sample.
- Annealed has higher conductivity, followed by as cast sample, while the hardened sample the least. Out of all the highest is AN3 sample, with electrical conductivity of 6.1 x 10^7S/m.
- It is observed that virtually all the as cast alloys micrographs show dendritic structures, while the hardened alloy shows slight modification of the micrographs of as cast alloy, annealed alloys micrographs are generally made up of spheroidised precipitates of the secondary phases

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