EFFECT OF ANNEALING ON THE HARDNESS OF COLD WORKED Al-6%Cu ALLOY

BY

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A PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A BACHELOR OF ENGINEERING (B.ENG) IN MECHANICAL ENGINEERING

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DEPARTMENT OF MECHANICAL ENGINEERING,

FEDERAL UNIVERSITY, OYE-EKITI,

NIGERIA

SEPTEMBER, 2016

DECLARATION

I OLADIPUPO MICHAEL DAMILARE with matriculation number MEE/11/0414 hereby declare that this research project titled "EFFECT OF ANNEALING ON THE HARDNESS OF COLD WORKED ALUMINIUM – 6% COPPER ALLOY" is a product of my research and it is original.

MEE/11/0414

OLADIPUPO MICHAEL DAMILARE

MATRIC NO. AND NAME

29/07/2016

SIGNATURE AND DATE

CERTIFICATION

This is to certify that this project work was carried out by OLADIPUPO MICHAEL DAMILARE with matriculation number MEE/11/0414, a student of Mechanical Engineering, Faculty of Engineering, Federal University, Oye-Ekiti, Ekiti State.

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DEDICATION

This project is dedicated to my parents, Mr and Mrs Abiodun Oladipupo, and my siblings, Israel and Rachael Oladipupo.

ACKNOWLEDGMENT

It gives me immense pleasure to express my deep sense of gratitude to God, the giver of life, and to Mr. O.C Okoye, my project supervisor for his invaluable guidance and assistance in the course of this work.

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ABSTRACT

Effect of annealing temperatures and annealing time on the hardness of engineering materials is of great importance which needs critical considerations. This work involves casting Al – 6% Cu alloy. Spectrochemical analysis on the alloy revealed that the alloy mainly contained 91% aluminium and 6% copper. After casting, homogenization annealing was conducted on 10 samples of the alloy at 450°C for 1 hour and the samples were allowed to cool in the furnace. The homogenized samples were then cold worked to achieve a reduction of 2% in the original length of the samples using a hydraulic press. Afterwards, 5 of the samples were annealed at 250°C; one sample was removed after 6 minutes, another after 12 minutes, another after 30 minutes, another after 60 minutes, and the last after 120 minutes. The samples were cooled in air. A similar procedure was carried out on the remaining 5 samples at 400°C. Hardness test was conducted on the annealed samples using the Brinnel Hardness Testing Machine. Generally, it was discovered that the hardness of the alloy decreases with an increase in annealing time. At the higher temperature (400°C), it was observed that the hardness value decreased much faster in each of the corresponding time intervals. This work provides a basis for the selection of the alloy to meet desired hardness requirements in the industrial applications.

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CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Aluminum and aluminum alloys have many outstanding attributes that lead to a wide range of applications, including good corrosion and oxidation resistance, high electrical and thermal conductivities, low density, high reflectivity, high ductility and reasonably high strength, and relatively low cost. (F.C. Campbell, 2008)

Aluminum's beneficial physical properties include its non-ferromagnetic behavior and resistance to oxidation and corrosion. Aluminum does not display a true endurance limit, however, so failure by fatigue may eventually occur, even at low stresses. Because of its low melting temperature, aluminum does not perform well at elevated temperatures. The weak nature of aluminium poses a serious limit to its use for most engineering purposes but when it is alloyed with elements like Copper, Zinc, Magnesium, Silicon, e.t.c, this weak and soft metal is converted to a hard and strong metal which makes it suitable for high end engineering applications. The alloys may be 30 times stronger than pure aluminum. (Askeland, 1994).

Cold working, however can be used to further increase the strength and hardness of the metal, and subsequent heat treatment like annealing is used to restore the ductility of the metal, though annealing causes a decrease in the hardness of the alloy.

The scope of this study is based on finding the effect of varying annealing temperatures and times on the hardness of 2% cold-worked Al-6%Cu alloy.

1.2 STATEMENT OF THE PROBLEM

This research work is carried out to understand the effect of the variation in annealing temperatures and time on the hardness of cold-worked aluminium-6% copper alloy.

1.3 OBJECTIVES OF THE STUDY

The objectives of the work undertaken in the report are as follows:

i. Studying the effect of varying annealing temperatures on the hardness of cold-worked Al-6%Cu.
ii. Studying the effect of varying annealing time on the hardness of cold-worked Al-6%Cu

1.4 SIGNIFICANCE OF THE STUDY

Aluminium in its pure form has a low density, and a good weight saving property but its weakness is a disadvantage, therefore, this research is useful for the following purpose:

i. It explains the advantages of alloying copper with aluminium, in terms of hardness and strength, which makes it suitable for selection of Al-6%Cu alloy for specific engineering and structural applications.
ii. The research justifies the balance that must be reached between cold-working and annealing so as to produce an alloy with increased hardness, weight saving advantage, and good ductility.

1.5 SCOPE OF THE STUDY

This study is focused on how annealing temperatures and time affects the hardness of cold-worked aluminium-6%copper alloy.

CHAPTER TWO: LITERATURE REVIEW

2.1 ALUMINIUM

Aluminium is the world's most abundant metal and is the third most common element, comprising 8% of the earth's crust. The versatility of aluminium makes it the most widely used metal after steel.

Although aluminium compounds have been used for thousands of years, aluminium metal was first produced around 170 years ago. In the 100 years since the first industrial quantities of aluminium were produced, worldwide demand for aluminium has grown to around 29 million tons per year. About 22 million tons is new aluminium and 7 million tons is recycled aluminium scrap. The use of recycled aluminium is economically and environmentally compelling. Pure aluminium is soft, ductile, corrosion resistant and has a high electrical conductivity. It is widely used for foil and conductor cables, but alloying with other elements is necessary to provide the higher strengths needed for other applications. (Kissel, 2002)

Aluminium is a strong electro-negative metal and possesses a strong affinity for oxygen; this is apparent from the high heat of formation of its oxide. For this reason, although it is among the six most widely distributed metals on the surface of the earth, it was not isolated until well into the nineteenth century. Alumina was known, however, in the eighteenth century, and the first unsuccessful attempts to isolate the metal were made by Sir Humphry Davy in 1807, when the isolation of the alkali metals had made a powerful reducing agent available. It was not, however, until 1825 that the Danish Worker, H.C. Oersted, succeeded in preparing aluminium powder by the reduction of anhydrous aluminium chloride with sodium amalgam; two years later, F. Wohler replaced the amalgam by potassium, and between 1827 and 1847 discovered and listed many of the chemical and physical properties. However, many years passed before the metal could be produced commercially.

The father of the light metal industry was probably the French scientist, Henri Sainte-Claire Deville, who in 1850 improved Wohler's method of preparation by replacing potassium by sodium, and by using the double chloride of sodium and aluminium as his source of the metal, thus making the production of aluminium a commercial proposition; the price of the metal, however, was still comparable with that of gold. The production of aluminium received a further impetus when Robert Bunsen and, following him, Deville, showed how the metal could be produced electrolytically from its ores. In 1885, the brothers Cowie produced the first aluminium alloys containing iron and copper, soon after which the invention of the dynamo made a cheaper supply of electricity available and resulted, in 1886, in Herault's and Hall's independent French and American patents for the electrolytic production of aluminium from alumina and molten cryolite (AlF3NaF). Afterwards, the production of aluminium in Europe centred round the first factory in Neuhausen, while Hall's process was applied in the U.S.A. in Pittsburgh. Modern production of aluminium begins from the mineral bauxite, which contains approximately 25% of aluminium. This is converted to alumina by digestion with a solution of sodium hydroxide under pressure (the Bayer process), and the purified alumina produced is added to a molten mixture of cryolite and fluorspar. This mixture is electrolysed in a cell with carbon anodes and the molten mixture is tapped from the bottom of the cell. (ASM, 2001)

Table 2.1: Principal properties of 99.9% pure aluminium *(John, V.B. (1992).*

Melting Point	660°C
Crystal structure	Face centred cubic
Young Modulus, E	70.5 GPa
Tensile Strength	45 MPa
Electrical resistivity	2.66×10^{-8} Ωm at 20°C
Corrosion resistance	very good

2.2 PROPERTIES OF ALUMINIUM

Among the most striking characteristics of aluminum is its versatility. More than 300 alloy compositions are commonly recognized, and many additional variations have been developed internationally and in supplier/consumer relationships. The properties of aluminum that make this metal and its alloys the most economical and attractive for a wide variety of uses are appearance, light weight, fabricability, physical properties, mechanical properties, and corrosion resistance. Aluminum can display excellent corrosion resistance in most environments, including air, water (including salt water), petrochemicals, and many chemical systems. Aluminum surfaces can be highly reflective. Radiant energy, visible light, radiant heat, and electromagnetic waves are efficiently reflected, while anodized and dark anodized surfaces can be reflective or absorbent. The reflectance of polished aluminum, over a broad range of wavelengths, leads to its selection for a variety of decorative and functional uses. (Campbell, 2008)

Aluminum is non-ferromagnetic, a property of importance in the electrical and electronics industries. It is non-pyrophoric, which is important in applications involving inflammable or explosive materials handling or exposure. Aluminum is also nontoxic and is routinely used in containers for foods and beverages. It has an attractive appearance in its natural finish, which can be soft and lustrous or bright and shiny. It can be virtually any color or texture. (Campbell, 2008)

2.2.1 Thermal and Electrical Properties.

Aluminum typically displays excellent electrical and thermal conductivity, but specific alloys have been developed with high degrees of electrical resistivity. These alloys are useful, for example, in high-torque electric motors. Aluminum is often selected for its electrical conductivity, which is nearly twice that of copper on an equivalent weight basis. The requirements of high conductivity and mechanical strength can be met by use of long-line, high-voltage, aluminum steel-cored reinforced transmission cable. The thermal conductivity of aluminum alloys, approximately 50 to 60% that of copper, is advantageous in heat exchangers, evaporators, electrically heated appliances and utensils, and automotive cylinder heads and radiators. (ASM, 2015)

2.2.2 Mechanical Properties.

Some aluminum alloys exceed structural steel in strength. However, pure aluminum and certain aluminum alloys are noted for extremely low strength and hardness. The tensile yield strength of superpurity aluminum in its softest annealed state is approximately 10 MPa (1.5 ksi), whereas that of some heat treated commercial high-strength alloys exceeds 550 MPa (80 ksi). Higher strengths, up to a yield strength of 690 MPa (100 ksi) and over, may be readily produced, but the fracture toughness of such alloys does not meet levels considered essential for aircraft or other critical-structure applications. The density of aluminum and its alloys is approximately 7 GPa (10 msi), which is lower than titanium (10 GPa, or 15 msi) and steel (21 GPa, or 30 msi) alloys. However, when measured on a stiffness-to-density basis, aluminum alloys are weight-competitive with the heavier titanium and steel alloys. One rather disappointing property of high-strength aluminum alloys is their fatigue performance; the fatigue limit of most high-strength alloys falls within the 137 to 172 MPa (20 to 25 ksi) range. Work hardening raises the strength of aluminum quite substantially. Commercial-purity aluminum (99.60% pure) has a yield strength of 27 MPa (3.9 ksi) when fully annealed, but if cold worked by swaging or rolling to 75% reduction in area. the yield strength increases to 125 MPa (18 ksi). As with most metals with the fcc crystalline structure, there is no ductile-to-brittle transition; aluminum remains ductile at cryogenic temperatures, with tensile elongation actually increasing somewhat below −200 °C (−328 °F). Although aluminum alloys can achieve high strength at room temperature, tensile and creep strength decline sharply above 200 °C (392 °F). (ASM, 2015)

2.3 Applications

Aluminum is a consumer metal of great importance. Aluminum and its alloys are used for foil, beverage cans, cooking and food processing utensils, architectural and electrical applications. and structures for boats, aircraft, and other transportation vehicles. Alloy 3004, which is used for beverage cans, has the highest single usage of any aluminum alloy, accounting for approximately one quarter of the total usage of aluminum. As a result of a naturally occurring tenacious surface oxide film (Al_2O_3), a great number of aluminum alloys provide exceptional resistance to corrosion in many atmospheric and chemical environments. Its corrosion and oxidation resistance is especially important in architectural and transportation applications. With a yield strength comparable to that of mild steel, 6061 is one of the most widely used of all aluminum alloys for general construction. The 5xxx alloys are used extensively in the transportation industries for boat and ship hulls; dump truck bodies; large tanks for carrying gasoline, milk, and grain; and pressure vessels, especially where cryogenic storage is required. The weldability of these alloys is excellent, and they have excellent corrosion resistance. (ASM, 2015)

On an equal weight and cost basis, aluminum is a better conductor than copper. Its high thermal conductivity leads to applications in the production of radiators and cooking utensils. Its low density is an advantage in hand tools and all forms of transportation, especially aircraft.

The high-strength 2xxx and 7xxx alloys are competitive on a strength-to-weight ratio with the higher-strength but heavier titanium and steel alloys and thus have traditionally been the dominant structural material in both commercial and military aircraft. In addition, aluminum alloys are not embrittled at low temperatures and become even stronger as the temperature is decreased without significant ductility losses, making them ideal for cryogenic fuel tanks for rockets and launch vehicles. Aluminum-lithium alloys are attractive for aerospace applications because the addition of lithium increases the modulus of aluminum and reduces the density (each 1 wt% of lithium increases the modulus by approximately 6% while decreasing the density approximately 3%). (ASM, 2015)

2.4 ALUMINIUM ALLOYS

Aluminum alloys are classified in various categories regarding their chemical composition and the processes they are subjected to. Every alloy is characterized by unique properties and exhibits different structural behavior. There are wrought alloys, which are worked to shape and cast alloys, which are poured in a molten state into a mould that determines their shape. While strength and other properties for both products are dependent on their ingredients or the selective addition of alloying elements, further variations on these properties can be achieved by tempering, a process that refers to the alteration of the mechanical properties of a metal by means of either mechanical or thermal treatment. Temper can be produced in wrought products by the strain hardening that results from cold working. Thermal treatments may be used to obtain temper in cast products, as well as in those wrought products identified as heat-treatable. Conversely, the wrought alloys that can only be strengthened by cold work are designated non-heat-treatable. (*Charalambos C. Baniotopoulos, 2012*)

2.4.1 Designation: Aluminum alloys can be divided into two major groups: wrought and casting alloys, depending on their method of fabrication. Wrought alloys, which are shaped by plastic deformation, have compositions and microstructures significantly different from casting alloys, reflecting the different requirements of the manufacturing process. Within each major group, we can divide the alloys into two subgroups: heat-treatable and non heat-treatable alloys.

Aluminum alloys are designated by the numbering system shown in Table 2.2. The first number specifies the principal alloying elements, and the remaining numbers refer to the specific composition of the alloy.

The degree of strengthening is given by the **temper designation** T or H, depending on whether the alloy is heat treated or strain hardened (Table 2.4) Other designations indicate whether the alloy is annealed (O), solution treated (W), or used in the as-fabricated.

Table 2.2; WROUGHT ALLOYS

1xxx	Commercially pure Al (99% Al)	Not age hardenable
2xxx	Al-Cu and Al-Cu-Li	Age hardenable
3xxx	Al-Mn	Not age hardenable
4xxx	Al-Si and Al-Mg-Si	Age hardenable if magnesium is present
5xxx	Al-Mg	Not age hardenable
6xxx	Al-Mg-Si	Age hardenable
7xxx	Al-Mg-Zn	Age hardenable
8xxx	Al-Li, Sn, Zr, or B	Age hardenable
9xxx	Not currently used	

Table 2.3; CASTING ALLOYS

1xx.x.	Commercially pure Al	Not age hardenable
2xx.x.	Al-Cu	Age hardenable
3xx.x.	Al-Si-Cu or Al-Mg-Si	Some are age hardenable
4xx.x.	Al-Si	Not age hardenable
5xx.x.	Al-Mg	Not age hardenable
7xx.x	Al-Mg-Zn	Age hardenable
8xx.x.	Al-Sn	Age hardenable
9xx.x.	Not currently used	

(A)The first digit shows the main alloying element, the second digit shows modification, and the last two digits shows the decimal % of the Al concentration (e.g., 1060: will be 99.6% Al alloy).

(B)Last digit indicates product form, 1 or 2 is ingot (depends upon purity) and 0 is for casting.

(Source: Askeland, D.R. (1994)

Temper designations for aluminum alloys

Aluminium alloys are supplied in a very wide range of tempers with two principal groups:

Non-heat treatable alloys – Alloys whose strength/mechanical properties are achieved by cold working (rolling, extruding, e.t.c), sometimes called work hardening alloys, Temper is denoted by H.

Heat treatable alloys – Alloys whose strength/mechanical properties are achieved by heat treatment followed by cooling and natural or artificial ageing. Temper denoted by letter T

Table 2.4: Temper designation for aluminium alloys, (Askeland, 1994)

As fabricated (F)	Annealing (O)	Cold-worked (H)	Solution treated (W)	Age hardened (T)
Hot-worked		H1X – Cold worked only (X refers to the amount of cold work and strengthening)		T1 – Cooled from the fabrication temperature and naturally aged. T1 – Cooled from the fabrication temperature and naturally aged.
Forged		H12 – Cold work that gives a tensile strength midway between 0 and H14 tempers		T2 – Cooled from the fabrication temperature. cold-worked, and naturally aged.
Cast		H14 – Cold work that gives a tensile strength midway between the 0 and H18 tempers		T3 – Solution - treated, cold-worked, and naturally aged.
		H18 – Cold work that gives about 75% reduction		T4 – Solution – treated and naturally aged.
		H19 – Cold work that gives a tensile strength greater than 2000psi of that obtained by the H18 temper		T5 – Cooled from the fabrication temperature and artificially aged.
		H2X – Cold-worked and partly annealed		T6 – Solution – treated and artificially aged.
		H3X – Cold-worked and stabilized at a low temperature to prevent age hardening of the structure.		T7 – Solution – treated and stabilized by over ageing.
				T8 – Solution – treated. cold-worked, and artificially aged.
				T9 – Solution – treated. artificially aged and cold-worked
				T10 – Cooled from the fabrication temperature. cold-worked and artificially aged.

(Source: Askeland, D. R. (1994)

2.5 Cold working

Both Aluminium and Aluminium alloys are very flexible and can be plastically cold deformed with severe draft what causes the strengthening of the alloy. To remove the effects, strain annealing is used, whose parameters depend on the degree of draft and chemical composition of the alloy. Large impact on the selection of parameters are also the dimensions of intermediates and type of the furnace ***(Singh, 2006).***

2.5.1 Characteristics of Cold working

There are a number of advantages and limitations to strengthening a metallic material by cold working or strain hardening.

- We can simultaneously strengthen the metallic material and produce the desired final shape.
- We can obtain excellent dimensional tolerances and surface finishes by the cold working process.
- The cold-working process can be an inexpensive method for producing large numbers of small parts.
- Some metals, such as HCP magnesium, have a limited number of slip systems and are rather brittle at room temperature; thus, only a small degree of cold working can be accomplished.
- Ductility, electrical conductivity, and corrosion resistance are impaired by cold working. Since the extent to which electrical conductivity is reduced by cold working is less than that for other strengthening processes, such as introducing alloying elements, cold working is a satisfactory way to strengthen conductor materials, such as the copper wires used for transmission of electrical power.
- Properly controlled residual stresses and anisotropic behavior may be beneficial; however, if residual stresses are not properly controlled, the materials properties are greatly impaired.

- Since the effect of cold working is decreased or eliminated at higher temperatures, we cannot use cold working as a strengthening mechanism for components that will be subjected to high temperatures during service.
- Some deformation processing techniques can be accomplished only if cold working occurs. For example, wire drawing requires that a rod be pulled through a die to produce a smaller cross-sectional area (Figure 2.1) For a given draw force *Fd*, a different stress is produced in the original and final wire. The stress on the initial wire must exceed the yield strength of the metal to cause deformation. The stress on the final wire must be less than its yield strength to prevent failure. This is accomplished only if the wire strain hardens during drawing. (Askeland, 1994)

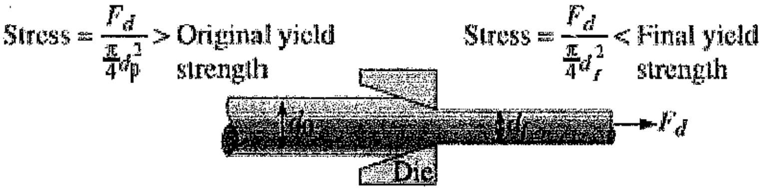


Fig 2.1; The wire-drawing process. The force Fd acts on both the original and final diameters. Thus, the stress produced in the final wire is greater than that in the original. If the wire did not strain harden during drawing, the final wire would break before the original wire was drawn through the die.

(Source: Askeland, 1994)

2.6 ANNEALING

Cold working is a useful strengthening mechanism, and it is an effective tool for shaping materials using wire drawing, rolling, extrusion, etc. Sometimes, cold working leads to effects that are undesirable. For example, the loss of ductility or development of residual stresses may not be desirable for certain applications. Since cold working or strain hardening results from increased dislocation density, we can assume that any treatment to rearrange or annihilate dislocations reverses the effects of cold working.

Annealing is a heat treatment used to eliminate some or all of the effects of cold working. Annealing at a low temperature may be used to eliminate the residual stresses produced during cold working without affecting the mechanical properties of the finished part, or annealing may be used to completely eliminate the strain hardening achieved during cold working. In this case, the final part is soft and ductile but still has a good surface finish and dimensional accuracy. After annealing, additional cold work can be done since the ductility is restored; by combining repeated cycles of cold working and annealing, large total deformations may be achieved. There are three possible stages in the annealing process.

Recovery stage: The original cold-worked microstructure is composed of deformed grains containing a large number of tangled dislocations. When we first heat the metal, the additional thermal energy permits the dislocations to move and form the boundaries of a polygonized subgrain structure. The dislocation density, however, is virtually unchanged. This low temperature treatment removes the residual stresses due to cold working without causing a change in dislocation density and is called **recovery**. The mechanical properties of the metal are relatively unchanged because the number of dislocations is not reduced during recovery. Since residual stresses are reduced or even eliminated when the dislocations are rearranged, recovery is often called a stress relief anneal. In addition, recovery restores high electrical conductivity to the metal, permitting us to manufacture copper or aluminum wire for transmission of electrical power that is strong yet still has high conductivity. Finally, recovery often improves the corrosion resistance of the material. (Askeland, 1994)

Recrystallization: When a cold-worked metal is heated above a certain temperature, rapid recovery eliminates residual stresses and produces the polygonized dislocation structure. New small grains then nucleate at the cell boundaries of the polygonized structure, eliminating most of the dislocations (Figure 8-16). Because the number of dislocations is greatly reduced, the recrystallized metal has low strength but high ductility. The temperature at which a microstructure of new grains that have very low dislocation density appears is known as the **recrystallization temperature**. The process of formation of new grains by heat treating a cold-worked material is known as **recrystallization**.

Grain Growth: At still higher annealing temperatures, both recovery and recrystallization occur rapidly, producing a fine recrystallized grain structure. If the temperature is high enough, the grains begin to grow, with favored grains consuming the smaller grains. This phenomenon, called *grain growth*, is driven by the reduction in grain boundary area. (Askeland, 1994)

CHAPTER THREE: METHODOLOGY

3.1 PREPARATION OF THE TEST SAMPLES.

For this research work, 10 samples of Al - 6%Cu (Al91%, Cu6%) with diameters of 15 mm and a height of 250 mm were used. The samples for the casting were prepared at JAMAH TECHNICAL WORKS, Idi-Ape, Ibadan, Oyo state, Nigeria.

3.1.1 MOULD PREPARATION

The apparatus used for the mould preparation are:

- Moulding box
- Spade
- Trowel
- Ram
- Sand mould
- Venting wire
- Brush

The casting method employed for this research is the sand casting method, a plastic cylindrical rod of 15 mm diameter and 250 mm length was used as the pattern.

The moulding sand was properly mixed with little quantity of water in the foundry with trowel, till the sand became compact and mouldable.

The patterns were placed in the molding box in a vertical position at a small distance from each other. The sand is poured into the moulding box, the trowel is used to level the sand while the ram was used to compact the sand so that it stuck together and form a mould. Pouring of sand, leveling and ramming is continued until the mould box is completely filled. At this point, the sand was sticky and tight enough to form the shape of the pattern. The venting wire is used to create air passage for the escape of gases during casting. The pattern is then removed from the mould carefully. Then, the mould was baked with fire to dry it up. Thus the mould was ready for casting operation.

3.1.2 Charge Preparation.

The charges used for this research work are Aluminium and Copper. The calculation used to analyze the various masses of the alloying elements to be casted are stated below:

3.1.2.1 Charge Calculation.

The Calculation used to define the various masses of the alloying elements is given below

Diameter of pattern, D = 15 mm = 1.5 cm

Length of pattern, h = 500 mm = 50 cm

Since the pattern is a cylindrical pattern

Volume of pattern, $V_P = (\pi/4)D^2h = (3.142/4) \text{ X } 1.5^2 \text{ X } 50$

$= 88.369\text{cm}^3$

Density of Aluminium, $\rho_{Al} = 2.7\text{g/cm}^3$

Density of copper, $\rho_{Cu} = 8.96\text{g/cm}^3$

The percentage by mass of each element is:

Aluminium, Al = 95.5%

Copper, Cu = 4.5%

Considering 100g of alloy;

Mass of Al in 100g of alloy = (95.5/100) x 100 = 95.5 g

Mass of Cu in 100g of alloy = (4.5/100) x 100 = 4.5 g

$$\text{Volume of Al in the alloy} = \frac{\text{mass of Al}}{\text{Density of Al}} = \frac{95.5}{2.7} = 35.3704 \text{ cm}^3$$

$$\text{Volume of Cu in the alloy} = \frac{\text{mass of Cu}}{\text{Density of Cu}} = \frac{4.5}{8.96} = 0.5022 \text{ cm}^3$$

Total volume of the alloy = 35.3704 cm^3 + 0.5022 cm^3

= 35.8726 cm^3

$$\text{Density of alloy, } \rho = \frac{\text{mass of the alloy}}{\text{Volume of the alloy}} = \frac{100}{35.8726} = 2.7876 \text{ g/cm}^3$$

The mass of alloy required to fill a mould cavity, m, is given by:

$m = V_P \times \rho = 88.369 \times 2.7876 = 246.337$ g

The mass of Al required = 246.337 x 0.955=235.25 g

The mass of Cu required = 246.337 x 0.045= 11.085 g

To account for the volume of the alloy that will fill the mould cavity and to ensure the alloy prepared is sufficient, the required masses of copper and Aluminium are multiplied by 21

Mass of Al = 235.25 x 21 = 4940.25 g

Mass of Cu = 11.085 x 21 = 232.785 g

Assuming 20% loss in the mass of Aluminium due to evaporation and slag, the mass that will be lost to evaporation and slag is:

$\frac{20}{100} \times 4940.25 = 988.05$ g

Mass of Aluminium used = 4940.25+988.05 = 5928.3 g= 5.9 kg

Mass of copper used = 232.785 g = 0.2 kg

Note: To achieve a 6%Cu in the alloy, 4.5%Cu was used for the charge calculation.

3.1.3 CASTING OF THE ALLOY

The apparatus used for casting are:

- Charcoal fired furnace
- Metallic pot
- Weighing scale
- Stirrer

The casting procedure is described as follows:

5.9 kg of Aluminium profile and 0.2 kg of Copper wire were measured out using the weighing scale. The metallic pot was placed in the furnace. The Aluminium measured out was put in the pot and allowed to heat up. 0.2 kg of copper was preheated by putting it near the furnace. The aluminium was heated to its melting point and afterwards the preheated copper wire was put into the furnace and stirred at interval, and it was observed that the copper melted almost instantly as shown in fig. 3.1. Fig. 3.2 shows the casted Aluminium-6%Copper alloy with the required dimension.

Fig 3.1 Melting the alloy in the earthened charcoal fired furnace

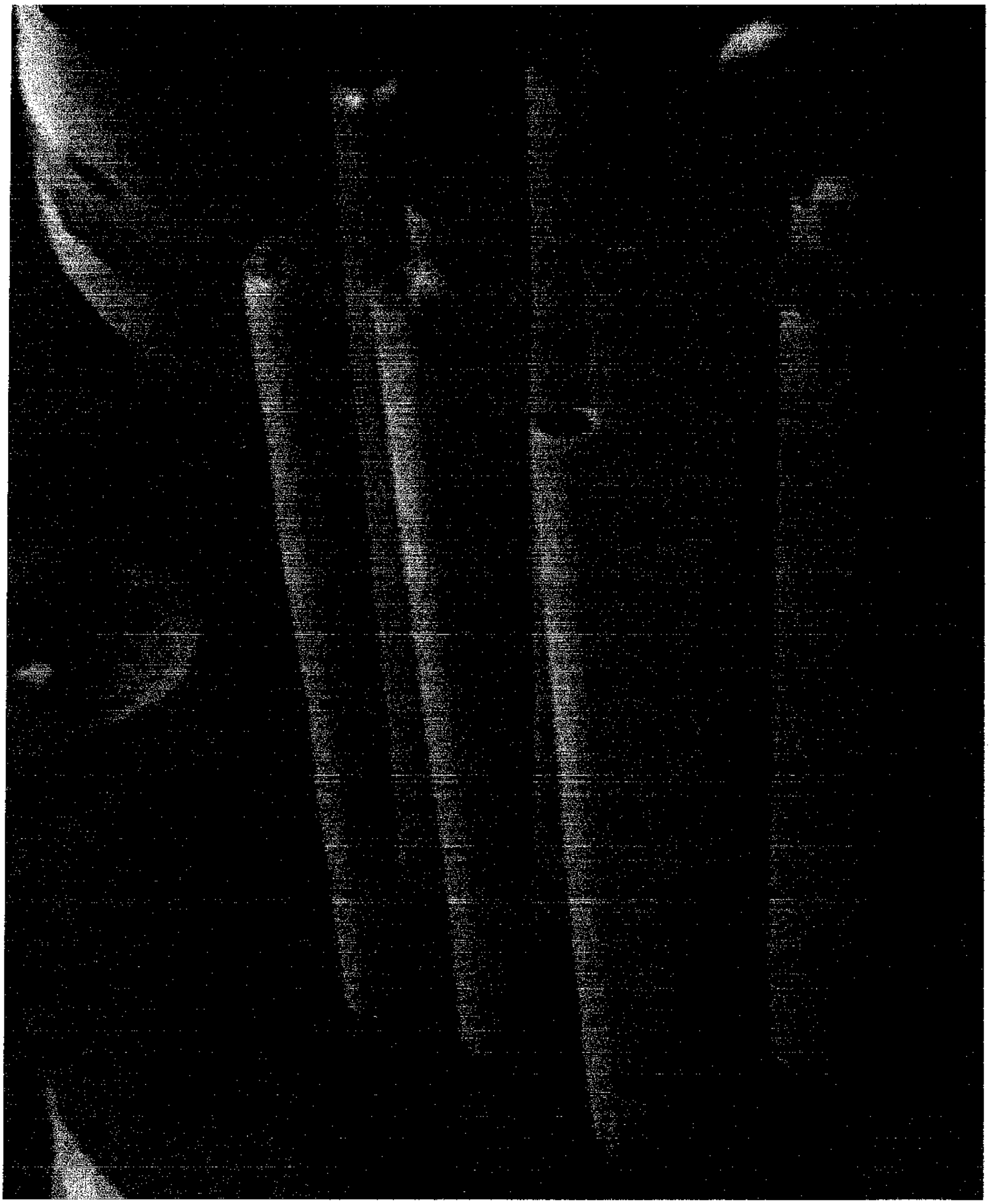


Fig 3.2 Aluminium-6% Cu alloy samples after casting

3.2 Homogenizing of the Alloy samples:

After casting the sample, homogenization was performed to maintain a uniform structure all over the length of each sample. 10 samples of the cast Aluminium copper alloy were loaded in an electric furnace and homogenized at a constant temperature of 450°C for an hour and then allowed to cool in the furnace, the furnace is shown in figure 3.3. One sample was left as cast (unhomogenized). Homogenizing of the sample was carried out at the heat treatment laboratory, Material and Metallurgy Engineering department, Federal University of Technology Akure (FUTA), Ondo state.

Fig 3.3; Homogenizing the samples at 450°C

3.4 Cold-working of the Alloy Samples

The samples were cold-worked at Federal Polytechnic Ado-Ekiti, Ekiti State, Nigeria. The samples were cold – worked using a hydraulic press. Each of the samples to be compressed is placed in between the blocks of the hydraulic press. The samples to be cold-worked are measured using a vernier caliper to verify its initial length as shown in figure 3.4, and then carefully aligned in between the pressure blocks of the hydraulic press. A compressive load was then applied for the sample to be cold-worked by 2%, as the compressive load was applied, the alloy shrinked in length until it has attain a 2% plastic deformation as shown in figure 3.5

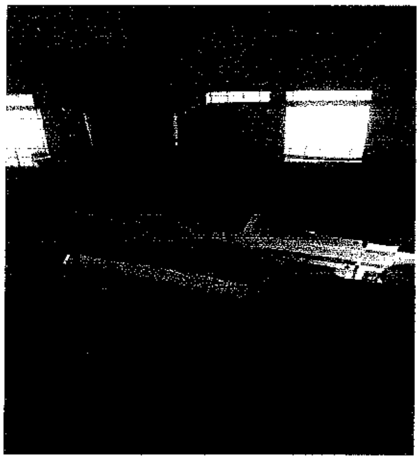


Fig 3.4; Measuring the alloy sample before compression

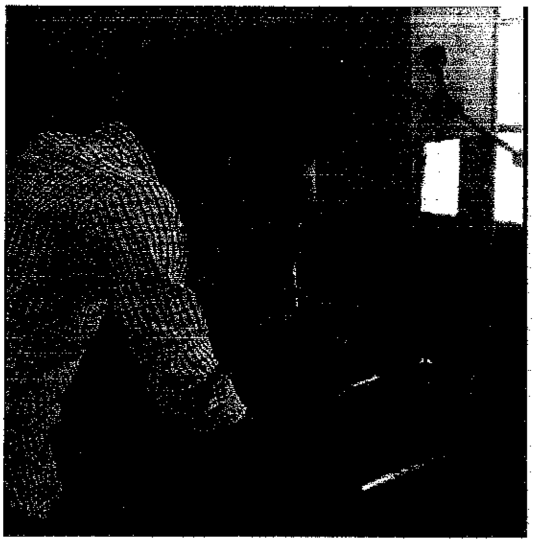


Fig 3.5 compressing the alloy using the hydraulic press

3.5 Annealing the cold-worked samples: The annealing of the cold worked sample was carried out using the Electric furnace in the Heat treatment laboratory of Federal University of Technology, Akure (FUTA), Ondo State.

5 cold worked samples were placed in the furnace chamber. The temperature of 250°C was set on the control panel of the furnace for the chamber. When the temperature of the furnace reached 250°C, the annealing timing begins, then, one of the samples were removed after 6 minutes, afterwards another one was removed after 12 minutes, and yet another one was removed 30 minutes later, the fourth one was removed after 60 minutes and the last one was removed after 120 minutes. The remaining 5 samples were placed in the furnace chamber, and similar procedure was carried out at annealing temperature of 400°C and annealing times of 6, 12, 30, 60, and 120 minutes.

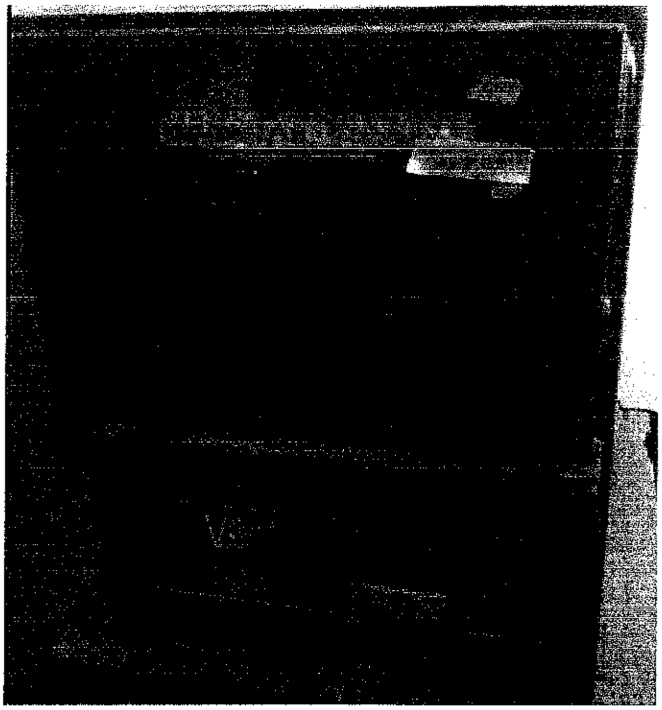


Fig 3.6; Annealing the cold worked samples at 400°C

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Spectrochemical Analysis: The Spectrochemical analysis was carried out using ARL Quandodest Optical Emission Spectrometer at the Department of metallurgical and material engineering, University of Lagos. The result of the analysis is presented in the table.

Table 4.1: Spectrochemical analysis of the alloy

Al	Si	Fe	**Cu**	Mn	Mg	Zn	Cr	Ni	Ti	Zr	V	Ca
91.59	0.2692	0.6636	**6.09**	0.0163	0.5227	0.2749	0.0515	0.1964	0.0299	0.008	0.009	0.0031

From the spectrochemical analysis shown, it was observed that the major constituents of the cast alloy sample are Al (91.59%) and Cu (6.09%).

4.2 HARDNESS TEST RESULT: Hardness test was carried for the samples in 5 different stages, namely;

- Hardness test for the Cold-worked samples after annealing at 400°C
- Hardness test for the Cold-worked samples after annealing at250°C
- Hardness test for the "As cast" sample
- Hardness test for the "sample that was not subjected to any other process"
- Hardness test for the cold-worked sample without annealing.

Fig. 4.1 shows the Brinnel Hardness testing machine used to carry out the hardness test.

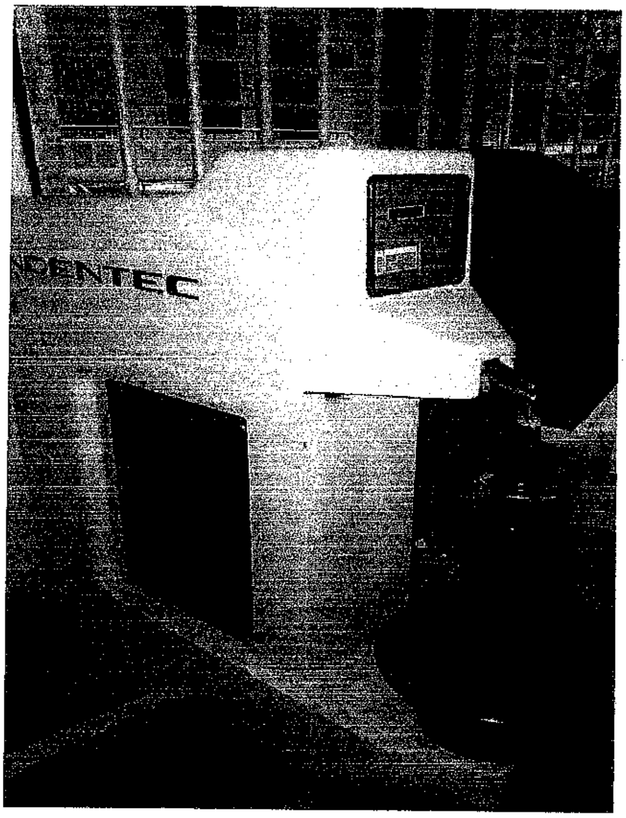


Fig 4.1 The Brinnel Hardness testing Machine

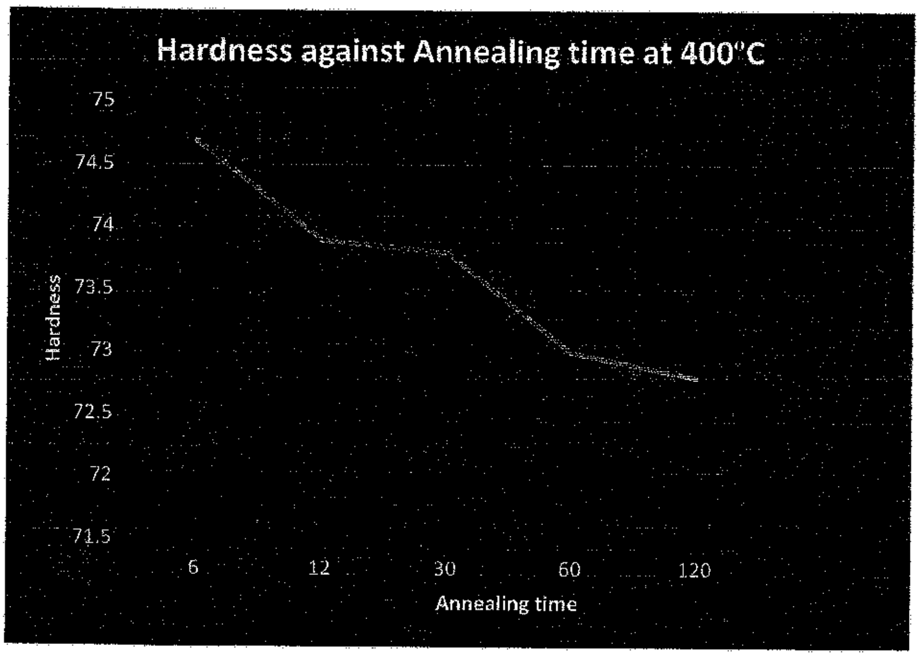
The results at each stage of the test are stated below.

Table 4.2; Hardness test for the Cold-worked samples after annealing @ 400°C

Annealing Time at 400°C	First reading (HBN)	Second reading (HBN)	Third reading (HBN)	Average value(HBN)
6 minutes	75.3	74.6	74.2	74.7
12 minutes	73.4	74.0	74.0	73.9
30 minutes	74.7	74.1	73.1	73.8
60 minutes	74.3	71.2	73.5	73.0
120 minutes	73.3	72.0	73.1	72.8

Indentation was made at three different point on the alloy sample, after which an average was taken to give the hardness of the sample at each annealing time as shown in table 4.2

Fig 4.2: A graph of hardness against Annealing time at 400°C



Discussion: Fig 4.2 shows the graph of hardness against annealing time at 400°C, It was observed that, as the annealing time increases, the hardness of the Aluminium alloy decreases.