Advanced Research in Electrical and Electronic Engineering
Print ISSN: 2349-5804; Online ISSN: 2349-5812 Volume 2, Number 1 October-December (2014) pp. 13-17

http://www.krishisanskriti.org/areee.html

Effects of Heat-Treatment Type on the Electrical Conductivity of Al-Ni Alloy Cast using Sand Mould

S.B. Tajiri and A. Tsoho

Mechanical Engineering Department, The Polytechnic of Sokoto State, Sokoto, Nigeria
E-mail: salihutbala@gmail.com

Abstract: *Aluminium has very wide and varied fields of application due mainly to its light weight, corrosion resistance, and good mechanical and electrical properties. This Paper compare the effects of annealing and age hardening on the ultimate tensile strength and electrical conductivity of aluminium-nickel cast using sand mould. Pure aluminium was melted and nickel added as an alloying element and the mixture stirred to allow for thorough mixing. Alloys developed varied from 2%, 4%, 6%, 8% and 10%, one annealed, the other age hardened and one left as cast. The result of the various tests carried out show that Al-6%Ni Annealed alloy has the highest electrical conductivity, with a value of 6.15 x 10^7 S/m and the least is 3.73 x 10^7 S/m for Al-4%Ni Hardened alloy.*

Keywords: *Heat-Treatment, Strength, Conductivity, Sand-mould, Alloy*

1. INTRODUCTION

Aluminium has very wide and varied fields of application (such as in space, aircraft, vehicle, electricity, building, packaging, electronics, kitchen utensil and some many others) due mainly to its light weight, corrosion resistance, and good mechanical and electrical properties. Aluminium is a light metal and can be given great strength by alloying, mechanical and heat treatment thereby improving the mechanical properties (Aniyi&Bello-Ochende, 1996 and Abifarin&Adeyemi, 2003).

Aluminium is the most widely used non-ferrous metal. Global production of aluminium in 2005 was 31.9 million tons. It exceeded that of any other metal except iron (837.5 million tons). Forecast for 2012 is 42–45 million tons, driven by rising Chinese output (Aweda and Adeyemi, 2007).

Aluminium is a good thermal and electrical conductor, having 59% the conductivity of copper, both thermal and electrical. Aluminium is capable of being a superconductor, with a superconducting critical temperature of 1.2 Kelvin and a critical magnetic field of about 100 gauss (10 milliteslas) (William *et al*, 2009).

Pure aluminium has a low tensile strength, but when combined with thermo-mechanical processing, aluminium alloys display a marked improvement in mechanical properties, especially when tempered. Aluminium alloys form vital components of aircraft and rockets as a result of their high strength-to-weight ratio. Aluminium readily forms alloys with many elements such as copper, zinc, magnesium, manganese, and silicon (e.g., duralumin). Today, almost all bulk metal materials that are referred to loosely as "aluminium", are actually alloys. For example, the common aluminium foils and beverage cans are alloys of 92% to 99% aluminium (Pio, Sulaimin and Mamouda, 2005).

According to Chen; Lin; Zeng and Chen (2008), an alloy is a mixture or metallicsolid solution composed of two or more elements. Complete solid solution alloys give single solid phase microstructure, while partial solutions give two or more phases that may or may not be homogeneous in distribution, depending on thermal (heat treatment) history. Alloys usually have different properties from those of the component elements.

The addition of alloying elements to aluminum is the principal method used to produce a selection of different materials that can be used in a wide assortment of structural applications. If we consider the seven designated aluminum alloy series used for wrought alloys, we can immediately identify the main alloying elements used for producing each of the alloy series. We can then go further and examine each of these elements' effects on aluminum. (Wierzbinska&Sieniawski, 2006).

Aluminium alloys are alloys in which aluminium (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al-Si, where the high levels of silicon (4.0% to 13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required (Degarmo*et al*, 2003).

Electrical conductivity or specific conductance is the reciprocal quantity, and measures a material's ability to conduct an electric current. It is commonly represented by the Greek letter σ (sigma), but κ (especially in electrical engineering) or γ are also occasionally used. Its SI unit is siemens per metre ($S\cdot m^{-1}$) and CGSE unit is reciprocal second (s^{-1}) (Reliy*et al*, 2010):

$$\sigma = \frac{1}{\rho}.$$ Eqn. 1

Where:

$$\boldsymbol{\rho} = \frac{\mathbf{AR}}{\mathbf{L}} = \frac{\mathbf{VA}}{\mathbf{IL}}$$ (Ω-m); such that

$$\boldsymbol{\sigma} = \frac{\mathbf{1}}{\boldsymbol{\rho}} = \frac{\mathbf{L}}{\mathbf{AR}} = \frac{\mathbf{IL}}{\mathbf{VA}}$$

in 1/Ω-m (Siemens, S) Eqn. 2

(Reliy*et al*, 2010).

Rohatgi and Prabhakar (1975), have asserted that aluminium – nickel alloys ranging from 0 to 6.1%Ni (by weight), solidified in 41mm diameter permanent moulds, can be processed to 1.78mm diameter wire using either hot extrusion, or hot rolling, followed by cold drawing. The alloys in wire form possess excellent combination of high strength and high electrical conductivity.

According to Aweda and Adeyemi (2007), the value of electrical conductivity increases fairly slowly at die temperatures maintained between room temperature and temperature of 80°C. Above this temperature, electrical conductivity rises with tool heating temperature to a peak value of 2.88 x 10^{+8} $(\Omega\text{-m})^{-1}$ at die temperature of 150°C and dropping from this value to a lower value of 0.832 x 10^{+8} $(\Omega\text{-m})^{-1}$ at maximum tool temperature of 310°C. The reduction in electrical conductivity at elevated pre-heat temperature is possibly due to high thermal conditions (Aniyi& Bello-Ochende, 1996 and Abifarin&Adeyemi, 2003). Electrical conductivity increases with increase in applied pressure up to an applied pressure level of 105MPa. With die temperature, electrical conductivity reaches a maximum value of 3.20 x 10^{+8} $(\Omega m)^{-1}$ at die temperature of 150°C and falls again when die temperature exceeds 150°C (Aweda and Adeyemi, 2007).

2. MATERIALS AND METHOD

The developed alloys were prepared into appropriate shapes for various tests required for the research such as; electrical test, tensile test, hardness test and microscopic examination.

Two types of heat treatments (Annealing and Age hardening or Precipitation hardening) were carried out on two out of each set of the alloys.

3. RESULTS AND DISCUSSIONS

The result of the test is displayed on table1 below:

Table 1: Electrical properties of Al-Ni Alloys Samples

Speci mens	L (m)	D (m)	A (m2)	Lx (m)	Rx (Ω)	ρ (X10 - 8Ω-m)	σ (X107 S/m)
ANE1	0.090	0.000 15	1.77 X 10-8	4.3	0.09	1.77	5.65
ANE2	0.091	0.000 14	1.54 X 10-8	4.8	0.10	1.69	5.91
ANE3	0.090	0.000 13	1.33 X 10-8	5.1	0.11	1.63	6.15
HNE1	0.090	0.000 13	1.33 X 10-8	7.0	0.15	2.22	4.51
HNE2	0.092	0.000 14	1.54 X 10-8	7.5	0.16	2.68	3.73
HNE3	0.090	0.000 13	1.33 X 10-8	7.7	0.17	2.51	3.98
CNE1	0.091	0.000 13	1.33 X 10-8	5.7	0.12	1.75	5.70
CNE2	0.090	0.000 12	1.13 X 10-8	6.3	0.14	1.76	5.69
CNE3	0.089	0.000 13	1.33 X 10-8	6.5	0.14	2.09	4.78

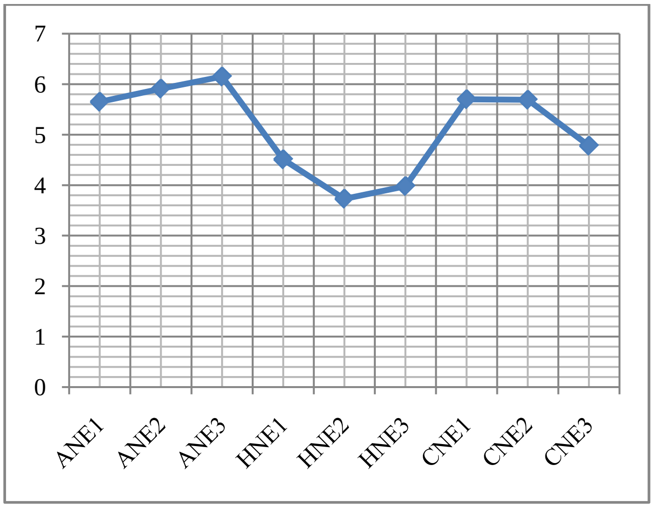

Fig. 1: Electrical Conductivity of Al-Ni Alloy Samples

In fig.4 above, it is observed that annealed alloys conductivity increased from 2%Ni to 6%Ni alloys samples, indicating that increase alloying composition favour electrical conductivity, whereas hardened alloy sample decreased from 2%Ni to 4% and increase again, which is an uncertainty pattern of effect, as such there is no directional behaviour. As cast alloys seems to be steady from the first alloying composition, but decreased rapidly at 6%Ni which show some degree of uncertainty in the effect of the alloying composition. As Cast alloys are next in values to the annealed alloys, while hardened alloys are the lowest in values. Generally, it will be notice that the annealed alloy series have higher conductivity than the hardened and the as cast alloy series.

Individually, it can be observed as shown on fig.5 below:

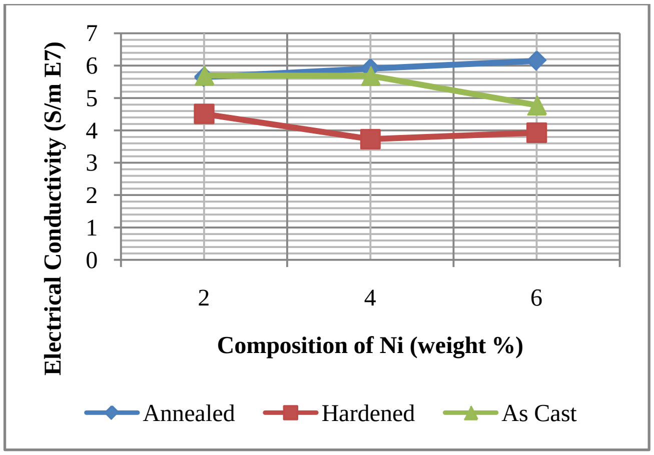

Fig. 2: Behaviour of the various Treatments on the Alloys Samples

From the figure above, it can be observed that annealed alloy samples electrical conductivity seems to be directly proportional to the alloy composition, such that 2%Ni alloy is lower than 4%Ni alloy and as the addition increased to 6%Ni, the conductivity increased from 5.65 to 5.91 and then to 6.15 (x 10^7 S/m). In the case of the hardened alloy samples behave in such a way that alloy with composition of 2%Ni has the highest conductivity, which decreased with increase alloy composition from 2% to 4%, then it increased little with increase in alloy composition from 4% to 6%Ni, from4.51 to 3,73 and then to 3.98 x 10^7 S/m. While the as cast alloy samples behave in an inversely proportional manner, so that increase in alloying result in decrease electrical conductivity from 5.70 to 5.69 to 4.78 x 10^7 S/m. It can be concluded here that annealing an aluminium-nickel alloy result in increase in the electrical conductivity, whereas hardening the alloy will reduce the electrical conductivity, leaving the alloy untreated will impact moderate conductivity to the alloy.

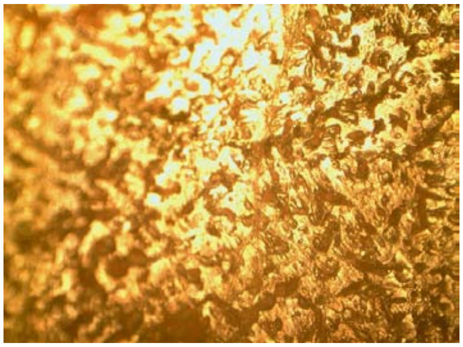

Plate 1: Annealed Al-2%Ni Alloy

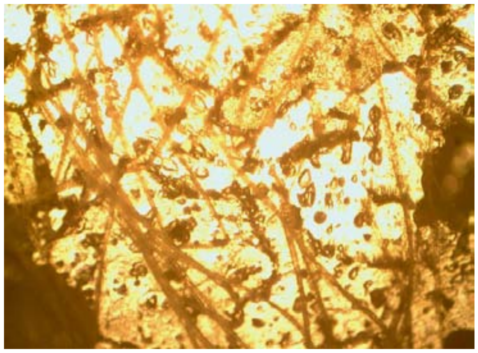

Plate 2: Annealed Al-4%Ni Alloy

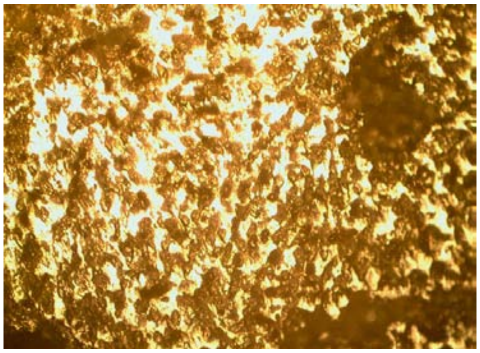

Plate 3: Annealed Al-6%Ni Alloy

In plate1 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. Plate2 can be seen having some patches of whitish primary phases of Al, spread within diffused precipitates of Ni, with dark patches of precipitates at bottom left and middle right of the matrix, nodular structure intermixed with fibrous structures of $NiAl_3$ dispersoids and continuous precipitates can be seen, Plate 3 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,

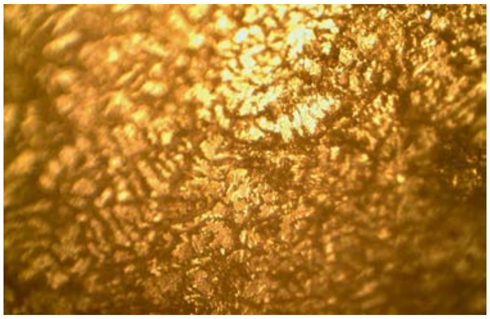

Plate 4: Al-2%Ni Hardened Alloy

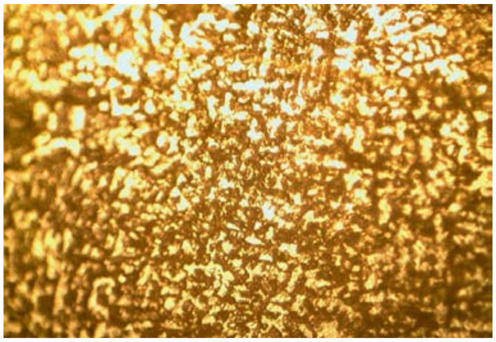

Plate 5: Al- 4%Ni Hardened Alloy

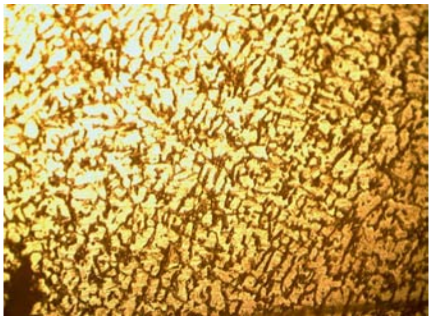

Plate 6: Al-6%Ni Hardened Alloy

In plate 4, the diffusion of the precipitates is much pronounced, with little patch of white patch of primary Al around the top center of the graph. Plate 5 shows patterns of mixed white primary phases and dark precipitates of Ni all over the matrix, the structure consist of small polygonal grains with patches of the eutectoid between them and interspersed with small globules of Ni and tiny acicular shapes can be seen, while plate6 is with lamellar precipitates of Ni throughout the Al-matrix, with a concentrated dark portion at the bottom left corner, there are recrystallized and twinned grains with straight twin lines and small grain size.

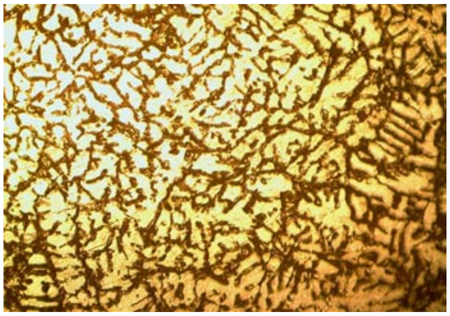

Plate 7: Al-2%Ni as Cast Alloy

Plate 7 shows dendrites of the precipitated Ni all over the Al matrix. A cored grain with remnant of dendritic structure can be seen on the matrix, acicular and twinned structures can be seen on the right side of the graph. While plate 8 shows dendritic networks of precipitated Ni with a concentrated dark portion near bottom right of the graph. The micrograph is made up of acicular, dendritic, bonded and lenticular structure intermixed in the matrix of Al. While plate 9 has dendrites of primary phases of Al over the precipitates of Ni, dendritic, segregation, which brightened from right to the left intermixed with acicular structures.

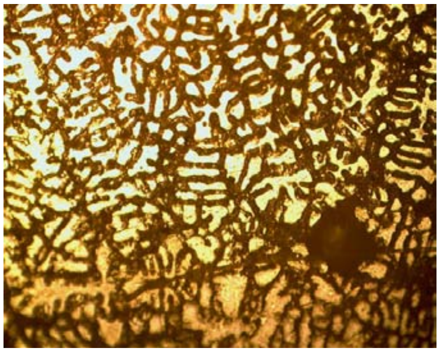

Plate 8: Al-4%Ni as Cast Alloy

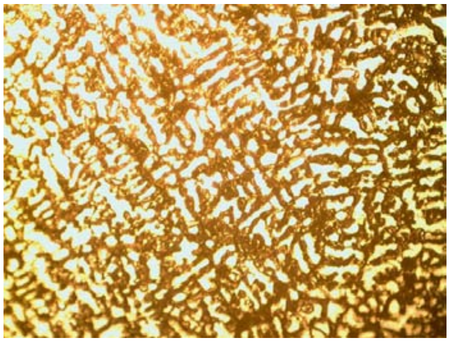

Plate 9: Al-6%Ni as Cast Alloy

4. CONCLUSION

It is observed from the research that annealed alloys favour increase in electrical conductivity, whereas hardened alloys result in decrease conductivity, while untreated alloys have moderate effect on the conductivity of the alloy.

REFERENCES

[1] Aniyi, J. A.; Bello-Ochende, F. L. and Adeyemi, M. B. (1996). Effects of pressure, die and Stress relief temperatures on the residual stresses and mechanical properties of aluminium rods, *Journal of Materials Engineering and performance*, Vol5 (3), pp. 399-404.

[2] Abifarin, M. S. and Adeyemi, M. B. (2003). Influence of process variables on the mechanical properties of squeeze cast aluminium alloy. *Nigerian Journal of Technological Development*, Vol3 (1), pp. 1-7.

[3] Aweda, J. O. and Adeyemi, M. B. (2007). Effects of applied pressure and die temperature on The electrical conductivity of squeeze cast aluminium rods. *Nigerian Journal of Technological*

Development Vol6 (1), pp. 45-56. doi:10.1016/S0010-2180(00)00101-2. doi:10.1016/S0026-0576(06)80099-1.

[4] William, B. F.; Warren, E. H.; Robert, K. D.; Douglas, A. G.; Maurice, W. W.; Kenneth, J. C. and Thomas, B. B. (2009). "Aluminum" in *Ullmann's Encyclopedia of Industrial Chemistry*, Wiley-VCH, Weinheim. doi:10.1002/14356007.a01_459.pub2

[5] Pio, I. Y.; Sulaimin, S. and Hamouda, A. M. (2005). Grain Refinement of LM6Al-Si alloy and castings to enhance Mechanical properties. *Journal of Materials Processing Technology*, Vol.162-163 pp. 435-441.

[6] Chen, B.; Lin, D-I.; Zeng, X-Q and Chen, L. (2008). Equal-channel Angular Pressing of Magnesium Alloy AZ91 and its Effects on Microstructure and Mechanical Properties. *Materials Science and Engineering A*, Vol. 483-484 (1-2). Pp 113-116

[7] Wierzbinska, M. and Sieniawski, J. (2006). Effects of Morphology of Eutectic Silicon Crystals on Mechanical Properties and Cleavage Fracture Toughness of AlSi5Cu Alloy. *Journalof Achievements in Materials and Manufacturing Engineering.* Vol. 14 pp 31-36

[8] Riley, K. F.; Bence, S. J. and Hobson, M. P. (2010). *Mathematical Methods for Physics and Engineering* (3rd Edition), Cambridge University Press, 2010, ISBN 9 780521 769718

[9] Rohatgi, P. K. and Prabhakar, K. V. (1975). Wrought Aluminium-Nickel for High Conductivity Applications. *Journal of Metallurgical Transactions A*, vol6A, pp. 12-18.

[10] Degarmo, E. P.; Black, J T. and Kohser, R. A. (2003), *Materials and Processes inManufacturing* (9th ed.), Wiley, pp. 133 & 277-286. ISBN 0-471-65653-4.