INVESTIGATIONS INTO THE QUALITY OF MILL PLATE WEAR USING ATTRITION MILLS IN GHANA.

By

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DECLARATION

I hereby affirm that, the submission is my individual work in fulfillment of MSc work and to the best of my knowledge, no material hitherto published by another person or material which has been acknowledged for the award of any degree of the University, except where citing has been made.

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ABSTRACT

Attrition mills are machines used for size reduction (grinding) of fibrous material especially agro-food produce such as maize, millet sorghum, cassava chips, pepper etc., into a desirable flour sieve size. In the Attrition mill, two roughened disc with teeth or grooves, which are made from cast iron are mainly engaged for the grinding. Observation has proven that the teeth wear out rampantly during milling. Hence the objective of the work was to investigate, identify the causes of wear and develop a solution technique to rectify the problem. The method used for the study included the purchased of grinding disc samples from known foundries at Suame Magazine Industrial Area in Kumasi. The samples were prepared and their elemental compositions were determined at Tema Steel Works (TSW). The specimen was compared to ascertain the correlation between the elemental composition, and the foundry practices. The dial indicator was used to determine the parallelism and concentricity of the mill plates. Soaked maize was milled using the grinding disc samples. The resulting flour sample was taken to GAEC laboratory and analyzed to determine the amount of iron particles present.

Results indicated that hardness of the grinding mill plates was deduced from the depth of penetration using Brinell hardness method and there was a moderately strong correlation between wear and hardness. The hardness values obtained ranged between 429 BHN and 534 BHN and the penetration values were between 2.65 mm and 2.95 mm. It was established that, the lesser penetration the greater the value of the hardness and the lesser the wear. It was shown that, the wear rates ranges from 1.5×10^{-3} kg/min to 5.167×10^{-3} kg/min.

From the analysis, it was established that significant metals particles existed in the milled flour. The study revealed that heavy metal particle was found in the mill flour

with values ranging from 14.71 mg/kg to 21.55 mg/kg of flour. For the limit of contaminants levels, Asare and Nulux indicated an average value of 50 %. Abudia and Atanga were 100 % below the contaminant limits, suggesting a good standard. Navin and Babawala having 75 % above the contaminants limits indicating poor standard.

It could be concluded that the relationship between wear rate of $1.5 \times 10^{-3}\ kg/min$ to $5.167 \times 10^{-3}\ kg/min$, hardness value of 429 BHN and 601 BHN, 2.65 mm to 2.5 mm penetration and 2.41 kg and 3.00 kg concentricity mass has been established. It could be recommended that, the result could be used to improve the general performance of the foundries while the redesigned version could be recommended for adaptation.

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DEDICATION

This thesis is dedicated to Mr. Apollonius Isaac Nyarko of blessed memory with whom I worked at CSIR-Food Research Institute for several years. Mr. Nyarko was a friend who discussed advanced learning with me at any opportune time we met. He encouraged me and gave me hope to pursue the MSc. Mechanical Engineering programme at the Kwame Nkrumah University of Science and Technology.

Mr. Nyarko also submitted his MSc thesis at the Food Science Department, University of Ghana Legon, only to pass-on to glory few weeks before his graduation day. Indeed, I am indebted to him and I regret that he could not wait for our celebrations into the world of "Aristocrats" as he always likes to put it. He describes people with advanced degrees as upper class citizens. I shall forever miss you. Rest in peace

Apollonius, affectionately called (Great Apo).

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LIST OF SYMBOLS

CODEX ALIMENTARIUS-	International recognized standards/guideline for food
EU-	European Union
MoFA-	Ministry of Food and Agriculture

FSANZ-	Food Standard of Australia, New Zealand
FDA- USA,	Food and Drug Administration
GB-	Great Britain
MAINLAND-	China National Standard
GAEC.	Ghana Atomic Energy Commission
AAS-	Atomic Absorption Spectrometer
BHN-	Brinell Hardness Number
TSW-	Tema Steel Works
PH-	Phase
KW-	Kilowatts
ICED-	Iron Carbon Equilibrium Diagram
Ps, R-	Reliability
UV-	Ultra Violet
K-	Kelvin
BC-	Before Christ
t-	Time
ATSDR-	Agency for Toxic Substances and Disease Control
NSP-	National Service Person
KNUST-	Kwame Nkrumah University of Science and Technology.
HOD-	Head of Department
SG-	Spheroidal Graphite
CD-	USA Center for Disease Control
USEPA-	United States Environmental Protection Agency
UTS-	Ultimate Tensile Strength

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AFS- American Foundry Society

OSHA- Occupational Safety and Health Administration

IRRI- International Rice Research Institute CSIR- Council for Scientific and Industrial Research

FRI- Food Research Institute.

SS- Sums of Square

DF- Degrees of Freedom

SEE- Standard Error Estimates

CC- Correlation Coefficient

ANOVA- Analysis of Variance

MAE- Mean Absolute Error

DW- Durbin - Watson

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I am most pleased to the Almighty Allah for the strength and direction that has brought me far with this study. Above all, I am particularly grateful for his continues compassion, mercies and abounding grace.

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CHAPTER ONE INTRODUCTION

This chapter discusses the background, the objectives and the significance of the research.

1.1 Background

The indigenous man achieved milling by the use of stone slabs, pestles and mortar when the advent of technology was almost non-existence. These implements were carved by craftsmen from their knowledge of species of trees and special stones slabs. With the advent of technology, societies have switched almost entirely to the use of modern machines for their milling needs due to drudgery, convenience and food safety reasons. The reduction in size of agricultural products is brought about by mechanical means without change in chemical properties of the materials (Enrique, 2012). The challenge is that, mating and rotary machine parts still exhibit some wearing characteristics. Material loss generally progressive involving a relative motion between a damage solid surface and substances engaged is defined as wear (Gurumoorthy et al, 2007). From the beginning of life, wear and friction of material and substances have been with man (Mehulic et al, 2005).

Milling in food processing (also loosely termed grinding) is generally refers to as size reduction or the process to convert coarse and fibrous material into fine particles. Grain milling technology involves size reduction operations in which the grain kernel is broken into pieces of various sizes by machine, (Akinoso et al, 2013). Grain milling undoubtedly, is a big industry in the sub-region. FAO, (2012) ranked maize, sorghum and millet as third, fifth and sixth important cereal in the world. It contributes significantly in the preparation of the food by households, restaurants and street-food

vendors. Most communities operates Attrition mill also called Burr or Plate mill. The study focus on the wear of small scale domestic Attrition mill plate in Ghana.

Leland (2008) reported that application of size reduction forces can be broken into four categories namely Impact milling, Attrition milling, Knife milling (cutting), Directpressure milling (crushing). The hammer mill uses impact rotating fixed metal beaters called the hammers pound and beat the softer food product to pass through a metallic screen of a desired sieve size. Crushers reduce or crush the material by pressing or squeezing it until the material breaks. The Attrition mill consists essentially of two roughened plates, stationary and rotating. The material is fed between the plates. The plates reduce the material by crushing and shearing. Attrition mills use friction and therefore the rate of wear is higher. Galanty, (2006), stated that over-feeding of the grinder with substances, causes constituent or particles to rub more intimately together thereby increasing temperature more than the normal free feeding, it reduces the efficiency of the grinder.

Figure. 1.1 Attrition Mill. (Source : FRI, Accra, 2014)

The Attrition mill is used to grind a wide range of non-grain materials. Akinoso, et al (2013), endorses that, Attrition mill is more appropriate for wet milling. In the West African sub-region the most commonly used mill in domestic food preparation is the Attrition mill. In Nigeria, for example attrition milling accounts for more than 80% of

small-scale size reduction operation (Badmus et al, 2012). According to Kwofie et al, (2011), MoFA, (2001), many African countries process maize into flour by milling and is a key activity, as over 95% of the people of Ghana adore delicacies such as 'banku', 'kenkey', 'akple', 'aprenprensa', and porridge. Generally, domestic food preparation deals with the size reduction of staple agro-produce such as maize, millet, rice, sorghum, cassava, dried pepper, etc. Milling is accomplished sometimes by pretreating the coarse material in cold or warm water (wet milling). It may also be accomplished by direct milling without any conditioning (dry milling).

Figure 1.2. Disc with Back Cover. (Source: FRI, Accra 2014)

1.2 Problem Statement

Observation has shown that the Attrition mills used as 'commercial service mill' has a very high rate of wear of the grooves or flutes engraved on the disc plate during casting. Obviously, the iron fillings as a result of the wear ends up in the milled product and ultimately get into the food prepared from such production. There is the possibility of Households, Restaurants and people who patronize street-vended food consuming such crudely fortified metal particles without knowing the health implications. It has been suggested that the maximum allowable lead (Pb) concentration for example is 0.3 mg/kg of food sample or 0.025 mg per kg body weight (Sinayobye and Saalia, 2011).

Figure 1.3. Mill Plate with Grooves. (Source: Kumasi Magazine, 2015)

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1.3 Objectives

The main objective is to investigate, identify the causes and effect of wear of the indigenous manufactured attrition plate mill and find solutions.

The specific objectives of the work are;

(i) to determine the material composition of the Attrition disc.

(ii) to determine the possible factors of wear of disc.

(iii) to evaluate the amount of iron particles that ends up in a milled maize flour and also to ascertain if particles are within acceptable limits.

(iv) to redesign the grinding disc and develop a solution technique to rectify the problem.

1.4 Research Question

(i) what is the elemental composition of the samples grinding disc

(ii) what is the hardness properties of the grinding disc

(iii) what is the amount of iron particle resulting from milling

(iv) what are the levels and kinds of metal particles acceptable to human?

(v) how can the problem be rectified

1.5 Justification.

As cited by Kwofie et al. (1999, 2011), Bhaskaram, (2001), Bothwell, (1979), Corbett, (1995), Dallman, (1986), Haas and Brownlie, (2001), iron is a needed constituent in man, and over exposure of iron would lead to toxicity or death (WHO, 1973). The first few years of infant's exposure to lead (Pb) concentration in its growth can lead to the possibility of neurotoxicity effects and handicap development (Shannon, 1998). The phenomenon certainly would have health implications for the people who depend on such cast iron type attrition mills plate for their milling needs. It is a known fact that consumption of heavy metals can cause cancer and therefore there could be health risk associated with food milled by such practices.

To safeguard the health of the people and to improve on food safety, it will be necessary to investigate and evaluate by the use of engineering research approach the extent of contaminants due to the wear rate of the attrition type mill plate. Kwofie et al, (2011) argued that, the effect of moisture content of maize on wear rate of milling plates as well as the level of metal contamination of milled maize has not been investigated. It is hoped that the study will discover better understanding of the phenomenon, to create awareness to the general public so as to find solution to the seemingly problems and to promote the use of durable alternative.

1.6 Structure of Thesis

For the purposes of this research work, a population of five local foundries houses and two foreign brands from India shall be considered. It is believed that the seven pair of plate will give the needed information to enable the gathering of enough data to help answer the research question within the time frame.

Prelude to the main five chapters of the study are the tittle page, certification, list of figure, list of tables and acknowledgment. The five main chapters ensuing are introduction, literature review, methodology, results and discussion, conclusion and recommendation. The introduction elucidates the history of milling and how indigenous milling has given way largely to modern technology. It explains the different kinds of milling machines available for food processing and the reasons why wear exist with mating parts.

The chapter two review existing literature on casting processes with the use of Cupola furnaces to produce Chilled Cast Irons. It further evaluates the hardness properties of the mill plate with the use of Brinell hardness machine. It shows the level of contaminants and exposure of heavy metals to human. Chapter three explains the materials and methods used to achieve the results such as the identification and selection of mill plate, flour samples taken to the laboratory of GAEC for evaluation.

Chapter four deals with results and discussions based on experiment carried out. The last chapter talks about the conclusions and recommendation which is centered on the findings. The final part is the references and appendices with some illustration.

CHAPTER TWO LITERATURE REVIEW

In this chapter, a review with emphasis on interactions with local foundry operators and other studies will be the focus. The use of literature to evaluate the current work will also be executed.

2.1 Cupola Furnace

The sample selected for the experiment was produced from Cupolas built locally. Indeed the indigenously made Cupola has existed many years back. It has been passed-on from entrepreneur to another, the exact years was quite sketchy. The assumption is that; it has existed over scores of years. Cupolas have been used for many years to melt cast irons, copper, and bronze and ni-resist iron. Cupolas are economical, simply, environmentally friendly and the most widely used in the foundry industry.

Though it is an old method of melting, it is widely meant for cast iron making. Electric furnaces have also come to replace cupolas but for the high electrical tariff, it is only used for special metals. Cupola furnace was used in the 3rd century B.C. by the Chinese, officialdom say Rene-Antoine Ferchault de Reaumur was the first to build one in 1720AD, (www.industrialmetalcasting.com.). Cupola furnace is cylindrically shaped and place on a four legged structure for a support, (www.industrial metalcasting.com). The shell of the cupola, being usually made of steel, has refractory brick and refractory patching material lining it. The bottom is lined in a similar manner but often a clay and sand mixture may be used, as this lining is temporary.

The bottom lining is compressed or 'rammed' against the bottom doors, (seminarproject.com). Some cupolas are fitted with cooling jackets to keep the sides cool and with oxygen injection to make the coke fire burn hotter, (www.help4engineersblogspot.com). The other equipment is arranged around the cylinder and the bottom of the cylinder has a door through which the molten metals can be dropped down, (www.industrialmetalcasting.com). The top of the cylinder is usually open for the gas to escape. A typical cupola melting furnace consists of a water-cooled vertical cylinder which is lined with refractory material, (www.industrialmetalcasting.com).Coke, limestone and the metal plus the fuel are fed

into the cylinder. Air is supplied through tuyeres and it goes through the bottom part of the cupola. In most cases, this process is preferred to electric furnace, (www.industrialmetalcasting.com), because most impurities get remove while the iron is melted.

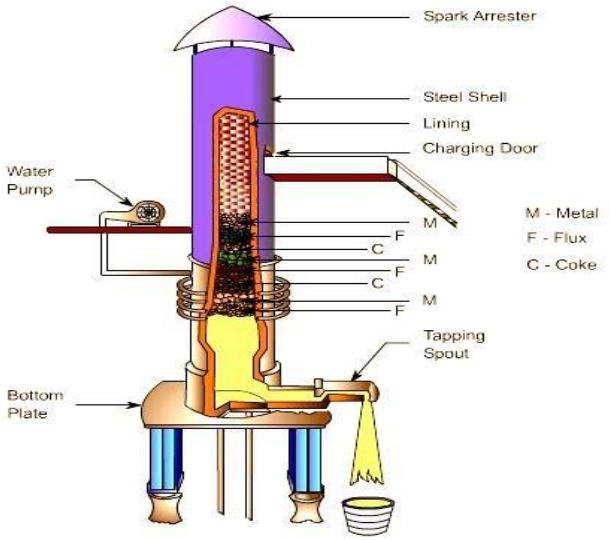

Figure. 2.1 Cupola Furnace (source : http://ntpd.ac.in)

Production run is began normally called “cupola campaign” is filled with layers of ignited coke with torches. Smaller cupolas are sometime ignited with biomass or wood to start the coke burning.

At red hot of the coke, solid metal pieces are charged into the furnace through the charging door at the top. Additional layers of fresh coke are added when the metal is alternated. Rising heat within the stack melts the metal. Limestone serves as flux when added. The melted metal drips down through the bed of coke, (www.projectseminar.org) and collect at the bottom just above the lower doors. Reaction of heat or thermodynamics takes place. Carbon monoxide is formed when the carbon in the coke combines with oxygen in the air. The carbon monoxide burns further

to form carbon dioxide. The falling droplets of molten metal pick up the carbon and it raises the carbon content of the iron, (www.techsciencenews.com).

Briquettes of ferromanganese and silicon carbide may also be used to charge the materials. Carbon and silicon enter into the molten melt whilst silicon carbides disassociates. Similarly, ferromanganese combines into the pool of the liquid iron in well at the bottom. The impurities are mostly removed when the molten metal is still liquid. The process is economical, simple and it can be used for wide range of metals. Cupolas are eco-friendly because they take the heating energy from the coke in the furnace, (www.industrialmetalcasting.com).

Local entrepreneurs at Kumasi Magazine use Cupolas which have similar features as shown in Figure 2.1; there exist several challenges are associated with their designs. Some of the cited challenges were, blowers that help give the needed amount of air for combustion were chosen arbitrary, the tuyeres or pipes carrying the air were leaking and charging door platform was inadequate. There were several safety concerns such as housekeeping, proper clothing, and fire extinguishers during production. However, owners are striving hard to improve on some of the listed challenges. Industrial extension could be placed for the benefit of such foundry artisan by Government agencies.

2.2. Cast Iron

Mill plate is produced from cast irons in a process called sand casting. The cast plate is generally from Chilled Cast Iron. The description below categorizes cast irons into class of types. Cast iron is about alloy of iron, carbon and silicon and is hard and brittle. Carbon content is always often around 3%. Carbon may be present in two forms: as

free carbon or graphite and as combined carbon or iron carbide (Fe_3C). Cast iron castings are of following types:

Grey iron, malleable iron, chilled iron, spheroidal or nodular graphite iron, austenitic iron and abrasion resistance casting.

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2.2.1. Grey Iron Casting

It is a type of cast iron and the carbon is mainly in graphite form, grey in color and is called grey cast iron. They are extensively used for machine parts because they are inexpensive, can be given almost any desired form and have high compressive strength. Graphite is an excellent lubricant, and grey cast iron is easily machined as the tool is lubricated easily and chips break off readily. The freedom with which articles slide over a smooth surface of cast iron is largely due to graphite in the surfaces. However, brittleness and lack of ductility and shock resistance prohibit their use in parts subject to high tensile stress or suddenly applied loads. Its use above a temperature of 573 K is avoided.

The grey iron castings used for general engineering purposes are designated by letters FG followed by ultimate tensile strength in kg/sq. mm viz. FG20, FG35.

The grey iron castings where chemical compositions are more important are indicated as FG35Sil5 where the important element Si is also added in designation. The details of grey cast iron are given in BIS: 210-1965. In these properties of standardized designated castings, according to BIS, FG15, FG25, FG30, FG35 and FG40 are given. The properties given are minimum ultimate tensile strength and results of transverse test such as breaking load, rupture stress and deflection, for the above grey cast iron. The hardness values as Brinell hardness number are also given for them. Ferrous

castings in which carbon is in form of iron carbide are referred to as white cast iron because they have a whitish appearance. Iron carbide is a hard, brittle substance and its presence increases hardness of cast iron. White cast is almost un-machine able and is used somewhat in parts which require abrasion resistance.

When Silicon in cast irons is kept low in percentage and carbon is mostly in chemical combined state, the cast iron is called white or chilled cast iron.

White cast iron present as carbon free and has no graphite and therefore the grain surface is white. It is produced by:

i. Adjusting the carbon and silicon to a low composition ii.
   Cooling grey cast iron very fast after casting.

When white cast iron is rapidly cooled after production of grey cast iron against metal chills or in metal molds the product is called chilled grey cast iron, and can be adjusted in composition with elements like, C, Cr, V, Mo, Ni to increase formation of iron carbide, (Kaushish, 2010).

2.2.2. Properties and uses of Chilled Cast Irons

According to Kaushish, (2010), white cast iron consist of Carbon: 1.7 to 2.4%, Silicon: 0.85 to 1.2%, manganese 0.5%, Phosphorus 0.2%, Sulphur 0.12%, it is hard, wear resistant, brittle and not suitable for most foundry general works due to difficulty in fluidity, however if Ni 4.5% and Cr 1.5% is added its strength and toughness multiplies in twofold and hardness will increase from 400 to 700BHN. Chilled cast irons are used for abrasion resistance components such as hammer mills, wear plate mills (grinding disc teeth), crushers, and car wheel and railway brake blocks.

2.2.3. Malleable Cast Iron

Malleable cast iron is white cast iron which is rendered malleable by proper annealing. Malleable iron is an inexpensive material, tougher than grey cast iron and more resistant to bending and twisting.

Malleable cast iron is white classified as black heart, pearlite and white heart and they are designated as follows:

a) Black heart BM35, BM32 and BM30

b) Pearlitic PM70, PM65, PM55, PM50 and PM45

c) White heart WM42 and WM35.

The number after letters indicates ultimate tensile strength in kg/sq. mm.

Malleable cast iron is useful for many purposes such as gear housings, brake pedals, plough, tractor and various automobile parts. Method of designating some important ferrous castings is given below:

2.2.4. Spherical or Nodular Graphite Iron

This cast iron has graphite in form of spheres or nodules. This type of cast iron has good elongation. They are designated by letter SG and a percentage elongation is also specified along with. Spheroidal graphite irons available and designated are SG80/2, SG70/2, SG60/2, SG50/2, SG42/12 and SG38/17. The first number indicates the tensile strength in kg/sq. mm and the number after the oblique is percentage elongation.

In order to have had durable surface, the castings are chilled. Such castings are produced by burying iron plates in the mold. As a result, the metal coming in contact

with these plates will be cooled rapidly and will be harder than the rest of the casting. The transition from graphite gray to white cast iron arises from the nucleation and growth competition between the graphite gray and white eutectics and is related to chill cast iron, according to (Fras et al, 2005)

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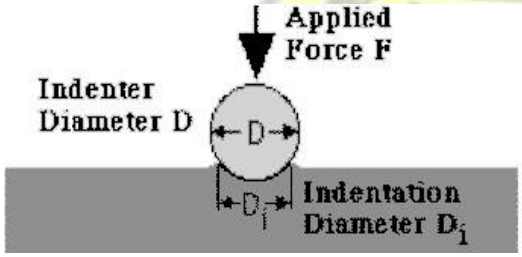
2.3. The Brinell Hardness Test

To compare some properties of the mill plate and to ascertain it make-up, the quality of samples with regards to scientific measurement to be obtained must be accurate. In this regard some measurement of hardness test was required. There are several simply hardness test available, destructive and non-destructive. The most widely used hardness test is the Brinell Hardness Number, (BHN).

The Brinell hardness test method consists of indenting the test material with a 10 mm diameter hardened steel or carbide ball subjected to a load of 3000 kg. For softer materials the load can be reduced to 1500 kg or 500 kg to avoid excessive indentation. The full load is normally applied for 10 to 15 seconds in the case of iron and steel and for at least 30 seconds in the case of other metals.

The diameter of the indentation left in the test material is measured with a low powered microscope. The Brinell hardness number is calculated by dividing the load applied by the surface area of the indentation.



$$BHN = \frac{F}{\frac{\pi}{2} D \cdot (D - \sqrt{D^2 - D_1^2})}$$

Figure 2.2. Hardness Test and Equation (Source: http:/www.gordoengland.co.uk)

The diameter of the impression is the average of two readings at right angles and the use of a Brinell hardness number table can simplify the determination of the Brinell hardness. A well-structured Brinell hardness number reveals the test conditions, and looks like this, "75 HB 10/500/30" which means that a Brinell Hardness of 75 was obtained using a 10mm diameter hardened steel with a 500 kilogram load applied for a period of 30 seconds. On tests of extremely hard metals a tungsten carbide ball is substituted for the steel ball. Compared to the other hardness test methods, the Brinell ball makes the deepest and widest indentation, so the test averages the hardness over a wider amount of material, which will more accurately account for multiple grain structures and any irregularities in the uniformity of the material. This method is the best for achieving the bulk or macro-hardness of a material, particularly those materials with heterogeneous structures. (www.gordoengland)

2.3.1. Mechanical Failure Cast Irons

There are two types of mechanical failure of cast irons and they are relatively common problems that are encountered regularly. Due to the manufacturing process of cast iron there are various imperfections that occurs.

During pouring of the molten metal, air holes interrupt, uneven cooling, cinders to form the imperfection of manufacturing. These imperfections normally weaken the piece mechanically and sometimes too severe weakness occurs. Such manufacturing defect are generally not seen at inspection. However, non-destructive techniques are 43available to identify these types of defects. The non-destructive test notably is fluorescent fluid, ultraviolet lamps and X-rays.

These are specialized non-destructive technique and require specially trained personnel to handle such high level equipment. Ordinarily maintenance staff is not train to handle such instrument. Mechanical failures can be detected by visible inspection whenever the failure has occurred or began to occur. Stress cracks defects in paints or metals could be symptomatic of these problems.

Failure starts with gradual separations and is visible upon inspection. It may be detected and corrected before a total catastrophic failure of the material occurs. Monitoring and investigation should be conducted on paint films for linear cracks.

These results obtained and deductions made from a series of ultimate tensile strength (UTS) and hardness tests involving austempered chilled ductile iron containing 0.1% Mo and Cu contents varying from 0.5 to 4.2%. By using metallic (copper) and nonmetallic (graphite) chills, the effect on ultimate tensile strength (UTS) and hardness of varying the chill rate was also examined. All the tests were carried out in conformance with AFS (American Foundry man's Society) standards. It was found that austempered chilled ductile iron is highly dependent on the location on the casting from where the test samples are taken and also on the Cu and Mo content combination of the material, as well as the rate of chilling. It was found that the hardness and tensile strength is highly dependent on the rate of chilling. Finally, comparative studies of using different chills and without using any chills have been made to see that effect of chilling is influencing the properties of composite under investigation.

The experimental results of the hardness tests done on castings chilled using different metallic and nonmetallic chills and without using any chills are tabulated in many literatures. It is a well-known fact that for metallic materials, hardness increase as tensile strength increases. The results obtained for hardness are therefore not surprising.

It can be seen that, as in the case of UTS, changing the different chill does have a significant effect on the hardness of the casting.

2.4. Human Health and Heavy Metals Exposure

The toxicity of metals most commonly involves the brain and the kidney, but other manifestations occur, and some metals, such as arsenic, are clearly capable of causing cancer. An individual with metals toxicity, even if high dose and acute, typically has very general symptoms, such as weakness or headache. This makes the diagnosis of metals toxicity in a clinical setting very difficult unless a clinician has the knowledge and training to suspect the diagnosis and is able to order the correct diagnostic test. Chronic exposure to metals at a high enough level to cause chronic toxicity effects (such as hypertension in individuals exposed to lead and renal toxicity in individuals exposed to cadmium) can also occur in individuals who have no symptoms.

Much about metals toxicity, such as the genetic factors that may render some individuals especially vulnerable to metals toxicity, remains a subject of intense investigation. It is possible that low-level metals exposure contributes much more towards the causation of chronic disease and impaired functioning than previously thought.

This part focuses on exposure to the four “heavy” metals on the ATSDR list mentioned above leads, mercury, arsenic, and cadmium—as they are arguably the most important metal toxins from a global as well as U.S.A perspective. Some additional remarks are also made regarding a few other metals of concern.

2.4.1 Lead Exposure

For centuries, lead has been mined and used in industry and in household products. Modern industrialization, with the introduction of lead in mass-produced plumbing, solder used in food cans, paint, ceramic ware, and countless other products resulted in a marked rise in population exposures in the 20th century.

The dominant source of worldwide dispersion of lead into the environment and into people for the past 50 years has clearly been the use of lead organic compounds as anti-knock motor vehicle fuel additives. Since leaded gasoline was introduced in 1923, its combustion and resulting contamination of the atmosphere has increased background levels everywhere, including the ice cap covering Northern Greenland, where there is no industry and few cars and people. (US-EPA, 1985). Although a worldwide phase-out of leaded gasoline is in progress it is still being used all over the world.

The current annual worldwide production of lead is approximately 5.4 million tons and continues to rise. Sixty percent of lead is used for the manufacturing of batteries automobile batteries, in particular, while the remainder is used in the production of pigments, glazes, solder, plastics, cable sheathing, ammunition, weights, gasoline additive, and a variety of other products. Such industries continue to pose a significant risk to workers, as well as surrounding communities.

In response to these risks, many developed countries over the last 25 years have implemented regulatory action that has effectively decreased actual exposures to the general population. However, exposures remain high or are increasing in many developing countries through a rapid increase in vehicles combusting leaded gasoline and polluting industries some of which have been “exported” by corporations in

developed countries seeking relief from regulations. Moreover, some segments of the population in developed countries remain at high risk of exposure because of the persistence of lead paint, lead plumbing, and lead-contaminated soil and dust, particularly in areas of old urban housing.

According to Moore, (1985), a number of causes can change the impact of lead exposures. For example, water with a lower pH such as drinking water stemming from the collection of untreated "acid rain" will leach more lead out of plumbing connected by lead solder than more alkaline water. Ward and Savage, (1994), suggested that Lead (Pb) from soil tends to concentrate in root vegetables (e.g., onion) and leafy green vegetables (e.g., spinach).

Individuals will absorb more lead in their food if their diets are deficient in calcium, iron, or zinc (Mahaffey, 1990), other more unusual sources of lead exposure also continue to be sporadically found, such as improperly glazed ceramics, lead crystal, imported candies, certain herbal folk remedies, and vinyl plastic toys.

2.4.2 Toxicity

Lead has been center of environmental medicine research for a long time. Analysis on and in people were significantly helped by the improvement of techniques, (for example, graphite atomic absorption spectroscopy) for the exact and solid estimation of lead in blood (measured in units of micrograms per deciliter [µg/dL]), a system that is presently broadly accessible and utilized for screening and monitoring, as well as scientific discovery.

The general assemblage of studies on lead poisonous quality demonstrates that, contingent upon the measurements, lead introduction in youngsters and grown-ups can

bring about a wide range of medical issues, such as from shakings, unconsciousness, renal failure, and negative impact on digestion system and knowledge at low exposures, (ATSDR, 1999). Kids are especially powerless against the neurotoxic impacts of lead. Epidemiologic studies has convincingly shown that low-level lead presentation in kids under five years old with blood lead levels in the 5-25 µg/dL range results in shortfalls in scholarly improvement as showed by lost insight remainder focuses, (Banks et al, 1997). Thus, in the U.S. A, the Centers for Disease Control (CD), (1991), brought down the admissible measure of lead in a youngster's blood from 25 to 10 µg/dL and prescribed widespread blood lead screening of all kids between the ages of six months and five years.

In any case, various issues still stay uncertain regarding lead poisonous quality in kids. According to Silbergeld, (1919) the most essential amongst them is the danger postured to the baby by preparation of extensive skeletal stores of lead in pregnant ladies. Additionally, maternal bone lead stores are activated at a quickened rate amid pregnancy and lactation as reported by (Gulso et al, 1997).

Hu et al, (1998) insist that bone lead stores persisted for a long time, can remain a danger or threat to health numerous years after environmental exposure had actually been curtailed. As opposed to youngsters, grown-ups are by and large permitted by regulations to be presented to higher measures of lead. In the U.S.A, for instance, the Occupational Safety and Health Administration requires that the blood lead levels of uncovered laborers be kept up underneath 40 µg/dL as a method for counteracting dangerous impacts to nerves, the cerebrum, kidney, conceptive organs, and heart. This standard is maybe outdated, on the grounds that, the standard above all else does not

ensure the hatchlings of ladies who get to be pregnant while at work, Secondly, epidemiologic studies have connected blood lead levels in the scope of 7-40 µg/dL with confirmation of poisonous quality in grown-ups, for example, neurobehavioral decrements, (Schwartz, 2001) and renal impairments (Kin et al, 1996,)

Thirdly, late studies utilizing a recently created method, K-x-beam fluorescence, to straightforwardly measure bone lead levels rather than blood lead levels have given proof exhibiting that total lead introduction in people with blood lead levels well beneath 40 µg/dL is a noteworthy danger component for the improvement of hypertension (Hu,et al.1996, Korrick, 1999, Cheng, et al, 2001) cardiovascular conduction delays, (Cheng et al. 1999) and subjective disabilities (Stewart, 1999, Payton, 1998). Onalaja, (2000) reported that progressions examination to depict the full toxicological ramifications of lead introduction, learns at the interface of hereditary qualities and natural wellbeing are starting to find subgroups of persons who might be primarily helpless against the poisonous quality of lead.

2.4.3 Arsenic Exposure

Arsenic (As) for instance has been contended to have a metalloid of incredible ecological worry because of its poisonous quality and wealth. In some nations, for example, Bangladesh, China, Hungary and India, as is found at high focus in ground water and surface soil (Chen et al., 2006). Adjacent to its characteristic frequency, (As) is additionally discharged into the earth from refining and mining (Aldrich et al., 2007). Because of that, the U.S. Ecological Protection Agency brought down the standard of as in drinking water from 50 to 10gAsL−1 (USEPA, 2001), in spite of the fact that at present, there is no referred as far as possible for As. Table 2.1 alludes to every day iron admission of newborn child and sexual orientation.

Table 2.1. National Research Council Recommended Daily Dietary Iron Allowances.

Age group	Age (yrs.)	Iron (mg)
Infants	From 0.5	10
	0.5-1.0	15
	1-3	15
Children	4-6	10
	7-10	10
	11-14	18
	15-18	18
Males	19-22	10
	23-50	10
	50+	10
Females	19-22	18
	23-50	18
	50+	10

Source: Kwofie et al (2011).

CHAPTER THREE

METHODOLOGY.

The chapter covers the steps taken to achieve the specific objectives, the various test such as the elemental composition, use of Brinell hardness, placing each pair of mill plates in an Attrition mill machine for specimen flour samples. Flour samples sent for chemical analysis using Atomic Absorption Spectrometer (AAS). It sums-up the procedure involved in gathering data for analysis and further discussion of the study.

3.1 Study Area.

The area of the study is situated at “Kumasi Magazine” at Suame Sub-Metro, where most of the foundries can be found. It is a vast commercial industrial enclave north of

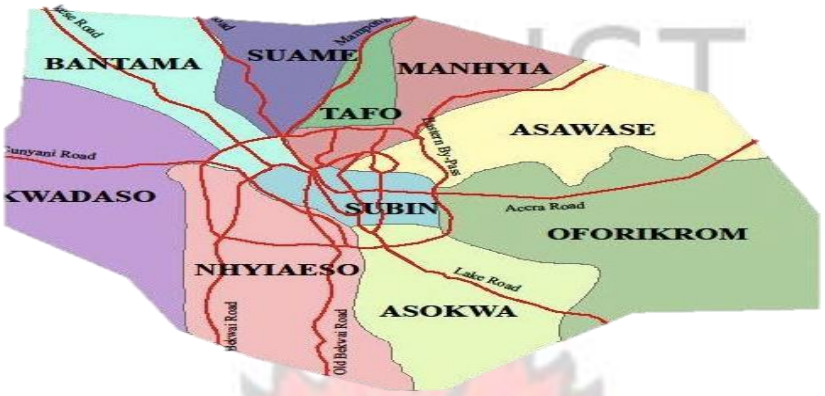


Figure 3.1 Map of Kumasi Sub-Metro. (Source: http:/ mci.ei.columbia.edu/millennium-cities/kumasi-maps-population-data) Kumasi, the capital town of the Ashanti Region. The place is inhabited mostly by equipment fabricators, foundry shops, motor vehicle mechanics, motor vehicle parts shops, machine tool shops, welders and many other businesses.

A random sample of five mill plate manufacturers was selected out of ten foundries within a section of the area noted for foundry activities for the studies. The foundries were, Babawala Foundry, Atanga Foundry, Asare Foundry, Abudia Foundry, and Nyamekye Foundry. Nulux and Navin mill plate imported from India were part of the samples.

3.2 Production of the Mill Plate

The material for the experiment was manufactured using coal and charcoal fired Cupola. The cupola was preheated for about 45 minutes. It was then charged with a prepared scrap material through an entrance called the charging door. As the heat

intensified and by means of an air blower, air was directed through small ports call tuyeres, it was to help maintain and stoke-up the fire whilst more scraps were added until it got to a maximum of seven tons. After, about another 45 minutes, the molten metal was ready and was then tapped from the bottom of the cupola intermittently into a green sand mold that mimic's the grinding mill plate. (Figure 3.2 and Figure 3.3).

Figure.3.2. Tapping the Melt **Figure.3.3. Pouring Melt into Mold**

(Source: Babawala Foundry Magazine Kumasi, 2015).

The process was repeated until all the seven tons were completed. The sand mold was destroyed to remove the grinding mill plate after it had been allowed to cool completely over night for about 12 hours. The grinding mill plate were cleaned and inspected for flaws. The defective ones were rejected.

The high spots on the manufactured grinding mill plates were also removed using an abrasive grinding machine. The groove or the teeth of the grinding plate were ground to a depth of about 2 mm. All the pair of plate used for the experiment was taken through the same procedure after which the Vernier gauge was used to measure the depth. (Table 3.1).

Table 3.1. Depth of Grooves

Foundry	Flute depth (mm)
Babawala, (local)	2.00

Atanga, (local)	2.20
Asare, (local)	2.30
Abudia, (local)	2.00
Nyamekye, (local)	2.10
Navin,(India)	2.10
Nulux,(India)	2.00

3.3. Hardness, Dynamic wear and Concentricity Testing.

Four types of mechanical test were performed namely hardness, dynamic wear, concentricity and a destructive elemental composition test.

3.3.1 Hardness Test

The Brinell is one of the most widely employed hardness test method for metals. The seven pair of mill plate material was cleaned with a wire brush. Each plate was placed under the Brinell hardness test machine. With a 10 mm diameter (D) hardened steel ball and a constant load (F) of 3000 kg was applied onto the mill plate for 15 seconds. An indentation (D_1) was registered on the scale. The depth of the indentation in the test material was measured with a low powered microscope. The results of penetrations obtained were computed using Eq. 3.1 and the values of the BHN were obtained and the results are tabulated and presented in Table 3.2.

$$BHN = \frac{F}{\frac{\pi D}{2}\left(D - \sqrt{D^2 - D_i^2}\right)} \quad \text{.....Eq.3.1}$$

Table 3.2. Brinell Penetration and BHN.

	Babawala	Atanga	Asare	Abudia	Nyamekye	Navin	Nulux
Brinell Penetration (mm)	2.7	2.7	2.7	2.7	2.65	2.95	2.9
Hardness Number	514	514	514	514	514	429	444

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3.3.2 Dynamic Wear Test

Using a digital scale (Testut EBW-60) with a reading range of 0.05 kg to 60 kg, each specimen of mill plate was initially weighed. After the milling process, the final mass of mill plate were also weighed, the results tabulated and presented in Table 4.1.

3.3.3 Concentricity Test.

The mill plate was fixed to the lathe machine on a face plate. The headstock gear was set in neutral so that the face plate can rotate freely. The face plate was moved by hand through 90^0. With the use of dial test indicator and a scribing block, the measurement of deviations across the face of the plate (m) were recorded (Table 3.3).

Table 3.3. Concentricity Factors

Foundry	Mass (m)(kg)	Error. (mm)	r(mm)	R(mm)
Babawala,(local)	4.50	0.02	75	140
Atanga,(local)	5.00	0.02	75	142
Asare,(local)	4.85	0.04	76	143

Abudia,(local)	5.90	0.03	74.5	140
Nyamekye,(local)	5.25	0.02	75	144
Navin,(India)	5.30	0.05	77	145
Nulux,(India)	5.20	0.06	77	146

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With a try and error procedure, the unbalance mass values of the out of balance forces were deduced. The process was repeated for the rest of the samples. For a mass of the disc (M) rotating at a speed (N) and having a radius (R) will then counter balance a small mass (m), rotating at the same speed but a radius (r) then using centrifugal balance force equation.

Mass x rotational speed x distance.

The balance force, $M = \frac{mr}{R}$ ----- Eq.3.2

Using Table 3.3 and Eq. 3.2, the results obtained for the mas (M) are presented in Table 3.4

Table 3.4 Out of Balance Mass.

Foundry	**mass (M) kg of Specimen.**
Babawala, (local)	2.41
Atanga, (local)	2.60
Asare, (local)	2.63
Abudia, (local)	3.0
Nyamekye, (local)	2.81
Navin, (India)	2.81

Nulux, (India)	2.76
Redesign, (local new)	2.60

3.4. Elemental Composition Test.

A destructive test activity was carried out at the Tema Steel Works (TSW) laboratory. Each of the seven mill plate was cut into two halves and the cut surfaces ground to get a uniform surface area. An Aloxin resin paper was used to clean and polish along the cut surfaces for better instrument penetration.

A Spark Emission Spectrometer instrument was used to determine the elements. The results were retrieved from a connected computer. The elements that showed significant values were recorded as presented in Table 3.5.

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Table 3.5 The Elements in Grinding Plates.

	Fe	C	Mn	P	S	Si	Cu	Ni	Cr	V	Al	Sn	B
Babawala	95.57	2.81	0.28	0.14	0.14	0.50	0.24	0.08	0.20	0.02	0.01	0.01	0.02
Atanga	94.55	3.04	0.92	0.42	0.08	0.50	0.12	0.20	0.12	0.06	0.01	0.02	0.01
Asare	94.35	2.79	1.05	0.44	0.04	0.66	0.18	0.23	0.09	0.03	0.01	0.02	0.01
Abudia	95.57	2.87	0.19	0.14	0.15	0.50	0.16	0.12	0.26	0.02	0.01	0.01	0.02
Nyamekye	93.21	3.77	0.97	0.21	0.12	0.77	0.14	0.18	0.28	0.06	0.01	0.02	0.02
Navin	95.14	3.21	0.24	0.30	0.33	0.56	0.06	0.03	0.07	0.01	0.00	0.00	0.04
Nulux	94.71	3.28	0.53	0.13	0.32	0.87	0.08	0.03	0.05	0.01	0.01	0.04	0.04

3.5. Milling Processes.

Maize was purchased from the open market for the study. Raw maize of about 50 g for each experiment was weighed and for analysis. This was used to estimate the baseline of element in the raw maize before milling.

The rest of the maize was soaked overnight, approximately for 12 hours. The steeped maize was drained of water using a perforated basket. The maize was weighed and poured into the hopper for the milling operation. At the beginning of the milling an average samples of 100 g flour was taken and also at every intervals of 100 kg of milling until a total of 600 kg of maize was milled, thus completing one experiment. Feed rate of 5 kg/min was used during the milling. It took about 120 minutes to complete one set of experiments. A hand held scale was used for the weighing of sample. The process was repeated for the rest of the mill plates. In all a total of 56 maize flour samples were collected.

Figure. 3.3 Potable Scale (Source : IRRI, Philippines, 2010)

3.6 Determination of Metal Particle Deposit in Maize Flour.

Chemical analysis was used to determine the amount of iron particles deposited in the maize flour at Chemistry department of Ghana Atomic Energy Commission (GAEC). Each sample weighed approximately 0.50 g and was dissolved in nitric acid to a suitable solution. It was placed in the atomic absorption spectrometer (AAS) which is based on

the Beer Lambert theory. All the 56 samples were taken through the same process. An attached detector was used to measure the amount of light absorbed. The results were recovered from an attached computer, (Table 3.6 and Appendix. Table A1.12 to A1.17, and Figure B4).

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Table 3.6. Metallic Deposit in Maize Flour in mg/kg, flour. (Sample Nulux).

Element	Fe	Cu	Pb	Mn	Co	Cr	Mg	As
Control sample	0.0050	0.0060	0.0000	0.0030	0.0000	0.0000	0.0215	0.0000
Sample 1	8.3730	0.0530	0.0400	0.0900	0.0220	0.0010	1.7754	0.0010
Sample 2	0.2570	0.1220	0.0010	0.0430	0.0130	0.0010	1.7880	0.0010
Sample 3	0.2710	0.1940	0.0130	0.0440	0.0050	0.0010	1.7956	0.0010
Sample 4	0.2790	0.0700	0.0010	0.0430	0.0050	0.0010	1.7658	0.0010
Sample 5	0.1850	0.0090	0.0010	0.0380	0.0050	0.0030	1.7747	0.0010
Sample 6	0.5050	0.0330	0.0070	0.0520	0.0100	0.0010	1.8161	0.0010

3.7. Redesign of Grinding Disc.

Using Babawala foundry, a redesigned version was formulated to help address the objective of finding solution to wear. The version was taken through the same experimental processes just as the main specimen for the experiment as vividly described in (Chapter 3.2) with the aim of improving the grinding disc.

The raw material was initially tested from weighed scraps of engine blocks, stainless steel and nickel steel. An obtained ratio of (0.88: 0.076: 0.044) respectively was used for the production of the redesigned specimen. The sample was placed on a Brinell

testing machine and it registered 2.50 mm penetration with a deduced corresponding value of 601 Brinell hardness number (BHN). Test for elemental composition and concentricity were carried out, (Refer to Table 3.7). The redesigned grinding mill plate was used in a maize milling process similar to (Chapter 3.6) after which the resulted flour samples were taken to GAEC laboratory for the determination of metal particles, (Refer to Appendix Table A1.17).

Table 3.7 The Elements in the Redesigned Grinding Disc.

Element	Fe	C	Mn	P	S	Si	Cu	Ni	Cr	V	Al	Sn	B
Redesign	91.74	3.57	0.65	0.05	0.04	1.87	0.26	0.53	0.53	0.04	0.00	0.60	0.01

CHAPTER FOUR RESULTS AND DISCUSSIONS

The chapter looks at the results and discusses the findings of the study based on literature, tables, graphs and illustrations. The results are used to explains and discuss the elemental composition of the Attrition disc, mechanical test, and factors of wear resistance, amount of iron deposit and its effect to human exposure.

4.1. The Constituents of the Grinding Mill Disc.

Table 3.5 shows the trend of chemical composition of the specimen and the rest in (Appendix Figure A1.1 to A1.7). Using Babawala specimen, the results indicates Iron (Fe) constituent of 95.57 %, followed by carbon content of about 2.81 %.

Manganese (Mn) shows a value of 0.28 %. The values for Phosphorous (P), Sulphur (S), Silicon (Si), Copper (Cu), Nickel (Ni) and Chromium (Cr) were, 0.14, 0.14, 0.50,

0.24, 0.08 and 0.2 % respectively. The rest of the elements were Vanadium (V), Aluminum (Al), Tin (Sn) and Boron (B).

The trend in the entire sample specimen selected for the test and the remaining metals are as presented in (Table 3.5). The trends from Figure 4.1 also suggest that two foundries specimen, Babawala and Abudia registered similar values of 95.57 % whilst the rest of the foundries specimen had different values ranging between 931.21 to 95.14 %. It can be inferred that because each foundry has its own method of preparation and formulation during production, the percentages of Fe and other elements differed significantly.

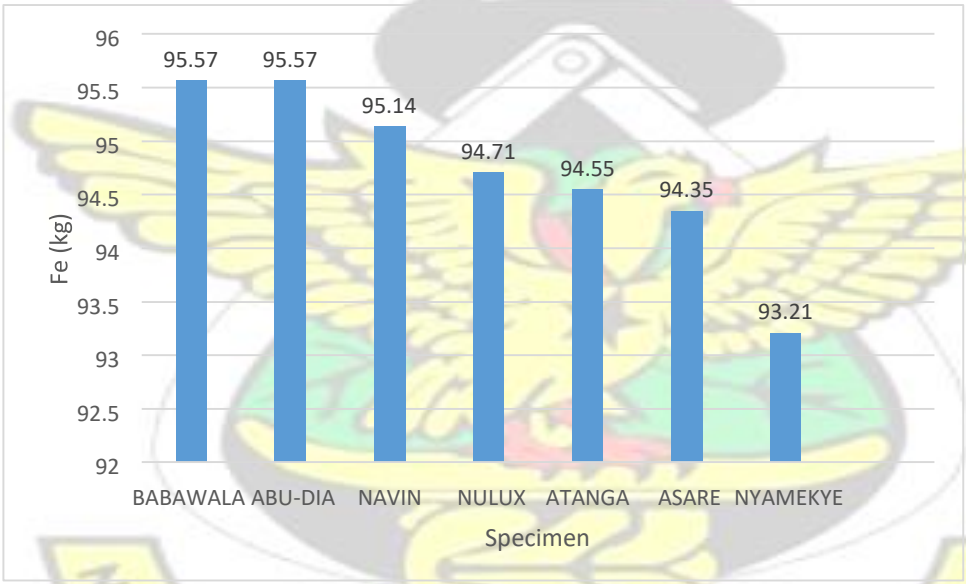

Figure 4.1 Trend of Iron Constituents

In foundry practices and in the production of mill plate, the percentage iron content determines how much other elements can exist as various alloys. To purposely attain certain qualities during solidification, these alloying elements forms combinations to attain properties such as strength, scratch resistance, hardness, corrosion resistance, and elevated temperature requirements.

Fe and Carbon (C) content are the main elements that are key in the classification of cast-irons. Iron also combines with many other alloying elements such as vanadium, chromium, boron, manganese, nickel, and silicon so that it can be altered in many ways to suite an extremely wide variation of design requirements. It is worth noting that such alloys can be complicated as they transform from structure to structure which influences the final product.

From Table 3.5 the Carbon values were plotted as shown in Figure 4.2. Nyamekye specimen has the highest 3.77 % value in Carbon, whilst that of Asare specimen was the lowest 2.79 %. Generally, carbon is a non-metallic element, and one of the most important elements in the formation of ferrous metal in generally.

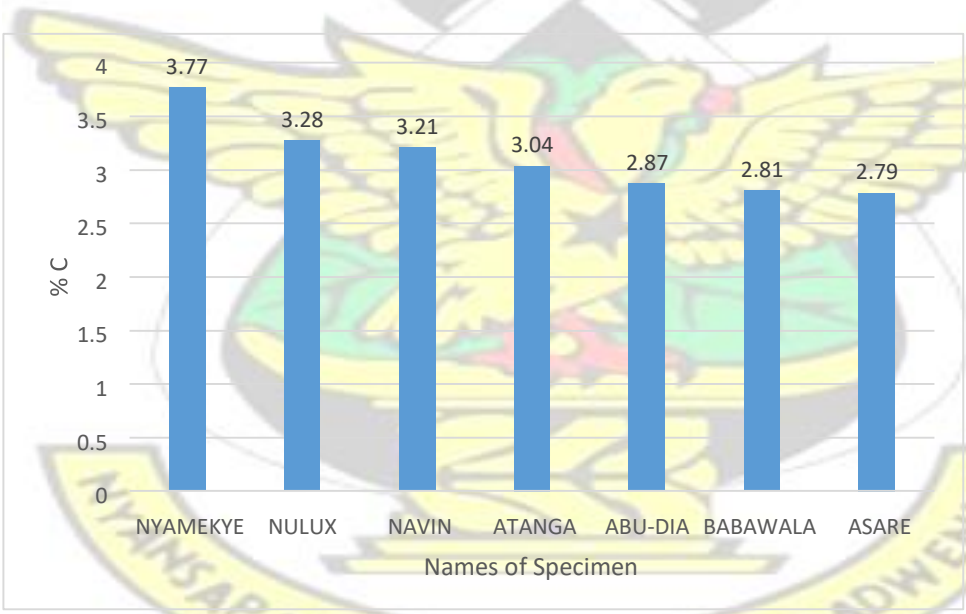

Figure 4.2 Trend of Carbon content

Carbon content between 2 to 4 % is generally classified as Cast Irons. From the results of Carbon content amongst the foundry samples and from (Appendix A1.11), it can be

inferred that grinding disc plates falls under the class of White Cast Iron which is between 2.5 to 3.75 %.

The obtained carbon values, particularly that of Nyamekye, being high amongst the specimen can aid the formation of iron carbide. Iron carbide influences hardness and strength. From the study of Iron-Carbon Equilibrium Diagram (ICED) it is known that carbon controls the melting temperature in the Cupola, approximately 1200°C. Very high Carbon turns to give poor bending strength and turns to aid fracture in a brittle manner quite abruptly therefore a control is necessary.

As shown in Table 3.5. Manganese ranges from 0.19 to 1.05 % and apart from Asare specimen that was 1.05 %, the rest were below 1%. From the study of foundry metallurgy, the presence of Manganese in such composition is good because it combines with Sulphur to (MnS) to help reduce the quantity of injurious Sulphur. Mn can be as high as about 1.5 % in some classes of cast iron.

Phosphorus ranges from 0.13 to 0.44 %. Similarly, the values of Sulphur were from 0.04 to 0.33 % and both P and S are impurities which cause blowholes, porosity and must be kept very low. Significant levels of P and S were recorded but these are undesirable. V, Al, Sn and B indicate very low values whilst Cu, Ni and Cr are responsible for promotions of corrosion resistance, fluidity and other physical properties.

From the result of the elemental composition it could be attested that the grinding mill plate depends on wide variation of constituents. These constituents' form combinations to give properties such as hardness, penetration, strength, toughness suitable for grinding mill disc to reduce wear.

4.2 Causes of wear

The factors that were considered in finding out the causes of wear included hardness, concentricity of disc and elemental composition. The result and correlation to wear are as described.

4.2.1 Dynamic Wear

Table 4.1 shows the difference between the initial mass and the final mass. These include the rotating and the fixed mill plates used in the milling operations. The difference in mass is recorded as wear.

Table 4.1. Results of Measurement of Mill Plate.

Names of Foundries	Initial mass (kg)	Final mass (kg)	Wear (kg)
Babawala	9.85	9.55	0.30
Atanga	10.45	10.10	0.35
Asare	9.99	9.70	0.29
Abudia	12.20	11.85	0.35
Nyamekye	9.98	9.80	0.18
Navin	10.40	9.96	0.44
Nulux	10.60	9.98	0.62

Appendix, Figure, A 1.9 shows a graph plot indicating wear of each specimen using Table 4.1. The specimen from Nyamekye shows a lower wear rate of 0.18 kg while Asare, Babawala, Atanga and Abudia range 0.29 to 0.35 kg. Navin and Nulux registered 0.44 and 0.62 kg, indicating the highest amongst the wear.

Factors that might also contribute to dynamic wear may be due to general foundry practice, principally the cooling rate during solidification of the melts. Large crystals

make the metal weak and ductile, whilst, the fine grain structure is associated with strength, toughness and hardness. Lack of the control of critical points such as, temperature distribution of heat sources, mode of melting, arrangement of scrap material in furnaces and quality of mold or pattern are also factors that could contribute to inferior product.

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It could be established from the wear of 0.18 kg being the least and a maximum of 0.62 kg that, the wear rates ranges from $1.5 \times 10^{-3}\ kg/min$ to $5.167 \times 10^{-3}\ kg/min$ respectively.

4.2.2 Hardness

The resistance to wear which is the amount of penetration in mm is as shown in Figure 4.3. One of the commonly used test method is the Brinell hardness. The trend shows an obtained penetration values and deduced BHN (Brinell Hardness Number). From the graph, Nulux and Navin shows penetrations levels of 2.9 mm and 2.95 mm and the deduced hardness values of 444 and 429 BHN. Nyamekye registered 2.65 mm and hardness of 534 BHN. The rest of the samples were 2.7 mm and hardness of 514 BHN. It can therefore be inferred that the higher the Brinell number the better the resistance to penetration. It is known from heat treatment of steel that, carbon increases hardness. From Figure 4.2 the Nyamekye specimen shows the highest carbon of 3.77 % and also from Figure 4.4 it shows the highest 534 BHN, it can therefore be suggested that, the more the carbon content the higher BHN.

This could be one of the key factors of resistance to wear by Nyamekye specimen. The other reasons may be due to differences in production processes and raw material variations. Computation of penetration resulted in the plot of Figure 4.3 that shows hardness verses penetration.

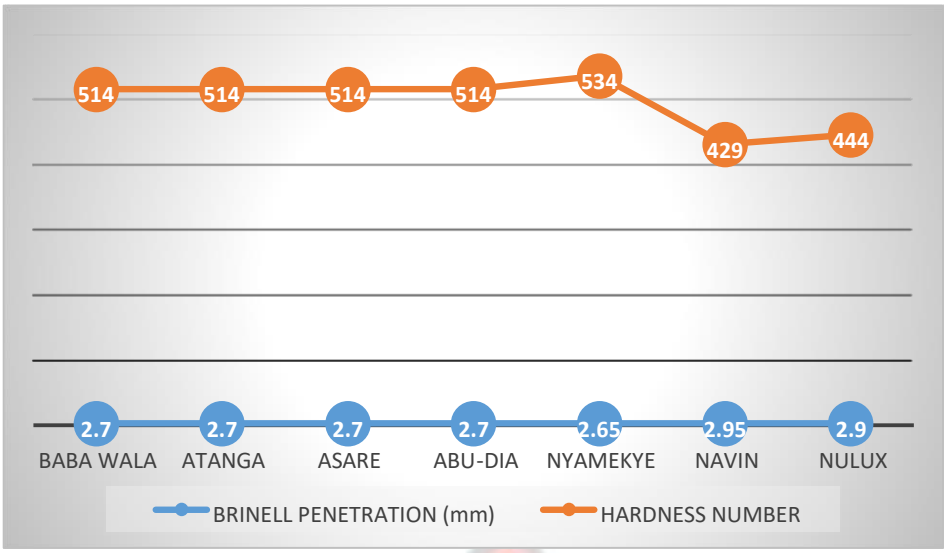

Figure 4.3. Graph of Penetration and BHN.

Figure 4.4 illustrates the correlation between the wear and hardness for the seven specimen used. The plot shows three significant interactions that falls far from the best fit line.

From the graph of Figure 4.4, the coefficient and ANOVA tables were generated and presented in Table 4.2 and Table 4.3.

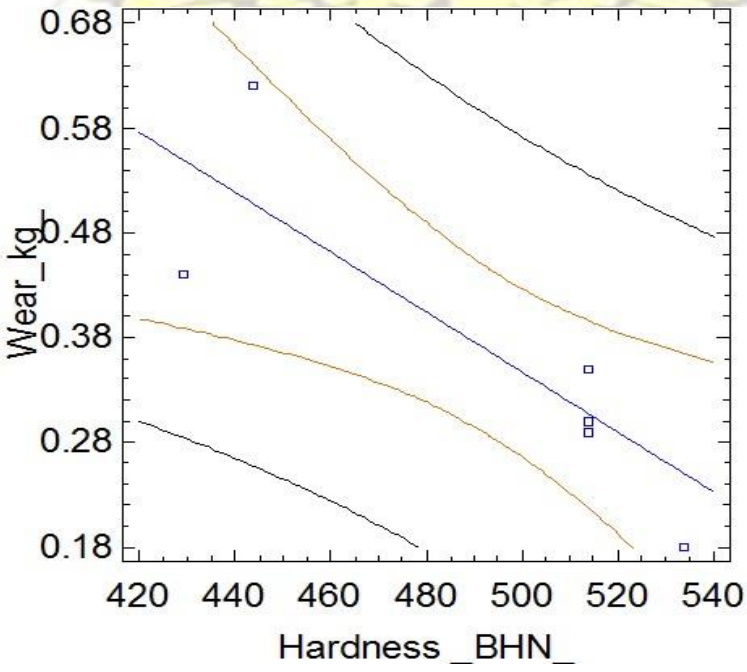

Figure 4.4. A Plot of Fitted Model of Wear vs. Hardness

Table 4.2. Coefficients.

	Least Squares	Standard	T	
Parameter	Estimate	Error	Statistic	P-Value
Intercept	1.778	0.409	4.344	0.007
Slope	-0.003	0.001	-3.471	0.019

Table 4.3. Analysis of Variance

Source	Sum of Squares	D. F	Mean Square	F-Ratio	P-Value
Model	0.081	1	0.081	12.05	0.018
Residual	0.034	5	0.007		
Total (Corr.)	0.115	6			

Since the P-value in the Table 4.2 is less than 0.05, there is a statistically significant relationship between Wear (kg) and Hardness (BH) at the 95.0 % confidence level.

Hence to ensure a fitting linear model, where W is the wear and H is the hardness to describe the relationship between Wear (kg) and Hardness (BHN) was obtained.

The equation of the fitted model, $W = 1.78 - 2 \cdot 86 \times 10^{-3}H$.

The R-Squared statistic indicates that the model as fitted explains 70.67 % of the variability in Wear (kg). The correlation coefficient equals -0.841, indicating a moderately strong relationship between the variables. The standard error of the estimate shows a standard deviation of the residuals to be 0.082. This value can be used to construct prediction limits for new observations.

The mean absolute error (MAE) of 0.057 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in the data. Since the Pvalue is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the

95.0 % confidence level. It can be seen from the graph that hardness increases with decreasing in wear.

Figure 4.6 illustrates the correlation between the wear and penetration also for the seven specimens. The plot shows significant interactions of a fitting model with an outlier. The plot shows that, as penetration increase the wear also increases.

From the graph in Figure 4.5 the coefficient and ANOVA tables were generated and presented in Table 4.4 and Table 4.5.

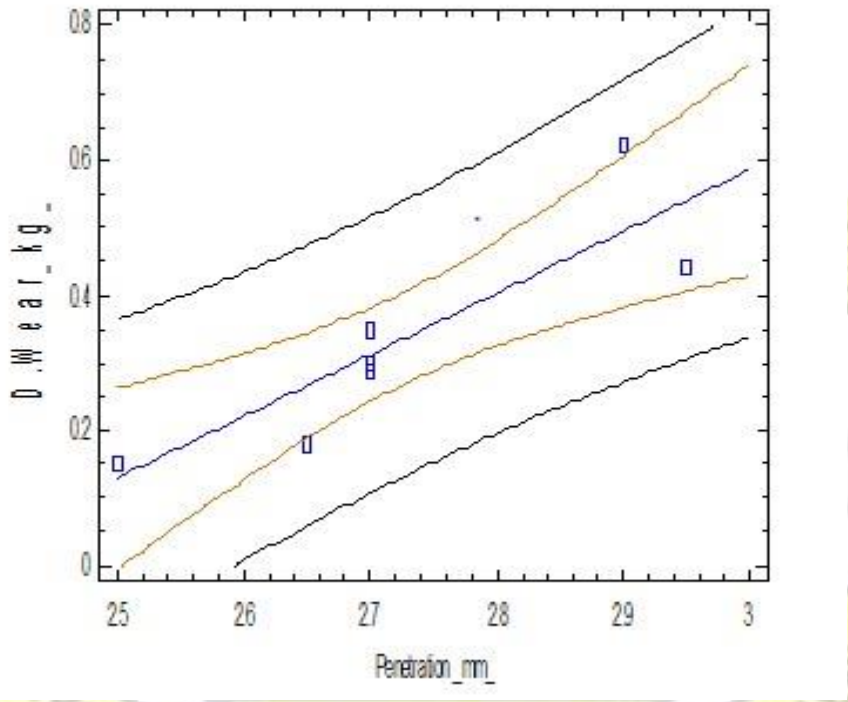

Figure 4.5. A Plot of Fitted Model of Wear vs. Penetration

Table 4.4. Coefficients

	Least Squares	Standard	T	
Parameter	Estimate	Error	Statistic	P-Value
Intercept	-2.156	0.574	-3.75744	0.009
Slope	0.914	0.210	4.34627	0.005

Table 4.5. Analysis of Variance

Source	Sum of Squares	D.F.	Mean Square	F-Ratio	P-Value
Model	0.117	1	0.117	18.89	0.005
Residual	0.037	6	0.006		
Total (Corr.)	0.154	7			

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Since the P-value in the table 4.4 is less than 0.05, there is a statistically significant relationship between Wear (kg) and Penetration (mm) at the 95.0 % confidence level.

Hence, to ensure a fitting linear model the description of the relationship between Wear (kg) and Penetration (mm).

The equation of the fitted model is $W = -2 \cdot 156 + 9.14 \times 10^{-2}\ P$, where W is the wear and P is the penetration.

The R-Squared statistic indicates that the model as fitted explains 75.89% of the variability in Wear (kg). The correlation coefficient equals 0.871, indicating a moderately strong relationship between the variables. The standard error of the estimate shows a standard deviation of the residuals to be 0.079. This value can be used to construct prediction limits for new observations.

The mean absolute error (MAE) of 0.055 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in the data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the 95.0 % confidence level.

The Figure 4.6 shows unusual residuals plot of all the observations which have Studentized residuals greater than 2 in absolute value.

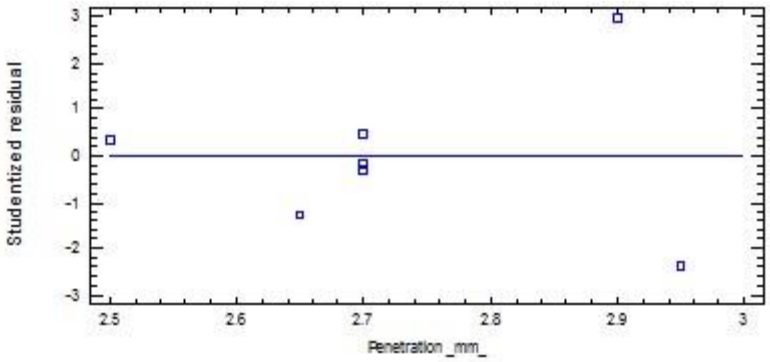

Figure 4.6 Residual Plot, Wear vs. Penetration.

Studentized residuals measure how many standard deviations each observed value of Wear (kg) deviates from a model fitted using all of the data except that observation. In this case, there are 2 Studentized residuals greater than 2, but none greater than 3. It is established from the plot that penetration increases, with increasing in wear.

4.2.3 Concentricity

Table 4.6, indicates the values of results obtained from the concentricity test and as shown, each of the grinding disc sample shows deviations of mass. Babawala shows 4.50 kg (M) and out of balance mass 2.41 kg (m) and error of 2.09. The rest of the specimen follows similar pattern.

The initial mass of each foundry specimen is not the same and therefore each error is foundry specific. The shift of mass may cause imbalance during rotation. Lack of, parallelism, concentricity and surface flatness allows the disc to run out of center, such phenomenon may cause vibration and eccentricity thereby increase wear disproportionately.

Breaking in period is the initial rubbing of new mill teeth during milling. This is a phenomenon that is caused by the mass imbalance. It occurs during solidification of the molten metal during the production of the grinding mill plate. The initial rubbing is a

serious source of wear as shown in almost every first sample of the mill flour results (Appendix Tables A1.12 to A 1.17). The trend in Appendix figure A 1.10 shows how each specimen deviates in concentricity. Babawala has a lower value and Abudia the highest value.

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Table 4.6. Deviation of Mass

Foundry	Mass (kg)	Out of balance mass (kg)	Error.
Babawala	4.50	2.41	2.09
Atanga	5.00	2.60	2.40
Asare	4.85	2.63	2.22
Abudia	5.90	3.0	2.90
Nyamekye	5.25	2.81	2.44
Navin	5.30	2.81	2.49

Figure 4.7 illustrates the correlation between wear and the concentricity.

The coefficient and ANOVA tables were generated and presented in Tables 4.7 and Table 4.8. The graph shows significant outliers from the best fit line and as concentricity increases wear also increases marginally.

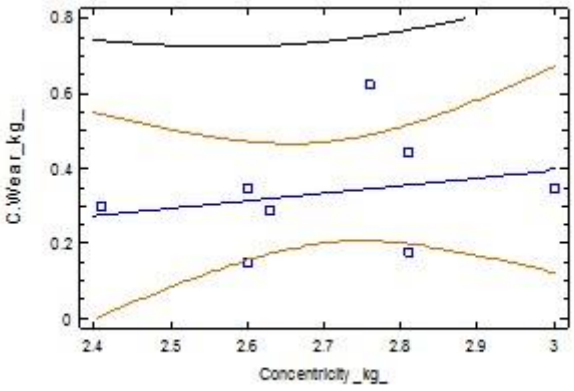

Figure 4.7. Plot of Fitted Model, Wear vs. Concentricity.

Table 4.7. Coefficients.

	Least Squares	Standard	T	
Parameter	Estimate	Error	Statistic	P-Value
Intercept	-0.218	0.883	-0.247	0.813
Slope	0.205	0.326	0.627	0.553

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The P-value in the Table 4.7 is greater or equal to 0.05, there is not a statistically significant relationship between Wear (kg) and Concentricity (kg) at the 95.0 % or higher confidence level.

Hence to ensure a fitting linear model the description of the relationship between Wear (kg) and Concentricity (kg).

Table 4.8. Analysis of Variance

Source	Sum of Squares	D.F	Mean Square	F-Ratio	P-Value
Model	0.009	1	0.009	0.39	0.553
Residual	0.145	6	0.024		
Total (Corr.)	0.154	7			

The equation of the fitted model is, $W = -21 \cdot 80 \times 10^{-2} + 20 \cdot 26\, C,$ where W is the wear and C is the concentricity.

The R-Squared statistic indicates that the model as fitted explains 6.158% of the variability in Wear (kg). The correlation coefficient equals 0.248, indicating a relatively weak relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 0.155. This value can be used to construct prediction limits for new observation.

The mean absolute error (MAE) of 0.104 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in the data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the 95.0 % confidence level.

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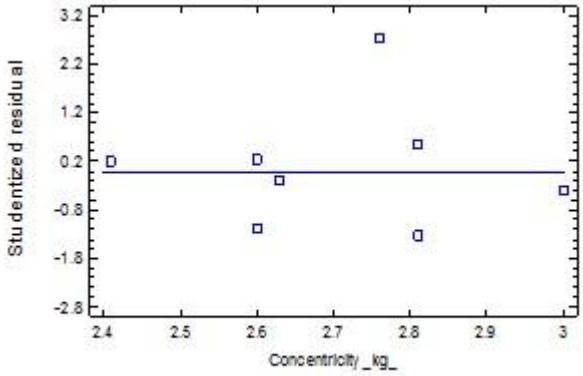

Figure 4.8. Residual Plot Wear vs. Concentricity

The Figure 4.8 shows unusual residuals plots of all observations which have Studentized residuals greater than 2 in absolute value. Studentized residuals measure how many standard deviations each observed value of Wear (kg) deviates from a model fitted using all of the data except that observation. In this case, there is one Studentized residual greater than 2, but none greater than 3. With the concentricity plot, as concentricity increases, there is a weak or moderate increase in wear. From the three results, it can be established that the hardness and the penetration has insignificant effect on the wear.

4.3. Amount of Metal Particles in the Maize Flour.

Table 4.9 shows the amount of metal deposited in the milled maize. From the results, the quantity of iron deposition ranges from 3.243 mg/kg to 9.875 mg/kg of flour with Nulux recording the maximum and Asare the least.

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Table 4.9. Summary of Metal Particles.

Foundries	Fe	Cu	Pb	Mn	Co	Cr	Mg	As	Total (iron filings, mg/kg, flour)
Nulux	9.875	0.487	0.063	0.313	0.06	0.008	10.737	0.006	21.55
Babawala	7.172	0.128	0.47	0.728	0.238	0.032	10.606	0.006	19.38
Navin	6.85	0.046	0.325	0.342	0.096	0.01	10.966	0.006	18.64
Atanga	6.687	0.182	0.041	0.397	0.062	0.006	10.486	0.006	17.87
Abudia	4.98	0.161	0.011	0.276	0.055	0.012	10.546	0.006	16.05
Asare	3.243	0.186	0.114	0.429	0.052	0.012	10.665	0.006	14.71

Similarly, Copper also ranges from 0.062 to 0.487 mg/kg of flour while Lead ranges from 0.011 to 0.47 mg/kg of flour. Manganese is between 0.156 and 0.728 mg/kg of flour whilst Cobalt is 0.052 and 0.238 mg/kg of flour. Finally, Arsenic (As) is 0.006 throughout the trend. The total metal particles range from 14.71 to 21.55 mg/kg of flour. The amount of iron particles found in the flour specimen differs from foundry by foundry.

The inability to control critical factors of production might account for poor grade of mill plate. Differences in raw material and other inputs for production may significantly also contribute to poor quality. It was observed that, during the production of mill plate many assumptions were made by foundry operatives based on the knowledge and skills of operators.

From the result the total metallic particles found in the mill flour ranges from 14.71 mg/kg to 21.55 mg/kg of flour. Certainly the results are above the contaminant levels set out by Codex Alimentarius.

4.4 Effect of Element and Human.

Metals that are essential to the human body have the potential to be harmful at very high levels of exposure in fact the dose makes it poisonous. Iron is one such element and it consumption in such unusual way may be problematic. Table 4.10 shows the limit of exposure as described by (Codex Alimentarius STAN 153-1985). These values were compared with specimen from Asare's shop and the results are tabulated and presented in Table 4.10

Table 4.10 Limit of Contaminants Comparison

No	Heavy Metal	Limit of Exposure (iron fillings, mg/four, kg)	Asare (Iron filings, mg/flour, kg)	Difference
1	Copper (Cu)	2.00	0.186	+1.814
2	Lead (Pb)	0.10	0.114	-0.140
3	Arsenic (As)	0.100	0.006	-0.094
4	Mercury (Hg)	0.010	0	0.010
5	Cadmium (Cd)	0.020	0	0.020
6	Zinc (Zn)	30.00	0	30.00
7	Iron (Fe)	15.00	3.243	+11.757

Copper and iron recorded a positive value whilst lead and Arsenic recorded negative values. From the results, about 50 % were less than the limit of contaminants whilst 50 % were above. Lead and Arsenic (As) are known to have wide spectrum of toxicity. The process was repeated for the remaining 5 specimens and the results are presented in Table 4.11.

Table 4.11. Comparisons

Heavy Metal	Navin	Nulux	Babawala	Atanga	Abudia
Copper (Cu)	1.954	-0.441	-0.082	+1.818	+1.839
Lead (Pb)	-0.225	+0.265	-0.145	+0.059	+0.089
Arsenic (As)	+0.094	+0.094	+0.094	+0.094	+0.094
Mercury (Hg)	0	0	0	0	0
Cadmium (Cd)	0	0	0	0	0
Zinc (Zn)	0	0	0	0	0
Iron (Fe)	+8.15	-3.025	-0.322	+8.313	+10.02
Above	75%	50%	75%	0%	0%
Below	25%	50%	25%	100%	100%

From Table 4.11, the result shows that Abudia and Atanga values are below the exposure limit as compared with Navin and Babawala which indicated above the limits. Nulux indicated an average value 50 % limit.

Hence Abudia and Atanga are rated good at 100 % below the contaminant limits whilst Navin and Babawala are rated poor at 75 % above the contaminants limits.

4.5. Improved Grinding Disc

The quality of the grinding mill disc was redesigned by changing the composition as illustrated in Table 3.7. The results obtained for the hardness, penetration, concentricity and wear are presented in Table 4.12. Total metallic particle in flour was

12.05 mg per kg of flour, (Refer to Appendix Table A1.17).

Table 4.12. Wear Factors.

No	Parameter	Values
1	Hardness (BHN)	610
2	Penetration (mm)	2.50
3	Concentricity (kg)	2.60
4	Wear rate (kg/min)	0.00125

The value obtained for the hardness is 601 BHN which shows a significant increase as compared with the seven specimens selected for the test. The value of penetration was 2.50 mm whilst concentricity, being an out of balance mass indicates 2.60 kg and wear rate was, $1 \cdot 25 \times 10^{-3}\, kg/min$.

The results from the redesigned version of the grinding mill disc were compared with the seven specimens. The percentage differences were generated and presented as shown in Table 4.13, Table 4.14 and Table 4.15.

Table 4.13. Hardness

S/N	Specimen	% difference	Remarks
1	Babawala	+0.14	fair
2	Atanga	+0.14	fair
3	Asare	+0.14	fair
4	Abudia	+0.14	fair
5	Nyamekye	+0.11	good
6	Navin	+0.29	Below average
7	Nulux	+0.26	average

(+) represent improvement and (-) represent worsen

Table 4.14. Penetration

S/N	Specimen	% difference	Remarks
1	Babawala	-0.08	fair
2	Atanga	-0.08	fair
3	Asare	-0.08	fair
4	Abudia	-0.08	fair
5	Nyamekye	-0.06	good
6	Navin	-0.18	below average
7	Nulux	-0.16	average

(+) represent worsen and (–) represent improvement.

Table 4.15. Wear.

S/N	Specimen	% difference	Remarks
1	Babawala	-1.00	Fairly good
2	Atanga	-1.33	fair
3	Asare	-0.93	Fairly good
4	Abudia	-1.33	fair
5	Nyamekye	-0.20	good
6	Navin	-1.93	Fairly poor
7	Nulux	-3.13	poor

(+) represent worsen and (–) represent improvement.

Using Tables 4.13, Table 4.14 and Table 4.15 and the result obtained for the hardness, penetration and wear, the redesigned grinding disc showed a general remarkable improvement when its values were compared with the seven specimen.

CHAPTER FIVE CONCLUSION AND RECOMMENDATIONS.

The study was to investigate, identify the causes and effect of wear of the indigenous manufactured attrition plate mill and find solutions. The specific objectives of the work were; (i) to determine the material composition of the Attrition disc. (ii) to determine the possible factors of wear of disc. (iii) to evaluate the amount of iron particles that ends up in milled maize flour and also to ascertain if particles are within

acceptable limits. (iv) to redesign the grinding disc and develop a technique to rectify the problem. From the results the following were the key findings.

5.1 Key Findings

i) The study attested that the grinding mill plate depends on wide variation of elemental constituents. These constituents' forms combination with other alloying element to give suitable properties such as hardness, penetration and wear, for grinding mill disc during production. Key amongst the constituents was, Iron 93.21 % to 95.57 %, Copper from 0.06 % to 0.24 %, Carbon from 2.79 % to 3.77 % and Manganese from 0.19 % to 1.05 %.

ii) The results from the dynamic wear shows that, the least wear amongst the specimen was 0.18 kg and a maximum was 0.62 kg and after 120 minutes of milling, wear rates were:

$1.5 \times 10^{-3}\ kg/min$ and $5.167 \times 10^{-3}\ kg/min$ respectively.

iii) P-value of wear versus hardness was less than 0.05 at the 95.0% confidence level. The equation of a fitted model was:

$W = 1.78 - 2 \cdot 86 \times 10^{-3}H$. The correlation coefficient equals -0.841. Hence, there was a statistically significant relationship between Wear (kg) and Hardness (BH) indicating a moderately strong relationship between the variables.

iv) The R-Squared statistic (wear vs. hardness) indicates that the model as fitted explains 70.67 % of the variability in Wear (kg). The standard error of the estimate shows a standard deviation of the residuals to be 0.082.

This value can be used to construct prediction limits for new observations.

v) The P-value of (wear vs. penetration) was also less than 0.05, at the 95.0% confidence level. The equation of a fitted model was:

$W = -2 \cdot 156 + 9.14 \times 10^{-2}\ P$. The correlation coefficient equals 0.871. The result shows statistically significant relationship between Wear (kg) and Penetration (mm), and also indicating a moderately strong relationship between the variables.

vi) The R-Squared statistic (wear versus penetration) indicates that the model as fitted explains 75.89 % of the variability in Wear (kg). The standard error of the estimate shows a standard deviation of the residuals to be 0.079. This value can be used to construct prediction limits for new observations.

vii) It can be shown that as concentricity increases, there were marginal increases in wear. Therefore, it can be inferred that, wear was weak or insignificant during the concentricity test.

viii) The study revealed that heavy metal particle certainly was found in the mill flour with values ranging from 14.71 mg/kg flour to 21.55 mg/kg flour.

ix) For the limit of contaminants exposure, Asare and Nulux indicated an average value 50 %. Abudia and Atanga were 100 % below the contaminant limits whilst Navin and Babawala were at 75 % above the contaminants limits.

x) The redesigned grinding disc showed an elemental composition of iron of 91.74 %, wear rate of $1 \cdot 25 \times 10^{-3} mg/kg$, hardness value of 601 BHN and 2.5 mm penetration. The amount of iron particle showed 12.05 mg/kg flour, exposure level.

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5.2 Conclusions

The investigation and identification into the causes and effect of attrition disc wear was carried out. It can then be concluded that;

i) The elemental composition test of the grinding disc results, shows a wide variation of elemental constituents that forms alloys to help improve on properties such as hardness, penetration and wear

ii) The study also showed correlation between wear and penetration and the wear versus hardness. Brinell hardness number increases with hardness, with decreasing in wear. Also, penetration increases with increasing in wear. From the three results, it can be established that the hardness and the penetration has significant effect on the wear.

iii) The study revealed that heavy metal particle was found in the mill flour with values ranging from 14.71 mg/kg to 21.55 mg/kg of flour. Certainly the results are above the contaminant levels set out by Codex Alimentarius, therefore further investigations and study will be appropriate to ascertain the various levels of consumption of iron fillings and its adverse effect on mammals.

iv) The redesigned grinding disc showed an elemental composition of iron as

91.74 %, wear rate of $1 \cdot 25 \times 10^{-3} mg/kg$, hardness value of 601 BHN and 2.5 mm penetration. The amount of iron particle showed 12.05 mg/kg of flour, a reduction in values as compared with the six specimens and is within the CODEX standard. Hence, the redesigned version shows a remarkable improvement and it is evident that it will help reduce the amount of iron fillings that might get into milled flour which eventually ends up in the preparation of food to be consumed. This will help to reduce many health risk associated with heavy metal exposure.

5.3 Recommendation

i) Industrial extension, seminars and workshops in foundry practice, metallurgy, plant installation, maintenance practices, electrical wiring, estimation of power requirement and many more such services to upgrade the skills of proprietors and mill attendants would be necessary.

ii) Residual stress-relieving methods after casting could be employed to reduce many unwanted stresses related problems.

iii) The process where every metallic scrap is thrown into the cupola furnace will need to change and the required amount of elements must be controlled.

iv) Mill plate should have cut-off point of use, the situation where it used until the last mm of the thickness is finished, is not advisable.

v) Use of hammer mill should be encouraged especially with dry product

vi) Very strong iron magnets need to be incorporated in the setup especially at the hopper part to catch any un-noticed metals such as nails. The spout end should also be fixed with stronger magnet to attract very fine iron fillings. This will reduce the amount of iron fillings. vii) Improper cleaning could lead to many microbial load due to cross contamination of other products, therefore, food safety standards and environmental hygiene must be promoted or be part of any training.

viii) There is the need to legislate and control the exposure of heavy metals to mammals.

ix) Attention should focus towards research on prevention, the most important aspect of which is probing the causes and relative importance of numerous risk factors.

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APPENDICES

APPENDIX A

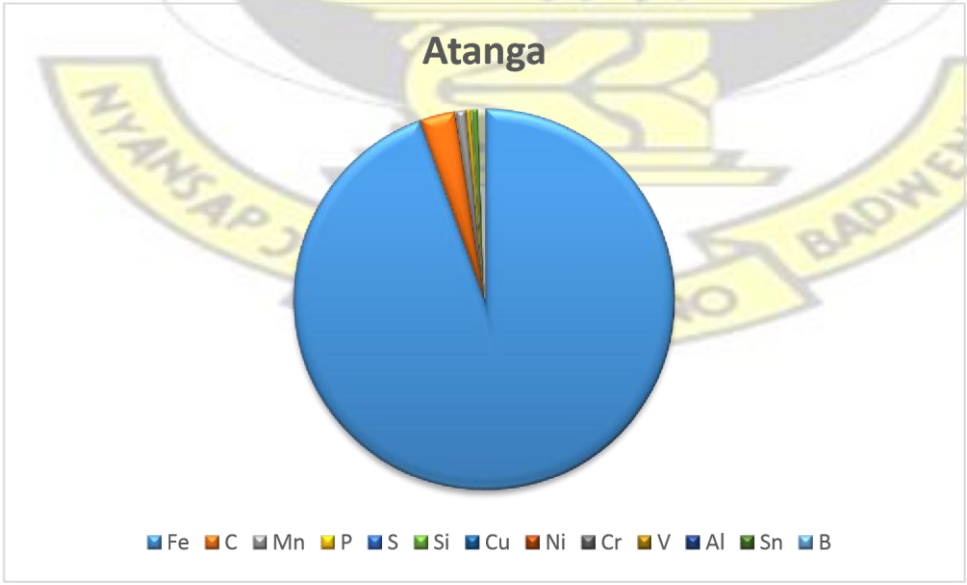


Figure A1.1 Atanga Element

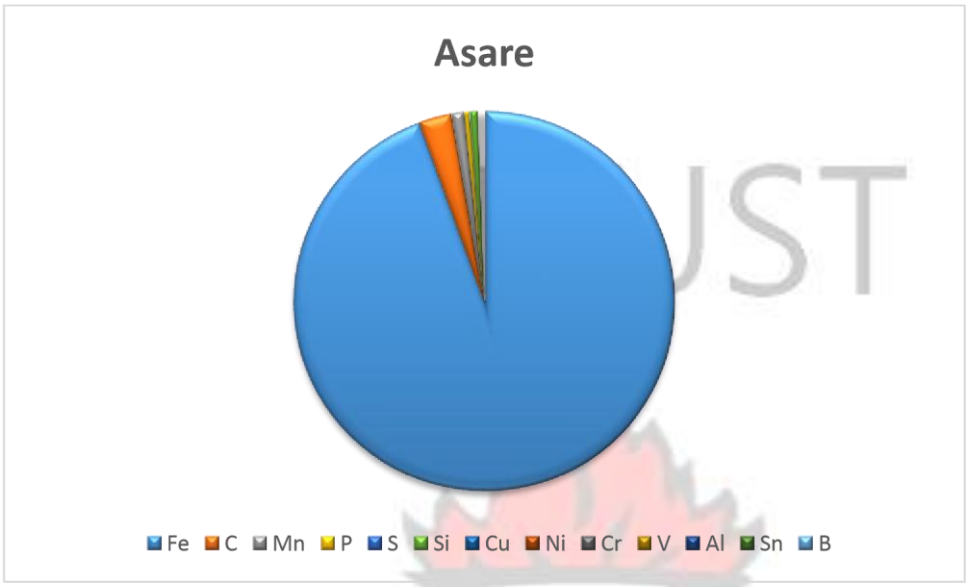


Figure A1.2 Asare Element

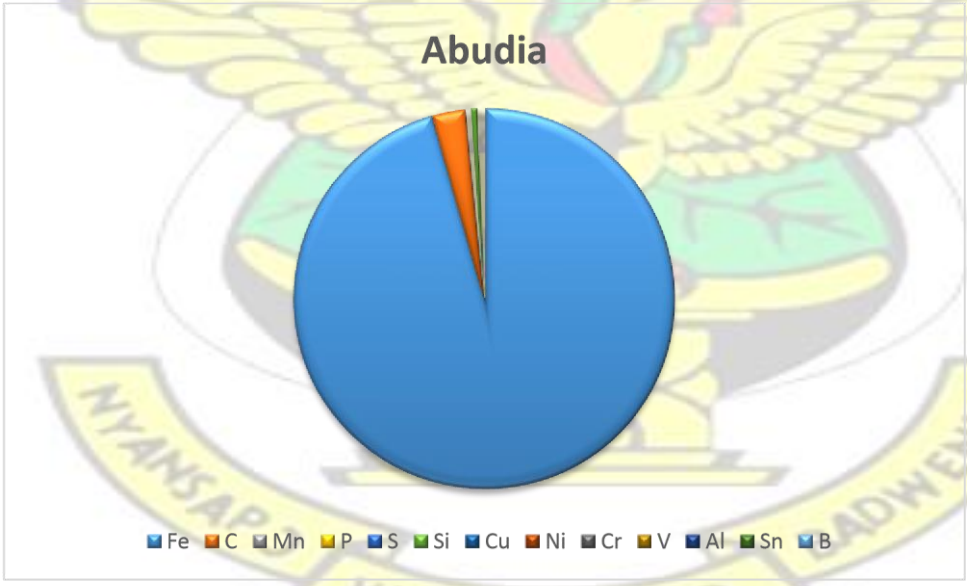


Figure A1.3 Abudia Element

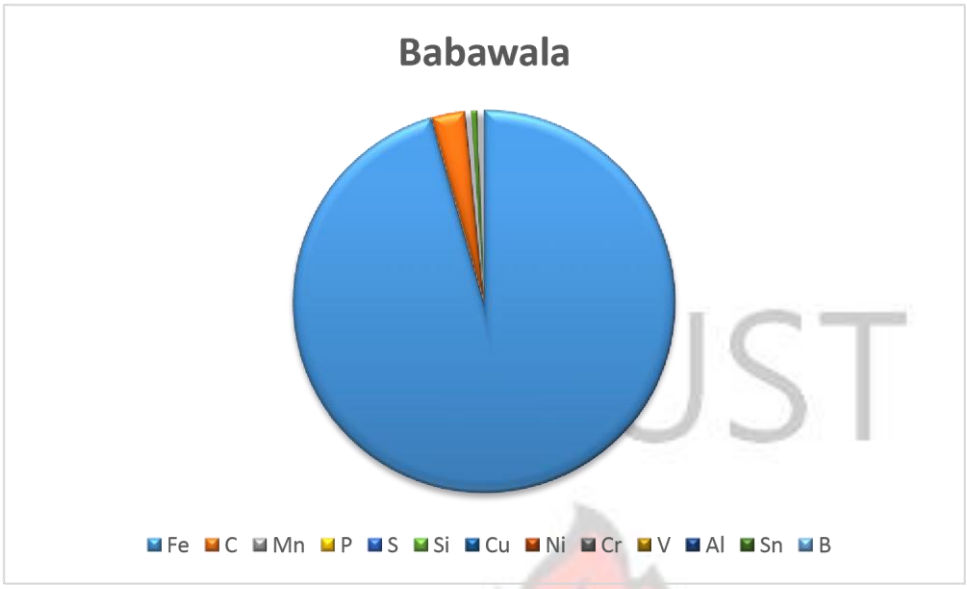


Figure A1.4 Babawala Element

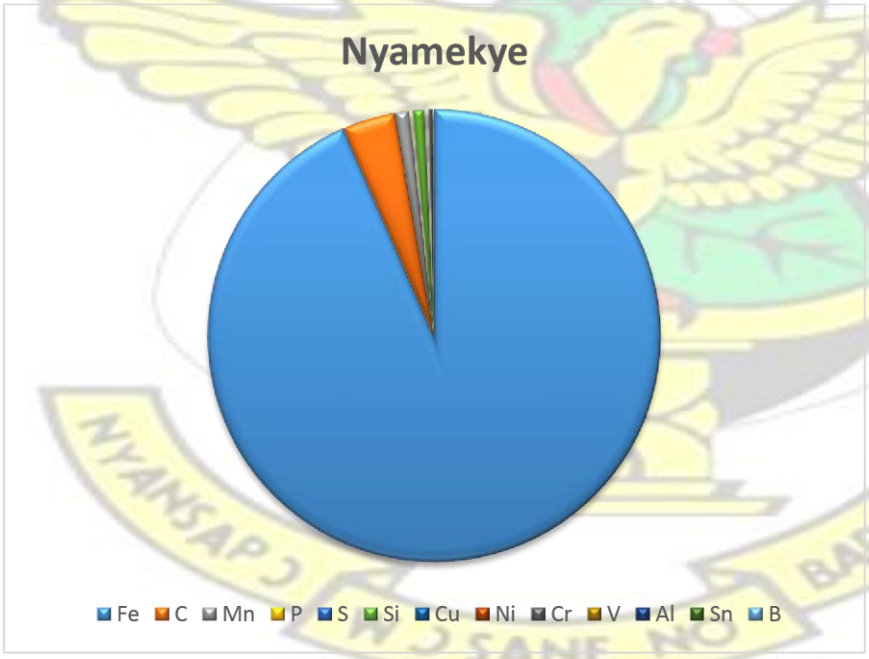


Figure A1.5 Nyamekye Element

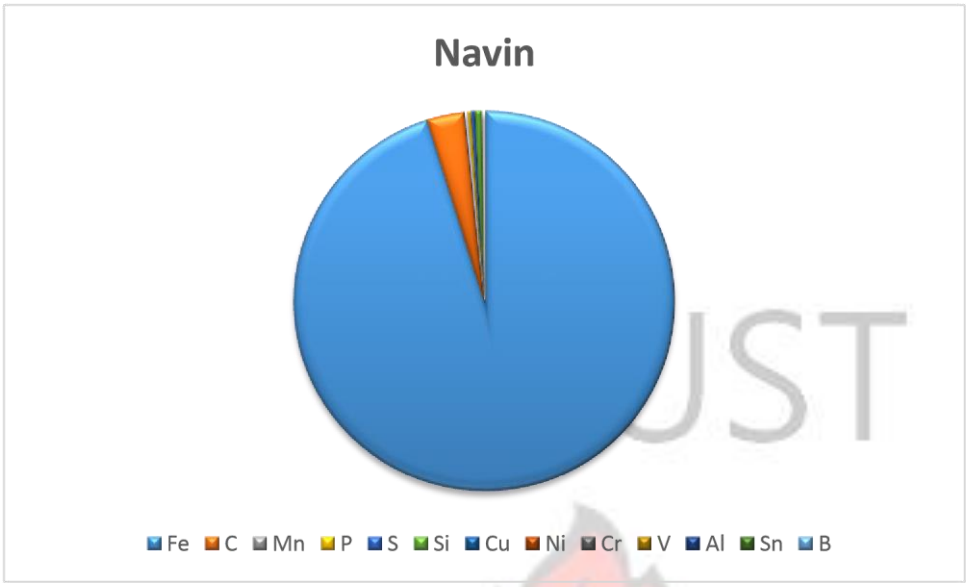


Figure A1.6 Navin Element

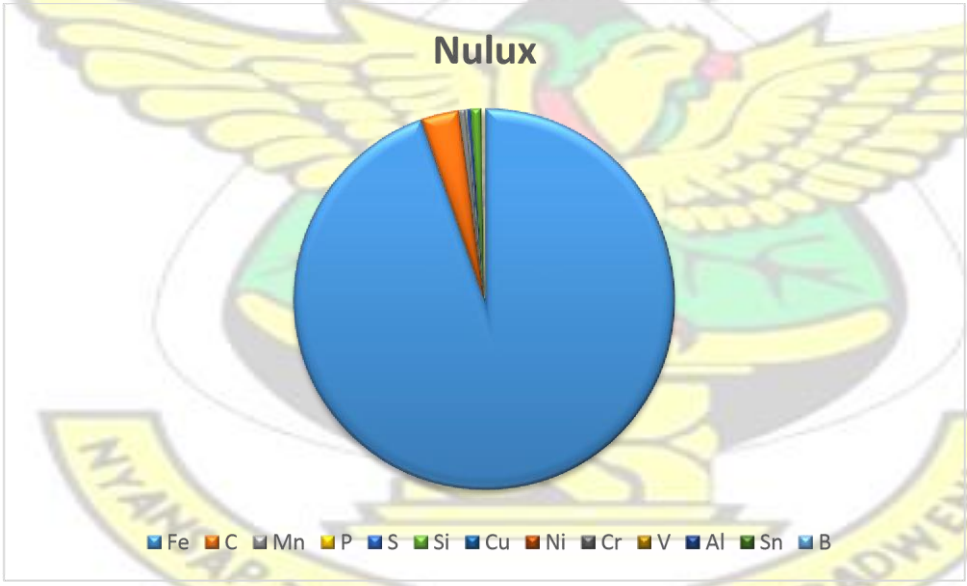


Figure A1.7 Nulux Element

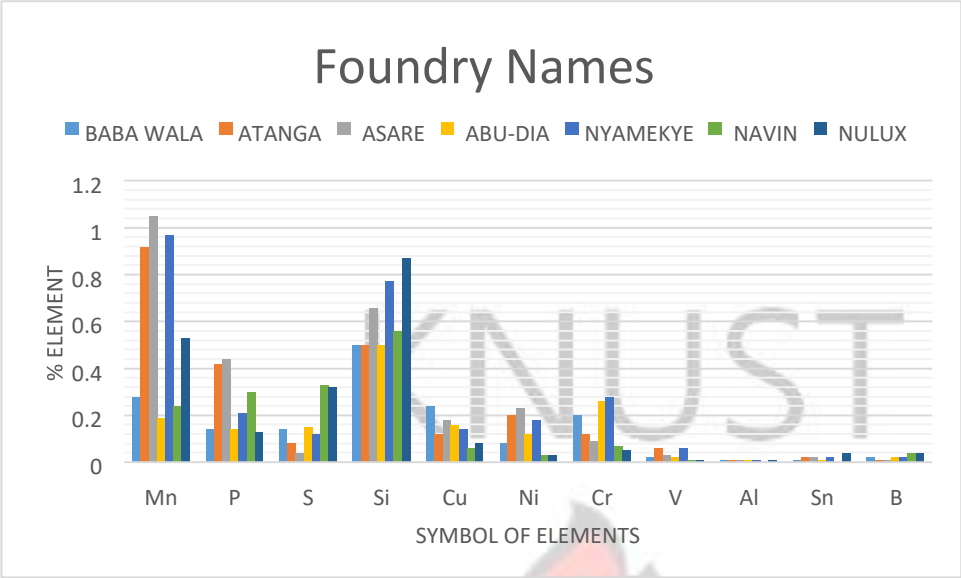
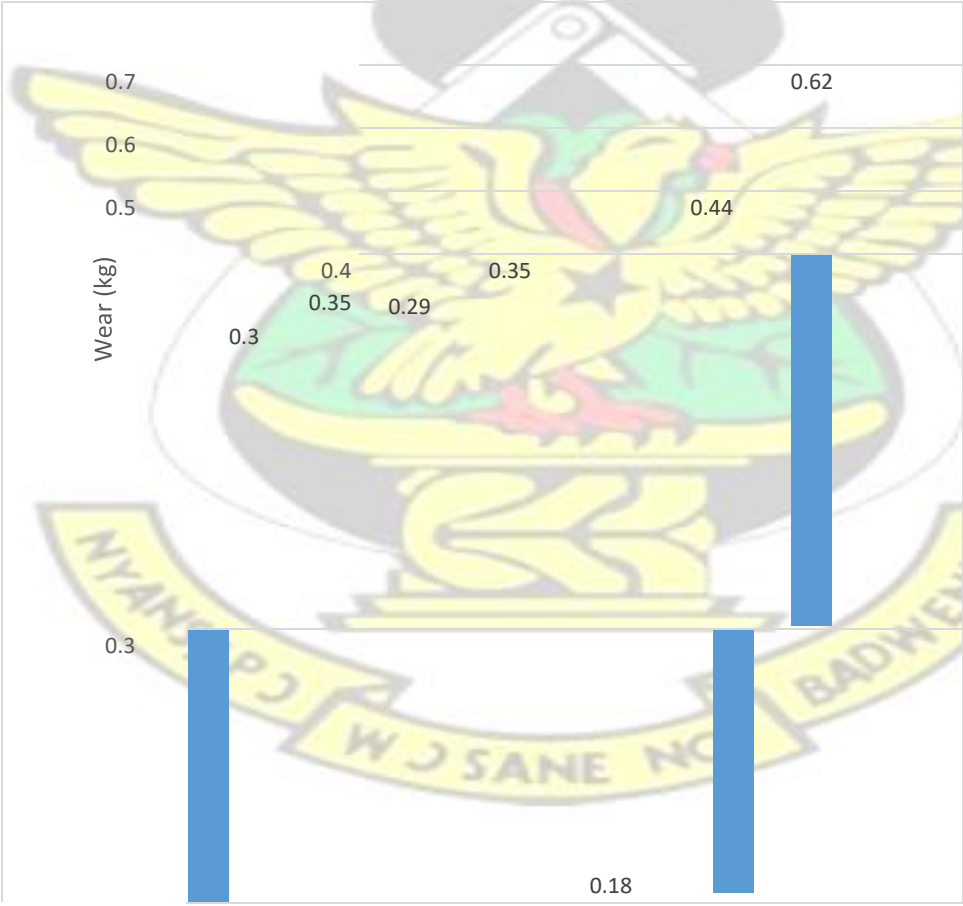


Figure A1.8 Detail Elements



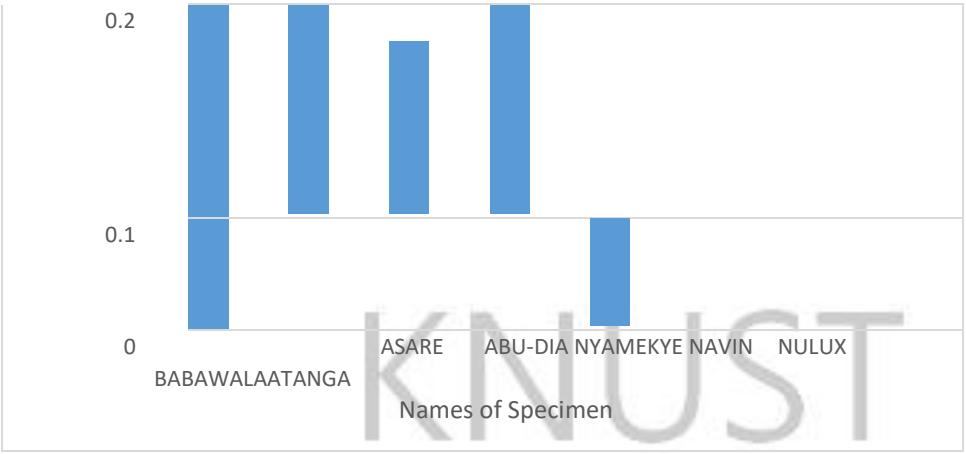


Figure A1.9

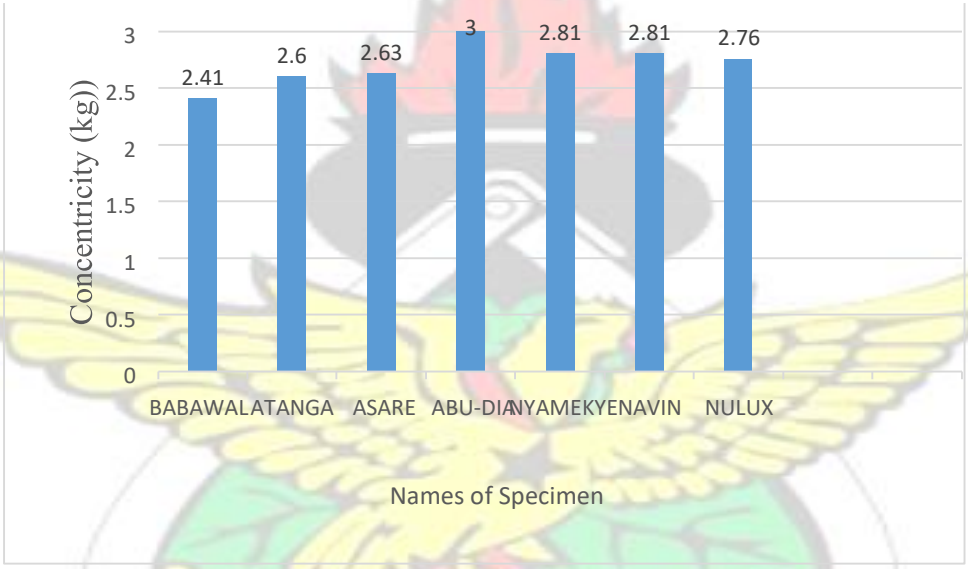


Figure A1.10

Table A1.11: Standard composition of mill plate

C	Si	Cu	Mn	Mg	Mo	S	P	Fe
3.37	2.54	0.59	0.57	0.04	0.01	0.03	0.14	92.74
3.23	2.64	1.31	0.56	0.03	0.01	0.03	0.14	92.06
3.19	2.64	1.80	0.55	0.03	0.01	0.03	0.14	91.62
2.98	2.82	2.56	0.56	0.02	0.01	0.03	0.14	90.89

Table A 1.12

Corn-Dough Babawala Sample- Kumasi Ghana

Element	Fe	Cu	Pb	Mn	Co	Cr	Mg	As
Control sample	0.3130	0.0030	0.0010	0.0350	0.0240	0.0010	0.0215	0.0010
Sample 1	0.4070	0.0330	0.1330	0.0720	0.0130	0.0060	0.4050	0.0010
Sample 2	0.5800	0.0190	0.0620	0.0880	0.0600	0.0010	0.3968	0.0010
Sample 3	0.5500	0.0170	0.0480	0.0700	0.0220	0.0080	0.3779	0.0010
Sample 4	0.4260	0.0090	0.0300	0.0500	0.0360	0.0010	0.3880	0.0010
Sample 5	2.0860	0.0220	0.0310	0.2250	0.0290	0.0060	4.3556	0.0010
Sample 6	3.1180	0.0220	0.1660	0.2200	0.0780	0.0100	4.6620	0.0010

Table A1.13

Corn-Dough Atanga Sample- Kumasi Ghana

Element	Fe	Cu	Pb	Mn	Co	Cr	Mg	As
Control sample	0.005	0.006	0.000	0.003	0.000	0.000	0.022	0.000
Sample 1	3.746	0.050	0.006	0.146	0.009	0.001	1.749	0.001
Sample 2	0.825	0.040	0.011	0.062	0.008	0.001	1.752	0.001
Sample 3	0.507	0.015	0.016	0.034	0.008	0.001	1.729	0.001

Sample 4	0.723	0.022	0.001	0.055	0.011	0.001	1.715	0.001
Sample 5	0.437	0.019	0.001	0.051	0.018	0.001	1.733	0.001
Sample 6	0.444	0.030	0.006	0.046	0.008	0.001	1.786	0.001

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Table A 1.14

Corn-Dough Asare Sample- Kumasi Ghana

Element	Fe	Cu	Pb	Mn	Co	Cr	Mg	As
Control sample	0.0050	0.0060	0.0000	0.0030	0.0000	0.0000	0.0215	0.0000
Sample 1	0.7050	0.0440	0.0400	0.1120	0.0130	0.0010	1.8011	0.0010
Sample 2	0.0650	0.0340	0.0220	0.0530	0.0050	0.0010	1.7656	0.0010
Sample 3	0.6250	0.0270	0.0250	0.0910	0.0050	0.0030	1.8320	0.0010
Sample 4	0.6240	0.0290	0.0010	0.0470	0.0050	0.0050	1.7348	0.0010
Sample 5	0.4190	0.0200	0.0010	0.0360	0.0020	0.0010	1.7600	0.0010
Sample 6	0.8000	0.0260	0.0250	0.0870	0.0220	0.0010	1.7506	0.0010

Table A1.15

Corn-Dough Abudia Sample- Kumasi Ghana

Element	Fe	Cu	Pb	Mn	Co	Cr	Mg	As
Control sample	0.0050	0.0060	0.0000	0.0030	0.0000	0.0000	0.0215	0.0000
Sample 1	0.4230	0.0170	0.0010	0.0420	0.0160	0.0010	1.7250	0.0010
Sample 2	0.4090	0.0190	0.0010	0.0380	0.0190	0.0010	1.7426	0.0010

Sample 3	1.1730	0.0230	0.0010	0.0540	0.0050	0.0030	1.8139	0.0010
Sample 4	0.1150	0.0190	0.0010	0.0450	0.0050	0.0050	1.7751	0.0010
Sample 5	0.6610	0.0100	0.0060	0.0430	0.0050	0.0010	1.7803	0.0010
Sample 6	2.1940	0.0670	0.0010	0.0510	0.0050	0.0010	1.6881	0.0010

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Table A 1.16

Corn-Dough Navin Sample- Kumasi Ghana

Element	Fe	Cu	Pb	Mn	Co	Cr	Mg	As
Control reading	0.0200	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sample 1	4.5660	0.0190	0.0450	0.1040	0.0120	0.0050	1.9953	0.0010
Sample 2	1.9300	0.0140	0.0280	0.0610	0.0090	0.0010	1.9885	0.0010
Sample 3	0.0530	0.0040	0.0750	0.0370	0.0280	0.0010	1.7071	0.0010
Sample 4	0.0970	0.0030	0.0750	0.0440	0.0050	0.0010	1.7616	0.0010
Sample 5	0.0700	0.0030	0.0410	0.0420	0.0200	0.0010	1.7350	0.0010
Sample 6	0.1140	0.0030	0.0610	0.0540	0.0220	0.0010	1.7785	0.0010

Table A 1.17

Corn Dough-Redesign version (Metallic Sample Results).

Element	Fe	Cu	Pb	Mn	Co	Cr	Mg	As	Total
Control sample	0.0200	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0200
Sample 1	0.3230	0.0200	0.0770	0.0320	0.0060	0.0010	1.9122	0.0010	2.372
Sample 2	0.1460	0.0130	0.0330	0.0260	0.0270	0.0010	1.9182	0.0010	2.165
Sample 3	0.2080	0.0090	0.0010	0.0150	0.0210	0.0010	1.9835	0.0010	2.239
Sample 4	0.1030	0.0080	0.0010	0.0240	0.0270	0.0030	1.9455	0.0010	2.112

Sample 5	0.0390	0.0040	0.0010	0.0020	0.0130	0.0010	1.8617	0.0010	1.922
Sample 6	0.1280	0.0080	0.0630	0.0570	0.0180	0.0010	0.9457	0.0010	1.221
Total	0.9670	0.0620	0.1760	0.1560	0.1120	0.0080	10.5668	0.0060	12.053

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Table A 1.18

Table Hardness Range Type of Gray Iron	Matrix Microstructure around Flake Graphite	Brinell Hardness
Soft-Annealed	All Ferrite	110-140
Ordinary	Pearlite and Ferrite	140-200
Higher Strength	Fine Pearlite	200-270
Alloyed-Acircular	Bainite	260-350
Austenitic (Ni-Resist)	Austentite	140-160
Heat Treat Hardened	Martensite	480-550
Hardened and Tempered	Tempered Martensite	250-450
Chilled (white iron)	Pearlite and Carbides	400-500

APPENDIX B.

Figure B1 Attrition Mill

Figure B2 Preparation to soak maize

Figure B3. After Milling

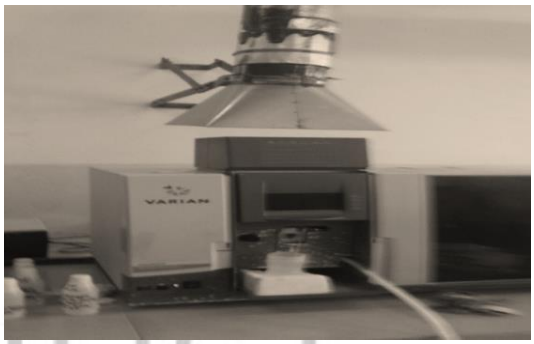


Figure B4 AAS Laboratory GAEC

Figure B5 AAS Laboratory GAEC

Figure B6 Mold Filling

Figure B7 AAS Babawala Cupola

Figure B8 Tapping Melt.

Figure B9 Scrap before Melt.

Figure B10 Mold after Melt.

Figure B11 Breaking scrap.

Figure B12 Charcoal.

Figure B13 Breaking up Mold

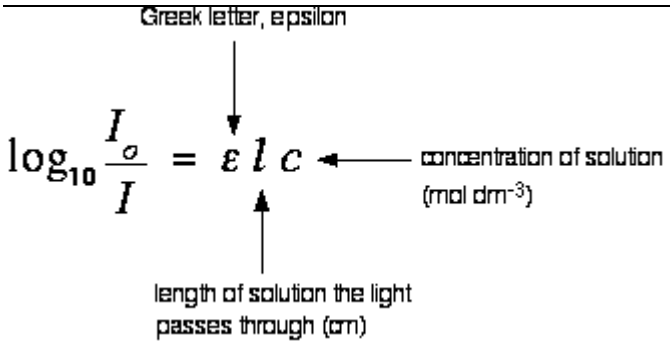
Figure B14 Sample mill plate.

APPENDIX C.

Beer Lambert's law

What the Law looks like

Various different symbols are given for some of the terms in the equation - particularly for the concentration and the solution length.



The expression on the left of this equation is the absorbance and equals to A below to simplify the equation.

$$A = \log_{10} \frac{I_o}{I} = \varepsilon l c$$

The Greek letter epsilon in these equations is called the **molar absorptivity** - or sometimes the molar absorption coefficient. If you rearrange the simplest of the equations above to give an expression for epsilon (the molar absorptivity), you get:

$$\varepsilon = \frac{A}{l c}$$

The absorbance of a solution varies as the concentration or the size of the container varies. Molar absorptivity compensates for this by dividing by both the concentration and the length of the solution that the light passes through. Essentially, it works out a value for what the absorbance would be under a standard set of conditions - the light travelling 1 cm through a solution of 1 mol dm^{-3}. It means one can make comparisons between one compound and another without having to worry about the concentration or solution length

Table C 1.1 AA240FS instrument parameters

Element	Wavelength mm	Slip width mm	Lamp current mA	fuel	support
Fe	248.3	0.2	5	Acetylene	Air
Cu	324.7	0.5	4	“	“
Pb	217.0	1.0	5	“	“
Mn	279.5	0.2	5	“	“
Co	240.7	0.2	7	“	“
Cr	357.9	0.2	7	“	“
Mg	285.2	0.5	4	“	“
As	193.7	0.5	10	“	Argon

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APPENDIX D

Apppendix.D.1

International / National Standards for Heavy Metals in Food**.**

Dr. YY Choi, Chemist Government Laboratory October 2011, Local Situation

Cap. 132V Food Adulteration (Metallic Contaminants) Regulations. Available International / National Standards: Codex Alimentarius Commission (CODEX). Mainland. US Food and Drug Administration (FDA). European Commission (EU). Australia, (FSANZ).

Table. D 1. Maximum permitted concentration of certain metals naturally present in specified foods.

Heavy Metal	**Limit of Exposure mg/kg**

Copper (Cu)	2 .00
Lead (Pb)	0.10
Arsenic (As)	0.10
Mercury (Hg)	0.01
Cadmium (Cd)	0.02
Zinc (Zn)	30 .00
Iron (Fe)	15.00

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Metal	Description of food	Maximum permitted concentration in parts per million
First Schedule	Maximum permitted concentration of certain metals naturally present	tin specified foods
Arsenic (AS2O3)	Solids being fish and fish products	6
	Solids being shellfish and shellfish products	10

Table. D.3. Maximum permitted concentration of certain metals in specified foods.

Metal	Description of food	Maximum permitted concentration in parts per million
Antimony (Sb)	Cereals and vegetables	1
	Fish, crab-meat, oysters, prawns and shrimps	1
	Meat of animal and poultry	1
Arsenic (As203)	Solids other than- fish and fish products; and shellfish and shellfish products	1.4
	All food in liquid form	0.14
Cadmium (Cd)	Cereals and vegetables	0.1
	Fish, crab-meat, oysters, prawns and shrimps	2

	Meat of animal and poultry	0.2

Metal	Description of food	Maximum permitted concentration in parts per million
Chromium (Cr)	Cereals and vegetables	1
	Fish, crab-meat, oysters, prawns and shrimps	1
	Meat of animal and poultry	1
Lead (Pb)	All food in solid form	6
	All food in liquid form	1
Mercury (Hg)	All food in solid form	0.5
	All food in liquid form	0.5
Tin (Sn)	All food in solid form All food in liquid form	230 230

Appendix. D.3.

Some Established Standards.

Codex standards, CODEX STAN 193-1995 (Amendment: 2010)

Established Maximum of Five Heavy metals

Arsenic, Cadmium, Lead, Mercury (including methylmercury), Tin http://www.codexalimentarius.net/download/standards/17/CXS_193e.pdf Mainland, GB Standard: GB 2762: Maximum levels of contaminants in food Established maximum levels of SIX heavy metals:

Arsenic, Cadmium, Chromium, Lead, Mercury (including methylmercury), Tin.

US Food and Drug Administration (FDA) – Maximum level in selected food •

Mercury (including methylmercury), Allowable levels in bottled water

Arsenic, Antimony, Cadmium, Chromium, Lead, Mercury, USA.

Recommended maximum level in Candy likely to be frequently consumed by children

•Lead,http://www.fda.gov/Food/GuidanceComplianceRegulatoryInformation/GuidanceDocuments/Seafood/FishandFisheriesProductsHazardsandControlsGuide/ucm256690.htm

http://www.fda.gov/Food/GuidanceComplianceRegulatoryInformation/GuidanceDocuments/ChemicalContaminantsandPestic ides/ucm077904.htm

http://www.fda.gov/Food/GuidanceComplianceRegulatoryInformation/GuidanceDocuments/ChemicalContaminantsandPesticides/ucm077969.htm#cadm

http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?Fr=165.110.

European Commission: (EC) No. 1881/2006 - maximum of four heavy metals in foodstuff: Cadmium, Lead, Mercury, Tin.

Http://eurlex.europa.eu/LexUriServ/site/en/oj/2006/l_364/l36420061220en00050024.pdf

European Commission: Council Directive 98/83/EC, – Quality of water intended for human consumption including six heavy metals of interest Arsenic, Antimony, Cadmium, Chromium, Lead, Mercury.

http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1998:330:0032:0054:EN:PDF

Australia: Food Standards Australia New Zealand (FSANZ).

Contaminants and Natural Toxicants laid down maximum levels of five heavy metals in specified food: Arsenic, Cadmium, Lead, Mercury, and Tin. http://www.comlaw.gov.au/Details/F2011C00542.

Table.D.4. Effect of arsenic, cadmium, chromium, lead and mercury on mammals.

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Element Effects: References Arsenic Acute: nausea, vomiting, “rice-water” diarrhea, encephalopathy, multi-organ dysfunction, syndrome, long QT syndrome, painful neuropathy, Soghoian and Sinert (2008). Chronic: diabetes, hypopigmentation/ hyperkeratosis, cancer: lung, bladder, skin, encephalopathy, Soghoian and Sinert (2008).Toxic concentration: 24-h urine: ≥50g/L, or 100g/g creatinine, Soghoian and Sinert (2008). Other effects: promotes bladder, lung, skin, and prostate cancer, Salgado-Garcia et al. (2006)

Cadmium Acute: pneumonitis (oxide fumes) Soghoian and Sinert (2008). Chronic: proteinuria, lung cancer, osteomalacia Soghoian and Sinert (2008). Toxic concentration: proteinuria and/or≥15g/g creatinine Soghoian and Sinert (2008). Other effects: kidney and bone damage WHO (1992). Inhibition of progesterone and estradiol Zhang et al. (2008). Alterations in uterus, ovaries and oviduct Massanyi et al. (2007). Progesterone synthesis of ovaries Zhang and Jia (2007). Endocrine disruption Henson and Chedrese (2004). Act as estrogen in breast cancer Brama et al. (2007).Excess risk of cardiovascular mortality Jarup (2003).

Chromium Acute: gastrointestinal hemorrhage, hemolysis, acute renal failure (Cr6+ingestion) Soghoian and Sinert (2008). Chronic: pulmonary fibrosis, lung cancer (inhalation) Soghoian and Sinert (2008).Toxic concentration: no clear reference standard Soghoian and Sinert (2008).

Chromium (VI): potential lungs, liver, and kidney cancer producer; DNA damages Dong et al. (2007).

Lead Acute: nausea, vomiting, encephalopathy (headache, seizures, ataxia, obtundation) Soghoian and Sinert (2008). Chronic: encephalopathy, anemia, abdominal pain, nephropathy, foot-drop/wrist-drop Soghoian and Sinert (2008).Toxic concentration: Pediatric—symptoms or [Pb] ≥45/dL (blood); Adult—symptoms or [Pb] ≥70/dL. Soghoian and Sinert (2008).Other effects: damages central nervous system, excretory system, circulatory system, and cardiovascular system Ma (1996).

Mercury Acute: Elemental (inhaled)—fever, vomiting, diarrhea, acute lung injury. Inorganic salts (ingestion)—caustic gastroenteritis, Soghoian and Sinert (2008).

Chronic: nausea, metallic taste, gingiva-stomatitis, tremor, neurasthenia, nephrotic syndrome; hypersensitivity (Pink disease).Soghoian and Sinert (2008) Soghoian and Sinert (2008). Toxic concentration: Background exposure "normal" limits: 10g/L (whole blood); 20g/L (24-hurine), Soghoian and Sinert (2008).Other effects: cough, dyspnea, fever, tremor, malaise, motor neuropathy, gum disease, delusions and hallucinations, Guzzi and La Porta (2008).

Table D5. Properties of Chilled Cast Iron

Fe	C	Mn	P	S	Si	Cu	Ni	Cr	V
90.58	2.4	0.5	0.2	0.12	1.20	0	4.5	0.5	0

Source: Kaushish, (2010)...

D 6. Determination of iron particles.

$$\text{Final concentration (mg/kg)} = \frac{concentration of dilution factor\ X\ nominal volume}{sample weight\ in\ grams} \text{ -- eq.3.5}$$

Nominal volume = 30ml = final volume after digestion.

Initial volume = 7.0 ml

Sample weight = 0.5gram.

All concentrated element which showed significant value was taken through the same tabulation.

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D 6.Wear vs. hardness

Correlation Coefficient = -0.870346
R-squared = 75.7502 percent
R-squared (adjusted for D.F.) = 70.9002 percent
Standard Error of Est. = 0.0860857
Mean absolute error = 0.0621471
Durbin-Watson statistic = 2.07588 (P=0.5198)

D7. Wear vs. Concentricity

Correlation Coefficient = 0.248143
R-squared = 6.1575 percent
R-squared (adjusted for D.F.) = -9.48292 percent
Standard Error of Est. = 0.155298
Mean absolute error = 0.104266
Durbin-Watson statistic = 2.19012 (P=0.5138)

D8.Wear vs. Penetration

Correlation Coefficient = 0.871172
R-squared = 75.894 percent
R-squared (adjusted for D.F.) = 71.8764 percent
Standard Error of Est. = 0.0787098
Mean absolute error = 0.0553571
Durbin-Watson statistic = 2.34517 (P=0.6641)

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