DEVELOPMENT AND PERFORMANCE EVALUATION OF AN AGITATED QUENCHING TANK/BATH

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BY

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APRIL, 2015

DECLARATION

I declare that the work in this thesis entitled “Design, Construction and Performance Evaluation of an Agitated Quenching Bath”, has been carried out by me under the able supervision of Prof. S. Y. Aku and Dr. D. S. Yawas.

All other sources of information used in this project work were duly acknowledged in the text and also enlisted in the references. Also I declared that this thesis has never been submitted anywhere for any award.

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CERTIFICATION

This thesis entitled " Design, Construction and Performance Evaluation of an Agitated Quenching Bath" by Ma'aruf ISYAKU, meets the regulations governing the award of Master of Science Mechanical Engineering (Production) of Ahmadu Bello University, Zaria, Nigeria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This project work is dedicated to my late father Malam Isyaku Mani who died in 1980 and my late daughter Jamila Ma'aruf who died in 2011, may their souls rest in perfect peace, Amin.

ACKNOWLEDGEMENT

All thanks go to Almighty Allah for allowing the possibility of completing this thesis. Special thanks goes to my able supervisors, Prof. S.Y Aku and Dr. D. S. Yawas for their help, support, patience and understanding during the course of this project.

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ABSTRACT

Heat treatment is one of the most important industrial finishing operations which helps in the improvement of mechanical properties such as hardness, tensile strength and impact strength of components being used in our day-to-day activities. A common method of achieving this is through quenching (agitated and static). An agitated quenching bath with capacity of $0.1m^3$ and four different speeds of agitation was developed and its performance evaluated. Medium carbon steel and ductile cast iron alloy samples were used for the performance evaluation of the quenching bath. Water at room temperature was used as quenchant. Hardness, impact strength and microstructural analysis tests were carried out on the quenched samples, results obtained and graphs plotted. Quenching in the agitated bath resulted to an increase in hardness and tensile strength, whereby hardness of medium carbon steel increased from 231HBN to 621HBN and that of ductile cast iron from 263HBN to 662HBN. It was discovered that at Speed III (250rpm) the optimum speed to produce maximum increase in hardness.

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LIST OF SYMBOLS

ρ - Density (kgm^{-3})

A - Area (m^2)

V - Volume (m^3)

P - Power (W)

N - Speed of rotation (rpm)

β - Blade Angles (^{o})

Z - Number of blades

h - Vertical height above impeller (m)

g - Acceleration due to gravity (m/s^2)

б - Stress (Nm^{-2})

R - Reaction force (N)

H - Total head of impeller (m)

M_w - Mass of water (kg)

G - Modulus of rigidity (GNm^{-2})

D_e - Equivalent diameter (m)

K - Roughness (m)

R_e - Reynolds number

Q - Velocity flow rate (m^3/s)

η - Efficiency

R_m - Mean radius of blade (m)

R_o - Outer radius of blade (m)

υ_{f2} - Exit flow velocity (m/s)

υ_i - Inlet blade velocity (m/s)

υ_f - Outlet blade velocity (m/s)

d_o - Outer shaft diameter (m)

m_t - Total mass of assembly (kg)

S_s - Allowable stress without keyway (Nm^{-2})

t - Thickness of plate (m)

β_1 - Inlet blade angle (^{o})

β_2 - Outlet blade angle (^{o})

R_i - Internal diameter radium of blade (m)

υ_b - Blade velocity (m/s)

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Agitation of a quenching bath is one of the techniques used to create turbulence in a liquid (water or oil) during quench hardening heat treatment of steel/cast iron components which is usually applied to manufactured machine components before they are finally put into service or the market.

The hardening process is usually carried out by using heat treatment equipment comprising a heating furnace and a quenching tank (bath) containing a liquid medium (usually water, brine, oil, caustic soda solution, or polymer solution) at room temperature (Higgins, 1984). Although, there are some types of hardening methods that do not required quenching in a liquid medium. Allen (1979) defined hardening as a number of heating and controlled cooling operations that will provide desired properties in a metal or alloy. According to Rajan *et al,* (1988), heat treatment is a process of heating and cooling operation(s) applied to metals and alloys in the solid state so as to obtain the desired microstrcutures and properties. Among engineering metals and alloys, steels and cast irons are more versatile and this versatility is based on the fact that their properties can be controlled and changed at will by heat treatment.

There are various types of heat treatments, and they include: - annealing, normalizing, quench hardening, spheroidizing, case or surface hardening, tempering, martempering and austempering (Rajan *et al.,* 1988). In this research work the quench hardening heat treatment method is under investigation. It involves heating a steel or cast iron component to the austenite range (800 - 950°C), allowing the component to stay at that temperature for some time (for uniform temperature throughout the component), then removing it and dropping it into a liquid medium (quenchchant) in a container called a quenching bath at room temperature. This process is referred to as quenching, and it makes the quenched component acquire high hardness due to the formation of martensite which is known to be hard and brittle. This resultant high hardness makes possible the use of steel for metal cutting tools which can maintain sharp cutting edges under severe operating conditions, and for dies which can resist abrasion and wear Quench hardening is also used for hardening machining tools to make them resistant to wear during machining operations and to increase their life span.

There are basically two types of quenching baths: -

a. Static or unagitated quenching baths
b. Agitated quenching baths

Considering the importance of heat treatment as one of the industrial finishing operations which help to increase the service life of components in service, there is need to contribute through research, the development of the metal industry. Therefore, the objective of this work is to design, fabricate and evaluate the performance of an agitated quenching bath. The agitation rate will be varied using a variable speed electric motor drive, while carbon steel and ductile cast iron alloys will be used to test or evaluate the performance of the fabricated agitated quenching bath.

1.2 Statement of the Problem

Quench hardening of machine components for the purpose of improving their mechanical properties is done either in a static quenching bath or in an agitated quenching bath. The result of survey of most small and medium scale metal casting and fabrication industries and metal workshops of mechanical engineering departments of most tertiary institutions in the country show that a majority of these use the static quenching baths for their quench hardening operations. The reason for this may be unavailability of agitated quenching bath due to high cost of importation of these baths. But in terms of achieving better mechanical properties, the use of an agitated quenching tank is preferred, but it costs more because it is imported. Hence there is need to design and construct locally an agitated quenching bath that would be affordable to indigenous metal casting and fabrication industries and mechanical workshops of tertiary institutions.

1.3 Justification of the Study

Among all engineering metals/alloys, steels and cast irons are more versatile. This versatility is based on the fact that their properties can be controlled and changed at will by heat treatment. The mechanical properties of metals generally are related and dependent on their composition, microstructural make-up and metallurgical properties (Rajan *et al.*, 1988). Quenching is a critically important process in the development of desired mechanical properties of many steels and cast irons. Proper agitation of the quench bath is often considered as a single parameter that dictates the success of the quenching process itself, hence there is need to pay attention to the study and improvement of quench tank agitator design in order to assist and contribute to the development of industrial finishing operations.

1.4 Significant of Study

The research work is important because, if successful, it will help indigenous metal producing industries to improve the quality of their products. The agitated quenching tanks will be cheaper than imported ones and will reduce, hence save the country some foreign exchange. The quench tank will also be useful in tertiary institutions for research and teaching. The fabricated equipment could also be exported to earn our country foreign exchange. The equipment will also assist in the further development of industrial finishing units of metal producing industries.

1.5 Aim and Objectives

This research work was aimed at the successful design; construction and testing of an agitated quenching bath that is suitable for effective quench hardening of steel and cast iron components not more than 300 mm long and 100 mm width and upto 5 kg in weight. The specific objectives are as follows: -

(i) to design a portable agitated quenching bath with the ability of varying the speed of agitation.

(ii) to construct the designed agitated quenching bath.

(iii) to use carbon steel and ductile cast iron alloys to evaluate the performance of the quenching bath

(iv) to determine the effect of speed of agitation on the hardness and find the optimum speed.

(v) to compare the results of agitated and unagitated or static baths.

1.6 Scope of the Study

Based on available resources and associated cost, this research work shall be limited to the following:

(i) The designed and constructed tank will be limited to a volume of 20 litres and the shape will be of rectangular section (for faster heat removal during quenching as explained in section 2.7).

(ii) Variable speed electric motor with four speed drives will be used to vary the agitation

(iii) Plain carbon steel and ductile cast iron samples will be used to test the performance of the agitated quenching bath.

(iv) The tests to be carried out on the quenched samples (both in static and agitated baths) are hardness, tensile strength, impact strength and microstructural analysis.

(v) Water at room temperature will be used as quenching medium in both static and agitated conditions. The choice of water is due to some of its good properties, for instance, water is the most popular quenching medium; it meets the requirements of low cost, easy availability, ease of handling and safety (non-harzadous). Water has high cooling power (high cooling rate). According to Vigendra (2009), the cooling rate of water falls between that of brine and oil. High specific heat and high latent heat of vapourization of water are responsible for its high cooling rate.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Quench Hardening Heat Treatment

Quench hardening is one of the many kinds of heat treatment available Kakani and Amit (2009) defined heat treatment as the heating and cooling operations required to alter the properties of metals, alloys, plastics and ceramic materials. Changes in a material’s properties result from changes made in the microstructure of the material. Heat treatment can be applied to ingots, castings, semi-finished products, welded joints and various elements of machines and instruments.

Quenching, as one of the most important processes of heat treatment can improve the performance of various metallic alloys greatly; but an important criteria in quenching is to select the quenchant medium and process that will minimize the various stresses that develop within the part to reduce cracking and distortion while at the same time providing heat transfer rates sufficient to yield the desired as quenched properties such as hardness.

The performance of a quenchant can be characterized by its ability to extract heat from the part surface sometimes by measuring mechanical properties such as harness and tensile strength.

For various fabrication and manufacturing operations, heat treatment is very important. The purpose of heat treatment is to achieve any one or more of the following objectives: To:

i. Harden a metal component in order to improve its mechanical properties.
ii. Remove strain hardening of a cold worked metal and to improve its ductility.

iii. Relieve internal stresses set up during cold – working, casting, welding and hot-working treatments.
iv. Soften a metal to improve its machinability, and to increase the resistance to wear, heat and corrosion.
v. Improve the cutting ability of a steel tool.
vi. Refine grain structure after hot working a metal.
vii. Soften and toughen a high carbon steel piece.
viii. Harden non-ferrous metals and alloys, especially aluminium alloys and to produce a single phase alloy in stainless steel.
ix. Produce a hard, wear resistant case on a tough core of a steel part and to toughen a hardened steel piece at the cost its hardness.

The principal kinds of heat treatment are: annealing, normalizing, quench hardening, tempering, case hardening, surface hardening, ageing and isothermal quenching.

Quench hardening heat treatment is a process in which steel or cast iron is heated to the austenite range (800-950 °C), held at this temperature, removed and quenched (rapidly cooled) in a liquid medium such as water, oil, brine, molten salt baths. This sudden cooling (quenching) results in the formation of an extremely hard, needle shaped structure known as martensite.

2.2 Quenching Media

A quenching medium is one into which heated objects are plunged in order to withdraw heat from the objects rapidly. Quenching of ferrous alloys usually results in the transformation of austenite to martensite. According to Rajan *et al.,* (1988), during cooling, heat must be extracted at a very fast rate from the steel piece. This is possible only when a steel piece is allowed to come in contact with some medium which can absorb heat from the steel piece within a short period. A medium that is used for quenching is known as a quenchant (quenching medium).

2.2.1 Types of Quenching Media

There are many types of quenching media in use. Table 2.1 below show some quenching media in use industrially with corresponding comparison of cooling rate with that of water.

S/NO	QUENCHING MEDIUM	COOLING RATE COMPARED TO WATER	APPLICATION
1	Water	1.00	Steel, Aluminium alloys and other nonferrous metals
2	Caustic Soda	1.38	Ferrous metals
3	Brine	1.96	Low-alloy, Low Carbon Steels
4	Mineral Oil	0.36	All Steels
5	Animal Oil	0.31	All steels
6	Vegetable Oil	0.29	All Steels
7	Air	0.015	Highly alloyed Steels

Table 2.1: Type of Quenching Media

2.2.2 Characteristics of Quenchants

According to Rajan *et al.,* (1988), the effectiveness of a quenching medium (quenchant) depends largely on its characteristics. Some of the factors which control quenching characteristics are as follows:

i. Temperature of the quenchant.

The cooling rate of any quenching medium varies with its temperature; hence to get uniform results, you must keep the temperature within prescribed limits.

ii. Latent heat of vaporization of the quenchant

It the heat absorbed when a quenching medium changes from liquid to gas phase. The higher the laten heat of vapourisation of the quenchant, the better the quenching effect.

iii. Specific heat of the quenchant.

The higher the specific heat of the quenchant the better the cooling rate and hence better quenching properties.

iv. Thermal conductivity of the quenchant.

Quanchants with higher ability to conduct heat are better in quenching than those with lower conductivity.

v. Viscosity of the quenchant.

Quenchants with low viscosity values perform better in quenching than those with higher values.

vi. Degree of agitation of the quenchant bath.

The absorption of heat by the quenching medium depends largely on the circulation of the quenching medium or the degree its agitation. Higher the agitation means high rate of heat removal by quenching medium.

2.3 Mechanism of Cooling during Quenching in a Liquid Medium

The mechanism of removal of heat from the work-piece as a result of quenching is not as simple as that associated with annealing or normalizing. The removal of heat during quenching is complex in the sense that heat is removed in three stages. As soon as the work piece comes into contact with the liquid coolant (quenchant), the surrounding quenchant layer is instantaneously heated up to the boiling point of the quenchant and vaporizes due to the high temperature of the work piece. This vapour forms an envelope round the work-piece and thus checks further cooling of the work-piece. This is so because the vapour film is a poor conductor of heat. The piece is cooled at this stage by conduction and radiation through the vapour film. Only the surface of the work-piece is cooled considerably prior to the formation of this vapour blanket stage (1st stage).

The first stage is followed by the second stage known as the vapour transport cooling stage or liquid boiling stage. As the temperature of the work-piece comes down, the vapour film is no longer stable below a particular temperature. This is the start of the second stage. From here, as soon as the vapour film is broken, the quenchant comes in contact with the surface of the work-piece and is immediately pushed away from it in the form of bubbles. Fresh coolant now comes in contact with the work-piece surface and the process is repeated.

This process continues until the temperature of the surface of the work-piece comes down to below the boiling point of the liquid. Very rapid cooling takes place at this stage as the quenchant is always in contact with the surface of the work-piece.

Figure 2.1 shows the three stages of cooling on a cooling curve for a work-piece quenched in a liquid medium. This third stage is known as liquid cooling stage or convection stage. It starts when the temperature of the surface of the work-piece becomes equal to the boiling point of the quenchant. Cooling at this stage takes place by both conduction and convection processes.

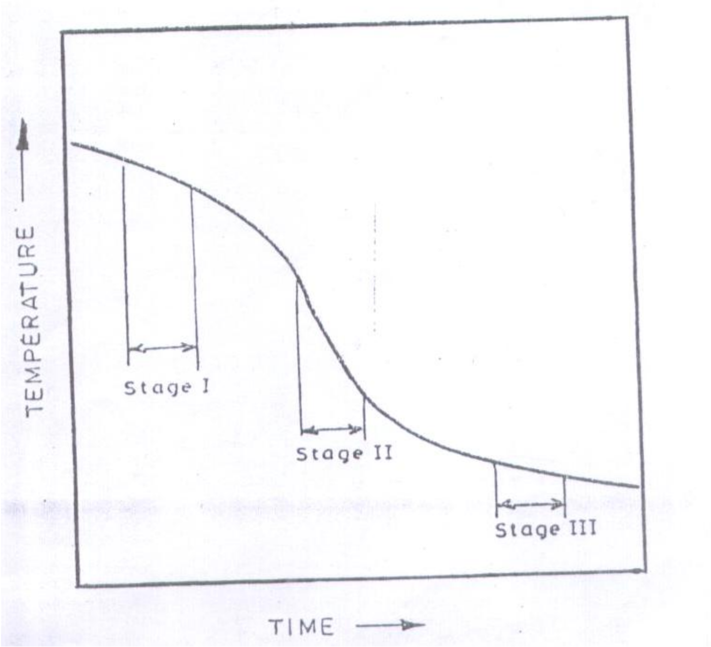

Figure 2.1: Various stages of heat removal during quenching (Rajan *et al,* 1988)

2.3.1 Wetting Kinematics during Quenching

During quenching in liquid media with boiling temperatures far below the initial temperature of the body, three stages of heat removal occur. These are referred to as the:

(i) Film boiling or vapour blanket stage

(ii) Nucleate boiling stage

(iii) Convection stage

In the film-boiling stage the surface temperature of the work-piece is sufficiently high to vaporize the quenching liquid and form a stable film around the part. The vapor film has an insulating effect; therefore, the cooling rate during film boiling is relatively slow, the vapor film then collapses and nucleate boiling begins. In this stage, the liquid in contact with the hot surface evaporates, which results in a high rate of heat transfer from the metal to the fluid. Upon further cooling, the surface temperature becomes less than the boiling point of the liquid, and the surface is permanently wetted by the fluid. The cooling rate is low and determined mainly by the rate of convection and the viscosity of the liquid quenchant. Accordingly, quenching in water and oil usually results in slow wetting with a clearly visible wetting front. Agitation rate and additives (salt, polymers and other chemicals) can strongly influence the wetting process. If a polymer solution is used as a quenchant, on the surface of the sample, a polymer film forms that provides a uniform breakdown of the vapor blanket and reduces heat transfer in the lower temperature range. When the polymer film has completely redissolved, heat transfer is achieved entirely by convection.

The velocity of the spreading wetting front and the time interval of the simultaneous presence of film boiling and nucleate boiling can be strongly influenced by changing the physical properties of the quenchant and the sample. The items varied are:

(i) Type of quenchant as described by its boiling temperature, viscosity, thermal capacity, and surface tension.

(ii) Additives to the quenchant, and their concentration

(iii) Temperature and agitation rate of the quenchant

(iv) Thermal characteristics of the body and its transformation behaviour.

2.4 Agitation of a Quenching Medium and its Importance

2.4.1 Agitation of a Quenching Medium

To agitate a liquid bath means to cause turbulence in the liquid bath. When the liquid is made to move violently in the container (bath) the bath is said to agitated. This agitation can be provided by various methods including recirculating pumps, submerged spray, mechanical impeller stirrers, actual movement of the parts themselves, or a combination of two or more of these methods (Totten and Lally, 1992). Hence agitation of a bath can be referred to as the externally produced movement of the medium and this agitation has extremely important influence on the heat transfer characteristics of the quenching bath.

The quenchant must therefore not be confined to unidirectional flow but must have general turbulence. Propellers produce both forward and spiral motion. When a quenchant with this type of motion is directed against a baffle, side or bottom of the tank, the directionality is broken up into numerous eddy currents. In a properly designed tank with propeller agitation, the eddy currents are uniformly distributed throughout the quenching section, hence, the exact location of a part in the tank and its complexity are not critical. With impeller agitation, brine or caustic soda solutions for quenching are not necessary because the vapor barrier broken up by these salt solutions can be removed more effectively by agitation (Bergmann, 1981).

Taking quenching dynamics into considerations, when a hot ferrous component (fully austenitic) is initially dropped into a quenchant with no agitation, it is enveloped in a vapor. To create this vapor, heat must be extracted from the part. But the vapor acts as a heat insulating layer. Then, if the vapor barrier remains sufficiently long, transformation to ferrite and pearlite can occur, which is undesirable. For water quenching, ordinary salt or sodium hydroxide can be added to help break up the vapor film surrounding the part. Additives to water such as salt usually have bad effects on the quenching equipment, and the concentration of the salts in the solution must be held within certain limits for optimum performance. A better way of removing the vapor barrier produced by quenchants is by agitation which washes away the vapour and brings liquid to the hot surface. If all surfaces of the part are not equally washed free of the vapor, local soft spots and excessive warpage can result.

After the vapor phase has been removed by agitation, the second stage of quenching occurs, during which heat is extracted at a most rapid rate. The liquid in contact with the surface is vaporized into many, small, short – lived bubbles. Since these bubbles have a short life span, the surface of the quenched component is constantly being supplied with liquid (quenchant).

2.4.2 Importance of Agitation Quenching Medium

Proper agitation of the bath during quenching is usually the single parameter that dictates the success of the quenching process itself. Agitation of the bath facilitates the rupture of the vapour blanket around the hot metal during the first stage of cooling. Increasing agitation rates will result in a corresponding increase in heat transfer rates in all the three cooling stages during the quenching process. According to Totten and Layy (1992), the most common and cost-effective method of providing agitation is by the use of an impeller mixer. This mixer provides fluid motion and shear.

Steel and cast iron parts are usually quenched to develop specific mechanical properties and these mechanical properties are dependent upon the microstrcuture obtained after quenching. To obtain a fully martensitic microstructure, a part must be quenched rapidly enough to prevent higher transformation products such as ferrite, pearlite, and bainite. Transformation to martensite is essentially temperature dependent. The temperature at which martensite starts to form is primarily dependent on carbon content. Agitation of a quenching medium usually helps to increase the rate of heat removal by facilitating the breaking of the vapor blankets formed around on the surface of the quenched component (Rajan, 1988).

Good agitation of a quenchant in a tank can greatly increase the cooling rate and thereby harden the quenched component. Ideally, agitation should provide uniform flow rate of the quenchant over all surfaces of the part being quenched regardless of its complexity to ensure uniform hardening and minimum distortion and cracking.

Agitation of the quenchant increases the rate of heat transfer by mechanically removing the vapor bubbles (therefore assuring their short life) by bringing a fresh supply of quenchant to the surface. Uniform agitation of the quench on all surfaces of the part is again important to assure uniform cooling (Bergmann, 1981).

After the surface temperature cools to below the vaporization temperature of the quenchant, cooling is by conduction. The cooling rate is relatively slow and depends primarily on the temperature differential between the surface of the part and the quenchant.

2.5 Hardenability

The ability of ferrous metal/alloy to form martensite when cooled at various rates is measured by its hardenability. A material with higher hardenability will form martensite in large sections on quenching. Hardenability depends on factors such as composition of the alloy in terms of carbon content, and grain size.

The main objectives of hardenability are:

(i) To increase the hardness of the metal, so that it can resist wear

(ii) To enable it to cut other metals i.e. make it suitable to serve as a cutting tool. (Sharma, 2007).

2.6 Classification of Heat Treatment Methods

All the methods used in heat treatment of ferrous alloys are based on the fact that there is a eutectoid reaction occurring whereby the austenite phase (at 800-950°C) is transformed on cooling (slow or fast) to other desired structures. According to Khanna (1999), steel and cast iron heat treatments are made possible by the presence of the eutectoid reaction.

Heat treatment methods can be classified into the followings: -

2.6.1 Annealing and Normalizing:

Callister (1997) described annealing as a heat treatment process whereby a ferrous metal component is heated in a furnace to the austenite range (800 – 950 °C), soaked for some time, then it is allowed to cool inside the furnace i.e. the furnace is turned off and both the furnace and component are allowed to cool to room temperature at the same rate. This cooling usually takes several hours. The resulting microstructure is usually soft and ductile. Hence, the major aim of annealing is to soften the component to enable it to be sawn, machined, or mechanically worked by methods such as extrusion, cold pressing, cold – bending, hammering etc. Annealing is also used to relief or eliminate internal stresses.

Annealing is sub-divided into: stress relief annealing, process annealing, spheroidising annealing and full annealing (Khanna, 1999).

Normalizing heat treatment method which is also called air quenching and consists of heating steel or cast iron to the austenite range, soaking it at that temperature for some time, then removing and cooling in air on the floor. According to Khanna (1999), normalizing treatment on steel usually produces pearlite (dark areas) in the matrix of ferrite (white) in hypo-euctoid steel (e.g. 0.5 – 0.7 % C). The main purpose of normalizing is to:

(i) Refine the grain structure of steel/cast iron which may have been unduly coarsened after casting

(ii) Produce a uniform structure

(iii) Produce a harder and stronger component than annealing

(iv) Improve structures in weldments

(v) Generally improve engineering properties of steels.

2.6.2 Quenching (quench hardening) and Tempering

Quench hardening heat treatment, according to Rajan *et al.,* (1998) consists of heating a ferrous component to the austenite range, soaking it there for sometime, then removing and cooling it rapidly by dropping it into a liquid medium such as water, oil, acqeous solutions in unagitated or under agitated conditions. The liquid medium (quenchant) extracts heat rapidly from the quenched component resulting to the transformation of austenite into martensite (a hard structure).

To get a component hardened properly by quenching depends upon.

(i) Composition of the steel/cast iron

(ii) Nature and properties of the quenching medium

(iii) Temperature of the quenching medium and the temperature of the component in the austenite range (hardening temperature)

(iv) Size of the component to be quenched

(v) Degree of agitation

(vi) Surface condition of the component (i.e. whether there are oxide scales on the surface)

(vii) Extent/amount of alloying elements like Cr, Ni, V, Mn present in the component.

Tempering is a heat treatment process which is usually applied to a component that has been previously quenched. During quenching, because of rapid cooling, high internal stresses are developed in the hardened steel. Therefore, hardened steel components are not usually used in the as-quenched condition. A tempering operation is usually carried out before putting the component into service. Therefore, tempering is done by reheating a quenched component to a temperature below the lower critical temperature (727 °C), holding it for the desired length of time (1 hour to 6 hours) then removing the component from the furnace and cooling it in air.

The main purpose of tempering it to:

(i) Relieve residual stresses

(ii) Reduce hardness marginally

(iii) Improve ductility and toughness

According to Callister (1997) and Rajpot (2006), tempering treatment lowers hardness, strength and wear resistance of quench – hardened steels marginally, but this marginal loss is adequately compensated for by the advantages gained by relieving of internal stresses, restoration of ductility and toughness and transformation of retained austenite.

Tempering may be classified into the following types:

(i) Low temperature tempering: This treatment is carried out in temperature range of 150 – 250 °C

(ii) Medium temperature tempering: Is carried out in the temperature range 300 – 450 °C

(iii) High temperature tempering: Is carried out in the temperature range 500 - 650 °C (Khanna, 1999).

Other methods of heat treatment include; interrupted quenching which is sub-divided into austempering, martempering, aussforming. Case hardening heat treatment, which is sub-divided into carburizing, flame hardening, induction hardening, nitriding and carbonitriding.

2.7 Agitation Selection and Impeller Arrangements

Quench tank agitation can be provided by various methods, including recirculation pumping, submerged spraying, impeller stirring, ultrasonics, and actual movement of the part itself or a combination of two or more of these methods.

Ultrasonic agitation is effective but typically the relatively expensive manual movement of the part itself does not assure uniformity. Agitation using recirculation pumps also will not provide quench uniformity throughout the tank, hence in these cases, submerged sprays are often used. On the other hand, recirculation pumps require approximately ten times the power to provide the same amount of linear flow rate as an impeller mixer (stirrer). However, the most common and cost effective method of providing agitation is an impeller mixer.

Figure 2.2 shows different ways in which impellers can be arranged in an agitation quench tank. A mixer impeller is usually used to provide fluid motion and shear. Common mixing processes that occur in quenching practice such as fluid mixing and heat transfer are strongly related to impeller flow.

Mixing impellers used for quenching operations are either open-impeller or draft-tube systems. Open impeller mixers do not have a flow-directing surface encasing the impeller but rely on the impeller itself, or a baffle to direct flow into the quenching region of the tank.

A common impeller used for open systems is an axial – flow impeller such as marine propeller. This axial flow impeller directs fluid flow parallel to the impeller shaft. Axial – flow impellers can either be top – entering, side entering or angled top – entering as shown in Figure 2.2.

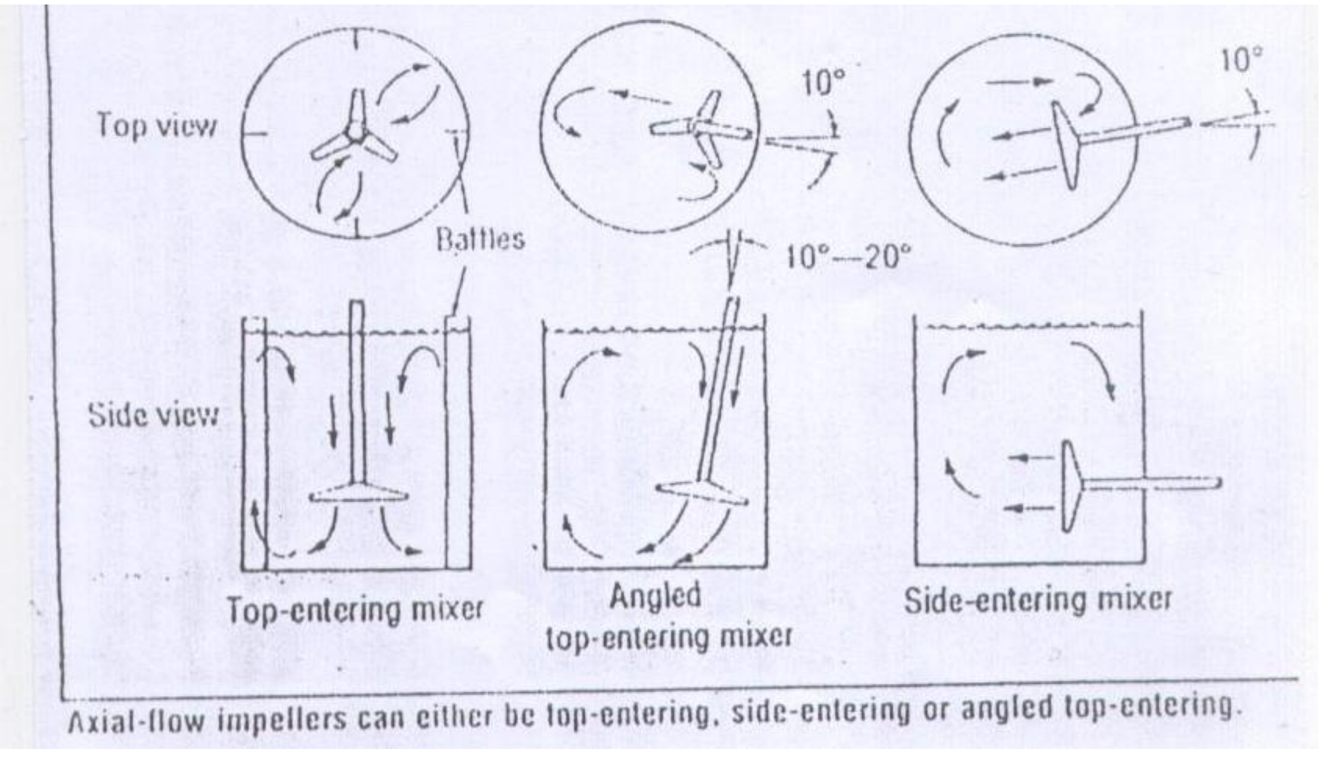

Figure 2.2: Impeller Arrangements, Flow Patterns (Totten and Lally, 1992)

2.8 Carbon Steels and Cast Irons

2.8.1 Carbon Steel

Plain carbon steels (un-alloyed steels) are classified as:

i. Low carbon steels, these are of two types:
    a). Dead mild steels
    b). Mild steels
ii. Medium carbon steels
iii. High carbon steels

2.8.2 Dead Mild Steels

These are cold worked low carbon steels containing below 0.1 percent carbon. Because of their high ductility, these steels find applications in the form of cold-rolled sheets. Their excellent formability suits well cold-formed processes such as stamping, for automobile bodies, refrigerator bodies, tin cans, corrugated sheets and solid drawn tubes (Vijendra Singh, 2009). Other uses include building, fencing and mattress wires, etc.

2.8.3 Mild Steels

These are hot-worked steels with carbon content between 0.15-0.25%. They have higher strengths but lower ductility than the dead mild steels; that is why they (mild steels) are usually hot rolled or forged and air cooled. These steels cannot be hardened by quenching due to their low carbon content. These steels find applications for structural components, examples are heavy plates for tanks, ship hulls, pressure vessels, boilers, for bridges and building construction as I-beams, channels, angles, girders (plate and box), H-beams, oil pipe lines, etc. These steels have good weldability.

2.8.4 Medium Carbon Steels

These are steels with 0.25-0.55% carbon. They have higher strength but lower ductility than mild steels. They are usually used in normalized condition for a great variety of components such as camshafts, connecting rods, gears and piston rods. These steels form base components for machines and are often called machinery steels (Vijendra (2009).

2.8.5 High Carbon Steels

These steels normally have carbon contents between 0.55-1.4%. They are the hardest strongest but least ductile of the carbon steels: They are heat-treated steels to attain high hardness, wear resistance cutting properties. They are mainly tool steels. Some of their applications include: - for railway rails, laminated springs for railways and automobiles; wheel spokes, saws, hammers, shear blades, chisels, punches, dies, axes, milling cutters, razor blades, wood working tools, etc.

2.8.6 Cast Irons

Cast irons are basically iron-carbon alloys having carbon contents of more than 2.1%. Cast irons have eutectic structure present in the microstrcuture after solidification. The presence of eutectic in the structure makes cast irons exclusively to be “cast” to the desired shapes (Kakani and Amit 2009; Vijendra, 2009). The industrial cast irons have carbon content in the range of 2.11 – 4.0%, along with other elements like silicon, manganese, sulphur and phosphorus in substantial amounts. Cast irons are brittle generally, and cannot be forged, rolled, drawn, etc, but can only be “cast” into desired shapes and sizes (with or without machining) by melting and pouring the molten alloy into a mould of desired shape and allowing it to solidify.

Because casting is the only and exclusively suitable method to shape these alloys, they are therefore called cast irons.

2.8.7 Types of Cast Iron

The best method of classifying cast irons is based on the type of microstructure, i.e. the shape, distribution and form of carbon in the microstructure. The major types of cast iron are:

(i) Gray cast iron
(ii) White cast iron
(iii) Malleable cast iron
(iv) Ductile (nodular) cast iron
(v) Alloy cast irons.

The main factors effecting the formation of white or gray iron are: - chemical composition and cooling rate from the molten state. In general, typical chemical compositions of a cast iron contain mainly iron, carbon, silicon, sulphur, manganese and phophorus (Allen, 1979).

Most of the heat treatment methods applicable to steels are also applied to cast irons, especially gray and ductile cast irons can be subjected to quench hardening heat treatment in order to give them high hardness and wear resistance.

2.9 Types of Defects in Quenched Components

During quench hardening heat treatment, some of the major defects found to occur in quenched components are:

(i) **Mechanical properties not up to specifications:** This type of defect is usually common, especially in hardened tools and other machine elements. Hardness, tensile and impact properties are usually low. Insufficient fast cooling by the quenchant could be responsible for such a defect. According to Vijendra (2009), the presence of scales on the surface, and inadequate agitation or circulation of coolant during quenching may also result in such a defect. Other factors that can cause such a defect include shorter austenitising time, lower austenitising temperature, and decarburisation.

(ii) **Soft spots:** Soft areas on the hardness are called soft spots. This defect can be caused by the presence of adhering scales on the surface of a quenched component, or decarburisation of some areas, or prolonged vapour – blanket stage due to overheated coolant or insufficient agitation of the bath.

(iii) **Quench cracks:** These are cracks that occur in a quenched component as a result of internal stresses due to sudden phase transformation from austenite to martensite. Quench cracks can occur if carbon content or alloying elements are high. Cracks can also results due to drastic cooling (fast rate of cooling) due to violent agitation of the bath, combined with high cooling capacity of the quenchant. Cracking can also be caused by expansion resulting from the austenite-to-martensite transformation in the interior of the part while the previously transformed martensite on the outside is experiencing thermal shrinkage due to cooling. This resulting tensile stress on the surface is liable to cause brittle fracture. Other defects that may occur include distortion, warpage, change in dimensions, oxidation, (Vijendra, 2009). Figure 2.3 is the illustration made by Vijendra (2009) explaining that when a heated steel object (say at 840 °C) is plunged into a bath of water, the cooling curve so obtained has three stages as: Stage A – vapour blanket stage, stage B – intermittent – contact stage (Liquid – boiling stage) Stage C – Direct contact stage (Liquid – cooling stage).

Figure 2.3 below shows different stages of heat removal / cooling (graphical and schematic) of a small steel cylinder quenched in water at room temperature.

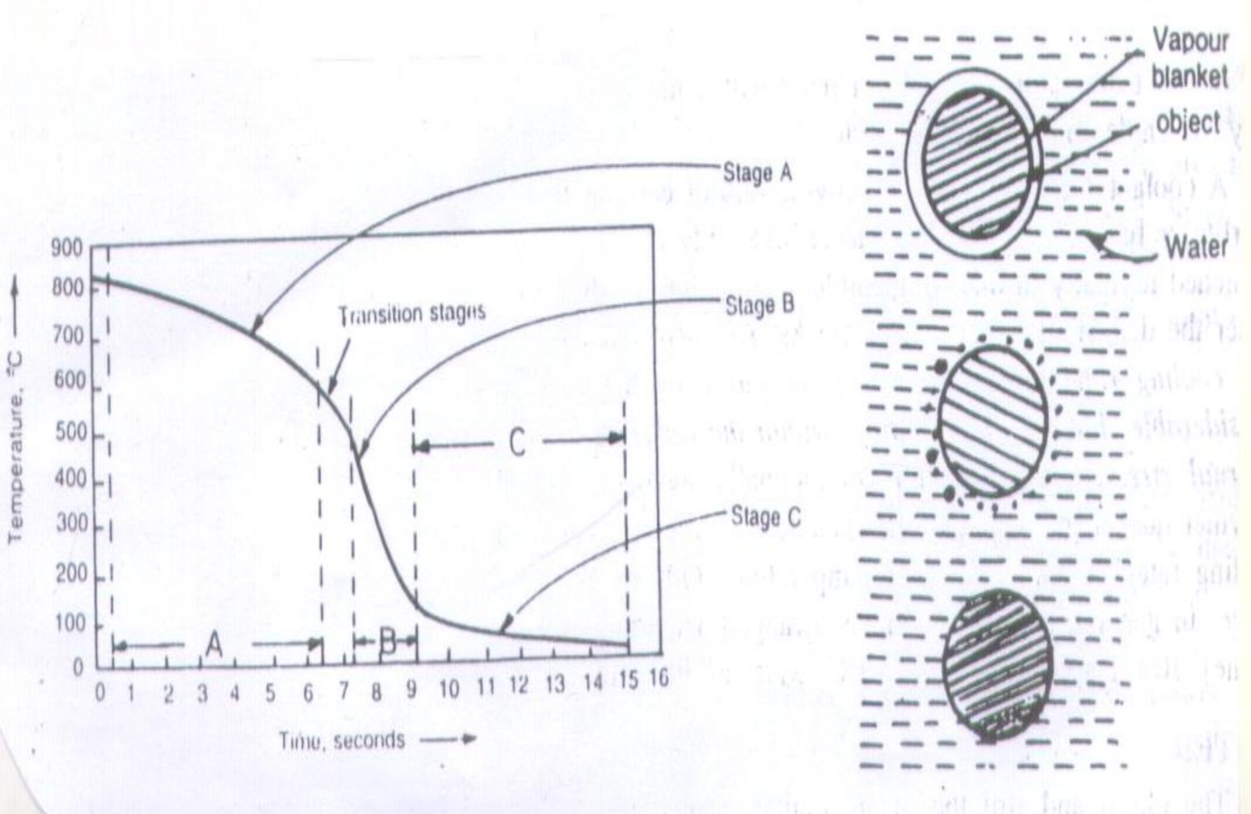

Figure 2.3: Stages of heat removal of a small steel cylinder quenched in cold water (Vijendra, 2009).

2.10 Heat Transfer During Quenching

Heat is a form of energy which is transferred from one body to another at a lower temperature, usually by virtue of the temperature difference between the bodies. Transfer of heat is the major process that takes place during heat treatment operations in workshops. Here, the transfer of heat is from a hot metal removed from the furnace (say at 900 °C) and quenched in a liquid medium (quenchant) at room temperature (30 °C). When those two bodies (hot and cold liquid) are brought into contact, there will be a transfer of heat from the hot metal to the cold liquid until the temperature of the metal and liquid are equal, then at this point, no heat transfer takes place between the bodies, and they are said to be in thermal equilibrium. Heat transfer is the transmission of energy from one region to another as a result of temperature gradient. Whenever there is exchange of heat, then heat is consumed. Heat is lost by the hot body and gained by the cold body. Generally, heat transfer takes place by three modes: -conduction, convection and radiation. However, in the quenching process, the mode of heat transfer is by convection because cooling will be in a liquid medium (water). One of the important properties of solids and liquids involved in this type of heat transfer process is specific heat capacity, other important properties include mass and volume.

Specific heat capacities of solid metals and liquid quenchants play significant roles in the process of heat transfer during quenching. Specific heat capacity of a solid or liquid is usually defined as the heat required to raise a unit mass through one degree temperature rise; $dq = mcdT$, where m is the mass, dT is the increase in temperature and c is the specific heat capacity. Therefore, specific heat capacities are important properties of metals and liquids (quenchants) involved in quench hardening heat treatment.

From the concept of applied thermodynamics specific heat capacities are properties of fluids, hence in the limit.

$$cv = \left(\frac{\partial u}{\partial T}\right)_P \; and \, Cp\left(\frac{\partial h}{\partial T}\right)_P$$

$dq = mcpdT$ ……………………………………………………(2.1)

For a reversible non flow at constant P

$dq = mcvdT$ ……..…………………………………………… (2.2)

For a reversible non flow at constant V

integrating for (2.1) and (2.2), we have,

q = mcp ($T_2 - T_1$) ………………………………………….....(2.3)

q = mcv ($T_2 - T_1$) ……………………………………………(2.4),

q is the net heat supplied.

Generally, for heat transfer, it is usually given that;

$\Delta H = mc\Delta t$ ………………………………………………..(2.5)

According to Higgins (1984), the volume of quenching medium necessary to cool a given mass of steel can be calculated easily, provided the hardening temperature of the steel and the permissible temperature rise of the quenching medium are known. For instance,

Let m = mass of the steel in Kg

c_s = specific heat capacity of the steel (J/kg °C)

Th = hardening temperature of the steel (°C)

Tq = temperature of the steel when it is removed from the quenching tank (°C)

S = relative density of the quenching medium (Kg/m^3)

Cq = specific heat capacity of the quenching medium (J/Kg°C)

Tv = permissible temperature rise of the quenching medium (°C)

V = volume of the quenching medium required (m^3)

Then;

Heat given out by steel = m.Cs. (Th – Tq)

Heat absorbed by the quenching medium = V.S.Cq.Tr

Therefore heat absorbed = heat given out

V.S. Cq. Tr = m.Cs. (Th – Tq) ………………………………………(2.6)

Hence $V = \frac{m.Cs.(Th - Tq)}{S.Cq.Tr}$ …………………………………………...(2.7)

This is the minimum volume of quenching medium which is capable of absorbing the heat liberated by the work when no cooling system is employed. However, when circulating/agitation and cooling systems are used, the amount of quenching medium will be less than in equation 7.

2.11 Past Work on Design and Construction of Agitated Quenching Bath/Tank

Sopirinye (2006) carried out a project on design and fabrication of an agitated quench tank. The fabricated tank consisted of a shaft of circular cross-sectional area that transmits mechanical power from a 0.5 hp at 1300 rpm electric motor to an axial impeller located towards the bottom of the tank. However, he did not carry out performance tests on the designed and fabricated agitation tank. Hence there existed a gap which needed to be filled.

Bergmann (1981) designed and constructed agitation tanks on the basis of side entry of impeller shafts into the tank and top entry of impeller shafts and reported that both were equally effective for quenching. He further reported that studies were carried out in the tanks using water and oil in cold and hot conditions, and that the results showed that water at 66°C with mild agitation was less severe than oil at 37°C with strong (high) agitation.

Femandes and Prabhu (2007) carried out an investigation on the effect of section size and agitation on heat transfer during quenching of steel. They used two different sizes of steel specimen (ϕ 28 mm x 56 mm height and ϕ 44 mm x 88 mm height) for agitated quenching in brine, water, palm oil and mineral oil quench media. They reported that after agitation of each of the quenchants, the peak heat flux was increased and that peak hardness was obtained on the surface of each of the workpieces and also for the entire workpiece with the smaller diameter.

Fontedchio, Maniruzzaman and Sisson (2009) carried out an investigation on effect of bath temperature and agitation rate on the quench severity of 6061 aluminium in distilled water. They quenched the 6061 aluminium by varying bath temperature and level of agitation. They reported that there was an increase in maximum cooling rate as bath temperature decreased and agitation level increased. Also they found out that at higher speeds of agitation (above 1000 rpm), the quenchant flow became turbulent hence reduced improvement to the mechanical properties.

Bogh (1994) carried out a mechanical survey on the design of closed propeller flow and open propeller flow of agitation source in order to measure the type of flow in quenchants during agitation. He reported that the open propeller flow type is more effective for measurement of turbulent flow.

Taraba, Duehring, Spanielka and Hajdu (2012) carried out on investigation on effect of agitation work on heat transfer during cooling in oil ISORAPID277HM. They reported that the effect of oil agitation on the cooling process was reflected in the vapour phase and a significant influence of agitation in the convective heat transfer.

2.12 The Present Work

This present work is geared towards modification and improvement of the work done by Sopirinye (2006) on which some shortcomings were observed. For instance, he used an electric motor with one speed, and after the fabrication of the tank, no experiment/test was conducted using the bath to ascertain the effect of agitation rate. Hence, in the present work, an electric motor with four variable speeds will be used to produce four different degrees of agitation. The experiment is designed such that carbon steel and ductile cast iron samples will be used at various speeds to find the effect speed of the motor on properties of the quenched samples. Water is used in each case as the quenching medium to test the performance of the designed and fabricated agitation tank.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Developed Agitated Quenching Bath

The agitated quenching bath was developed at the main Mechanical Engineering Department workshop at Ahmadu Bello University, Zaria, and operated for performance testing at the Department of Metallurgical Engineering, Ahmadu Bello University, Zaria with and electrically powered furnace.

The agitated quenching bath assembly has five main sections as listed below and shown in Drawing No. 1

(i) The quenching bath
(ii) The electric motor assembly
(iii) The impeller blade with shaft
(iv) The electric motor regulator\
(v) The wire mesh

The first section is the quenching bath with the dimensions of 480 mm x 430 mm x 515 mm (0.11 m^3) produced from galvanized metal sheet of 2 mm thickness. It accommodates the impeller shaft and blade as well as the workpiece to be quenched. It is also housed by a frame made from 25 mm x 25 mm (3 mm thick) mild steel angle iron for more rigidity.

The second section is the electric motor of input power of 400 watts and variable speeds between 150-300 rpm which provides the power of agitation to the impeller. The electric motor and its housing are standard materials selected for the purpose of this project to provide variable speeds of agitation during quenching of various metals.

The third section is the impeller shaft coupled to the blade to provide the required agitation of the fabricated quenching bath. Both the shaft and the 6no. blades impeller are standard materials selected for the purpose of the project. The shaft is made from mild steel while the blades are from alumimium. The shaft is of 16 mm diameter and 500 mm length while blade is of 200 mm diameter.

The fourth section is the electric motor regulator which is a standard material providing four different / variable speeds to the electric motor for the purpose of having 4no. variable speeds of agitation (i.e 150, 200, 250 and 300 rpm). It is mounted on the extended frame of the quenching tank using screws / welding.

The fifth section is the wire mesh positioned about 110 mm before the bottom of the quenching tank and being suspended by 4no. wire strands. The purpose of the wire mesh is to allow the workpiece to rest on it so as to have homogenous heat removal by allowing quenchant flow under the workpiece. It has a dimensions of 478 x 513 mm and the thickness of 6 mm.

3.2 Design Consideration and Specifications

3.2.1 Design of Quench Tank

In conformity with present-day requirements, quenching systems are integrated into heat treatment lines, and automation is normally used to process many types of parts. It is seldom economically feasible to design a tank from only one type of material, as one of the major goals of the design is to obtain as much flexibility in the quenching system as possible without appreciably affecting the total cost of the system. The design of a quench tank should not be based on total quantity of steel / alloys to be quenched per unit time, but based on their respective sizes, shapes, sections, grade of materials to be quenched and their various weights. The following are the practical considerations in the design of quenching tank:

(i) The time needed to “quench out” the part to be treated should be known and allowance should be made for it in the hourly rating or capacity of the quench tank.

(ii) Adequate space should be provided around the work piece in order for it to get the full benefit of circulation and maximum heat absorption from the quenched parts by the quenchant.

(iii) As it is difficult to control distortion caused by thermal strains during quenching, the hot work-piece should not be mutilated and deformed by allowing it to fall onto the bottom of the quenching tank with great force.

(iv) The quenching tank should be designed with accessibility to facilitate maintenance and cleaning.

(v) If caustic soda or brine are to be used as quenching media, enough ventilation should be provided to protect the operator from fumes so as to improve the working condition.

(vi) If oil is to be used as the quenching medium, fire hazard protection should be provided.

(vii) The speed of agitation should be moderate and not violent to avoid the occurrence of foam on the surface of the tank, which will reduce the maximum benefit of circulation by producing air pockets.

(viii) The design of the quench tank should provide flexibility and control of such conditions as time cycle of quenching, volume of circulation.

3.2.2 Design of Agitation Impellers

The blades of the impeller are to be designed according to the required flow rate of the selected quenching media.

The number of impeller units required depends on the power output of the electric motor. Several small impellers provide more uniform agitation than one large impeller. The angle of the impeller should be made smaller for smooth circulation and uniform agitation as impellers with large angles tend to produce excessive turbulence in the quench medium. The velocity of quenching medium can be varied for better results by using a variable speed control electric motor or variable-pitch impeller.

Impellers must be properly located in the quench tank in order to function effectively and should be fixed with a flexibility of removal for servicing.

3.3 Design Theory for Different Materials

3.3.1 Determination of Thickness of Sheet Metal for Tank

Maximum hoop stress,

$$\varsigma_{2\text{max}} = \tfrac{1}{3}\,(\text{UTS}) \tag{3.1}$$

Using water as fluid, pressure exerted towards bottom of the tank due to head of the fluid

$$P = \rho g h, \tag{3.2}$$

Where P = pressure exerted

Assuming a factor of safety of 2

Design stress $\sigma_\theta = \frac{1}{2}\sigma_{\theta\max}$

According to Sopirinye (2006), thickness is given by

$$t = \frac{PD}{6\sigma_\theta} \text{------------------------------------} (3.3)$$

where: π

t = thickness of the sheet metal to be use for the tank

3.3.2 Determination of Impeller Shaft Diameter

The general formular for the calculation of impeller shaft diameter (ASME formula is reduced by Hall *et al* (1922) as follows:

$$d_0 = \left[\frac{16K_t m_t}{\pi Ss(1-K^4)}\right]^{1/3}, \text{------------------------------------} (3.4)$$

where: - K = roughness of the surface

K_t = 1.0 (for load gradually applied to rotary shaft)

M_t = Total mass of assembly (kg)

S_s = Allowable stress without keyway

3.3.3 Determination of Number of Impeller Blades

The following three factors influence the selection of the number of impeller blades for proper performance.

(i) A small number of blades lead to high pressure grade and boundary layer build-up.

(ii) An increase in the number of blades reduces the blade loading and hence the step. Hence an impeller with a large number of blades should have higher value of step factor than one with the lower number of blades when all working conditions remain the same.

(iii)An increase in the number of blades leads to higher frictional losses.

Stepanoff (1960) gave the optimum number of blades as

$$Z = \frac{\beta_2}{3} --(3.5)$$

while Pfeider (1963) gave the empirical formular for optimum number of blades as

$$Z = 6.5\frac{(Ro + Ri)\,Sin\,\beta_m}{(R_0 - R_i)}, ---------------------------------------(3.6)$$

where: $\beta_m = \frac{\beta_1 + \beta_2}{2}$,

where: β_m = Mean blade angle

R_o = Outer radius of blade (m)

R_i = Inner radius of blade (m)

β_1 = Inlet blade angle

β_2 = Outlet blade angle

3.3.4 Determination of Power Required from Electric Motor

The overall efficiency of the impeller is given by

$$\eta_o = \frac{Energy\,in\,the\;fluid}{Energy\;from\,the\,electric\;motor}$$

$$= \frac{\rho g H Q}{Pe} --(3.7)$$

Hence power required

$$Pe = \frac{\rho g H Q}{\eta_o}, ------------------------------ (3.8)$$

where: P_e = Power of electric motor required

Q = Velocity flow rate (m^3/S)

ρ = Density of fluid (water)

g = Acceleration due to gravity

H = Total head

3.3.5 Determination of Impeller Blade Angles (Inlet and Outlet)

Hydraulic efficiency $\eta_h = \frac{Energy\,in\ fluid}{Energy\ from\,blades}$

According to Sopirinye (2006)

$$\beta_1 = Tan^{-1}\left[\frac{V_1}{V_b}\right] ------------------------------ (3.9)$$

$$\beta_2 = Tan^{-1}\left[\frac{V_b \;\; V_{f2}}{V_h{}^2 \;\; \frac{gH}{\eta_H}}\right] ---------------------------- (3.10)$$

where: V_1 = Inlet blade velocity

V_b = Blade velocity

V_{f2} = Exit flow velocity

3.4 Design Calculations

3.4.1 Determination of Thickness of Sheet of Metal for Tank

Initial Data	Calculations and Sketches	Result
P = 10.7 KN/m^2 D = 0.360 m $\sigma_\theta = 0.5 MN/m^2$	From equation (3.3) $t = \frac{PD}{6\sigma_\theta} = \frac{10700\, x 0.360}{6 x 0.5 x 10^6}$ = 0.00129 m = 1.29 mm	t = 1.3 mm

3.4.2 Determination of Impeller Blade Angles

	From equation (3.8)	
$\eta_H = 0.9$ (assumed efficiency)	$\beta_1 = Tan^{-1}\left[\frac{V_i}{V_b}\right] = Tan^{-1}\left[\frac{1.54}{3.14}\right]$	$\beta_1 = 26.1°$
$\upsilon_b = 3.14 m/s$ (blade velocity) $\upsilon_b = \upsilon_{f2}$ (for axial flow)	$\beta_1 = 26.1°$ From equation (3.9)	
g =9.8m/s H = 0.750m (Total head)	$\beta_2 = Tan^{-1}\left[\frac{V_b\, x V_{f2}}{V^2{}_b - \frac{gH}{\eta_H}}\right]$	
	$= Tan^{-1}\left[\frac{3.14\, x 3.14}{3.14^2 - \left[\frac{9.81 x 0.75}{0.9}\right]}\right]$	$\beta_2 = 6.9°$

3.4.3 Determination of Power Required from Electric Motor

$\eta_o = 75\% = 0.75$ $\rho = 1000\, kg/m^2$ g = 9.81 m/S^2 H = 0.75 m Q = 0.4758 m^2	From equation (3.7) $Pe = \frac{\rho g H Q}{\eta_o}$ $= \frac{1000\, x 9.81 x 0.75\, x 0.04768}{0.75}$ = 466.76W	$Pe = 466.76W$ $Pe \approx 0.5 kW$

3.4.4 Determination of Impeller Shaft Diameter

K$_t$ = 1.0 M$_t$ = 4.74 Nm S$_S$ = 55 MN/m^2 K = 0.75	From equation (3.4) $do = \left[\frac{(16 k_1 M_1)}{\pi S_S (1 - K^4)} \right]^{1/3}$ $= \left[\frac{16\, x 1.0\, x 4.74}{3.15\, x 55\, x 10^6 (1 - 0.75^4)} \right]^{1/3}$ = 14.30 mm	d$_o$ = 14.30 mm

3.4.5 Determination of Number of Impeller Blade

R$_o$=0.100 m R$_i$ = 0.025 m $\beta_1 = 19.7^\circ$ $\beta_2 = 24.7^\circ$	From equation (3.5) $Z = 6.5 \frac{(R_o + R_i)}{(R_o - R_i)}^{Sm \beta_m}$ $= \left[\frac{6.5 x 0.125}{0.075} \right]^{Sm\, 22.2}$ = 4.007	Z = 4 (minimum)

3.4.6 Determination of Impeller Blade Velocity

N=300 rpm (max motor speed) R_m= 0.1 m (mean radius of blade)	From Sopirinye (2006) $$\upsilon_b = \frac{2\ \pi N R m}{60}$$ $$= \frac{2 \text{ x } 3.14 \text{ x } 300 \text{ x } 0.1}{60}$$	υ_b = blade velocity = 3.14 m/s

3.5 Selection of Materials

The following major factors were considered in addition to the various dimensions obtained in the calculations above, in selecting various materials for the development of the agitated quenching bath:

(i) Availability

(ii) Durability

(iii) Cost

(iv) Flexibility in fabrication

(v) Ease of maintenance

3.5.1 Materials for Quenching Bath

The quenching bath which is rectangular in section was made from 2mm thick galvanized steel. Galvanised steel was chosen against stainless steel because of its low cost and good corrosion resistance properties. Galvanised steel as major material in the construction of the quenching tank has the following properties:

(i) Density = 7800 kg/m^3

(ii) Poisson’s ratio = 0.29

(iii) Modulus of Rigidity, ‘G’ = 80 GN/m^2

(iv) Modulus of Elasticity, E = 207 GN/m^2

(v) Roughness, K = 0.15 mm

3.5.2 Materials for Frames and Supports

The tank frame, the tank supports and electric motor supports were made from 25 mm (3 mm thick) angle iron, having calculated the thickness of the tank body to be 1.3 mm. Mild steel angle iron was selected because of its hardness and toughness properties so as to carry the entire load of the quenching machine without failure.

3.5.3 Electric Motor and Regulator

An electric motor with low speed (single phase 220V/AC/400W) was selected for the purpose of this project. The selection of this low speed motor (standard) was based on the fact that high speed may cause the entire quenchant to spill out of the tank due to turbulence (Fontecchio, Manirruzzaman and Sisson 2009). Also it has advantage of low power consumption of 400W and low cost as it is sourced from a domestic electric fan.

The motor regulator (electric voltage variable type) was selected so as to provide four different motor speeds [150 rpm (speed I), 200 rpm (speed II), 250 rpm (speed III) and 300 rpm (speed IV) all at 220V/50Hz] for the purpose of having four different agitation speeds. It is also a standard equipment of low cost and high durability.

3.5.4 Impeller Shaft and Blades

The impeller shaft used is a standard part/component of 16 mm diameter. It is made from mild steel and selected for the purpose of this project to provide smooth transmission between the electric motor and impeller blades with minimum vibration as it has vibration absorption effect.

The impeller is also a standard material made from aluminium. It has six blades of 200 mm outside diameter. It was selected because of its low weight, low cost and resistance to corrosion.

3.5.5 Bearings and Rollers

The bearings selected are of the ball type and of 16 mm bore. They are standard equipment and are used in the project to provide support to the impeller shaft in order to avoid wobbling during operation. The rollers are standard parts selected to provide free movement of the entire quenching machine with reduced friction.

3.6 Fabrication Process

S/NO	COMPONENT	MATERIAL	PROCESSS DESCRIPTION	EQUIPMENT USED
1	Tank Frame (refer to drawing No.10)	3 mm thick 25 mm angle iron of 6 m length	The 6 m longs angle iron was cut into 12 pieces: - 4no. of 480 mm, 4no. of 430 mm and 4no. of 515 mm. These 12 pieces were joined together by welding to form a cuboid frame (480 mm x 430 mm x 515 mm)	* Scriber * Measuring tape * Electric cutting machine * Bench vice * Electric arc welding machine * Gauge 12 electric welding electrodes
2	Quenching Tank (refer to drawing No.2)	2 mm thick sheet of galvanised steel	Two (2) pieces of 515 mm x 430 mm were cut from the sheet to form 2no. sides of the tank. Also 2no. pieces of 515 mm x 480 mm and 2no. pieces of 430 mm x 480 mm were also cut from the remaining sheet to form the other 4 no. sides of the tank. Five of these parts were formed together by welding to form the tank including the base. The other part of 515 mm x 430 mm was cut into two with a hole drilled at its centre (40 mm) to form the tank top cover.	* Scriber * Measuring tape * Electric cutting machine * Drilling machine and 40 mm drill. * Electric arc welding machine * Gauge 12 electric welding electrodes
3	Tank in its Frame (refer to drawing No.1)	Tank frame and Tank	The tank was positioned in its frame and then joined by welding to form a single component	* Electric arc welding Machine * Gauge 12 electric welding electrodes
4	Electric motor regulator housing (refer to drawing No.10)	3 mm thick 25 mm angle iron of 6 mm length	2no. pieces of 480 mm and 2no. pieces of 200 mm were cut from the 6 mm long angle iron. The first two were joined with other two to form a rectangular structure with two of its ends projected out and then welded to the tank frame at its top.	* Scriber * Measuring tape * Electric cutting machine * Electric arc welding machine * Gauge 12 electric welding electrodes * Bench vice

5	Electric motor and shaft Support (refer to drawing No. 5 and 6)	3 mm thick 25 mm angle iron of 6 m length	Two (2) pieces of 400 mm length were cut from the 6 m long angle iron and then welded to 2no. tank frame members and their upper parts welded to the electric motor housing. Another short piece of 230 mm was also cut from the remaining length of the angle iron and then welded at the opposite side of the other 2 members to the motor housing and to the centre of the motor regulator frame. Hence the 3no. members welded formed the electric motor and shaft support.	* Scriber * Measuring tape * Electric cutting machine * Bench vice * Electric arc welding machine * Gauge 12 electric welding electrodes
6	Tank base Stand (refer to drawing No.3)	3 mm thick 25 mm x 25 mm angle iron of 3 m length	4 no. pieces of 400 mm were cut from the 3 m long angle iron. These 4no. pieces were welded to the bottom of the tank frame thereby forming 4 no. legs stand	* Scriber * Bench vice * Measuring tape * Electric arc welded machine * Gauge 12 electric welding electrodes
7	Wire mesh (refer to drawing No.4)	* Wire mesh of 6 mm thickness and 480 mm x 520 mm and * 1.2 m length of wire strap with thickness of 5 mm	The 480 mm x 520 mm wire mesh was trimmed so as to fit into the quenching bath and suspended 110 mm from its bottom by 4no. wire straps of 340 mm length each.	* Measuring tape * Electric cutting machine * Plier
8	Drain tap Assembly (refer to drawing No. 8)	12 mm plastic tap (standard) with rubber washer and plastic screw	The one end bottom of the tank was drilled to 14 mm wide and the plastic tap was inserted. The plastic screw and the rubber washer were then inserted and screwed to the tap from the inner side of the tank to make a fluid tight coupling	* Shifting spanner * 14 mm drill * Electric drilling Machine *Measuring tape

9	Electric motor, centre bearings, impeller shaft and impeller blade assembly (refer to drawing No.1)	* 400 w (100 mm x 120 mm) Electric Motor * 2no. 16 mm roller bearings * 16 mm diameter 600 mm length shaft * 200 mm diameter with 6no. blades impeller *4nos. 5 mm screws * 2nos. 3 mm screws * 2nos. mild steel standard brackets 100 mm x 10 mm) with holes at both ends.	The 600 mm shaft is a standard material with holes at both ends. The electric motor output shaft was inserted in the impeller shaft at one end and then screwed for maximum tightening. The 2no. bearings were inserted into the shaft and rolled up to a distance of 100mm to the electric motor. They are then welded together to each other and also welded to the bracket holding the electric motor to form a rigid coupling. The other end of the impeller shaft was then inserted inside the impeller blade shaft and then screwed for maximum tightness. The whole assembly was then carried into the quenching bath and the electric motor was positioned into its support and 2nos. iron brackets were used to hold the whole assembly by the use of 4nos. screws screwed to maximum tightness.	* Screw driver * Electric welding machine * Gauge 12 welding Electrodes
10	Electric motor speed regulator (refer to drawing No.1)	* 1no. standard regulator (60 mm x 60 mm x 25 mm) * 4 m length of 2 mm^2 flexible electric cable. * 1no. roll of black insulating tape	The speed regulator was welded to its support and then connected to both the mains plug and the electric motor using the 2 mm^2 electric wire. Joints were taped using the black tape to provide maximum insulation.	* Measuring tape * Electric welding Machine * Gauge 12 electric welding electrodes * Screw driver
11	Tank stand rolling assembly (refer to drawing No. 9)	* 4nos. metallic (standard) rollers	The 4nos. metallic rollers were welded to each of the 4no. stand legs of the quenching bath	* Electric welding machine * Gauge 12 welding Electrodes

3.6.1 Pictorial representation of the Developed Agitation Quenching Bath

After fabricating the quenching bath assembly, various pictures of different views of it were taken and are placed below:

Plate 3.1: Picture of completed quenching bath assembly showing its overall view.

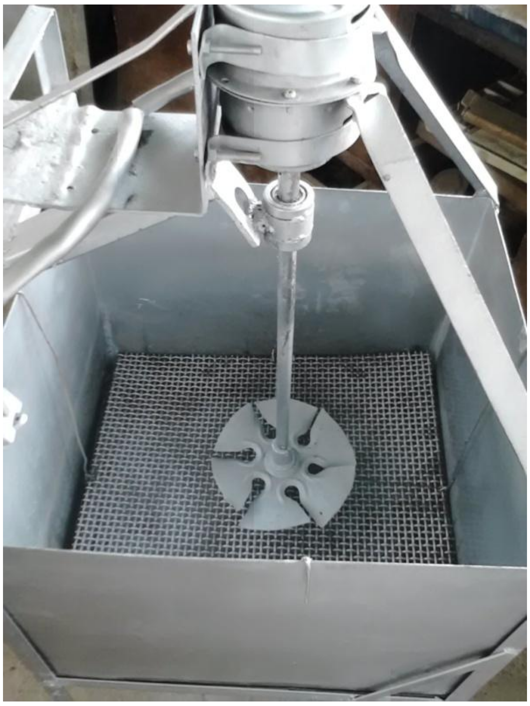

Plate 3.2: Picture of plan view of the quenching bath showing the impeller blades and the suspended wire mesh.

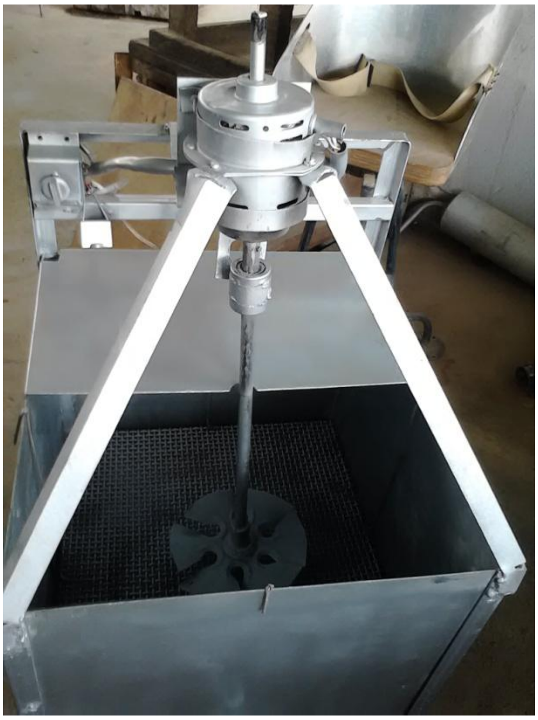

Plate 3.3: Picture of a full view of electric motor and its support with its regulator on the top side of the quenching bath.

Plate 3.4: Picture of completed quenching bath assembly showing its overall view without its top cover.

3.7 Cost Analysis

The total cost incurred during the construction process of the quenching machine is shown below:

S/N	Material Description	Quantity	Price per Unit (₦)	Total Price (₦)
1	Angle iron 25 mm (3 mm thick)	2	1,000	2,000
2	Galvanized steel sheet (2 mm thick)	1	7,500	7,500
3	Wire mesh	1	500	500
4	16 mm diameter shaft	1	1,000	1,000
5	Hp Electric motor	1	5,000	5,000
6	4-speed electric motor control	1	1,000	1,000
7	Electric wire (flexible)	2 yards	150	300
8	Centre bearing (16 mm) including handling	2	600	1,200
9	Total construction, labour, cost including welding and cutting	-	-	10,000
10	Total painting cost	-	-	4,500
11	Tank Rollers	4 No.	250	1,000
	Total construction Cost	-	-	**₦34,000:00**

CHAPTER FOUR

4.0 EXPERIMENTAL METHOD, RESULTS, DISCUSSION AND PERFORMANCE EVALUATION OF THE DEVELOPED AGITATED QUENCHING BATH

4.1 Experimental Method

4.1.1 Materials

The major materials used during the performance evaluation experiment include: medium carbon steel, ductile cast iron. Other materials used include: abrasive grinding papers, polishing cloth, nital (solution of nitric acid in alcohol) and cotton wool.

4.1.2 Equipment

The following items of equipment were used during the performance evaluation process: electric muffle furnace, hardness testing machine, impact testing machine, universal tensile testing machine, optical metallurgical microscope, and galvanized iron buckets, and the fabricated agitated bath.

4.2 Experimental Procedures

4.2.1 Machining of Test Samples

The medium carbon steel and ductile cast iron were cut and machined to the required standard sample sizes and shapes for:

i. Tensile test

ii. Impact test

iii. Hardness and microstructural tests

4.2.2 Heat Treatment Operations

a) From the standard test samples that were machined, two samples of tensile, impact, and hardness samples were taken from the medium carbon steel and kept aside to serve as untreated or as-received to serve as a control group. The same set was done to the ductile cast iron samples.

b) Normalizing Heat Treatment: After keeping aside some controlled samples and kept aside in as described in (a) above, all the remaining samples were normalized by heating them in the furnace to 900 °C, soaking them for 30 minutes, removing and cooling them in air. The aim of this was to refine the grains and condition the specimen by subsequent quenching.

c) Quenching in Un-agitated and in Agitated Bath

   i. A galvanized iron bucket was filled with tap water at room temperature to serve as un-agitated quenching bath. From the heated samples in the furnace (at 900 °C) a set of samples arranged in a crucible (containing 2 samples each of tensile, hardness and impact specimen) was removed and quenched in the un-agitated water in the bucket.

   ii. Quenching in Agitated Bath: The fabricated agitated bath with four speeds was filled with tap water at room temperature. It was set to the 1st speed of agitation (as explained in section 3.4.3), samples of medium carbon steel (two samples each for tensile, impact and hardness) arranged in the furnace at 900 °C were removed and quenched in the fabricated agitated bath at speed I. This quenching operation was also done on the ductile cast iron samples.

The same process was repeated by adjusting the fabricated agitated bath to speeds II, III and IV respectively. After the quenching process, all the samples (mild steel and ductile cast iron) in the different treatment conditions were taken and subjected to the following tests.

4.3 Mechanical Properties Test

4.3.1 Tensile Properties Test

All the tensile test samples (both in the untreated, normalized and quenched condition) were taken set by set and subjected to tensile tests using the universal tensile testing machine with two samples for each treatment condition.

During the process of the tensile test the initial gauge length (Lo) and initial diameter of the same sample were measured. The test sample was then fixed securely in the specimen holder and stressed till fracture occurred.

4.3.2 Hardness Test

Hardness tests were carried out on all the samples of medium carbon steel and ductile cast iron involved in the investigation using the Brinell hardness testing machine. The prepared surfaces of the samples were ensured to be flat to enable the samples sit flat on the stage of the hardness testing machine. Each sample for hardness test was prepared by grinding and polishing to obtain a smooth surface finish.

4.3.3 Impact Test

Standard notched impact test samples of medium carbon steel and ductile cast iron (in the as-received condition and heat treated condition) were tested at room temperature in a standard impact testing machine. The test involved releasing the pendulum in order to zero the scale. The sample was then gripped horizontally in a vice, the force required to break the bar was released from the pendulum, and the blow was applied by freely swinging the pendulum of the machine through an angle. This angle had a corresponding value as the energy absorbed in the sample; the impact value was then taken from a calibrated scale.

4.3.4 Preparation of Samples for Microstructural Examination

All the samples of medium carbon steel and ductile cast iron in both the as-received and heat treated condition were subjected to microstructural examination. The samples were prepared by using standard metallographic techniques by first grinding using rough silicon carbide abrasive papers (60 – 180 grits), followed by fine machine grinding using 240 – 600 grit abrasive papers. The ground samples were then subjected to polishing to obtain a mirror surface finish. The samples were then etched using 2% nital solution (2% nitric acid in ethanol). The etched samples were then placed one by one on the optical metallurgical microscope whereby the microstructure were viewed, taken and printed.

4.4 Results

Medium carbon steel and ductile cast iron test samples were used to test the performance of the fabricated agitated quenching bath. The results obtained are shown in Tables 4.1 to 4.6, and Figures 4.1 to 4.4 with their respective titles. The microstructures are shown on Plates 4.1 to 4.12.

Table 4.1: Chemical composition of medium carbon steel and ductile cast iron samples.

Elements Materials	%C	%Si	%Mn	%P	%S	%Mg	Cr	Ni	%Fe
Medium Carb Steel	0.57	0.31	0.93	0.02	0.01	-	0.33	0.03	97.80
Ductile Cast Iron	3.82	2.71	0.25	0.06	0.04	0.0	-	-	93.12

Table 4.2: Mechanical Properties of as-received condition of medium carbon steel and ductile cast iron.

Mech. properties Sample Court	Hardness (HBN)	Tensile strength (N/mm^2)	Elongation (%)	Reduction (%)	Impact strength (J)
Medium Carb St	220	903	15	38	32
Ductile Cast Iron	252	510	5	7	24

Table 4.3: Mechanical properties of normalized medium carbon steel and ductile cast iron.

Mech. Properties Sample Court	Hardness (HBN)	Tensile strength (N/mm^2)	Elongation (%)	Reduction (%)	Impact strength (J)
Medium Carb St	231	912	14	37	36
Ductile Cast Iron	263	518	0	0	27

Table 4.4: Mechanical properties of medium carbon steel and ductile cast iron quenched in un-agitated water bath.

Mech. Properties Material	Hardness (HBN)	Tensile strength (N/mm^2)	Elongation (%)	Reduction (%)	Impact strength (J)
Medium Carb St	520	985	12	25	17
Ductile Cast Iron	565	681	0	0	11

Table 4.5: Mechanical properties of medium carbon steel quenched in the fabricated agitated water bath at various speeds.

Mech. Properties / Speed	Hardness (HBN)	Tensile strength (N/mm^2)	Elongation (%)	Reduction (%)	Impact strength (J)
I (150rpm)	542	1100	11	22	15
II (200rpm)	580	1140	10	20	12
III (250rpm)	621	1161	9	15	6
IV (300rpm)	621	1160	9	15	4
Un-agitated bath	520	985	12	25	17

Table 4.6: Mechanical properties of ductile cast iron quenched in the fabricated agitated water bath at various speeds.

Mech. Properties / Speed	Hardness (HBN)	Tensile strength (N/mm^2)	Elongation (%)	Reduction (%)	Impact strength (J)
I (150rpm)	581	765	0	0	6
II (200rpm)	625	860	0	0	4
III (250rpm)	660	902	0	0	3
IV (300rpm)	662	903	0	0	3
Un-agitated bath	565	681	0	0	11

4.5 Discussion

4.5.1 Effect of Normalizing on the Mechanical Properties and Microstructures of Medium Carbon Steel and Ductile Cast Iron

The chemical composition of the two ferrous alloys used are shown in Table 4.1, while Table 4.2 shows the mechanical properties of the two alloys in the as – received condition. The microstructures of the as received are shown in Plate 4.1 and 4.2. The as - received samples were normalized before quenching; the normalized properties are as shown in Table 4.3. It is seen that normalizing treatment has caused increase in hardness and tensile strength respectively. The microstructure is also refined (changed as shown in plate 4.3 and 4.4).

4.5.2 Effect of Quenching in Still Water (un-agitated bath) on the Mechanical Properties

Table 4.4 shows the mechanical properties of medium carbon steel and ductile cast iron heated to 900°C and quenched in water in un-agitated condition. The results show that hardness, tensile strength and impact strength have increased from the normalized condition to higher values. For instance, the hardness of medium carbon steel and ductile cast iron increased from 231 and 263 HBN in the normalized condition to 552 and 565 HBN respectively in the water quenched condition. The increase in hardness is due to the formation of martensite structure in the metal samples. The corresponding microstructures are shown in plates 4.5 and 4.6.

4.5.3 Effect of Quenching in the Agitated Bath using Different Agitation Speeds

Table 4.5 shows the values of mechanical properties of medium carbon steel samples quenched in various speeds (un-agitated, speed 150 rpm, 200 rpm, 250 rpm and 300 rpm respectively). Table 4.6 also shows the values of mechanical properties of ductile cast iron quenched under similar agitation speeds. Generally, it is seen that the tensile strength and hardness of the quenched samples increase as the speed of agitation increases up to 250 rpm then remain almost constant at 300 rpm, indicating that an optimum speed of agitation to provide optimum value of the mechanical properties has been reached. However, the impact strength decreased as the agitation speed increased for the two alloys. For medium carbon steel, the percentage elongation and reduction in area are seen to decrease with increase in agitation speed. For ductile cast iron, no significant percent elongation was recorded during the test. This is because; cast iron generally is known to have poor tensile properties especially in terms of elongation and reduction in area due to the fact that no definite yielding occurs due to their brittle nature.

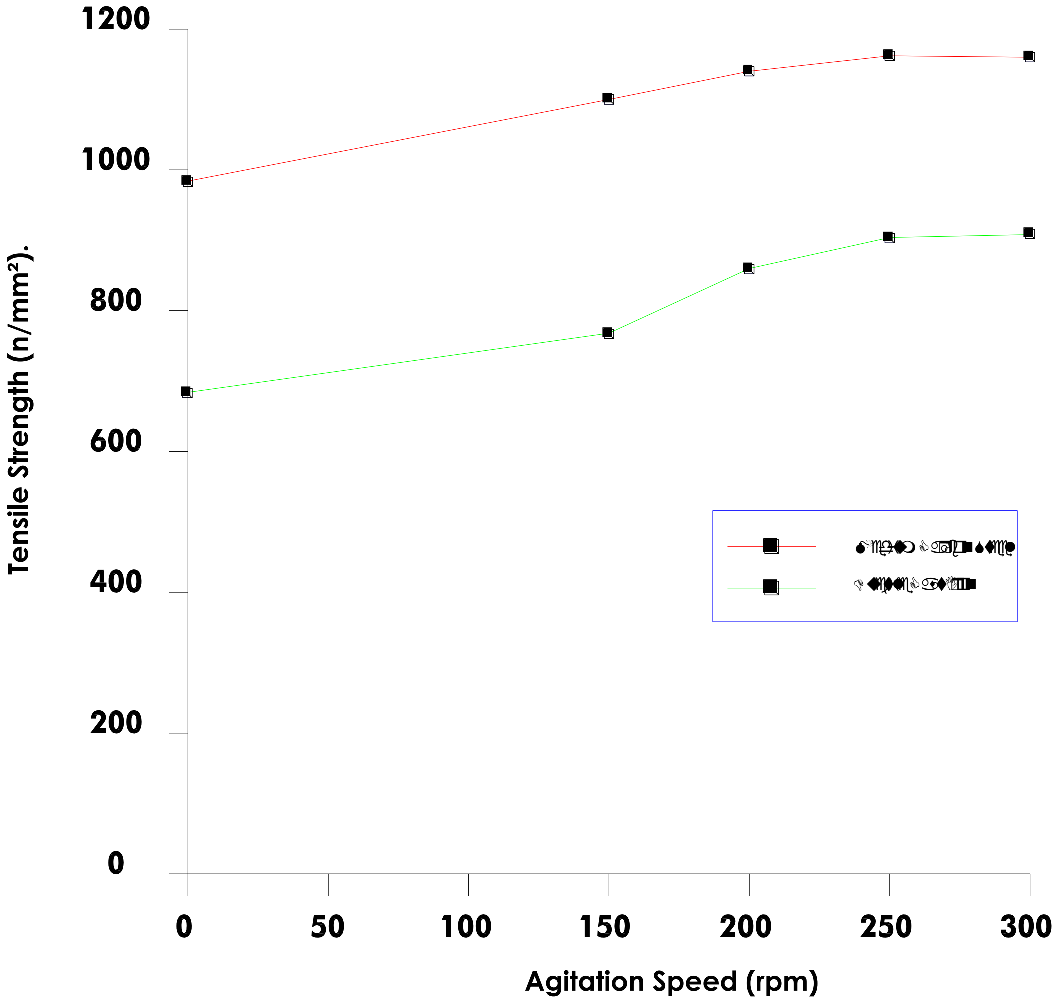

Figure. 4.1 Effect of Agitation Speed on Tensile Strength of Medium Carbon Steel and Ductile Cast Iron.

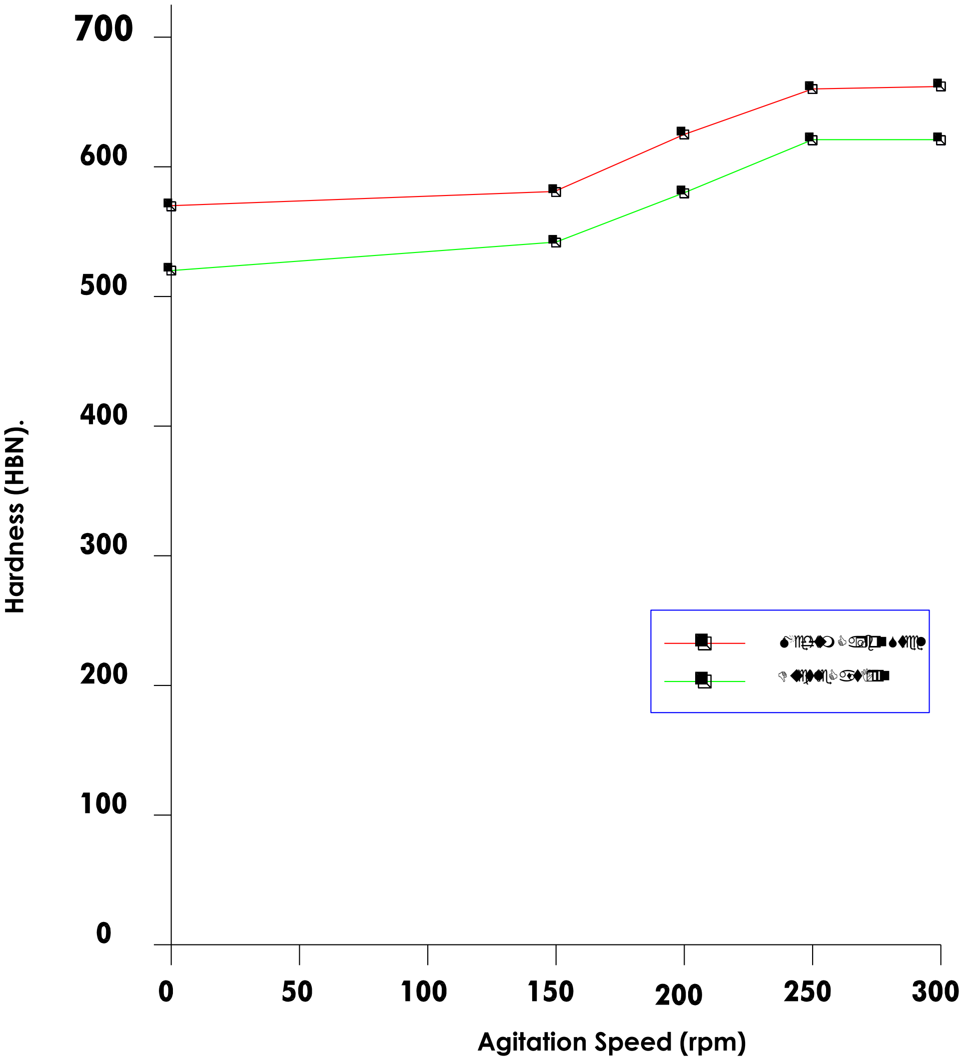

Figure. 4.2 Effect of Agitation Speed on Hardness of Medium Carbon Steel and Ductile Cast Iron.

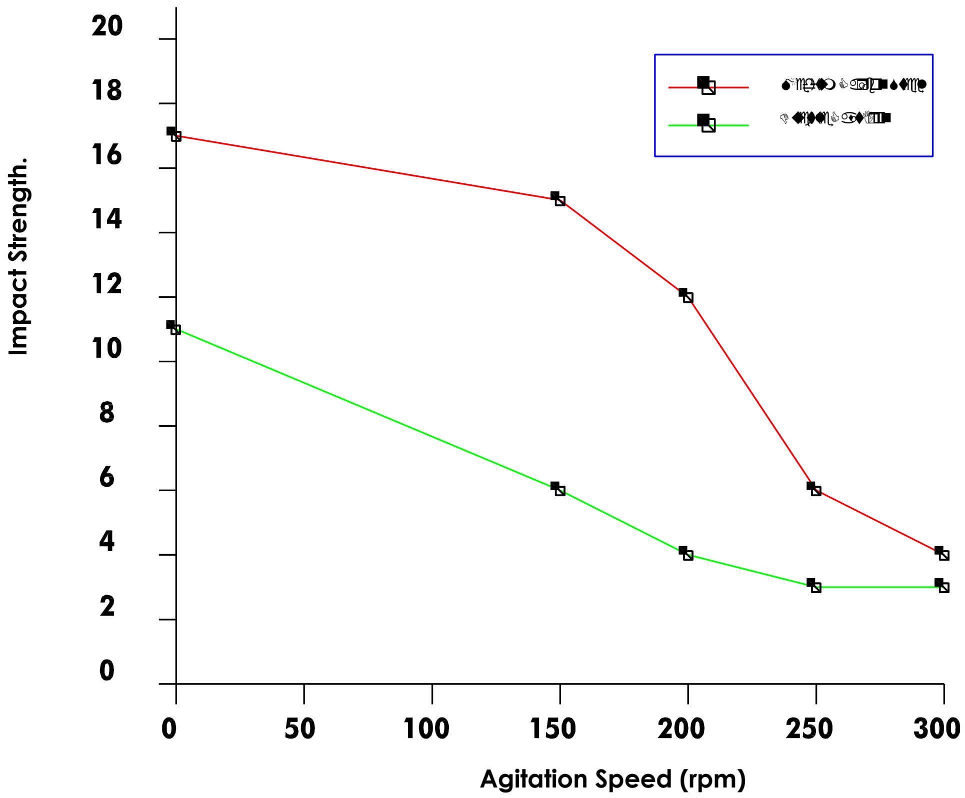

Figure. 4.3 Effect of Agitation Speed on Impact Strength of Medium Carbon Steel and Ductile Cast Iron.

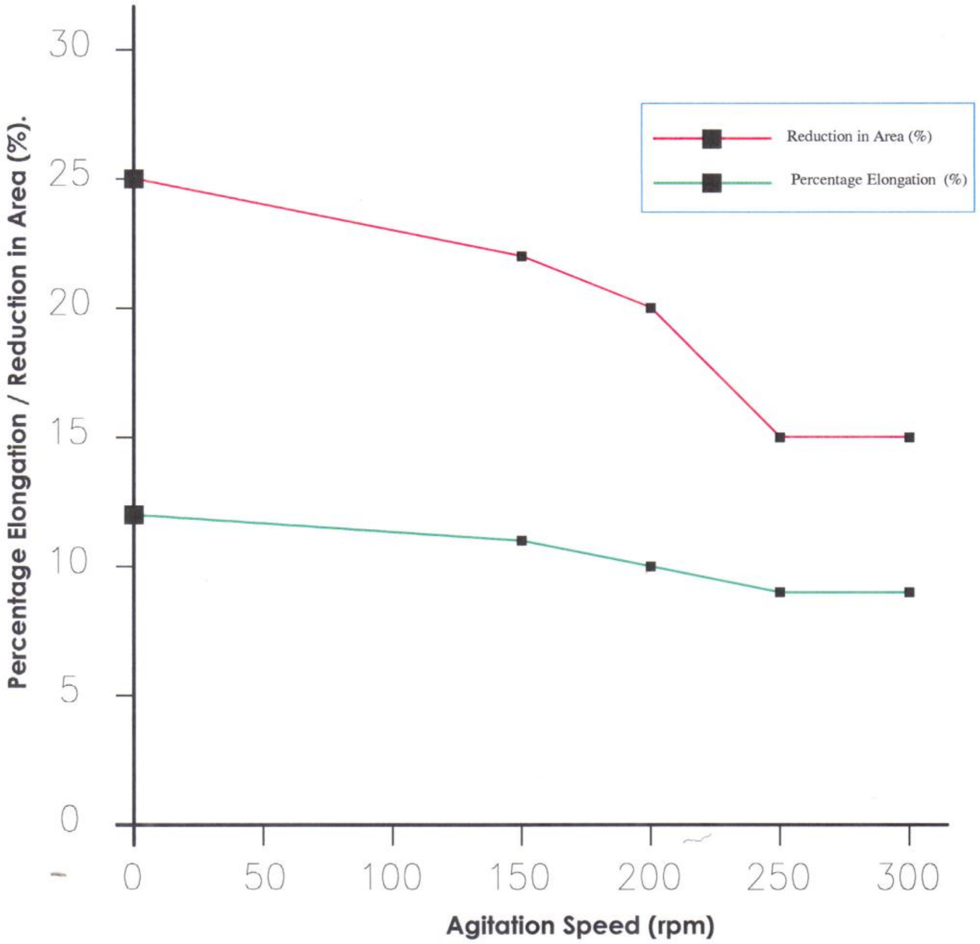

Figure. 4.4 Effect of Agitation Speed on the Percentage Elongation and Reduction in Area of Medium Carbon Steel.

Figure 4.1 shows the plot of tensile strength against speeds of agitation. It is seen that as the agitation speed increases from speed zero (un-agitated) to I, II, III and IV, the tensile strength for the two alloys increases, but at speed III and IV, the tensile strength remain constant. The increase in the tensile strength may be attributed to the hardening effect (quench hardening ability) of the agitated bath. The constant values obtained at speeds III and IV may probably mean that it is the maximum (peak) speed at which optimum hardening can be obtained.

Figure 4.2 shows a plot of hardness of the two alloys against agitation speed. It is also seen that, generally, the hardness increases as the agitation speed increases, reaches maximum at speed III and is almost constant at speed IV. However, at all the agitation speeds, ductile cast iron had higher hardness, this is due to the higher carbon content and high amount of cementite present in the cast iron. The increase in hardness as the agitation speed increases may also be attributed to formation of more martensite caused by the agitation process.

Figure 4.3 shows a plot of impact strength against agitation speed. It is seen that as the agitation speed increases, the impact strength decreases. This is because the formation of martensite in the alloys has made the two alloys to become hard, hence brittle. Here, ductile cast iron samples resulted to lower impact values than medium carbon steel.

Figure 4.4 shows a plot of percentage elongation and percentage reduction in area of medium carbon steel quenched at various agitation speeds. It is seen that, generally, the percentage elongation and reduction in area decreases as the agitation speed increases, this trend is also due the hardening effect of the quenching bath. It is also seen in Table 4.6 that for cast iron, there was no values recorded for percentage reduction in area and elongation. This is because cast iron is known to have poor tensile properties.

4.6 Microstructural Analysis

4.6.1 Microstructure of ductile cast iron at different agitation levels

Plate 4.1 shows the microstructure for the as-received condition while

plate 4.2 shows that of normalized condition. Plate 4.3 shows the microstructure of the un-agitated condition consisting of mixture of pearlite, graphite and martensite. Plate 4.4 shows the microstructure at agitation speed I with the mixture of graphite and martensite. Plate 4.5 shows the microstructure at agitation speed III with the mixture of more of martensite than graphite. Plate 4.6 shows the microstructure at agitation speed IV with mainly martensite which is responsible for the cracks seen due to the transformation and thermal stresses during its formation.

4.6.2 Microstructures of Ductile Cast Iron

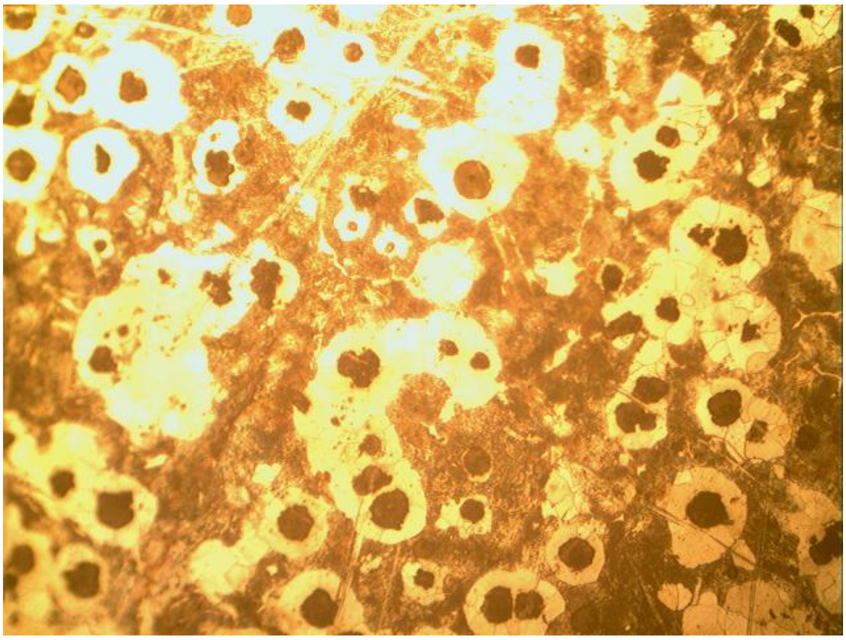

Plate 4.1: Microstructure of as-received ductile cast iron showing graphite nodules (black) surrounded by ferrite shell (white) in the matrix of pearlite. Etchart: 2% Nital. Mag x 200.

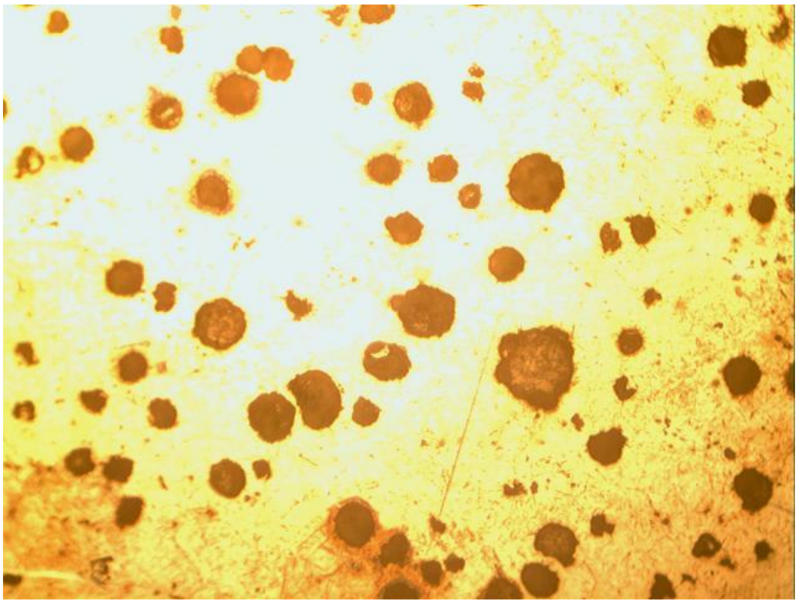

Plate 4.2: Microstructure of normalized ductile cast iron showing graphite nodules (black) in pearlite. Etchart: 2% Nital; Mag x 200.

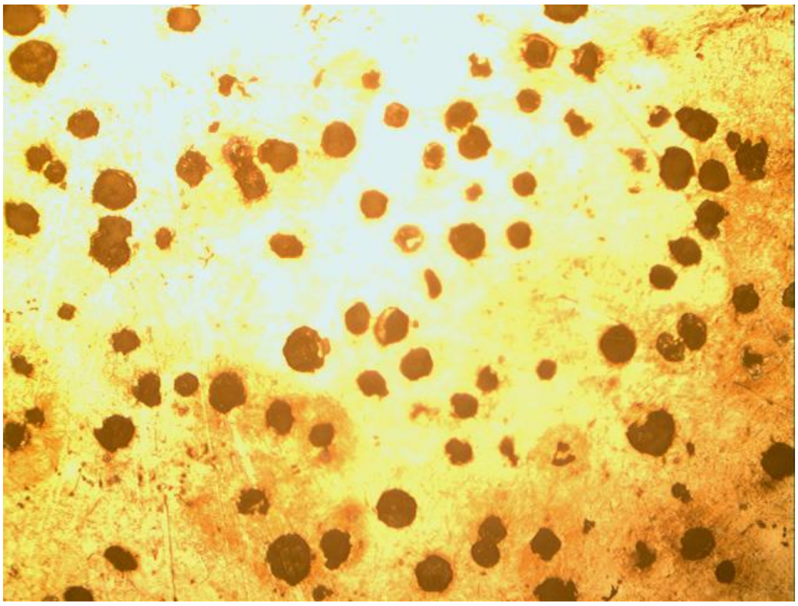

Plate 4.3: Microstructure of ductile cast iron quenched in un-agitated water showing black graphite nodules a mixture of martensite and pearlite. Etchart: 2%. Nital. Mag x 200.

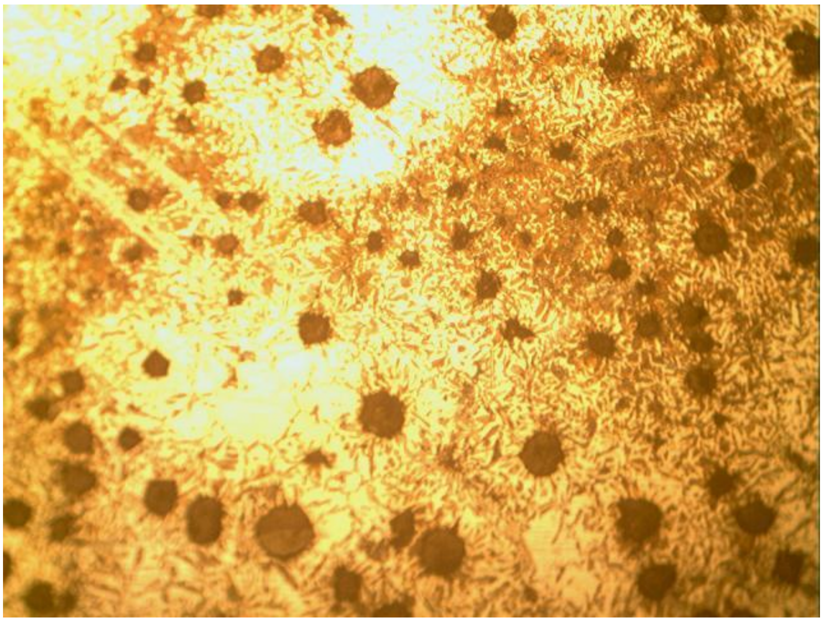

Plate 4.4: Microstructure of ductile cast iron quenched in agitated tank at speed I showing black graphite nodules in martensite . etchat: 2% Nital, Mag. x 200.

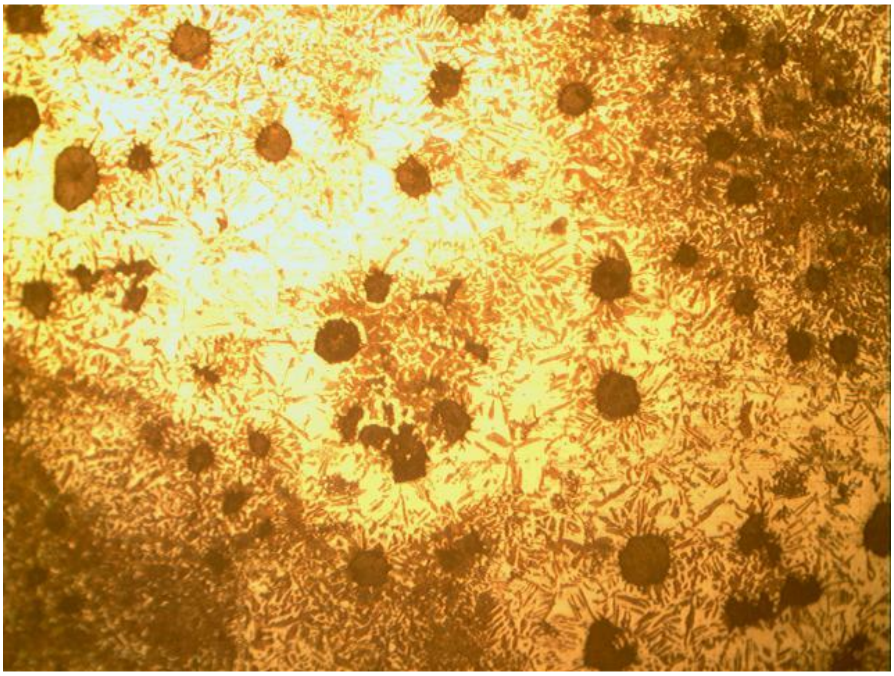

Plate 4.5: Microstructure of ductile cast iron quenched in agitated tank at speed III showing graphite nodules in martensite. Etchart; 2% Nital; Mag. x 200.

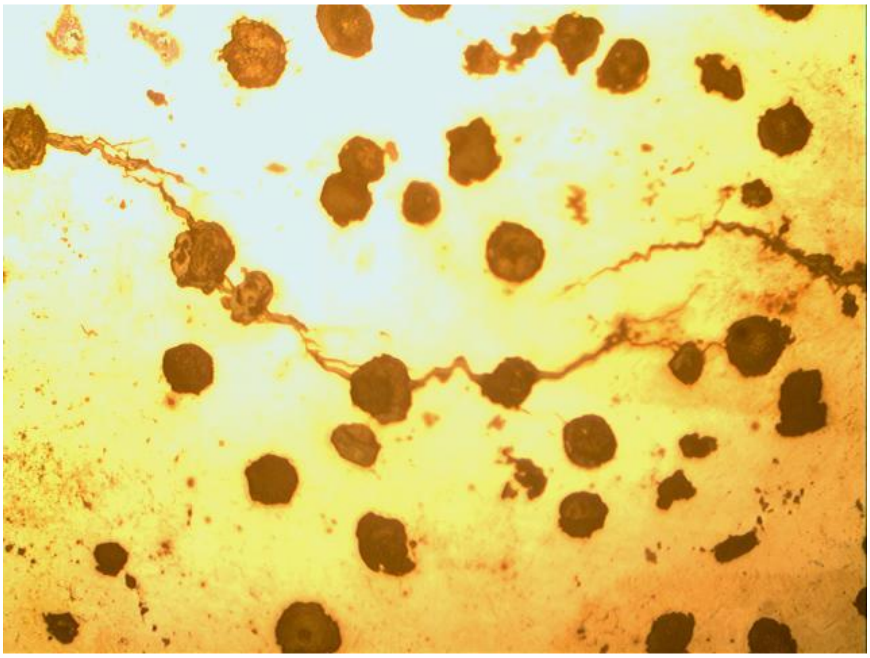

Plate 4.6: Microstructure of ductile cast iron quenched in agitated tank at speed IV showing graphite nodules (black and a crack in martensite structure. Etchart: 2% Nital; Mag. x 200.

4.6.3 Microstructure of medium carbon steel at different agitation levels.

Plate 4.7 shows the microstructure for the as-received condition while Plate 4.8 showed that of normalized condition. Plate 4.9 shows the microstructure of the un-agitated condition consisting of pearlite and martensite. Plate 4.10 shows the microstructure at agitation speed I (as explained in section 3.4.3) with mixture peartile and more martensite. Plate 4.11 shows the microstructure at agitation speed III with small quantity of pearlite and more of martensite. Plate 4.12 shows the microstructure at agitation speed IV with mainly martensite which is responsible for the cracks seen due to the transformation and thermal stresses during its formation.

4.6.4 Microstructures of Medium Carbon Steel

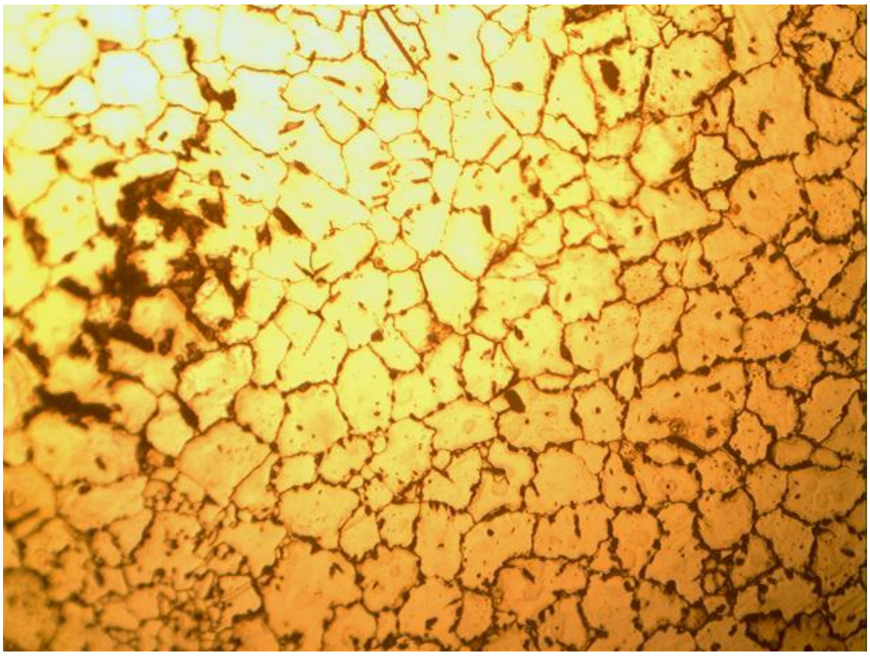

Plate 4.7: Microstructure of as-received medium carbon steel showing pearlite (black) in the matrix of ferrite used. Etchart: 2% Nital, Mag x 200

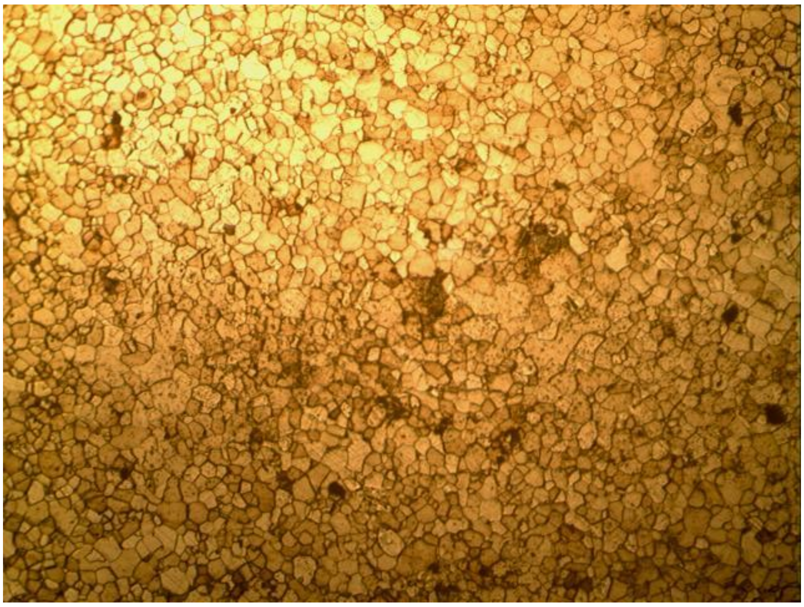

Plate 4.8: Microstructure of normalized medium carbon steel showing pearlite structure. Etchart: 2% Nital, Mag x 200.

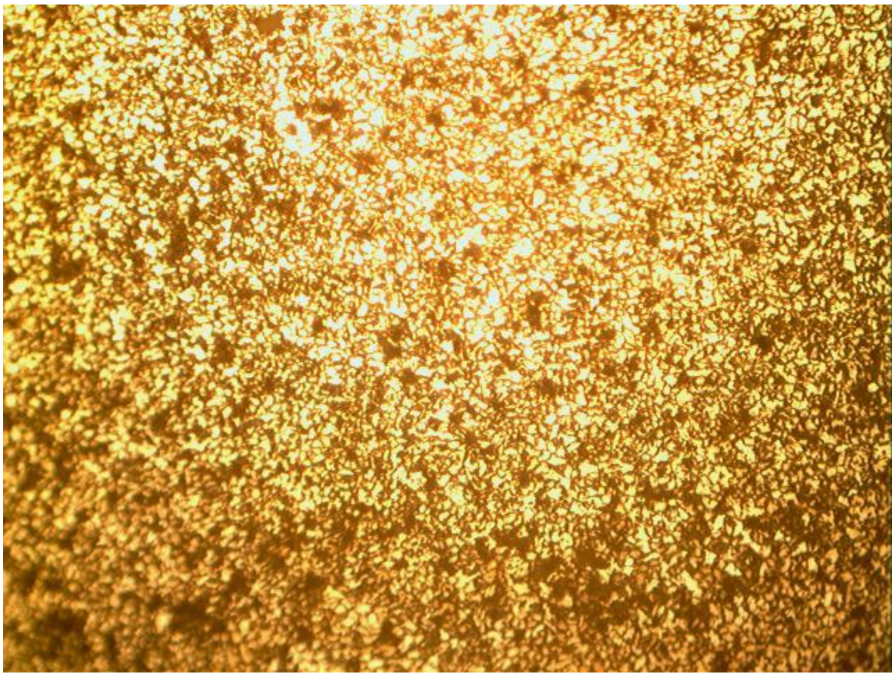

Plate 4.9: Microstructure of medium carbon steel quenched in un-agitated water showing a mixture of martensite and pearlite. Etchart: 2% Nital, Mag. x 200.

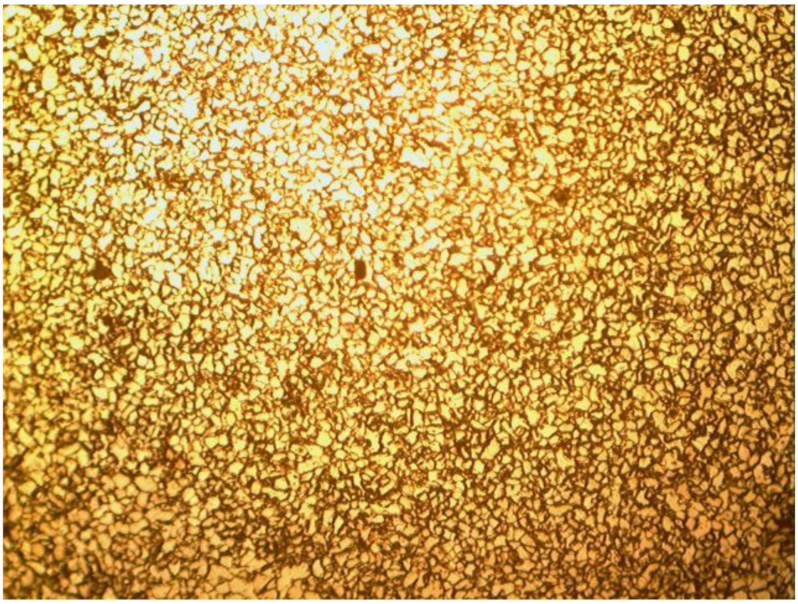

Plate 4.10: Microstructure of medium carbon steel quenched in agitated tank of speed I showing Martensite + Pearlite. Etchart: 2% Nital, Mag. x 200.

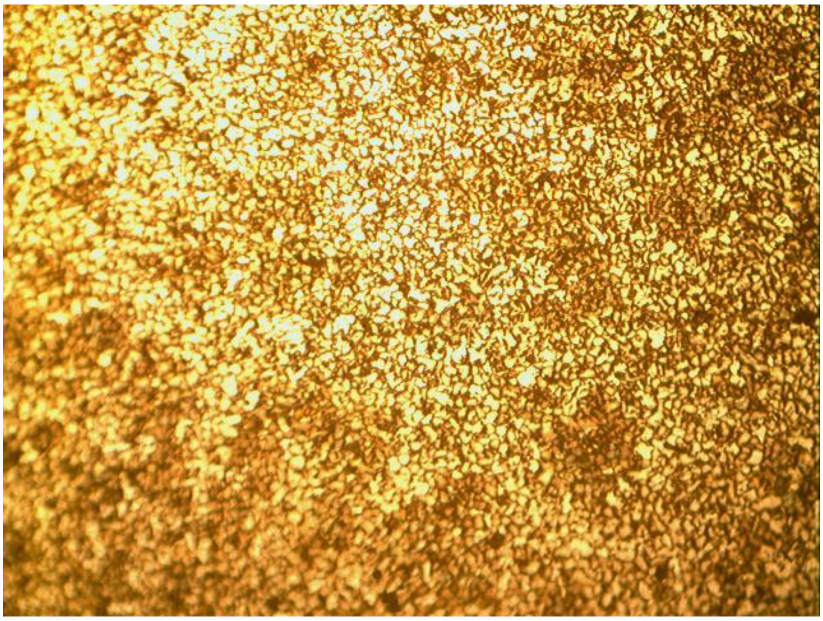

Plate 4.11: Microstructure of medium carbon steel quenched in agitated tank at speed III showing a mixture of martensite and pearlite. Etchart 2% Nital, Mag. x 200.

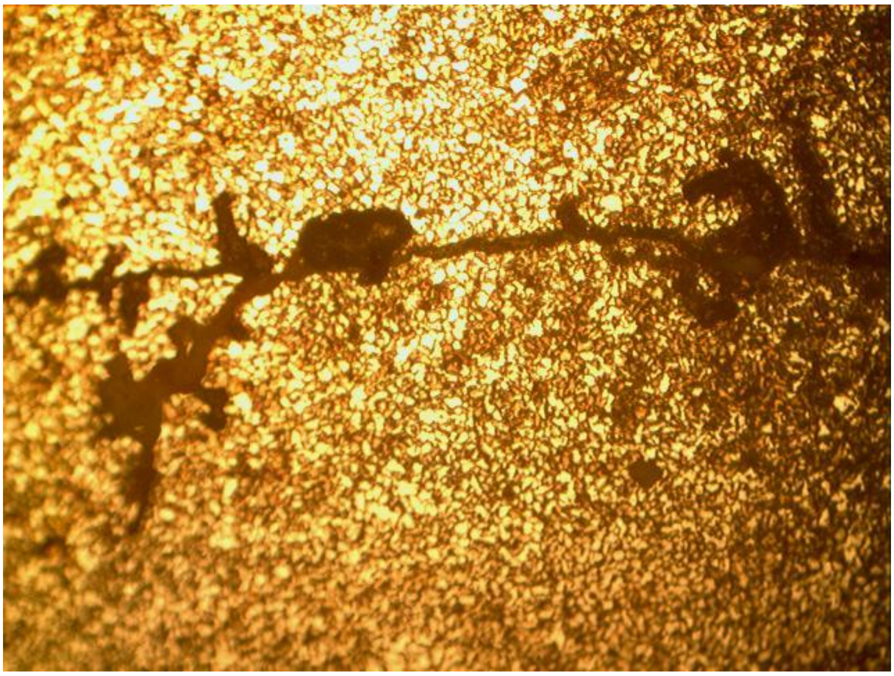

Plate 4.12: Microstructure of medium carbon steel quenched in agitated tank at speed IV showing a crack in martensite structure. Etchart; 2% Nital; Mag. x 200

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the results obtained from the performance, evaluation tests carried out on the fabricated agitated quenching tank, the following conclusions can be made:

1) The portable agitated quenching bath was designed, constructed and tested with medium carbon steel and ductile cast iron alloy samples for performances evaluation.
2) The effect of speed of agitation on hardness of the two different samples were determined as shown below:
    i) Quenching in the agitation bath resulted to increase of tensile strength of medium carbon steel and ductile cast iron. Tensile strength of medium carbon steel in the normalized condition (912 N/mm^2) increased to 1160 N/mm^2 at speed IV. While tensile strength of ductile cast iron in the normalized condition (263 N/mm^2) increased to 903 N/mm^2 at agitation speed IV.
    ii) Quenching in the agitated tank also resulted in increase in hardness whereby the hardness of medium carbon steel with the value of 231 HBN in the normalized condition was subsequently increased to 621 HBN at the agitation speed of IV (300 rpm), while the hardness of ductile cast iron in the same normalized condition was increased from 263 HBN to 662 HBN at the same agitation speed IV.
    iii) Quenching in the agitation bath resulted to a decrease in impact strength of medium carbon steel and ductile cast iron. Impact strength of

medium carbon steel in the normalised condition decreased from 36 J to 4J at the agitation speed of IV, while that of ductile cast iron decreased from 27 J to 3 J at the same agitation speed.

3) Agitation speed III (250 rpm) was the optimum speed to produce maximum increase in hardness.
4) The agitation tank proved to be effective for quench hardening heat treatment.
5) The fabricated agitation tank is suitable, and can be used for one of the industrial finishing operations called heat treatment – through quench hardening.

5.2 Recommendations

The fabricated agitated bath should be used by further researchers to further evaluate the quenching abilities of other quenching media like oils using various ferrous alloys.

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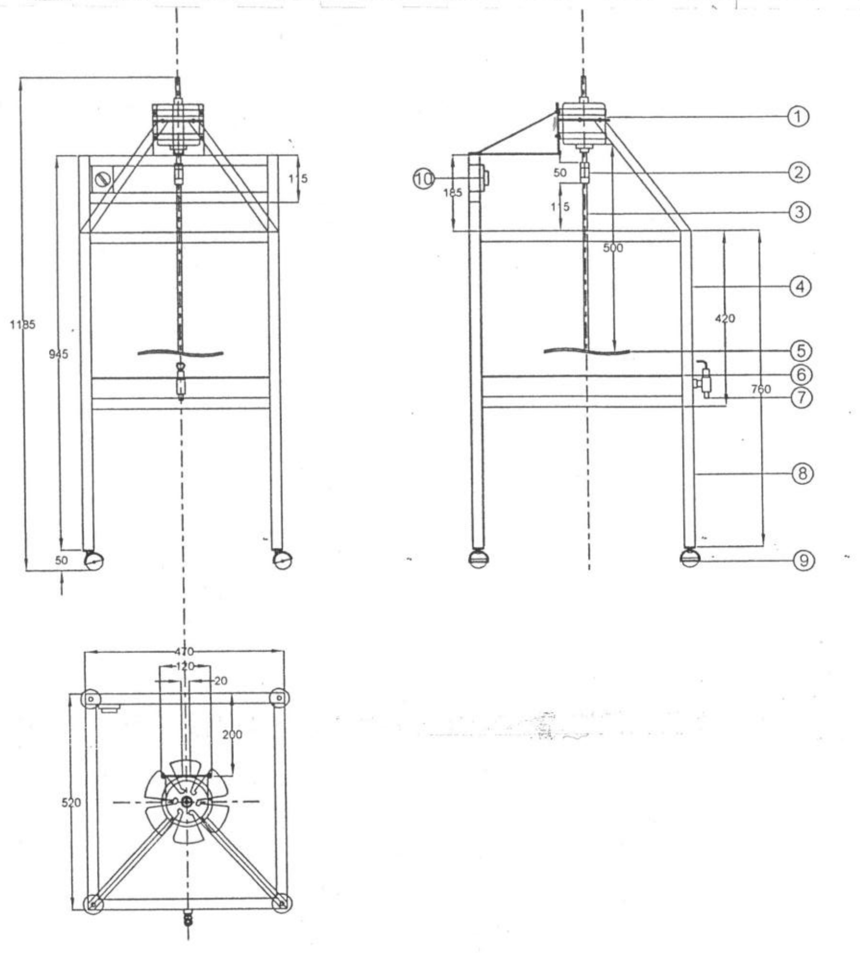

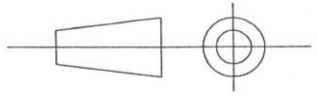

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9	STAND ROLLERS	4	STAINLESS STEEL/ROBBER	STANDARD
8	BASE STAND	1	MILD STEEL	CONSTRUCTED
7	DRAIN TAP	1	PLASTIC	STANDARD
6	WIRE MESH	1	MILD STEEL	CONSTRUCTED
5	IMPELLER BLADE	1	GALVANIZED SHEET	STANDARD
4	QUENCHING BATH	1	GALVANIZED SHEET	CONSTRUCTED
3	IMPELLER SHAFT	1	MILD STEEL	STANDARD
2	BALL BEARING	2	HARD CARBON STEEL	STANDARD
1	ELECTRIC MOTOR	1	-	STANDARD

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THE COMPLETE AGITATED QUENCHING BATH ASSEMBLY

	NAME	Signature	Date	
DRAWN	MAARAF ISYAKU			DRAWING NO: 01
CAD	MAARAF ISYAKU			SCALE: 1:15
CHECKED	DR. D. S. YAWAS			REG NO: MSC/ENG/9060/08-09
APPROVED	PRO. S. Y. AKU			

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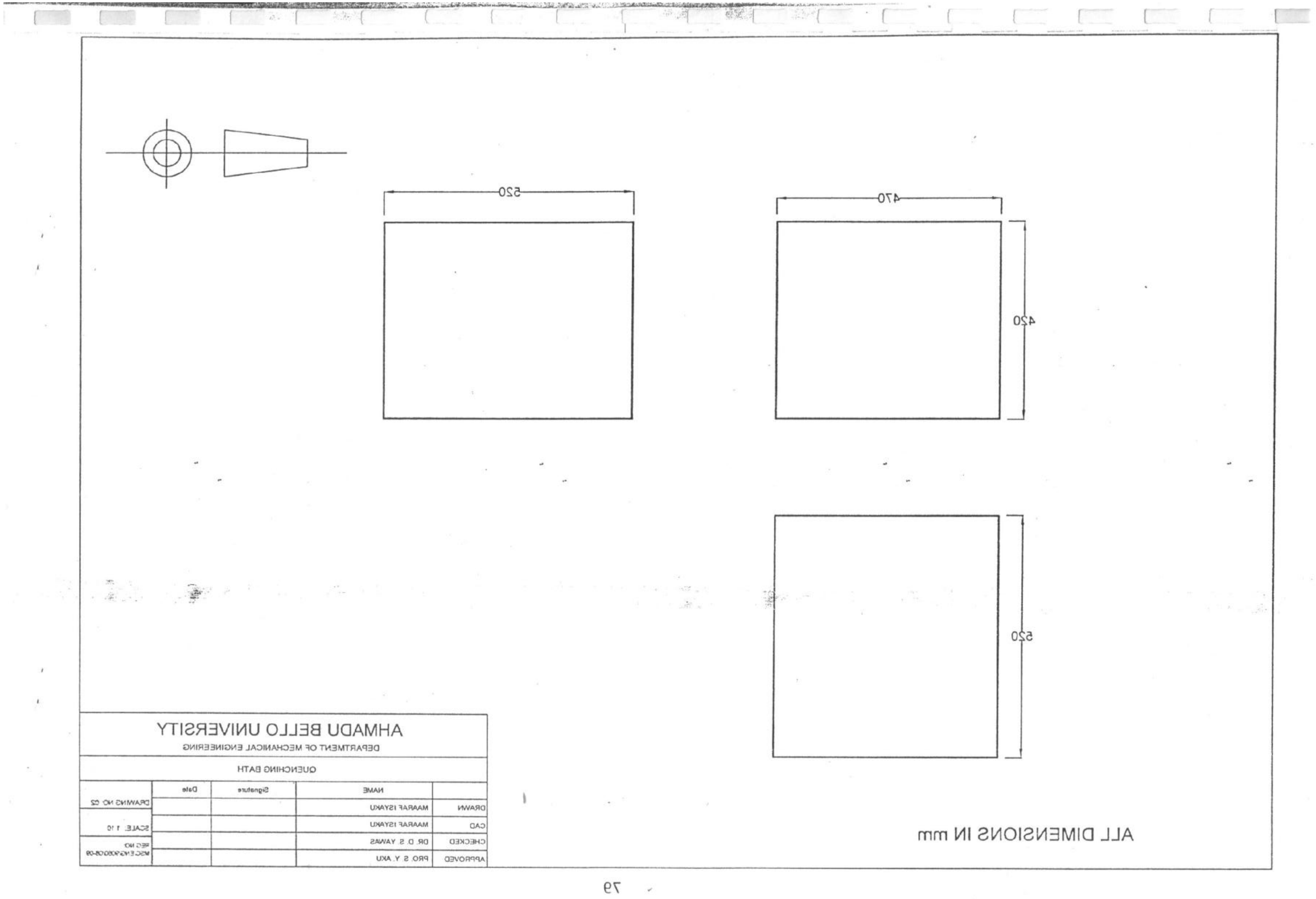
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DEPARTMENT OF MECHANICAL ENGINEERING
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MAARAF ISYAKU
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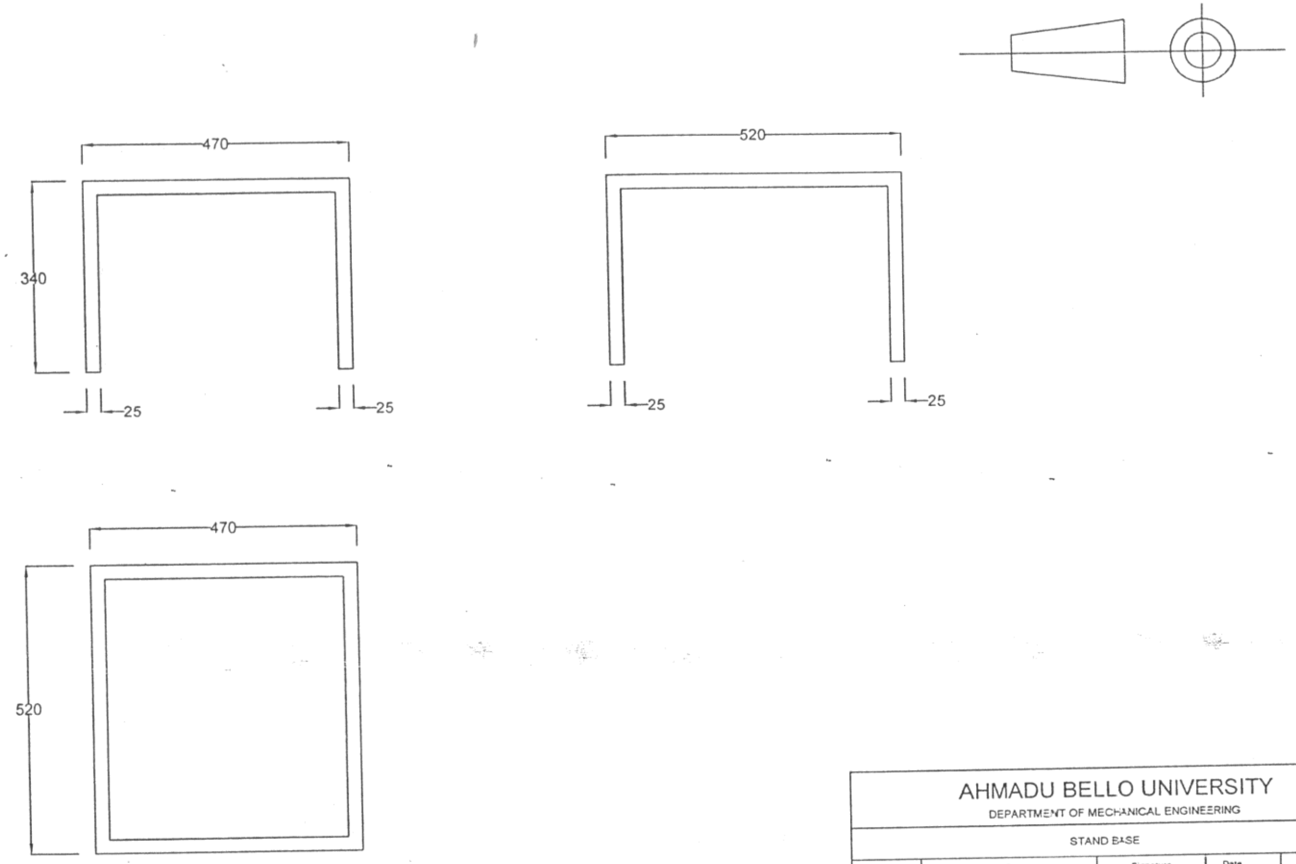

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STAND BASE

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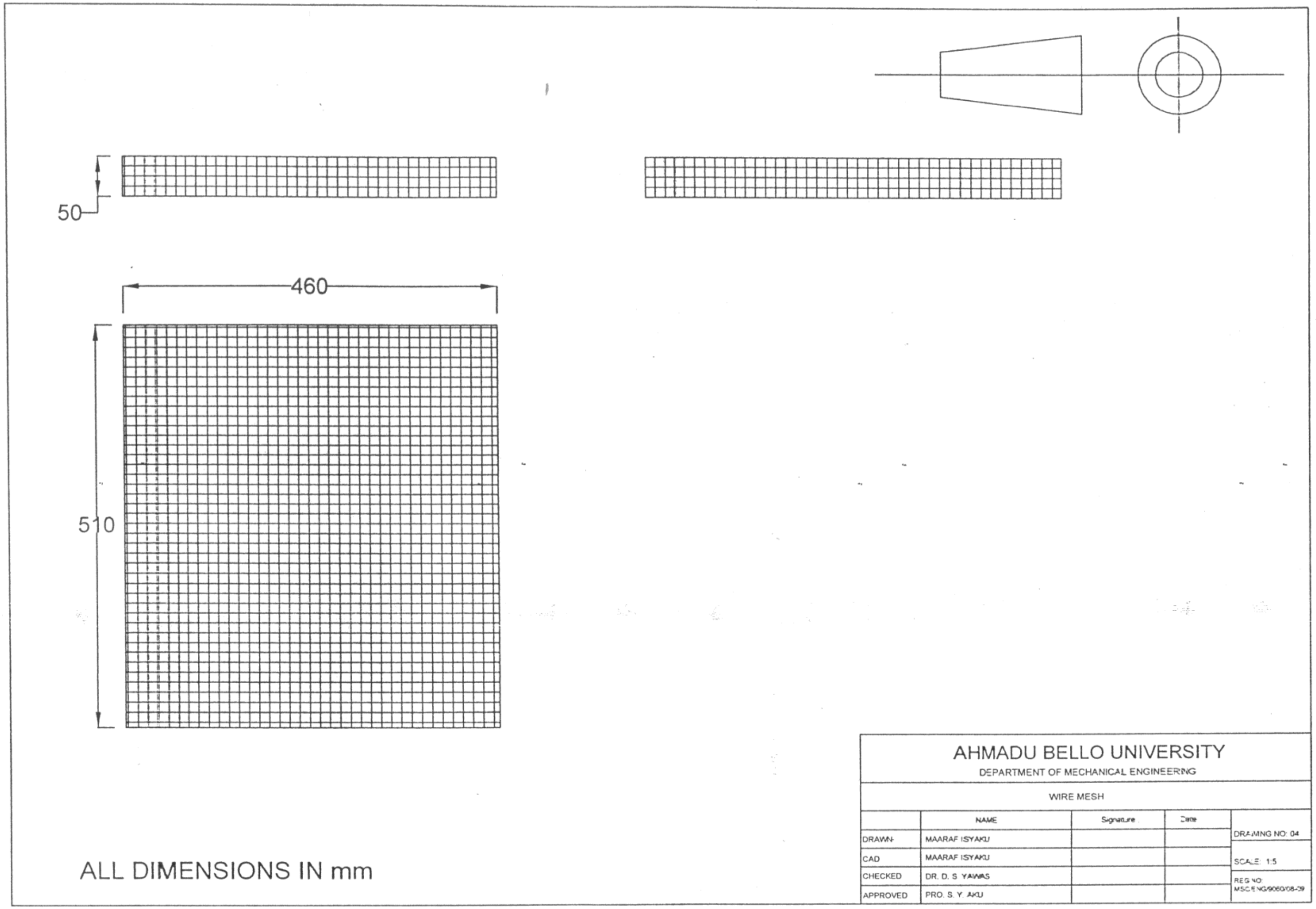

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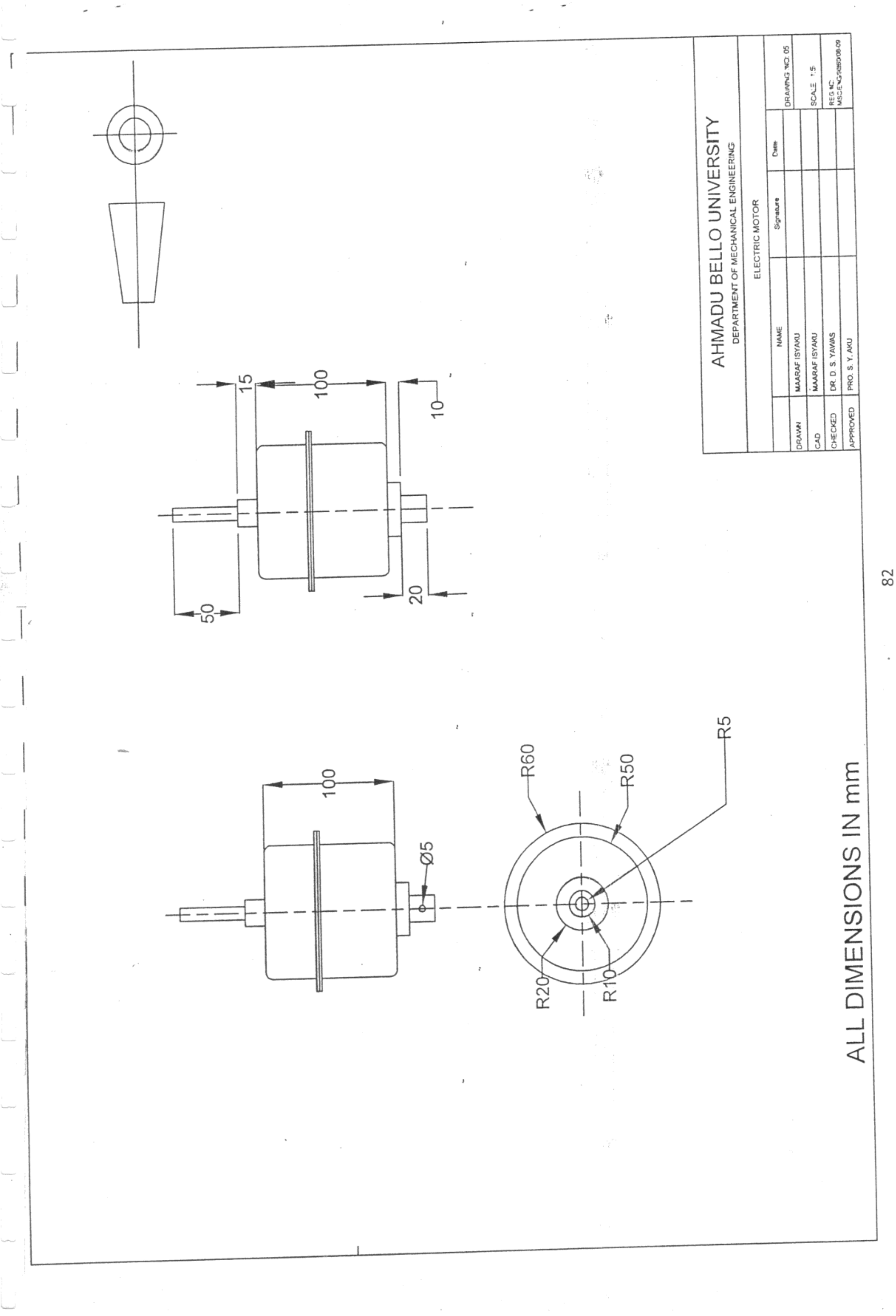
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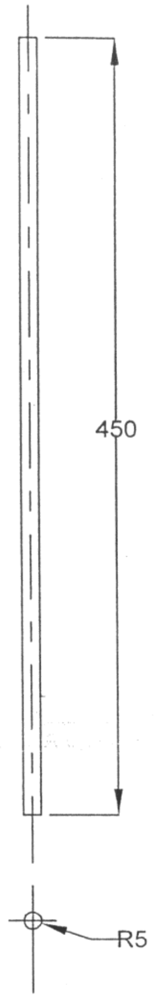

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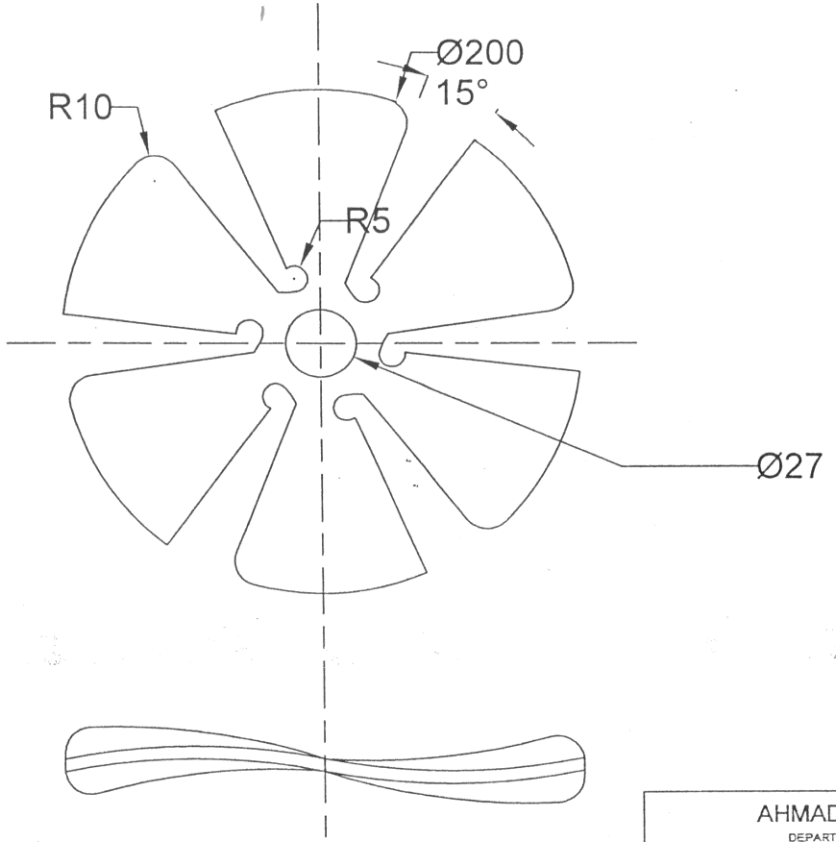

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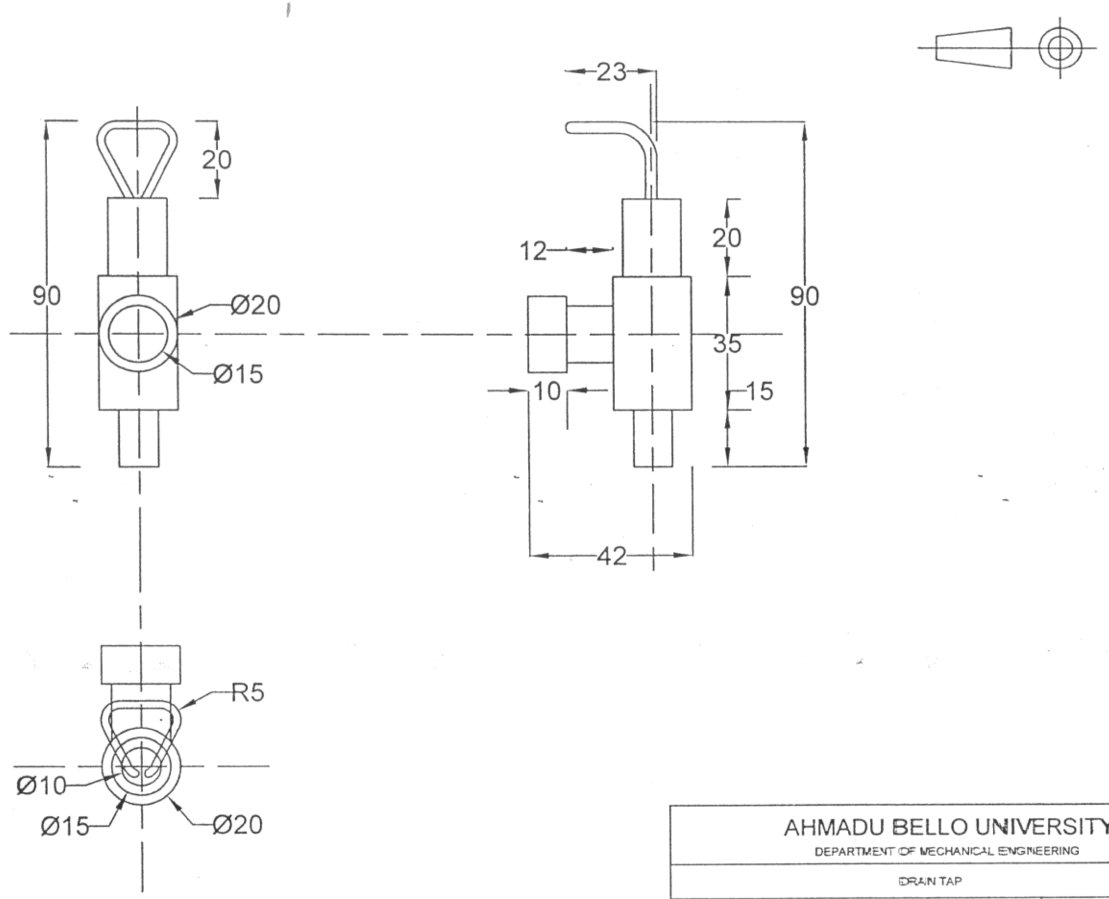

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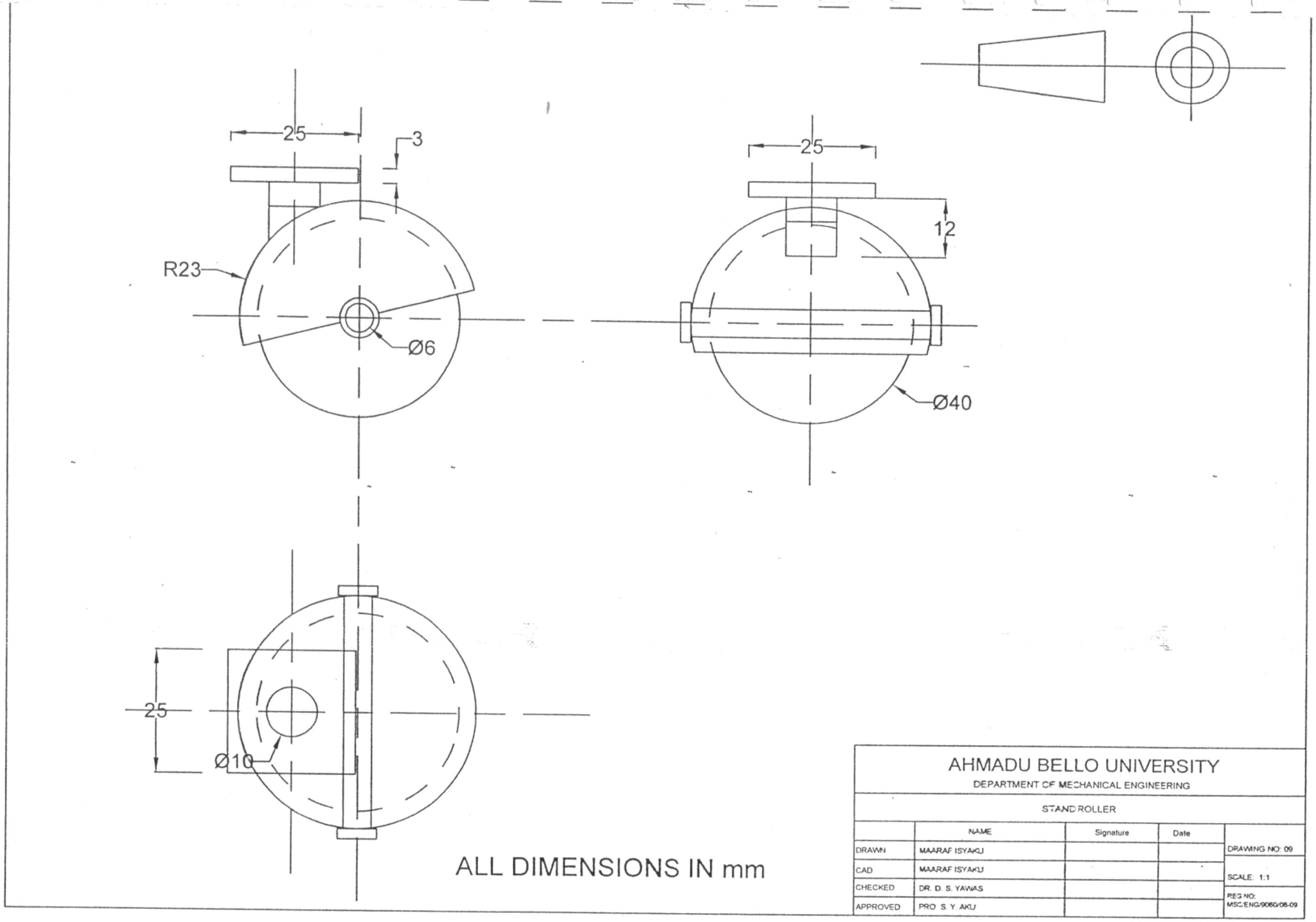

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STAND ROLLER				
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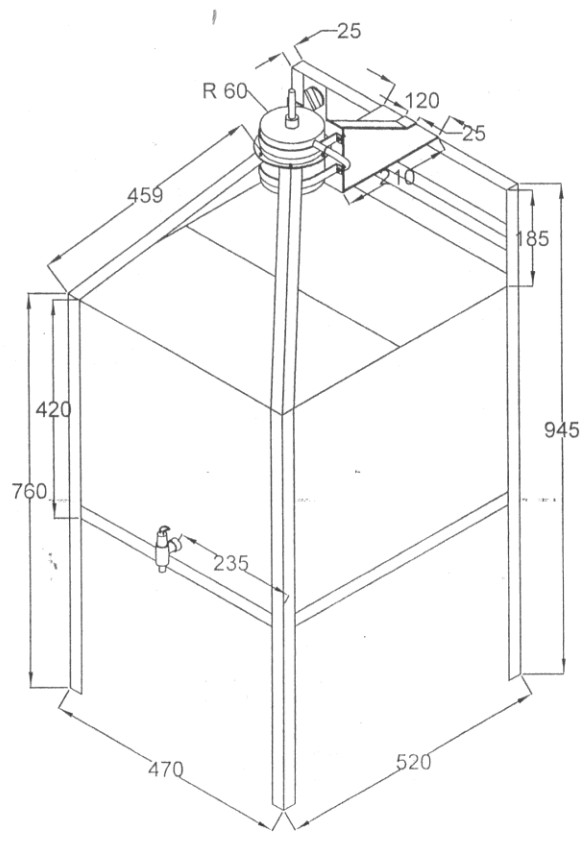

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