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

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MME/12/0875

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD

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DEPARTMENT OF MATERIALS AND METALLURGICAL ENGINEERING, B.ENG ENGINEERING, FEDERAL UNIVERSITY OYE-EKITI

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SUBMITTED BY

OBAREWON TOMIWA S.

(MAT NO: MME/12/0875)

UNDER THE GUIDANCE OF

Prof. Omotoyinbo

NOVEMBER -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 carried out by

OBAREWON TOMIWA S.

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Prof. J.A Omotoyinbo	Prof.A. Oni
....	....
Project Supervisor	**Head of Department**

DEDICATION

This report is dedicated to God Almighty, the maker of heaven and earth for His grace that never ends.

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 project work.

I sincerely convey my gratitude to my supervisor Prof J.A Omotoyinbo, who made me believe in myself and guided me through the whole process of dissertation writing. I am sure that this dissertation would not have been possible without his support, understanding and encouragement. I am also very grateful to my Head of Department, Prof. A. Oni for his moral support and love all through my years in school. I would also like to thank Mr Akin Folarin from Federal University of Technology Akure and Mr Alo from Obafemi Awolowo University Ile-Ife.

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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.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE
INTRODUCTION

1.1 Project background

Silicon bronze is an alloy of copper. Copper is non-polymorphous metal with face centered cubic lattice. Pure copper is a reddish color; zinc addition produces a yellow color, and nickel addition produces a silver color. Melting temperature is 1083 °C and density is 8900 kg.m-3, which is three times heavier than aluminum. The heat and electric conductivity of copper is lower compared to the silver, but it is 1.5 times larger compared to the aluminum.

Figure 1.1: Natural copper
(mtfdca, n.d.)

Before the copper products usage it has to pass through a number of stages. When recycled, it can pass through some stages over and over again. In nature, copper in its pure metal form occurs very often. Metallurgically from ores, where the chemical compound of copper with oxygen, sulphur or other elements occurs, copper is produced:

i. Chalcopyrite ($CuFeS2$) – contains around 34.5 % of copper;

ii. Azurite ($Cu3[OH-Co3]2$) and malachite ($Cu2[OH-Co3]2$) – alkaline copper carbonates;

iii. Cuprite ($Cu2O$) – copper oxide.

Coppers mechanical properties (Fig. 3) depend on its state and are defined by its lattice structure. Copper has good formability and toughness at room temperature and also at reduced temperature. Increasing the temperature steadily decreases coppers strength properties. Also at around 500 °C the coppers technical plastic properties decrease. Due to this behavior, cold forming or hot forming at 800 to 900 °C of copper is proper. Cold forming increases the strength properties but results in ductility decreasing. In the as cast state, the copper has strength of 160 MPa. Hot rolling increases coppers strength to 220 MPa. Copper has a good ductility and by cold deformation it is possible to reach the strength values close to the strength values of soft steel (Fintová, Copper and Copper Alloys: Casting, Classification and Characteristic Microstructures, Copper Alloys - Early Applications and Current Performance - Enhancing Processes,, 2012).

LIST OF PLATES

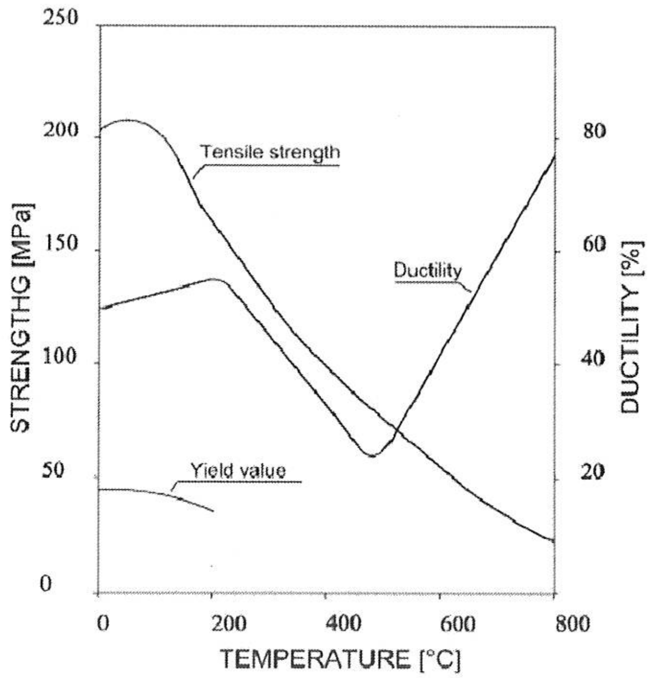

Figure 1.2: influence of temperature on strength and ductility (Skočovský, 2006)

Copper resists oxidation, however, it is reactive with sulphur and its chemical compounds, and during this reaction copper sulphide is created. Besides oxygen, the main contaminant, phosphor and iron are the significant copper contaminants. It is difficult to cast pure copper because large shrinkages during the solidification occur (1.5 %), and is the dissolving of a large amount of gasses at high temperatures disengaged during the solidification process and resulting in the melted metal gassing and the casting porosity. Cast copper microstructure is formed by non-uniform grains with very different sizes. Wrought copper microstructure consists of uniform polyhedral grains with similar grain size and it is also possible to observe annealing twins. Because of coppers reactivity, the dangers of surface cracking, porosity, and the formation of internal cavities are high.

The casting characteristics of copper can be improved by the addition of small amounts of elements like beryllium, silicon, nickel, tin, zinc, chromium, and silver. In copper based alloys 14 alloying elements, almost always in the solid solution dissolving area, are used. Most of the industrial alloys are monophasic and they do not show allotropic changes during heating or cooling. For some copper-base alloys precipitation hardening is possible. For the alloys with allotropic recrystallization heat treatment is possible. Single-phase copper alloys are strengthened by cold working. The FCC copper has excellent ductility and a high strain-hardening coefficient (Skočovský, 2006).

Copper and copper based alloys can be divided into 3 groups according to the chemical composition:

i. Copper and high copper alloys,

ii. Brasses (Cu-Zn + other alloying elements), □ bronzes (Cu + other elements except Zn).

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.

1.5 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.

1.6 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.

1.7. Copper and copper alloys casting

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

i. 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 aluminium bronzes, nickel bronze, manganese bronze alloys, chromium copper, and copper.

ii. Group II alloys – alloys that have an intermediate freezing range, that is, a freezing range of 50 to 110 °C between the liquidus and the solidus curves.

    i. These are the beryllium coppers, silicon bronzes, silicon brass, and copper-nickel alloys.

iii. 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 (Schmidt, 1998).

1.8 Bronzes

Manganese bronzes are carefully compounded yellow brasses with measured quantities of iron, manganese, and aluminum. When the metal is heated at the flare temperature or to the point at which zinc oxide vapor can be detected, it should be removed from the furnace and poured. No fluxing is required with these alloys. The only required addition is zinc, which is caused by its vaporization. The necessary amount is the one which will bring the zinc content back to the original analysis. This varies from very little, if any, when an all-ingot heat is being poured, to several percent if the heat contains a high percentage of remelt.

Aluminum bronzes must be melted carefully under an oxidizing atmosphere and heated to the proper furnace temperature. If needed, degasifiers removing the hydrogen and oxygen from the melted metal can be stirred into the melt as the furnace is being tapped. By pouring a blind sprue before tapping and examining the metal after freezing, it is possible to tell whether it shrank or exuded gas. If the sample purged or overflowed the blind sprue during solidification, degassing is necessary. For converting melted metal fluxes, are available, mainly in powder form, and usually fluorides. They are used for the elimination of oxides, which normally form on top of the melt during melting and superheating (Schmidt, 1998).

Nickel bronzes, also known as nickel silver, are difficult to melt because nickel increases the hydrogen solubility, if the alloy is not melted properly it gases readily. These alloys must be melted under an oxidizing atmosphere and they have to be quickly superheated to the proper furnace temperature to allow for temperature losses during fluxing and handling. After the furnace tapping the proprietary fluxes should be stirred into the metal for the hydrogen and oxygen removing. These fluxes contain manganese, calcium, silicon, magnesium, and phosphorus.

Tin and leaded tin bronzes, and high-leaded tin bronzes, are treated the same in regard to melting and fluxing. Their treatment is the same as in the case of the red brasses and leaded red brasses, because of the similar freezing range which is long (Schmidt, 1998). Tin bronzes have practically no feeding range, and it is extremely difficult to get fully sound castings. Alloys with such wide freezing ranges from a mushy zone during solidification, resulting in inter-dendritic shrinkages or micro shrinkages. In overcoming this effect, design and riser placement, plus the use of chills, are important and also the solidification speed, for better results the rapid solidification should be ensured. As in the case of leaded red brasses, tin bronzes also have problems with porosity. The castings contain 1 to 2 % of porosity and only small castings have porosity below 1 %. Directional solidification is best for relatively large, thick castings and for smaller, thin wall castings, uniform solidification is recommended. Sections up to 25 mm in thickness are routinely cast.

Sections up to 50 mm thick can be cast, but only with difficulty and under carefully controlled conditions (Schmidt, 1998).

Silicon bronzes

Silicon bronzes are relatively easy to melt and should be poured at the proper pouring temperatures. In the case of overheating the hydrogen, picking up can occur. For degassing, one of the proprietary degasifies used with aluminum bronze can be successfully used. Normally no cover fluxes are used for these alloys.

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, 2006).

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of casting process

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.

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. 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. 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 (Schmidt, 1998).

2.1 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. 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.)

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.

2.2 More Reviews

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), significant 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.

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, weld ability, 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 Ɣ2 phase known to occur in Cu-Al binary alloys. The Ɣ2 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.

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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 jewelry, 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 crystalline 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 lead 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 3.1: 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

i. Copper – 96%
ii. Silicon – 2%
iii. Zinc – 2%

3.3 Equipment for metal mould casting

i. Crucible Furnace
ii. Metal Mold
iii. Bench Vice
iv. Crucible pots
v. Rammer
vi. Saw
vii. Chisel
viii. Stirrer
ix. Blower
x. Electric weighing balance

Plate 3.3: Pit crucible furnace

Plate 3.4: Bench vice holding the metal mold firm

Plate 3.5: metal mold

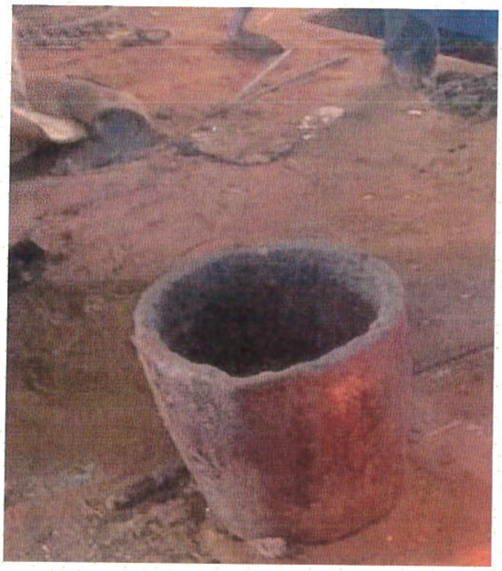

Plate 3.6: Crucible pot

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.

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

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

Hence

Mass of sample + shrinkage allowance

$$690.693 \times 2.0 = 1381.39 g$$

=

$$Cu = 0.96 \times 1381.39 = 1326.13 g$$
$$Zn = 0.02 \times 1381.39 = 27.6278 g$$

Mass of $Si = 0.02 \times 1381.39 = 27.6278 g$

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

$$Cu = 1326.13 \times 4 = 5304.42 g = 6 kg$$
$$Zn = 27.6278 \times 4 = 110.5 g = 111 g$$
$$Si = 27.6278 \times 4 = 110.5 g = 111 g$$

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

$$TS\ (MPa)\ 3.45 \times HB$$

TS (psi) 500 X 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.

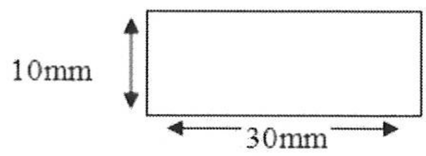

Figure 10. Microstructural Specimen

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 [18761946] 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.

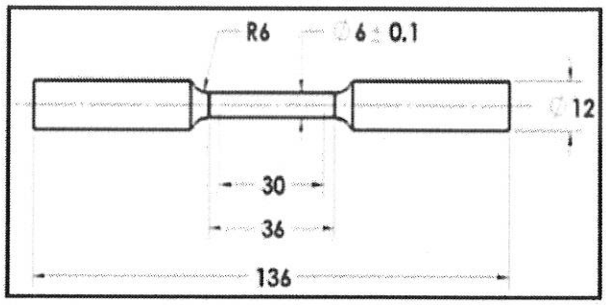

Figure 3.1: Drawing of tensile specimen

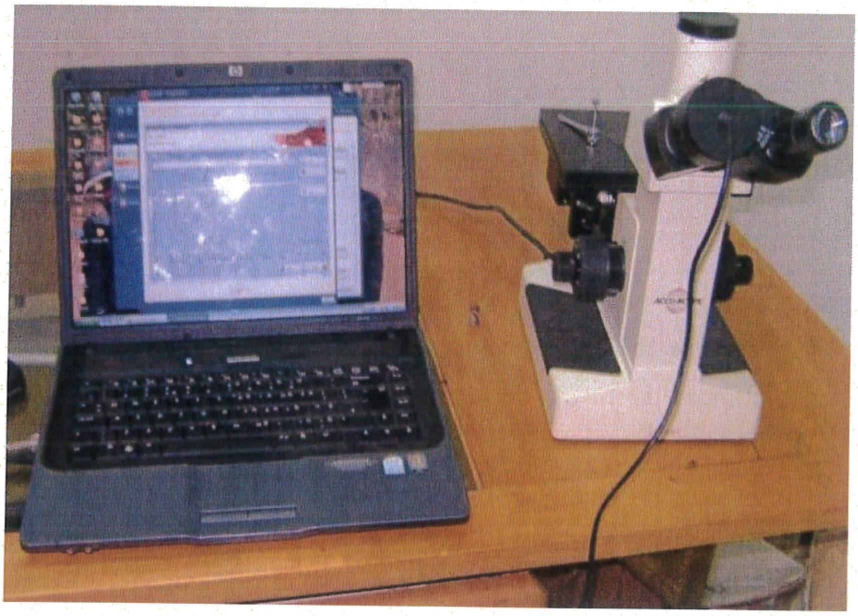

Plate 3.8: Accuscope microscope with camera (Serial no 0524011, Maker: Princeton,US

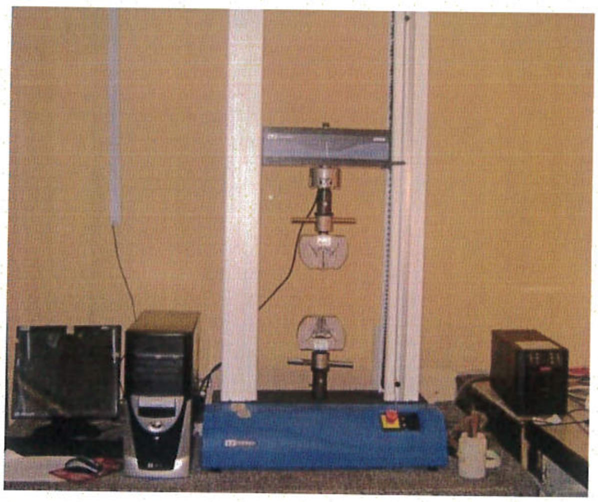

Plate 3.9: Universal Instron Machine,model 3369, maker (Instron)

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.

4.2 Tensile Test

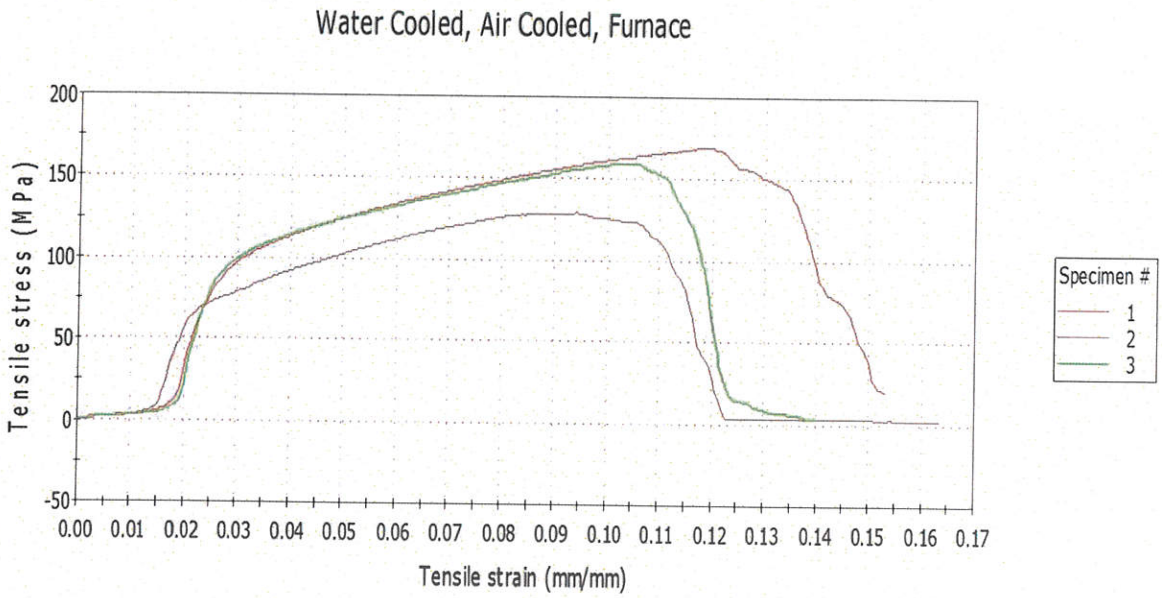

Figure 4.1 Plot of stress over strain of the three tensile specimens

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.

4.3. Microstructural examination

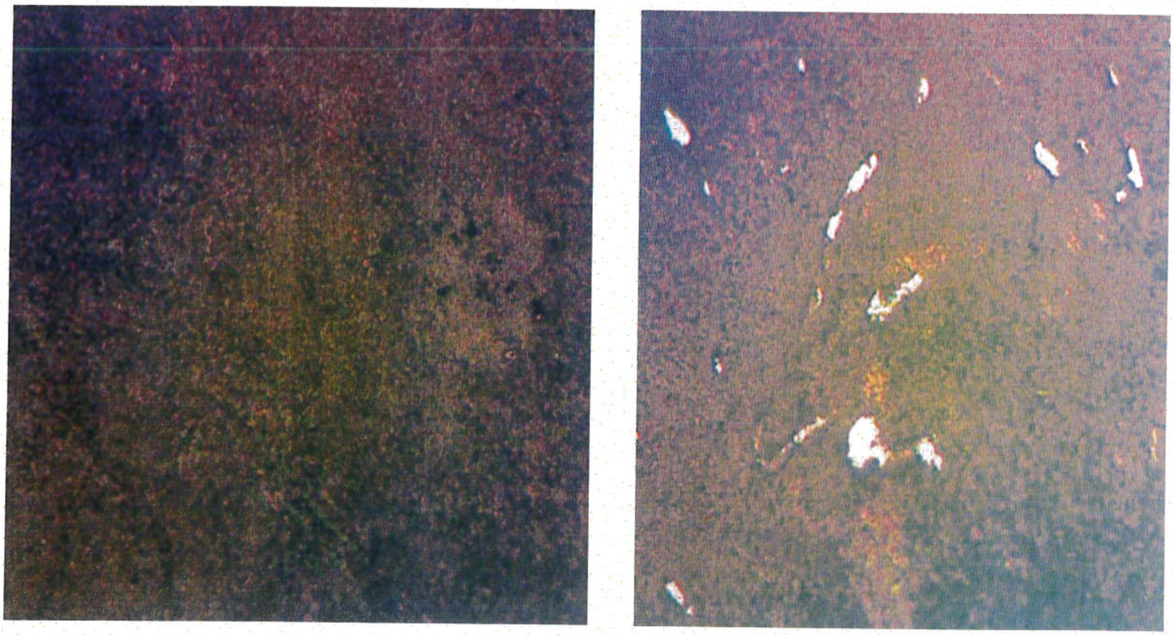

Figure 4.2: microstructure of Air cooled specimen at x400 and x800 magnification

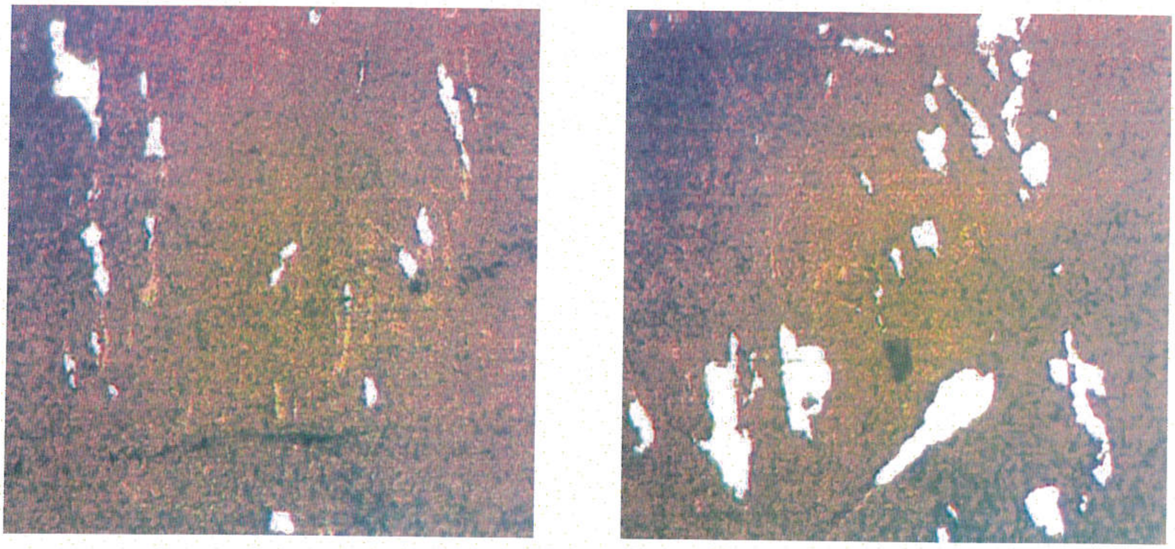

Figure 4.3: microstructure of mold cooled specimen at x400 and x800 magnification

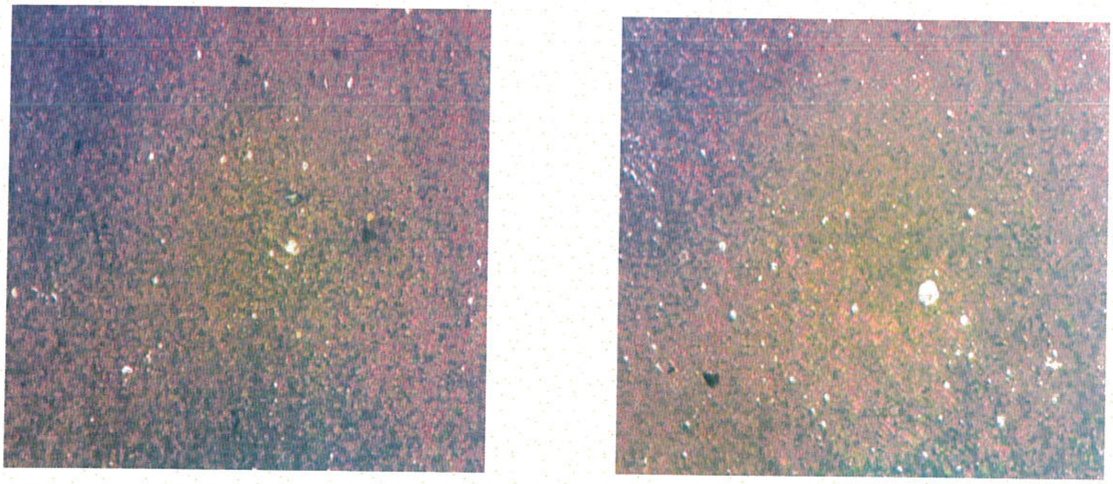

Figure 4.4 microstructure of water cooled specimen at x400 and x800 magnification

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 4.3 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

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

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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