The Influence of Cooling on the Mechanical Properties of Cast Silicon Bronze Alloys

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SUBMITTED BY

UZOR CHIGOZIE JOSHUA

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UNDER THE GUIDANCE OF

Prof. J.A Omotoyinbo

JUNE -2017

CERTIFICATION

This is to certify that the work presented in the dissertation entitled

"The Influence of Cooling on the Mechanical Properties of Cast Silicon Bronze Alloys"

Was been carried out by

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DEDICATION

This project report is dedicated to God Almighty, the maker of heaven and earth who has kept me throughout my stay in this great citadel of learning and also during the course of my project.

ACKNOWLEDGEMENT

It is indeed a pleasure for me to express my sincere gratitude to those who have always helped me towards the completion of this work.

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ABSTRACT

This paper is aimed to discuss the influence of cooling on the mechanical properties of cast silicon bronze alloy. Three Cu-Zn-Si alloy were cast using a pit crucible furnace fired then varying the cooling medium producing three different solidified samples with varying microstructure coarsenesses The first sample was cooled in air, second was cooled in water and the last was cooled in the mold resulting to different cooling rates using different cooling mediums.. The scope of the examination included: metallographic test, hardness, impact test and tensile test. The hardness, tensile strength, percentage and impact energy of the alloys were found to increase with faster cooling. The microstructure and lattice structure varies for the three samples because of their varying cooling mediums. The micro-examination of the three specimens showed that the water cooled specimen has a better mechanical properties due to its finer grains in the lattice structure.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Since the Bronze Age, casting techniques have involved liquid melt processing in one fashion or another. Very recently, however, a new technique has been introduced. Due to the differences in thermal history and rheological character between semi solid material and liquid metal, the necessary processing steps are not the same as they have been for thousands of years of foundry experience. The intuition of foundry men, developed as the trade itself did over the millennia, is not necessarily correct when it comes to semi solid metallurgy.

The project is being undertaken to know the influence of cooling on the mechanical properties of cast silicon bronze alloy on cast silicon bronze alloys. The result from this project would give knowledge of how different cooling medium would affect the properties of silicon bronze alloys manufactured using metal mould casting. In metalworking, casting means a process, in which liquid metal is poured into a mold that contains a hollow cavity of the desired shape, and is then allowed to cool and solidify. The solidified part is also known as a casting, which is ejected or broken out of the mold to complete the process. Unlike sand casting processes, in which a mold is destroyed after pouring to remove the casting, metal mold casting uses the mold repeatedly. Silicon bronze has elongations of upwards of 40% when made by casting in sand (Deitz *et al.,* 1938). Alloys fall into two categories: those with a short freezing range such as the silicon bronze alloys and those with a long freezing range such as gunmetal. The short freezing range alloys pass almost directly from the liquid to the solid state as do pure metals (CDA Publication, 1983).

1.2 Statement of the problem

Bronze is a copper alloy with a wide range of engineering uses because of its high strength, high toughness and good machinability. There is advancement of technology in the world today and emergence of new materials everyday which are mostly alloys of different materials solving technical issues in the world today. Therefore there is need to study the influence of cooling on the mechanical properties of cast silicon bronze alloys. This is necessary because knowledge of the structure influences the properties of the materials which in turn is the bridge to the materials application.

1.3 Aim

The project is being undertaken to know the influence of cooling on the mechanical properties of cast silicon bronze alloy on cast silicon bronze alloys.

1.4 Objectives

i. To review the available literature on the influence of moulding materials and cooling rate on cast silicon bronze alloys.

ii. To show the composition and alloying elements of cast silicon bronze alloys.
iii. Discuss the casting process used to manufacture cast silicon bronze alloys.
iv. To examine the influence of cooling on the mechanical properties of cast silicon bronze alloys. Properties such as; strength, tensile stress and impact energy.
v. To conduct microstructural analysis, physical and mechanical tests on the cast silicon bronze.

1.4 Justification

The result from this project would give knowledge of how different cooling mediums and rate would affect the properties of silicon bronze alloys manufactured using metal mould casting.

1.5 Limitations of the study

Due to the time and cost of the research, this research will be limited to tensile testing, hardness testing, and impact testing and microstructural analysis.

1.6 Introduction of copper and its alloys

Copper is the oldest material used by man, its uses dates back to prehistoric times. Copper and its alloys constitute one of the major groups of commercial metals. They are widely used because of their excellent electrical and thermal conductivities, outstanding resistance to corrosion and wear, ease of fabrication, to gather with good strength and fatigue resistance. Pure copper is used extensively for cables and wires, electrical contacts and a wide variety of other parts that are required to pass electrical currents. Copper is face Centre cubic. Melting temperature is 1083°C and density is 8900 kg/m3, which is three times heavier than aluminum. (Skočovský, 2006)

1.7 Designation of copper alloys

From the casting point of view, especially based on the solidification range (freezing range) copper cast alloys can be divided into three groups:

Group I alloys - alloys that have a narrow freezing range, that is a range of 50°C between the liquidus and solidus curves. These are the yellow brasses, manganese and aluminum bronzes, nickel bronze, manganese bronze alloys and chromium copper. (Skočovský, 2006)

Group II alloys - alloys that have an intermediate freezing range, which is a freezing range of 50 to 110°C between the liquidus and the solidus curves. These are the beryllium coppers, silicon bronzes, silicon brass and copper-nickel alloys.

Group III alloys- alloys that have a wide freezing range. These alloys have a freezing range of well over 110°C, even up to 170°C. These are the leaded red and semi-red brasses, tin and leaded tin bronzes and high leaded tin bronze alloys.

1.8 Classification of copper alloys

The most important commercial copper alloys may be classified as follows:

1. Brasses- These are alloys of copper and zinc. These can be further classified as Follows:

A. Alpha (α) brasses- This alloy is containing up to 36 percent zinc.

  i. Yellow alpha brasses are containing 20 to 36 percent zinc
  ii. Red brasses are containing 5 to 20 percent zinc

B. Alpha plus beta (α+β) brasses are containing 54 to 62 percent copper

2. Bronzes are copper based alloys with other alloying elements except zinc. The name of bronzes is defined according to the main alloying element; tin bronzes, aluminum bronzes, silicon bronzes etc. (Skočovský, 2006)

Various bronze alloys;

  i. Tin bronze
  ii. Aluminium bronze
  iii. Silicon bronze
  iv. Manganese bronze
  v. Phosphor bronze
  vi. Nickel bronze

3. Cupronickels- These alloys are made of copper and nickel.

4. Nickel silvers- These alloys are made of copper, nickel, and zinc.

Silicon bronze is a high strength, engineering alloy that has excellent resistance to a wide range of corrosives, including fresh and salt water.

1.9 Properties of copper alloys

1. Good castability
2. In-built corrosion protection
3. Low frictional properties and good resistance to wear
4. Good mechanical properties at ambient and high temperature
5. Machinability

1.10 Area of application of copper alloys

The term brass has been established for binary Cu-Zn alloys. Pure α- (Cu) solid solutions (up to about 38% Zn) are cold-working alloys. Wrought products of brasses and bronzes are used in automobile radiators, heat exchangers, and home heating systems, as pipes, valves, and fittings in carrying clean water and as springs, fasteners, hardware, small gears and cams, to give a few examples. Cast leaded red and semi-red brasses find their application as lower pressure rating valves, fitting, and pump components as well as commercial plumbing fixtures, cocks, faucets and certain lower-pressure valves.

General hardware, ornamental parts, parts in contact with hydrocarbon fuels and plumbing fixtures are made from yellow leaded brass. Yellow brass is suitable for structural, heavy-duty bearings, hold-down nuts, gears, valve stems and some marine fittings.

Bronzes are Cu-Sn, Cu-Al, and Cu-Si based alloys. Cast products of tin bronzes are used as high-quality valves, fittings and pressure vessel for applications at temperatures of up to 290°C, special bearings, pump parts, gears and steam fittings. Aluminum and silicon bronzes have very good strength, excellent formability and good toughness. They are used as gears, slides Gibbs, cams, bushings, bearings, molds, forming dies, combustion engine components, valve stems, and spark-resistant tools and in marine applications such as propellers, impellers and hydrofoils. Copper-nickel alloys show excellent corrosion resistance against seawater. Accordingly, they are used in shipboard components, power plants in coastal areas and saline-water conversion installations. Since Ni in Cu leads to a drastic decrease in electrical and thermal conductivity Cu-Ni alloys are also suitable for cryogenic applications.

CHAPTER 2

LITERATURE REVIEW

2.1 Materials

Most manufacturing materials can be classified into four groups: metallic, polymeric, ceramics and composites. Metallic materials are metals such as iron, steel, and aluminum etc. Polymeric materials include natural polymers like wood and rubber as well as synthetic polymers like plastics. Pottery, chine, porcelain and glass are examples of ceramic materials. Composite materials are actually combinations of two or more materials bonded together. Plywood is an example of a wood based composite material.

Metals are grouped in two broad categories, ferrous and nonferrous. Iron is the primary element in ferrous metals, while nonferrous metals contain little or no iron. The two major groups of ferrous metals are cast iron and steel. Cast iron and steel contain an alloy of iron, carbon, silicon, and other materials. Nonferrous metals commonly include aluminum, copper, zinc and lead. Aluminum is lightweight and strong, also is excellent conductor and resists corrosion so used in automobiles and airplanes manufacturing parts etc. Copper alloys are brass (copper and zinc alloy) and bronze (copper and tin alloy).

2.2 Bronzes

Bronzes are copper based alloys with other alloying elements except zinc. The name of bronzes is defined according to the main alloying element; tin bronzes, aluminum bronzes, silicon bronzes etc. (Skočovský, 2006). Bronzes perform well under boundary lubrication conditions (Hosford, 2006). Bronzes are unquestionably the most versatile class of bearing materials, offering a broad range of properties from a wide selection of alloys and compositions. Bearing bronzes offer broad ranges of strength, ductility, hardness, wear resistance, anti-seizing properties, low friction and the ability to conform to irregularities, tolerate dirty operating environments and contaminated lubricants (Grote, 2013).

2.2.1 Tin bronzes

Tin bronzes are alloys of copper and tin, with a minimal Cu-Sn content 99.3 %. Equilibrium diagram of Cu-Sn is one of the very difficult binary diagrams and in some areas (especially between 20 to 40 % of Sn) it is not specified till now. For the technical praxis only alloys containing less than 20 % of Sn are important. Tin bronzes with higher Sn content are very brittle due to the intermetallic phases' presence. Cu and Sn are absolutely soluble in the liquid state. In the solid state the Cu and Sn solubility is limited. Normally, the technical alloys crystallize differently as compared to the equilibrium diagram. Until 5 % of Sn, the alloys are homogenous and consist only of the solid solution (solid solution of Sn in Cu) with face centered cubic lattice. In the cast state the alloy structure is dendritic and in the wrought and annealed state the structure is created by the regular polyhedral grains. The resulting structure of alloys with larger Sn content (from 5 to 20 %) is created by α solid solution crystals and eutectic phase (α+δ). δ phase is an electron compound $Cu_{31}Sn_8$ (e/a = 21/13) with cubic lattice phase. δ phase is brittle phase, which has negative influence on the ductility and also decreases the materials strength in case of higher Sn content (above 20 %). Even though the solubility in the case of technical alloys decreases, the phase (Cu_3Sn with hexagonal lattice; e/a = 7/4) is not created. The ε phases do not occur because the diffusion ability of Sn atoms below 350 °C is low. εphase also does not occur at normal temperature with higher Sn content in bronze. Tin addition has a similar influence on bronzes properties as zinc addition in the case of brasses. For the forming, bronzes with around 9 % of Sn are used (it is possible to heat those alloys to single-phase state above 5 % Sn). Tin bronzes are used when bronzes are not sufficient in strength and corrosion resistance points of view. For casting, bronzes with higher Sn content are used; up to 20 % of Sn. Cast bronzes are used more often than wrought bronzes. Tin bronzes castings have good strength and toughness, high corrosion resistance and also good wear properties (the wear resistance is given by the heterogeneous structure (α + (α + δ)). Tin bronzes have small shrinkages during the solidification (1 %) but they have worst feeding properties and larger tendency to the creation of micro-shrinkages. (Skočovsky, 2000)

2.2.2 Wrought tin bronzes

Bronze CuSn1 contains from 0.8 to 2 % of Sn. In the soft state this bronze has tensile strength 250 MPa and 33 % ductility. It has good corrosion resistance and electric conductivity; it is used in electrical engineering. Bronze $CuSn_3$ with 2.5 to 4 % of Sn has in its soft state tensile strength 280 MPa and ductility 40 %. It is used for the chemical industry and electric engineering equipment production. Bronze CuSn6 with tensile strength 350 MPa and ductility 40 % (in soft state) is used for applications where β, a higher corrosion resistance is required for good strength properties and ductility; for example corrosion environment springs. $CuSn_8$ bronze has, from all wrought tin bronzes the highest strength (380 MPa) and ductility (40 %). It is suitable for bearing sleeves production and in the hard state also for springs which are resistant to fatigue corrosion.

2.2.3 Cast tin bronzes

Bronze CuSn1 with low Sn content has sufficient electric conductivity and so it is used for the castings used in electric engineering. CuSn5 and CuSn10 bronzes have tensile strength 180 and 220 MPa, ductility 15 % and they have good corrosion resistance. They are used for the stressed parts of turbines, compressors, for armatures and for pumps runners' production. Bronze $CuSn_{12}$ is used for parts used to large mechanical stress and wear frictional loading; spiral gears, gear rims. $CuSn_{10}$and $CuSn_{12}$ bronzes are used in the same way as bearing bronzes. High Sn content (14 to 16 %) bronzes usage have been, because of their expense, replaced by lower Sn containing bronzes, around 6 %, with good sliding properties (Skočovský, 2006).

2.2.4 Leaded tin bronzes and leaded bronzes

Leaded tin bronzes and leaded bronzes are copper alloys where the Sn content is partially or absolutely replaced by Pb. The Pb addition to copper, improves the alloys sliding properties without the negative influence on their heat conductivity. Cu-Pb system is characteristic by only partial solubility in a liquid state and absolute insolubility in a solid state. The resulting structure, after solidification, consists of copper and lead crystals. At a high cooling rate both the alloy components are uniformly distributed and the alloys have very good sliding properties. Leaded bronzes are suitable for steel friction bearing shells casting. They endure high specific presses, quite high circumferential speeds and it is possible to use them at elevated temperatures (around 300 °C). Lead (additive from 4 to 25 %) improves bearing sliding properties, and tin (from 4 to 10 %) improves strength and fatigue resistance. These alloys are used especially for bearings in dusty and corrosive environments (Skočovský, 2000.).

2.2.5 Aluminum bronzes

Aluminum bronzes are alloys of copper, where aluminum is the main alloying element. For the technical praxis alloys with Al content below 12 % are important. Aluminum bronzes with Al content from 4.5 to 11 % are used for forming elementary or complex. Al content from 7.5 to 12 % are used for casting only complex aluminum bronzes $CuAl_{15}$ bronze is used for cold forming. It is supplied in the form of sheets, strips, bars, wires and pipes. In the soft state this alloy can reach the tensile strength 380 MPa, ductility 40 % and hardness 70 to 110 HB. It is used in the boats building, chemical, food and paper making industry. Complex aluminum bronzes are normally used for hot forming. $CuAl_9Mn_2$ is used for the armatures (below 250 °C) production. $CuAl_9Fe_3$ is used for the bearings shells, valve seats production, etc. $CuAl_{10}Fe_3Mn_{1.5}$ alloy has heightened hardness and strength; it is suitable for shells and bearings production; it is replacing leaded bronzes up to temperature 500 °C, sometimes also till 600 °C, the $CuAl_{10}Fe_4Ni_4$ where Ni is replacing Mn is used. Nickel positively affects materials mechanical and corrosion properties. After the heat treatment the alloy has the tensile strength of 836 MPa and ductility 13.4 %. In the sea water corrosion environment this bronze reached better results compared to chrome-nickel corrosion steels. It is resistant against cavitational corrosion and stress corrosion. $CuAl_{10}Fe_4Ni_4$ is used for castings, also used for water turbines and pumps construction, for valve seats, exhaust valves and other components working at elevated temperatures and also in the chemical industry. Besides $CuAl_{19}Ni_5Fe_1Mn_1$ the nickel alloy consists also a higher content of manganese. It is suitable for cars worm wheels, compressing rings of friction bearings for high pressures etc. (Skočovský, 2006).

2.2.6 Beryllium bronzes

Beryllium is in copper limitedly soluble (max. 2.7 %) and in the solid state the solubility decreases (0.2 % at room temperature). The binary alloys with low beryllium content (0.25 to 0.7 %) have good electric conductivity, but lower mechanical properties, they are used rarely. More often alloys with higher be content and other alloying elements as Ni, Co, Mn and Ti are produced. Cobalt (0.2 to 0.3 %) improves heat resistance and creep properties; nickel improves toughness and titanium affects like grain finer. The main group of this alloy family is the beryllium bronzes with 2 % of Be content due to the highest mechanical properties after the precipitin hardening.

Beryllium bronzes thermal treatment consists of dissolved annealing (700 to 800 °C/1h) and water quenching. The alloy after heat treatment is soft, formable and it can be improved only by artificial aging. Hardening is in progress at temperature from 280 to 300 °C. After the hardening the tensile strength of the alloy is more than 1200 MPa and the hardness 400 HB. By cold forming, applied after the cooling from the annealing temperature, the materials tensile strength can be improved. Beryllium bronzes usage is given by their high tensile strength, hardness, and corrosion resistance which those alloys do not lose, even not in the hardened state. They are used for the good electric conductive springs production; for the equipment which should not sparkling in case of bumping (mining equipment) production; form dies, bearings, etc. (Skočovský, 2006)

2.2.7 Nickel bronzes

Copper and nickel are absolutely soluble in the liquid and in the solid state. Binary alloys are produced with minimal alloying elements content. Complex alloys, ternary or multi components, are suitable for hardening. Nickel bronzes have good strength at normal and also at elevated temperatures; good fatigue limit, they are resistant against corrosion and also against stress corrosion, and they have good wear resistance and large electric resistance. Binary alloys Cu-Ni with low Ni content (bellow 10 %) are used only limitedly. They are replaced by cheaper Cu alloys. Alloys with middle Ni content (15 to 30 %) have good corrosion resistance and good cold formability. 15 to 20 % Ni containing alloys are used for deep-drawing. Alloys with 25 % Ni are used for coin production and alloys with 30 % Ni are used in the chemical and food industry. Complex Cu-Ni alloys have a wider usage in the technical praxis compared to the binary alloys. CuNi30Mn with Ni content from 27 to 30 %, Mn content from 2 to 3 % and impurities content below 0.6 % is characterized by high strength and corrosion resistance also at elevated temperatures. Because of its electric resistance this alloy is suitable for usage as resistive material till 400 °C. CuNi45Mn constantan is alloy with Ni content from 40 to 46 %, Mn content from 1 to 3 % and impurities content below 0.5 %. From the Cu-Ni alloys, this one has the largest specific electric resistance and it is used for resistive and thermal element material. Most often the Cu-Ni-Fe-Mn alloys are used. Iron and manganese addition improve the corrosion properties markedly, especially in the seas water and overheated water steam. CuNi30 alloy with iron content in the range from 0.4 to 1.5 % and manganese content from 0.5 to 1.5 % is used for seagoing ships condensers and condensers pipes production. In the new alloys also the niobium as an alloying element is used and the nickel content tends to be decreased because of its deficit. An alloy CuNi10Ge with nickel content from 9 to 10 % and Fe content from 1 to 1.75 % and maximally 0.75 % of Mn, which is used as the material for seagoing ships condensers (Skočovský, 2000).

2.2.8 Silicon bronzes

The silicon content in this type of alloys is in the range from 0.9 to 3.5 %. The Si content should not exceed 1 % when higher electric conductivity is required. Silicon bronzes more often in the form of complex alloys Cu-Si-Ni-Mn-Zn-Pb are produced; binary alloys Cu-Si only rarely are used. Manganese is dissolved in the solid solution; improving strength, hardness and corrosion properties. Zinc improves the casting properties and mechanical properties, as same as Mn. Nickel is dissolved in the solid solution but it also creates Ni2Si phase with silicon, which has a positive influence on the materials warm strength properties. Lead addition secure sliding properties.

Silicon bronzes have good cold and hot forming properties and are also used for castings production. They are resistant against sulphuric acid, hydrochloric acid and against some alkalis. Because of their good mechanical, chemical and wear properties, silicon bronzes are used for tin bronzes replacing; they outperform tin bronzes with higher strength and higher working temperatures interval. Formed CuSi3Mn alloy has in the soft state tensile strength 380 MPa and ductility 40 %. It is used for bars, wires, sheets, strips, forgings and stampings production. Casting alloys have normally higher alloying elements content and Si content reaches 5 % very often (Skočovský, 2000).

2.3 Casting

To obtain good results from the product quality point of view, the casting processes technological specifications are the most important factor. The lowest possible pouring temperature needed to suit the size and form of the solid metal should be used to encourage as small a grain size as possible, as well as to create a minimum of turbulence of the metal during pouring to prevent the casting defects formation

(Schmidt *et al.,* 1998). Liberal use of risers or exothermic compounds ensures adequate molten metal to feed all sections of the casting. Many types of castings for Cu and its alloys casting, such as sand, shell, investment, permanent mold, chemical sand, centrifugal, and die, can be used (Schmidt *et al.,* 1998). Each of them has its advantages and disadvantages. If only a few castings are made and flexibility in casting size and shape is required, the most economical casting method is sand casting. For tin, silicon, aluminum and manganese bronzes, and also yellow brasses, permanent mold casting is best suited. For yellow brasses die casting is well suited, but increasing amounts of permanent mold alloys are also being die cast. Definite limitation for both methods is the casting size, due to the reducing the mold life with larger castings. All copper alloys can be cast successfully by the centrifugal casting process. Because of their low lead contents, aluminum bronzes, yellow brasses, manganese bronzes, low-nickel bronzes, and silicon brasses and bronzes are best adapted to plaster mold casting. Lead should be held to a minimum for most of these alloys because lead reacts with the calcium sulfate in the plaster, resulting in discoloration of the surface of the casting and increased cleaning and machining costs.

Casting is a process which carries risk of failure occurrence during all the process of accomplishment of the finished product. Hence necessary action should be taken while manufacturing of cast product so that defect free parts are obtained.

Mostly casting defects are concerned with process parameters. Hence one has to control the process parameter to achieve zero defect parts. For controlling process parameter one must have knowledge about effect of process parameter on casting and their influence on defect.

2.4 Metal mould casting (aluminium permanent mould)

The permanent mold process works much like the sand casting process, where molten metal is poured into a mold that is made in two halves. In typical permanent mold casting, the metal is poured either directly by gravity or by pouring the metal into a cup attached to the mold and tilting it from a horizontal to a vertical position. Like diecasting, the metal mold aids in quicker solidification of the casting material, which results in highly desirable fine-grained structures that have high strength and soundness. While diecasting can produce castings with closer dimensional limits and thinner sections, permanent mold can produce castings with higher soundness.

Permanent mold castings typically contain lower levels of entrapped gas, resulting in superior pressure tightness and soundness. "With permanent mold, you have the ability to machine the part and not open up porosity," Braun said. "An un-machined die cast part is stronger than a permanent mold casting, but throughout the part, permanent mold has the advantage because of the lack of porosity." Permanent mold casting generally is used in high production volumes that will compensate for the high tooling costs. Permanent molds usually are made of a high-alloy iron or steel. The wear life of a permanent mold can range from 10,000 to 120,000 castings. A general number of castings needed to be produced annually in order for permanent mold to be economical is 3,000, although this varies by metal casting facility and by casting size (Grote, 2013).

"Tooling costs have become pretty low in the last few years, as more CNC machining is being used to make the tools," and you'll get better dimensions and mechanical properties with permanent mold" (AmericanfoundrySociety, n.d.). Casting size for permanent mold ranges from less than a pound to more than several hundred pounds. Surface finish varies between 150 to 400 RMS, basic linear tolerances are about +/-0.01 sq. in. and minimum wall thickness is 0.1 (AmericanfoundrySociety, n.d.). When designing for aluminum permanent mold castings, be aware that the process should not be expected to cast key ways, exterior screws, or threaded designs or holes. Because all casting features must be machined into the metal mold, the permanent mold process cannot produce the complexity capable with sand molds. However, permanent molding can be paired with sand cores for semi-permanent molding, and this method allows metal casters to achieve higher complexity in the design. The use of metal cores is more economical, but when a casting has cavities that do not allow a core to be pulled straight out, an expendable core often will do the trick. Too many sand cores in a permanent mold casting can result in the deterioration of its strength advantages, so highly complex castings may be better cast in a full sand process (Grote, 2013).

The application and acceptability of sand casting are an important aspect of foundry/casting practices ranging from the numerous cottage and large-scale manufacturing industries. Small and large engineering components (machine parts) are made from different metals and alloys such as steel, cast iron, copper, bronze, brass, and many other known aluminium alloys (Olawale, 2015).

The right practice of casting starts with the understanding the control and chemistry of the melt. Casting bronze alloy entails proper handling of materials: type of furnace, fuel, the melting pot, and the selection of fluxing additives, alloying elements, and the molding sand composition. The mechanical strength, hardness, and the microstructure of the silicon bronze cast could be improved by controlled melting, pouring temperature, and the solidification processes during casting (Schmidt *et al.,* 1998).

The pouring temperature, solidification, and cooling rate are tailored to control the microstructure of cast silicon bronze alloy. Casting technique is identified as a relevant method for the production of many silicon bronze alloy parts with outstanding metallurgical properties suitable for the desired level of application. The mould (raw) materials in moulds kept constant allow internal comparisons, but different mould materials will behave differently and show different degrees of reactivity with the metal oxides. For example, clays richer in alumina, or heavily tempered with carbonaceous material, may be less reactive and therefore show comparatively lower traces of contamination than those richer in free silica (Thérèse Kearns *et al.,* 2010).

According to the cast products quality the Cu based foundry alloys can be classified as high shrinkage or low-shrinkage alloys. The former class includes the manganese bronzes, aluminum bronzes, silicon bronzes, silicon brasses, and some nickel-silvers. They are more fluid than the low-shrinkage red brasses, more easily poured, and give high-grade castings in the sand, permanent mold, plaster, die, and centrifugal casting processes (Fintová *et al.,* 2012).

Some of the research works and recent reports published in literature related to silicon bronze alloy studies are discussed below;

(Trofimov, 2016) Carried out an experiment on bronzes of copper-nickel-silicon systems which are materials with perfect combination of high strength, hot-resistance, thermal and electrical conductivity. With reference to Samoilova, Bronzes of the kind are classified as precipitation hardening alloys. Samoilova and Trofimov concluded that addition of chrome to nickel-silicon bronze enhances metal ductility, and does not practically influence precipitation hardening. The work defines that chrome addition results in coarsening of grain growth effect in nickel-silicon bronze during thermal treatment. Decrease of grain sizes allows reaching better ductility at high hardness and hot-resistance values in aged state.

Phase equilibrium, after crystallization in the system under research with increase of silicon content, could be described as follows:

i. at minimum silicon concentrations (thousandths of one percent), chrome will be in equilibrium with (Cu) – solid copper-based solution;

ii. Starting with silicon basis points, not only chrome, but also chrome silicide Cr3Si will be in equilibrium with solid copper-based solution. Formation of nickel silicide Ni3Si (at nickel concentrations exceeding 1 wt%) is also possible;

iii. then, with increase of silicon concentration the area of chrome equilibrium is vanished, but the following silicides are sequentially formed: chrome silicide Cr3Si, then nickel silicides Ni5Si2 and Ni2Si;

iv. when the silicon concentrations reach about 3 wt%, chrome silicide Cr5Si3 formation begins;

v. when the silicon concentrations reach 4 wt% nickel silicide Ni3Si2 is formed;

vi. When the concentrations reach about 5 wt% Si in the system under research, copper silicide Cu33Si7 could be formed.

(Deitz *et al.,* 1938) carried out an experiment on three sample alloys of copper, silicon and zinc with the following compositions;

Table 2.1 Specimen 1 composition

Copper	95.30%
Silicon	3.36%
Zinc	1.24%

Table 2.2 Specimen 2 composition

Copper	95.97%
Silicon	3.08%
Zinc	0.95%

Table 2.3 Specimen 3 composition

Copper	94.75%
Silicon	4.25%
Zinc	1.00%

The first specimen were tested to rupture under tensile stress and gave elongation of 42% when cast in sand, the second gave 74.5% and the third specimen gave elongation of 24%. This result shows that with the decrease in silicon content in the sample of alloys of copper and zinc, gives an increase in elongation of the alloys when tested to rupture under tensile stress (Deitz *et al.,* 1938).

According to (Nwambu *et al., 2*017), Micro alloying technology was originally developed for micro alloyed steels. Although the amount of micro alloying elements is usually less than 1%, they lead to improved combinations of strength and ductility, weldability, toughness, and corrosion resistance. Micro alloying is basically to improve the mechanical properties such as strength, hardness, rigidity, corrosion resistance and machinability, and also sometimes to improve the fluidity and other casting properties. From the authors review, I came up with the claim that with the addition of silicon even at a percentage less than one (1%) as micro alloying elements improves the mechanical properties such as strength, hardness, rigidity, corrosion resistance and machinability.

According to (Okayasu *et al.,* 2016); maintaining the chemical composition of copper alloy in the range recommended by the standards does not guarantee the required mechanical properties. Even small differences in the chemical composition of individual heats may significantly affect the mechanical properties while maintaining the same casting conditions. Changes in chemical composition of the alloy are generally associated with specific changes in the microstructure of castings which in turn explains the reason for the changes in mechanical properties of obtained castings.

(Sláma *et al.,* 2013)), investigated influence of heat treatment on the microstructure and mechanical properties of aluminium bronze. According to the authors the β phase of aluminium may undergo a martensitic transformation into the unstable phase β, which, being very hard and brittle, enhances the strength and reduces the ductility of the material Depending on the cooling rate and the subsequent heat treatment. In addition, other phases are found in the microstructure, which are termed κ, which consist mostly of Fe and Al or Ni^{3}¬5 or the γ2 phase known to occur in Cu-Al binary alloys. The γ2 phase in alloys containing less than 11.8 % aluminium forms during slow cooling or in the course of annealing at temperatures below 565 °C. These phases increase the strength and reduce the ductility of the alloy.

(Ilangovan *et al.,* 2014) analyzed the mechanical strength and ductility of aluminum bronze and brass, their microstructural characteristics were investigated by EBSD (electron backscatter diffraction analysis). An attempt was made to create copper alloys with favorable tensile properties (high strength and ductility) via microstructural modification using forging and casting processes under various conditions. For the rolling process, the rolling rate and temperature were varied, whereas for the casting process, the solidification rate was varied. Microstructural characteristics, as examined by electron backscatter diffraction analysis, were found to differ among the alloys. Complicated microstructures formed in the rolling process leading to high hardness and high tensile strength, but low ductility. For casting at a high solidification rate allowed an increase in ductility to be obtained as a result of fine grained structure and low internal stress. The results of this study indicate that copper alloys with excellent mechanical properties can be produced.

The ultimate physical and mechanical properties of the cast metal will depend upon both intrinsic factors (chemical composition, cooling rate during solidification and heat and mechanical treatment after solidification) and extrinsic factors (metal cleanliness, additives for microstructure control, casting design, riser and gating design, solidification rate control, and temperature control subsequent to solidification) present in each casting event and in the processing events subsequent to casting.

The ultimate physical and mechanical properties of the cast metal will depend upon both intrinsic factors (chemical composition, cooling rate during solidification and heat and mechanical treatment after solidification) and extrinsic factors (metal cleanliness, additives for microstructure control, casting design, riser and gating design, solidification rate control, and temperature control subsequent to solidification) present in each casting event and in the processing events subsequent to casting.(Ilangovan *et al.,* 2014). Cooling rate has a big influence on the dendritic segregation: low cooling causes microstructure homogenization and decay of dendrites, by a cooling rate typical for a given alloy, instead of dendritic microstructure a grained microstructure in present. Achieving of a certain temperature leads to maximal segregation of dendrites, by very high cooling rates a fine-grained microstructure will be achieved by very high differences of the chemical composition of individual grains. (Krupińska *et al.,* 2010).

The effects of appliance of big cooling rates and in the consequence of increased solidification rates onto the cast micro-structure are: avoiding of segregation (block and dendritic), sig-nificant phase dispersion (also a decreasing distance between the eutectics plates). By cooling rates dT/dt > 106 to 108 °C/s appears in succession: unstable or metastable solid solutions, new meta-stable phases as well solidification in the amorphous state (Górny, 1992).

(Krupińska *et al.,* 2010) Investigated Zn-Al alloy. He came to the conclusion that change in the cooling rate to about 0.6°C/s causes an microstructure refinement as well an increase of the alloy hardness about 24.9%. Increase of the cooling rate causes mainly changes in the morphology of the eutectics.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 List of materials

Copper: copper is a chemical element with symbol Cu and atomic number 29. It is soft, malleable and ductile metal with very high thermal and electrical conductivity. A freshly exposed surface of copper has a reddish-orange color. Copper is used as a conductor of heat and electricity, as a building material, and as a constituent of various metal alloys, such as sterling silver used in jewellery, cupronickel used to make marine hardware and coins, and constantan used in strain gauges and thermocouples for temperature measurement.

Silicon: This is a chemical element with symbol Si and atomic number 14. A hard and brittle cyrstalline solid with blue-grey metallic lustre, it is a tetravalent metalloid and semiconductor. It is a member of group 14 in the periodic table, along with carbon above it and germanium, tin, and kead below. It is rather unreactive, though less than germanium, and has a very large chemical affinity for oxygen; as such, it was first prepared and characterized in pure form only in 1823.

Zinc: Zinc is a chemical element with symbol Zn and atomic number 30. It is the first element in group 12 of the periodic table. Zinc is the 24th most abundant elements in Earth's crust and have five stable isotopes.

Plate 3.1: Zinc

Plate 3.2: Silicon

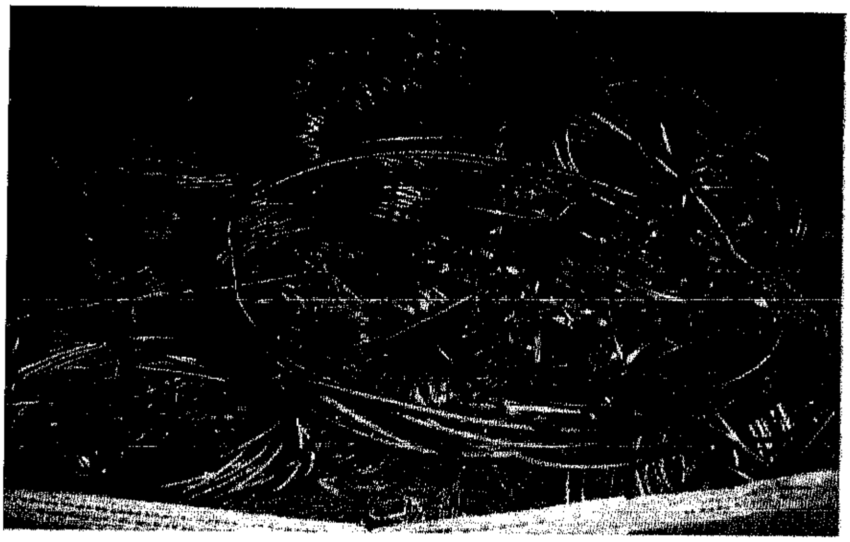

Figure 1.1: Copper

3.2 Physical properties and Chemical composition

Table 3.1 Physical properties of Cu, Si and Zn.

	Phase(at STP)	Melting point (C)	Boiling point (C)	Density (g/cm3)	Heat of fusion (kJ/mol)	Heat of vaporization (kJ/mol)	Molar heat capacity (j/(mol-k))
Copper	Solid	1084.62	2562	8.96	13.26	300.4	24.440
Silicon	Solid	1414	3265	2.3290	50.21	383	19.789
Zinc	Solid	419.53	907	7.14	7.32	115	25.470

Chemical composition

1. Copper – 96%
2. Silicon – 2%
3. Zinc – 2%

3.3. Equipment for metal mould casting

4. Crucible Furnace
5. Metal Mold
6. Bench Vice
7. Crucible pots
8. Rammer
9. Saw
10. Chisel
11. Stirrer
12. Blower
13. Electric weighing balance

Plate 3.3: pit crucible furnace

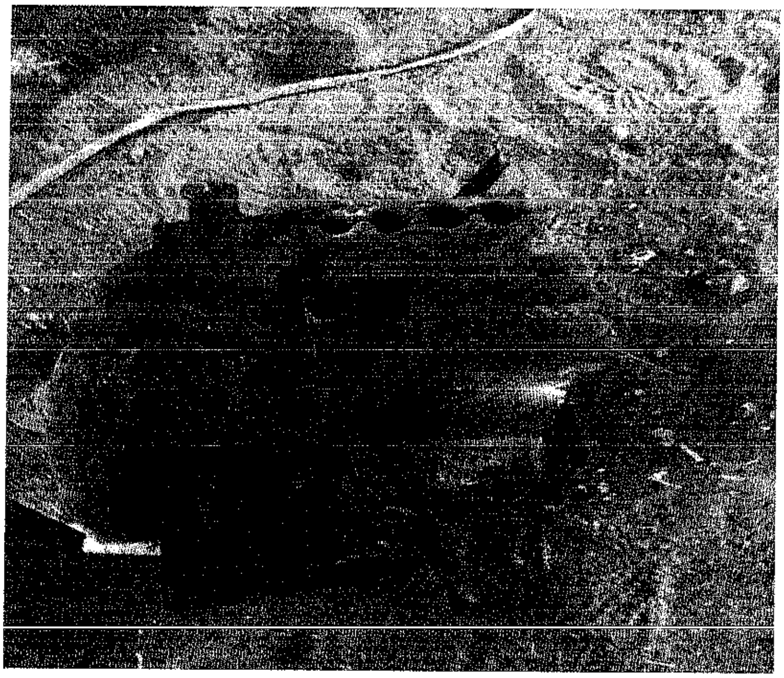

Plate 3.4: Bench vice holding the metal mold firm

Plate 3.5: metal mold

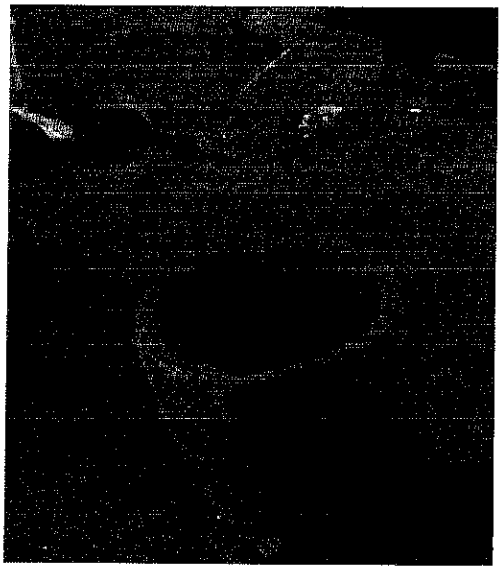

Plate 3.6: Crucible pot

3.4 Charge calculation

ROD SAMPLES

$$\phi = 20mm = 2cm$$
$$l = 250mm = 25cm$$
$$volume = \frac{22}{7} \times 1 \times 1 \times 25(\pi r\text{^}2h)$$
$$= 78.57cm\text{^}3$$

Table 3.2: Density of the charges

Elements	Density (g/cm^3)
Cu	8.96
Zn	7.13
Si	2.3296

All samples having same composition such as, 96% Cu, 2% Zn and 2% Si.

$$\rho A = (0.96 \times 8.96) + (0.02 \times 7.13) + (0.02 \times 2.3296)$$
$$= 8.6016 + 0.1426 + 0.046592$$
$$= 8.7908 g / cm\text{^}3$$

$$mass \rightarrow \rho A \times V$$
$$= 8.7908 \times 78.57$$
$$= 690.693g$$

Hence

Mass of sample + shrinkage allowance

$$690.693 \times 2.0 = 1381.39g$$

=

$$Cu = 0.96\times1381.39 = 1326.13g$$

$$Zn = 0.02\times1381.39 = 27.6278g$$

Mass of $Si = 0.02\times1381.39 = 27.6278g$

Grand total for three (3) samples with the above composition

$$Cu = 1326.13\times4 = 5304.42g = 6kg$$

$$Zn = 27.6278\times4 = 110.5g = 111g$$

$$Si = 27.6278\times4 = 110.5g = 111g$$

3.5 Methodology

Al-Zn-Si alloys with same composition were prepared by melting commercially pure copper, zinc and silicon in a pit crucible furnace at a temperature suitable to effect a homogeneous composition. The metal was cast in a metal mold held firmly by two vices. Copper, silicon and zinc were measured using an electric weighing balance to calculate the amounts and placed into three crucible pots, each containing the right composition of the alloy. The furnace was heated continuously till the charges had completely melted (Around 1085 degree Celsius). After the melting and homogeneity was attained in each melt, each melt was poured into a metal mold cavity which then takes the shape of the mold. The first cast was allowed to cool in air, the second was allowed to cool in water and the third was allowed to cool in the mould. This different cooling media shows the cast cooling at different rate. Then the samples were machined to test pieces suitable for impact, hardness, tensile and metallographic tests. Impact, hardness, tensile and metallographic tests were carried out on those test pieces which produces results which were analyzed and discussed.

3.6 Brinell hardness tests

In Brinell tests, as in Rockwell measurements, a hard, spherical indenter is forced into the surface of the metal to be tested. The diameter of the hardened steel (or tungsten carbide) indenter is 10.00 mm (0.394 in). Standard loads range between 500 and 3000kg in 500-kg increments; during a test, the loads is maintained constant for a specified time (between 10 and 30s). Harder materials require greater applied loads. The Brinell hardness number, HB, is a function of both the magnitude of the load and the diameter of the resulting indentation. This diameter is measured with a special low-power microscope, utilizing a scale that is etched on the eyepiece. The measured diameter is then converted to the appropriate HB number using a chart; only one scale is employed with this technique. Semiautomatic techniques for measuring Brinell hardness are available. These employ optical scanning systems consisting of a digital camera mounted on a flexible probe, which allows positioning of the camera over the indentation. Data from the camera are transferred to a computer that analyzes the indentation, determines its size, and then calculates the Brinell hardness number. For this technique, surface finish requirements are normally more stringent that for manual measurements.

Maximum specimen thickness as well as indentation position (relative to specimen edges) and minimum indentation spacing requirements are the same as for Rockwell tests. In addition, a well-defined indentation is required; this necessitates a smooth flat surface in which the indentation is made.

3.6.1 Correlation between hardness and tensile strength

Both tensile strength and hardness are indicators of a metal's resistance to plastic deformation. Consequently, they are roughly proportional, for tensile strength as a function of the HB for cast iron, steel, and brass. The same proportionality relationship does not hold for all metals as a rule of thumb for most steels, the HB and the tensile strength are related according to

$$\text{TS (MPa) } 3.45 \times \text{HB}$$

$$\text{TS (psi) } 500 \times \text{HB}$$

3.6.2 Procedure

Sample was provided and it was cut in order to get a specific length, after that the sample being cut was filed using hand file in order to harden the surface of the sample, this was said to have been done properly provided one could see the image of the teeth of the surface of the filed sample. It was later grinded by using grinding machine in which polishing the surface came after then. After which the sample was fixed into the tensiometer where which it was subjected to compression of load of 250kg for about 15 seconds after which the indented diameter was measured by eye scope. We now used the conversion table to know the brinnel or hardness number of the material.

Brinell hardness (BHN) which is the pressure per unit surface area of the identification in kg per square metres is calculated as follow

$$BHN = \frac{W}{(\pi D/2)(D - \sqrt{D^{\wedge}2 - D^{\wedge}2}}$$

Where W is load on indenter, kg

D is diameter of steel ball, mm

d is average measured diameter of indentation, mm

3.7 Metallography

Metallography is the study of the crystalline structure of metals and alloys and the relationship of this structure to the physical properties of metals. Microscopic examination of suitably prepared specimens makes it possible for the determination of size, structure, and orientation of the metal crystals. By means of such examinations, metallurgists can frequently identify a metal or alloy and check on the effectiveness of heat treatments for hardening or annealing. Metal specimens for metallographic examination are usually highly polished and then etched with etchants; this treatment brings out the grain structure by attacking the boundaries between the grains or by attacking one of the constituents of an alloy. Then, metals are examined under high magnification of a low power microscope, a thin, electron-transparent replica or cast of the etched surface can be made, because bulk metals do not transmit an electron beam. Alternatively, an extremely thin specimen can be made; the microstructure that is observed is a projection of that contained within the thin specimen.

Metallographic Examination

Visual examination is good enough for macro-examination but on the micro-level, there is the need for aided media. The samples under consideration were prepared for micro-examination.

3.7.1 Sample preparation

This is the primary stage involved in metallographic examination processes. These include grinding, polishing, etching before final examination under the metallurgical microscope.

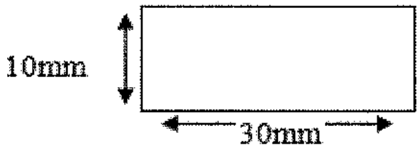

Figure 3.2 Microstructural Specimen

3.7.2 Grinding

This operation aims at producing a perfectly flat and smooth surface Silicon carbide papers of different grades placed on the grinding machine was used in the order of 220,320,400 and 600, i.e. from coarse grade to fine grade. The grinding process was done under running water to wash away the grits and also to avoid overheating. The samples was turned through 90^0 while changing from one grit size to another in the materials laboratory at OAU Ile – Ife. This is to neutralize the scratching effect of the previous grinding of the former grit size.

3.7.3 Polishing

A universal polishing machine was employed. A polishing cloth (selvt cloth) was placed on the polisher for the initial polishing swamped with solution of one micron of silicon carbide solution, then, followed by the final polishing stage with selvt cloth swamped with solution of 0.5μm Silicon carbide until a mirror-like surface is attainable. It is then washed and dried.

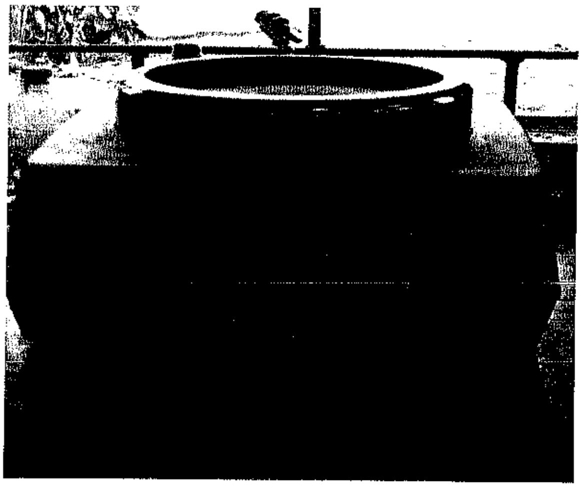

Plate 3.7: Grinder /polisher Machine, model 900, maker (South bay Technology)

3.7.4 Etching

This is done to reveal the microstructure of the polished surface. Etching is the selective attack on the grain boundaries being a region of high energy and dislocation density. The mirror-like surface was etched in 2% NITAL (2% NITRIC ACID and 98% of Ethyl Alcohol) while Sodium hydroxide is for non-ferrous materials. Again, it is washed, dried and later viewed under the metallurgical microscope (Accuscope microscope with camera (Serial no 0524011, Maker: Princeton, US) with magnification 400x and 800x respectively.

3.8 Impact test

Prior to the advent of fracture mechanics as a scientific discipline, impact testing techniques were established so as to ascertain the fracture characteristics of materials. It was realized that the results of laboratory tensile tests could not be extrapolated to predict fracture behavior; for example, under some circumstances normally ductile metals fracture abruptly and with very little plastic deformation. Impact test conditions were chosen to represent those most severe relative to the potential for fracture---namely, (1) deformation at a relatively low temperature, (2) a high strain rate (i.e., rate of deformation), and (3) a triaxial stress state (which may be introduced by the presence of a notch).

3.9 Impact testing techniques

Two standardized test, the charpy and Izod were designed and are still used to measure impact energy sometimes also termed notch toughness.

3.9.1 Izod impact test

The test is named after the English engineer EDWIN GIDERTIZOD [1876-1946] who described it in his 1903 address to the British association. Impact is a very important phenomenon in governing the life of a structure. An arm held at a specific height [constant potential energy is released. The arm hit this sample and breaks it from the energy absorbed by the sample its impact strength is determined.

The izod impact differs from the charpy impact test in that the sample is held in a cantilever beam configuration as opposed to the three point bending configuration. This test can also be used to determine the notch sensitivity.

3.10. Tensile test

Tensile strength testing of all specimens were conducted as per ASTME 8 standard. Three identical tests specimen for each section thickness per sample were tested at room temperature with a strain/ loading rate of 5 mm/mm using a computerized Instron Testing Machine (model 3369). Load displacement plots were obtained on an X – Y recorder and ultimate tensile strength, yield strength and percentage elongation values were calculated from this load displacement diagrams.

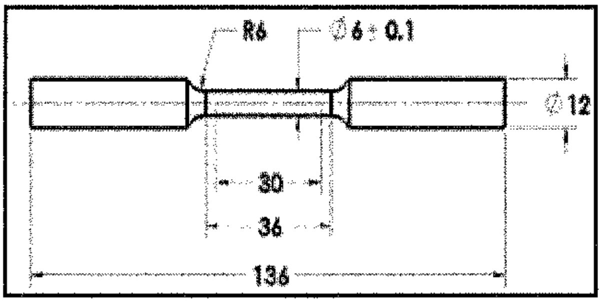

Figure 3.3: Drawing of tensile specimen

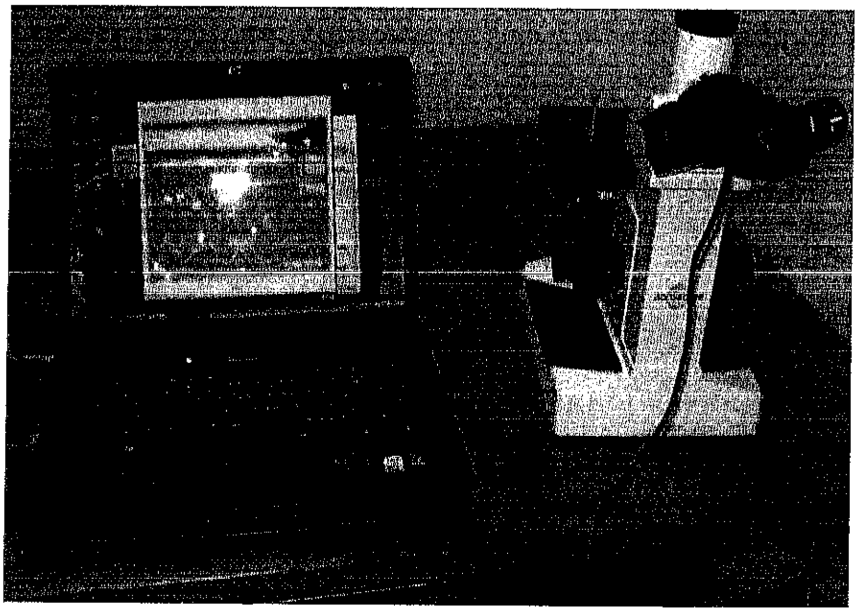

Plate 3.8: Accuscope microscope with camera (Serial no 0524011, Maker: Princeton,US

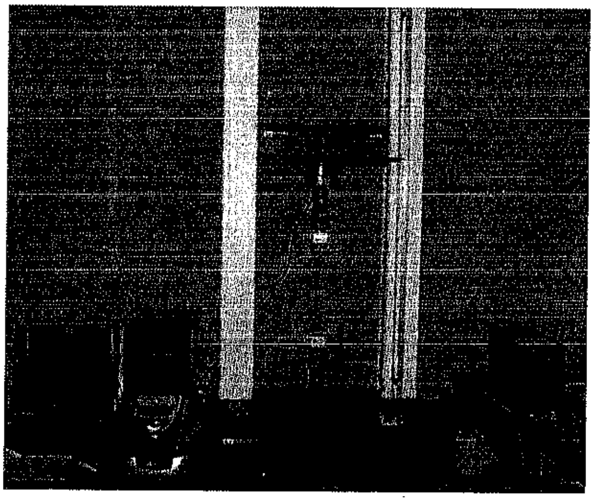

Plate 3.9: Universal Instron Machine, model 3369, maker (Instron)

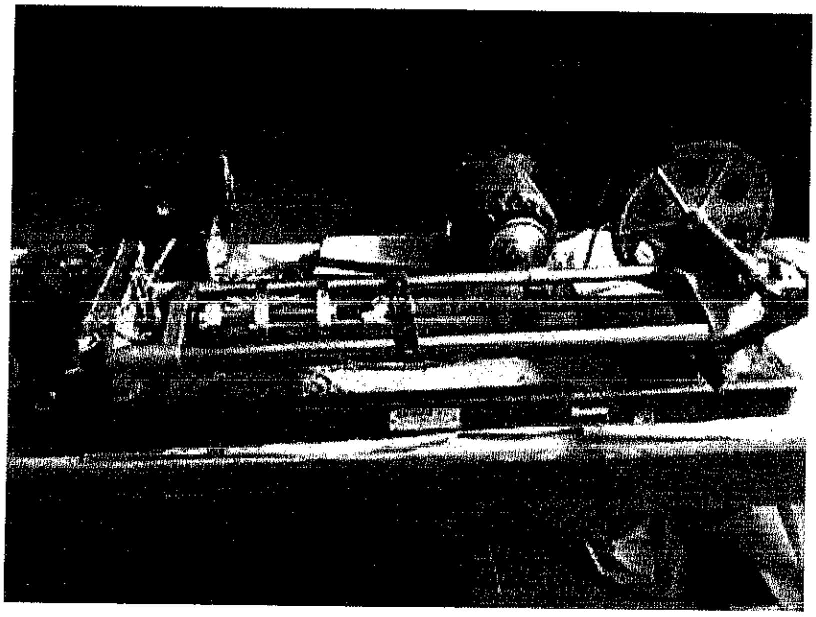

Plate 3.10: Monsanto Testing Machine for hardness and shearing

Plate 3.11: Izod Impact machine

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1. Hardness and impact test

Table 4.1 Tensile and impact test values

SAMPLE	IMPACT(joules)	HARDNESS(BRINELL)
WATER COOLED	20.4	79.5
MOLD COOLED	51.7	34.3
AIR COOLED	37.8	51.9

The table above shows the result of the impact and hardness test of the specimen. It is observed that at fast cooling, the hardness value increases. The specimen cooled in the mold cooled slowly resulting to a hardness value of 34.3 as compared with the water cooled specimen (higher cooling rate) of 79.5 using Brinell hardness test.

The table also shows that at increased cooling rate, the impact energy is lower. The cooled specimen having an impact energy of 20.4joules compared to the mold water cooled specimen with 51.7joules.

Tensile Test

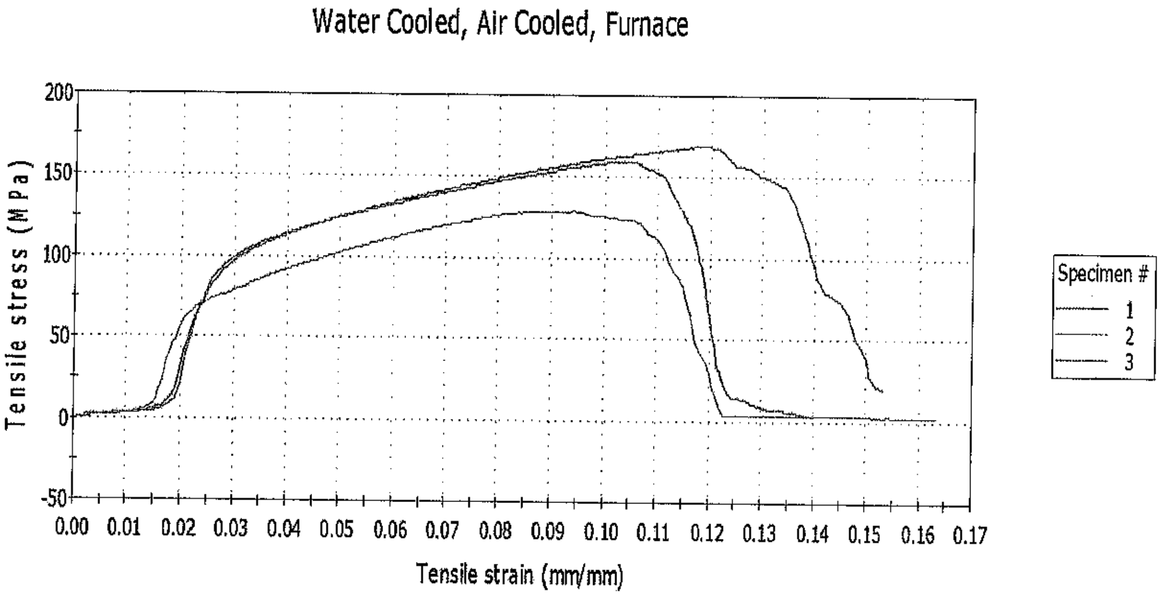

Figure 4.1 Plot of stress over strain of the three tensile specimens

Table 4.2 Shows the Specimens dimensions and Maximum Tensile stress

	Length (mm)	Diameter (mm)	Maximum Tensile stress (N/mm^2)
1	29.55000	5.14000	169.25035
2	29.55000	5.14000	128.92379
3	29.55000	5.14000	159.66879
Mean	29.55000	5.14000	152.61431
Standard Deviation	0.00000	0.00000	21.06851

Table 4.3 shows the applied load at maximum tensile stress

	Load at Maximum Tensile stress (N)	Tensile strain at Maximum Tensile stress (mm/mm)	Tensile extension at Maximum Tensile stress (mm)	Energy at Maximum Tensile stress (J)	Tensile stress at Break (Standard) (MPa)
1	3511.92877	0.11902	3.51700	8.25648	20.09089
2	2675.15648	0.09391	2.77506	4.90140	2.50929
3	3313.11226	0.10406	3.07506	6.67134	3.46352
Mean	3166.73250	0.10566	3.12237	6.60974	8.68790
Standard Deviation	437.16958	0.01263	0.37322	1.67839	9.88680

Table 4.4 shows the load at break, tensile strain at break, tensile extension at break, energy at break and tensile stress at yield.

	Load at Break (Standard) (N)	Tensile strain at Break (Standard) (mm/mm)	Tensile extension at Break (Standard) (mm)	Energy at Break (Standard) (J)	Tensile stress at Yield (Zero Slope) (MPa)
1	416.88415	0.15312	4.52475	10.61519	169.25035
2	52.06757	0.16328	4.82494	6.66854	128.92379
3	71.86763	0.14046	4.15056	8.16046	159.66879
Mean	180.27312	0.15229	4.50008	8.48140	152.61431
Standard Deviation	205.15018	0.01143	0.33786	1.99280	21.06851

Table 4.5 shows the load at yield (zero slope) and young modulus

	Load at Yield (Zero Slope) (N)	Modulus (E-modulus) (MPa)
1	3511.92877	11168.84308
2	2675.15648	10459.97238
3	3313.11226	13330.30548
Mean	3166.73250	11653.04031
Standard Deviation	437.16958	1495.17164

As a general rule, UTS is a function of hardness of the alloy. That is, if the hardness decreases, the UTS proportionally decreases. The result of the tensile test on the specimen shows that the water cooled specimen (higher cooling rate) with highest hardness as the highest tensile value and the mold cooled specimen has the lowest tensile value as calculated by the UTS machine as shown in table 4.4. Other tables further proves that the water cooled specimen has better tensile properties than other cooling mediums. The water cooled specimen could withstand the highest loading as shown in table 4.5.

4.2. Microstructural Examination

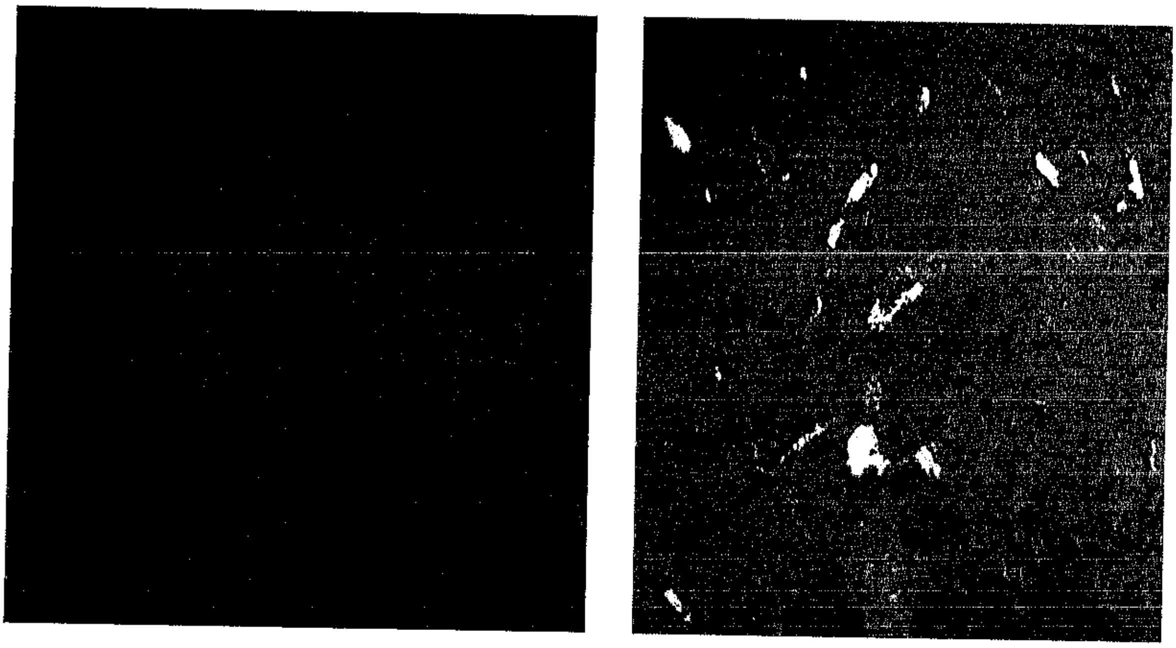

Figure 4.2: microstructure of Air cooled specimen at x400 and x800 magnification

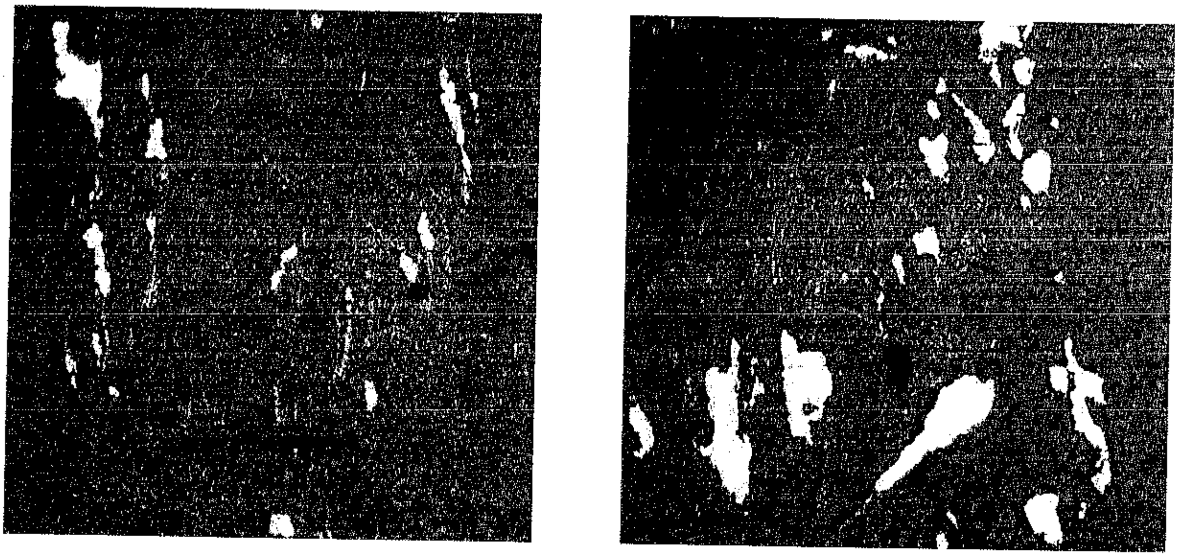

Figure 4.3: microstructure of mold cooled specimen at x400 and x800 magnification

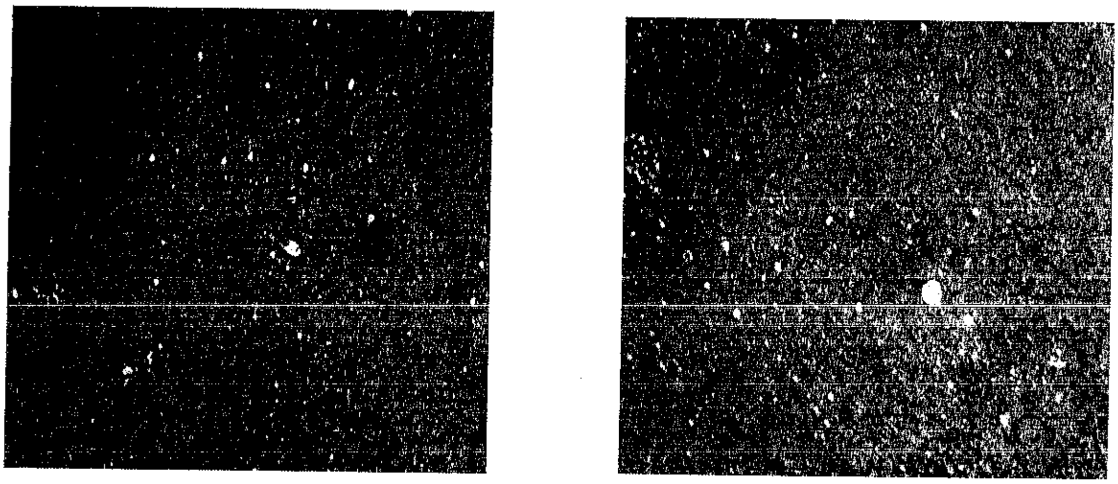

Figure 4.4: microstructure of water cooled specimen at x400 and x800 magnification

The cooling rate determines the coarseness of the microstructure including the dendrite arm spacing, SDAS, Which is often used as a measure of coarseness of a microstructure. The microstructure of the alloy specimen (figures 4.2 – 4.4) is chosen so as to find a significant difference in grain structure. By comparing figures 4.2 to 4.4, it is observed that the grain size of the specimen cooled slowly in the mold is larger which is due reason that the dendrite arms of the grains had enough time to grow and expand and hence giving a declining trend in mechanical properties. Figure 15 which shows the microstructure of mold cooled specimen (slow cooling rate) has the largest grain size with fewer but larger pores appearing on the surface of the specimen. Figure 4.4 has finer grain size and it takes a longer time for dislocation to cross the grain boundaries, thereby increasing its hardness and fracture toughness. This specimen is more suitable for engineering applications if hardness and fracture toughness is to be considered.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The influence of cooling on cast silicon bronze alloy is studied and the following conclusions are derived.

i. Cooling can be determinant of material properties. Casting that tend to cool rapidly have better mechanical properties as compared to the slowly cooled ones that cooled rapidly i.e. water cooled specimen, the deposition of partially soluble compounds at the boundaries is very less; hence these areas have better mechanical properties.
ii. At high cooling rate, the impact energy is lower.
iii. The microstructure and lattice structures may vary depending on the temperature and rate at which cooling occurs. The subtle changes produce a marked effect on the properties of cast component.
iv. The size of grain structure increases when subjected to slow cooling leading to larger dendrite arms. The larger the grain structure, the weaker the Specimen.

v. Ultimate Tensile Strength is low at slow cooling rate. The reason being, that the hardness is lower for when the specimen is slow cooled leading to low tensile strength. The larger grain size decreases its hardness and tensile strength due to slow cooling.

vi. The fast cooled specimen with small grain size is more suitable for engineering applications if hardness and fracture toughness is to be considered.

5.2 Recommendation

i. Further research should be geared towards silicon bronze alloys so advancement in the application of the material into solving human problems

ii. Silicon bronze should be able to resist very low frost temperature (t = <-20 degree Celsius) and still perform excellently in its application.

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