DETERMINATION OF MECHANICAL PROPERTIES OF DUCTILE IRON PRODUCED FROM SLEEVE SCRAPS

BY

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A

RESEARCH PROJECT

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CERTIFICATION

We certify that this research project was carried out by ADEDIJI, OMONIYI IBUKUN with MATRICULATION NUMBER: MME/11/0419 and has been carefully supervised, read, approved and found satisfactory for the award of Bachelor of Engineering in Materials and Metallurgical Engineering, Federal University Oye-Ekiti, Ekiti State, Nigeria.

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DEDICATION

[illegible] Almighty God: the Alpha and Omega, the Rose of Sharon, the mightiest in battle and [illegible] of grace.

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ABSTRACT

This study examines the determination of the mechanical properties of ductile iron produced from sleeve scraps. The method adopted for this work includes extensive literature review, acquisition and preparation of experimental materials, alloys formulation, laboratory experimental procedures, testing and analysis. The use of rotary furnace as an indigenous technology was employed in the production process. The hypotheses of the study were tested and compared with the ISO standard of the grade of ductile iron and the findings revealed that ductile iron that corresponds with ISO standard was successfully produced from automobile sleeves scraps (solid waste). It was recommended among others that the effort should be made towards the conversion of automobile sleeve scraps to ductile iron, in order to minimize the menace of environmental pollution which leads to numerous health hazards and mortality.

CHAPTER ONE

1.0 INTRODUCTION

Cast irons are engineering materials from the ferrous metal taxonomy that was developed in 1948 with carbon contents above 2.1wt% (Rilwan, 2015). Base on the application and the inclusion of other relevant alloying elements especially silicon in practice, cast irons contains 3-4.5wt% carbon. The carbon concentration minimizes the melting temperature from the eutectic point 1150°C-1300°C which is lower than that of steel there by making castability relatively easy due to its fluidity. In cast irons production, addition of other alloying element may however affect the maximum solubility of carbon in austenite in which case eutectic structures with less than 2wt% carbon can be attained in such alloys (Rilwan, 2015). The microstructures of cast irons are formed and largely dependent on chemical composition which determines the mechanical properties and characteristics of the cast iron. Gray cast irons are described as flaky graphites in either pearlitic or ferritic matrix, but ductile or nodular iron through the addition of magnesium and/or cerium in a process known as nodularization produces ductile iron with spheroidal or nodular graphite similarly in either pearlitic or ferritic matrix. The flaky graphite in gray cast irons acts as stress concentrators making it exceedingly prone to brittle fracture compared to the spherical graphite in ductile iron. The other types of cast irons are white irons which are more brittle because of carbon existing mostly as cementite in its microstructure (Rilwan, 2015).

Cast irons belong to a family of ferrous alloys with a wide range of mechanical properties. They are being produced by casting into shape as opposed to being formed. This makes them suitable for the manufacture of engineering components (Bocus *et al;* 2010). Cast irons are also referred to as the multi-component alloys which solidify with a eutectic microstructure. It primarily solidifies according to the thermodynamically metastable system or the stable system depending on the cooling rate and solidification pattern. The rich carbon phase in the eutectic microstructure is the iron carbide if the metastable path is followed, while if the stable solidification path is followed, the carbon rich phase is graphite (Seidu, 2014). However, the pig iron as the product of the blast furnace is inappropriate for castings as impurities usually confined in high percentage. In order to make it suitable for desired purpose, it is then refined in the furnace called Cupola

(Rajput, 2013). Due to its low cost and versatility, cast iron is commonly in use. From the wide range of physical properties which are possible as a result of the addition of alloying elements and various heat treatment procedures, its versatility arises (Jezerski *et al:* 2007). It has been reported in every year that, cast iron find new fields of application as a substitute material mostly due their properties that in most cases superior to those of carbon steels (Seidu, 2014).

1.1 BACKGROUND OF THE RESEARCH

Scrap is a term used to describe used and recyclable materials left over from every manner of product such as parts of vehicles (metal, tyre e.t.c.), paper, nylon, computer parts etc. Often confused as waste, scrap in fact has significant monetary value. Scraps are articles that are not wanted but are of some value for the material they are made of and metal scraps are useful because of the iron they contain. Examples of metal scrap includes automobile parts (where cast iron sleeves can be obtained), ship parts, industrial parts, building parts and household parts that metal can be extracted from. Many important metals are being recovered and recycled including iron and steel, copper, brass, aluminum (Ohimain, 2013). Recycling of metal scrap prevent air, water and soil pollution, saves energy and raw materials and reduce greenhouse gas emissions. Recycling also conserve space in landfill sites. Energy savings during the recycling of metals are 95% for aluminum, 85% for copper, 65% for lead and 60% for zinc. Recycling contributed 76.9 metric tonnes of metal, valued at $ 14.2 billion or 58% of apparent metal supply in the U.S (Ohimain, 2013). Whereas, many used automobile component parts (such as engine block, piston, connecting rods, etc.) have been recycled to produce useful engineering materials, this project is exploiting the use of sleeve scraps for the production of useful engineering materials of ductile iron specification.

1.2 AIM AND OBJECTIVES OF THE RESEARCH

1.2.1 **Aim of the Research:** The aim of the research work is to determine the suitability of mechanical properties of the ductile iron produced from sleeve scraps for engineering application.

1.2.2 Objectives of the Research: The objectives of the research work are to:

i. produce ductile iron using sleeve scraps;

ii. machine mechanical testing samples from (i) above; and

iii. carry out the mechanical test on the samples (tensile and hardness).

1.3 SCOPE OF THE STUDY

The scope of the study is limited to the use of sleeve scraps in the production of the ductile iron using a 100Kg capacity rotary furnace fired by diesel oil. The research covers sourcing of raw materials and the production of ductile cast iron. ASTM standard test samples will be prepared to investigate their tensile strength, hardness property, and microstructural examination.

1.4 JUSTIFICATION FOR THE RESEARCH

The sleeve scraps are waste cylindrical cast iron materials in the engine block of an automobile. They are available in large quantities in the mechanic workshop. Instead of leaving the sleeve scraps to liter the environment which will cause the environmental pollution; they can be converted into wealth to reduce the environmental pollution that may be hazardous to the human's health. This project was design to employ the use of the solid waste that are disposed indiscriminately in our environment can be converted to wealth by recycling in the metallurgical melting furnace to produce ductile iron that find useful engineering application through the use of indigenous technology of rotary furnace.

1.5 CONTRIBUTION TO KNOWLEDGE

The research was able to provide information on the means in which waste materials (cast iron sleeves scraps) can be recycled. The frontier of knowledge will also be expanded while it will provide more information about the behaviour of materials. It will reduce importation of parts that can be produced locally.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 CAST IRON

Cast irons are mainly iron-carbon alloys that have carbon more than 2% which is more than the maximum solid solubility of carbon in austenite. They are eutecti-ferous iron-carbon alloys, in which eutectic reaction takes place during solidification. The presence of eutectic in the structure makes cast irons fully to be 'cast' to desire shapes. Hypothetically, the carbon content of cast irons can lies between 2.11% to 6.67%, but because higher carbon content tends to make them more brittle, the industrial cast irons have carbon normally in the range of 2.11% to 4.0%, along with other elements such as silicon, manganese in significant amounts, then, sulphur and phosphorus are also present. Although, cast irons are brittle, and cannot be forged, rolled, drawn, etc, but can only be 'cast' into desired shape and size (with or without machining), by pouring the molten alloy of desired composition into a mould of desired shape and allowing it to solidify. The only suitable process to shape these alloys is by casting, and hence, they are called cast irons (Vijendra, 2011).

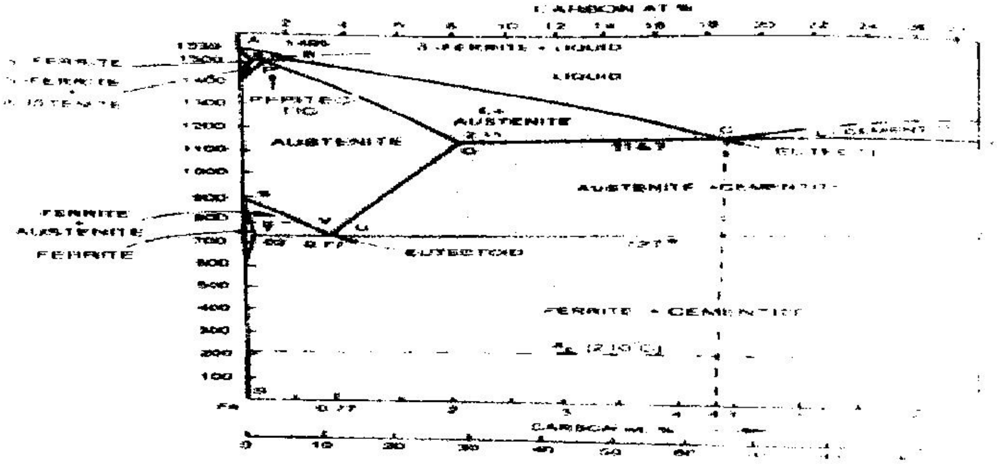


Figure 2.0: The true Equilibrium Diagram for Iron and Carbon

A metastable compound is cementite (Fe_3C), and under some conditions it can be made to dissociate or decompose to form α-ferrite and graphite, according to the equation 2.1:

$Fe_3C \rightarrow 3Fe(\alpha) + C$ (Graphite) .... **Equation 2.1**

According to figure 2, the eutectic and eutectoid temperatures for the Fe-Fe_3C systems are approximated to 1147°C and 727°C, respectively (William and David, 2014). The tendency to form graphite is controlled by the composition and rate of cooling. The formation of graphite is promoted by the presence of silicon in concentration greater than about 1wt %. Also, during solidification, slower cooling rates favour graphitization. For most cast irons, the carbon exists as graphite, and both microstructure and mechanical behavior depend on composition and heat treatment. The most common cast iron among others are: grey cast iron, nodular or ductile cast iron, white cast iron, malleable cast iron, compacted cast iron, mottled cast iron, alloy cast iron, chilled cast iron, etc.

2.1.1 TYPES OF CAST IRON

2.1.1.1 Grey Cast Iron

The carbon and silicon contents of grey cast iron differ between 2.5 and 4.0% wt and 1.0 and 3.0%wt separately. For most of these cast irons, the graphite occurs in the form of flakes (similar to corn flakes), which are usually surrounded by α-ferrite or pearlite matrix. A fractured surface takes on a gray appearance just because of these graphite flakes. Mechanically, gray iron is relatively week and brittle in tension as a result of its microstructure; the orders of graphite flakes are sharp and pointed. When an external tensile stress is applied, some of these orders serve as points of stress concentration. However, the compressive loads and strength are much higher. They are very effective in damping vibrational energy; base constructions for machines and heavy equipment that are exposed to vibrations are often constructed of this material. They also exhibit a high wear resistance (Callister and David, 2014). The microstructure of gray cast irons contains of graphite flakes surrounded in the matrix, of variable amounts of ferrite and pearlite. The properties of gray cast iron are determined by the properties of both of the matrix, and the amount, size, shape and distribution of graphite inclusion. This cast iron derives its name from the gray colour of the fracture imparted by the carbon present in free form as graphite flakes embedded in matrix as shown in figure 2.1 (Vijendra, 2011).

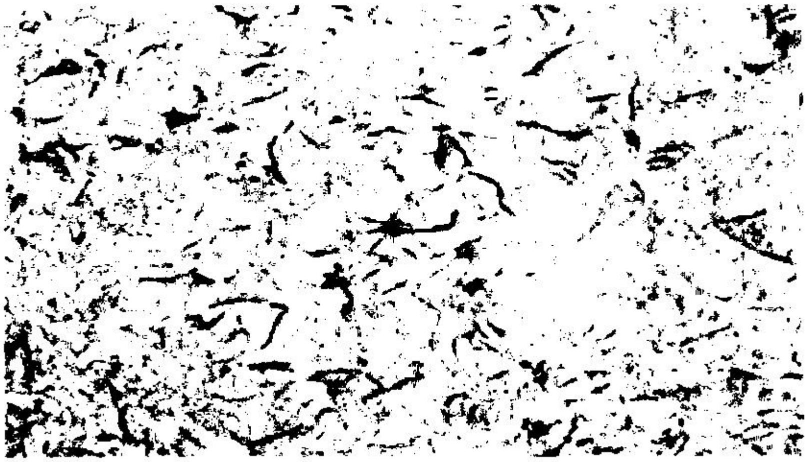


Figure 2.1: The Microstructure of Grey Cast Iron (x200)

2.1.1.2 White Cast Iron

For low-silicon cast irons having less than 1.0 wt % Si and rapid cooling rates, most of the carbon occurs as cementite instead of graphite, as it is shown in figure 2.2. A fracture surface of this alloy has a white look, and therefore, it is termed white cast iron (Callister and David, 2014).This cast iron develops its name to the arrival of its fracture, which is white and dull as all the carbon in the cast iron is existing in the combined form as white cementite and has more than 2.11% carbon. It is also hard, wear resistant, brittle and practically non-machinable. All commercial white cast irons are referred to as hypoeutectic white cast irons. The ledeburite is a coarse mixture rather than fine mixture distinctive of many eutectic mixtures, as the eutectic reaction takes place at a relatively high temperature. Moreover, the divorcement of eutectic is almost complete, i.e., eutectic austenite (during solidification) deposits on the primary austenite dendrites, and then leaving behind layers of interdendritic massive free cementite (Vijendra, 2011).

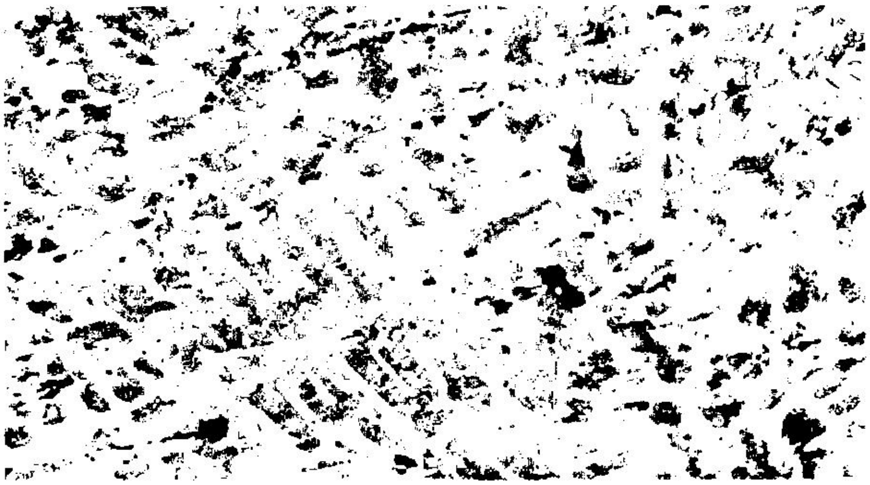


Figure 2.2: The Microstructure of White Cast Iron (x200)

2.1.1.3 Malleable Cast Iron

In general, white iron is used as an intermediary in the production of another cast iron and malleable iron (William and David, 2014). It can be achieved by giving a long time annealing to cast iron. Steel scrap from 10 to 40% may be added to lower the total carbon contents in order to get high duty cast irons. The method of obtaining malleable cast iron involve packing the white cast iron casting along with silica in a steel pot and heated in a muffle oven or continuous type thermal kiln. The temperature is kept at 870°C for 60 hours and casting is then cooled slowly in the furnace, iron carbide dissociates as $Fe_3C \rightarrow Fe + C$ and thus reduces to malleable cast iron. Malleable cast iron is of two types;

i. Black heart
ii. White heart

By keeping temperature and time relatively of high values, white heart malleable cast iron shown in figure 2.3 can be achieved (Rajput, 2013).

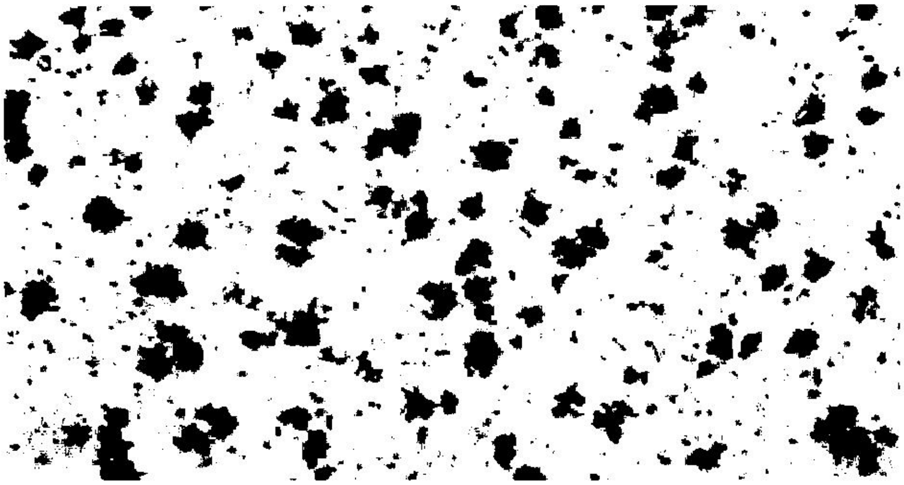


Figure 2.3: The Microstructure of Ferritic Malleable Cast Iron (x200)

2.1.1.4 Alloy Cast Irons

These are cast irons in which the properties and microstructure of most of the key cast irons are improved by the addition of the alloying elements (Vijendra, 2011).

2.1.1.5 Ductile (or Nodular) Iron

This is iron-carbon alloy that have a structure of nodules of graphite inside the matrix. During the process of solidification, these nodules of graphite are made directly from the liquid. The nodules are more regular, sharp and compact spheres (Vijendra, 2011). The addition of a small amount of magnesium and/or cerium to the gray iron before casting produces a clearly different microstructure and set of mechanical properties. Graphite still forms, but as nodules or sphere-like particles instead of flakes. The resulting alloy is referred to as nodular or ductile iron (William and David, 2014).

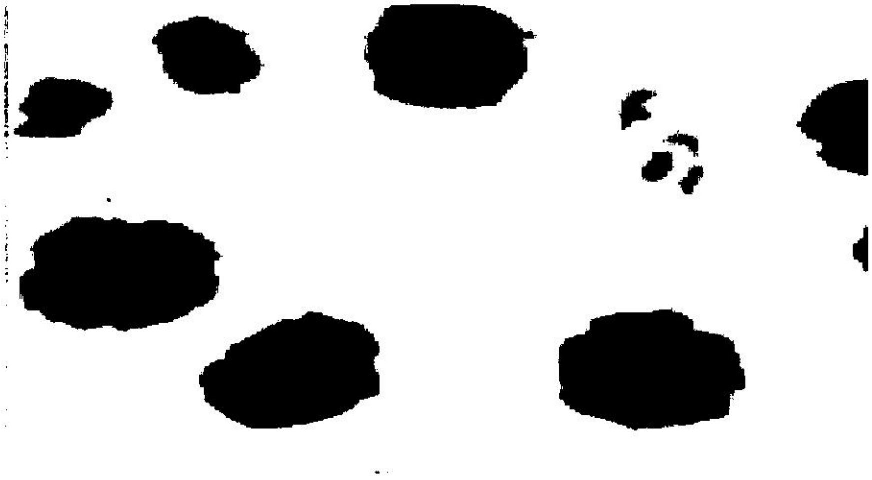


Figure 2.4: A395 Material Showing Random Graphite Flakes Nodules. Etched, Magnification (x250).

2.2 DUCTILE IRON

Ductile iron is one of the most essential engineering materials, in view of its excellent castability. It possesses better mechanical properties alow cost (Bockus, and Dobrovolskis, 2006). It belongs to a class of cast graphitic irons which have high strength, ductility and resistance to shock. It also denotes the fastest growing section of the iron market. More so, it is to be expected in the medium term, that the market share of nodular iron will level off at 40 % to 45 % (Bockus, and Dobrovolskis, 2006). In ductile iron, the addition of a few hundredths of 1% of magnesium or cerium causes the graphite to form in small spheroids rather than flakes. These create fewer discontinuities in the structure of the metal and produce a stronger, more ductile iron. Annealed cast ductile iron can be bent, twisted or deformed without fracturing. Its strength, toughness and ductility reproduce many grades of steel and far exceed those of standard gray irons. Thus, it has the advantages of design flexibility and low cost casting procedures similar to gray iron. The difference between ductile iron and gray iron is in the graphite formation. Ordinary gray iron is characterized by a random flake graphite pattern in the metal matrix. By achieving the full potential of ductile iron, it requires superior metallurgical process control, as well as the highest levels of skill in melting the ductile iron base, spheroidizing and inoculation (Bockus, and Dobrovolskis, 2006). It is this graphite formation which accounts for the fact that ductile iron is also referred to as "nodular iron.

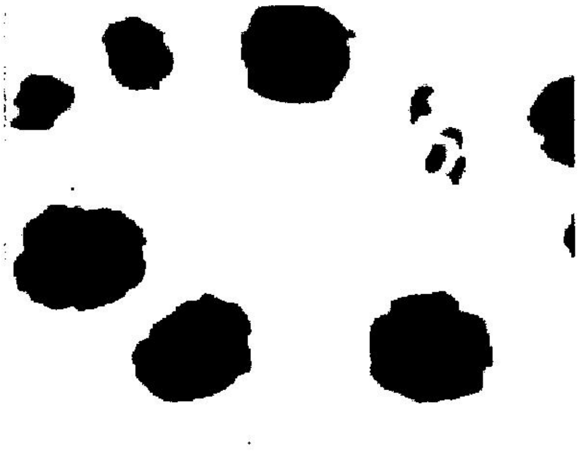


Fig. 2.5: Ductile Iron
A395 material showing random graphite . nodules. Unetched, magnification 250x.

Fig. 2.6: Gray Iron
A395 material showing random graphite flakes. Unetched, magnification 250x.

With ductile iron, the safety and reliability of process equipment is improved. The as-cast ductile irons (ductile cast iron) have many advantages, which include the energy-saving, equipment investment decreasing, production cycles shortening, productions costs reducing and competitiveness promoting, compared with heat treated ductile irons. Also, some defects from heat treatment, such as high temperature oxidation and deformation, can as well be avoided in the as-cast ductile irons. About 80% ductile iron casting components in automotive applications involved are manufactured in as-cast. Thus, the research and development in producing as-cast ductile irons for heavy duty applications are of great importance of metallurgical engineers. The mechanical properties are far above that of gray iron and this increases its resistance to breakage. The corrosion resistance of ductile iron is equally superior to gray cast iron and to cast steel in many corrosives media. Its wear resistance is similar to some of the best grades of steel and superior to gray iron in heavy load or impact load situations. From its high yield strength, the large advantages are obtained and ductility makes it an economical choice for many applications (Dayton *et al;* 2011). However, most varieties of cast iron are brittle, and ductile iron is much more malleable and elastic, due to its nodular graphite inclusions. The graphite improves the desirable properties of cast iron like improved casting and machining properties and better thermal conductivity. The graphite that produced ductile iron commercially is not always in perfect spheres, but in the form of spherical nodules in ductile iron, rather than flakes that are found in typical cast iron which prevent the creation of cracks and providing the better or improved ductility that give the alloy its name. However, it can also occur in a somewhat irregular form, but if it is still solid, the properties of the iron will be similar to cast iron with spheroidal graphite. When the metal solidifies, the shape of the graphite is well-known, and it cannot be changed in anyway but by re-melting the metal. Nevertheless, ductile iron can be reasonably alloyed to have an entirely pearlitic matrix as-cast. The well-known tensile properties are tensile strength, yield strength and percent elongation. The relation between tensile properties and hardness depends on microstructure. Ferritic matrix irons, regularly annealed, have very low combined carbon content. Hardness and strength are dependent upon hardening of the ferrite by the elements dissolved in it, silicon being the most important. Manganese and nickel are also common ferrite hardeners. Reducing cooling times in the mould and hot shakeout temperature increases strength because the castings are effectively normalized by this treatment. The formation of nodules have high advantages over its steel counterpart, and it has a better mechanical properties with wide range of applications in the automotive industry for defense, agriculture, construction and mining components etc.,(Adeyemi *et al;* 2014).

Development or the production of ductile iron cannot be achieved without one of the primary raw materials namely- cast iron scrap often categorized under solid waste. The management of solid wastes has been a major challenge in Nigeria. Solid wastes are frequently disposed along the streets, gutters, drainage channels, rivers, abandoned plots of land etc. Poor waste disposal has been linked to blockage of gutters and other drainage channels causing flood, poor aesthetics, release of foul odour and greenhouse gases, obstruction of traffic flow and pollution of surface and ground water (Ohimain, 2013). Scrap metals is an important components of the municipal solid wastes (MSW), in Nigeria, it accounts for 1.8%, 10.8% and 3 - 20% of the MSW generated in South West, South East and North Western part of the country respectively (Ohimain, 2013). Through the activities of scavengers, useful materials are often recovered from MSW including metal scraps, wood, plastics etc. Scrap metals are among the most important and priced materials in MSW. In Nigeria, the demand for metal scraps can be traced to the very increasing growth of building construction where they are used as steel bars. Approximately, about 70% of recycled metal product in Nigeria end up been used in the construction industry. The Market for the metal scrap in Nigeria is huge and expanding. The estimated size of the local market is put at about ₦3 Billion annually (Ohimain, 2013).

2.3 COMPOSITION

The chemical composition of ductile iron and the cooling rate of the casting have direct effect on its tensile properties by influencing the type of matrix structure that is formed. All of the regular grades of ductile iron can be made from the same iron provided that the chemical composition is suitable so that the desired matrix microstructure can be obtained by either controlling the cooling rate of the casting after it is poured or by successive heat treatment. For most casting necessities, the chemical composition of the iron is mostly a matter of enabling production. An uncommon combination of properties is obtained in ductile iron because the graphite occurs as spheroids rather than as graphite flakes as in grey iron. This mode of solidification is achieved by adding a very small, but specific amount of Mg and Ce or both to molten iron of appropriate composition. The base iron is strictly controlled in the allowable contents of certain minor elements that can delay with graphite spheroid formation. The added Mg reacts with S or O in the melt or molten iron and the way the graphite is formed. Control procedures have been advanced to make the processing of ductile iron reliable (Anita, 2009). The high C & Si content of ductile iron deliver the casting process valuable, but the graphite nodules have only the nominal effect on the mechanical properties of the melt. Ductile iron, like malleable iron, shows a linear stress- strain ratio, a considerable range of yield strengths as its name denotes, ductility. Castings are made in a wide-range of sizes with sections which are very thin or very thick (Anita, 2009).

Ductile iron is described by having all of its graphite occurs in microscopic spheroids. Although this graphite constitutes about 10% by volume of ductile iron, its compact spherical shape reduces the effect on mechanical properties. It is not a single material, but a family of materials developed through microstructure control. Its mechanical properties are determined by the ductile iron matrix with a high percentage of graphite nodules present in the structure (Ductile Iron Society, 2005). Ductile iron is produced by varying gray cast iron melt with magnesium added in the range of 0.15% to 0.45% and later protected with ferrosilicon. By addition of nodularizing elements, the formation of nodules is accomplished, most commonly magnesium and less often, cerium, into the melt which changes the condition and growth of a graphite nucleus so that it turns into a spheroid or nodule (Anita, 2009); the nodules formed prevents the formation of cracks and provides the better ductility that gives the alloy its name. The inoculant addition ranges from 0.2% to 1.2%, offering a wide range of properties. Addition of Ferrosilicon up to 3.6% - 3.8% to magnesium cast iron increases the mechanical properties of ductile iron after isothermal quenching. More increase in the concentration of silicon >3.8% leads to a decrease in the strength and ductility of the of isothermally quenched magnesium cast iron (Voloshcenko *et al*; 2003). After isothermal quenching from the temperature of the ferritic austenitic state, the enhancement of the mechanical properties is obtained. The significance of inoculation on magnesium treated melt had been considered and detected that about ninety seven percent nodularity was achieved in magnesium treated cast iron melt that was protected with seventy five percent ferrosilicon grade (Alasoluyi *et al*; 2013). Matrix control, reached in conventional Ductile Iron either "as-cast" through a mixture of composition and process control, or through heat treatment yields various grades of ferritic ductile iron, ferritic-pearlitic ductile iron, pearlitic ductile iron, martensitic ductile iron, bainitic ductile iron and austenitic ductile iron; thus gives the designer the choice of selecting the grade of ductile iron which provides the most appropriate mixture of properties (Anita, 2009). Ductile iron has the following required features which include high tensile strength and toughness, good machinability (equal to gray iron of the same hardness), high modulus of elasticity, good shock resistance and wear resistance, excellent ductility, cast into most shapes.

2.4 Areas of Applications

Ductile iron castings are used in automotive components, agricultural equipment, construction equipment, lawn and garden equipment, heavy equipment, railroad equipment. The automotive industry has produced components such as steering knuckles, brake callipers etc., using ductile iron where they have been found to perform well in service with high degree of safety (Ductile Iron Society, 2005).

2.5 Grades of Ductile Iron accepted as per International Standard

The present ISO standard of ductile iron, ISO 1083-2004, classified on the basis of one of the mechanical properties such as tensile strength, hardness elongation or Brinell hardness. Tensile strength is the common basis for the Material Designation or characterisation and shown in the table 1.1 (Bishnu, 2014).

Material Designation	Tensile Strength (N/mm²)	Elongation (%)
ISO 1083/JS/350-22/S	350	22
ISO 1083/JS/400-18/S	400	18
ISO 1083/JS/400-15/S	400	15
ISO 1083/JS/450-10/S	450	10
ISO 1083/JS/500-7/S	500	7
ISO 1083/JS/550-5/S	550	5
ISO 1083/JS/600-3/S	600	3
ISO 1083/JS/700-2/S	700	2
ISO 1083/JS/800-2/S	800	2
ISO 1083/JS/900-2/S	900	2

Table 1.1: Grades of Ductile Iron accepted as per International Standard (Bishnu, 2014).

2.6 Smelting Furnace for Ductile Iron

The rotary melting furnace is the most flexible and universal design of equipment to recycle cast iron scraps. It is alternative melting equipment for all small and medium size foundries using cupola furnaces or induction furnaces. This is because gray, nodular or malleable cast iron can be manufactured with high critical accuracy at a low investment cost, with minimal personnel operating it (www.industrialmetalcastings.com, 2009). Rotary furnace of 100kg to 300kg capacity have been designed and constructed at Engineering Development Institute (EMDI) Akure, as a way of providing one of the most important missing associations in the metal producing technology and building capacity in the foundry industries (Adewoye, 2005). It has been observed that considerable amount of graphite essential to produce molten cast iron from rotary furnace for Mg treatment and inoculation for ductile iron production is to some extent lost due to oxidation and mechanically due to high air pressure from blower. This produces ductile cast iron melt of carbon equivalent of 2.0 % – 2.5% which in principle is hypoeutectic and has low fluidity and low nodule count.

2.7 Production of Ductile Iron Processes

The first step of the production of ductile iron castings is the selection of the charge materials carefully. Manganese and chromium have the great influence on all mechanical properties (Alasoluyi *et al;* 2013). For this reason, their concentration in metal is of importance. These elements are usually introduced into the charge from steel scrap, iron units and returns. Ideally, the same advice would be given for Mn but, unfortunately, all steel scraps contain Mn, the majority being at the 0.5 percent level. It is particularly important for the production of ferritic ductile iron. Charge materials result in the average size of graphite spheroids. The vast majority of ductile irons cast today are melted in cupolas and induction melting furnaces. Ductile iron is particularly prone to the formation of primary carbides during solidification. One of reason for this susceptibility is high superheat temperatures. Increasing of holding time in a furnace increases the number of primary carbides too. The addition of magnesium or magnesium alloy to cast iron with the purpose of changing graphite shape from flake to spheroidal is an essential processing step for manufacturing ductile iron. Majority of ductile irons manufactured today are melted in cupolas and induction melting furnaces (Bockus and Dobrovolskis, 2006). Nevertheless, good quality ductile iron have been made from a rotary furnace, that was designed and developed through indigenous technology at Engineering Materials Development Institute, Akure, Nigeria. This innovation is directed towards providing the essential missing relation in the metal producing technology and also a way of structure capacity in the foundry industries (Alasoluyi *et al;* 2013).

2.8 Pattern

A pattern in casting is a replica of the object to be cast, used to make the cavity into which molten material will be poured during the casting process (Bawa, 2004 and Ammen, 1999). Patterns used in sand casting may be made of wood, metal, plastics or other materials. A pattern differs from the actual component in the following ways.

i. It carries pattern allowances
ii. It has provision for core prints

2.8.1 Allowances

To recompense for any dimensional and structural modifications which will occur during the casting or patterning process, allowances are usually made in the pattern. The various types of allowances include contraction allowances /shrinkage allowance, draft allowance, finishing or machining allowance, shake allowance and distortion allowance (Praveen, 2011 and Rao, 2003).

2.8.2 Pattern Making

The making of patterns is termed pattern making. It is a skilled trade that is interrelated to the trades of tool and die making and mold making, but also regularly incorporates elements of fine wood working. Patternmakers learn their skills through apprenticeships and trade schools over many years of skill. Although an engineer may help to design the pattern, it is usually a patternmaker who carries out the design (Shelly and Joseph, 1999). There are various types of patterns depending upon the complexity of the job, the number of castings required and the moulding procedure adopted. These include solid or single piece pattern, split pattern or two-piece pattern, multi piece pattern, cope and drag pattern, match plate pattern, gated pattern, skeleton pattern, sweep pattern, loose piece pattern, hollow board pattern and segmented pattern (Shelly and Joseph, 1999). The key functions of a pattern are to produce the mould cavity of fitting shape and size, to produce seats for cores in which cores can be placed; and to establish the parting surfaces and lines in the mould, to minimize the cost of casting (Radhakrishna, 2011).

2.8.3 Pattern Materials

Pattern materials are wood, metals, plastics, plaster and wax. The selection of a pattern material for making the pattern is influenced by the following factors which are number of castings to be made, method of moulding to be employed i.e hand or machine, type of casting method to be used, degree of accuracy in dimensions and quality of surface finish required on the castings, design of casting (Foundry Technology note book). Mahogany is the most generally used material for patterns, mainly because it is soft, light, and easy to work, but also once properly preserved it is about as steady as any wood available, not subject to warping or curling (Radhakrishna, 2011).

2.8.4 Pattern Design

A sand casting pattern is alike in shape to the cast product (but not exactly the same). The dimensions of the pattern are different from the final dimensions of the required owing to the various reasons which include shrinkage allowance, finishing or machining allowance, draft allowance, rapping or shake allowance, distortion allowance, mould-wall movement allowance, eliminating holes, fillet. Pattern design can be treated as a series of transformations starting from the product shape to finally obtain the shape corresponding to the mould cavity (Ravi, 2012).

2.9 Sand Preparation

Moulding sand should have good flowability for better replica of pattern details, adequate green strength to prevent its collapse during moulding, dry strength to prevent erosion and collapse during mould filling, sufficient refractoriness to withstand molten metal temperature, enough permeability to allow entrapped air and gases generated inside the mould to escape, and collapsibility for ease of shakeout. These are achieved by a suitable composition of sand, binders, additives and microstructure. Silica sand is the most widely available and economical mould material. The most commonly used binder is bentonite clay (sodium or calcium bentonite), which imparts strength and plasticity to silica sand when water is added. Additives include coal dust (to improve surface finish by gas evolution at metal-mould interface), Iron oxide (for high temperature resistance), dextrin (for improved toughness and collapsibility), and molasses (for high strength and collapsibility) (Ravi, 2012).

2.10 Applications of Ductile Iron or Spheroidal Graphite (S.G) Irons

The applications of the S.G. iron have improved extremely in recent times in the production of engine crank shaft, brake caliper, disc-brake anchor, brake anchor plate, machine-tool bed, electric insulator post and cap, steering knuckle, rack and pinion of steering assembly, piston for impact drills, rolling mill rolls, moulding boxes and mould box clamps, brake shoe for heavy duty brakes, glass moulds, spacer cage for rolling bearing, piston rings and wind mill items (Anita, 2009).

CHAPTER THREE

2 MATERIALS AND EXPERIMENTAL PROCEDURE

3.1 RESEARCH METHODOLOGY

The method adopted for this work includes extensive literature review, acquisition and preparation of experimental materials, alloys formulation, laboratory experimental procedures, testing and analysis.

3.2 EXPERIMENTAL MATERIALS

The following materials were used for the work;

i. Grey cast iron sleeve scraps as base metal
ii. Ferro-silicon alloy (FeSi)
iii. Magnesium-ferro-silicon (MgFeSi)
iv. Others are graphite, coal dust, bentonite and green moulding sand.

3.3 EXPERIMENTAL EQUIPMENT

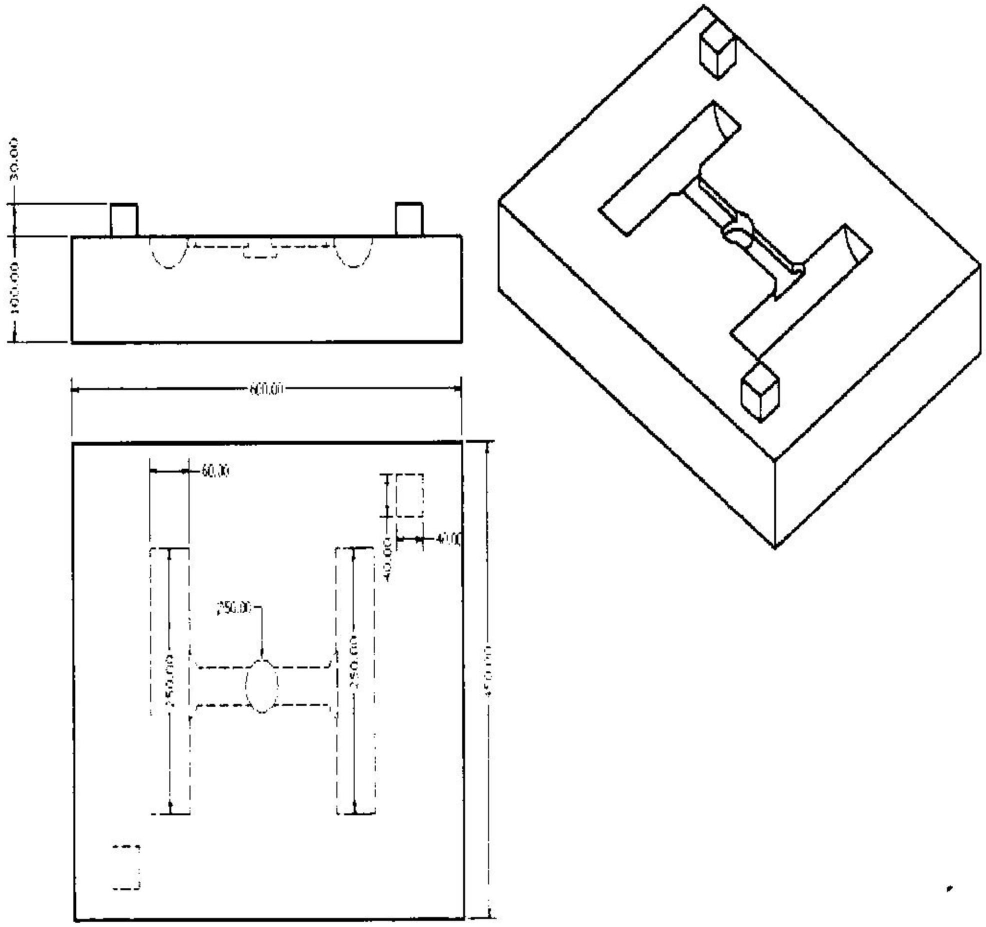
The equipment used for this work includes

i. 100 kg capacity diesel – fired rotary furnace
ii. Digital weighing balance
iii. Moulding box and its accessories
iv. Instron universal tester
v. Nikon Eclipse ME600 metallurgical microscope
vi. Grinding machine
vii. Polishing machine
viii. Portable hacksaw
ix. Lathe machine and its accessories

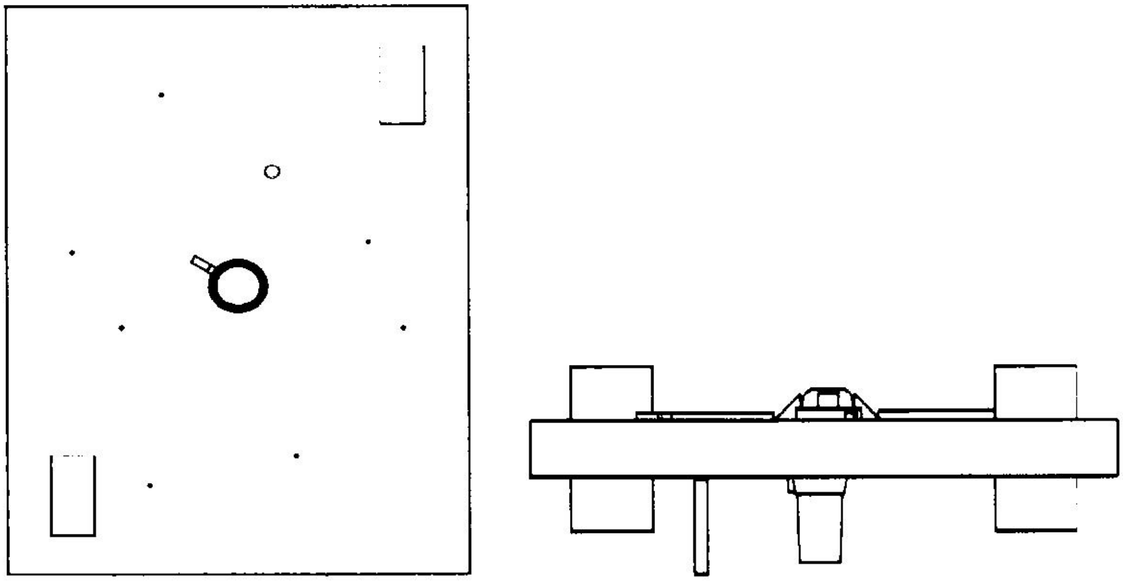
3.4 MATERIALS AND METHOD

3.4.1 Pattern Materials/Making

Pattern was produced from the designed drawing or sketch with considerations given to all the necessary allowances. The wooden pattern is of diameter 60 mm by 250 mm in length was turned using the wood lathe. The pattern design layout is as shown in figure 3.1. An overflow of diameter 80 mm by 250 mm in length and down sprue of diameter 40 mm tapered to diameter 30 mm and 200 mm in length were also produced to ensure easy withdrawal from mould. Contraction allowance of 1.5% was used to produce the pattern materials to avoid severe shrinkage on the castings.



(a) Top view



(b) Bottom view (c) Side view

Figure 3.1: Engineering Design of the Pattern using Pro-e software (Dimension: mm)

3.5 MOULDING SAND PREPARATION

Coarse silica sand for casting was sieved into fine grain size. It was then mixed with water in a correct proportion to make it moist. Binders and additives were added in a correct proportion to give the silica sand strength and then fuse together properly. The mixing was done manually based on the personal experience.

Figure 3.2: Moulding Sand

3.5.1 Equipment for the Mould Preparation

Some of the equipment that were used for moulding process include: showel, trowel , riddle, rammer , draw spike, swab , vent wire, slick tool etc.

i) **Shovel:** The shovel tool was used for mixing and tempering moulding sand and for packing the sand pile to moulding box.

Figure 3.3: Shovel

ii) **Hand Trowel:** Trowel was used to shape and smooth the surfaces of the mould and for doing small repairs. They are made of steel and are relatively long and narrow.

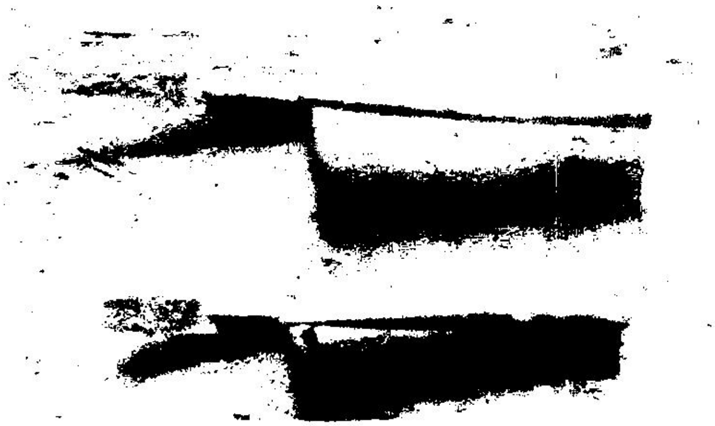


Figure 3.4: Hand Trowel

iii) **Riddle:** Riddle tool is a screen or sieve used to reduce big sizes of coarse sands into the desire sizes of fine sands.

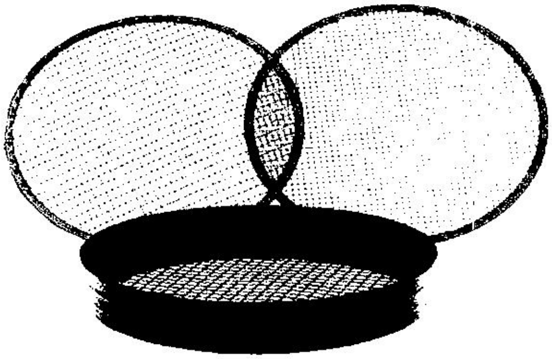


Figure 3.5: Riddle

iv) **Rammer:** Rammer was used to compress the moulding sand. The hand rammer is made of steel and resembles a handless mallet with one end flat and the other end blunt edge.

Figure 3.6: Rammer

v) **Draw Spike:** Draw spike tool was used to remove the pattern from the mould and also used for rapping the pattern gently to loosen it from the sand to assure a clean draw.

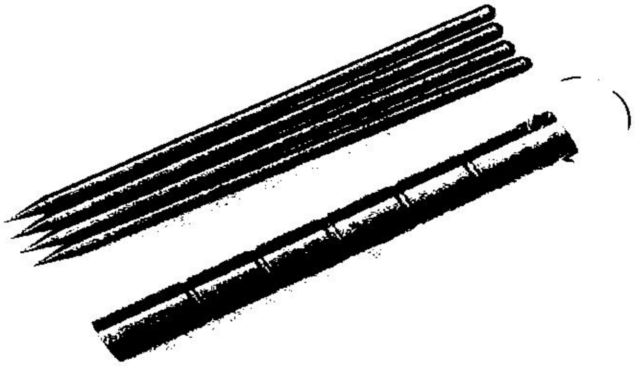


Figure 3.7: Draw Spike

vi) **Swab:** Swab is made of foam and was used for applying water to the mould around the corners and edges of the patterns. This tool prevents the sand edges from crumbling, when the pattern was removed from the mould.

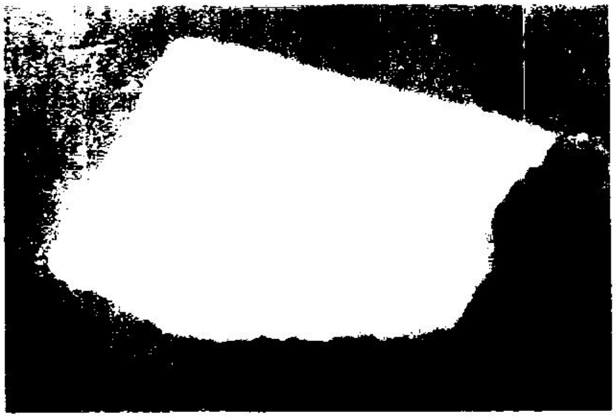


Figure 3.8: Swab

vii) **Vent Wire:** Vent wire is a thin rod or wire carrying a pointed edge at one end and a wooden handle at the other end. Vent wire was used to make small holes called vents in the sand mould.

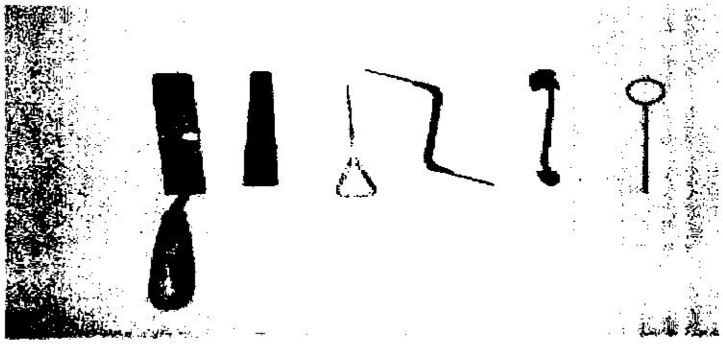


Figure 3.9: Vent Wire

viii) **Scrapper:** Scrapper is a tool made of metal and it was used to level the surface of the mould after ramming.

Figure 3.10: Scrapper

ix) **Bellow:** Bellow is a vacuum device that was used to blow off the particle sands from the surface of the mould.

Figure 3.11: Bello

x) **Moulding Box:** The moulding box that was used for the sand casting was made of metal and it consist cope and drag.

Figure 3.12: Moulding Box

3.5.2 Moulding Materials/Practice

White silica sand obtained from Igbokoda, Ondo State was mixed with bentonite as the binder, coal dust was added as carbonaceous material to increase permeability and water was reasonably added to ensure mouldability and flowability of the sand. The mixed sand was moulded in a moulding box of size 500 mm by 350 mm by 250 mm to produce moulds for the ductile iron cast. The mould was left to dry naturally for a day before it was fire-dried.

3.5.3 Preparation of Charge Materials

Spark analysis of the base metal (sleeve scraps) purchased from local vendor was carried out using Spectrographic analyzer to determine the elemental composition. The result is shown in table (4.1). Also, the composition of the ferro- alloys: FeSi, MgFeSi and Graphite as revealed by the manufacturers are shown in tables 4.3, 4.4 and 4.5 respectively. The sleeve scraps of grey cast iron specification were carefully sorted and cleaned to avoid contamination during melting (Karsay, 1994). The scraps were appropriately sized with the aid of a sledge hammer to facilitate easy charging and fast melting in the furnace. More so, the other charged materials including ferro-alloys were pulverized into smaller sizes before they were charged into the rotary furnace.

3.5.4 Charge Calculation for Melting with Rotary Furnace

Table 3.1: Expected Chemical Composition of the Alloyed Ductile Iron

Sample No	C	Si	Mn	Ni	P	S	Mg	Fe
A	3.25-3.50	1.5-2.50	0.05-0.15	0.01-0.09	<0.005	<0.005	0.03-0.05	Bal.

To obtain in weight the quantity of the required metal scraps and alloying elements in order to carry out the melting process, the formula in equation 3.1, as proposed by Khanna, (2009) and Ziokowskia and Wrona (2007) was applied:

$$\begin{pmatrix}\text{Weight of the}\\ \text{element in kilogram}\end{pmatrix} = \begin{pmatrix}\text{weight of the total}\\ \text{charge or furnace capacity}\end{pmatrix} \times \begin{pmatrix}\text{fraction of element}\\ \textit{in the constituent}\end{pmatrix} \qquad (3.1)$$

Given that the furnace capacity or total charge = 10 kg

The targeted constituents for the alloy elements are: % Si = 1.8, % Mg = 0.04 and % C = 3.375.

Bearing in mind that there will definitely be loss of elemental constituent during melting, an appropriate percentage addition was introduced to balance the charge composition. For the ferro-alloys whose alloying elemental content exceeds 50 % (referred to as high value ferro-alloys), 8 - 10 % loss allowance is required during melting, while 15 - 20 % is allowed for low value ferro-alloys (Khanna, 2009 and Ziółkowskia and Wrona, 2007).

Hence, with high value ferro-alloy (Fe-73% Si) used for this research, 10% of the ferro-alloy was added to make up for the furnace losses incurred during melting. Also 20% alloy addition was introduced to make up for the loss incurred in the 5% Mg in the low value magnesium ferro-alloy used.

The quantity (in weight) of the ferro-alloys required in the furnace for the various heats was calculated thus;

I. For Ferro-73% Silicon Addition;

Weight of Fe-73% Si = 10 x (1.8/73 - 0.01522)

= 0.094 kg

With 10% FeSi addition due to elemental loss in furnace:

= 0.103 kg

II. For 5% MgFeSi Addition;

Weight of 5% MgFeSi = 10 x (0.04/5)

= 0.08 kg

With 20% MgFeSi addition due to elemental loss in the melt:

= 0.096 kg

III. For the Graphite Used;

Weight of 10% C Recarburizer = 10 x (3.35/66 - 0.03092)

= 0.1983 kg

With 10% C addition due to oxidation of carbon in the furnace:

= 0.218 kg

Following the weight compositions obtained from the charge calculation above for the percentage compositions of the ferro-alloys and graphite (carbon) used, table 3.2 represents the summary of the charge compositions required for melting.

Table 3.2: Weight Composition (kg) of the Alloying Element Charged into the Melt

Cast Iron Scrap (kg)	FeSi (kg)	MgFeSi (kg)	Graphite (kg)
10	0.103	0.096	0.218

3.6 MOULD

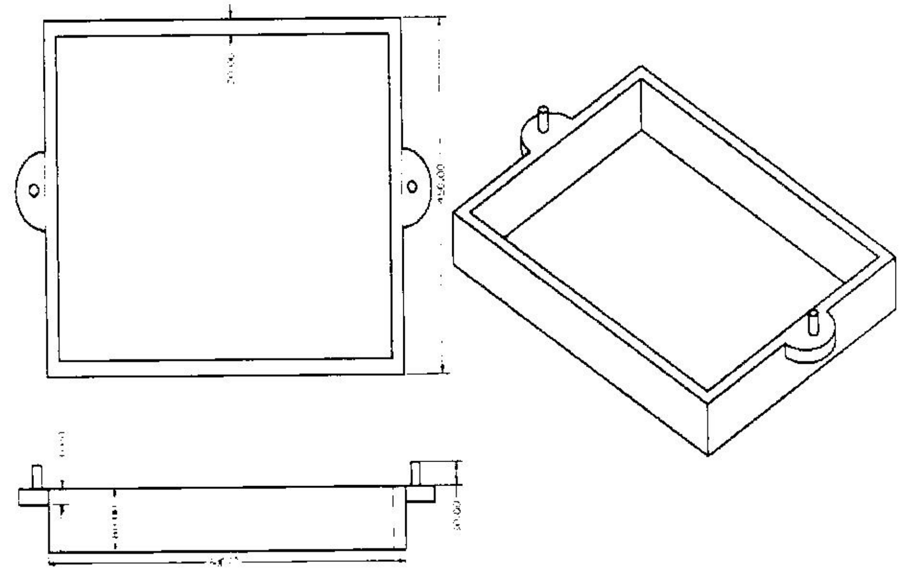


Figure 3.13: Drag Box

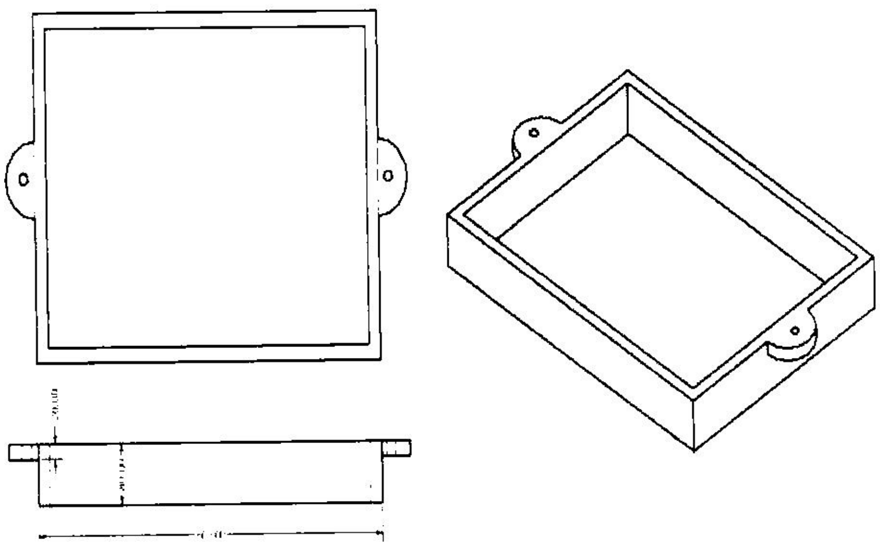


Figure 3.14: Cope Box

The figures 3.13 and 3.14 show the Moulding Box consisting Cope and Drag used for Ductile Iron Production.

3.6.1 CASTING METHOD

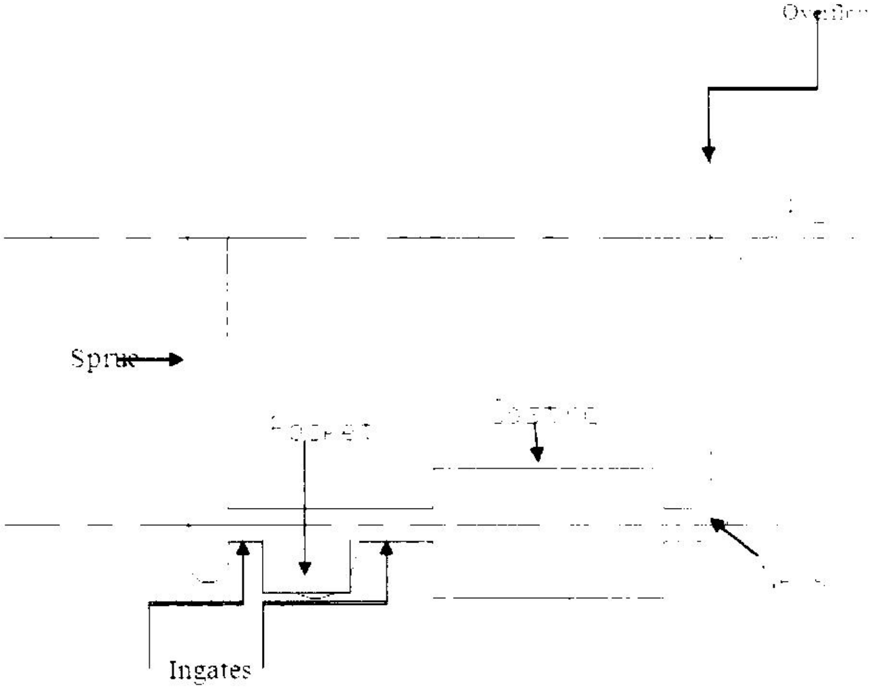


Figure 3.15: Schematic Diagram of Mould Produced

3.6.2 Dimension of the Mould Sections

Density of Molten Ductile Iron =6.98 x 10^{-6} kg/mm^3

Sprue dimension = 500 mm x Ø50 mm

Ingate dimension = 25 mm x 32 mm x 47 mm (2 locations)

Pocket dimension = 77 mm x 45 mm x 45 mm

Casting dimension = 300 mm x Ø60 mm

Riser dimension = 500 mm x Ø76 mm

Sprue dimension = 500 mm x Ø50 mm:

$V = \pi r^2 h$, where $D = 2r$, $r = \frac{D}{2}$ $V = \pi \frac{D^2}{4} h$ = 981,875 mm^3

Ingate dimension = 25 mm x 32 mm x 47 mm (2 locations) = 37,600 x 2 = 75,200 mm^3

Pocket dimension = 77 mm x 45 mm x 45 mm 155,925 mm^3

Casting dimension = 300 mm x Ø60 mm: $V = \pi \frac{D^2}{4} h$ = 848,340 mm^3

Riser dimension– 500 mm x Ø76 mm; $V = \pi \frac{D^2}{4} h$ $= 2,268,524\ mm^3$

The volume of the mould sections was estimated by adding the volume of the sprue, the ingates, pocket, casting and riser which gave a total of $4,329,864\ mm^3$.

Poured weight = Density of the molten ductile iron x Total volume of cast

$= (6.98 \times 10^{-6}) \times (4,329,864)$

= 30.222 kg or 30.2 kg

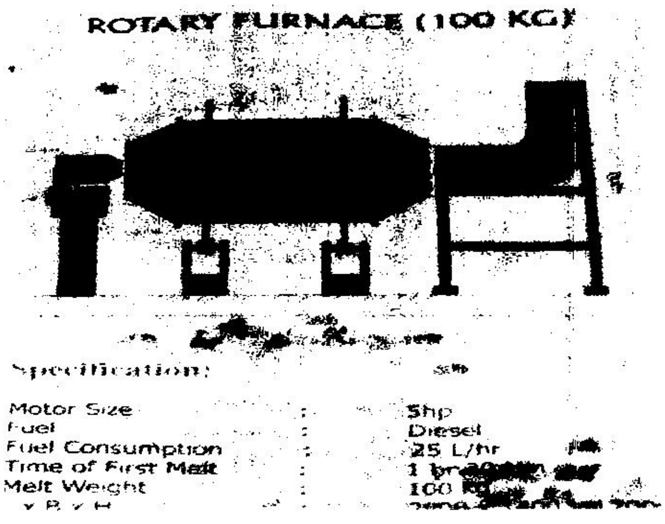
Cast weight = Density x V (Casting); where V (casting) is the volume of casting

$= (6.98 \times 10^{-6}) \times (848,340)$

= 5.92 kg or 6 kg (approx.)

3.7 ROTARY FURNACE

A 100 Kg rotary furnace is an example of a diesel-fired furnace which is very useful in carrying out operation having the following advantages, low cost of operation, fuel economy, low cost of manufacture, high thermal efficiency and low maintenance. It consists of a cylindrical steel drum lined with refractory material and supported by a structural steel frame, in between two conical frustums. The primary heat source of the furnace could be either a natural gas burner or a liquid fuel burner.



Specification:

Motor Size	:	5hp
Fuel	:	Diesel
Fuel Consumption	:	25 L/hr
Time of First Melt	:	1 hr [illegible]
Melt Weight	:	100 [illegible]
x B x H	:	[illegible]

Figure 3.16: Rotary Furnace (100 Kg)

3.8 PRODUCTION PROCESS OF DUCTILE IRON

A 100 kg capacity rotary furnace was pre-heated for about sixty minutes (1hr) before charging the 60 kg of broken cast iron sleeve scraps and graphite. The inoculant (FeSi) was added thereafter to the melt in the furnace. The molten metal was later tapped into the ladle which contains nodulizer (MgFeSi) in the pocket of the ladle resulting in a violent reaction that was observed for about 10 seconds before being poured into the mould to take the shape of the cavity created.

3.8.1 Equipment for the Melting Operation

The equipment used for carry out the melting operation includes the following:

i. 100 kg rotary furnace;
ii. Ladle;
iii. Ladle carrier etc.

3.8.2 Ladle Preparation

A ladle with 20mm mild steel sheet of capacity 40kg was lined with white silica sand bonded with sodium silicate, pocket of dimension 100mm diameter by 50mm depth was combined at the centre to accommodate the noduliriser. The sandwich process of ladle treatment was implemented for the nodulization process.

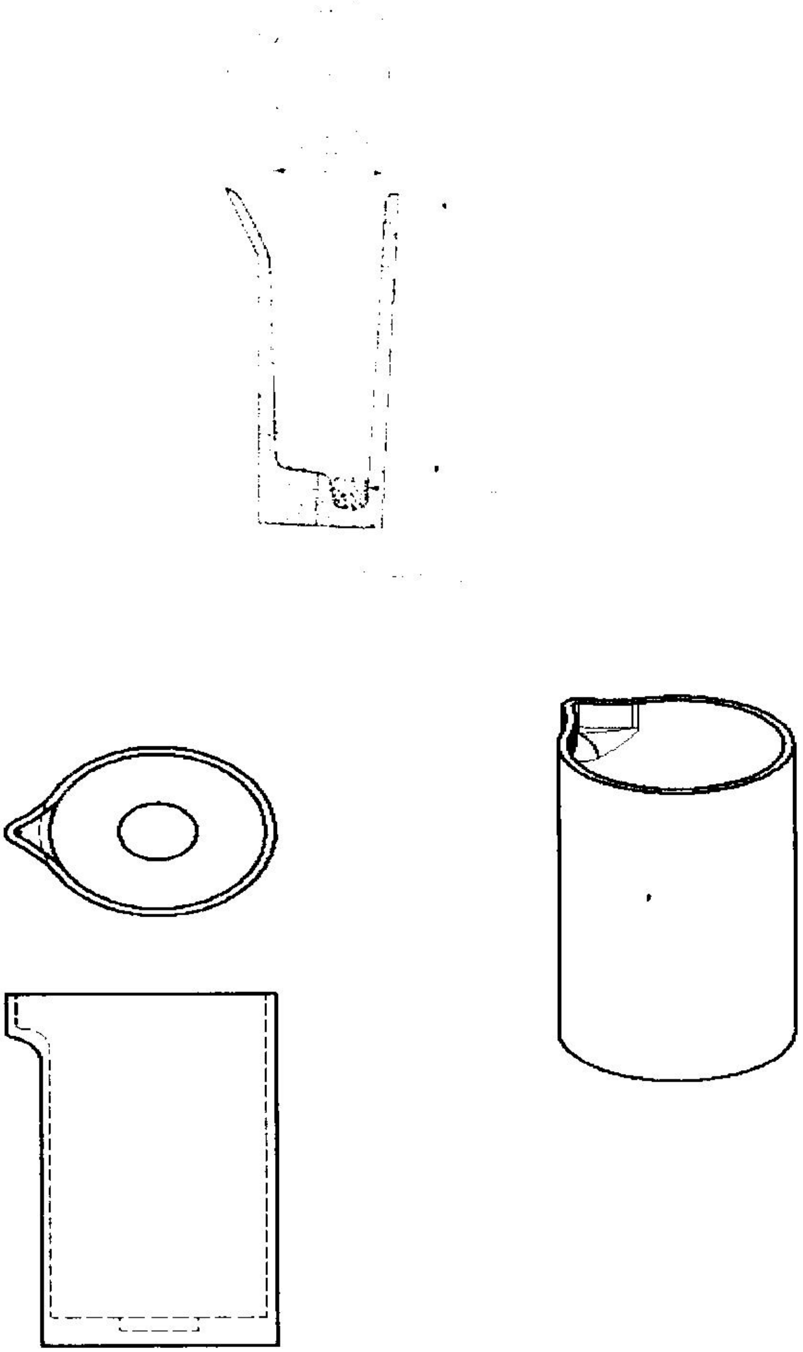


Figure 3.17: Ladle Design

Inoculation can be safely carried out in the range 0.2% to 0.75% for heavy ductile iron castings (Alasoluyi et al. 2013): to this end 0.24% inoculant was used as benchmark for inoculation in mould in this analysis.

Figure 3.18: Furnace Charging Hole

Figure 3.19: Ladle

Figure 3.20: Ladle Pocket

Figure 3.21: Ladle Carrier

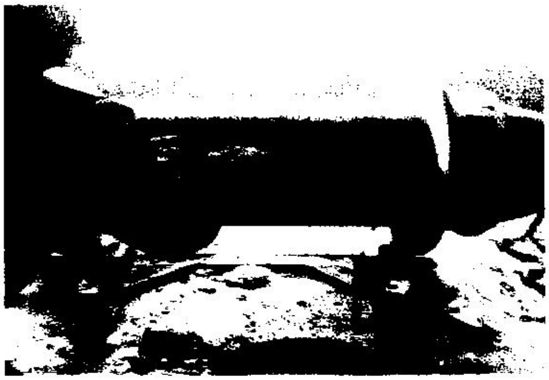


Figure3.22: After Charging of the Materials Figure 3.23: Firing Process Starts

Figure 3.24: Melt Ready for Tapping Figure 3.25: Tapping Process

Figure 3.26: Pouring Process

Figures 3.22- 3.26 showing the Melting Operation Process of the Ductile Iron production in100Kg Rotary Furnace and the Pouring Process from the Ladle into the Mould

3.8.3 Time and Temperature Recorded

The time and temperature recorded during the melting process can be seen in the table below:

Table 3.3: Time and Temperature Recorded after Charging

Time (minutes)	Inlet Temperature (°C)	Outlet Temperature (°C)
15	1,598	1,041
30	1,659	1,244
45	1,604	1,407
60	1,551	1,498

Preheating time was estimated to be 1 hour with an average temperature of 1500°C, the centre maximum tapping temperature was 1,661°C, whereas the molten metal in the ladle before being poured into the mould had a temperature of 1,349°C.

3.9 TESTING AND EXAMINATIONS

The various tests conducted were chemical analysis, microstructural examination, microhardness test and tensile test.

3.9.1 Chemical Analysis

Spectrography Analysis in Materials and Metallurgical Laboratory at University of Lagos was used in the analyses of the two produced as-cast ductile iron samples. A small section was cut out from the two materials and subjected to spark analysis to reveal their elemental compositions. The result is as shown in table (4.2) for the respective materials.

Figure 3.27: Filing Process

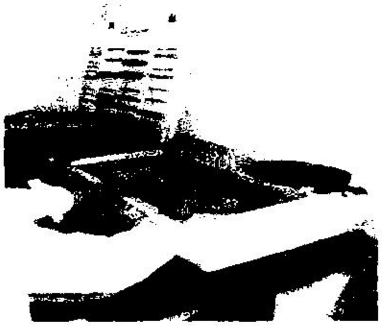


Figure 3.28: Grinding Process

Figure 3.29: Checking Process

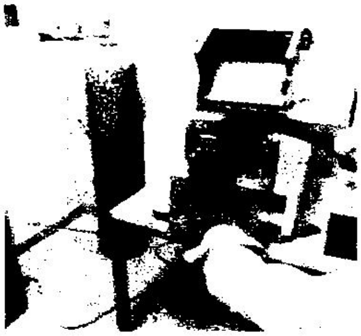


Figure 3.30: Placing Process

Figure 3:31: Closing Process

Figure 3.32: Running Process

3.9.2 Microstructural Examination

Nikon Eclipse ME600 metallurgical optical microscope of 800 maximum magnifications at E.M.D.I., Akure was used to carry out the microstructural examination for the two as-cast alloys samples. The micrographs for the two samples are shown in plates 1, 2, 3 and 4.

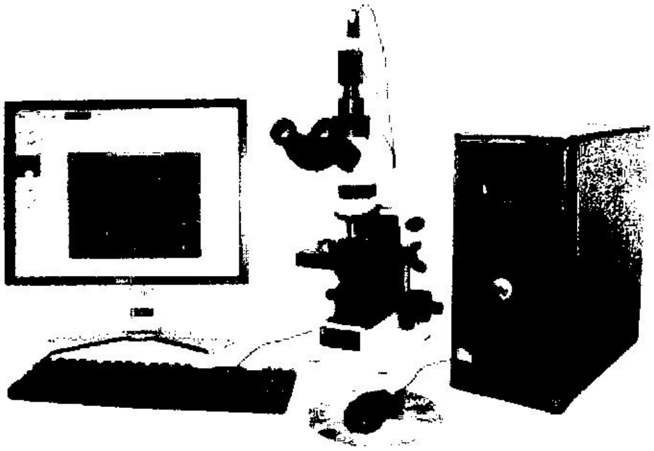


Figure 3.33: Metallurgical Optical Microscope of 800 maximum Magnification

3.9.3 Hardness Test

In accordance with ASTM E384 (Standard test method for microhardness of materials) the hardness test for the cast samples was conducted at E.M.D.I. using LECO Vickers Micro-hardness Tester of model LM700AT of 50mHv. The microhardness values for the two as-cast samples are shown in tables 4.8.

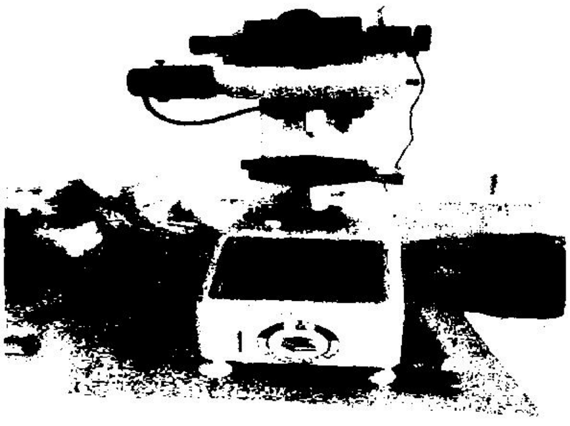


Figure 3.34: Vicker's Hardness Tester

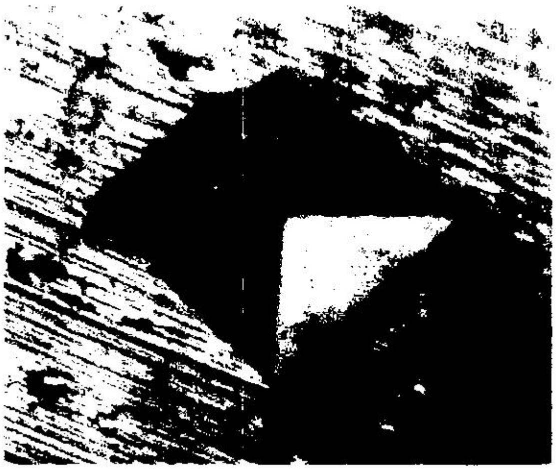


Figure 3.35: Specimen showing Indentation

3.9.4 Tensile Test

The standard test samples were then prepared for mechanical test, Instron universal testing machine at E.M.D.I. of 50KN capacity was used to carry out the tensile test. The tensile values for the two as-cast samples are shown in table 4.6 and 4.7.

Specification for Spherical Ductile Iron

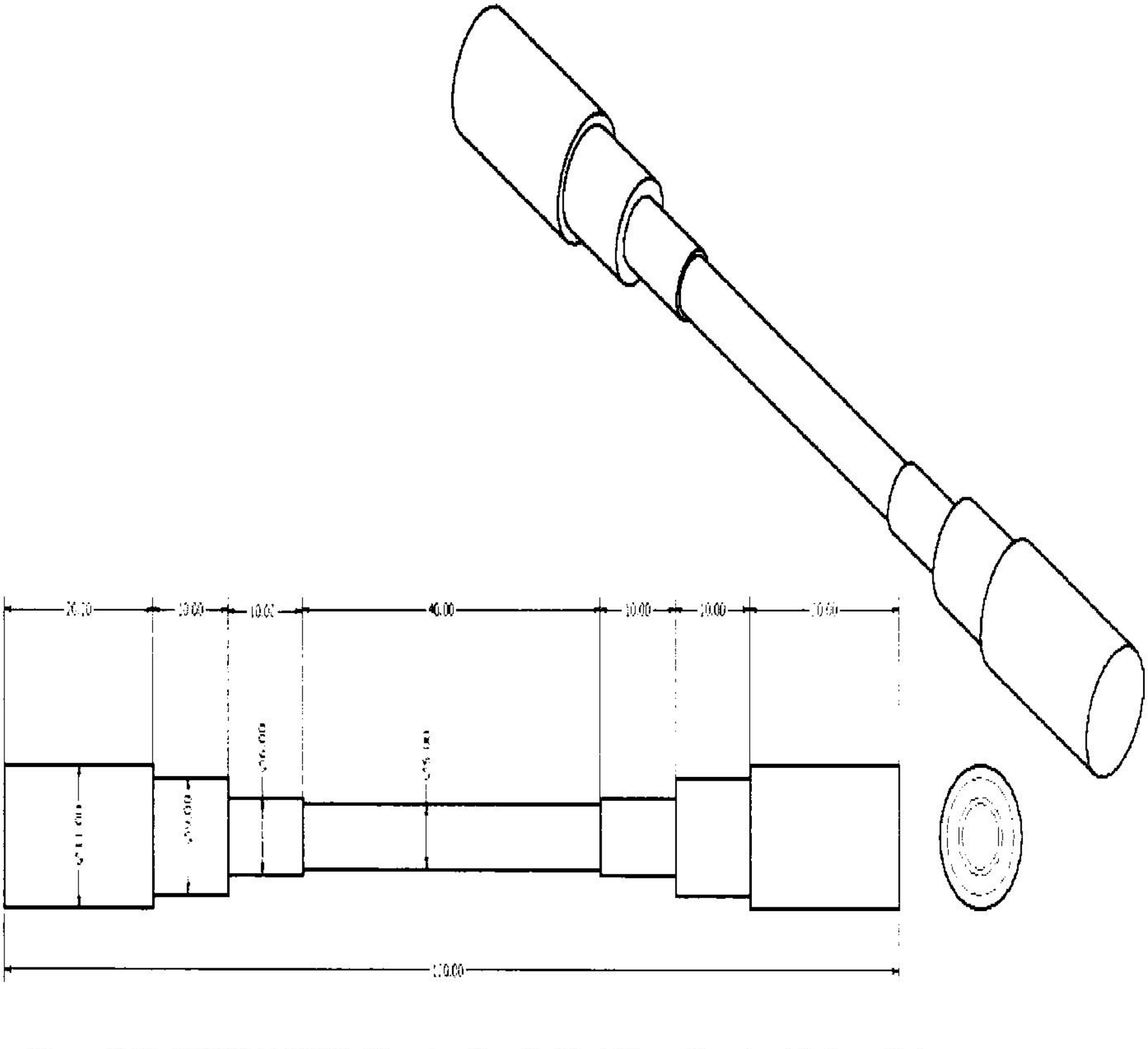


Figure 3.36: EMDI (ASTM) Circular Tensile Test Piece Standard 2-Step Grip

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 RESEARCH RESULTS

4.1.1 Chemical Composition of Charged Materials

The spark analysis of the cast iron sleeve scraps (the base metal) and the as cast ductile iron were carried out with the aid of Spectrographic analyzer and the results were shown in table 4.1 and 4.2 respectively. The composition of the graphite, nodulizer and inoculant used were stated in table 4.3, 4.4 and 4.5 respectively with reference to the manufacturers.

Table 4.1: **Composition of Cast Iron Sleeve Scraps Used for the Production of the Ductile Iron (wt. %)**

Fe	93.506	**Al**	0.00148
C	3.092	**Cu**	0.149
Si	1.522	**Ti**	0.036
Mn	0.749	**V**	0.03
P	0.263	**W**	0.0001
S	0.05	**Nb**	0.0001
Cr	0.378	**Mo**	0.071
Ni	0.137	**B**	0.002

Table 4.2: Composition of As-Cast Ductile Iron Produced (wt. %)

Element	Fe	C	Si	Mn	P	S	Cr	Ni
Percentage %	91.46	>2.465	2.156	0.1721	0.0735	>0.181	0.0545	0.1670
Element	**Mo**	**Cu**	**Al**	**Ti**	**V**	**Co**	**Nb**	**W**
Percentage %	0.2564	0.1735	0.1465	0.0157	0.0075	0.0160	0.1097	<2.427

Table 4.3: Composition of the Graphite Used

Carbon %	Ash %	Volatiles %	Sulphur %	Moisture %
66.00	30.20	3.10	0.570	0.10

Table 4.4: Composition of the Nodulizer (MgFeSi) Used for Treating Cast Iron Melt

CODE	CHEMICAL COMPOSITION (%)						
	Si	**Mg**	**Ca**	**RE**	**Sb**	**Al**	**Fe**
ZFSB-5	42 - 44	4.8 - 5.2	Moderate	0.8 - 1.2	Moderate	< 1.0	Bal.

Table 4.5: Composition of the Inoculant (FeSi) Used for Treating Cast Iron Melt

CHEMICAL COMPOSITION (%)					
Si	**RE**	**Al**	**Cu**	**Ba**	**Fe**
72.5	1.75	1	1	-	Bal.

4.1.2 Micrograph of the As-Cast Ductile Iron

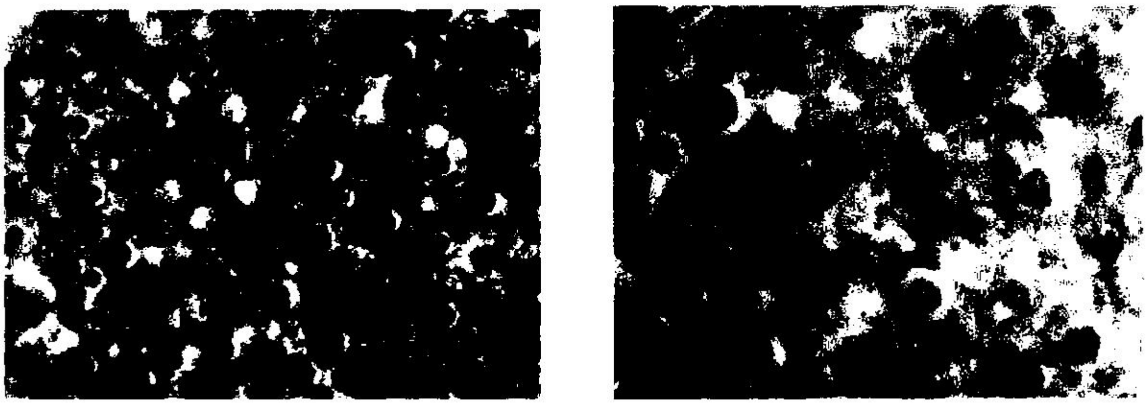


Plate 1: A X50 **Plate 2: A X100**

PLATES 1 and 2: Micrograph of the as-cast ductile iron showing graphite nodules in pearlitic matrix. Etched with 4% Nital

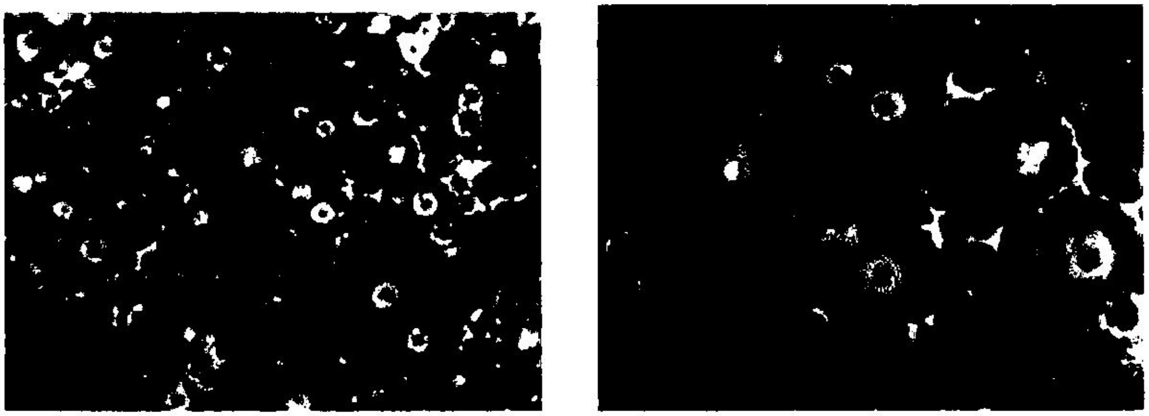


Plate 3: B X50 **Plate 4: B X100**

PLATES 3 and 4: Micrograph of the as-cast ductile iron showing graphite nodules in pearlitic matrix. Etched with 4% Nital

4.1.3 Tensile Test Result of the Ductile Iron Produced

Table 4.6: Tensile Test Result for Specimen A & B from the Raw Data

Sample A			**Sample B**		
Tensile Stress (MPa)	Length (mm)	Diameter (mm)	Tensile Stress (MPa)	Length (mm)	Diameter (mm)
324.883	40	5	362.049	60	5

Calculations

The calculations that are involve for Specimen A and B include percentage elongation, percentage reduction and Yield strength.

Specimen A

The parameters needed for the percentage elongation, percentage reductions and the yield strength in specimen A are:

Original Length (L_o) = 40 mm

Final Length (L_f) = 45 mm

Original Diameter (D_o) = 5 mm

Original Diameter (D_f) = 4 mm

Load at Break (L) = 6379.05449 N

Area (A) = 0.19635 cm^{-2} = 1963.5 m^2

$$A_o = \frac{\pi D^2}{4} = \frac{3.142 \times 5^2}{4} = 19.63 \text{ mm}^2$$

$$A_f = \frac{\pi D^2}{4} = \frac{3.142 \times 4^2}{4} = 12.56 \text{ mm}^2$$

The percentage elongation (%) $= \frac{\Delta L}{L_o} \times 100\,\% = \frac{L_f - L_o}{Lo} = \frac{45-40}{40} \times 100\,\% = \mathbf{12.5\,\%}$

The percentage reduction (%) $= \frac{\Delta A}{Ao} \times 100\,\% = \frac{A_o - A_f}{Ao} = \frac{19.63-12.56}{19.63} \times 100\,\% = \mathbf{35.96\,\%}$

Yield strength $= \frac{Load\ at\ Break\ (N)}{Area\ (m^2)} = \frac{6379.05449}{1963.5} = \mathbf{3.2488\ N/m^2}$

Specimen B

The parameters needed for the percentage elongation, percentage reductions and the yield strength in specimen B are:

Original Length (L_o) = 60 mm

Final Length (L_f) = 70 mm

Original Diameter (D_o) = 5 mm

Original Diameter (D_f) = 4 mm

Load at Break (L) = 7108.81278 N

Area (A) = 0.19635 cm^{-2} = 1963.5 m^2

Area (A) = 0.19635 cm^{-2} = 1963.5 m^2

$A_o = \frac{\pi D^2}{4} = \frac{3.142 \times 5^2}{4} = 19.63\ mm^2$

$A_f = \frac{\pi D^2}{4} = \frac{3.142 \times 4^2}{4} = 12.56\ mm^2$

The percentage elongation (%) $= \frac{\Delta L}{L_o} \times 100\,\% = \frac{L_f - L_o}{Lo} = \frac{70 - 60}{60} \times 100\,\% = \mathbf{16.67}\,\%$

The percentage reduction (%) $= \frac{\Delta A}{Ao} \times 100\,\% = \frac{A_o - A_f}{Ao} = \frac{19.63 - 12.56}{19.63} \times 100\,\% = \mathbf{35.96}\,\%$

Yield strength $= \frac{Load\ at\ Break\ (N)}{Area\ (m^2)} = \frac{7108.81278}{1963.5} = \mathbf{3.62048}\ N/m^2$

Table 4.7: Tensile Test Result for Specimen A & B

Material/Rate of Fracturing	Tensile Stress (MPa)	% Elongation to fracture	%Reduction of Area	Time to Fracture (s)
As-Cast Ductile Iron (A)	324.883	12.5	35.96	15.2
As-Cast Ductile Iron (B)	362.049	16.7	35.96	14.4
Average Values	**343.466**	**14.6**	**35.96**	

4.1.4 Hardness Test Result of the As-Cast Ductile Iron

Table 4.8: Hardness Result for Specimen A & B

HV		HRC	
Sample A	**Sample B**	**Sample A**	**Sample B**
349.9	342.0	35.5	34.0
370.9	344.2	37.8	34.9
363.1	347.7	37.7	35.3
361.3	**344.6**	**36.7**	**34.9**
Average = 352.95 HV		**Average = 35.8 HRC**	

4.2 DISCUSSION

4.2.1 Microstructure Examination

Plates 1, 2, 3 and 4 showed the micrographs of as-cast ductile iron produced. The structure shows mainly pearlite network around the ferrite ring with graphite nodules embedded inside the ring. The addition of ferrosilicon as inoculant enhances the fluidity of the molten metal and is also responsible for the formation of the ferrite rings around the graphite nodules, giving rise to BULLS EYE structure. Graphite addition functions as recarburizer which accounted for the carbon equivalent of the produced ductile iron. The introduction of the magnesium ferro silicon (MgFeSi) serves as the nodulizer which is responsible for the transformation of the morphology of the graphite flakes to spheroids (nodules), impacting a combined property of ductility and strength to metallurgical overcome the brittle nature of grey cast iron needed in several engineering application.

4.2.2 Mechanical Properties of the As-Cast Ductile Iron

The mechanical test of the as-cast ductile iron namely- tensile test and hardness test are shown in tables 4.7 and 4.8 respectively. The average hardness value of the as-cast ductile iron is 352.95 HV or 35.8 HRC. The average tensile test result obtained for the as-cast ductile iron which is 343.466 MPa corresponds with the ISO standard tensile strength characterization of 350 N/mm^2. The percentage elongation of the as-cast specimen of %14.6 also correlates with the ISO standard value with %22 maximum and according to Bishnu, 2014, the tensile strength is the common basis for the material designation or characterization.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Ductile Iron that corresponds with ISO standard was successfully produced from automobile sleeves scraps (solid waste). The ductile iron material find application in many engineering fields – it can be a direct replacement for carbon steel bars in a number of gears in the automotive, hydraulic, machine tool, and other industries. Generally, the ductile iron casting produced can be widely used in industrial areas most especially, agricultural and automotive in the production of components such as bushings, brakes, steering, crankshaft, wrenches, pulleys, brackets and cranes. This will further assist in building the our local technology and also reduce dependency of foreign importation of parts which have adverse effect on the nation's economy.

5.2 Recommendation

Whereas this work highlighted the conversion of automobile sleeve scraps to ductile iron, other scraps materials from machine parts that are disposed indiscriminately in the environment which contribute to the burden of solid waste could be venture into and converted to other useful engineering products, in order to minimize the menace of environmental pollution which leads to numerous health hazards and mortality.

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