EFFECT OF COMPOSITIONAL CHANGES ON MECHANICAL PROPERTIES OF GREY IRON THROUGH CASTING OF GUTTER GRATINGS

By

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CERTIFICATION

This is to certify that this project work was carried out by **MATHEW SAMUEL TUNDE** with matriculation number **HND/23/MEC/FT/0052** has met the requirement and regulations governing the award of Higher National Diploma (HND) in Mechanical Engineering, Kwara State Polytechnic, Ilorin and under the supervision of the project supervisor.

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DEDICATION

This project is dedicated to the supreme Architect of the universe, who designed the blueprint for life and guided my efforts.

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Thank you for being part of this engineering feat.

ABSTRACT

This research work investigates the effect of compositional changes on mechanical properties of grey cast iron through casting of gutter grating. The effect of varied FeSi inoculants on the mechanical property of grey cast iron samples produced in a green sand mould was carried out. The charge was melted in a rotary furnace and poured into the green sand moulds with different ladle inoculation of 0.1% FeSi, 0.2% FeSi, and 0.3% FeSi respectively. Also the melt was poured into another green sand mould without ladle inoculated. The mechanical tests were then carried out on the prepared test specimens gotten from the various samples of each percentage of varied ferro-silicon and on the un-inoculated cast samples. Result shows that the higher the carbon equivalent value of the grey cast iron, the lower the tensile strength and hardness.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of Study

Cast irons make up a family of ferrous metals with a wide range of mechanical properties They are produced by being cast into shape as opposed to being formed This makes them particularly suitable for the manufacture of engineering components. The widespread use of cast iron results from its low cost and versatility. Is versatility arises due to the wide ranging physical properties which are possible due to alloy addition and various heat treatment procedures.

Grey cast iron is named after its grey fractured surface, which occurs because the graphitic flakes deflect a passing crack and initiate countless new cracks as the material breaks Gray iron is one of the oldest cast ferrous products. In spite of competition from newer materials and their energetic promotion, gray i.

Iron is still used for those applications where its properties have proved it to be the most suitable material available. Next to wrought steel, gray iron is the most widely used metallic material for engineering purposes. There are several reasons for its popularity and widespread use. It has a number of desirable characteristics not possessed by any other metal and yet is among the cheapest of ferrous materials available to the engineer.

Gray iron is one of the most easily cast of all metals in the foundry. It has the lowest pouring temperature of the ferrous metals, which is reflected in its high fluidity and its ability to be cast into intricate shapes. As a result of a peculiarity during final stages of solidification, it has very low and, in some cases, no liquid to solid shrinkage so that sound castings are readily obtainable. For the majority of applications, gray iron is used in its as-cast condition, thus simplifying production. Gray iron has excellent machining qualities producing easily disposed of chips and yielding a surface with excellent wear characteristics. The resistance of gray iron to scoring and galling with proper matrix and graphite structure is universally recognized.

The properties of grey cast iron are affected by many factors simultaneously. The most important factors, which influence the mechanical quality of cast iron are:

- Chemical structure (chemical composition)
- Metallurgical factors influencing crystallization.
- Treatment of the cake fusion.
- Cooling conditions

However, the chemical composition of the iron is assumed to be the most important factor by many researchers and producers, and therefore its change is treated as a simple technique for regulating and ensuring the required mechanical properties.

Surprisingly enough, in spite of gray iron being an old material and widely used in engineering construction, the metallurgy of the material has not been understood until comparatively recent times: In spite of the widespread use of gray iron, the metallurgy of it is not clearly understood by many users and even producers of the material, and It is known that the deceleration of crystallization in the process of solidification, which is typical for many-ton castings, worsens considerably the mechanical properties of gray iron. The properties of such castings cannot be changed substantially even by alloying. The recommendations made in available works do not give rational solutions of this problem for large-size iron castings. Therefore the problem of improving the strength of such casting remains important (Melnikov, 2003). One of the first and most complete discussions of the mechanism of solidification of cast irons was presented in 1946 by Boyles (Boyles, 1942). The most recent review of cast iron metallurgy and the formation of graphite (Wiser et al., 1972).

The development and extensive use of a procedure to indicate the carbon equivalent value of the molten iron at the melting furnace is described by Redshaw and Payne (Redshaw, 1962) and (Kasch, 1963). This test enables the foundryman to control the composition of the iron within narrower limits and thus ensures more uniform properties of the castings.

The addition of small amounts of tin was instrumental in improving the properties of gray iron in the heavier sections without creating hardness problems in the lighter sections. The improved properties obtained with high-purity raw materials in making gray iron should stimulate further investigations particularly in regard to obtaining greater toughness. There is a need for a grade of iron between conventional gray iron and nodular iron providing it can be made with the same ease as gray iron. The large investments in gray iron foundries during the past few years is an indication that gray iron will be considered a valuable engineering material for some time to come.

1.2 Aim of the Research Work

The aim of this project is to investigate the effect of compositional changes on the Hardness, Tensile strength of gray cast iron through casting of gutter grating.

1.3 Objective of the research work are to;3

(1) Determine the right chemical composition which will give the required Hardness, Tensile strength of gray cast iron through casting of gutter grating.

(2) Determine the effects of variation of each alloying elements in gray cast iron, and on its Hardness, Tensile strength.

(3) Investigate the effect of variation of carbon equivalents in gray cast iron on its matrix and graphite structure which are direct factors determining its mechanical properties.

1.4 Justification

It is known that the deceleration of crystallization in the process of solidification, which is typical for many-ton castings, worsens considerably the mechanical properties of gray cast iron.

The purposes of this research is justified by investigating the effect of compositional changes on the Hardness, Tensile strength, of gray cast iron for ensuring and regulating the required mechanical property and also reduce early failures in grey castings(This especially can be seen in large castings of gray cast iron).

CHAPTER TWO

2.0 LITERATURE REVIEW

The literature review analyzes past efforts in the effect of compositional changes on mechanical changes properties of grey cast iron through casting of Gutter Grafting and identifies the gaps that this project will address:

Table 2.1: Literature Review

AUTHOR	CONTRIBUTION	LIMITATIONS
lee, j., & Kim, B. (2018)	Effect of carbon content on the microstructure and mechanical properties of grey iron. Journal of Materials Science, 53(10), 7233-7242.	The study might have only focused on the effect of carbon content, without considering other compositional changes or alloying elements that could impact mechanical properties.
Chen, Y., & Liu, X. (2020).	Influence of silicon content on the microstructure and mechanical properties of grey iron. Materials Science and Engineering A, 774, 138924.	The research focused on how silicon content affects the microstructure and mechanical properties of grey iron.
Kim, J., & Lee, S. (2019).	Effect of manganese addition on the microstructure and mechanical properties of grey iron. Journal of	The study focused on the effect of manganese addition on grey iron's microstructure and mechanical properties. However, other alloying

	Alloys and Compounds, 785, 1234-1242.	elements or compositional changes might also impact the material's performance in gutter grating applications.
Wang, Y., & Zhang, J. (2017).	Influence of chromium addition on the microstructure and mechanical properties of grey iron. Materials Science and Technology, 33(10), 1230-1238.	The study focused on the influence of chromium addition on grey iron's microstructure and mechanical properties. However, other alloying elements or compositional changes might also impact the material's performance.
Ding et al. (2018)	Investigated the effect of Mo addition on the microstructure and mechanical properties of grey cast iron. Found that Mo addition refined the microstructure and improved the mechanical properties.	The study focused on a specific range of Mo content, and the results may not be applicable to other compositional ranges.
Janowak and Gundlach (1982)	Studied the effect of alloying elements on the microstructure and mechanical properties of grey cast iron. Found that careful control of composition can lead to	The study was conducted using a specific set of alloying elements, and the results may not be generalizable to other elements.

	improved mechanical properties.	
Kovacs and Keough (1993)	Investigated the physical properties and applications of austempered grey iron. Found that austempering can produce a microstructure with high strength and toughness.	The study focused on austempered grey iron, and the results may not be directly applicable to other types of grey cast iron.

2.1 Cast Iron

Cast iron is made when pig iron is re-melted in small cupola furnaces (similar to the blast furnace in design and operation) and poured into moulds to make castings. Cast Iron is generally defined as an alloy of Iron with greater than 2% Carbon, and usually with more than 0.1% Silicon. Cast Irons are a family of ferrous metals with a wide range of properties produced by being cast into shape as opposed by being formed Cast Irons contain 2% to 4% Carbon and 1% to 3% Silicon, as well as other elements such as manganese (Mn), phosphorus (P), and sulphur(S), and with the balance made of iron.

2.1.1 Types of Cast Iron

(1) White Iron: large amount of carbide phases in the form of flakes, surrounded by a matrix of either Pearlite or Martensite. The result of metastable solidification has a white crystalline fracture surface because fracture occurs along the iron carbide plates considerable strength, insignificant ductility.

(2) Gray Iron: Graphite flakes surrounded by a matrix of either Pearlite or a- Ferrite Exhibits gray fracture surface due to fracture occurring along Graphite plates.

The product of a stable solidification considerable strength, insignificant ductility.

(3) Ductile (Nodular) Iron: Graphite nodules surrounded by a matrix of either - Ferrite, Bainite, or Austenite. Exhibits substantial ductility in its as cast form.

(4) Malleable Iron: cast as White Iron, then malleabilized, or heat treated, to impart ductility. Consists of tempered Graphite in an a-Ferrite or Pearlite matrix.

Sub Classifications

(1) Chilled Iron: White Iron that has been produced by quenching through the solidification temperature range.

(2) Mottled Iron Solidifying at a rate with extremes between those for chilled and gray irons, thus exhibiting micro-structural and metallurgical characteristics of both.

(3) Compacted Graphite Cast Iron: consists of a microstructure similar to that of Gray Iron, except that the graphite cells are coarser and more rounded. Namely, it consists of a microstructure having both characteristics of Gray and Ductile Irons

(4) High-Alloy Graphitic Irons: produced with microstructures consisting of both flake and nodule structures. Mainly utilized for applications requiring at combination of high strength and corrosion resistance.

2.1.2 Uses and application of cast iron

Cast iron tends to be brittle, except for malleable cast irons. With its relatively low melting point, good fluidity, castability, excellent machinability, resistance to deformation and wear resistance, cast irons have become an engineering material with a wide range of applications and are used in pipes, machines and automotive industry parts, such as cylinder heads (declining usage), cylinder blocks and gearbox cases (declining usage). It is resistant to destruction and weakening by oxidation (rust).

2.2 Gray Cast Iron

Grey Cast Iron is so called because of the colour of the fracture face. Gray irons usually contain 2.5 to 4% C, 1 to 3% Si, and additions of manganese, depending on the desired microstructure (as low as 0.1% Mn in ferritic gray irons and as high as 1.2% in pearlitics). Sulphur and phosphorus are also present in small amounts as residual impurities (Wieser, et al., 1967).

The composition of gray iron must be selected in such a way to satisfy three basic structural requirements:

- The required graphite shape and distribution
- The carbide-free (chill-free) structure
- The matrix structure

Microscopically, all gray irons contain flake graphite dispersed in a silicon- iron matrix. How much graphite is present, the length of the flakes and how they are distributed in the matrix directly influence the properties of the iron The basic strength and hardness of the iron is provided by the metallic matrix in which the graphite occurs. The presence of the graphite provides several valuable characteristics to cast iron. These include:

- The ability to produce sound castings economically in complex shapes such as water cooled engine blocks.
- Good machinability even at wear resisting hardness levels and without burring.

- Dimensional stability under differential heating such as in brake drums and disk.

2.3 Microstructure and Mechanical Properties

The usual microstructure of gray iron is a matrix of pearlite with graphite flakes dispersed throughout. Foundry practice can be varied so that nucleation and growth of graphite fakes occur in a pattern that enhances the desired properties. The amount, size, and distribution of graphite are important. Cooling that is too rapid may produce so-called chilled iron, in which the excess carbon is found in the form of massive carbides. Cooling at intermediate rates can produce mottled iron, in which carbon is present in the form of both primary cementite (iron carbide) and graphite.

Flake graphite is one of seven types (shapes or forms) of graphite established in ASTM A 247. Flake graphite is subdivided into five types (patterns), which are designated by the letters A through E. Graphite size is established by comparison with an ASTM size chart, which shows the typical appearances of flakes of eight different sizes at 100x magnification. Type A flake graphite (random orientation) is preferred for most applications. In the intermediate flake sizes, type A flake graphite is superior to other types in certain wear applications such as the cylinders of internal combustion engines.

Type B flake graphite (rosette pattern) is typical of fairly rapid cooling, such as is common with moderately thin sections (about 10 mm) and along the surfaces of thicker sections, and sometimes results from poor inoculation.

The large flakes of Type C flake graphite are formed in hypereutectic irons. These large flakes enhance resistance to thermal shock by increasing thermal conductivity and decreasing elastic modulus. On the other hand, large flakes are not conducive to good surface finishes on machined parts or to high strength or good impact resistance.

The small, randomly oriented interdendritic flakes in Type D flake graphite promote a fine machined finish by minimizing surface pitting, but it is difficult to obtain a pearlitic matrix with this type of graphite. Type D flake graphite may be formed near rapidly cooled surface or in thin sections. Frequently, such graphite is surrounded by a ferrite matrix, resulting m soft spots in the casting.

Type E flake graphite is an interdendritie form, which has a preferred rather than a random orientation Unlike type D graphite, type E graphite can be associated with a pearlitic matrix and thus can produce a casting whose wear properties are as good as those of a casting containing only type A graphite in a pearlitic matrix. There are, of course, many applications in which flake type has no significance as long as the mechanical property requirements are met (Internet reference: no 3).

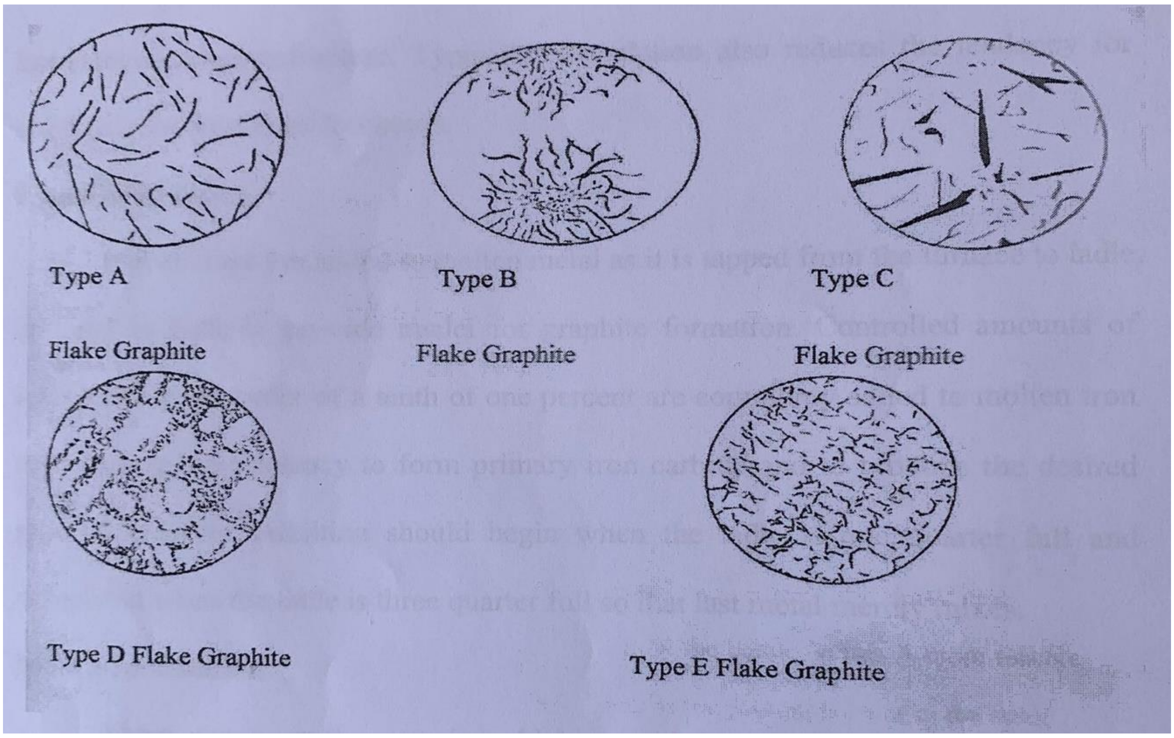


Fig. 2.1: Showing the types of various flake graphite

2.4 Grey Iron Inoculation

2.4.1 What is Inoculation

Inoculation is a means to control and improve the microstructure and mechanical properties of cast iron. The inoculation process will provide sufficient nucleation sites for the dissolved carbon to precipitate as graphite rather than iron carbides (cementite). The most common inoculants is a ferrosilicon based alloy with small and defined quantities of either Ca, Ba, Sr, Zr, rare earth's, and Al. Consequently, the effects of grey and inoculation are improved machineability, increased strength and ductility, reduced hardness and section sensitivity and a more homogeneous microstructure. Typically, inoculation also reduces the tendency for solidification shrinkage formation.

Ladle Inoculation

Inoculations are added to molten metal as it is tapped from the furnace to ladle, or ladle to ladle to provide nuclei for graphite formation. Controlled amounts of inoculants in the order of a tenth of one percent are commonly added to molten iron to minimize the tendency to form primary iron carbide and to produce the desired type of graphite. Addition should begin when the ladle is one quarter full and completed when the ladle is three quarter full so that last metal merely mixes.

Mould Inoculation

There are several ways in which mould inoculation can be performed Powdered inoculants can be placed in the pouring bush, or it can be placed at the bottom sprue. A more reliable method is to use pre-cast slugs or sachets of inoculants in the pouring bush or in the running system.

Alloy addition

The various alloys present in grey iron may be classified as either graphitizers or carbide stabilizers, depending on the influences on iron during solidification. Carbon, silicon, aluminium, titanium, nickel and copper are called graphitizers because they tend to promote the formation of graphite in the iron during solidification. Manganese, molybdenum, chromium are stabilizers, since they retard graphite precipitation and increase the tendency to form iron carbides. The tendency of all additions in moderate amount (except for an increase in carbon and silicon) is to increase the hardness and strength of grey irons.

Ferro-alloys

Silicon, manganese, chromium, phosphorus and molybdenum may all be added in form of ferro-alloys. Ferro-silicon in lump form, containing either 75 - 80% or 45-50% Si may be used. Ferro-manganese in lump form contains 75 - 80% Mn. Both must be accurately weighed before adding to the charge.

2.5 Effect of Compositional Changes on Properties of Gray Cast Iron

The properties of gray iron are primarily dependent on its composition. Gray iron is commercially produced over a wide range of compositions. Foundries melting the same specifications may use different compositions to take advantage of lower cost raw materials locally available and the general nature of the type of castings produced in the foundry. For these reasons, inclusion of chemical composition in purchase specifications for castings should be avoided unless essential to the application. The range of compositions which one may find in gray iron castings is as follows: total carbon, 2.75 to 4.00 percent; silicon, 0.75 to 3.00 percent, manganese, 0.25 to 1.50

percent; sulphur, 0.02 to 0.20 percent, phosphorus, 0.02 to 0.75 percent. One or more of the following alloying elements may be present in varying amounts molybdenum, copper, nickel, vanadium, titanium, tin, antimony, and chromium. Nitrogen is generally present in the range of 20 to 92 ppm.

The concentration of some elements may exceed the limits shown above, but generally the ranges are less than shown.

Carbon is by far the most important element in gray iron. With the exception of the carbon in the pearlite of the matrix, the carbon is present as graphite. The graphite is present in flake form and as such greatly reduces the tensile strength of the matrix. It is possible to produce all grades of iron of ASTM Specification for Gray Iron Castings (A 48 - 64) by merely adjusting the carbon and silicon content of the iron. It would be impossible to produce gray iron without an appropriate amount of silicon being present. The addition of silicon reduces the solubility of carbon in iron and also decreases the carbon content of the eutectic. The eutectic of iron and carbon is about 4.3 percent. The addition of each 1.00 percent silicon reduces the amount of carbon in the eutectic by 0.33 percent. Since carbon and silicon are the two principal elements in gray iron, the combined effect of these elements in the form of percent carbon plus percent silicon is termed carbon equivalent (CE). Carbon equivalent value (CEV) = %TC+[%(Si+P/(3)]

Gray irons having a carbon equivalent value of less than 4.3 percent are designated hypoeutectic irons, and those with more than 4.3 percent carbon equivalent are called hypereutectic irons. For hypoeutectic irons in the automotive and allied industries, each 0.10 percent increase in carbon equivalent value decreases the tensile strength by about 2700 psi. If the cooling or solidification rate is too great for the carbon equivalent value selected. The iron may freeze in the iron-iron carbide metastable system rather than the stable iron-graphite system, which results in hard or chilled edges on castings. The carbon equivalent value may be varied by changing either or both the carbon and silicon content. Increasing the silicon content has a greater effect on reduction of hard edges than increasing the carbon content to the same carbon equivalent value.

Silicon has other effects than changing the carbon content of the eutectic. Increasing the silicon content decreases the carbon content of the pearlite and raises the transformation temperature of ferrite plus pearlite to austenite.

Manganese the most common range for manganese in gray iron is from 0.55 to 0.75 percent. Increasing the manganese content tends to promote the formation of pearlite while cooling through the critical range. It is necessary to recognize that only that portion of the manganese not combined with sulphur is effective.

Sulphur Virtually, all of the sulphur in gray iron is present as manganese sulphide, and the manganese necessary for this purpose is 1.7 times the sulphur content. Manganese is often raised beyond 1.00 percent, but in some types of green sand castings, pinholes may be encountered. Sulphur is seldom intentionally added to gray iron and usually comes from the coke in the cupola melting process. Up to 0.15 percent, sulphur tends to promote the formation of type a graphite. Somewhere beyond about 0.17 percent, sulphur may lead to the formation of blowholes in green sand castings. The majority of foundries maintain sulphur content below 0.15 percent with 0.09 to 0.12 percent being a common range for cupola melted irons. If the sulphur is decreased to a very low value together with low phosphorus and silicon, tougher irons will result and have been designated as "TG," or tough graphite irons.

The phosphorus content of most high-production gray iron castings is less than 0. 15 percent with the current trend toward more steel in the furnace charge, phosphorus contents below 0.10 percent are common: Phosphorus generally occurs as an iron iron-phosphide eutectic, although in some of the higher- carbon irons, the ternary eutectic of iron iron-phosphide iron-carbide may form. This eutectic will be found in the eutectic cell boundaries, and beyond 0.20 percent phosphorus a decrease in machine ability may be encountered. Phosphorus contents over 0.10 percent are undesirable in the lower-carbon equivalent irons used for engine heads and blocks and other applications requiring pressure tightness. For increased resistance to wear, phosphorus is often increased to 0.50 percent and above as in automotive piston rings. At this level, phosphorus also improves the fluidity of the iron and increases the stiffness of the final casting.

Copper and nickel behave in a similar manner in cast iron. They strengthen the matrix and decrease the tendency to form hard edges on castings. Since they are mild graphitizers, they are often substituted for some of the silicon in gray iron. An austenitic gray iron may be obtained by raising the nickel content to about 15 percent together with about 6 percent copper, or to 20 percent without copper as shown in ASTM Specification for Austenitic Gray Iron Castings (A 436-63).

Chromium is generally present in amounts below 0.10 percent as a residual element carried over from the charge materials. Chromium is often added to improve hardness and strength of gray iron, and for this purpose, the chromium level is raised to

0.20 to 0.35 percent. Beyond this range, it is necessary to add a graphitizer to avoid the formation of carbides and hard edges. Chromium improves the elevated temperature properties of gray iron.

Molybdenum: One of the most widely used alloying elements for the purpose of increasing the strength when it is added in amounts of 0.20 to 0.75 percent, although the most common range is 0.35 to 0.55 percent. Best results are obtained when the phosphorus content is below 0.10 percent, since molybdenum forms a complex eutectic with phosphorus and thus reduces its alloying effect. Molybdenum is widely used for improving the elevated temperature properties of gray iron. Since the modulus of elasticity of molybdenum is quite high, molybdenum additions to gray iron increase its modulus of elasticity.

Vanadium has an effect on gray iron similar to molybdenum, but the concentration must be limited to less than 0.15 percent if carbides are to be avoided. Even in such small amounts, vanadium has a beneficial effect on the elevated temperature properties of gray iron. It has been found that additions of up to 0.05 percent antimony have a similar effect. In larger amounts, these elements tend to reduce the toughness and impact strength of gray iron, and good supervision over their use is necessary.

2.6 Mechanical Properties of Gray Iron

Microscopically, all gray irons contain flake graphite dispersed in a silicon- iron matrix. How much graphite is present, the length of the flakes and how they are distributed in the matrix directly influence the properties of the iron. The basic strength and hardness of the iron is provided by the metallic matrix in which the graphite occurs.

The properties of the metallic matrix can range from those of a soft, low carbon steel to those of hardened, high carbon steel the matrix can be entirely ferrite for maximum machine ability but the iron will have reduced wear resistance and strength. An entirely pearlitic matrix is characteristic of high strength gray irons, and many castings are produced with a matrix microstructure of both ferrite and pearlite to obtain intermediate hardness and strength. Alloy additions and/or heat treatment can be used to produce gray iron with very fine pearlite or with an acicular matrix structure. Graphite has little strength or hardness. It decreases these properties of the metallic matrix, however, the presence of the graphite provides several valuable characteristics to cast iron. These include:

- The ability to produce sound castings economically in complex shapes such as water cooled engine blocks.
- Good machinability even at wear resisting hardness levels and without burring.
- Dimensional stability under differential heating such as in brake drums and disks.
- High vibration damping as in power transmission cases.
- Borderline lubrication retention as in internal combustion engine cylinders.

2.6.1 Hardness

Hardness is the most commonly determined property of metal because it is a simple test and many of the useful properties of metal are directly related to its hardness. Within a class or type of gray iron, hardness is a good indicator of its engineering properties, but this relation is not useful between types of gray iron because differences in graphite structure have more of an effect on tensile properties than on hardness.

Specifying the hardness at a designated place on each casting is an excellent method of establishing consistency of castings in production quantities where the type of iron Compression strength does correlate very well with hardness for all types of iron because hardness is essentially a compression test. Hardness usually gives a good indication of tool life in machining, however, the presence of free carbides in the microstructure will reduce the machinability much more than it increases the hardness.

The Brinell hardness test is used for all irons because the Brinell test impression is large enough to average the hardness of the constituents in the microstructure. Rockwell hardness B or C scale tests can be used satisfactorily on machined surfaces where the supporting surface is also machined. Several Rockwell tests should be made and averaged, but extreme values should be discarded because of inordinate influence by a graphite flake or a hard constituent. A conversion chart between Rockwell and Brinell hardness values can be used accurately for steel but deviations from this relation for steel occur with gray irons. This deviation increases with high carbon equivalent irons. The amount of flake graphite present influences the two tests differently. This is evident from a comparison of microhardness test results on the matrix of gray irons compared to standard Rockwell C values on the same irons. The microhardness impressions do not include the graphite flakes that are present under the Rockwell C hardness indenter. (www.Mid-AtlanticCasting.com).

2.6.2 Factors Affecting Strength

The mechanical properties of gray iron are determined by the combined effect of its chemical composition, processing technique in the foundry, and the solidification and cooling rates. Thus the mechanical properties of the metal in a casting will depend on its shape, size and wall thickness as well as on the iron that is used to pour it.

2.6.3 Base Chemical Composition

The tensile strength of gray iron is influenced by both the normal elements present in plain irons such as carbon, silicon, phosphorus, sulphur and manganese, and the presence of alloying additions and trace elements. Carbon and silicon are very important elements and are combined, usually with phosphorus, in a carbon equivalent expression. Irons with a carbon equivalent of more than 4.3 are hypereutectic and usually contain coarse graphite. They are of lower strength, but are excellent in thermal shock applications and for vibration damping. Gray irons with less than 4.3 carbon equivalent are hypoeutectic and of higher strength because the amount and size of the graphite flakes decrease with the CE value.

The effect of higher carbon equivalent is to reduce strength because of the formation of larger amounts of coarser graphite and, commonly, more ferrite. Manganese, sulphur and phosphorus are present in plain gray irons and influence the tensile strength to some extent. Sulphur is a very significant element because it exerts marked effects on the solidification behaviour of iron, For this reason, the sulphur content in iron is usually controlled within limits and with a selected ratio to the manganese content since sulphur combines chemically with manganese to form manganese sulphide. The minimum manganese content in iron is generally 1.7 times the sulphur content plus 0.12% manganese. This assures sufficient manganese so that all of the sulphur is combined with manganese rather than with iron. Manganese in excess of this amount is a mild carbide stabilizer, refining the pearlite and increasing the hardness and tensile strength.

An excess of manganese or phosphorus can cause dispersed internal porosity in heavier sections such as bosses. For this reason, phosphorous is kept as low as practical except for special purpose irons. Increasing phosphorus provides a somewhat higher tensile strength, but a content over 0.20% reduces drilling machinability particularly in drilling operations.

(www.Mid-AtlanticCasting.com).

2.6.4 Fatigue Properties

Camp Metals which are subjected to repeated or fluctuating loads, such as alternating between tension and compression, can break after a large number of loading cycles even though the maximum stress was well below the static strength of the metal. This type of fracture is called a fatigue failure, although the rate of load application or the length of time over which the cycles occur are not significant. The occurrence of a fatigue crack is directly influenced by the maximum unit stress and the cumulative number of times it is applied.

A fatigue crack starts in an area of high stress concentration after a large number of loading cycles. It is always a brittle type of fracture even when occurring in ductile metals. As the crack progresses, it increases the stress concentration, and the rate of propagation under the cyclic loading increases. When the cross section of the remaining metal becomes insufficient to support the maximum load, complete failure occurs as it would under an excessive steady stress. The number of stress applications that will induce a fatigue failure is less at higher maximum stress values, and conversely a larger number of stress cycles can occur at a lower maximum stress level before a fatigue crack is initiated. When the number of cycles without failure exceeds 10 million, the endurance life is considered infinite for body-centered-cubic ferrous metals. The maximum stress that will allow this number of cycles is established as the endurance limit, or the fatigue strength or fatigue limit. (www.Mid-AtlanticCasting.com)

2.6.5 Damping Capacity

The relative ability of a material to absorb vibration is evaluated as its damping capacity. The quelling of vibration by converting the mechanical energy into heat can be very important in structures and in devices with moving parts. Components made of materials with a high damping capacity can reduce noise such as chatter, ringing and squealing, and also minimize the level of applied stresses. Vibration can be critical in machinery and can cause unsatisfactory operation or even failure.

An accumulation of vibrational energy without adequate dissipation can result in an increasing amplitude of vibration. Excessive vibration can result in inaccuracy in precision machinery and in excessive wear on gear teeth and bearings. Mating surfaces normally considered in steady contact can be caused to fret by vibration.

The exceptionally high damping capacity of gray cast iron is one of the most valuable qualities of this material. For this reason it is ideally suited for machine bases and supports, engine cylinder blocks and brake components. The damping capacity of gray iron is considerably greater than that of steel or other kinds of iron. This behaviour is attributed to the flake graphite structure of the gray iron, along with its unique stress-strain characteristics.

Damping capacity decreases with increasing strength since the larger amount of graphite present in the lower strength irons increases the energy absorbed. Larger cast section thicknesses increase damping capacity and inoculation usually decreases it. (www.Mid-AtlanticCasting.com).

2.6.6 Tensile Properties

The tensile properties of gray iron (tensile strength, yield strength, ductility and modulus of elasticity) can be established by a conventional test, as specified by the ASTM2. Although yield strength and ductility may be measured, they are seldom determined or specified. The modulus of elasticity of gray iron is not constant, as in the case of steel, and varies with the class of iron and type of loading (www.brainspark.ca)

2.6.7 Fracture Toughness

The fracture toughness of a material is a measure of the work required to fracture it. This required work is related to the material's resistance to crack initiation and growth. The work or energy dissipated in fracturing a material is associated with the elastic and plastic deformation of the material and/or crazing (microcracking) that precedes final fracture. The fracture toughness will generally vary with temperature, state of stress and strain-rate, all of which influence the amount of deformation which precedes fracture. (www.brainspark.ca)

CHAPTER THREE

3.0 METHODOLOGY

3.1 Selection of Materials

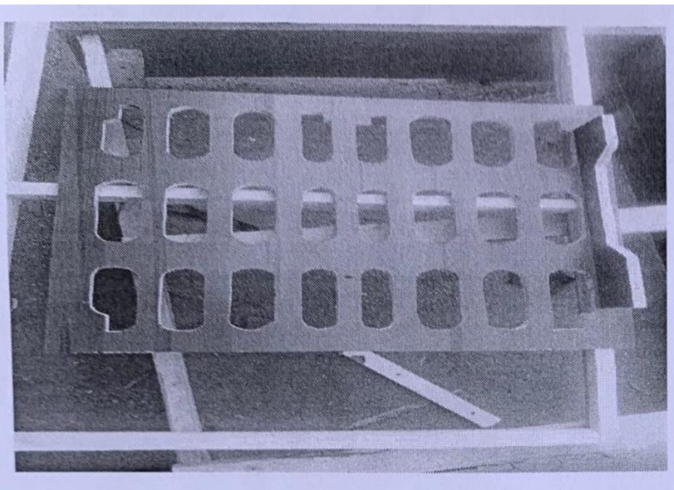
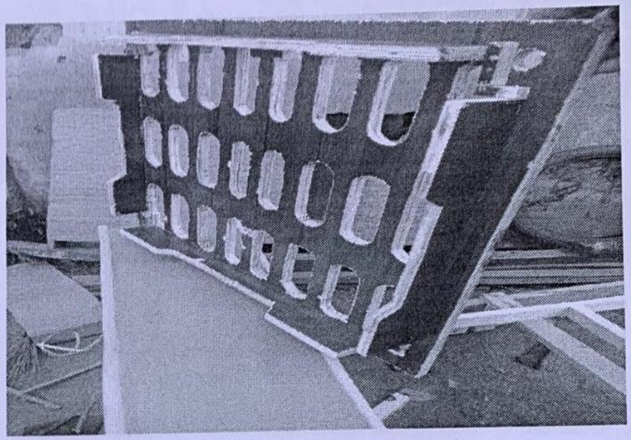
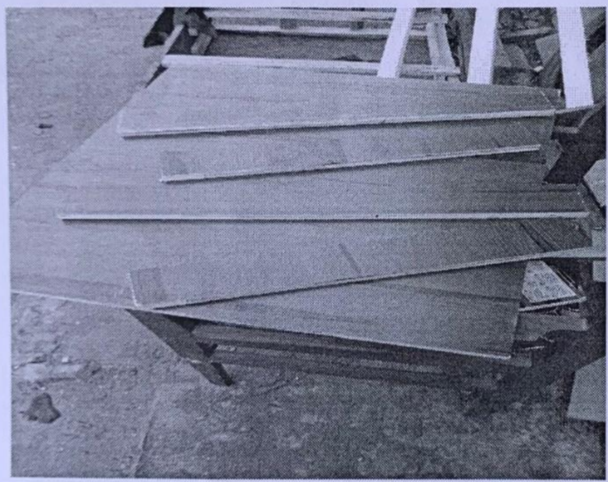
The materials used for this research work include grey cast iron scraps, steel scraps, graphite, ferro-manganese, ferro-silicon, plastic wooden pattern (with diameter of 16mm by 200mm length), silica sand, bentonite, coal dust, water, moulding flask, 2% nitric acid to 98% alcohol natal etchant, emery paper, and diamond paste

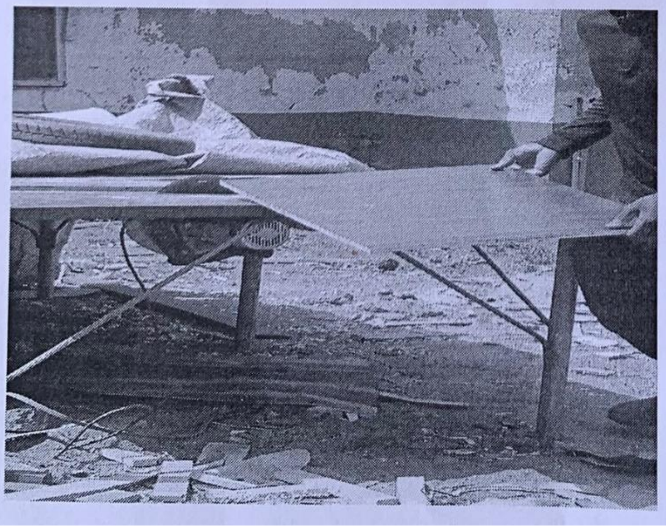
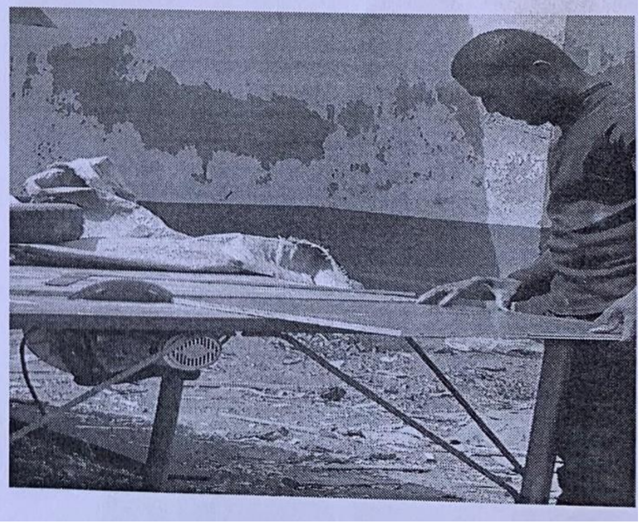
3.2 Equipment

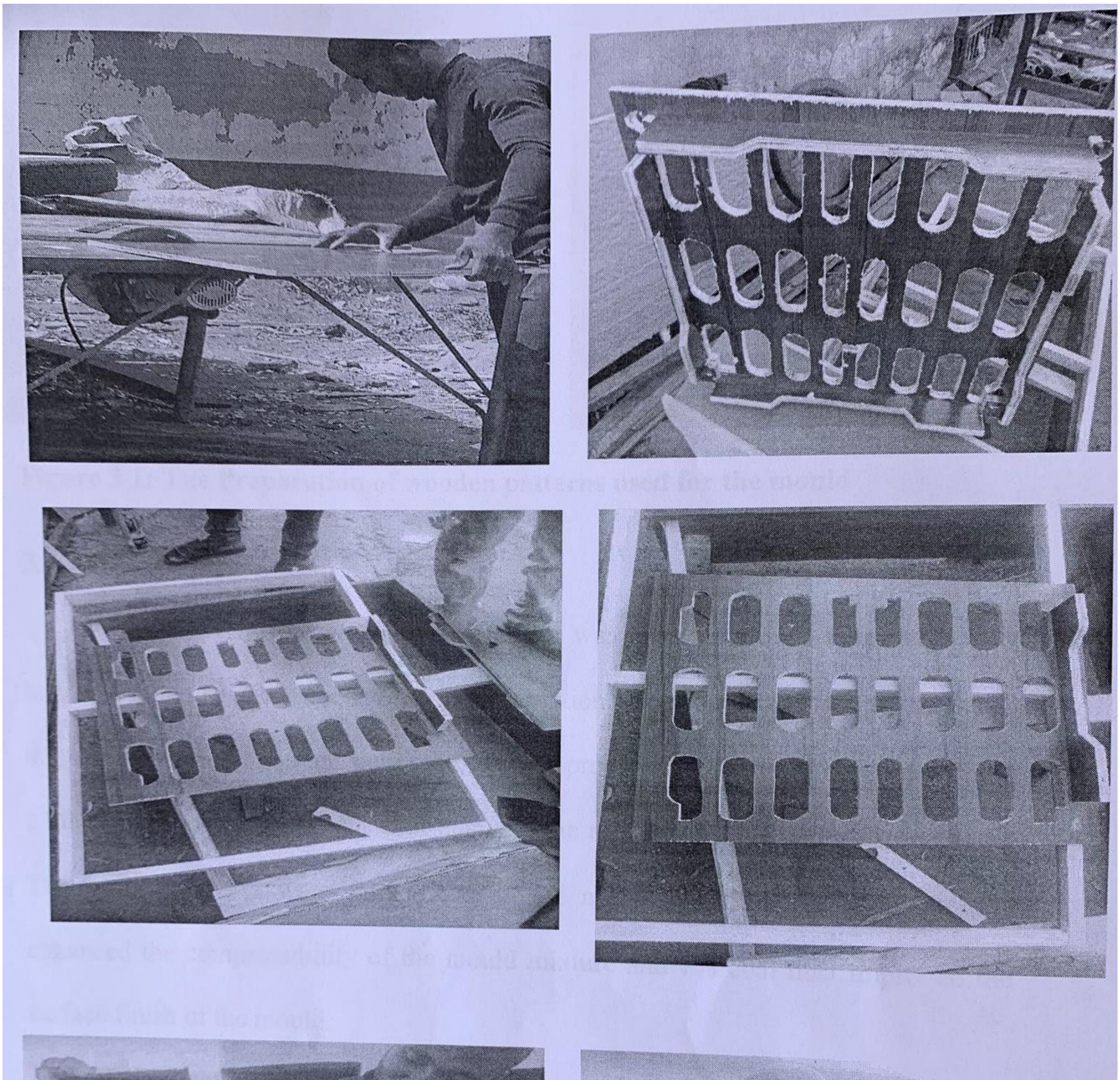
The equipment that were used at various stages of this research work are sledge hammer, wood lathe, 100kg oil-fired rotary furnace, ladle, hacksaw, weighing scale, lathe machine, table vice, atomic mass absorption spectrometer (AMAS), Rockwell hardness tester in KWASU, Instron Universal Tensile Tester at E.M.D.I., Akure, SBT Model 900 and Metaserv 2000 grinder/polishing machine in KWASU, and Nikon Eclipse ME600 metallurgical optical Microscope of X800 maximum magnification at KWASU.

3.3 Pattern Making

Wooden patterns were used in a green sand mould. Each pattern is 200mm long and of diameter 16mm. The sizes of the patterns were made to provide for the necessary allowances to compensate for any metal contraction during solidification, distortion and machine losses. Also the tapering allowances were taken care of to allow for easy removal of the patterns from the mould. Figure 3.1 below shows the wooden hollow Patterns used for the research work.



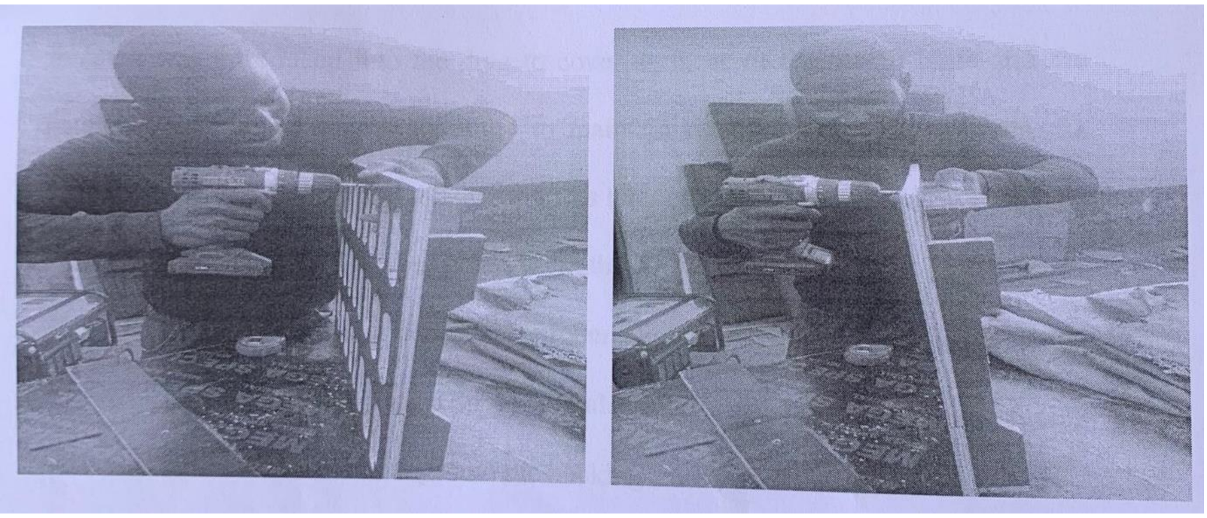


Figure 3.1: The Preparation of wooden patterns used for the mould

3.4 Mould preparation

The moulding box used for this project was made of wood. Three moulding box was made to accommodate for each variation of ferro-silicon, which are 0.1%, 0.2%, and 0.3%. The green sand moulds were prepared from sand mixes containing 13% bentonite, 5% water, 1% coal dust and the remaining 84% being natural sand. The addition of 5% water brought about the necessary plasticity. The bentonite enhanced the compressibility of the mould mixture and 1% coal dust improved the surface finish of the mould.

3.4.1 Process of mould preparation

The pattern was placed in cope and drag of the moulding box by means of a locating pin. The drag was placed on the board and was properly aligned with the pattern board. This provide the necessary dimension accuracy and prevented cope and drayg mismatch. After this, facing sand, which has been sieved for aeration and fineness was introduced into the drag to cover surfaces of the match plate and the pattern. Ramming was done carefully to maintain relative alignment between the board, pattern and the drag. Backing sand was later introduced to fill the cavity of the drag and rammed to the required green strength.

The mould assembly was inverted and proper alignment with the match plate was ensured using dowel pins. Down sprue was also put in place after which the facing sand was introduced into the cope and the backing sand added and rammed. The cope and drag halves were separated and the match plate removed. By carefully tapping, the pattern and the sprue were removed from the mould. The two halves were left together in the foundry workshop for a week before coupling together in readiness to receive the melt.

3.5 Charge Preparation 28

The charged materials used in carrying out this project are grey cast iron scraps, ferro silicon and ferro manganese and graphite. These charge materials were calculated to determine the relative amount of each material needed to achieve the production of grey cast iron.

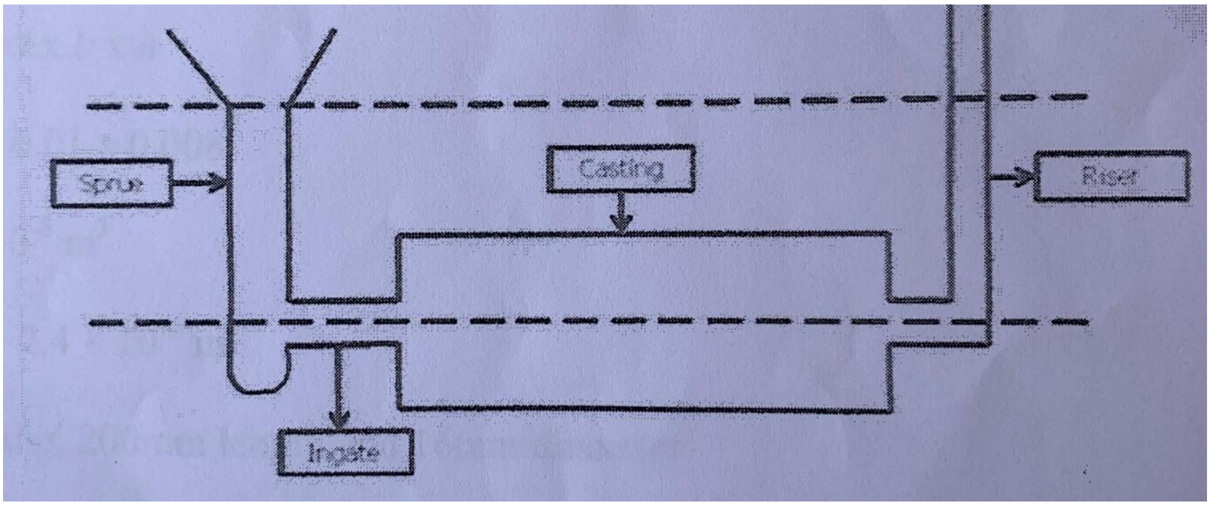


Fig. 3.2: Schematic diagram of the mould

Dimensional Integrity of the Mould Sections

Density of molten grey iron = 7340kg/m^3

Sprue dimension = 30mm by 80mm

Ingate dimension = 30mm by 10mm by 8mm

Casting dimension = ?

Riser dimension = 20mm by 80mm

Volume of the Mould Sections

For Sprue, 30mm by 80mm

Volume of a cylinder is $= \pi r^2 h$

$V_{(sprue)} = \pi r^2 h$

$= \frac{22}{7}$ x0.015^2 x 0.08

= 5.6549 x 10^{-5}m^3

$V_{(sprue)}$ = 5.65 x 10^{-5}m^3

For Ingate, 30mm by 10mm by 8mm

Volume of a rectangle is *1* x b x h

$V_{(Ingate)} = l \; x \; b \; x \; h$

= 0.03 0.01 x 0.008

= 2.4 x 10^{-6}m^3

$V_{(Ingate)}$ = 2.4 × 10^{-6}m^3

For Casting, 200mm length and 16mm diameter

Volume of a cylinder is $\pi r^2 h$

$V_{(Casting)} = \pi r^2 h$

$= \frac{22}{7}$ x0.008^2 x 0.2

$V_{(Casting)}$ = 4.02 x10^{-5}m^3

For Riser, 20mm by 80mm

Volume of a cylinder is $\pi r^2 h$

$V_{(Riser)} = \pi r^2 h$

$= \frac{22}{7}$ x0.01^2 x 0.08

=2.5133 x 10^{-5}m^3

$V_{(Riser)}$ = 2.51 x 10^{-5}m^3

The total volume per cast:

$\{V_{(Sprue)} + V_{(ingate)} + V_{(casting)} + V_{(Riser)}\}$

= {(5.65×10^{-5})+(2.4×10^{-6}) + (4.02×10^{-5}) + (2.51×10^{-5})

=1.242×10^{-4}m^3

Density of grey cast iron is 7340kg/m^3

$Density = \frac{Mass}{Volume}$; $Mass = Density$ x $Volume$

Therefore,

$Mass = \frac{7340kg}{m^3}$ x 2.88 x 10^{-4}

= 2.11kg per mould

4 x 2.11kg = 8.44kg was used the four moulds prepared

Hence, four moulds were used to obtain four castings of 0.0%, 0.1%, 02% and 0.3% ferrosilicon addition respectively; and the castings were out into six samples each.

3.6 Melting and Casting Procedure

A 100kg oil-fired rotary furnace was used in order to carry out the melting process. The selected materials were charged into the rotary furnace and weighed, properly sized so that materials were easily charged into the rotary furnace where the melting process took place. The charge was then heated to about 1500°C. The melt was held at this temperature for 15 minutes for homogenization before tapping. During tapping, inoculants (ferro - silicon and ferro - manganese) addition took place. The addition began when the ladle is one quarter full and completed when the ladle is three quarters full, so that the last metal merely mixes after thorough mixing, the melt was poured into the green sand mould.

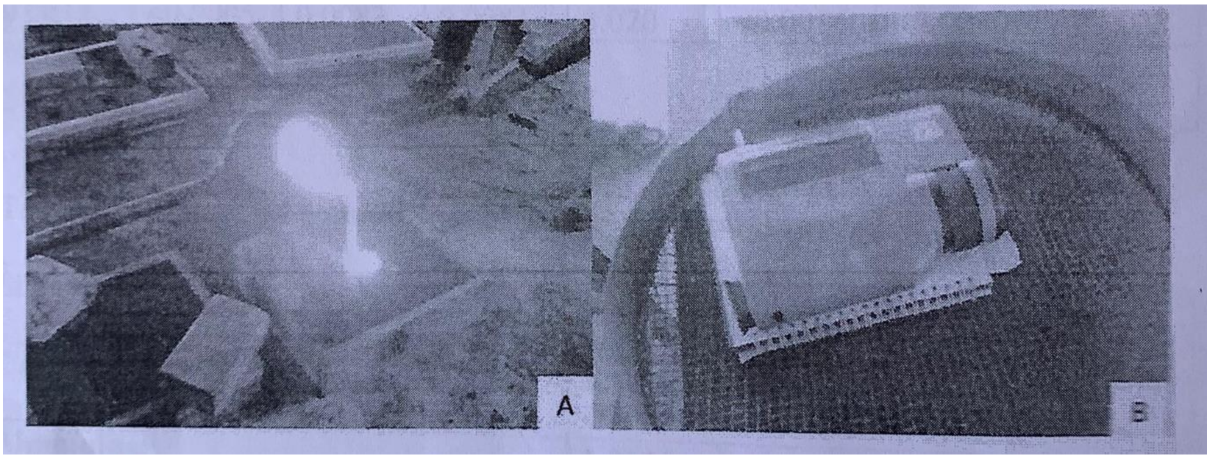


Figure 3.3: Pouring of melt into the mould and pyrometer used in measuring temperature of melt in the rotary furnace (A, B).

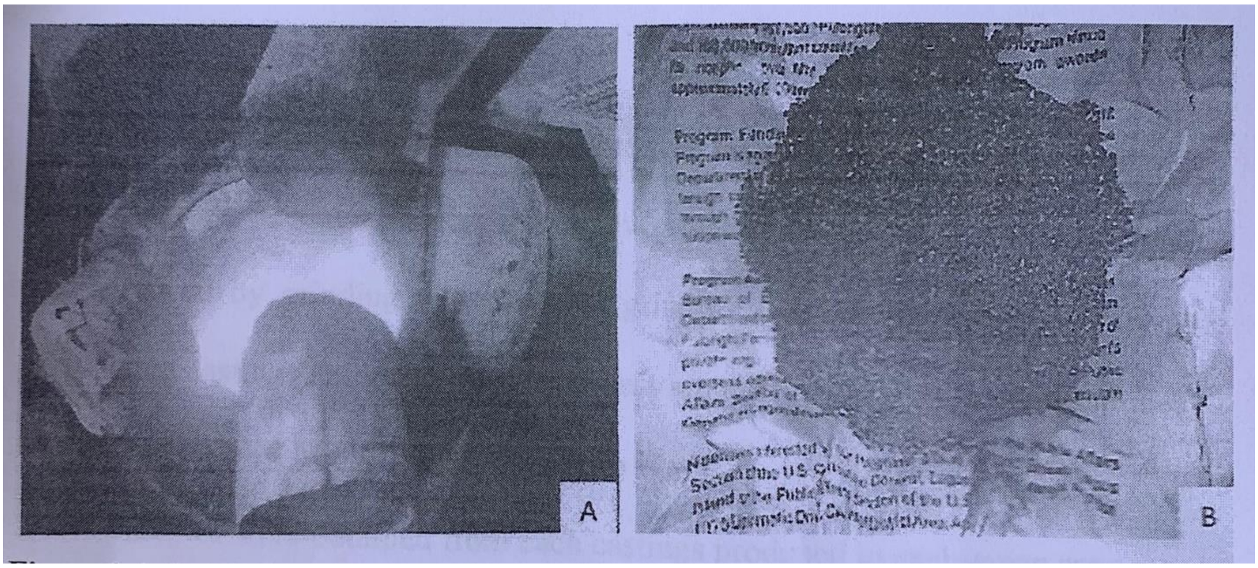


Figure 3.4: Pre-heating of the ladles to be used for tapping and FeSi inoculants (A, B).

Table 3.1: Elemental composition of scrap from auto parts charged into rotary furnace

%C 3.97	**%Si** 1.94	**%Mn** 0.87	**%P** 0.088	**%S** 0.131	**%Cr** 0.163	**%Ni** 0.058	**%Mo** 0.0015
%Al 0.0058	**%Cu** 0.137	**%Co** 0.015	**%Ti** 0.0015	**%Nb** <0.0025	**%V** 0.0099	**%W** 0.010	**%Pb** 0.0083
%Mg 0.0033	**%B** <0.0005	**%Sn** 0.0081	**%Zn** 0.0081	**%As** 0.02	**%Bi** 0.02	**%Ce** <0.0015	**%Zr** <0.0015
%La <0.0033	**%Fe** 92.5						

Table 3.2: Elemental composition of the Fe-Si inoculants used

Silicon	**74.22%**
Calcium	**2.44%**
Aluminium	**1.21%**
Zirconia	**1.21%**

3.7 Cleaning/Fettling of the Casting

All the castings were sand blasted to remove sand that adhered to them. After this, the sprues were removed using abrasive wheel-cutting machine. Finish cleaning was achieved by grinding with abrasive grinding machine to smoothen the sprue areas of the castings and removing any excess metal remaining on the cast samples.

3.8 Cut-off and Machining Operations

Samples were obtained from each castings produced in each green sand mould, using a hard - grinding machine to cut off specimens of 30mm long for hardness test. Also from each castings, test specimen of 60mm long were obtained for tensile tests. Thereafter, these specimens were machined into various standard test specimens for tensile tests using a lathe machine. The tensile test specimen used for this project is shown below:

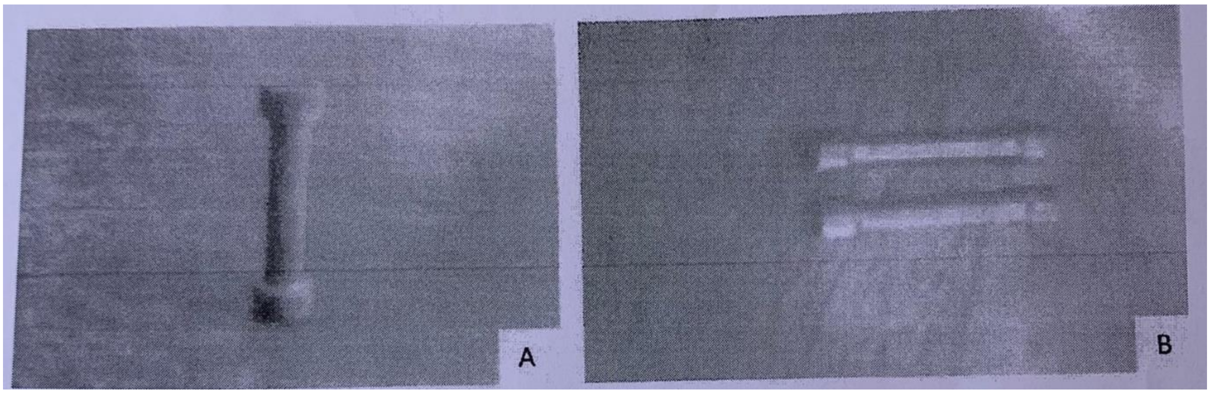


Figure 3.5: Showing the test specimen for the tensile test (A, B)

3.9 Determination of Mechanical Properties of Grey Cast Iron Samples

The following mechanical properties (tensile, hardness) were experimentally determined on the various test specimens produced.

3.9.1 Tensile test

The tensile test was performed in accordance with the American foundries men's society (AFS) standards. Each test piece was clamped on to the Hounsfield tensometer capable of producing load-extension graph on attached graph paper. A graphical result of the applied load against extension was obtained from the auto graphic reading drawn by the tensometer, and from which the maximum load was obtained and corresponding stress calculated.

3.9.2 Hardness Test

All hardness test was performed with the aid of a digital Rockwell hardness tester in physical metallurgy laboratory in KWASU. In the process, the surface of each test specimen, on which an indentation was made, was ground using grinding papers to make them flat and smooth.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

4.1.1 Result of Experimentally Determined Chemical Analysis

Table 4.1: Un-inoculated grey cast iron sample

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Fe
% composition	2.85	1.02	0.234	0.03	0.0801	0.090	0.003	0.002	94.90

Table 4.2: 0.1% Inoculated grey cast iron sample

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Fe
% composition	3.157	2.250	0.2229	0.0283	0.0703	0.123	0.096	0.021	93.82

Table 4.3: 0.2% Inoculated grey cast iron sample

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Fe
% composition	2.783	3.252	0.313	0.158	0.063	0.110	0.050	0.011	93.04

Table 4.4: 0.3% Inoculated grey cast iron sample

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Fe
% composition	3.100	3.300	0.209	0.038	0.040	0.094	0.061	0.025	92.13

4.1.2 Result of Calculated Carbon Equivalent Value (CEV)

Carbon equivalent value (CEV) = % TC + [% (Si+P) (3)]

For Un-inoculated grey cast iron sample

Carbon = 2.85

Silicon = 1.02

Phosphorus = 0.03

CEV = 2.85 + [(1.02 + 0.03)/ 3] = 3.20

For 0.1% innoculated grey cast iron sample

Carbon = 3.157

Silicon = 2.250

Phosphorus = 0.0283

CEV = 3.157 + [(2.250 + 0.0283)/ 3]

= 3.916

For 0.2% Innoculated grey cast iron sample

Carbon = 2.783

Silicon = 3.252

Phosphorus = 0.158

CEV = 2.783 + [(3.252 + 0.158)/ 3]

= 3.920

For 0.3% Innoculated grey cast iron sample

Carbon = 3.100

Silicon = 3.300

Phosphorus = 0.038

CEV = 3.528 + [(3.701 + 0.038)/ 3]

= 4.14

Table 4.5: Showing samples and % of FeSi added and their respective carbon equivalent value

% of FeSi Added	Carbon Equivalent Value (CEV)
Un-Inoculated	3.20
0.1%	3.916
0.2%	3.920
0.3%	4.14

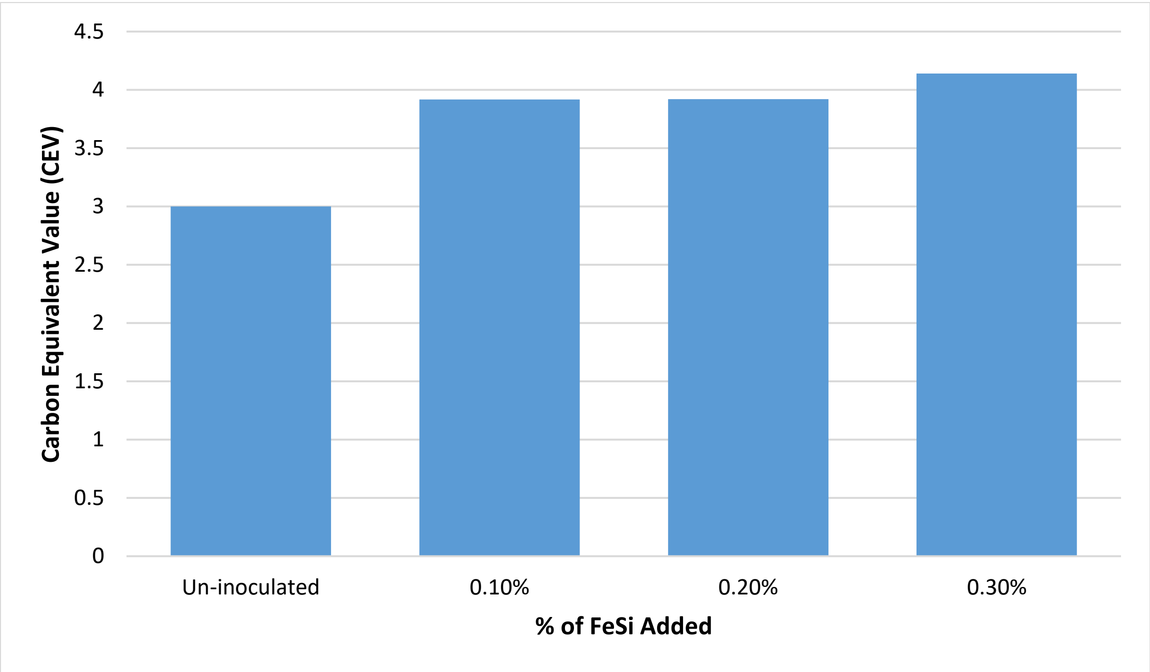


Fig. 4.1: Showing variation of inoculant with carbon equivalent values

Table 4.6: Showing the result of tensile tests obtained from specimens from each varied ferro silicon and un-inoculated sample

% of FeSi Added	Peak Load (N)	Gauge Diameter (mm)	Ultimate Tensile Strength (N/mm^2)	Maximum Displacement (mm)
Un-inoculated	7936.2	6.23	260.31	1.46
0.1%	7129.7	6.17	238.43	1.24
0.2%	4138.6	5.42	179.35	0.92
0.3%	3255.9	5.4	142.15	0.80

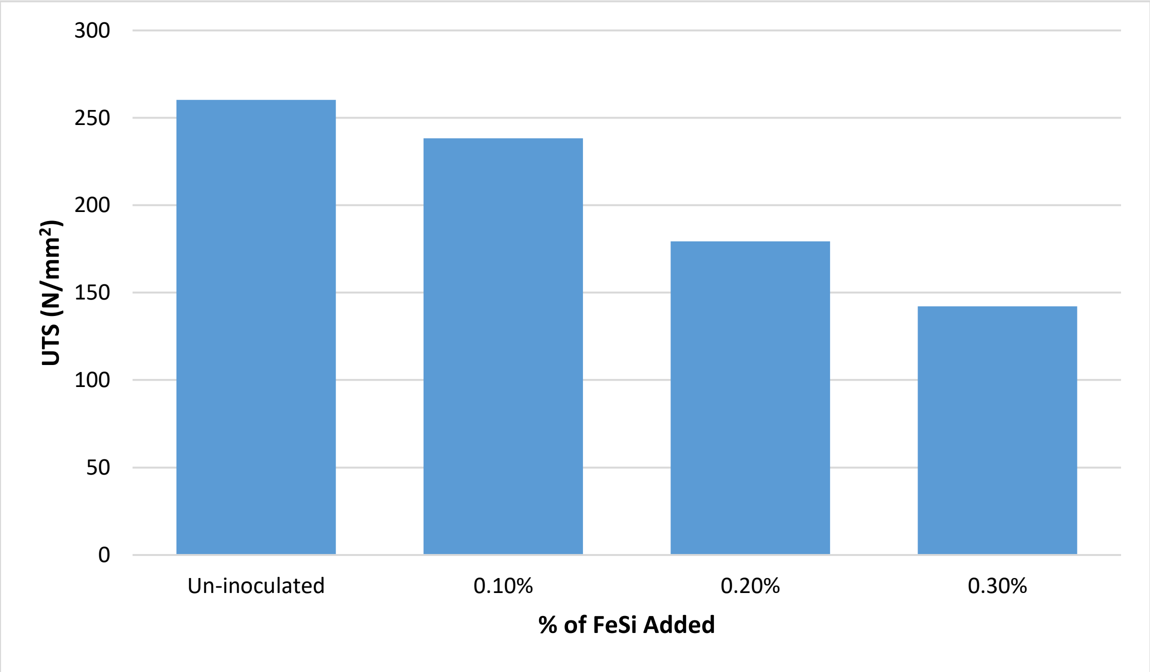


Fig. 4.2: Showing variation of tensile strength with carbon equivalent values

Table 4.7: Showing the hardness results of specimens of varied ferro silicon and un-inoculated grey cast iron using a Rockwell hardness tester

% of FeSi Added	Reading 1	Reading 2	Reading 3	Reading 4	Average value of readings
Un-inoculated	59.9	55.9	59.7	60.1	58.9
0.1%	51.6	51.5	52.0	50.3	51.35
0.2%	46.3	47.7	45.7	43.8	45.88
0.3%	42.9	45.6	42.1	48.2	44.70

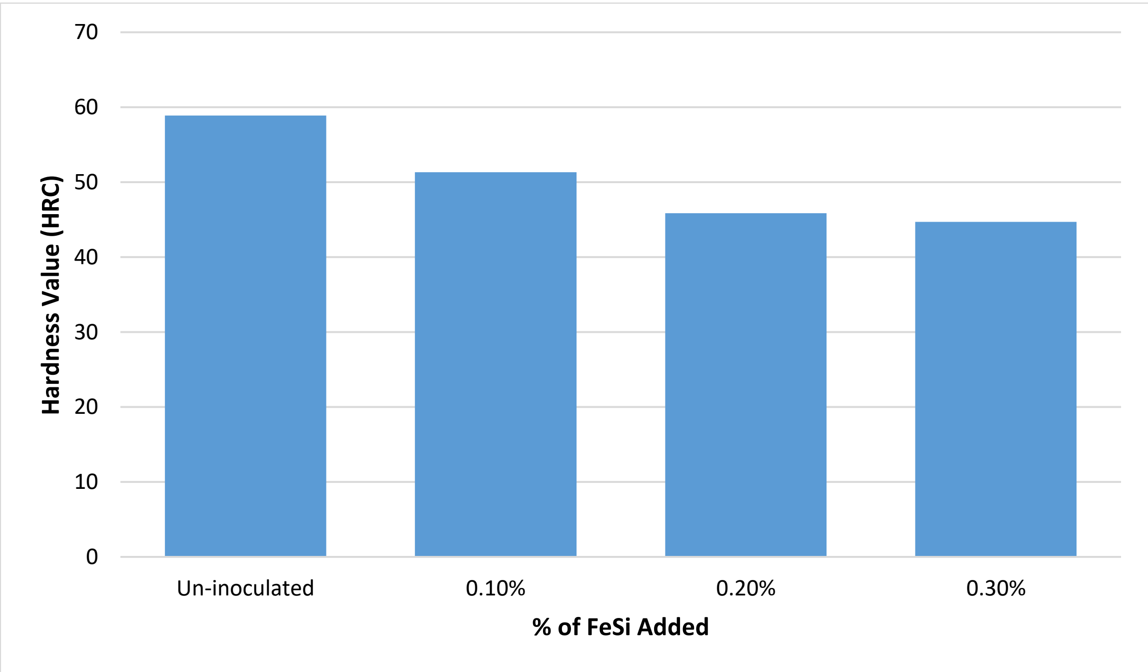


Fig. 4.3: Showing variation of Rockwell Hardness with carbon equivalent values

4.2 Discussion of Results

4.2.1 Effect of Carbon Equivalent on Tensile and Hardness

The effects of Carbon Equivalent Values (CEV) on mechanical properties of grey cast iron have been investigated and results presented in figure 4 2 and 4.3. It was found that as the CEV increased, all mechanical properties, that is tensile and hardness values of grey cast iron decreased linearly.

For a given cooling rate the carbon equivalent value, determines how close a given composition of iron is close to the eutectic, and therefore how much free graphite is likely to be present, and consequently the probable strength in a given section.

The CEV of grey cast irons is an indicator of the structure in relation to the potential for carbon precipitation and hence the % of eutectic formed. In this respect, the higher the CEV, the greater the tendency for graphite precipitation during the eutectic reaction and percentage eutectic formed. In addition high carbon equivalent values in grey cast irons results in low matrix continuity. All these factors are expected to cause low tensile strength and low hardness in grey cast iron. These observed effects are in accordance with (Kasch, 1963).

4.2.2 Effect of compositional changes on the mechanical properties

4.2.2.1Effect of silicon and carbon and phosphorus

As the silicon content of the gray cast iron samples increased, so also is the degree of graphitization in them increases, thereby leading to the reduction of the tensile strength and hardness of the Fe-C matrix. It may be noted that as the percentage of silicon increases, it shifts the eutectic point of the gray cast iron samples to the left in the iron-carbon phase diagram. The eutectic shift is described by the carbon equivalent value of each gray cast iron sample. The addition of silicon reduces the solubility of carbon in iron and also decreases the carbon content of the eutectic.

It was observed that as the percentage of phosphorus decreased in the cast samples, so also it causes a proportional decrease of the hard constituent of the cast samples, and therefore decreases the hardness and brittleness.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

During the research work, the effect of varied FeSi inoculants on the mechanical properties of gray cast iron was studied. It was observed that increasing the carbon equivalent value of a gray cast iron by varying the percentage of inoculants added, leads to a decrease in its mechanical properties, i.e. tensile strength and hardness. Also as the silicon and carbon content of the gray cast iron samples increased, so also the degree of graphitization in them increases, thereby leading to the reduction of the tensile strength and hardness of the Fe-C matrix, and also a decrease in the percentage of phosphorus lead to a corresponding decrease in hardness, while a decrease of the sulphur content lead to an increase in the carbon equivalent value, which amounts to the increase in the degree of graphitization as the percentage of FeSi inoculants added increases.

5.2 Recommendation

Foundry practice adopted in production industries should be that which assures of homogenous chemical composition in castings of grey cast iron, as change in chemical composition of grey cast iron castings results to change in mechanical properties of the castings and might result into early failure of the casting in engineering application. This effect is more felt in long castings of grey cast iron.

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