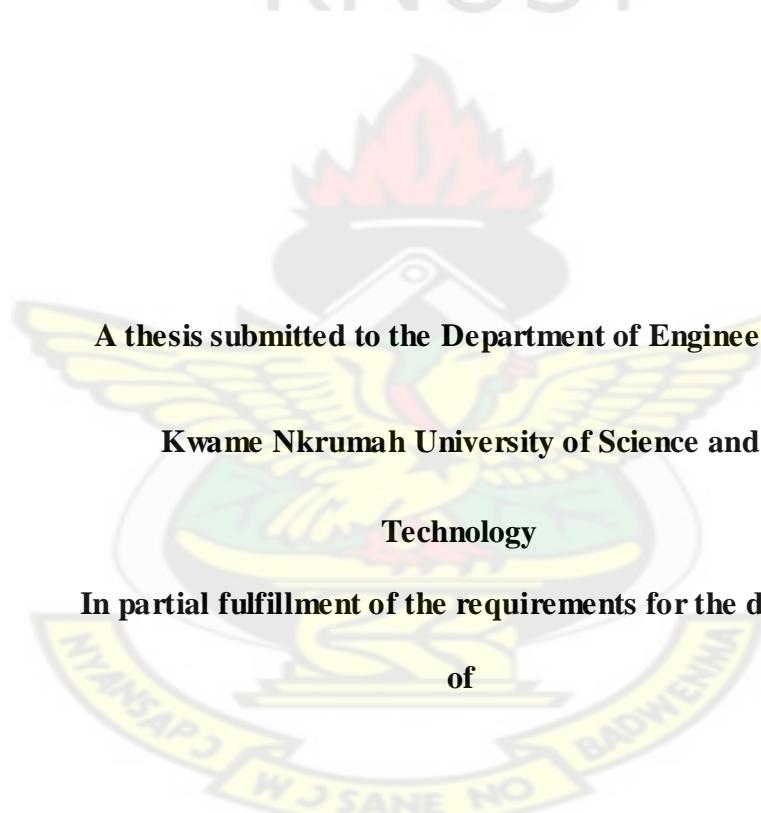


**ENHANCING THE INTRODUCTION OF SHELL MOULD CASTING  
TECHNIQUE IN GHANAIAN PRACTICE**

**by**

**BONIFACE NII TETTEH ANKAMA ADAMS (BSc. Mech. Eng.)**



**A thesis submitted to the Department of Engineering,**

**Kwame Nkrumah University of Science and**

**Technology**

**In partial fulfillment of the requirements for the degree**

**of**

**MASTER OF SCIENCE**

**Department of Mechanical Engineering**

**College Of Engineering**

**October 2011**

## **DECLARATION**

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

BONIFACE NII TETTEH ANKAMA ADAMS .....  
(Student Name & ID PG1414207) Signature Date

**Certified by:**

DR .A. AGYEI-AGYEMANG .....  
First Supervisor's Name Signature Date

**Certified by:**

DR. G. TAKYI .....  
Second Supervisor's Name Signature Date

**Certified by:**

PROF. F.K. FORSON .....  
Head of Dept. Name Signature Date

## **ABSTRACT**

The increase in demand of cast goods in Ghana including some machine and engine parts, calls urgently for the development of additional and better methods other than sand casting (especially where sand casting which is about the most widely practiced in Ghana and for casting only few simple items such as corn milling plates, cannot meet the casting standards (close tolerance and good surface finish) required). As a contribution to this development the shell mould method which gives better surface finish and close tolerances than the sand casting process was developed in this project for use in Ghana. Phenol formaldehyde (PF) resole resin and calcium stearate synthesized locally from beef tallow and calcium oxide were used instead of phenol formaldehyde (PF) novolac type. This was successful for the production of the core but collapsed during the production of the main mould. The collapsed resole precoated sand was, however, utilized by reinforcing it with sodium silicate and the hot box route slightly altered to produce the main mould. A hand operated muller and a shell mould ejector mechanism were fabricated and were utilized to produce the shell core and mould which were used to cast a machine part. Among the findings, collapsed precoated sand is not a waste. It can be used again by making a shell “pattern imitator” to go with the pattern, at a maximum allowance of 10 mm from pattern surface on an “opened–top metallic table” and then ramming onto the metal pattern before drying in furnace and then stripping from the pattern surface. This can be duplicated for mass production.

Binders can be developed from local sources such as cashew nut shell oil, corn, cassava, protein/peptide materials and also from gum Arabic. All these are readily available in Ghana.

## TABLE OF CONTENTS

	<b>PAGES</b>
DECLARATION .....	ii
ABSTRACT .....	iii
TABLE OF CONTENTS .....	iv
LIST OF TABLES .....	vii
LIST OF FIGURES .....	viii
SYMBOLS .....	x
ACKNOWLEDGMENTS .....	xii
CHAPTER ONE .....	1
INTRODUCTION .....	1
1.1 Background .....	1
1.2 Problem Statement .....	3
1.3 Objectives .....	3
1.3.1 General objective .....	3
1.3.2 Specific Objectives .....	3
1.4 Justification of the Project .....	3
1.5 Methodology .....	4
1.6 Report Presentation .....	4
CHAPTER TWO .....	6
LITERATURE REVIEW .....	6
2.1 General Review of Casting Processes with emphasis on Shell Mould Casting .....	6
2.1.1 Expendable mould casting: .....	6
2.1.2 Non-expendable (Permanent) mould Casting .....	11
2.2 The Shell Mould Casting .....	12
2.2.1 Properties of shell Moulding Sands and their Places of Occurrence in Ghana .....	23
2.2.2 Shell Pattern and Core making Techniques .....	26
2.2.3 Getting pattern ready for the Process .....	26
2.3 Flowability - A Property of Sand for Moulding .....	27
2.4 Binders .....	27
2.4.2 Binders associated with shell moulding .....	37
2.4.2.1 Identifying cashew in Ghana for a future production of phenol formaldehyde resin .....	37
2.4.3 Selecting the binder .....	38
2.5 Some Additives of Foundry Materials .....	39
2.6 Environmental Impact, Health and Safety .....	39

2.6.1 Emission:.....	39
2.6.2 Health hazards and safety.....	40
2.6.3 Control measures .....	43
<b>CHAPTER THREE.....</b>	<b>44</b>
<b>EXPERIMENTAL PROCEDURE-Materials and Methods .....</b>	<b>44</b>
3.1. Identification of available local sand .....	44
3.2. Washing of the sand .....	44
3.3. Testing the conformity of the sand used with shell moulding sands-silica sand analysis .....	44
3.4 Selecting the machine component to be cast.....	47
3.5 Wood work-Machining of wood .....	48
3.6 Sized Cope and Drag.....	49
3.7 Production of Shell Pattern .....	50
3.8 Machining and shaping of the cast iron to form shell mould metallic pattern and metal core box.....	51
3.9 Manually operated Hand Mixer .....	55
3.10 Dump box Construction. ....	57
3.11 Search for suitable shell mould resin and its attendant chemicals .....	58
3.12 Simple tests with some of the resin and the chemical with sand .....	59
4.13 Shell sand coating: Pre-coating the sand with the resin and the chemical.....	60
3.14 Shell Core making: Forming the shell core with the pre-coated sand .....	62
3.15 Forming the shell mould with the pre-coated sand .....	63
3.16 Testing the prepared shell core and the shell mould by casting a suitable machine part.....	69
<b>CHAPTER FOUR.....</b>	<b>70</b>
<b>ANALYSIS OF RESULTS AND DISCUSSIONS .....</b>	<b>70</b>
4.1 Results and Discussion on Sand analysis .....	70
4.2 Results and Discussion on Other Experimental Set-Ups and the shell mould casting process .....	79
4.3. Results and analysis on Cast Piece from the Shell Process .....	81
<b>CHAPTER FIVE.....</b>	<b>82</b>
<b>CONCLUSIONS AND RECOMMENDATIONS .....</b>	<b>82</b>
5.1 Conclusions .....	82
5.2 Recommendations: .....	84
<b>REFERENCES .....</b>	<b>87</b>
<b>APPENDICES .....</b>	<b>93</b>
<b>APPENDIX A .....</b>	<b>93</b>
<b>APPENDIX B .....</b>	<b>116</b>

APPENDIX C .....	133
APPENDIX D .....	143
APPENDIX E.....	144



## LIST OF TABLES

TABLE	PAGES
Table 2.1 Advantages and disadvantages of plaster castings, [12] .....	7
Table 2.2 Advantages and disadvantages of Investment casting .....	8
Table 2.3 Advantages and Disadvantages of shell mould casting .....	10
Table 2.4 Advantages and disadvantages of Die casting [24].....	12
Table 2.5 Starch source distribution in global market (excluding China) .....	33
Table 2.6 Some specifications of starch- Tapioca / Cassava Starch .....	35
Table 2.7 Some physical properties of starch in cereals, roots and tubers .....	35
Table 3.1 Sticking Test Experiment of two tests - Test1 and Test 2 - to find how best resin-sand can adhere to pattern surface .....	59
Table 4.1 Organic content test determination .....	70
Table 4.2 Grading Test of Unwashed sample .....	71
Table 4.3 Silt content test.....	71
Table 4.4 Hydrometer test results for determination of clay and silt content of Unwashed sample – values used to plot Figure 4.1 .....	72
Table 4.5 Grading test on sample SI .....	73
Table 4.6 Hydrometer test results for determination of clay and silt content of sample SI- values used to plot Figure 4.1 .....	74
Table 4.7 Grading test on washed sample.....	75
Table 4.8 Summary on results of the percentage of clay, silt, sand and gravel ....	76
Table 4.9 Thermal conductivity, Total Dissolved Solids (TDS) and pH measure at Geotechnical Engineering water laboratory section at KNUST of sand against existing silica sand, SI .....	77
Table 4.10 Results of the Contents of Washed and Unwashed Sand samples compared to the Silica SI samples obtained, at Chemistry Department of KNUST.....	77
Table A 1.1 Total number of foundries (in production units) of a country in the area of iron, steel and non-ferrous metals in 2008. ....	101
Table A1.2 Comparison of Several Casting Methods.....	102
Table A1.3 Comparison of some Casting Methods .....	103
Table A1.4 General Characteristics of Casting.....	104
Table A1.5 Summary of casting processes .....	105
Table A 1.6 Some Casting summary and Processes .....	106
Table A 1.7 Types of Patterns and Moulds Used in the casting Process .....	107
Table A2.0 Survey of Various Resin Types and Their Applicability .....	108
Table A2.1 Quantities of Chemicals Released in the Shell Process. ....	110
Table A 2.2 Quantities of Chemicals Released in the Hot Box Process. ....	111
Table A2.3 Chemical Constituents of Common Foundry Binders .....	112
Table A2.4 Chemical Constituents of Common Foundry Binders .....	113
Table A2.5 Chemical Constituents of Common Foundry Binders .....	114
Table A2.8 Region or Estimated world starch production (1992) (000 tonnes). ...	115
Table C3.1 Process Chart of shell Moulding Technique for sand coating.....	133
Table C3.2 The process chart for shell moulding using coated sand .....	135
Table C3.3 Process Chart- Making shell metal pattern using Wooden Pattern and employing sand casting.....	137
Table C3.4 Process Chart For machining of shell metal core box from Foundry..	142

## LIST OF FIGURES

	<b>PAGES</b>
Figure 2.1 Examples of sand castings [11] .....	7
Figure 2.2 Some investment castings [14] .....	8
Figure 2.3 Examples of some shell mould castings: (a), (b) and (c)[17], and d [18] .....	9
Figure 2.4 (a) and (b) are Aluminium die casting, (c) Aluminium, Zinc and Brass die castings [23].....	12
Figure 2.5 (a) Hexamethylene tetramine (b) Decomposition of hexamethylene tetramine into formaldehyde and ammonia .....	13
Figure 2.6 Example of a possible structure of Phenol Formaldehyde resin (Source: Google Books) .....	14
Figure 2.7 The shell mould process (a) simple pattern (b)dump box containing precoated sand in series of operation in coating the pattern and (c) shell mould on pattern being cured in an oven,[27]. .....	20
Figure 2.8 (a) The use of ejectors in the shell mould (b) shell mould and core assembly (c) pouring of molten metal and (d) actual cast part from knockout [27]......	20
Figure 2.9 Another shell process: (a) above, shell mould making, and below: (b) shell core making and (c) assemble of the shell mould together with the shell core ready for casting (adapted from [21, p. 239]) .....	21
Figure 2.10 (a) Acacia Senegal with gum exudate from its bark, (b) flowers and (c) young stem and flower Photos from [39] .....	30
Figure 2.11 (a) Acacia Seyal tree, (b) acacia Seyal bark and (c) red acacia Seyal leaves .....	31
Figure 2.12 (a) and (b) showing combretum grandiflorum [41] .....	32
Figure 2.13 Amount of starch in some Typical Starchy foods .....	32
Figure 3.1 Set-up for particle determination showing (a) particle size determination, hydrometer set-up for (b) meniscus correction and (c) determination of soil particles below 75 microns .....	45
Figure 3.2 Wood pattern 1 for sand casting (Cast to be used for metallic shell mould pattern).....	48
Figure 3.3 Detailed drawing of the shell core box .....	49
Figure 3.4 (a) Geometrical model drawing used for calculation and (b) sectional drawing of metal to be cast in the shell mould process (1,2,3,4,5 and 6 show isolated geometric shapes used for calculation and estimation ) not drawn to scale .....	52
Figure 3.5 Diagram for determining the static head of metal pored through a funnel .....	53
Figure 3.6 Shell metal pattern with holes for spring ejectors .....	54
Figure 3.7 Orthographic drawing of a the metallic shell mould pattern mechanism on the left is its isometric .....	54
Figure 3.8 Mixer constructed for mixing sand and resin to obtain shell coated sand .....	56
Figure 3.9 Mixer-Stirrer mechanism containing detailed orthographic drawing .....	56
Figure 3.10 Dump box constructed to be used to hold resin coated sand for moulding. The holes at the top were used as slots that could help in locking the pattern unto the top. .....	57
Figure 3.11 Orthographic drawing of the dump box and metal pattern assembly ..	58

Figure 3.12 Flow diagram of shell moulding technique for sand quoting .....	61
Plate 3.1 shows some shell mould cores made with the coated-sand of phenol formaldehyde resole resin with ADX.60P hardener from Allied Resins and obtained from Naja David Veneer and Plywood Limited .....	63
Figure 3.13 Flow diagram on the shell moulding using the pre-coated sand.....	65
Figure 3.15 Opened-top metallic table .....	66
Figure 3.16 Exploded view in 3- dimesion of pattern imitator - shell pattern - metallic table assembly.....	67
Figure 3.17 Isometric and Orthographic projection of the assembly of the newly constructed mould mechanism with the pattern .....	68
Figure 4.1 Logarithm graph of percentage of clay, silt, sand and gravel passing each sieve .....	76
Figure A1 Major cashew producing areas in Ghana [54] .....	100
Figure B4 Pressure head during casting in relation to the static head and the external pressure .....	128
Figure B5 (a) Force exerted by a melt and (b) the buoyant force on the cope and drag as the molten metal begins to fill the mold.....	131



## SYMBOLS

$\alpha$	expansion coefficient
$\Delta H_F$	the heat of fusion in $\text{Jkg}^{-1}$
$\rho_c$	the density of the cast metal
$\rho_m$	density of the mould material respectively.
$\rho_L$	the density of melt
$\rho_S$	the density of sand core
$\tau$	time
$\tau_p$	the time of metal pouring into a mould
$\lambda_m$	thermal conductivity
$a_m$	thermal diffusivity of the mould material
A	the total surface area of the casting
$b_m$	coefficient of heat accumulation ,it is a measure of the rate of heat absorption by mould material
$B_S$	mold constant
$c_c$	specific heat capacity of a casting
$c_m$	specific heat capacity
c	specific heat in $\text{Jkg}^{-1}\text{^oC}^{-1}$
d	inner diameter (smaller)
D	outer diameter(bigger)
E	coefficient of gas evolution (it characterizes the gas generating capacity of sand and core mixture)
$F_1$	its area in $\text{m}^2$
$F_c$	surface area of the casting
F	force in newtons
$F_m$	the cross sectional area of the mould
g	acceleration due to gravity in $\text{ms}^{-2}$
G	the quantity (mass) of gases evolving from moulding material
h	height(depth) in metres ,m
H	the height of liquid metal in the mould is denoted by
$H\rho_o$	the ferrostatic head
J	flux of heat
K	thermal conductivity
$K$	gas permeability
$K_M$	thermal conductivity of mould
$l_m$	the thickness of the mould wall
L	the specific latent heat of solidification
$M_1$	the mass in kg
p	pressure
$P_1$	the initial gas pressure in the sections of a passage
$P_1'$	the reduced mass of the casting or its component, $\text{kg/m}^2$
$P_2$	the final gas pressure in the sections of a passage
$P_m$	the excess gas pressure at the metal-mould interface S
$P_{ex}$	the external pressure
q	the heat flux
Q	total heat through the interface of area A
$Q_F$	latent heat of solidification
$Q_m$	the quantity of heat absorbed by a mould

$Q_s$	superheat
$R$	the resolved dimension of a body
$S$	is the metal-mould interface
$t_c$	is the temperature of the casting interface ,it is also defined as the time of cooling of a casting in a mould to any temperature
$t_s$	is the temperature of the mould external surface.
$t_s$	is the solidification time
$t$	is temperature,
$t$	is time
$t_1$	liquidus temperature,
$t_{in}$	the initial temperature of molten metal in the mould
$t_{init}$	initial temperature
$t_{init.m}$	the initial temperature of a mould
$t_{kn}$	the temperature of the casting at knockout out from the mould
$t_o$	the time of flow of the metal to the mould section under examination
$t_-$	time from the beginning of charging
$T_{fr}$	the freezing temperature
$T_{1init}$	the initial temperature of the metal in the given section of the casting ,K.
$T_m$	melting point
$T_0$	final or ambient temperature after cooling
$T_p$	pouring temperature
$u$	the volume rate of freezing of the metal
$u$	the linear solidification rate
$v$	the volume of metal frozen at time $t$ , in $m^3$ $v_s = t_c - t_s$
$V$	volume
$V_c$	the volume of the casting
$x$	the distance from the metal-mould interface (it is positive in the metal and negative in the mould) ;it is also thickness of the solidified metal layer in a sand mould
$X$	the size of casting in metres v, m

## **ACKNOWLEDGMENTS**

I owe a profound gratitude to Dr. A. Agyei-Agyemang, my first supervisor, for the effort he made in supervising this work. I must also thank Dr. G. Takyi, my second supervisor, for the advice and guidelines he gave for this work. My sincerest gratitude also goes to Dr .E.S.D. Afrifa. His help ranges from spending his money on fueling his car to take me round different factories or companies to look for phenol formaldehyde, the main resin for shell moulding. On other occasions he took me to look for sand. He also took my mould equipments and materials in his car to Suame Magazine for casting. His guidance, advice and direction have helped immensely in realizing this work. He gave me valuable guidelines and constructive criticisms about the justification of my topic as well as some guidelines to follow so as to enrich the dissertation and make it more technical. Mr. Selorm Agorku, a lecturer of the Department of Chemistry, KNUST was also of immense help to me during the determination of the properties of suitable sand for shell mould. The same can also be said of Mr. David Washington of the same Department of Chemistry who also helped with the sand analysis. I am very grateful to Mr. Gilbert Fiadzo and Mr. Botchwey of the Soil and Water divisions respectively of the Department of Civil Engineering, KNUST. I must also thank Mr. Abobagri Ibrahim and Mr. Addai Brenya all in the Department of Civil Engineering. I also owe Tema Steel Works an immense gratitude, especially Mr. G.V. Rajendran, the foundry manager, and some workers of the company such as Maxwell, Peter Voryce, Vasco Kaletsi, Victor Dedome, Frederich Abotsi, Yaw Akoto, Isaac Nyatoame and Prince Otwey. I am also indebted to Mr. Kofivi Hormeku of Hormeku Engineering Works Limited for some materials and some directions. My other thanks also goes to GRATIS Foundation as they were readily available to help, especially, effort of Godson Tetteh

a past student of KNUST for giving me videos on ceramic shell mold casting. I cannot forget the immense effort of Mr Yaw Akwoyire Aviamu of Department of Agricultural Science's library of KNUST who was of great help during the literature review of some local binders. I should also commend Mr. Robert Obeng-Tham of Mechanical Engineering department machine workshop and Mr. John Ampomah and Francis Dumasi of the Mechanical engineering welding shop who availed themselves at any time to weld for me.

My sincerest thanks also goes to Dr. Y.A.K. Fiagbe of the Department of Mechanical Engineering for providing me with a thermocouple and a camera for my practical works. My thanks also go to the following for providing some chemical for this research: Ms. Georgina Kweesi, the head of the National Science Resource Centre, Mr S.T.E.K. Adzraku of St. Thomas Aquinas Senior High School and Mrs. D. D. O. Welbeck, head of Presbyterian Secondary School, PRESEC, Osu. Mr. Victor Andoh of PRESEC, Osu was also of good help. My other thanks go to Abu Dia Company for providing molten Cast iron for the casting and the Geological Survey Department, Ghana, for giving me data on some sand occurrences.

My immense gratitude goes to Najar David Plywood and Veneer Limited for donating some quantity of phenol formaldehyde resole resin as well as the hardener that goes with it. The whole project would not have been possible without the resin donated by this company. My sincere thanks go to Mr. Boakye, Production Manager of the company, his subordinate supervisor, Solomon Kojo Eshun and, Mr. James Sarfo, the personnel manager. The efforts made by Professor Abeeku Brew-Hammond with links outside for possible donation of some reasonable quantity of phenol formaldehyde novolac resin and some other chemicals at the later part of the experiments could not be overlooked. A contact for early assistance could have been

positive. I also thank Pastor Joshua Akrasu of Christ Revival Church, Ahwiah Branch, Kumasi and a foundry owner at Suame Magazine who gave me about 500 ml of sodium silicate (water glass) free of charge to enable me carry on a test on this research.

My other thanks go to my father Walter G. Adams for giving me a lot of encouragement when the going was tough. My mother, Elizabeth, cannot be forgotten. To Sarah, my wife, and children, I also thank you all for being patient with me for being away from you most of the time during the course of this work.

May the Almighty God bless you all.



## **CHAPTER ONE**

### **INTRODUCTION**

#### **1.1Background**

Most industrial countries that have advanced economically have sound manufacturing or production foundations of which casting is part. Casting forms a major activity in most machine building operations. This leads to such production as: cast iron sleeves for diesel engines; cement, mining, minerals and earthmoving machinery; electrical and textile machinery; heavy trucks; the aviation and aerospace industrial needs as well as that of military and marine industries [1], [2]. Others range from the manufacturing of railway rolling stocks, pumps, compressors and valves to bathroom tubs, pipes, sanitary pipes and fittings, light or lamp holders and castings for other applications. But recently, more demand in the casting industry is tied to the automobile industry [1], [3], [4], [5].

Countries like Britain, U.S.A., Germany, Russia and China that are advanced industrially have foundries forming the backbones of their machine production industries. Countries like Malaysia, India and Indonesia that had their independence just a little before or around the same time as Ghana, are now making giant strides in the world today due to the establishment of strong machine building base founded on casting of machine and other components. India, for example, is the sixth largest producer of castings after USA, China, Japan, Russia and Germany [4]. There were about 5000 foundry units in India in 1999 (out of a total of 28,152 foundry units in the World) with 95% of them in small scale sector [4], [5], [6]. All the known casting processes are practiced in all the countries mentioned above [4].

Global casting production increased moderately to 95 million tons in 2007, a 4% increase from 2006. Different countries are constructing or increasing their

production capacity by increasing or adding to global metric tonnage and this leads to creation of more job opportunities. Appendix A1 is an excerpt from Modern Casting's data of Global Castings production showing the total number of foundries (in production units) in various countries in the area of iron, steel and non-ferrous metals as published in 2008 [7].

The trends and competitions based on the above information show that casting is indeed boosting the economy of these countries and giving their citizens employment whereas Ghana, which just achieved a middle income status, is having her artisans laying down their tools. Sand casting which used to be common is now becoming a thing of the past as most artisans and technicians are abandoning their tools and most shops are closing down because of cheap and probably better quality of imported spare parts. These may stem from the fact that artisans in Ghana are not looking at the more refined way of sand castings and other processes so as to improve on their products and make them attractive.

The known casting processes in Ghana are mainly investment casting and sand casting. Investment casting is mainly used to produce metal artifacts and crafts while sand casting is used for engineering and machine components manufacture. Most components produced by sand casting lack good surface finish, close tolerance and involve excess machining. Sand casting in Ghana is used to produce mainly corn-mill plates and occasionally some machine or engine components. Meanwhile, the numerous refined casting processes such as, die casting, other permanent mould castings and sand-shell mould casting that give products with good surface finish, tight tolerance and better dimensional accuracy than the sand casting are virtually not practiced in Ghana.

## **1.2 Problem Statement**

In order to produce parts with better surface finish and close tolerance, casting processes such as permanent mould casting (e.g. die casting) and non-permanent mould casting (e.g. sand-shell mould casting and investment casting) are used. The introduction of these casting processes in Ghana (where only green sand mould casting is predominant) is necessary to improve and widen the base of machinery building. Of these processes sand-shell mould casting is the easiest and the cheapest to develop by comparing the advantages and disadvantages of shell mould casting with other casting methods (see Appendices A1.2 -1.6).

## **1.3 Objectives**

### **1.3.1 General objective**

To enhance the machine components casting processes widely used in Ghana by adapting shell mould casting techniques to suit local production needs.

### **1.3.2 Specific Objectives**

- Identify local binders (if available)
- Develop and produce a set of shell moulds
- Use the shell moulds to cast a machine component.

## **1.4 Justification of the Project**

The enhancement of the casting processes in Ghana with sand shell mould casting process will widen the machinery building base and particularly lead to manufacture of machine tools. This will help accelerate the country's industrial development and create employment. Spare parts of some agricultural machines which require cast components for their repair could be produced. Part of the transportation problems may be solved as some vehicle components could be made

readily available. Machine tool production can lead to the production of other machines.

### **1.5 Methodology**

The methodology adopted in this work comprises:

Review of shell casting processes; Literature search for some binders used in other countries; Search for local binders (if available); Develop a pair of shell mould from a pattern; Conduct test to demonstrate the efficacy of the developed mould by using it to cast.

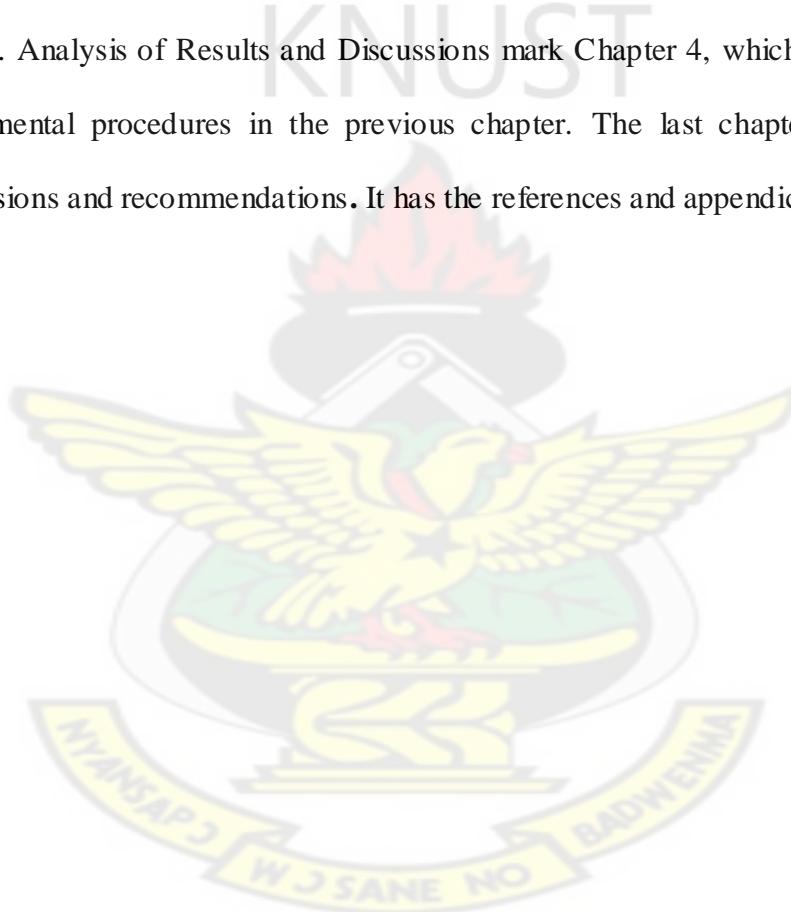
### **1.6 Report Presentation**

The fore chapters of this dissertation are the title page, certification page and the abstract. This also includes lists of tables, figures and acknowledgement. The report contains five main chapters in three sections. The first part consists of Chapters 1 and 2. The second part deals with Chapters 3 and 4 and the last part is Chapter 5. References and Appendices are the concluding parts of this work.

The first chapter is an introduction. It elaborates on casting being part of activities which countries that have developed and those that are on the verge of developing use and how this improves their economy. In citing examples, it reviewed some major casting processes and compared them with the existing casting processes in Ghana. Chapter two reviews existing literature on casting. It looks at general review of casting processes with emphasis on shell mould casting, the various sands used in the Shell Moulding process, their properties and occurrences or places of location in Ghana. In addition, in trying to come out with the pair of shell moulds, effort was made to review available local binders and their sources. Environmental impact, health and safety as well as emissions, and control measures were also considered. This is to ensure the smooth operation of the process should it be

accepted and commonly practiced in Ghana. To document the procedures, some process charts (Appendix C) and flow diagrams for the shell moulding – shell core processes are developed in Chapter 3.

Moreover, this chapter describes the beginning of pattern making through the shell moulding stage. It is mainly on experimental procedure - (Materials and Methods). It looks at the various activities, experiments and tests as well as constructions of a machine and a mechanism for the carrying out of the shell mould casting. Analysis of Results and Discussions mark Chapter 4, which is based on the experimental procedures in the previous chapter. The last chapter discusses the conclusions and recommendations. It has the references and appendices following it.



## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 General Review of Casting Processes with emphasis on Shell Mould Casting

A cast is an object that has been produced by solidification of a melt in a mould. The mould cavity, in every detail, has a shape identical to the component to be produced. A pattern of the product is made in wood, plastic, metal, or other suitable material. This is usually placed in a flask or moulding box. The flask is then filled with moulding mixture which is compacted (by a machine) or rammed (with a hand tool). The moulding mixture normally consists of sand, a binder and water [8].

The selection of the appropriate casting process is dependent on the types and number of castings required and engineering properties sought. There are two main sub-groups of casting. These are: expendable types and non-expendable types.

**2.1.1 Expendable mould casting:** This is a generic classification that includes sand, plastic, shell, and investment (lost-wax technique) mouldings. All of these involve the use of non re-usable moulds [9]. Below are brief descriptions of the most important features of the various expendable mould casting techniques:

**i. Sand casting:** Sand casting uses natural or synthetic sand (lake sand) which is mostly the refractory material, silica ( $\text{SiO}_2$ ), as the mould material. The sand grains are mixed with small amounts of materials like clay and resins to improve the mouldability and cohesive strength of the mould. The mould is packed around a pattern which has the shape of the desired casting [10]. Figures 2.1 (a), (b) and (c) show some examples of sand castings.



Figure 2.1 Examples of sand castings [11]

**ii. Plaster casting (of metals):** It is similar to sand mould casting except that plaster is substituted for sand. Plaster gel compound comprises of 70-80 % gypsum and 20-30 % strengthener (e.g. fibers) and water. There are small additions of talc, terra alba, or magnesium oxide to the gypsum, to prevent cracking and to reduce the setting time. Lime or cement is added to control expansion during baking. Lead time is at most 3 weeks. Two important casting processes that use the plaster mould process are investment and Shaw casting processes [12]. Table 2.1 shows the advantages and disadvantages of plaster casting.

Table 2.1 Advantages and disadvantages of plaster castings, [12]

Advantages	Disadvantages
Good dimensional accuracy and surface finish	Moisture in plaster mould causes problems:- (i) mould must be baked to remove moisture (ii) mould strength is lost when over-baked yet moisture content can cause defects in products
Capability to make thin cross-sections in castings	Plaster moulds cannot stand high temperatures

**iii. Investment casting (lost wax process):** This casting method involves producing a "wax pattern" by injecting wax or plastic into a pattern die. The pattern is attached to gating and runner systems and this assembly is dipped in hard setting refractory slurry, which is then cured. The pattern is melted out of the mould to leave

an exact cavity. The mould is heated to cure the refractory and to volatilize the remaining wax pattern material. The moulds are baked and molten metal is poured into the mould cavity. On solidification of the casting, the mould material is broken away from the castings [13]. Figures 2.2 (a), (b) and (c) below show some investment castings. Also, Table 2.2 shows some advantages and disadvantages of investment castings.



Figure 2.2 Some investment castings [14]

Table 2.2 Advantages and disadvantages of Investment casting

Advantages	Disadvantages
Good accuracy	High mould cost
Good mechanical properties	Size limitations
Good surface finish	
Thin components can be cast	
No shape limitations	
Can be used for all casting metals	

**iv. Shell mould casting:** Whilst this is the focal method of casting in this research work, a brief overview of it is offered here for completeness of the literature review. Shell moulding is a process for producing simple or complex near net shape castings, maintaining tight tolerances and a high degree of dimensional stability [15]. It consists mainly of the core and mould. It is also defined as a precision sand casting

process capable of producing casting with a superior surface finish and a greater dimensional accuracy than conventional sand casting.

Better qualities and precision can be obtained in a wider range of alloys and with greater flexibility in design than die casting and at a lower cost than die casting. The fundamental feature of the process is the use of fine-grained high purity sand that contributes to the attribute of a smooth surface and dimensional accuracy to mould cores and castings alike. In conventional casting the use of such fine sand is precluded because it would dramatically reduce mould permeability [16].

The metal pattern used to prepare the mould pattern should have good heat capacity as well as a good thermal conductivity. Figures 2.3 a, b, c and d show some shell mould castings.

The moulds are usually prepared in two halves and placed together. If cores are to be present, they are properly located and then clamped or glued.



Figure.2.3 Examples of some shell mould castings: (a), (b) and (c)[17], and d [18]

The full mould is adequately backed up at the outside, using metal pellets, gravels or sand, to provide the necessary strength to the mould before the molten metal is poured [19]. Table 2.3 gives the advantages and disadvantages of the shell mould casting. Since the focus of this work is on shell casting process, a more critical assessment of the advantages and disadvantages will be given later.

Table 2.3 Advantages and Disadvantages of shell mould casting

Advantages	Disadvantages
Excellent surface finish	Uneconomical in small scale production
Reproduces details with clean sharp edges rendering fettling and machining unnecessary	
Smoothen surfaces of the casting (in the range of about 300 micro cm-root-mean-square)	Low carbon steels castings show depressions on their upper surfaces
Total sand handling is about 5 to 10% of that normally required in green sand moulding	
Less foundry space required	The comparatively small amount of break down sand from shell moulds is not normally economically recoverable
Casting as thin as 1.5 mm and of high definition can be cast satisfactorily	
Being excellent heat insulator, there is no surface chilling or skin hardening of casting	
Cooling rate of cast metal, being slow, castings possess grain sizes larger than those obtained in green sand moulds	Resin costs are comparatively high
Tolerances of the order of 0.002 to 0.003mm per mm are possible to obtain	Shapes in which proper parting and gating cannot be obtained are not suitable for production with the process
Semi-skilled operators can handle the process	
Possesses permeabilities than other types of moulds	
Can be mechanized	The maximum size of the casting is limited by the maximum size of the shell which can be feasibly produced and poured
Shells can be stored for a long time before use	
Components requiring appreciable-after machining or finishing can be far more economically cast by shell moulding technique	

Adapted from [20, pp 355-6]

### **2.1.2 Non-expendable (Permanent) mould Casting**

Non-expendable mould casting differs from expendable mould casting in that non-expendable mould needs not be reformed after each production cycle. This technique includes at least four different methods; permanent, die, centrifugal, and continuous castings [9], which are described below:

**Die casting:** A die is a casting mould made of steel, iron or aluminium alloy which is filled with molten metal under the action of gravity or some other forces. The die casting process differs from other processes in that the metal mould (die) as a whole, or many of its elements, is used repeatedly for making large number of castings. Some elements of a die, mainly core to form intricate inner cavities, may be made of sand mixture with a binder and used only once [21, p. 247]. There are three types of die casting: gravity, low pressure and high pressure die casting.

Liquid metal forced into a die cavity under high pressure intrudes into parting trace joints, around ejector pins, into overflow wells, and through any cracks. Clearances in dies are held as small as practicable, and the metal in the cracks solidifies into thin and fragile extrusions called flash. The flash as well as sprues and runners must be removed to finish a casting. In large-scale production of a suitably shaped piece, the flash can be removed quickly in a shaving die in a press. For small production runs, the excess metal maybe broken off by hand and the edges cleaned by filing or buffing. Dimensions can be held closely enough for most purposes, and only a minimum of machining is usually necessary [22]. Figures 2.4 a, b and c below show some die castings. Also, Table 2.4 shows some advantages and disadvantages of die castings.



(a)

(b)(c)

Figure 2.4 (a) and (b) are Aluminium die casting, (c) Aluminium, Zinc and Brass die castings [23]

Table 2.4 Advantages and disadvantages of Die casting [24]

Advantages	Disadvantages
Most metals can be cast	It is generally limited to metals with low melting points
It is economical to large production quantities	
It has good dimensional accuracy and surface finish	
Thin sections are possible	
Rapid cooling provides small grain size and good strength to casting	Part geometry must allow removal from die cavity.

## 2.2 The Shell Mould Casting

In this section, we give a more detailed overview of the process as practiced worldwide with a view to finding what adaptations are needed in the Ghanaian context.

Shell moulding was invented in 1944 as the Croning process after Johannes C.A. Croning in Germany and was used in German foundries in 1953. The process used silica sand and phenolic resin binder (phenol formaldehyde, PF, a finely ground powder 2.5-4.5% of sand volume).

The chemical reaction for this process involves reacting phenol with an excess of formaldehyde and an aqueous weak acid (usually ammonium chloride or

hexamine from 11- 14% of resin volume). This reaction yields a strong three dimensional polymer network which is then either solvent coated or heat coated with hexamine reaction to completion upon the addition of heat. The acid provides the hydrogen ions which catalyze the reaction. The resin is allowed to polymerize until the reaction is stopped, still in the liquid state. The cure time of the resin binding the sand is a function of the temperature of the core box and the catalyst type. The reaction is an exothermic reaction; therefore, the resin continues to cure even after it is removed from the core box. The cure speed is a function of time and temperature. Hot box binders have a high hot strength and fewer shakeout problems than other binders [19]. The thickness of the shell, typically around 10 mm, is determined by the contact time between the sand and pattern [21], [25].

Phenol formaldehyde having formaldehyde/phenol ratio lower than 1 is called phenolic "novolac" (i.e. phenol formaldehyde novolac) resin. Hexamethylene tetramine (also called urotropin or 1,3,5,7 tetraazaademantane) Figure. 2.5 (a) is used as a hardener. It decomposes at 160 °C into two basic components: formaldehyde and ammonia as shown in Figure 2.5 (b) below.

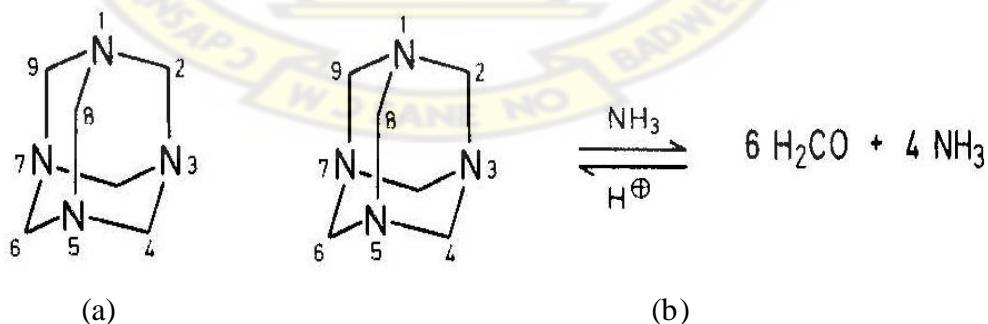


Figure 2.5 (a) Hexamethylene tetramine (b) Decomposition of hexamethylene tetramine into formaldehyde and ammonia

When pre-coated sand comes into contact with a heated pattern, the hexamethylene tetramine forms the characteristic strong bond with phenol formaldehyde. Figure. 2.6 shows a structure of phenol formaldehyde.

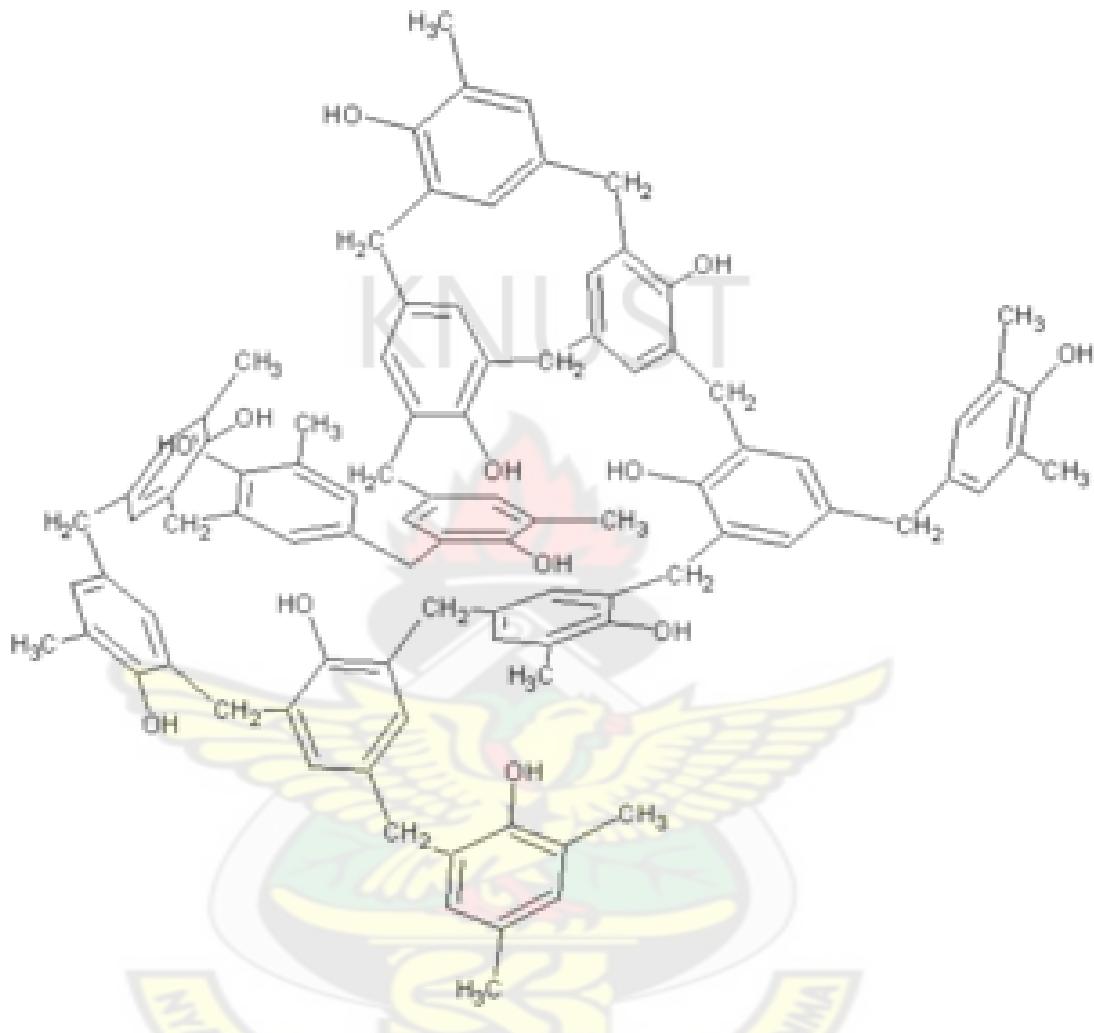


Figure 2.6 Example of a possible structure of Phenol Formaldehyde resin (Source: Google Books)

Patterns, pattern plates and core boxes for the process are mostly made of cast iron and less frequently, of steel or aluminium alloys. Shell half pattern plates are preheated to 200-250 °C. The working surface of the plate is sprayed with a parting composition to prevent the pre-coated sand sticking to the pattern. Silicone oil or other liquid composition is used for the purpose. A hot pattern plate is put and fastened on the mouth of a tilting bunker and the latter is tilted through 180°. In this way sand resin mixture (pre-coated sand) is poured onto the pattern plate. The heat of

the pattern plate heats up a layer 6-10 mm deep of the sand – resin mixture in 15-25 seconds to the fusion point. Thus, grain sands are held together by fused resin. The bunker is then returned into the original position and the pattern plate with the semi-hard shell on it is placed into an oven at a temperature of 300-350 °C, where the shell hardens irreversibly in 50-60 seconds. The hardened half shell mould is taken off from the pattern plate by means of pushing pins. The second half mould is made in the same manner. For quicker shaping of the shell, and the increasing of its density and strength in hardened state, sand mixture above the pattern and pattern plate is rammed slightly [21, p. 240].

Essentially the same process is used for making shell cores. A core box is preheated and coated inside with a parting composition, after which sand–resin mixture is poured into it. In 15-20 seconds, a time sufficient for fusion of a sand layer at the core surface, the remaining loose mixture is removed from the box. The core shell hardens finally in the box. The latter is then opened and the core is taken out [21].

When filled with molten metal, shell moulds are heated by the heat of the molten metal. Above 400 °C, the binder breaks down and the shells gradually lose strength, so that the rest of moulding mixture can be easily knocked out from the castings. Shell moulds, thus, have easy knocked down properties.

The shell process has several unique properties which make it an important process to the foundry. These properties were in focus during the casting process and they included: Dry free flowing mix; Excellent blow ability; Use of very fine sand; Excellent casting finishes; Accurate dimensions of castings; High thermal stability; Possible use of hollow cores; Low sand-to-metal ratio; High humidity resistance of cores; Indefinite shelf life of coated sand.

**i. Advantages of the Shell Process:** The following are more detailed evaluation of the advantages of the shell casting process in the production of machine parts as outlined in [26 a, b]:

**Excellent Surface Finish:** Excellent surface finishes as well as fine details are attainable by using this process. ;

**Dimensional Accuracy:** Tight dimensional tolerance is achieved. Here machining allowance can be reduced which ultimately helps in reducing fettling and finishing cost;

**Hollow Cores:** Hollow cores and thin profile moulds can be made possible. This characteristic gives economic usage of sand and ease of handling. Hollow cores increases the permeability hence usage of fine sand is also possible;

**Sand to Metal Ratio:** This is the only process which gives hollow cores and thin walled mould which results in substantial weight reduction and material saving. Normally sand to metal ratio is 1:1 which is much lower than other processes;

**Ease of Handling:** Sand moulds and cores are exceptionally resistant to damage through handling and storage. This happens due to high resistance to humidly. The shell cores and moulds can be stored for months without difficulty;

**Resistant to Moisture Pickup:** The shell process is resistant to moisture pick up. The cores and moulds can be stored for long period even in high humid conditions. The resin used for the process is stable and moisture resistant;

**Simple Process:** The already pre-coated sold sand is supplied in the form of ready to use and thus need not require sand mixers;

**No Skill is Required:** Since with the already prepared pre-coated sold sand, everything is ready to use and with minimum training any worker can produce, repeatedly, precision moulds and cores;

**Excellent Flow-Ability:** Due to the dry coating on sand, it gives better flowing ability and blowing ability than processes based on wet sand mixes. This property of shell sand helps for the production of intricate cores and moulds, and cores to be blown to a greater density. Better flow ability of sand also helps for blowing coarser and high permeable sand which may not be possible with other processes e.g. cores for water jacket;

**High Out of Box Strength:** sand after curing has very high out of box strength. This property of shell sand helps to produce ultrafine and intricate cores, which are required to suit the demands of modern advanced engine design and enable foundries to operate just in time production methods;

**Less Inclusions and High Thermal Stability:** Shell sands are less prone to erosion by molten metal, because of high thermal stability of the phenolic resins. This characteristic of shell sand helps to reduce nonmetallic, burn in and scabs etc;

**No Need of Refractory Wash:** Cores or molds are cured in contact with pattern resulting in better surface finish of molds or cores. This helps in making castings with accurate dimensions. But sometimes cores or molds may require refractory wash for specific purpose;

**Little or No Pattern Wear:** Since patterns are made up of cast iron, very little or no wear is observed resulting in longer pattern life. This helps to produce a large number of casting without any dimensional problems;

**Longer Shelf Life:** Shell sand has indefinite shelf life, if properly stored. Thus shell sand can be stored and used as needed by the foundry;

**Low Capital Investments:** Molds and cores making equipments is of moderate cost and where necessary can be added as cells. In shell process, base sand can be easily changed to suit specific requirement of the casting;

Economics: Hollow cores, contoured shells, backup systems, low fettling and cleaning, with good dimensional accuracy, makes process economically viable;

High Cost of the Process: Phenolic resins used for the shell process are costly and at the same time percentage usage of resins are high compared to other processes. Hence process requires a tight control of the shell thickness otherwise competitiveness of the process will be sacrificed;

High Tooling Cost: Shell process is thermo set and requires high temperature to cure, hence patterns used are of cast iron with smooth surface and have very low expansion coefficient. All these results in higher cost compared to other processes.

High Energy Cost: Shell process operates at around 250 °C. Tooling temperature requires energy either by the way of electricity or Liquefied Petroleum Gas (L.P. G).

The cost of energy is very high, when compared with other processes;

Cycle Time: Comparatively cycle time required for shell process is more than either cold box or CO<sub>2</sub> processes;

Limited Casting Weight: Shell process is best for small intricate light weight casting. With shell process casting weight up to 80kg is produced. In [26 a,b] weights up to 300 kg are recorded.

The above enumerated advantages of shell casting notwithstanding, it have its limitations.

**ii. Limitations of the Shell Process.** The following are some enumerations of the limitations: The weight of castings is limited to 100 kg; Pattern costs and pattern wear tend to be higher than for conventional sand moulding; The process requires heat to cure the mould and this makes energy costs higher; Sand inputs need to be of higher quality than traditional sand casting; Emissions from the process are noxious, so effective extraction systems are required [27, p. 14], Component Castings p. 6, [26

a, b]; The size of the shell mould is limited (half-moulds) for the reasons of rigidity and warpage; The cast metal may pick up carbon in surface, which makes the shell mould process poorly suitable for casting low-carbon, in particular, corrosion-resisting steels. This limitation can be eliminated by using moulding mixtures with inorganic binders [28]; Profitable series size for masses between 0.1–1.0 kg must be at least 50 000 – 100 000 components; Very small taper (not more than 1°) on the pattern wall is sufficient [20]; Relative inflexibility in gating and risering system has to be provided in the shell itself [20].

**Applications of shell mould casting:** The following are some areas where shell mould casting's application is felt:

Product Description is ideal for mass production of small castings where the degree of intricate parts causes high rejection rates in green sand moulding; It is suitable for ferrous and non-ferrous alloy castings in the range of 0.1 to 10 kg. Typical metals cast include cast irons (grey and especially malleable), alloy steels, carbon steels and stainless steels, aluminium and copper alloys (including brasses and phosphor bronze), etc [20]; Mostly automobile components like wheel, rocker arms, valves and valve bodies are manufactured with good accuracy by this method [16]; Other automobile components include suspension, steering, engine parts, brake drums, brake discs, gear blanks, shelf brackets and crank shafts; It Can be used to cast small pipes, camshafts, bushings, spacers, brackets, manifolds, bearing caps, shafts and gears; [29] other source- Vital Castings.

**iii. Preparation of shell moulds:** The moulding starts by first warm coating the sand with metallic resin. A metallic pattern is heated to about 150 – 250 °C (Operating temperatures of the box are in the range of 232.2-287.8°C) and the coated sand is applied to the surface of the pattern. This forms a thin hard layer on the

surface of the pattern. It is allowed to cure and it is then stripped off from the pattern. Two halves are used: a cope and a drag. The two halves each of thickness between 6-10 mm are assembled.

Research is still under way to allow for easy flowability (by lubricating agents like calcium stearate, zinc stearate and carnauba wax), ‘disintegrability’, collapsibility, blowability and suitability of the sand in the casting process. The versatility of the process enables it to be used for all types of metals both ferrous and nonferrous. This will further enhance the viability of the process. Figures 2.7 (a), (b) and (c) in the diagrams below show shell pattern, pre-coated sand as well as cured shell on a heated pattern. Other shell processes can be found in Figures 2.8 to 2.9.

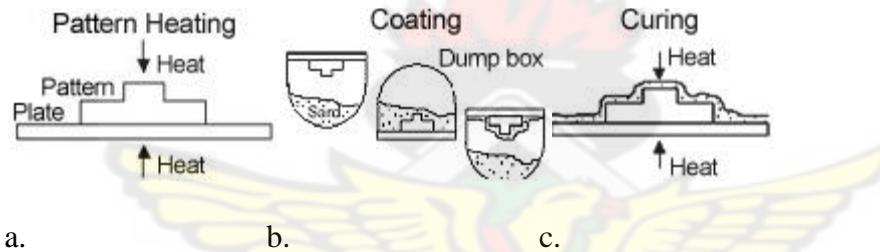


Figure 2.7 The shell mould process (a) simple pattern (b)dump box containing precoated sand in series of operation in coating the pattern and (c) shell mould on pattern being cured in an oven,[27].

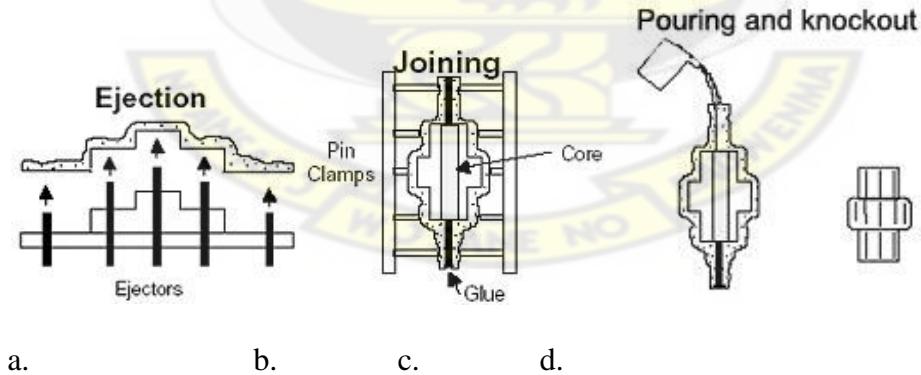


Figure 2.8 (a) The use of ejectors in the shell mould (b) shell mould and core assembly (c) pouring of molten metal and (d) actual cast part from knockout [27].

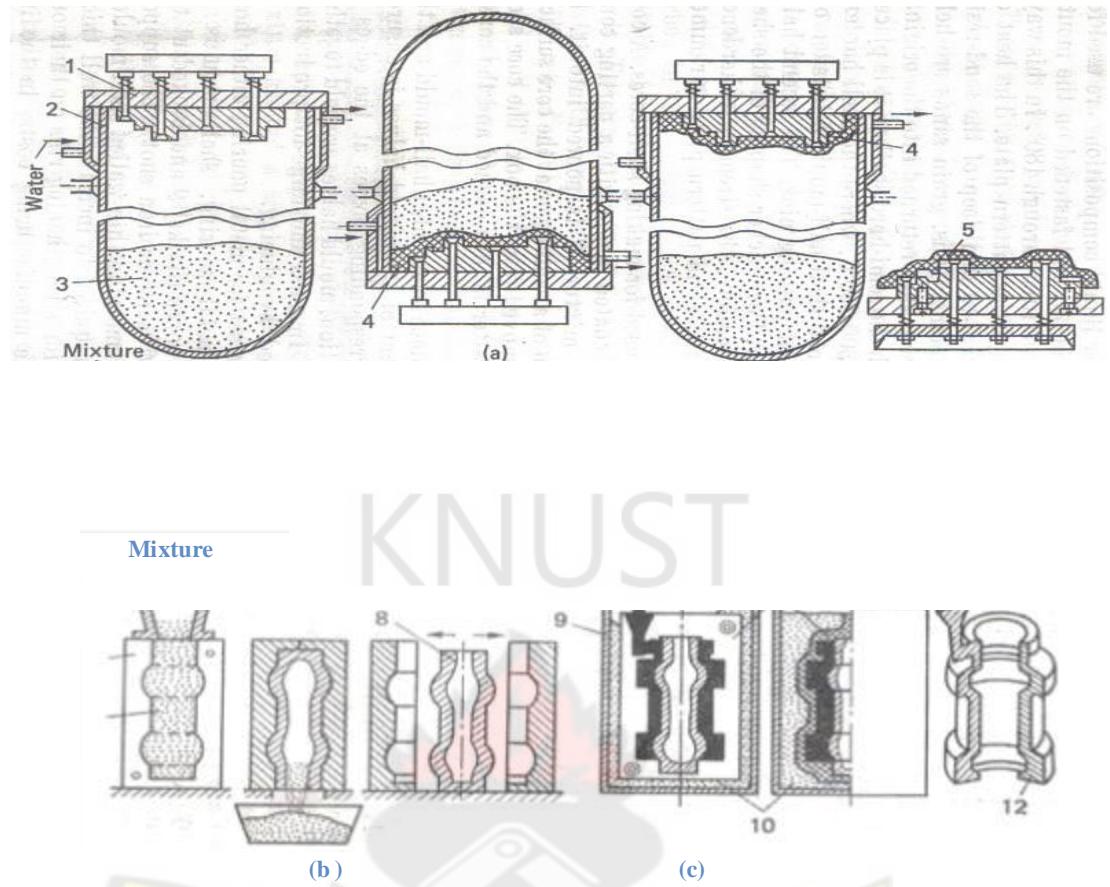


Figure 2.9 Another shell process: (a) above, shell mould making, and below: (b) shell core making and (c) assemble of the shell mould together with the shell core ready for casting (adapted from [21, p. 239])

The following shows the description of the numbers in Figure 2.9: 1. Pattern plate; 2. Tilting bunker (dump box); 3. Sand resin mixture (or precoated sand); 4. shell mould as result of fused sand - resin mix; 5. Hardened shell mould half; 6. Core box; 7. Sand - resin mixture; 8. Shell core formed from fused sand - resin mix; 9. Metal boxes (flasks); 10. Support material (course sand, gravels or iron shot); 11. Shell moulds; 12. Cross section of shell mould wall.

If a core is to be included it is properly inserted before the two are assembled through clamping or gluing of the parts (Figures 2.8 b and c and 2.9 c) and the backs are adequately reinforced with sand or metal pellets in a mould box. Core making process that makes use of pre-coated sand usually makes use of five processes: blow, invert, drain, cure, and strip as in Figure 2.9 b. The texture of the core sand should not have to be the same as that of the mould.

**iv. Raw Materials Required for Shell Sand.** This paragraph is an excerpt taken from [26 a, b]: Silica sand has loose bulk density of 1.4 gm/cc minimum. Suitable sand includes those from coastal belts and those from mines. Normally coastal sands are round to sub angular with good sieve distribution whereas mine sands are angular with erratic sieve distribution. For foundry terminology, sand grain shape is referred to as round, sub angular and angular. Round grain sands required less binder for high cold strength, but less hot strength with high permeability. Whereas angular sand results in lower cold strength and higher hot strength with low permeability, sub angular sand grains exhibit the best compromise between low resin binder content medium, cold strength and high hot strength. Shell moulds and cores made with sub angular sands show least tendency to washing and metal penetration. Silica sand grains size has direct effect on the refractory properties of sand mass. The finer the grains are, the lesser the refractory mass. But in the case of shell sand, carbonaceous residue of burned out synthetic resin binder improves the refractory property of the mass. So that much finer silica sand can be used without any problem. Sand grain size also determines the usage of binder to maintain the required cold and hot strength properties. Surface areas of the individual grains increase with decrease in fineness.

Shell sand is manufactured by three processes : Warm air process, Hot coating process and Ignition Process. The ideal silica sand for shell process includes the following:

1. Grain Shape: Round to sub angular;
2. Clay Content: 0.2% maximum;
3. Chlorides: 0%;
4. Carbonates: 0%;
5. Acid demand Value <6 ml of KOH/100 gm of sand;
6. Silica Content 98% minimum;
7. Loss on ignition 0.2% maximum;
8. AFS No 50-80;
9. Sieve distribution-Minimum 80% retention on the consecutive sieve.

With increase in already commercially coated sand more foundries are beginning to purchase such pre-coated sand for the following reasons [26 a, b]:

Capital expense is reduced; Emissions are reduced; More floor space is made available; Productivity is increased; Customized formulations are available; Latest technology is available; Application oriented special sand is available; Faster curing resins are available; Faster built-up time is assured; Faster shakeout shell sand is common; It gives Indefinite shelf life and it is applicable to a wide range of metals.

Dhumal [26 a, b] indicated that such advantages have significant effect in terms of reducing casting cost and improving productivity in the following ways as follows: Improved de-coring for aluminum casting; Accelerated cure speed; Elimination of peal back and Smooth Operational flexibility. The heat transfer must be uniform in order to ensure proper binding of the sand.

### **2.2.1 Properties of shell Moulding Sands and their Places of Occurrence in Ghana**

In this section, we make readily available the information about properties of sand used in shell moulding process and places in Ghana where deposits of these sands could be obtained. The various sand in context includes the following:

**i. Silica sand:** Silica sand is composed of the mineral "quartz" ( $\text{SiO}_2$ ). Its dry specific weight fluctuates between 2.5 to 2.8. The dry bulk density (or loose volume weight) of silica sand is 1.4 to 1.6 g/cm<sup>3</sup>. The thermal expansion of silica sand generates a mould movement upon pouring and cooling and these occurrences therefore could cause casting errors. Silica sand is neutral and is compatible with all binders and normal cast alloys [2].

**Occurrences :** These occur in Ghana at the following places: Nzima area deposits; Bodwenseango deposits and Takwa mine tailings silica sand deposits.

Other areas include: Southern Volta Region deposits; Petepong, Asomasi Kuranti and Huni Valley silica sand deposits [30];

**ii. Chromite sand:** Chromite is a chromium ore, with the theoretical formula  $\text{FeO} \cdot \text{Cr}_2\text{O}_3$ , which contains other components such as magnesium and aluminium oxides. For its use in foundries, its silica content must be lower than 2 % in order to prevent sintering at low temperatures [2]. Its characteristics are as follows: Density: 4.3 to 4.6,  $\text{g/cm}^3$ ; Theoretical melting point: 2180 °C, but the presence of impurities can lower this to 1800 °C; Thermal diffusivity: more than 25 % higher than that of silica sand; Thermal expansion: regular, without a transition point, and lower than that of silica sand; pH: rather basic, from 7 to 10. Chromite sand is more refractory than silica. It is more thermally stable and has a greater chilling power. Chromite sand provides a better surface finish on large castings. It is therefore used for the production of large castings and in areas of the mould where chilling is required [2].

**Occurrences:** Chromite was discovered at Agbenu Hills in Volta Region, about 15 miles south-west of Ho. Another limited occurrence was also found at Tete man in Greater Accra Region [31].

Report on this shows that once chromite has been identified in these areas, chromite sand which finds its use in iron and steel foundries as base sand in moulds before being backed up with ordinary silica sand could be used to avoid molten metal penetration. Currently, at Tema Steel Works where special castings are gaining recognition alongside continuous casting, chromite sand for special castings is imported from South Africa and the United Kingdom. Chromite sand that can be obtained from this area could help save manufacturing cost and foreign exchange.

**iii. Zircon sand:** Zircon is obtained from zirconium silicate,  $\text{ZrSiO}_4$ . Zircon is the most widespread of zirconium ore. Its characteristics are as follows: Density is

between 4.4 to 4.7 g/cm<sup>3</sup>; Melting point is higher than 2000 °C; Thermal diffusivity is more than 30 % higher than that of silica sand; Thermal expansion is regular, without a transition point, and lower than that of silica sand. The general characteristics of zircon sand are similar to that of chromite, but zircon sand produces a better finish as a finer grade is used. These physical and thermal properties account for its use for moulding or core-making in difficult cases, in spite of its very high price [2].

**Occurrences:** Sand deposits along the courses of Oda and Ofin rivers are said to contain zircon [31].

At Tema Steel Works, zircon sand is imported from the United Kingdom. The availability of this sand in Ghana will go a long way in saving production cost.

**iv. Olivine sand:** Olivine sands are a mineral group which includes forsterite, fayalite and others. The characteristics of olivine sands are as follows: Melting point: Forsterite-1890 °C and Fayalite -1205 °C; Density: 3.2 -3.6 g/cm<sup>3</sup>; pH: around 9. The basic pH makes this type of sand not suitable for use with acid catalyzed binder systems.

Olivine sand is produced by crushing natural rocks, which explains its diverse characteristics. It is usually used for moulding and core-making in manganese steel casting. The presence of manganese prohibits the presence of silica as these two components react to give a very fusible compound [2]. The reported purchase price in Spain is EUR 130/tonne (2002) [2].

**Occurrences:** It is found to be associated with many basic igneous parent materials. These materials can weather easily and form clay from gneiss rocks in Ghana [32].

### **2.2.2 Shell Pattern and Core making Techniques**

Shell cores are used in foundries for creating holes in sand castings, shell mould castings, die and some other casting processes. This is because they have good strength, smooth surface, good dimensional accuracy, good collapsibility, low cost. Figures 2.7b and 2.8 above show some shell core making. Most of the binders in the cores is burnt off in the pouring process, so only minor amounts remain in the sand. Broken cores and sand that have set up prematurely or inadequately may have higher levels of resin [33].

Literature shows that, normally, investment or ceramic shell process is used in shell mould patterns as well as shell core pattern making, and if possible, followed by precision machining. These casting processes are preferably used because after adopting them, there is little or no need for any further machining. These processes, inevitably, are not employed for casting metals like aluminium, cast iron, steel in Ghana.

The magnitude of expected shrinkage is expressed as a percentage of linear dimensions and indicated in the drawings of cast parts. Also, included is the rate of contraction of some cast metals (Appendix Tables A1.7 and A1.8 respectively).

### **2.2.3 Getting pattern ready for the Process**

**i. Preparatory activities:** Pattern temperatures should be checked by means of surface pyrometers or other devices, e.g. thermocouple. About 232.2 °C (450 °F) is best for most application with variations of not more than 30 °F from the coldest to the hottest source of heat. Gas or oil ovens, gas or electric radiant heaters or improved radiant heaters with parabolic reflectors, calrod type heaters attached to the base of the pattern, oven with a temperature range of 316-788 °C (600-1450 °F) should be used in order to obtain good heat transfer for fast production [25].

**ii. Heating pattern:** Preheat pattern to a temperature of 200-250 °C; spray pattern with a parting agent (dilute silicone emulsion [25] p. 246, silicone oil) to cause free release of shell from pattern (other methods are brushing or dipping); reheat to operation temperature 250°F, finally, spray with a light coat [25].

### **2.3 Flowability - A Property of Sand for Moulding**

Flowability is the property which enables a sand to flow readily into a mould and fill up the interstices when subjected to ramming. It is influenced by things like moisture, permeability, grain shape fineness and clay content, [20]. Additives like dextrines improve the flowability and moisture so as to prevent moulds from drying out and edges becoming friable. A mixture of sand, dicalcium silicate, water and wetting agents is an example of a good flowable sand. This combination, based on a process of Russian origin achieves a higher degree of flowability than either the conventional sand mix or those with organic additives. The flowability of the flux can be improved by using granular and low bulk density powders. Cereal binders also have effect on flowability. Details will be given under starch binders in the next chapter.

Because shell moulds are thin, permeability for gas escape is excellent allowing use of finer sands. Finer sand and excellent flowability produce dense mold surfaces and contribute to the high quality surface finish of shell mold castings. High flowability and high compactability increase the amount of sand that makes it into deep pockets during squeeze [34].

### **2.4 Binders**

A binder is a material, other than water, added to foundry sand to bind the particles together, sometimes with the use of heat. A resin, any of a class of solid or semi-solid viscous substances obtained either as exudations from certain plants or prepared by

polymerization of simple molecules, can be used interchangeably most of the time as binders. Below are some binders:

#### 2.4.1 Local Binders

**i. Clay:** This is the major binder that is used for casting in Ghana. Its uses range from the casting of small to medium casting as well as home cooking utensils and some engineering parts including corn milling plates. It is readily abundant.

**ii. Gum Arabic:** Gum Arabic is a plant gum exuded from bark of some species of trees called acacia species. Gum Arabic, as binder, mainly in the form acacia Seyal, combretum and acacia Senegal is good for sand casting. The first two are available in Ghana [35] with the possibility of the last one existing. Though these materials are new as foundry binders in Ghana, their potential is being exploited in neighboring Nigeria.

Nigeria produces four different grades of gum Arabic in commercial quantities that include grade 1 (acacia Senegal), grade 2 (acacia Seyal), grade 3 (combretum) and grade 4 (neutral). In finding the suitability of Nigerian acacias species (gum Arabic) for binding casting sands, Ademoh and Abdullahi [36] showed that it possessed the required physio-chemical properties for foundry application. They researched with grade 1 Nigerian gum Arabic. They showed that the material, in powdered form, with 2 - 3% moisture was suitable for nonferrous, malleable, grey iron but unsuitable for steel casting. Grade 2 acacia was also found to be suitable for non-ferrous alloys at a composition of 4.5 - 13% exudates and 3% water. The grade 3 acacia was found suitable for non-ferrous and grey iron sand mould at 6 - 9% content [36].

Nigeria, the second largest producer of Gum Arabic in the world has no registered commercial uses for it. The research investigated the viability of casting

steel in sand moulds bonded with grade 4 Nigerian gum Arabic. Sand specimens bonded with the material were subjected to standard foundry property analysis that included green and dry compressive strength, hardness and permeability, shatter index and moisture content tests. The result when compared with standard green and dry compressive strengths of most metals showed that 4.5 - 8.0% binder content in powdered form was found suitable for casting non-ferrous alloys, malleable and grey iron while 8 - 13% was found suitable for light steel. In solution form it was also found suitable for non-ferrous alloy.

Conclusions on their research revealed that exudates of grade 4 Nigerian acacia species were suitable for both green and dry moulding sand. The mechanical properties of moulded sand specimen showed that the material added in the form of a solution gave weaker bonds than when it was applied in the dried powdered form. Sand Mould bonded with 4.5-8% of the powdered material was suitable for green and dry casting of non-ferrous alloys, malleable and heavy grey iron. However for steel casting bond strength, hardness and shatter index were adequate but green permeability was below standard.

Literature shows that the grades 1, 2, 3 in the above are three main gum arabic and are botanically called acacia Senegal, acacia seyal and combretum grandiflorum respectively [37]. Little is said about the neutral type. Below are these types with the last two (2 and 3) being surely found in Ghana. Literature points out the possibility of the first being found in Ghana as they are found in the Northern part of Nigeria [35] and of Upper Côte d'Ivoire [38].

**a. Acacia Senegal** (Gum acacia of commerce): The gum is a leguminoseae. It yields on poor to top dry soil on unhealthy conditions on hot sandy soil. Attempts to improve on its conditions tend to produce lower yields. Natural exuded gum has been

found in Northern Nigeria [36] and Upper Côte d'Ivoire [38]. Though it is not being identified in Ghana it is believed that it can thrive in northern part of Ghana, [35 p. 328].



Figure 2.10 (a) Acacia Senegal with gum exudate from its bark, (b) flowers and (c) young stem and flower Photos from [39]

**b. Acacia Seyal (Red acacia):** It is also a leguminoseae. It is also known as Shittim wood or Shittim tree) and it is a thorny, 6-10 m (20-30 ft) high tree with a

greenish or reddish bark. At the base of the 3-10 cm (1-4 in) feathery leaves there are two straight, light grey thorns. The blossoms form round, bright yellow clusters approximately in 1.5 cm (0.5 in) diameter, growing to 7-20 cm (3-8 in) long. It is distributed from Egypt to Kenya and west Senegal. In the Sahara, it often grows in damp valleys [40].

In Ghana it can be found in Afram Plains, Tamale, Nangodi and Han, This gum is inferior to gum senegal and is collected from the natural exudations, [35 p. 323], Figure 2.11 shows a picture of acasia seyal.

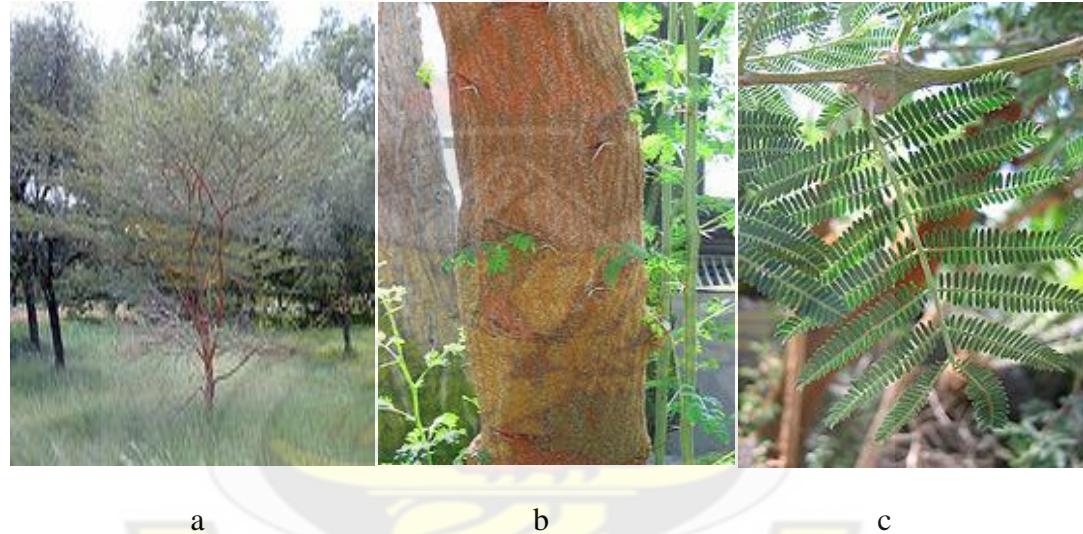


Figure 2.11 (a) Acacia Seyal tree, (b) acacia Seyal bark and (c) red acacia Seyal leaves

c. **Combretum** (*Combretum grandiflorum*): It is a showy tropical vine that will reach 20 feet in the greenhouse setting. The plant needs full sun to partial shade with intermediate to warm temperatures. Since the vines grow to 20 feet, they need a lot of room to grow [41]. *Combretum grandiflorum* is easily propagated from cuttings or by layering in early spring. It is found in Ghana - Don Atlas map of Ghana [42, p. 179]. Figure 2.12 shows picture of combretum.



Figure 2.12 (a) and (b) showing *combretum grandiflorum* [41]

**iii. Starch binders:** Most cassava starch binders are used in core moulding.

Those ones that can be used for actual mouldings for steel castings are cereal binders. Typical binders in this category are the corn binders (containing actual starch and dextrin). Corn is mostly preferred because of its availability and its abundance. See Table 2.5, Appendix Table A2.8 as well as its properties (esp. physical properties) see Figure 2.13.

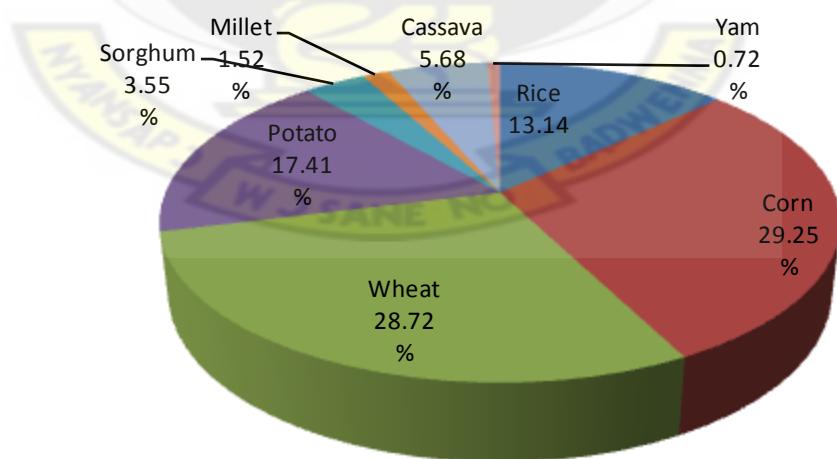


Figure 2.13 Amount of starch in some Typical Starchy foods

Table 2.5 Starch source distribution in global market (excluding China)

Starch type	Percentage in Global Market
Maize (Corn)	80
Potato	8
Cassava	6
Wheat	4
Rice and others	0.5

**Source:** Institute for Scientific Information (ISI) 1998

Below are some of the starch binders:

**iv. Cereal starch binders:** Cereal binders of starches usually produced from corn are of two kinds:

1. The gelatinous type or corn flours which swell with water but do not dissolve;
2. The foundry dextrins which are produced by chemical treatment of corn starch are soluble in water.

Cereal binders are used mainly in steel foundries to increase the strength and toughness of the green sand. There are two main types of cereal binder: starch and dextrin. Starch is the basic material and is produced from a number of plant materials, with maize starch being the most commonly used for foundry purposes. Dextrin is a re-polymerised form of starch, produced through a subsequent acid and thermal treatment of starch.

Starches can help to reduce expansion defects, since as they burn out, they allow the sand grains to deform without deforming the mould. Cereals increase the green strength, dry strength and toughness but can reduce the flowability. Dextrins improve the flowability and moisture retention, preventing moulds from drying out

and edges becoming friable. Cereal additions do not improve the erosion resistance of the sand or its resistance to metal penetration [43]. Further advantages of cereals are that they are especially useful with sharp sand and dry quickly in oven.

In contact with the hot metal, they burn out rapidly and completely give good collapsibility and easy removal. In general, the cereals and especially the dextrines give a high return in binding power for the money spent (Kaiser Aluminium).

To increase Cereal binders flowability, fluxes are produced by converting the raw mixed powders into aqueous slurry followed by addition of requisite water soluble binders and drying the so formed fine droplets in a stream of hot air. The product is in the form of solid or hollow spheres of close granule sieve distribution. The fluxes of this variety are known for better covering power due to reduced density, excellent spreadability and flowability due to the spherical shape, low moisture pick up due to the reduced surface area of the granules and less dust generation. Selection of mould fluxes is made for production of high quality steel ingots [34].

**v. Tapioca starch:** Tapioca starches are basically carbohydrates, known as polysaccharides, i.e., multiple molecules of sugar. For commercial use, they are derived from a variety of cereals like rice, wheat, sorghum, corn and tubers like potato, sweet potato, etc. Internationally popular forms of starch are mostly derived from corn and tapioca due to their easy availability.

Due to a peculiar phenomenon called gelatinization – an irreversible swelling of starch granules when treated with hot water, starch turns into a thick paste. When cooled and with certain additives, it forms a gel. This gives it high viscosity which forms the basis of its many uses (Table 2.6). It is clear that the information available

on the physical properties of cassava, sorghum, millet and yams cannot compare with the four major starches (Table 2.7).

### **Specifications:**

Table 2.6 Some specifications of starch-Tapioca / Cassava Starch

Properties	Specifications
Starch	90% min.
Moisture	13.12% max.
Viscosity	780 BU
pH	6 .99
Whiteness	80.8% min.
SO <sub>2</sub>	0 mg/kg

Tapioca / Cassava Starch [44]

Table 2.7 Some physical properties of starch in cereals, roots and tubers

Starch Species	Granule Size Range (µm) (Coulter Counter)	Aver age size µm	% Amylose	% starch
Waxy Rice	2 – 13	5.5	0	-
Rice	n.a	n.a	n.a	13.14
High Amylose Corn	4 – 22	9.8	70	-
Corn	5 – 25	14.3	28	29.25
Wheat	3 – 34	6.5, 19.5	26	28.72
Potato	10 - 70	36	20	17.41
Sorghum	3 – 27	16	O	3.55
Millet	n.a	n.a	n.a	1.52
Cassava	3 – 28	14	17	5.68
Yam	n.a	n.a	n.a	0.72
Sweet Potato	4 – 40	18.5	18	-
Arrowroot	9 – 40	23	21	-
Canna (Aust. Arrowroot)	22 - 85	53	n.a	-
Sago	15 - 50	33	26	-
Total %	-	-	-	100

Adapted from the Functional properties of starch [45]

In a paper by Xia Zhou et al [46] on ‘Study on synthesis and properties of modified starch binder for foundry’ [46], modified starch binder was synthesized

using a new dry method with the aid of the compound catalysis of methanol and sodium hydroxide. The effects of various factors on the properties of the binder and its bonded core sand were discussed. The results have shown that granular carboxymethyl starch (CMS) with suitable degree of substitution (DS = 0.3–0.5) can be obtained by making corn starch to be carboxy methylated using this method. The modified starch binder has suitable viscosity and higher specific bonding strength as compared with native starch; besides, the binder bonded core sand has excellent comprehensive property and can partially replace synthetic resin binder bonded sand [46].

**vi. Protein/Peptide Binder.** Although this binder is put under local existing binders, it is not employed in any foundry work in Ghana. Rather, the country abounds in a lot of raw materials for the production of these proteins. Literature shows that protein can be made soluble in water, which causes it to disperse readily in mixing and that it gives good flowability to the sand, dries rapidly in baking, and has reasonably good resistance to humidity or moisture absorption in storage.

Kramarova D. et al [47], showed that protein/peptide binder system showed higher flexural and tensile strengths, good flowability of the sand, good surface property, easy shaking out under temperature of 650 °C for aluminium casting and removal of moisture absorption. Their study was to research and develop a new foundry moulding mixture with new binder system based on proteins/peptides [47]. The results showed good flowability of the binder, good solubility with water, plasticity which varies with water up to a point, a reasonable good or satisfactory surface quality of cast. And above all, also showed that flawed cores could be reused and that any scrap core can be recycled without adding any additional binder.

#### **2.4.2 Binders associated with shell moulding**

The binders associated with shell moulding are mainly phenolic resins and phenolic related resins. Resins are polymers made by repeatedly linking discrete molecules (monomers) together to form chains or networks [48]. These resins tend to exhibit plastic behaviour when used within certain temperature range. Most Phenolic resin binders used with foundry work are acid catalysed ones called novolac types. Base catalysed ones (resole) when used normally have some percentage of the former type in combination with it.

**Phenolic resin (Phenol formaldehyde resins)** – This is a group of varied and versatile synthetic resins. They are made by reacting almost any phenol and an aldehyde. In some cases, hexamethylene tetramine is added to increase the aldehyde content. Both types of materials are used separately or in combination in the blending of commercial molding materials [43].

The shell oil of cashew nut (*anacardium occidentale*, which is one of the cash crops in Ghana) is found to be an important source of phenolic resin, which is used for commercial purposes [35],[38],[49],[50],[51],[52] including foundry work [38]. It is said that oil is contained in the shell of the nut, called Cashew Nut Shell Liquid, CNSL. Oller Riera et al [53] applied the use of cashew nut shell oil to modify phenol formaldehyde in shell mould casting. There has not been any foundry use of the crop, in Ghana, probably, because there have not been serious foundry activities.

##### **2.4.2.1 Identifying cashew in Ghana for a future production of phenol formaldehyde resin**

The earlier stated information about Abbiw and some others including Oller Reira et. al about cashew nuts being a source for phenolic resins led into investigating the extent of availability of cashew nuts in Ghana. Investigation of the above can be obtained in [54] with an excerpt as follows:

Cashew is grown as a cash crop in the coastal belt; Central, Greater Accra, and Volta Regions; the transitional belt north of Ashanti, Brong-Ahafo, and guinea savanna belt, parts of Northern, Upper West and East regions. The ideal rainfall regime is between 750mm – 1300mm. Cashew is a hard crop which grows well on marginal land.

The major production districts are Ashanti Region (e.g. Ejura Sekyeredumase, Sekyere West, Offinso, Sekyere East), Eastern Region (e.g. Afram Plains, Suhum Kraboa and Asuogyaman), Western Region (e.g. Ahanta West, Mphohor Wassa, Bibiani and Wassa Amenfi), Greater Accra Region (Ga West and Dangbe West), Central Region (Gomoa, Asikuma and Twifo Hemang districts), Brong Ahafo (Jaman, Wenchi, Kintampo, Nkoranza, Techiman and Atebubu districts), Northern Region (West Gonja, Bole, Yendi and Mamprusi districts), Volta Region (Nkwanta, Hohoe, Kpandu, Akatsi and Keta districts), Upper West (Nadowli, Jirapa-Lambussie and Sissala districts) and Upper East (Bawku, Builsa and Kassina-Nankena districts) [54]. See appendix Figure A2.

At the moment the cashew nuts are mostly roasted for exports. There are about six major processing factories in Ghana with about 11 in Accra. For the rest, one is found in Berekum and the other is located in Akim Tafo [54].

#### **2.4.3 Selecting the binder**

The binder selected was phenol formaldehyde (novolac resin). This was because it was the highly recommended shell mould binder for shell mould making. This binder could be obtained in liquid or powdered (ground) form. It was selected because apart from the other phenolic related binders it was the only one that was normally used.

## 2.5 Some Additives of Foundry Materials

**i. Seacoal:** Ground bituminous coal is used as an ingredient in molding sands to control the thermal expansion of the mold, and to control the composition of the mold cavity gas during pouring [43].

**ii, Alloy:** A mixture having metallic properties and composing of two or more chemical elements, at least one of which is an elemental metal. Alloying Element is an element added to a metal to effect changes in properties, and which remains within the metal. [43].

**iii. Flux:** A substance added to molten metal to help remove impurities and prevent excessive oxidation, or promote the fusing of the metals [43]

When additives such as MnO<sub>2</sub>, ammonium borofluoride, lignin and iron (iii) oxide are used, the shell acquires special characteristics like better surface finish, resistance to thermal cracking, distortion and substantial strength [55]

## 2.6 Environmental Impact, Health and Safety

The topics that fall under this literature is to draw attention to the fact that since the products of shell moulding give out harmful gases there is the need for one to be aware of certain basic facts associated with the environment about foundry practices globally and to ensure that for successful casting we should try to conform to, imitate or adopt the practices of some countries as mentioned below in Ghanaian foundries:

To start with there is the need to define the following:

**i. Pollutant Parameters:** Those constituents of wastewater determined to be detrimental to human health or the environment [43];

**2.6.1 Emission:** A major concern environmentally, is the emission of phenol. The possible emissions covered by the Clean Air Act Amendments of 1990 (CAA) (

when pouring metal into molds made by the shell process include Phenol, Formaldehyde, Aniline, Benzene, Toluene, m-Xylene ,o-Xylene, N,N dimethyl, formide, Naphthalene, Acrolein, Acetaldehyde and Hydrogen sulfide. It was reported that the amounts of chemicals released from shell process in molds during the pouring and cooling process. Given the amount of binder in kilograms, the emission of waste gases is given by

$$\text{Emission} = \text{Emission factor} \times \text{Weight of binder} \quad [19].$$

The same procedure is used to estimate emissions as shown in Appendix (Tables A 2.1-A2.5).

**2.6.2 Health hazards and safety:** In the numerous operations of foundry processes solid and gaseous waste materials are formed and these create a serious threat to both the foundry workers and foundry environment. The solid waste like the used molding and core sand, dust from dust collectors operating on melting installations, used lining from furnaces and ladles, and slag deposited on dumping grounds are all a potential threat to the underground water, soil and atmosphere. The contamination by heavy metals (Pb, Cd, Zn, Cr, and Fe) and by polycyclic aromatic hydrocarbons puts this waste into the class of hazardous materials [56]. The gases emitted from metallurgical process in foundries contain CO, SO<sub>2</sub>, NO<sub>2</sub>, volatile organic compounds (VOC), and sometimes also compounds of chlorine and fluorine, while gases emitted by the sand contain CO, NH<sub>3</sub>, HCN, SO, H<sub>2</sub>S, PH., phenol, benzene, toluene and acroleine. The gases emitted by a foundry shop may also contain dioxins or polycyclic aromatic hydrocarbons. The dust formed during foundry operations may contain oxides of heavy metals and/or silica. Practice confirms that there is a strict relationship between the hazard degree and frequency of its occurrence and the type of manufactured cast alloys (cast steel, cast iron and

non-ferrous metals alloys) as well as the type of equipment and technology applied in a foundry (mechanization, reclamation of the used sand, installations to protect natural environment) [56].

According to the research activities conducted in 20 Polish foundries (most produce cast iron) it was found that the total annual dust volume emitted to the atmosphere from iron foundries is from 0.1 to 94 kg relative to 1 tonne of castings produced, with the average rate of emissions amounting to 4.7 kg of dust per 1 tonne of castings [56]. Total annual gaseous pollutants like  $\text{SO}_2$ ,  $\text{NO}_2$ , volume emitted to the atmosphere from cupolas is from 0.1 to 108 kg relative to 1 tonne of castings, with the average rate of emissions amounting to 5.4 kg per 1 tonne of the ready castings. The gaseous pollutants from the hot sand can penetrate the ground and cause pollution of underground waters, and from that water cause trans-boundary pollution. Special attention deserves equipment and technology process and also deserves building new environmental protection equipment in foundries [56]. The respirable particulate matter (RPM) fraction of quartz is classified as carcinogenic. To ensure safety measures in Ghana if foundry processes are to gain strong industrial footing, the following measures can be adopted:

To ensure some safety measures, U.S. metal foundries have achieved a successful environmental story through education, information and guidance to minimize human health risks and to promote a safe workplace.

The American Foundrymen's Society (AFS) [57] has achieved measurable gains in its impressive record of the metal casting industry as confirmed by the U.S. EPA's 2008 Sector Performance Report, which reviewed the environmental performance of key U.S. industries. The report shows that just since 1996, there have

been measurable gains in minimizing its industry's impacts to the nation's air and water as well as reducing its waste. These include:

**Cleaner Air:** U.S. metal casters reduced their air emissions of all reportable chemicals and metals by 63% under EPA Toxics Release Inventory and then achieved a 82% Decline in Toxicity Score;

**Cleaner Water:** All metal casting companies, with process wastewater, operate under strict discharge limits, and have reported a drop by 52% in Regulated Wastewater Discharges of Chemicals for the industry;

**Less Waste:** 34% Less metal Waste being managed via effective treatment, disposal or recycling. Currently, the industry beneficially reuses 2.6 million tons of sand per year, or 28% of the total casting sand available for reuse. The industry is now pursuing a sand reuse goal of 50% by 2015;

**Sand:** Most of U.S. sand is safe and clean and can be beneficially reused in numerous ways, from being a key ingredient in soil mix for rain gardens, to filter storm water to essential fill material for roads and bridges [58],[59].

Other safety methods include measures adopted in the guidelines stipulated in "Success in GRP" [56] and are enumerated below for completeness of this chapter:

Require data sheet of health and safety information of resins purchased of any hazardous materials;

All employees are both to be adequately trained and efficiently supervised;

Chemicals should be subject to the normal codes of industrial practice.

- They should not be ingested, inhaled or allowed to contaminate the skin and eyes.
- In the event of skin contact, wash the contaminated areas with copious quantities of water.

- Seek medical aid at the earliest opportunity.
- In the event of ingestion, dilute corrosive materials with large volumes of fluid, or in the case of non-corrosive materials, induce vomiting. Seek medical aid immediately.
- In the event of eye contact, irrigate with copious quantities of water for at least 20 minutes and seek medical aid.
- combustible chemicals should be kept away from all heat sources.
- All spillages should be cleared up as soon as they occur.
- All labelling instructions should be read carefully and closely complied with.
- Due consideration should be given to the possibility that hazardous by-products could arise from the interaction of chemicals.
- Chemicals giving rise to vapours should only be handled in areas of adequate ventilation and fume extraction [60].

### **2.6.3 Control measures**

An individual worker has to ensure that for his personal safety he has adhered to almost all the following by wearing the items listed: goggles, gloves, protective clothes, nose masks and shoes must be used to Safety avoid accidents. It is recommended that a protective cream is used for skin protection when handling sand with oil or chemical additives and parting agents should be kept [61].

## **CHAPTER THREE**

### **EXPERIMENTAL PROCEDURE-Materials and Methods**

This chapter deals with the steps taken to achieve the main objective. It also covers how the shell mould was produced to cast the machine component. It includes various experiments performed. It also contains the design drawings for the various equipments developed to enhance the shell casting processes.

#### **3.1. Identification of available local sand**

A sand deposit from the Wewe River between (between the bridge at KNUST College of Engineering and the new Business School) was found to be suitable. This sand was found dug from the river and deposited near the bridge during the construction of the bridge. The sample taken from the site was analyzed and compared with an existing silica sand sample designated as sample SI, obtained from Tema Steel Works (T.S.W). Results are shown in Tables 4.1 to 4.7.

#### **3.2. Washing of the sand**

The sand obtained was divided into two. Large portion of it was washed sufficiently until all the clay and the silt particle were almost removed and dried for at least one week before collection. The washed part was sieved with BS test sieves of diameter between 0.212 mm and 0.500 mm. The remaining fraction was also sieved with BS sieve of 0.500 mm.

#### **3.3. Testing the conformity of the sand used with shell moulding sands-silica sand analysis**

This section examined the procedure and significance of the data taken and tools or materials used. Sand used for the mould was tested to compare its properties with that of Dhumal [26 a, b] (Chapter 4). Among some of the properties tested were:

Loss of organic content; Acid demand value; Chloride and carbonate contents; Silica content; Thermal conductivity and Total dissolved solids. All the tests were performed at KNUST Civil Engineering laboratory (Geotechnical Engineering and Water Laboratory) and the College of Science, Chemistry Department's laboratory. Results are indicated in Tables 4.1- 4.10 in chapter five. This experiment consists of the following determination:

**i. Particle size distribution:** Apparatus used were electronic weighing balance, BS sieves, mechanical sieves shaker and oven. Sample was first prepared for wet sieving. About 500 g of each sample was measured after passing through a reflex box .The weighed sample was sieved through a BS test sieve 2.36 mm. Soaked sample (less than 2.36) was washed over 0.075 sieves. Sand was dried in oven for at least 16 hours. BS test sieves were arranged in the order of sizes (0.075, 0.150, 0.212, 0.3, 0.425, 0.6, and 1.00 up to 2.00) mm as in Figure 3.1 (a)..

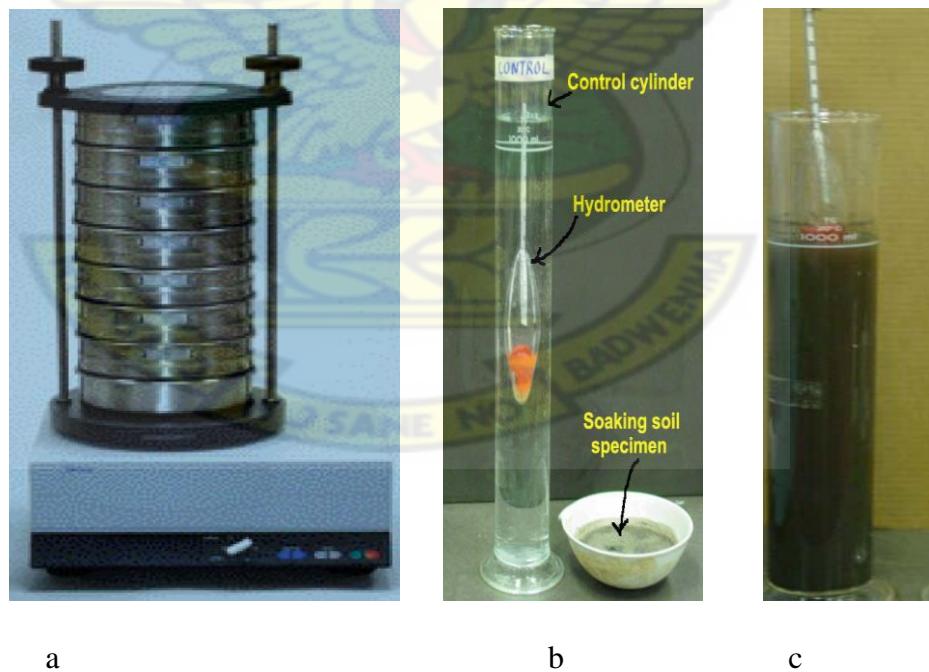


Figure 3.1 Set- up for particle determination showing (a) particle size determination, hydrometer set-up for (b) meniscus correction and (c) determination of soil particles below 75 microns

The samples were separated in various fractions by sieving through the above sieve in descending order with the help of the mechanical sieve shaker. From this, weight of soil retained on each sieve was recorded (Tables 4.2, 4.5 and 4.7).

**ii. Sample preparation for wet sieving-Hydrometer analysis:** Apparatus and materials used were hydrometer, two glass measuring cylinder 1000 ml and 100 ml, thermometer, stirring apparatus, BS test sieves of 0.075 mm (75 micron), stop watch, wash bottle containing distilled water, glass rod, and dispersion agent of sodium hexametaphosphate solution. 33 gm of sodium metaphosphate and 7 gm of sodium carbonate were dissolved in distilled water to make one litre of solution. Solution was added to weighed sand sample. Mixture was stirred properly and sieved with BS sieves for a fixed length of time through each sieve. Mass retained on each sieve was noted. Meniscus correction (hydrometer reading of pure distilled water and the difference in the upper and lower meniscus) as shown in Figure 3.1 (b) was found to be positive. The solution that passed through the sieve was transferred to a measuring cylinder with water. Hydrometer readings were taken after regular intervals as indicated in Figure 3.1 (c). Sedimentation time and hydrometer readings taken and these were used to determine the grain sizes according to the Stokes's Law.

**iii. Acid Demand Value:** About 100g of soil sample was weighed into 500 ml beaker and 100 ml distilled water was added. The mixture was stirred several times, with a magnetic stirrer, for two hours. It was then filtered. Five (5) ml of the filtrate was measured into 250 ml Erlenmeyer flask and 5 ml distilled water added. The solution was swirled and then titrated with 0.1M sodium hydroxide solution using phenolphthalein as the indicator. The total acidity was then calculated (Table 4.10).

#### **iv. Determination of chloride ion concentration: precipitation titration**

**(Mohr's method):** Apparatus include two conical flasks, beaker, filter paper, pipette, burette.

Fifty (50) ml of aliquot (portion) of a sample of water soaked from the soil after 24 hours was pipette into a conical flask and 1 ml of chromate indicator was added to give a faint lemon-yellow colour. The end point of the titration was identified as the first appearance of a red-brown colour due to silver chromate. Procedure was repeated with further aliquots until concordant results (titres agreeing within 0.1 ml) were obtained as shown in Table 4.10 in the next chapter.

**v. Carbonate concentration in soil:** Apparatus: Wagtech Alkaphot tablets; Wagtech photometer; Round test tubes, 10 ml glass (PT 515); Filter paper.

Sand was soaked for about 24 hours with distilled water and thereafter filtered. The filtrate was screened using Wagtech Alkaphot test. The test was carried out by adding Wagtech Alkaphot tablet to the sample in a 10 ml glass tube and the colour of the ensued result was measured with Wagtech Photometer (Table 4.10).

**vi. Testing the pH, Total Dissolved solids, TDS and Thermal Conductivity:** Apparatus: three conical flasks, digital conductivity meter.

10 g of sample sands were each put in conical flasks and soaked with 50 ml of distilled water. It was left for 48 hours. The filtrate was tested with a digital conductivity meter and the pH, conductivity and TDS were recorded. The results are given in Table 4.9.

### **3.4 Selecting the machine component to be cast.**

Since the main objective is to develop a pair of shell moulds for casting, a simple geometrical shape was chosen. It was machined and split into two. Only one-half

(symmetrical to the other half) of the cast iron work piece was finally polished and, together with gating systems, mounted on milled steel plate with small bolts. Sprue, riser and other gating system are to be exchanged about the fixed metal pattern by the help of screws or small bolts to produce a male and a female mould.

### 3.5 Wood work-Machining of wood

**i. Drawings.** The wooden pattern drawings below were developed and used to make green sand mould. Tolerances and allowances were placed on it. Figures 3.1 and 3.2 were used to make mould cavites for first casting in the sand casting process to produce a cast blank. Appendix F shows the enlarged drawings.

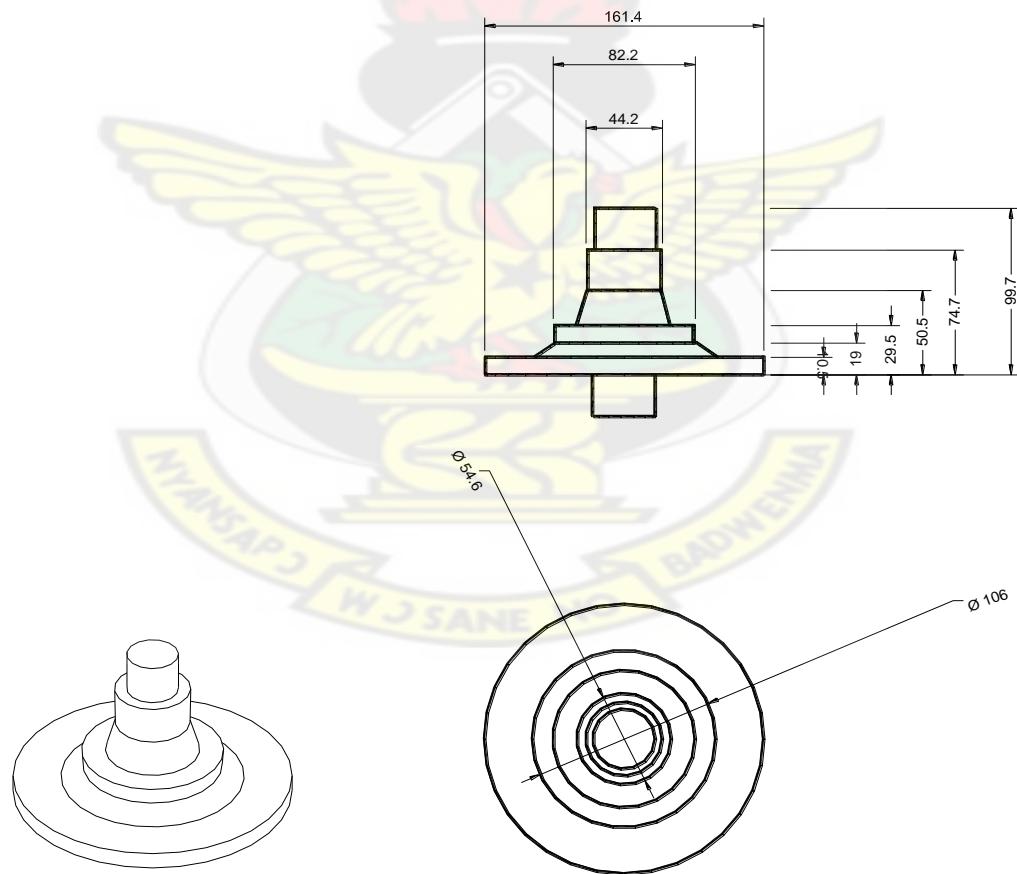


Figure 3.2 Wood pattern 1 for sand casting (Cast to be used for metallic shell mould pattern)

**ii. Core Box:** The following is the drawing for the core box made in wood. It was used to form a cavity in sand mould. The mould was later used to cast a metallic shell core box. Figure 3.3 shows a wooden core box used to cast blank for the metallic box.

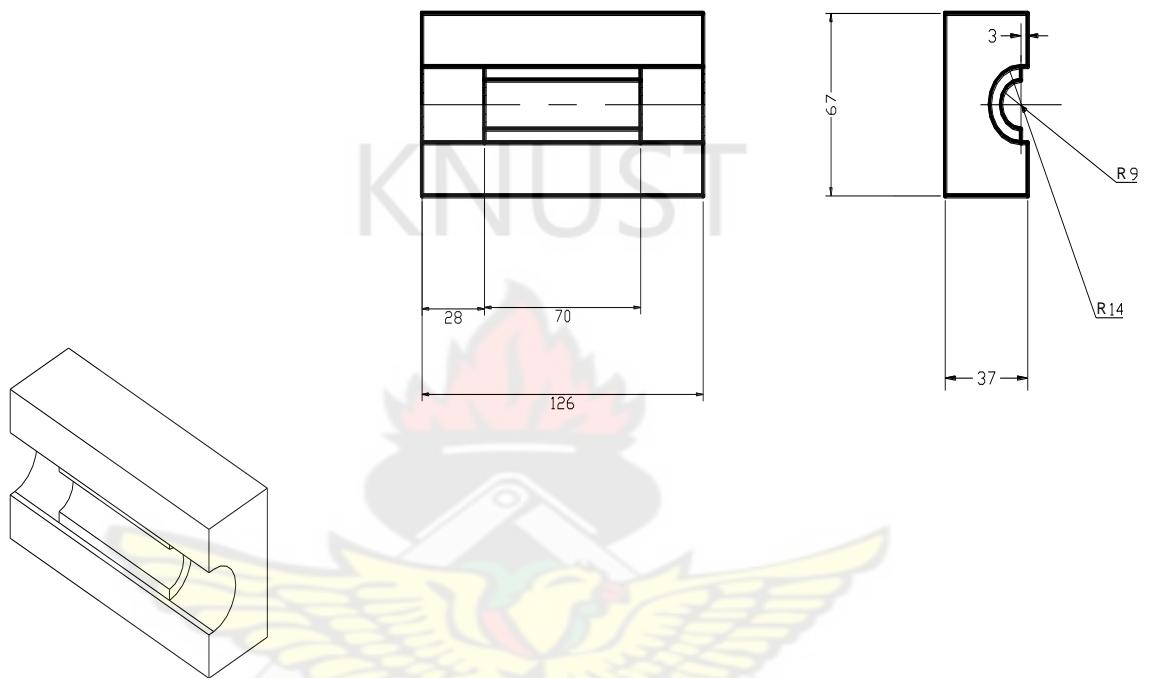


Figure 3.3 Detailed drawing of the shell core box

**iii. Core Making1-Using Wooden Core Box (for hole in the cast-iron core box):** The prepared wooden core box pattern was taken to Tema Steel Works to mould cores with chromite sand (Appendix Plate E 1). One of these cores was used in sand moulding for the metallic core box which was subsequently used for the production of shell cores.

### 3.6 Sized Cope and Drag

A metallic cope and drag for casting the parts shown in Figures 3.2 and 3.3 having adequate allowance were available at the Mechanical Engineering foundry shop. A dimension of 310 x 310 x 100 mm existed for Figure 3.2. Similarly, sized

cope and drag for the two halves of the core box of Figure 3.3 were also available with dimension of each half found to be 410 x 400 x 100 mm. The riser and the sprue for the metallic patterns were arranged and joined with gating systems for casting.

### **3.7 Production of Shell Pattern**

The metallic pattern to be used for the shell casting process needed to be created using the wooden pattern machined earlier in sand casting process. For this purpose, sand from specimen 2 (described earlier in section 3.5) adequate to fill two copies and drags was weighed alongside with sieved charcoal. The weights of sand and charcoal were 61.36 kg and 2.04 kg respectively. A combination of various sieved grades of powdered clay of total weight 10.45 kg was thoroughly mixed with the weighed sand and charcoal. The weights of the sieved clay grades were as follows:

Sieve range	weight (kg)
Below BS 150 mm	61.36
Between BS 150 and BS 300mm	1.82
Between BS 300 and BS 600 mm	2.27

Water was added during the mixing process until the mixture would stick under hand pressure.

After assembling the wooden pattern, chromite cores, the risers and gating systems in the mould boxes, the mixed sand mould material was rammed in place. The wooden pattern was removed and the mould allowed to dry. When the sand mould had dried adequately, the drag and cope were then assembled and molten cast iron was poured into the cavity to obtain the blank for the shell mould casting processes' pattern. The actual casting of the metallic pattern was executed at ABU-DIA Company's foundry. The obtained blank was machined and split into two. One

half was mounted symmetrically on a milled steel plate. Holes were perforated in the plate around the pattern. Long bolts pass through springs and nuts from the underside and then through the hole from the underside of plate. They were then fastened with nuts at the upper side of plate. The arrangements were such that it was possible to strip the mould off the pattern surface with the long bolts (see Figure 3.6 and Appendix Plate E8).

### **3.8 Machining and shaping of the cast iron to form shell mould metallic pattern and metal core box**

**i. Shaping The Cast Iron Pattern To Form The Shell Pattern:** The cast iron casts from the foundry were machined in the Mechanical Engineering Department machine workshop to the required dimensions. The shell pattern was shaped to half in the shaping machine. The metal plate on which the major pattern was mounted was first prepared by grinding in the surface grinding machine. Holes were drilled through to allow for fastening and spring loading. The gating systems were also shaped but this time with grinding machine. Threaded holes or taps were machined in the pattern, the gating system as well as the riser half. Holes were also drilled in the plate. Bolts were used to fasten the pattern, gating system and the riser firmly to the plate by screwing from the underside of the plate. These pieces were later on unfastened, polished and reassembled unto the polished metal plate.

The plate was spring loaded at the bottom side to aid stripping of shell mould stacked to pattern after each operation. This can be seen in Figures 3.6, Plate E 8 or in a process chart in Appendix Table C3.3. It should be noted that instead of using two halves of pattern set to form or cast the final pattern, only one half of the pattern set was moulded because the final piece was symmetrical (refer to Section 3.4).

## **ii. Designing the Gating Systems and the Riser for the Final Shell Pattern:**

Values of parameters based on gray cast-iron including total surface area, volumes of definite shapes and density, were employed in sizing the components to be mounted on the steel metal plate. Volumes and areas of various sections 1, 2, 3, 4, 5 and 6 (see Figure 3.4) were determined. These were used to calculate the modulus of the casting to determine where the molten metal will flow into the cast. Using the average density of solid cast iron of  $7.87 \times 10^3$  kg/m<sup>3</sup> (as in literature) and the overall volume of the cast piece with some allowance for sprue, riser and other gating system, the time taken for the filling of the mould was obtained as 4.5 seconds.

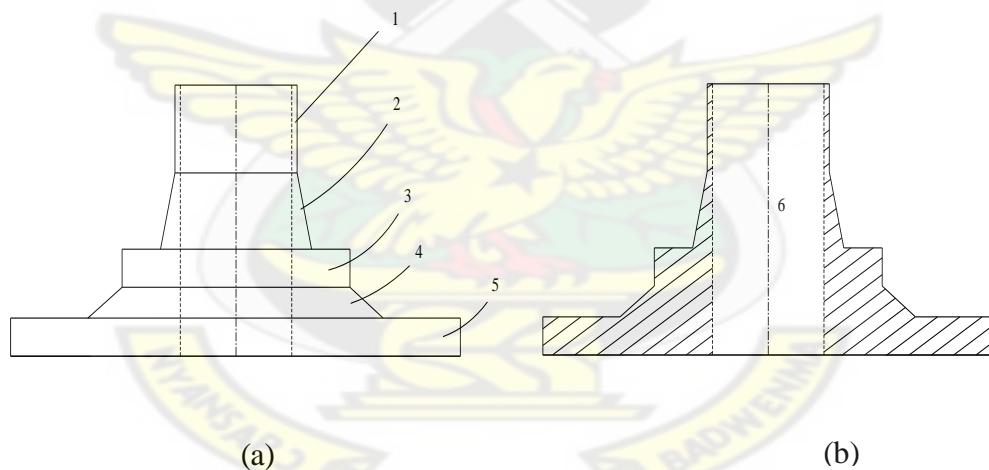


Figure 3.4 (a) Geometrical model drawing used for calculation and (b) sectional drawing of metal to be cast in the shell mould process (1,2,3,4,5 and 6 show isolated geometric shapes used for calculation and estimation ) not drawn to scale

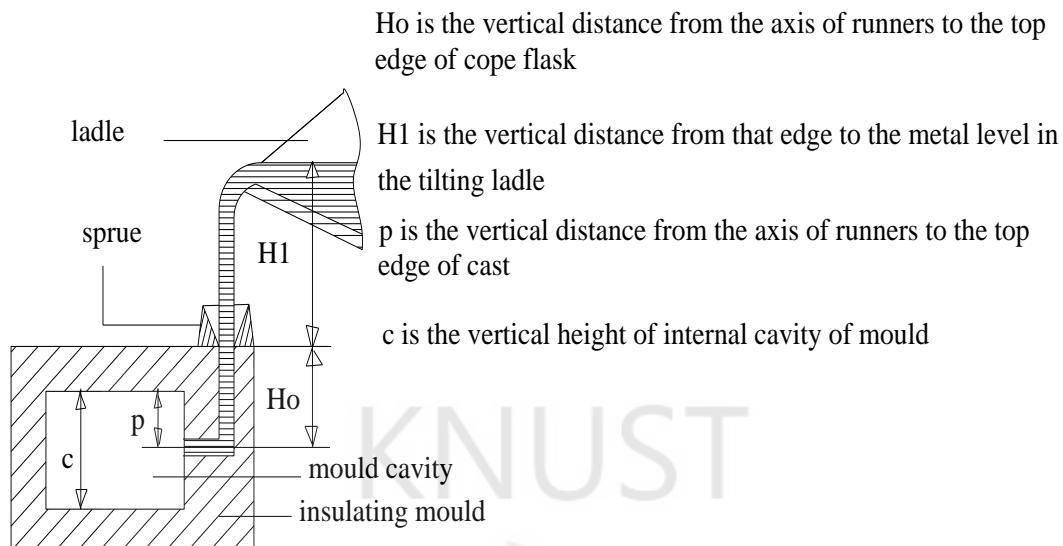


Figure 3.5 Diagram for determining the static head of metal pored through a funnel

With the system assumed pressurized (that is, the sprue remain full of mould such that back pressure is maintained) and also with the assumption that the pouring ladle was close to the sprue (at most 10mm) as in Figure 3.5, the static head ( $H_c = H_o + (p^2/2c) + H_1$ ) was computed (with  $H_o=27.5$  mm,  $p = 7$  mm,  $c = 68$  mm,  $H_1=10$  mm). The estimated cross sectional area was calculated to be  $225 \text{ mm}^2$ . Using a gating ratio of 2:1:1 in favour of sprue cross sectional area: riser cross sectional area: gating system cross sectional area respectively, the various members (all in halves: sprue, sprue base, riser, runners) were sized. Knowing in advance the cross sectional areas as well as dimensions of all other areas of the gating system, computations were made. Holes were drilled in a steel plate and metal pieces (sprue, riser and the gating systems) and mounted on the plate with screws (Figure 3.6).

The design pattern was made symmetrical about the middle of the plate. This was finished by spring-loading the assembly with long bolts and nuts to form a metallic shell pattern ejector (see Figure 3.6 and Appendix Plate E8). The other half

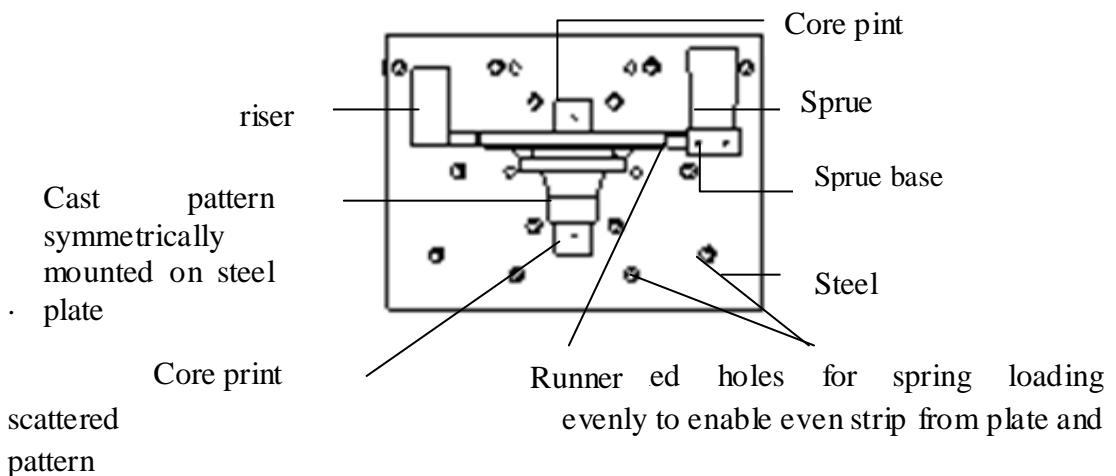
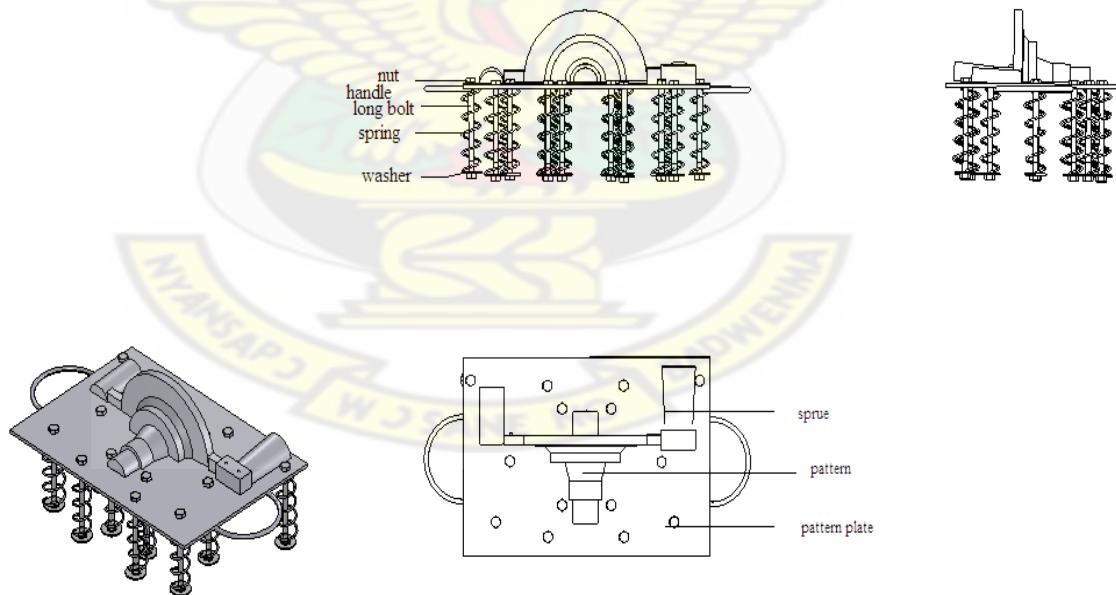


Figure 3.6 Shell metal pattern with holes for spring ejectors

pattern could be obtained by just maintaining the central metallic pattern and exchanging the sprue, riser and the gating systems about the axis of the plate. Figure 3.7 below shows an isometric and orthographic drawing of the spring-loaded metallic pattern.



Shell metallic pattern mechanism

Scale: 1:4

Figure 3.7 Orthographic drawing of a the metallic shell mould pattern mechanism: on the left is its isometric

## Description of Apparatus

The ejector consisted of long bolts which passed through springs and rested on washers. Holes were drilled through the plate around the shell pattern. The ends of the washers were made to pass through each hole from the underside of the plate and then secured with nuts at the upper side as indicated in Figure 3.7 above. The plate had two handles. When the handles were depressed on a flat surface, the bolts came out to remove anything on the surface of the plate as well as the surface of the pattern (For more description refer to Section 3.8 (i) and last paragraph of Section 3.8 (ii)).

## 3.9 Manually operated Hand Mixer

A small capacity mixer was fabricated to ensure homogeneity of the materials that were being used for experimentation. Figure 3.8 is an isometric and orthographic drawing of the mixer that was designed and manufactured to enhance the mixing process. Figure 3.9 also contains the details of the mechanism for the stirring. The hand operated mixer has an opening cover at the top. The capacity of the mixer is 6 kg.

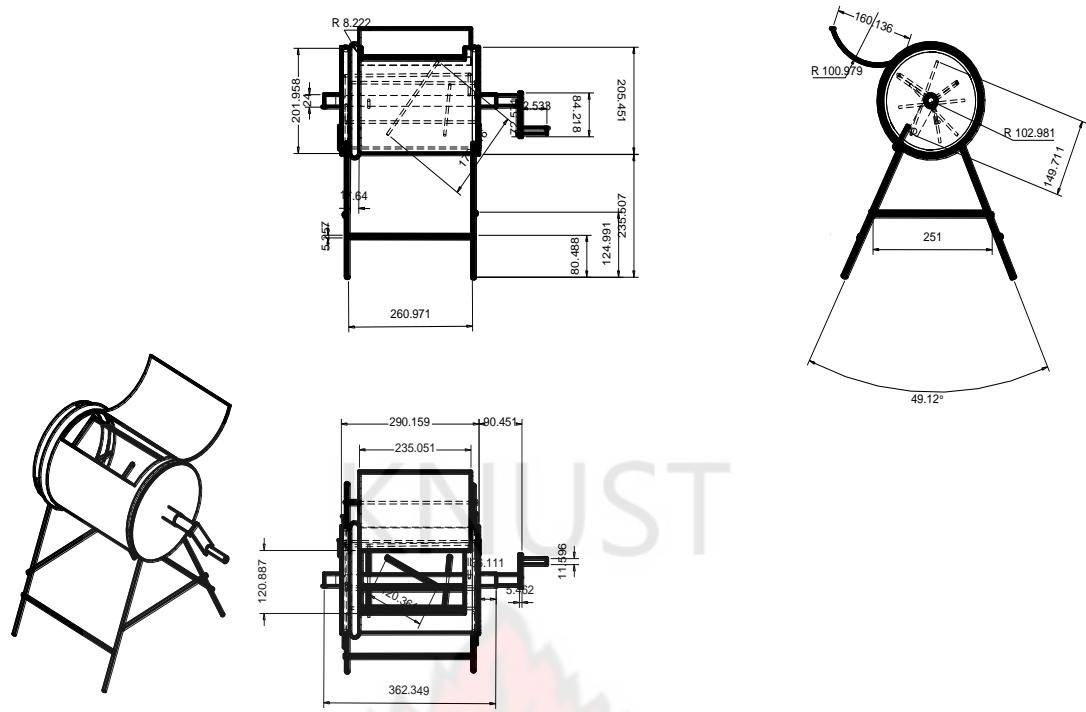


Figure 3.8 Mixer constructed for mixing sand and resin to obtain shell coated sand

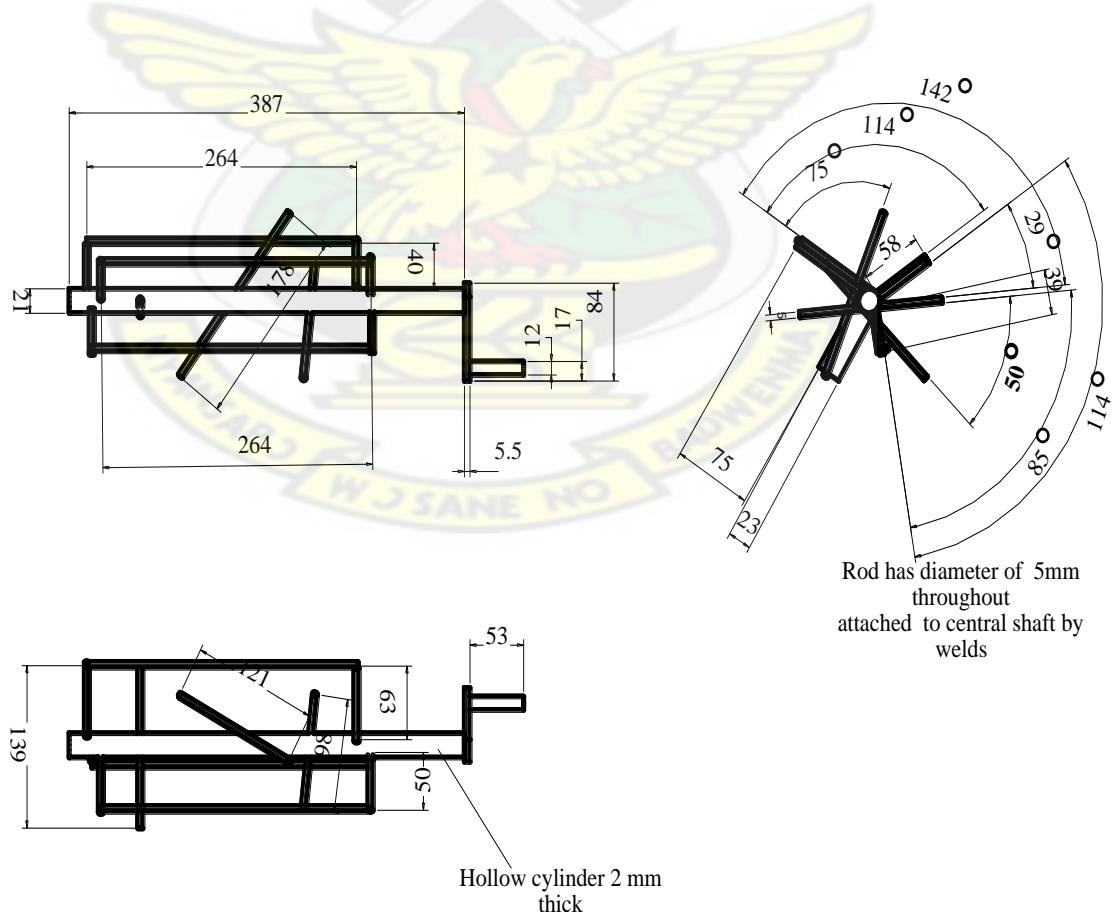


Figure 3.9 Mixer–Stirrer mechanism containing detailed orthographic drawing

**3.10 Dump box Construction.** The dump box with the drawing was constructed. Thin weldable steel sheet was used. Holes were drilled into it at the top to serve as fastening guides for two thin, but slender steel rod lockers (which were not shown). Figure 3.10 shows the dump box.

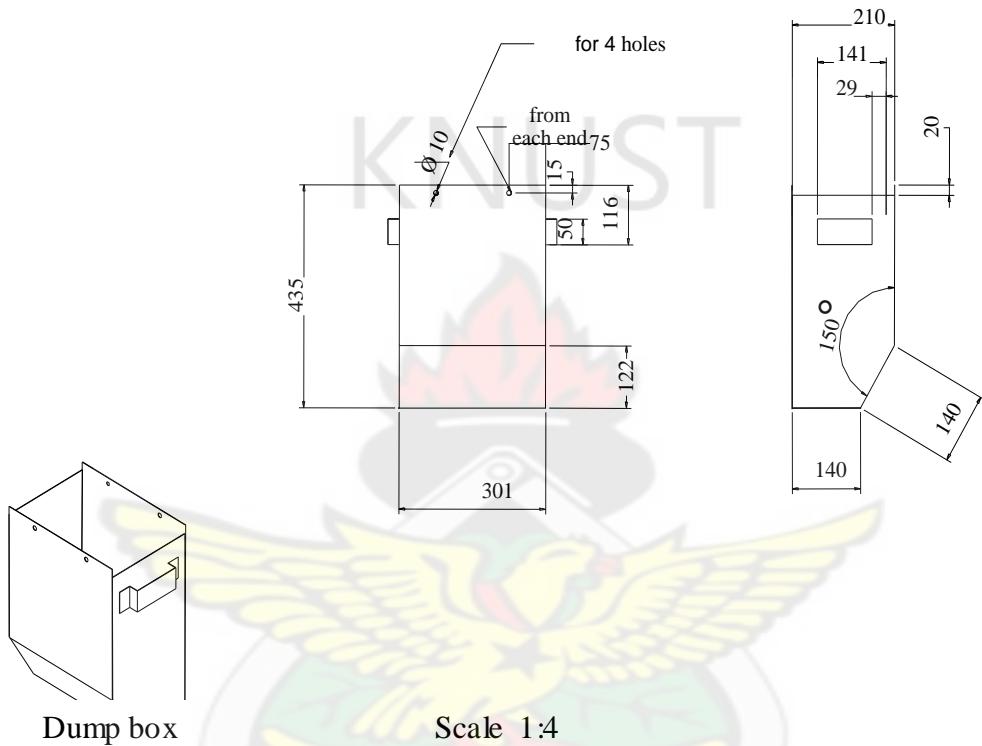


Figure 3.10 Dump box constructed to be used to hold resin coated sand for moulding. The holes at the top were used as slots that could help in locking the pattern unto the top.

### Description of Apparatus

The dump box is the container for the shell coated sand. Hot pattern (on steel plate) at about 200 -250 °C will be inverted and placed over the dump box (as shown in Figure 3.11). The whole set up will be locked in position by two slender metallic rods each of diameter 5mm. Pre-coated sand used should be about two-thirds full.

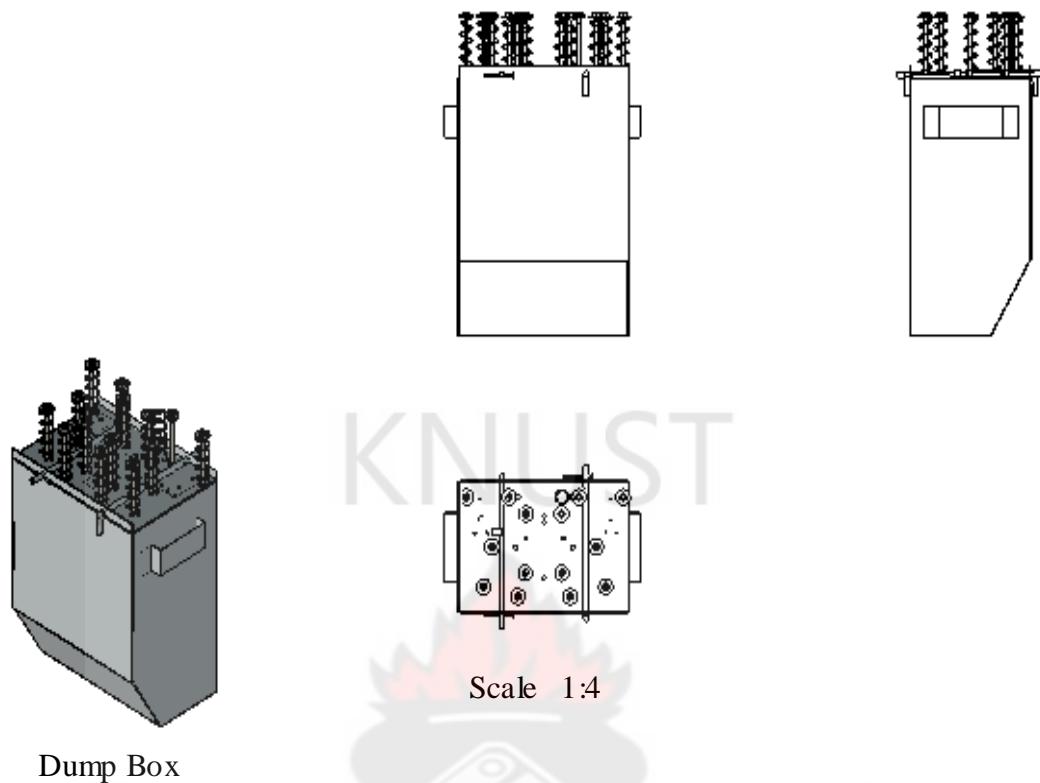


Figure 3.11 Orthographic drawing of the dump box and metal pattern assembly

### **3.11 Search for suitable shell mould resin and its attendant chemicals**

The main resin for the process, phenol formaldehyde novolac resin, could not be obtained from the Ghanaian market, even though that was the common chemical used for the shell moulding. Instead, resole resin was used. The resin came with another chemical labeled ‘Strongbond hardener-ADX.60P’ from Allied Resins and Chemicals and was obtained from Naja David Veneer and Plywood Ltd, Ghana. Hexamethylene tetramine could not be obtained instead a substitute ammonium chloride was obtained. Calcium stearate could not be obtained and was therefore prepared (Appendix D). A test on this stearate was performed in section 3.12.

### 3.12 Simple tests with some of the resin and the chemical with sand

**i. Sticking experiment test:** Table 3.1 shows the details of two tests. This test was performed to ascertain the way the phenol formaldehyde resole resin could adhere to or stick to the surface of a hot pattern after pre-coating sand with the resin and the hardener ADX.60P.

Table 3.1 Sticking Test Experiment of two tests - Test1 and Test 2-to find how best resin-sand can adhere to pattern surface

Test Description	Method / Procedure	Observation	Conclusion
Test 1	<p>Mass of phenol formaldehyde (resol), PF = 25 g          Mass of sand = 250 g          Mass of hardener = 5 g          Volume of water used = 10 ml          calcium stearate = 1g</p> <p>Procedure:</p> <ol style="list-style-type: none"> <li>1. Heat sand on gas flame to 150 °C</li> <li>2.Add phenol formaldehyde and stir for 30 s.</li> <li>3. Add hardener and stir for 25 s.</li> <li>4.Add the water</li> <li>5.Cool to about 60 °C , add the Calcium stearate and stir for 1min</li> <li>6.Heat thick iron plate over gas flame till it is about 250 °C</li> <li>7. Fan and allow the whole mixture to dry</li> <li>8. Apply a fraction of the whole mixture on the metallic plate and observe the sticking effect.</li> </ol>	<p>1. It was observed that when the temperature of the hot metal, 250 °C, is reached and the coated sand applied it turned to be plastic          2. If the temperature was set above 250 °C but less than 350 °C it turned to stick to the pattern relatively better.</p>	<p>It can be concluded that since Test 2 gives better result than Test 1, ratio of materials in Test 2 serves as the starting point for the measurement of materials for the shell mould and the shell core making.</p>
Test 2	<p>Mass of phenol formaldehyde, PF = 25 g          Mass of sand = 250 g          Mass of hardener = 10 g          Volume of water used = 10 ml          calcium stearate = 1g</p> <p>Procedure</p> <p>Follow procedure in test 2</p>	<p>There is better sticking ability at 250 °C than in Test 1 when the hardener was doubled from 5 g to 10 g.</p>	

**ii. Other experimental set-up:** 75 g of Sodium silicate was added to heated sand between the shell coating temperature range of 120-150 °C and at standard conditions of temperature and pressure. The mixture was stirred in the hand operated mixer and the product quenched after a few minutes with water. The process was repeated in another case by adding a solution of calcium hydroxide (residue obtained from carbide- acetylene gas generation). Result of this test is in Chapter Four.

#### **4.13 Shell sand coating: Pre-coating the sand with the resin and the chemical**

Five kilograms (5 kg) of silica sand was heated to about 240 °C. It was charged into the simple hand operated mixer described earlier. Thermo couple was used to take the temperature of sand till it dropped to about 152 °C. Between 150 to 120 °C phenol formaldehyde was charged and stirred for about 2 -3 minutes. After which water was added to the sand and stirred for at least 4 min. The hardener was charged into the mixer and stirred for about 1 min during which all got mixed with the heated sand. At this stage, the sand exhibited a plastic behaviour and the whole sand mixture behaved like a collection of live “maggots” or “worms”. Calcium stearate (lubricant) was then added and stirred for about 4 minutes and the product poured into a broad dish to cool. Still the maggot-like behaviour persisted (Appendix Plate E 10). Cooling of the mixture continued until single grains of sand began to show up and the intensity of the plastic (maggot-like) behaviour decreased to a halt. At this point it was then sieved to remove any lumps.

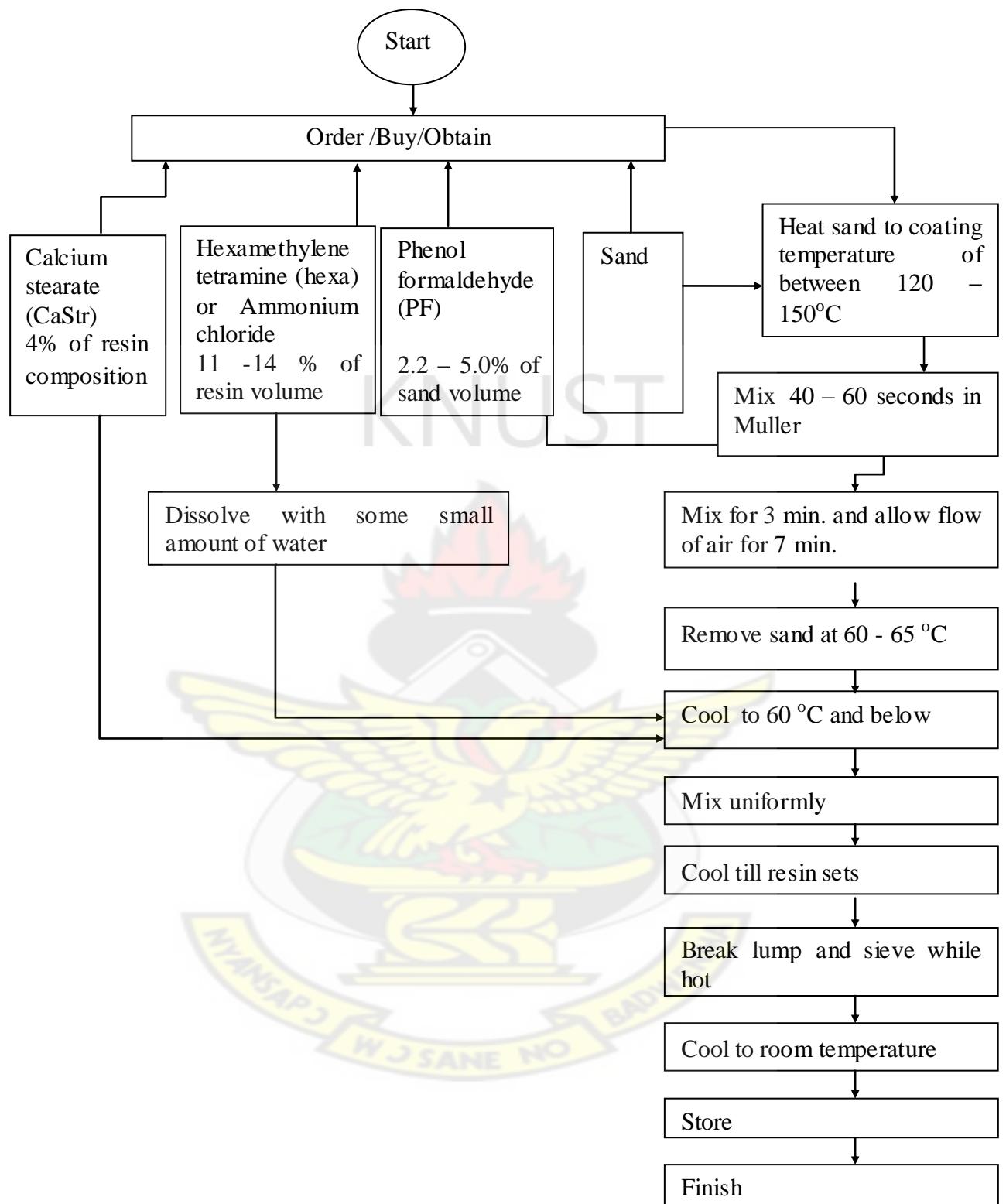


Figure 3.12 Flow diagram of shell moulding technique for sand quoting

## Description of Flow diagram for precoating of sand

- 1 Start
- 2 Order/buy or obtain calcium stearate (4% of resin composition), hexamethylene or ammonium chloride (11-14% of resin volume), phenol formaldehyde resin (2.2-5.0 % of sand volume) and sand.
- 3 Heat sand to coating temperature (120-150 °C )
4. Add Phenol formaldehyde and mix for 40-60 seconds in muller
5. Mix mixture for 3 minutes and allow for flow of air for 7 minutes
6. At around 60 °C add hardener (hexa or hexamethylene tetramine or ammonium chloride) dissolved in water and cool to 60 °C and below
7. Add calcium stearate and mix thoroughly for 3 minutes
8. Cool till resin sets
9. Break lumps and sieve while hot
10. Cool to room temperature
11. Store
12. End or Finish

### **3.14 Shell Core making: Forming the shell core with the pre-coated sand**

The shell cores were prepared using metal mould box. Metal core box was heated to about 200-250 oC in a furnace. The materials for the cores were freshly prepared coated sand with phenol formaldehyde resole resin, a hardener ADX.60P and prepared calcium stearate (Appendix D). First attempts at producing the cores resulted in rough surfaces of the cores. In subsequent attempts the core material had to be rammed in the metallic core box. The peel-backs in Plate1 below were the results of inadequate ramming. Successive production of the cores resulted in

improved surface finish. This process will need to be mechanized to provide the level of ramming that will not be subjective.



Plate 3.1 shows some shell mould cores made with the coated-sand of phenol formaldehyde resole resin with ADX.60P hardener from Allied Resins and obtained from Naja David Veneer and Plywood Limited

### **3.15 Forming the shell mould with the pre-coated sand**

The manufacture of the shell mould under conditions of local materials' availability posed some challenges. After the metal pattern had been machined, a first attempt at creating a shell mould by coating the pattern with the precoated sand using resole resin as binder was unsuccessful. The coating sand collapsed overnight. Meanwhile, the source of resole resin for the experimentation was short of supply. A search revealed that a minimum order quantity acceptable by most vendors was 25 kg at a price ranging from US\$3000 to US\$5000 excluding other expenses. An alternative solution had to be found. The collapsed coating sand was reused by mixing it with 4% by weight of sodium silicate (an amount enough to mix the dry

collapsed precoated sand). Mixing was carried out by using the hand operated mixer earlier fabricated.

Earlier on, a metal frame was fabricated to aid in the application of the collapsed sand. This frame, designated as ‘pattern imitator’ has an allowance of at most 10 mm from the metallic pattern. This helps to apply the collapsed sand mixed with the sodium silicate (water glass) to the pattern surface. Figure 3.13 shows the metal pattern imitator.

To help in the smooth operation of investing sand resin silicate to pattern an open Table as shown in Figure 3.13 was used. The metal pattern mechanism was suspended in the opened-top metallic table. This was done to avoid the weight of the load together with anything on the surface of pattern from having effect on the ejectors.

#### **Description of Flow Diagram for shell moulding using Precoated sand**

1. Start
2. Pattern is ready for the process
3. Heat it in fire from between 150 - 250 °C or in an oven from between 300 - 350 °C
4. If it has reach between 150 - 250 °C then remove pattern
5. Spray pattern with lubricating agent e.g. silicone oil for about 1 minute
6. Invert pattern and place it over a dump box containing precoated .The precoated sand fuse and bond to pattern surface
7. Remove pattern – fused sand (shell) and put the whole set- up in oven
8. If the oven is not at 300-350 °C do not proceed

9. If it is at 300-350 °C maintain it for about 1 minute.

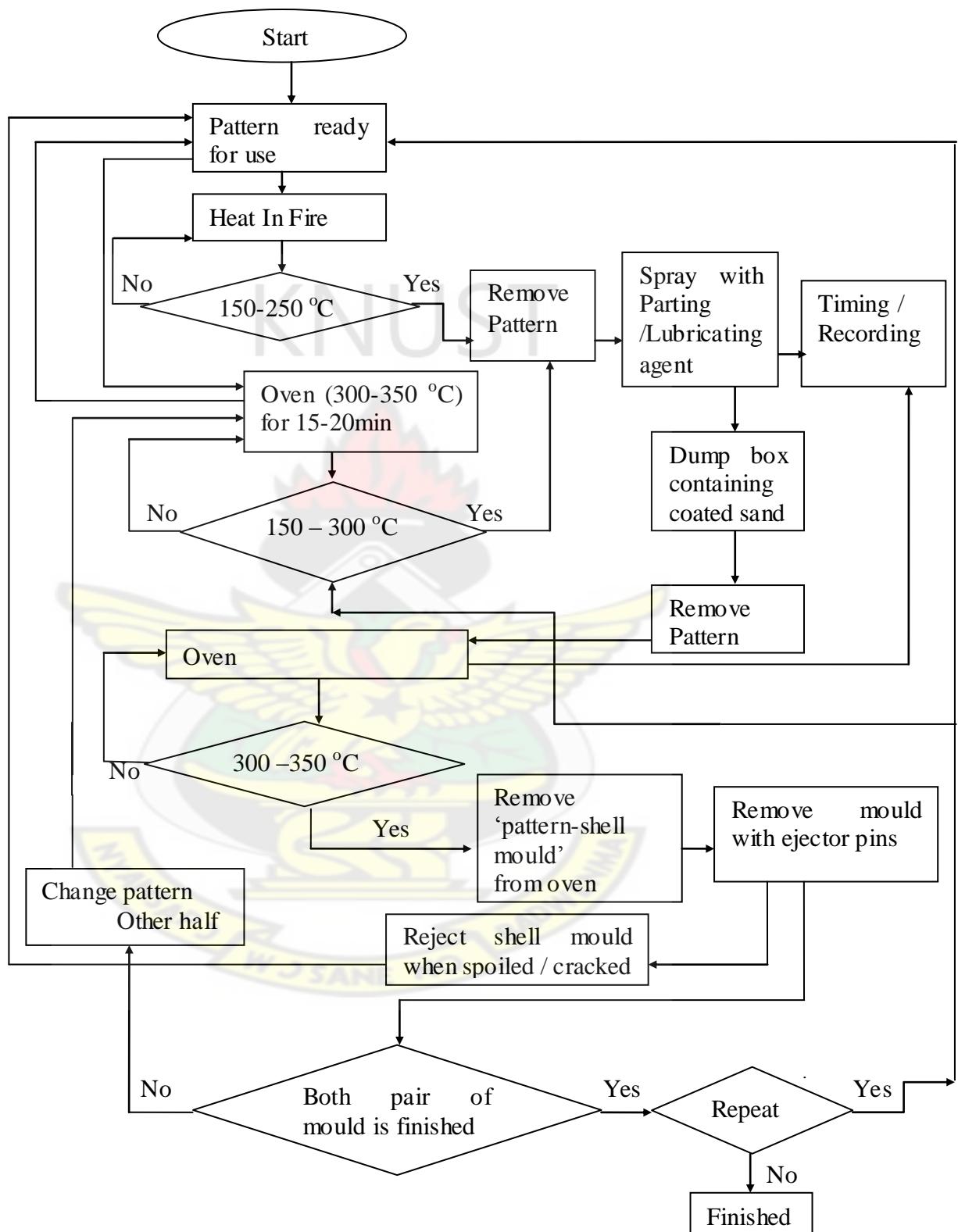
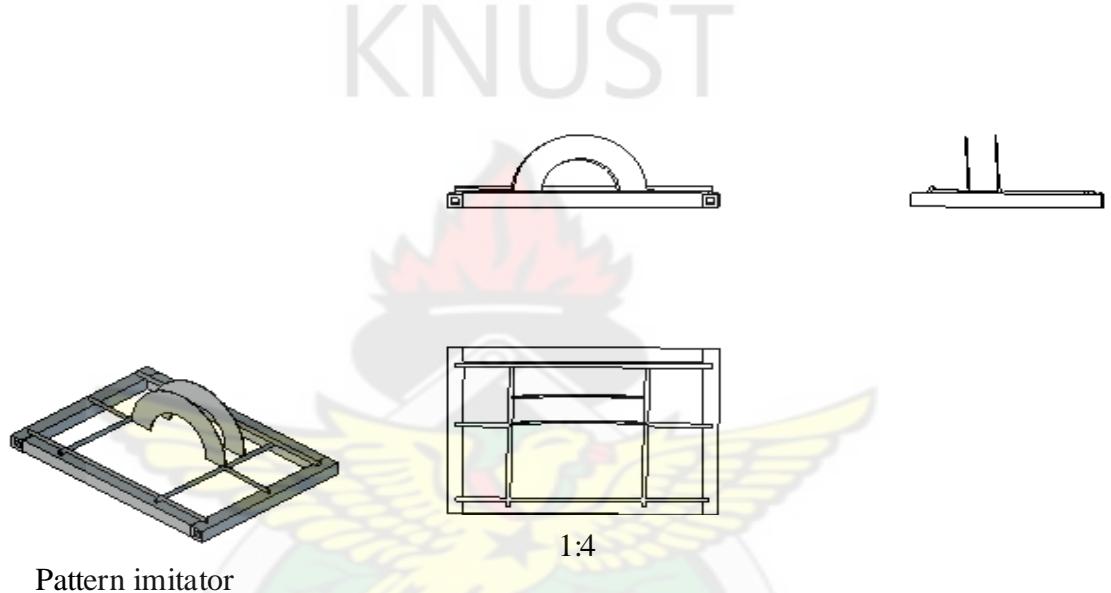


Figure 3.13 Flow diagram on the shell moulding using the pre-coated sand

13. From (12), if mould removes successfully then you may repeat the process from (2).

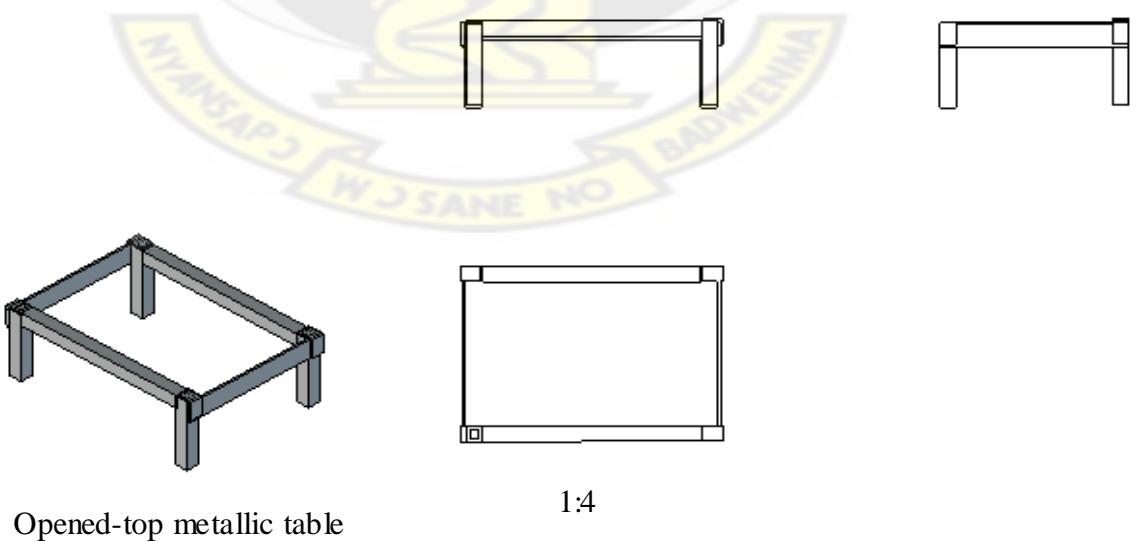
14. If both process (male and female mould) is not finished then change the pattern, other half, and move or else you heat in the furnace to between 150- 300 °C otherwise you heat in oven 15-20 minutes at 300 -350 °C before removing pattern and continuing with (5)

14. End or Finish (if you do not want to continue or repeat).



Pattern imitator

Figure 3.14 The Pattern imitator constructed with an allowance of 10mm from metallic pattern



Opened-top metallic table

14

Figure 3.15 Opened-top metallic table

## Description of apparatus

The metallic table with the flat top absent is constructed. The spring loaded metallic shell pattern is introduced in the hollow table from the top and the whole mechanism rests with its handles on the metallic table. The upper part (the imitated shell pattern contour) constructed to follow the critical part of the contour, in Figure 3.14, was introduced from the upper side of the set up in such a way that shell pattern mechanism was sandwiched between the table (Figure 3.15) and the guided contour. Figure 3.16 shows the Exploded view in 3-dimesion of “pattern imitator - shell pattern - metallic table” assembly which was used to arrive at the final assembly in Figure 3.17. The phenol formaldehyde coated sand mixed with the sodium silicate was applied to the surface and rammed. The metallic sheet guides helped the sand thickness not to be greater than 10 mm (see the end elevation in Figure 3.17).

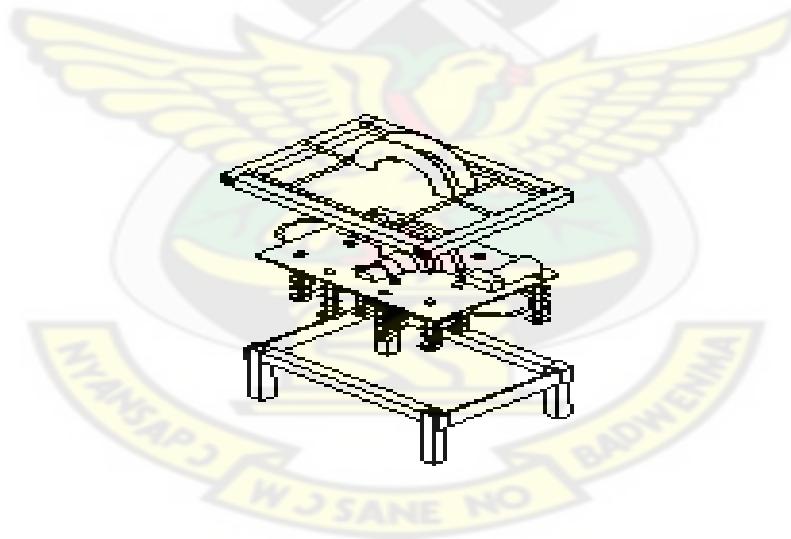


Figure 3.16 Exploded view in 3-dimesion of pattern imitator- shell pattern- metallic table assembly

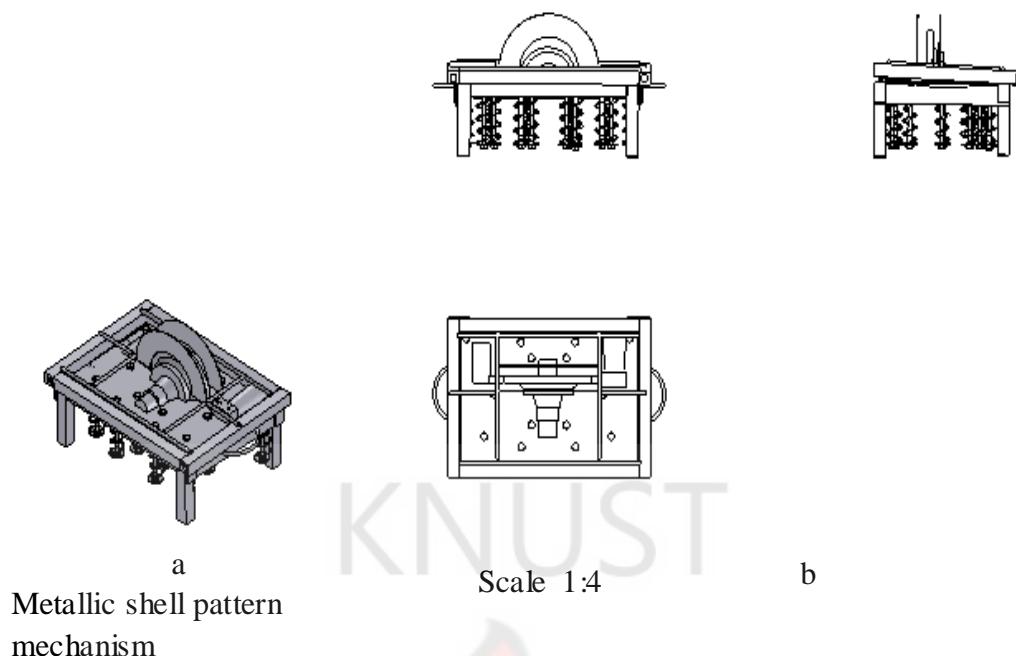


Figure 3.17 I (a) Isometric and (b) Orthographic projection of the assembly of the newly constructed mould mechanism with the pattern

The above silicate – precoated sand mix was rammed unto the pattern which was on the mechanism and was hardened with CO<sub>2</sub>. The mould (Plate 3.2 and 3.3) created was then ejected from the pattern surface by the spring-loaded ejectors.



Plate 3.2. Male and female mould and a shell core



Plate 3. 3. Male and female mould with core inserted. The numerous holes shown indicate the tips of the ejector pins

### **3.16 Testing the prepared shell core and the shell mould by casting a suitable machine part**

The prepared mould was used to cast cast-iron (Appendix Plates E 18-20). The mould proved strong against the hydrodynamic forces of the molten metal. The shell core proved strong and easily collapsible. Plate 3.4 below shows the final cast from the shell moulding process. The product showed some defects.



Plate 3.4 Final cast from the shell mould

## CHAPTER FOUR

### ANALYSIS OF RESULTS AND DISCUSSIONS

#### **4.1 Results and Discussion on Sand analysis**

The results of the experiment on some various types of sand analyzed in the laboratory were compared with existing silica sand (SI) used at Tema Steel Works for special types of casting:

Below is Table 4.1 which shows the analysis conducted at the Geotechnical laboratory of KNUST to determine the percentage of organic content in a sample of sand sourced from Wewe River at KNUST.

Table 4.1 Organic content test determination

Sample	Unit	Washed sample	Unwashed sample	SI
Container no.		A	4D1	4C3
Mass of container	g	49.86	70.03	67.50
Mass of container and oven dry soil	g	133.18	195.11	219.20
Mass of container and burnt soil	g	133.16	194.90	218.95
Loss of organic content	g	0.02	0.21	0.25
Mass of oven dry soil	g	83.30	124.87	151.45
Percentage Loss of Organic content	%	0.02	0.17	0.17

The results demonstrate that the washed and unwashed sand sampled respectively has a maximum of 0.02 and 0.17 % of organic matter as against 0.17 % for silica sand (SI) from Tema Steel Works. This washed sand value is in perfect agreement with Dhumal, 2006 and therefore recommends itself for use in casting in Ghana.

Table 4.2 Grading Test of Unwashed sample

GRADING TEST Weight (g) 61.6 g                      Unwashed Sample

Seive size		Weight retained (g)	Percentage retained (g)	Percentage passing (g)
BS Designation	Metric (mm)			
3 in	75.00			
2.5 in	63.00			
2 in	53.00			
1.5 in	37.10			
1 in	25.40			
3/4 in	19.00			
1/2 in	13.20			
3/8 in	9.50			
1/4 in	6.70			
3/16 in	4.75			100
1/8 in	3.35	1.70	2.8	97.24
No. 7	2.00	3.43	5.57	91.67
No.14	1.00	9.28	15.08	76.59
No. 25	0.600	9.38	16.21	60.37
No. 36	0.425	7.28	11.83	48.55
No. 52	0.300	7.32	11.89	36.65
No. 72	0.212	6.00	9.75	26.90
No. 100	0.150	6.32	10.27	16.64
No. 200	0.075	1.35	2.19	14.44
<b>Total % retained</b>			<b>85.59≈ 86</b>	

Table 4.3 Silt content test

Sample no.	Washed sample	Unwashed sample	SI
Total height of sample (mm)	79	76	69
Height of sand (mm)	78	69.5	64
Height of silt section (mm)	1	6.5	5
Silt content (g)	0.01	0.09	0.07
Percentage silt content	1.27	8.55	7.25

In a casting process it is important to know the clay (or silt) content in the sand to be used in creating the moulds. The above table demonstrates the results obtained during testing for clay(or silt). The result of the percentage silt content showed the washed sample to be relatively free from silt particles as compared to sample SI and therefore contained mainly sand particles.

The results of hydrometer content of clay and silt are as shown in Tables 4.4 and 4.6. Computations on these values together with values from Tables 4.3, 4.5 and 4.7 lead to the graph in Figure 4.1 below, which helps to determine the percentages of clay and silt contents. Analysis of result proved that there is more clay particles in the unwashed sample as expected followed by the SI sample, with the least or virtually none in the washed sample

Table 4.4 Hydrometer test results for determination of clay and silt content of Unwashed sample – values used to plot Figure 4.1

Elapsed time, (min)	Time (min)	Temp (°C)	Direct hydrometer reading	Actual Reading $Rh^1$	$Rh = Rh^1 + C_m$	$H_r$ (mm)	Viscosity	D (mm)	Temp Cor, $M_t$	$Rd = Rh^1 - R_0 + M_t$	K (%)
0.50	7.50	25.00	1.0080	8.00	8.5	167.0250	0.8879	0.0753	1.0349	5.4349	14.35
1.00	7.51	25.00	1.0078	7.80	8.3	167.8150	0.8879	0.0534	1.0349	5.2349	13.82
2.00	7.52	25.00	1.0073	7.30	7.8	169.7900	0.8879	0.0380	1.0349	4.7349	12.50
4.00	7.54	25.00	1.0070	7.00	7.5	170.9750	0.8879	0.0269	1.0349	4.4348	11.71
8.00	7.58	25.00	1.0066	6.60	7.1	172.5550	0.8879	0.0191	1.0349	4.0348	10.65
15.00	8.05	25.00	1.0065	6.50	7.0	172.9500	0.8879	0.0140	1.0349	3.9348	10.39
30.00	8.20	25.00	1.0063	6.30	6.8	173.7400	0.8879	0.0099	1.0349	3.7348	9.86
60.00	8.50	25.00	1.0054	5.40	5.9	177.2950	0.8879	0.0071	1.0349	2.8349	7.48
120	9.50	25.00	1.0050	5.00	5.5	178.8750	0.8879	0.0050	1.0349	2.4348	6.43
240	11.50	25.00	1.0046	4.60	5.1	180.4550	0.8879	0.0036	1.0349	2.0348	5.37
1440.00	7.50	25.00	1.0042	4.20	4.7	182.0350	0.8879	0.0015	1.0349	1.6348	4.32

$H_r$  is effective depth

D is equivalent particle diameter

$M_t$  is temperature correction

K is percentage by mass of particles smaller than the corresponding equivalent particle diameters

R<sub>h</sub><sup>1</sup> hydrometer reading at the upper rim of meniscus

R<sub>d</sub> hydrometer reading after the addition of dispersing agent

C<sub>m</sub> is meniscus correction

Table 4.5 Grading test on sample SI

Sample SI	Grading Test	Weight (g)	94.6	
Seive size	Metric (mm)	Weight retained (g)	Percentage retained (%)	Percentage passing (g)
BS Designation				
3 in	75.00			
2.5 in	63.00			
2 in	53.00			
1.5 in	37.10			
1 in	25.40			
3/4 in	19.00			
1/2 in	13.20			
3/8 in	9.50			
1/4 in	6.70			
3/16 in	4.75			100
1/8 in	3.35	0.13	0.1	99.86
No. 7	2.00	0.15	0.16	99.70
No.14	1.00	2.50	2.64	97.06
No. 25	0.600	11.97	12.66	84.40
No. 36	0.425	14.58	15.42	68.99
No. 52	0.300	16.50	17.45	51.54
No. 72	0.212	14.30	15.12	36.42
No. 100	0.150	23.64	25.00	11.42
No. 200	0.075	3.81	4.03	7.39
<b>Total % retained</b>			<b>92.58≈ 93</b>	

Table 4.6 Hydrometer test results for determination of clay and silt content of sample SI- values used to plot Figure 4.1

Elapsed time, (min)	Time (min)	Temp (°C)	Direct hydrometer reading $R_h^1$	Reading $R_h^1$	$R_h = R_h^1 + C_m$	$H_r$ (mm)	Viscosity	D (mm)	Temp Cor, $M_t$	$R_d = R_h^1 - R_0 + M_t$	K (%)
0.50	7.50	25.00	1.0060	6.00	6.5	174.9250	0.8879	0.0771	1.0349	3.4349	5.90
1.00	7.51	25.00	1.0050	5.00	5.5	178.8750	0.8879	0.0551	1.0349	2.4348	4.18
2.00	7.52	25.00	1.0048	4.80	5.3	179.6650	0.8879	0.0391	1.0349	2.2348	3.84
4.00	7.54	25.00	1.0047 c	4.70	5.2	180.0600	0.8879	0.0276	1.0349	2.1348	3.67
8.00	7.58	25.00	1.0046	4.60	5.1	180.4550	0.8879	0.0196	1.0349	2.0348	3.50
15.00	8.05	25.00	1.0045	4.50	5.0	180.8500	0.8879	0.0143	1.0349	1.9348	3.32
30.00	8.20	25.00	1.0044	4.40	4.9	181.2450	0.8879	0.0101	1.0349	1.8348	3.15
60.00	8.50	25.00	1.0042	4.20	4.7	182.0350	0.8879	0.0072	1.0349	1.6348	2.81
120	9.50	25.00	1.0040	4.00	4.5	182.8250	0.8879	0.0051	1.0349	1.4349	2.46
240	11.50	25.00	1.0037	3.70	4.2	184.0100	0.8879	0.0036	1.0349	1.1349	1.95
1440.00	7.50	25.00	1.0036	3.60	4.1	184.4050	0.8879	0.0015	1.0349	1.0349	2.73

The minimum retention of sand on consecutive sieves, as displayed in Tables 4.2, 4.5 and 4.7, shows 99 % retention on consecutive sieve for washed sand against 86 % of unwashed sample and 93 % of the SI sample. From the graph, the sample SI looks more flat between 0.002 and 0.06 than the unwashed sample meaning it has a lot of sand particles distributed in it than the unwashed sample. Between 0.06 and 0.2 the washed sample seems more flat than the unwashed sample and sample SI showing it to be more graded even though it looks similar to that of SI. On the whole, all three samples satisfy the shell mould sand criteria of 80 % minimum retention on consecutive sieves.

Table 4.7 Grading test on washed sample

Total Dry Weight (g) 89.0

Seive size		Weight retained (g)	Percentage retained (g)	Percentage passing (g)
BS Designation	Metric (mm)			
3 in	75.00			
2.5 in	63.00			
2 in	53.00			
1.5 in	37.10			
1 in	25.40			
3/4 in	19.00			
1/2 in	13.20			
3/8 in	9.50			
1/4 in	6.70			
3/16 in	4.75			
1/8 in	3.35			
No. 7	2.36			100
No.14	1.00	5.37	6.0	93.97
No. 25	0.600	22.76	25.6	68.41
No. 36	0.425	18.24	20.5	47.92
No. 52	0.300	17.51	19.7	28.26
No. 72	0.212	14.04	15.8	12.49
No. 100	0.150	9.48	10.6	1.84
no. 200	0.075	0.85	1.0	0.89
<b>Total % retained</b>			<b>99.20≈ 99</b>	

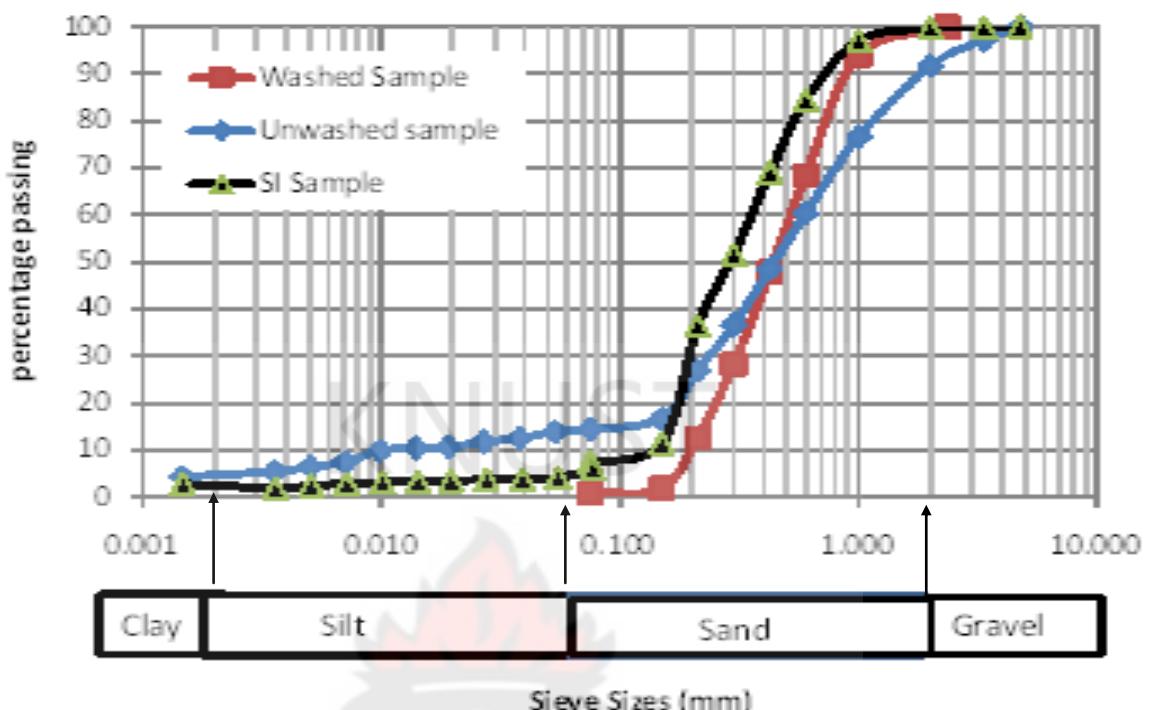


Figure 4.1 Logarithm graph of percentage of clay, silt, sand and gravel passing each sieve

Results from graph:

Table 4.8 Summary on results of the percentage of clay, silt, sand and gravel

Sample type Content(%)	Unwashed Sample	Washed Sample	SI Sample
Clay	5	0	2
Silt	10	0	2
Sand	77	100	96
Gravel	8	0	0
Total %	100	100	100

Figure 4.1 shows the plot of values in Tables 4.1 to 4.7. The silica content of washed sample was 100 %. It also gave 0 % of the clay meeting the maximum requirements of 0.2 % of clay for shell moulding silica sand.[26 a,b]. Sample SI also meet the requirement.

Table 4.9 Thermal conductivity, Total Dissolved Solids (TDS) and pH measure at Geotechnical Engineering water laboratory section at KNUST of sand against existing silica sand, SI

Specimen	Unwashed sand (Average Value)	Washed sand (Average Value)	Silica sand (SI) (Average Value)
Thermal conductivity ( $\mu\text{S}$ )	74.2	54.4	63.8
TDS (ppm)	73.0	25.5	25.0
pH	6.25	6.4	6.1

The pH tests were done to determine acidity or alkalinity of the soil. The thermal conductivity tests were to ascertain how well the particles can conduct heat especially from molten metal and the TDS tests were to find out how free the sand is from foreign materials. The washed sample compared favourably with the SI sample.

Table 4.10 Results of the Contents of Washed and Unwashed Sand samples compared to the Silica SI samples obtained, at Chemistry Department of KNUST

PARAMETER	UNWASHED (Average Value)	WASHED (Average Value)	SI (Average Value)
Chloride (mg/kg)	50.30 (0.005%)	43.91 (0.004%)	45.34 (0.05)
Carbonate (mg/kg)	24.52 0.0025	20.44 0.0020	23.49 0.0023
Acid Demand Value (ml/100 g NaOH)	7.8	7.4	7.6

Table 4.10 shows that the chloride and carbonate contents for all the samples are almost 0 % and this satisfies results by Dhumal, [26 a, b] criteria for shell

moulding. The acid demand values showed values of 7.4 to 7.8 which were slightly higher than the ' $<6$  ml of KOH / 100 gm of sand' as stated by [26 a, b]. This could be due to the use of NaOH instead of the KOH. American Foundrymen's Society number, AFS, No of 50 – 80 could not be ascertained because the sieves that were used were British Standard, BS, sieves which had their sieve sizes completely different from the AFS sieves. Relationship between BS sieves and AF sieves could not be obtained. Moreover, grain shape could not be measured as instruments were not readily available.

**Table 4.11 SUMMARY OF POINTS IN THE ANALYSIS OF RESULTS Sand**

Sand sample	Unwashed sample	Washed sample	Sample SI	Standard by Dhumal,2006, p. 22
Grain Shape:	Not available	Not available	Not available	Round to sub angular
Clay Content (%) (Table 4.8)	5	0	2	0.2% maximum
Chlorides (%) (Table 4.10)	0.005%	0.004%	0.05	0%
Carbonates (%) (Table 4.10)	0.0025	0.0020	0.0023	0%
Acid demand Value (Table 4.10)	7.8 ml of NaOH/100 gm of sand	7.4 ml of NaOH/100 gm of sand	7.6 ml of NaOH/100 gm of sand	$<6$ ml of KOH/100 gm of sand
Silica Content (%) (Table 4.8)	77	100	96	98% minimum
Loss on ignition (Loss of organic content) (%)	0.17 (Table 4.1)	0.02	0.17	0.2% maximum;
AFS No.	Not available	Not available	Not available	50-80
Sieve distribution (%)	85.59 Table 4.2	99. 20 Table 4.7	92.58 Table 4.5	Minimum 80% retention on the consecutive sieve.

## **4.2 Results and Discussion on Other Experimental Set-Ups and the shell mould casting process**

The calcium stearate produced was not fully tested. It was the pH that was however determined. Calcium stearate prepared from calcium oxide and stearic acid culminated in a product that looked physically similar (in terms of appearance, smell and the residue that was left in the preparation bowl) to the calcium stearate that was obtained with the calcium oxide and the beef tallow. The pH of the former was 8.2 while the latter was 8.3. The pH of calcium is normally quoted as 8.4.

Using the procedures and equipment developed in this work it was possible to prepare shell pre-coated sand which was used to cast a machine part. It was observed that shells prepared using phenolic resole binder were easily bonded however they collapsed with time barely after twelve hours. Ratio of 1:5 of the hardener (ADX.60P) to resin when used to coat silica sand bonded less than when the ratio of hardener to resin was doubled to 2:5. The small quantity of the resole available for the research could not permit further trials to determine the optimum hardener to resin ratio.

The shell coring was implemented. The strength was comparable with the reinforced sodium silicate- chromite-CO<sub>2</sub> cores produced at Tema Steel Works in February, 2010 (Appendix Plate A1). Tensile, compression and shear test could not be done at the Physics department, KNUST because of the reason earlier stated. The shell cores created could be compared with earlier used reinforced chromite cores on the grounds that both were used to create holes in cast iron melt. The shell cores were strong to resist the hydrodynamic forces of the molten metal without breaking (Appendix Plates E11-12). The physical appearance of the core constructed is similar to most of the cores seen on the internet.

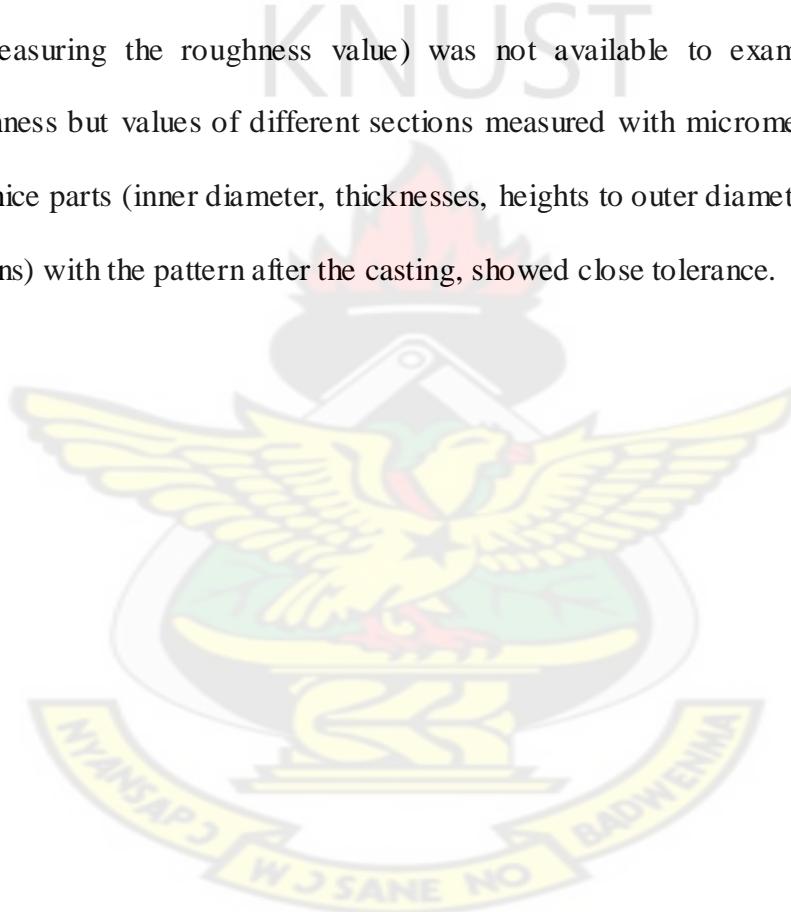
It was observed that the freshly prepared shell cores turned out to be strong initially but peeled off with time. The surface smoothness required to be improved. It must be acknowledged that the core had been kept for about three months before usage and therefore the peel off must have resulted from interaction with the atmosphere. Such influences may need to be investigated particularly under mass production. The collapsibility of the core after casting was extremely easy, (Appendix Plate E 20).

The pre-coating of sand was tried several times but bulk volume could not be made at a go. The prepared sand was collected and kept. Three successful precoating was added to obtain reasonable amount and kept for three weeks. When the sand was applied for moulding it could not fuse, bond and adhere to the heated pattern surface. The sand had collapsed.

The mould that was later prepared was made from the collapsed shell coated sand. It was mixed with sodium silicate and re-moulded with average maximum thickness of 10 mm. The silicate quantity was similar to the sand:water ratio employed in the shell coating method (1:25 gram of silicate to sand by weight). This was used to imitate the actual shell moulding process, (Appendix Plate E 13-15) by ramming unto the cold surface and drying in the furnace for one minute. The mould after casting was observed to be hard but was also able to collapse or undergo fettling with relatively reasonable amount of force. This hardness would have been too much if it had been ‘sodium silicate - CO<sub>2</sub>’ process that was used. Even though the sand already contained some phenolic resin the mould proved more reliable in terms of exhibiting appropriate hardness and collapsibility and was used to produce cast iron casting. Since it was used to cast cast iron it could be used to cast any metal that has a melting temperature below cast iron like aluminium, magnesium and many more.

#### **4.3. Results and analysis on Cast Piece from the Shell Process**

The cast piece produced from the shell process showed some pitting on the surface. This must be due to the fact that moisture analyser was not available to check the water content of the prepared mould for its complete dryness before pouring in the molten metal and therefore some gases could have formed at the metal-mould interface which could have resulted in the pitting. It should also be added that the core produced by the shell core left a smooth internal hollow surface. Profilometer (for measuring the roughness value) was not available to examine the surface smoothness but values of different sections measured with micrometer screw gauge at the nice parts (inner diameter, thicknesses, heights to outer diameter of the various divisions) with the pattern after the casting, showed close tolerance.



## CHAPTER FIVE

### CONCLUSIONS AND RECOMMENDATIONS

#### **5.1 Conclusions**

The shell moulding technique has been employed with some modification to produce a pair of shell moulds whose efficacy was tested by using it to cast a machine component made up of cast iron. The method employed in the mould making deviated slightly from the usual method of investing the pre-coated sand or the sand-resin binder mix onto the heated pattern. The recommended binder, phenol formaldehyde (novolac type) could not be obtained and therefore substitute, phenol formaldehyde (resole type) was used and the pre-coated sand using the resole type lost its property of bonding to the hot metallic pattern. This might be due to the limited shelf life of resole resin [62] as the pre-coated sand was shelved for about two and a half weeks before using. This is in contrast to novolac type which is reported to have unlimited shell life [62].

The modified method consisted of mixing the pre-coated sand which failed to bond to the heated metal pattern surface with sodium silicate (4% by volume ) and applying the sodium silicate mixture to the cold metal pattern. CO<sub>2</sub> gas was then used to harden it after which it was dried in a furnace (the drying could not be completed because the furnace broke down). The modified method was facilitated by the fabrication of simple devices such as shell pattern imitator, opened-top metallic table, hand operating mixer, shell mould metallic pattern with ejectors, dump box and thin slender metallic rod for fastening shell pattern to the dump box. Some calcium stearate was also prepared locally and was used. Even though the resole type could not be used for the main mould it was successfully used for the core. The core was produced with freshly prepared pre-coated sand which was rammed into the hot core

box and the axis aerated by piercing a thin steel rod through it. It proved to be relatively hard and resistant like that of chromite core from silicate-CO<sub>2</sub> process.

The bonding of collapsed precoated resole – silica sand with sodium silicate proved that it could be used to modify the resole resin for better results. Collapsed precoated sand is not waste. It can be used again by making shell pattern imitator to go with the pattern at a maximum allowance of 10 mm from pattern surface and an opened – top metallic table and then ramming onto metal pattern before drying in oven. This can be duplicated for mass production.

Simple type of machine component was chosen to demonstrate how the shell mould could be realized. The shell core produced was able to withstand the hydrodynamic forces of the cast iron. The core used exhibited good strength, permeability, ability to withstand heat and above all excellent collapsibility when used in the main casting to demonstrate the developed process.

Once it was able to cast cast-iron it could possibly be used to cast other designed machine components and automobile parts. It could also be employed in the casting of aluminium, magnesium and other metals whose molten temperatures are lower than that of cast iron.

Silicone oil which is not available, as parting agent for hot pattern surface, was made available by using engine head gasket silicone sealant and mixing it with turpentine (the only best solvent on the market) which dissolved it with difficulty (vigorous shaken).

Some local binders as well as potential source of binders were also established. The production of phenol formaldehyde locally from cashew nut oil is possible as the raw materials are readily available in most parts of Ghana. Local binders could also be developed from cassava and corn as these are readily available in Ghana. Gum

Arabic is also another source of local binders that could be developed. The development of protein/peptide binders is also possible in the country.

### **Limitations**

- i. Inability to get small amount (about 5kg) of phenol formaldehyde novolac resin and hexamethyle tetramine could not enable better test to be made.
- ii. Very small quantity of resole resin was donated this could not enable sufficient investigations to be made .
- iii. Moisture analyzer was not available to test the moisture content of the mould before the admission of molten metal and this could be the main factor for the pitting on the cast piece.
- iv. Small tensile and compression testing machines were out of order to test the strength of the core produced
- v. Standard shell core machines were not available to adequately produced core with better surface finish
- vi. profilometer was readily available to test the surface roughness of the better surface parts of the casting.

### **5.2 Recommendations:**

1. Investment casting which is one of the main inputs in the shell moulding process is in its crude state of application, not engineering-wise, for producing bronze and brass artifacts. Further studies in needed locally to improve on it from the present state of using it to cast artefacts to using it to cast machine parts in metals like cast iron and aluminium. When this is mastered, it will serve as a very good beginning, and the future shell moulding (shell mould and shell core production) can rely heavily on it for more technological advancement.

2. There are a lot of binder sources in Ghana. The preparation of resins from this is interdisciplinary in nature and calls for experts in areas of chemistry, chemical and material engineering to research into sources mentioned earlier to come out with resins to suite foundry industry in Ghana. When this initiative is conducted, some machinery and engine parts could be produced at a lesser cost.
3. Phenol formaldehyde resin (especially the novolac type), calcium stearate, and other chemicals should be investigated in other to improve on it.
4. More research work with the phenol formaldehyde (resole type) should be carried out to see how best it could be modified with other local materials to further enhance the shell moulding process in Ghana.
5. Standard Test equipments like Ridsdale Dieter Shell Mould Tensile Accessory (for mold tensile specimen making), Laboratory Shell Core Piece Blower, Shell Strength Accessory Machine (for breaking the transverse shell test specimen), Peel Back Tester (for assessing the proportion of resin coated sand which peels away from the main body of the cured mould), a muller (solid sand mixer), Scanning Electron Microscope (SEM) and a small X-ray gadget should be made available to enhance the casting process. Furnace facilities need to be developed in Ghana.
6. Furthermore, for impact in foundry technology in the Ghanaian society, the University should be able to have an isolated block which deals with foundry works and be equipped with simple foundry equipments and instruments like those mentioned above for research and introduction of certain foundry findings to artisans.
7. Finally, the collected washed Wewe River sand was found to be suitable in this work. This is because the sand exhibited desired properties similar to pure silica sand

used in shell moulding. Thus, the sand therefore could also be recommended for future use of shell casting research by the university.



## **REFERENCES**

1. Ness, Arnold R (1995) "Russian foundries: facing the challenge of freedom".<http://www.allbusiness.com/manufacturing/fabricated-metal-product-manufacturing/539064-1.html>. (Accessed 2009 May 6)
2. European Commission Directorate-General JRC. Joint Research Centre. Institute for Prospective Technological Studies Sustainability in Industry, Energy and Transport. European IPPC Bureau. Integrated Pollution Prevention and Control. Reference Document on Best Available Techniques in the Smelters and Foundries Industry (July2004). Foundries BREF first draft. [www.natura.minenv.gr/batelv/Docs/Smelters%20and%20foundries\\_Exec\\_Sum.pdf](http://www.natura.minenv.gr/batelv/Docs/Smelters%20and%20foundries_Exec_Sum.pdf) (Accessed 2009 April 25)
3. A century of German founding. (A Century of Service 1902-2002) (Thursday, August 1 2002) [www.AllBusiness.com.htm](http://www.AllBusiness.com.htm). (Accessed 2009 April 25)
4. Vaishnavi Naik. (2008) "Foundry Clusters in India" [www.metalworld.co.in/focus/0107.pdf](http://www.metalworld.co.in/focus/0107.pdf).(Accessed: 2009 April 27)
5. The Importance of Iron Casting in the New Automotive Industry [http://www.metalcastingzone.com/index%20MetalCasting%20DIY%20Home\\_Casting.htm](http://www.metalcastingzone.com/index%20MetalCasting%20DIY%20Home_Casting.htm).(Accessed 2009 May 6)
6. A Write up on Indian Foundry Industry<http://www.stelexchangeindia.com/insidesteel/home/indianfoundryindustry.htm>.(accessed 2009 April 27)
7. Modern Casting (Dec, 2008). [http://www.entrepreneur.com/tradejournals/article/191316060\\_1.html](http://www.entrepreneur.com/tradejournals/article/191316060_1.html). (Accessed 2009 May 08)
8. H. Frederickson and U. Akerlind.(2006), "Material Processing during Casting" John Wiley and sons, Ltd. – pdf (accessed 23/7/2008).
9. Advance Automation for Space Missions-Appendix 4B-Wikisource.htm. 31/7/2008,drengco.com (accessed 23/7/2008)
10. Degamo, E. Paul. (1979) "Materials and Processes in Manufacturing 5th edition", p. 260, Collier Macmillan Pub. London -Component casting pdf (Accessed 18/6/2008)
11. Sand Casting-Google Image Search.htm (accessed 2008 October 6)
12. Fundamentals of metal casting. [http://www.metawebnews.com/howto/casting/casting.pdf\\_2008](http://www.metawebnews.com/howto/casting/casting.pdf_2008) –accessed 2008 October 10)
13. Investment Casting. [http://www.castingprocesses.com/LCL\\_Castings\\_Ltd\\_Malton.htm](http://www.castingprocesses.com/LCL_Castings_Ltd_Malton.htm) (accessed July 19, 2008)
14. Investment castings from Dongying Tuopu Precision Casting Co, Ltd -China castings manufacturer, supplier, exporter, factory-Internet material
15. Shell Moulding. [www.metawebnews.com/howto/shell-moulding/shell-moulding.htm-73k](http://www.metawebnews.com/howto/shell-moulding/shell-moulding.htm-73k) (accessed 2008)
16. Shell Mould Casting. Anand Concast Limited. [www.aclmetals.com](http://www.aclmetals.com) (accessed July 19, 2008)
17. Shell mould casting. Continuous selling item from Tong Yuan Castings Could. Ningbo Yinzhou Tongyuan Industry & Trade Co., Ltd

- <http://www.tradeeasy.com/supplier/513790/selling-leads/943870/shell-mold-casting.htm>(accessed July20, 2008)
18. Shell mould casts from Port Shell Moulding, LLC
  19. Binder Processes and Potential Emissions. Emission Estimation Technique Manual for Non-Ferrous Foundries Pp 12-14. [http://www.npi.gov.au/handbooks/approved\\_handbooks/pubs/f2nonfer.pdf](http://www.npi.gov.au/handbooks/approved_handbooks/pubs/f2nonfer.pdf) (accessed July 19, 2008)
  20. R. B. Gupta (Prof) (2002) "Foundry Engineering", Text Book for Engineering Degree and AMIE (India) Section B. Satya Prakashan, Tech India Publications. 16/7698, New Market, New Rohtak Road, New Delhi-110005
  21. A.M. Mikhailov (Edited by-),(1989) "Metal Casting" pp. 238-240 Mir Publishers
  22. Hard Mold Casting Processes, Ch.3,[http://74.125.155.132/search?q=cache:4x\\_zWgJgG6AJ:www.most.gov.mm/techuni/media/ME03022\\_68\\_90.pdf+pdf+of+shell+mould+binding&cd=49&hl=en&ct=clnk&gl=gh](http://74.125.155.132/search?q=cache:4x_zWgJgG6AJ:www.most.gov.mm/techuni/media/ME03022_68_90.pdf+pdf+of+shell+mould+binding&cd=49&hl=en&ct=clnk&gl=gh)
  23. Die castings -Pacific Die Casting Corp - Home.htm (accessed 23/7/2008).
  24. Fundamentals of metal casting –<http://www.Metalwebnews.com/howto/casting/casting.pdf> –(accessed 10/10/2008)
  25. Casting Kaiser Aluminium, Casting Properties and Characteristics of Molten Aluminium-Pig and Ingots Product Data, 1956, 1st edition. [http://www.energymanagertraining.com/foundries/pdf/overview\\_of\\_foundry\\_processes.pdf](http://www.energymanagertraining.com/foundries/pdf/overview_of_foundry_processes.pdf)
  26. a. R. D. Dhumal, (November 2007) "Shell Casts Out an Advanced Mould Technology" A. V. P. – Foundry , Ajay Metachem Pvt. Ltd) Metalworld, <http://www.metalworld.co.in/technology1107.pdf> (Accessed 20th June, 2009)b. R. D. Dhumal, (November 2007) "Shell Casts Out an Advanced Mould Technology" A. V. P. – Foundry , Ajay Metachem Pvt. Ltd) Metalworld, <http://209.85.229.132/search?q=cache:5XLZoaq46zcJ:www.metalworld.co.in/technology1107.pdf+shell+mould+formation+pdf&cd=12&hl=en&ct=clnk&gl=gh>(Accessed 20th June, 2009)
  27. Limitations of shell Moulding, Cleaner Production Manual for the Queensland Foundry Industry UNEP, 1999 p. 14  
[http://www.ecoefficiency.com.au/Portals/56/factsheets/foundry/ecofndry\\_process.pdf](http://www.ecoefficiency.com.au/Portals/56/factsheets/foundry/ecofndry_process.pdf) (accessed 2008 October 6)
  28. Shell Casting <http://www.themetalcasting.com/shell-mold-casting.html> (accessed 8/10/2009)
  29. Veinik, Albert I. (1968), 'Thermodynamics' for the Foundryman. Maclarens and Sons Ltd, London
  30. Industrial Mineral Resources of Ghana, (prepare sheet), Ghana Geological Survey Department. 2009. Obtained 23<sup>rd</sup> October, 2009
  31. Geological Survey bulletin No. 27 .The Geology of  $\frac{1}{4}^{\circ}$  Field sheet No.127 Kumasi N.W latitude  $6^{\circ}45'$ -  $7^{\circ}00'$  N. longitude  $1^{\circ}45'$ -  $2^{\circ}00'$  W by P. A.Moon and published by Ministry of Information and Broadcasting on behalf

- of the Geological Survey Dept. and printed by the Government printing Department, 1962.
32. Ahmad N, Ahmet R. Mermut. Vertisols and Technologies for their Management. Google Books p. 143, [http://books.google.com.gh/books?id=WKkrR4xo8iIC&pg=PA143&lpg=PA143&dq=olivine+sand+areas+in+ghana&source=bl&ots=sGdf9ve1Lo&sig=9rOYEkJ4fXbUp0FH0xsh3XMUSeU&hl=en&ei=NIn4SvzpJ9iRjAf2wsHVCQ&sa=X&oi=book\\_result&ct=result&resnum=3&ved=0CAwQ6AEwAkgU#](http://books.google.com.gh/books?id=WKkrR4xo8iIC&pg=PA143&lpg=PA143&dq=olivine+sand+areas+in+ghana&source=bl&ots=sGdf9ve1Lo&sig=9rOYEkJ4fXbUp0FH0xsh3XMUSeU&hl=en&ei=NIn4SvzpJ9iRjAf2wsHVCQ&sa=X&oi=book_result&ct=result&resnum=3&ved=0CAwQ6AEwAkgU#)
  33. General characteristics of casting processes. [www.metalcasting.com](http://www.metalcasting.com) (accessed 10/10/2008)
  34. Stripping of a Pattern, Burnham Foundry LLC <http://www.burnhamfoundry.com/casting> (accessed July 19, 2008)
  35. F.R. Irvine,(1961) "Woody Plants of Ghana", p. 323, London, Oxford University Press
  36. Nuhu A. Ademoh and A.T. Abdullahi (2009) "Assessment of foundry properties of steel casting sand moulds bonded with the grade 4 Nigerian acacia species (gum arabic)" International Journal of Physical Sciences Vol. 4 (4), pp. 238-241, April, 2009 ISSN 1992 - 1950 © 2009 Academic Journals Accepted April 9, 2009 <http://www.academicjournals.org/IJPS> (accessed 12th June, 2009)
  37. [http://www.alibaba.com/countrysearch/NG-suppliers/Gum\\_arabic.html](http://www.alibaba.com/countrysearch/NG-suppliers/Gum_arabic.html) (accessed July 19, 2009)
  38. Abbiw, Daniel K., (1990) "Useful plants in Ghana" p. 16. Intermediate Technology Publications. Ltd, 103/05 Southampton Row WC 1B4HH, UK
  39. Picture of acacia Senegal bark. [http://www.google.com.gh/imgres?imgurl=http://www.minerva.unito.it/Chimica%26Industria/Dizionario/Supplementi02/AdditiviAlimentari/Immagini/GommaArabica.jpg&imgrefurl=http://www.minerva.unito.it/Chimica%26Industria/Dizionario/Supplementi02/AdditiviAlimentari/SchedaE414.htm&h=390&w=277&sz=68&tbnid=TfZr4WWx0LeSEM:&tbnh=123&tbnw=87&prev=/images%3Fq%3Dpictures%2Bof%2Bacacia%2Bsene gal&hl=en&usg=\\_\\_VBwpzbBfXkeZUDsFBtu48DU7RAk=&ei=tUb4StvgLtq5jAeRic3UCQ&sa=X&oi=image\\_result&resnum=2&ct=image&ved=0CAkQ9QEwAQ.](http://www.google.com.gh/imgres?imgurl=http://www.minerva.unito.it/Chimica%26Industria/Dizionario/Supplementi02/AdditiviAlimentari/Immagini/GommaArabica.jpg&imgrefurl=http://www.minerva.unito.it/Chimica%26Industria/Dizionario/Supplementi02/AdditiviAlimentari/SchedaE414.htm&h=390&w=277&sz=68&tbnid=TfZr4WWx0LeSEM:&tbnh=123&tbnw=87&prev=/images%3Fq%3Dpictures%2Bof%2Bacacia%2Bsene gal&hl=en&usg=__VBwpzbBfXkeZUDsFBtu48DU7RAk=&ei=tUb4StvgLtq5jAeRic3UCQ&sa=X&oi=image_result&resnum=2&ct=image&ved=0CAkQ9QEwAQ.)
  40. Acacia Seyal (Red acacia) [http://en.wikipedia.org/wiki/Acacia\\_seyal](http://en.wikipedia.org/wiki/Acacia_seyal) (Accessed: 28th July, 2009)
  41. Flora of Abaco [http://www.google.com.gh/imgres?imgurl=http://drralph.net/coconut\\_palm\\_x.jpg&imgrefurl=http://drralph.net/Flora\\_of\\_Abaco.html&h=352&w=350&sz=53&tbnid=qMhg\\_CgkAKThtM:&tbnh=120&tbnw=119&prev=/images%3Fq%3Dombretum%2Bgrandiflorum%2Bpictures&hl=en&usg=z23T0iu57HI5krXwLXGwI1ytX Y=&ei=0575Spe2Ic3RjAf586y6Cw&sa=X&oi=image\\_result&resnum=4&ct=image&ved=0CA0Q9QEwAw](http://www.google.com.gh/imgres?imgurl=http://drralph.net/coconut_palm_x.jpg&imgrefurl=http://drralph.net/Flora_of_Abaco.html&h=352&w=350&sz=53&tbnid=qMhg_CgkAKThtM:&tbnh=120&tbnw=119&prev=/images%3Fq%3Dombretum%2Bgrandiflorum%2Bpictures&hl=en&usg=z23T0iu57HI5krXwLXGwI1ytX Y=&ei=0575Spe2Ic3RjAf586y6Cw&sa=X&oi=image_result&resnum=4&ct=image&ved=0CA0Q9QEwAw) (accessed 10 Nov., 2009)

42. Pooler, F. Bongers, F.N. Kouamé, W.D. Hawthorne –Editors (2004) “An Ecological Atlas of Woody Plant Species”
43. Development Document for Effluent Limitations Guidelines Standards, Smitheries-and-Foundries Bref Reports: Manual of Standard Industrial Classification, 1967..... Epoxy Resins. Applied to Metal Section xlv ----- section xvi pp 543-562 [174, Brown, 2000], [175, Brown, 1999] <http://www.epa.gov/guide/metalcasting/files/guidelines13.pdf>
44. Cassava /Tapioca Starch.  
<http://209.85.229.132/search?q=cache:DV3Ceps8SHQJ:www.sulit.com.ph/index.php/view%2Bclassifieds/id/1660308/Tapioca%2B/%2BCassava%2BStarch+is+cassava+starch+used+as+foundry+binder%3F&cd=2&hl=en&ct=clnk&gl=gh#>.
45. Satin, Morton (Chief), Functional properties of starches, Agro-Industries and Post-Harvest Management Service,FAO Agricultural and Food Engineering Technologies Service.<http://www.fao.org/ag/ags/agsi/starch41.htm> (accessed 6/10/09)
46. Xia Zhou, Jinzong Yang and Guohui Qu (2006) “Study on synthesis and properties of modified starch binder for foundry” Dalian Heavy Machinery Cast Iron Limited Company, Dalian 116023, PR China Copyright © 2006 Elsevier B.V. accepted 27 October 2006. Available online 5 December 2006
47. Peptide/Protein Waste Materials Like Binders Of Foundry Sands Daniela Kramarova<sup>1</sup>, Frantisek Bunka<sup>1</sup>, Jiri Brandstetr<sup>2</sup>, Karel Rusin<sup>3</sup> and Ignac Hoza<sup>1</sup>[www.29eps.com/docs/0089.doc](http://www.29eps.com/docs/0089.doc))
48. Phenolic Novolac and Resol Resins: The Plenco Difference - Plastics Engineering Company (PLENCO) 3518 Lakeshore Road, P. O. Box 758 Sheboygan, WI 53082-0758 U.S.A Phone (920) 458-2121 Fax (920) 458-1923
49. Encyclopedia of Chemistry, information service p1
50. <http://www.chemie.de/lexicon/e/Cashew/> (accessed 2nd Dec.2009)
51. Tropical Plant Database, Data File for CAJUEIRO (anacardium occidentale i.e. Cashew Nut) p1<http://www.rain-tree.com/cajueiro.htm> (accessed 2nd Dec.2009)
52. Small Scale Cashew nut Processing. Uses of cashew, Ch3 p2  
<http://www.fao.org/inpho/content/documents/vlibrary/ac306e/ac306e04.htm> (accessed 2nd Dec.2009)
53. Oller Riera, Antonio; Fellis Prior; Armando and Iglesias Hernandez, Luis (Inventors), (2006) – Patent: Use of Modified Phenolic Resins in Shell Moulding Processes, (WO/2006/010777), World Intellectual Property Organization (WIPO)
54. Cashew Development Project, Status of Ghana Cashew Industry,published after 2007  
<http://www.ghanacashewproducts.com/documents/Articles>Status%20of%20Cashew%20Industry.pdf>(accessed 9<sup>th</sup> Nov. 2009)
55. Castings-The Journal of the Foundryman Vol. 25 p. 33 Nov /Dec 79

56. Oprasic, S., Omanovic, M., Mijanovic, K., Pasalic,I., (2003) "Importance of The ISO Standards for Casting Industry In Bosnia and Herzegovina". *Journal of Environmental Protection and Ecology* 4, No 2, 471-476 (2003) Environmental legislation, E-mail: senadoprasic@yahoo.com
57. Metal Casting...An Environmental Success Story American Foundrymen's Society <http://www.afsinc.org> (accessed 10<sup>th</sup> Nov,2009)
58. Clegg, A., (1991) "Precision Casting Processes", Cleaner Production in the Queensland Foundry Industry Project SummaryLoughborough University of Technology, Leicestershire, UK, Pergamum Press, Oxford
59. Luther, N (1999), "Metalcasting and Moulding Processes", Luther & Associates Cleaner Production in the Queensland Foundry IndustryProject Summary Available at: [http://www.Castingsource.com/articles/moulding\\_process.asp](http://www.Castingsource.com/articles/moulding_process.asp) (accessed, August 1999)
60. Success in GRP 12edition  
[http://www.kcmouldings.co.uk/K\\_C\\_Mouldings\\_Catalogue.pdf](http://www.kcmouldings.co.uk/K_C_Mouldings_Catalogue.pdf) (accessed Jan 2010)
61. Core Making ,1985-Training Practice for Basic Foundry Training, BTF 13-Broad Based Training- Engineering Industry Training Board, EITB- p. 2
62. Ramana Rao, T.V. Google books (principle and practice)-calculations on phenolic formaldehyde shell moulding p58 <http://books.google.com?gl=id=8JdDzipPGEIC&pg=calculation+on+phenolic+>
63. Estimation Technique Manual for Non-Ferrous Foundries Pp 12-14
64. Scott, W., Bates, C., and James, R (1977) "Chemical Emissions from Foundry Molds", AFS Transactions. Vol. 85, 1977, pp 203-208.
65. Shell Moulding Materials - GoldStar powder [http://www.goldstarpowders.com/files/shell\\_moulding.pdf](http://www.goldstarpowders.com/files/shell_moulding.pdf) (accessed 28<sup>th</sup> November, 2010)
66. Protobind <sup>TM</sup> 1000. [www.asianlining.com/pages/Protobind\\_1000.pdf](http://www.asianlining.com/pages/Protobind_1000.pdf) (Accessed 6th August,2009)
67. Kimura K. (1993), "Effect of the shell mold binder on the formation of abnormal graphite in spheroidal graphite iron castings", Journal, 1993 vol. 65, no3, pp. 204- v
68. Heat Cured Foundry Binder Systems and Their Uses US Patent; Chang, Ken, K.; (US). Dando, Thomas, E.; (US).Haugse, A., Leonard; (US).21.11.1996 Pub. No.: WO/1996/036448 International Application No.: PCT/US1996/007022 Filing Date: 15 05 1996 <http://www.wipo.int/pctdb/en/wo.jsp?wo=1996036448>(accessed 17th July, 2009)
69. Comparison of Several Casting Method  
[http://www.ecoefficiency.com.au/Portals/56/factsheets/foundry/ecofndry\\_process.pdf](http://www.ecoefficiency.com.au/Portals/56/factsheets/foundry/ecofndry_process.pdf) (accessed 8th March, 2009)
70. Cleaner Production Manual for the Queensland Foundry Industry November, 1999  
[http://www.epa.gov/compliance/resources/publications/assistance/sectors/note\\_books/metcstsna.pdf](http://www.epa.gov/compliance/resources/publications/assistance/sectors/note_books/metcstsna.pdf) p. 5 (accessed 20<sup>th</sup> March, 2010)

71. [http://www.energymanagertraining.com/foundries/pdf/overview\\_of\\_foundry\\_processes.pdf](http://www.energymanagertraining.com/foundries/pdf/overview_of_foundry_processes.pdf) (accessed 8th March, 2009)
72. [http://www.roymech.co.uk/Useful\\_Tables/Manufacturing/Casting.html](http://www.roymech.co.uk/Useful_Tables/Manufacturing/Casting.html)  
(Accessed 10/10/2008)
73. Veinik, A.I. (1960), Theory of solidification of casting, Mashgiz, McLaren and Sons Ltd, London
74. Rundman, Karl B. (Prof), Metal Casting (Reference Book for MY4130)Dept. of Material Science and Engineering, Michigan Tech. University



## APPENDICES

### Appendix A

#### A1.0 BINDER PROCESSES AND POTENTIAL EMISSIONS [63]

The new Clean Air Act Amendments of 1990 (CAAA) legislation requires more stringent control of the emission of the 189 hazardous air pollutants listed under Title III of the CAAA. One of the main sources for these HAPs from foundries are the binders used in core and mold production. Although not counted as a resin binder, green sand may be another source. All of these sources are discussed below with their potential emissions.

There are three main classes of binder systems: heat activated, no bake, and cold box. The heat activated class includes several different binder systems. Among these are the hot box, shell, warm box, and core oil.

#### **Hot Box**

This process is initiated by blowing a resin and a sand mixture into a heated corebox. The curing process begins immediately upon contact with the heated corebox. Operating temperatures of the box are in the range of 232.2- 287.8 °C. Emissions occur during the baking of the core and when the core is removed from the box.

Binders that are in the hot box category include phenolic resins, furan resins, and combinations of the two. These resins can also be modified by the addition of urea. The phenolic resins are phenol formaldehyde polymers. Sometimes urea formaldehyde is added in order to improve the tensile strength. The furan resins are mixtures of furfuryl alcohol and urea formaldehyde polymers.

The chemical reaction for the phenolic resin of this process involves reacting phenol with an excess of formaldehyde and an aqueous weak acid (usually ammonium

chloride). The acid provides the hydrogen ions which catalyze the reaction. The resin is allowed to polymerize until the reaction is stopped, still in the liquid state.

The cure time of the resin binding the sand is a function of the temperature of the corebox and the catalyst type. The reaction is an exothermic reaction, therefore, the resin continues to cure even after it is removed from the corebox. Hot box binders have a high hot strength and fewer shakeout problems than other binders.

Hot-box binders decompose during the casting process and emit possible pollutants covered by the CAAA. Formaldehyde is a concern because it is present in excess.

Table A is a list of possible HAP emissions covered by the CAAA when pouring metal in molds made by the hot box process.

Table A.Potential HAP Emissions from Hot Box Binders.

Phenols	Formaldehyde	m-Xylene	o-Xylene
Benzene	Toluene	Aniline	Naphthalene
Hydrogen cyanide	Acrolein	Acetaldehyde	Hydrogen sulfide

The laboratory experiments performed by Scott et al. [64] yielded information on the amounts of chemicals released during the pouring and cooling process. They obtained emissions data for 12 systems: green sand, dry sand, silicate-ester, core oil, alkyd isocyanate, phenolic urethane, phenolic nobake, low N<sub>2</sub> furan-H<sub>3</sub>P0<sub>4</sub>, medium N<sub>2</sub> furan TSA, furan hot box, phenolic hot box, and shell (phenolic). The test method used in their laboratory experiments was the quasi-stack method. The hot-box test molds were prepared using an irregular gear pattern designed by AFS Committee 80F. The gear casting with the gating system and riser weighed about 40 Kg and was poured in a mold weighing approximately 100 Kg. The castings were poured with a

gray iron at 1450 °C. The concentrations were measured in a constant 1000 L/min flow of gas through the stack. The sand-resin mixture was cured against a heated pattern and then baked to ensure proper curing. Table 2 lists the results from their hot-box experiments.

The Chemistry of the Phenol formaldehyde Resins from Wikipedia Source:

The earliest commercial synthetic resin is based on a Phenol formaldehyde resin(PF) with the commercial name Bakelite, and is formed from an elimination reaction of phenol with formaldehyde .

Phenol is reactive towards formaldehyde at the ortho and para sites (sites 2, 4 and 6) allowing up to 3 units of formaldehyde to attach to the ring. This forms a hydroxymethyl phenol. The hydroxymethyl group is capable of reacting with either another free ortho or para site, or with another hydroxymethyl group. The first reaction forms a methylene bridge, and the second forms an ether bridge.

Phenol formaldehyde resins, as a group, are formed by a step-growth polymerization reaction which may be either acid or base catalysed. The pathway the reaction follows varies depending on the catalyst type used;

Acid catalysed

Acid catalysed phenol formaldehyde resins are made with a molar ratio of formaldehyde to phenol of less than one and are called novolacs. Owing to the molar ratio of formaldehyde to phenol, they will not completely polymerize without the addition of a crosslinking agent. Novolacs are commonly used as photoresists;

Base catalysed

Common cross-linker used for this resin is paraformaldehyde. Base catalysed phenol formaldehyde resins are made with a formaldehyde to phenol ratio of greater than one (usually around 1.5). Phenol, formaldehyde, water and catalyst are mixed in the

desired amount, depending on the resin to be formed, and are then heated. The first part of the reaction, at around 70 °C, forms hydroxymethyl phenols. This results in a thick reddish-brown goo, the resin.

The rate of the base catalysed reaction initially increases with pH, and reaches a maximum at approx. pH = 10. The reactive species is the phenolic anion formed by deprotonation of phenol. The negative charge is delocalised over the aromatic ring, activating sites 2, 4 and 6, which then react with the formaldehyde.

Formaldehyde in solution does not exist as the aldehyde, but instead a dynamic equilibrium is formed creating a range of methylene glycol oligomers, and the concentration of the reactive form of formaldehyde depends on the exact conditions (temperature, pH) under which the reaction occurs. Thus the reaction rate law describing phenol and formaldehyde is not a simple one, and the chemical kinetics are highly complex; Hydroxymethyl phenols will crosslink on heating to around 120 °C to form methylene and methyl ether bridges. At this point the resin is starting to crosslink, to form the highly extended 3-dimensional web of covalent bonds which is typical of polymerised phenolic resins. It is this highly crosslinked nature of phenolics which gives them their hardness and their good thermal stability and which makes them impervious to most chemical attack and solvation. It is also the reason they are called thermosets.

#### Crosslinking and the phenol/formaldehyde ratio

Phenol can react with formaldehyde at any one of three possible sites, and formaldehyde can react with up to two phenols. Thus the theoretical functionality of phenol is three and the theoretical functionality of formaldehyde is two. The actual functionality that is found in the polymer depends on the phenol: formaldehyde ratio.

By adding a small amount of acid catalyst to phenol (something miscible, such as p-toluene sulphonic acid) and slowly adding formaldehyde, the formaldehyde will react between two phenols to form a methylene bridge, creating a dimer. This dimer is the substance bisphenol F, which is itself an important monomer in the production of epoxy resins. At higher concentrations of these dimers, there is the possibility of generating trimers, tetramers and higher oligomers. This is what occurs during the formation of bakelite. The average molecule generated depends on the ratio of formaldehyde to phenol. In bakelite this is usually around 0.8, and so, with 5 phenols for every 4 formaldehydes the average molecule is a pentamer (with respect to phenol).

When the molar ratio of formaldehyde: phenol reaches one, in theory every phenol is linked together via methylene bridges, generating one single molecule, and the system is entirely crosslinked. This is why bakelites ( $F: P < 1$ ) don't harden without the addition of a crosslinking agent, and why resins with the formula  $F: P > 1$  will [9]. Hexamethylene tetramine or Hexamine, in short, is one kind of such hardener. When Hexamine is added to Novolac (bakelite type) resin, it reacts to form methylene and dimethyl amino bridge at  $\geq 180$  deg C. This is called polymerization.

### A1.1 Shell Moulding Materials [65]

#### a. Refractory Products

**Mullite 55** is a high Alumina content refractory material for the back-up Slurry and Stucco.

**Zirconium Silicate** High purity sands are used for the specialist manufacture of Precision Casting grade materials for primary Slurries and Stuccos.

**Fused Silica** High purity Amorphous Silica is used to manufacture all grades suitable for both Slurry and Stucco applications.

#### b. Repair Products

**Rhoseal** is designed for shell repair in Aerospace applications where high purity is a pre-requisite.

**Silroc** is for all commercial shell repair applications.

Table A1.0 SHELL REPAIR PRODUCTS

Repair Product	Iron Content	Lead Content	Bismuth Content	Uses
RHOSEAL	< 1500ppm	< 50ppm	< 1ppm	High purity Aerospace
SILROC	0 - 1.5%	0.009%	N.A.	All forms of commercial casting”

[65]

#### A1.2 Protobind™ 1000 based Shell Moulding PF Resins [66]

Asian Lignin Manufacturing Pvt. Ltd

Asian Lignin Manufacturing Pvt. Ltd. has extensively worked on the development and optimization of PF resins based on Protobind™1000 for several applications, including shell moulding resins. Although various substitution levels are possible, 15% phenol replacement is recommended as a starting point that offers excellent performance and cost savings as compared to the use of phenol.

Resins based on Protobind™1000 have properties that are comparable to those of standard shell moulding PF resins. Protobind™1000 modified shell resin is a novolac type phenolic resin developed to maintain hot tensile strength as well as gas content at same addition level as control PF shell moulding resin. The resins based

this product are ideal binders for cores, which are surrounded by heavy metal sections.

### **Effect of the shell mold binder on the formation of abnormal graphite in Spheroidal Graphite Iron Castings**

Spheroidal graphite iron cast in shell mold sometimes has a skin layer containing abnormal graphite structure. By gas analysis, CO<sub>2</sub>, CH<sub>4</sub> and CO gases were detected in the evolved gas from the shell mold on casting. The formation of abnormal graphite layer was depressed by the addition of Al and Ca powder to the mold. From these experimental results, it was considered that CH<sub>4</sub> and CO gas might react with air in mold and form CO<sub>2</sub> and H<sub>2</sub>O gas, and they would oxidize Mg in iron, so the spherodization of graphite would be faded. Al and Ca powder might depress the oxygen potential in mold, and the fading would be avoided [67].

A1.3 HEAT CURED FOUNDRY BINDER SYSTEMS AND THEIR USES US Patent; CHANG, Ken, K.; (US).DANDO, Thomas, E.; (US).HAUGSE, A., Leonard; (US).21.11.1996 Pub. No.: WO/1996/036448 International Application No.:PCT/US1996/007022

A heat cured foundry binder system free of nitrogen and formaldehyde which prevents casting defects is useful in the fabrication of a mold for metal casting and comprises a furan resin and a curing catalyst composition containing water, copper aryl sulfonate, aryl sulfonic acid and a copper halide; optionally with polyvinyl alcohol, furfuryl alcohol, polyvinyl acetate and resorcinol pitch a /or bisphenol A tar [68]

## Major Cashew Production Zones

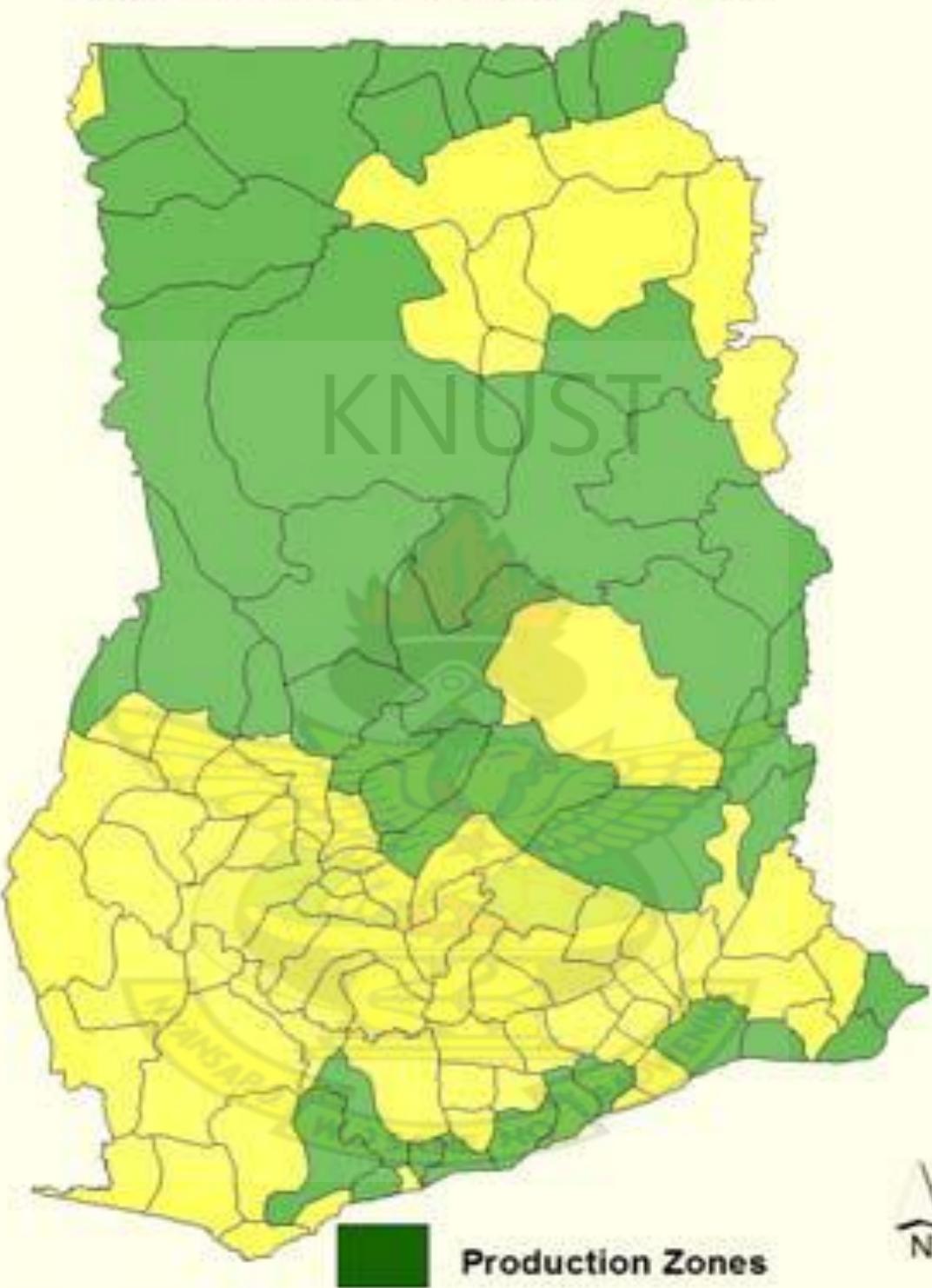


Figure.A1 Major Cashew producing areas in Ghana [54]

Table A 1.1 Total number of foundries (in production units) of a country in the area of iron, steel and non-ferrous metals in 2008.

COUNTRY	IRON	STEEL	NON-FERROUS	TOTAL
Austria	12	4	35	51
Belgium	16	9	10	35
Brazil	589	184	621	1,394
Canada (A)	55	28	83	166
China (A)	n.d	n.d	n.d	26,000
Croatia	13	4	21	38
Czech Republic	89	28	59	176
Denmark (A)	n.d	8	10	18
Finland	14	6	12	32
France	108	37	337	482
Germany	201	53	342	596
Great Britain	197	46	240	483
Hungary (A)	42	27	143	212
India	n.d	n.d	n.d	4,550
Italy	183	27	966	1,176
Japan	456	77	1169	1,702
Korea	510	145	220	875
Lithuania (A)	8	3	5	16
Mexico (A)	n.d	n.d	n.d	1,500
Netherlands(B)	n.d	16	5	21
Norway	7	3	15	25
Poland	n.d	185	245	430
Portugal	49	10	40	99
Romania	76	57	87	220
Russia	n.d	n.d	n.d	1,650
Slovenia	15	5	58	78
Slovakia (A)	12	7	32	51
South Africa(A)	87	51	117	255
Spain	62	32	55	149
Sweden	36	13	83	132
Switzerland(A)	17	3	32	51
Taiwan	478	40	330	848
Thailand (A)	230	26	220	476
Turkey	752	71	443	1,266
Ukraine (C)	400	233	437	960
U.S.	554	234	1342	2130

(A)2006 data (B) 2004 data (C) 2002 data Census of World Casting Production-2007  
(metric tons) Country Gray Ductile Malleable Steel [7]

## OVERVIEW OF FOUNDRY PROCESSES:

Table A1.2 Comparison of Several Casting Methods

	Sand casting	Die casting	Sand–shell	Investment casting
Tool costs	Low	High	Average	Average
Unit costs	Average	Low	Average	High
Maximum casting weight	over 1 tonne	30 kg	100 kg	45 kg
Thinnest section castable (mm)	2.5	0.8	2.5	1.6
Typical dimensional tolerance (mm)	0.3	0.25	0.25	0.25
Relative surface finish	Fair to good	Best	Good	Very good
Relative mechanical properties	Good	Very good	Good	Fair
Relative ease of casting complex designs	Fair to good	Good	Good	Best
Relative ease of changing design in production	Best	Poorest	Fair	Fair
Metal options	Most	Low	Average	High

Note: Actual casting characteristics vary depending upon the metal uses, casting geometry and other factors.

Sources: USEPA (1998) and Hitchener (1999)  
[69]

Table A1.3 Comparison of some Casting Methods

Metal Casting Industry Comparison of Casting Methods (approximate to and depending upon the metal)			Industrial Process Description		
Property	Green sand casting	Permanent Mould Cast	Die casting	Sand-Shell CO <sub>2</sub> -Core Casting	Investment casting
Relative cost in quantity	low	low	lowest	Medium high	highest
Relative cost for small numbers	lowest	high	highest	Medium high	medium
Permissible weight of casting	up to about 1 ton	100 lbs	60 lbs	Shell: Ozs-250 lbs CO <sub>2</sub> : ½ lbs-tons	Ozs - 100 lbs
Thinnest section castable, inches	1/10	1/8	1/32	1/10	1/16
Typical dimensional tolerance, inches (not including parting lines)	0.012	0.03	0.01	0.01	0.01
Relative surface finish	fair to good	good	best	Shell: good CO <sub>2</sub> : fair	very good
Relative mechanical properties	good	good	very good	good	Fair
Relative ease of casting complex designs	fair to good	fair	good	Good	Best
Relative ease of changing design in production	best	poor	poorest	Fair	Fair
Range of alloys that can be cast	unlimited	copper base and lower melting point metals preferable	aluminium base and lower melting point metals preferable	unlimited	Limited

Source: American Foundrymen's Society, 1981 [70]

Table A1.4 General Characteristics of Casting

Types of casting	Sand	Shell	Eva pora tive patt ern	Plast er	Inves tmen t	Perm anent mold	Die	Centrif ugal
Typical materials cast	All	All	All	Non ferrous (Al, Mg, Zn, Cu)	All	All	Non ferrous (Al, Mg, Zn, Cu)	All
Weight (kg): minimum maximum	0.01 No limit	0.01 100+	0.01 100+	0.01 50+	0.001 100+	0.1 300	<0.01 50	0.01 5000+
Typ. surface finish ( $\mu mR_a$ )	5-25	1-3	5-25	1-2	0.3-2	2-6	1-2	2-10
Porosity <sup>1</sup>	3-5	4-5	3-5	4-5	5	2-3	1-3	1-2
Shape complexity <sup>1</sup>	1-2	2-3	1-2	1-2	1	2-3	3-4	3-4
Dimensional accuracy <sup>1</sup>	3	2	3	2	1	1	1	3
Section thickness (mm): minimum maximum	3 No limit	2 -	2 -	1 -	1 75	2 50	0.5 12	2 100
Typ. dimensional tolerance (mm/mm)	1.6-4 mm (0.25 mm for small)	$\pm 0.0$ 03		$\pm 0.00$ 5- 0.010	$\pm 0.0$ 05	$\pm 0.015$	$\pm 0.001$ -0.005	0.015
Cost <sup>1,2</sup> Equipment Pattern/die Labor	3-5 3-5 1-3	3 2-3 3	2-3 2-3 3	3-5 3-5 1-2	3-5 2-3 1-2	2 2 3	1 1 5	1 1 5
Typical lead time <sup>2,3</sup>	Days	Weeks	Weeks	Days	Weeks	Weeks	Weeks - month s	Months
Typical production rate <sup>2,3</sup> (parts/mold-hour)	1-20	5-50	1-20	1-10	1-1000	5-50	2-200	1-1000
Minimum quantity <sup>2,3</sup>	1	100	500	10	10	1000	10,000	10-10,000

Notes: 1. Relative rating, 1 best, 5 worst. For example, die casting has relatively low porosity, mid- to low shape complexity, high dimensional accuracy, high equipment and die costs and low labor costs. These ratings are only general; significant variations can occur depending on the manufacturing methods used.

2. Data taken from Schey, J.A., “Introduction to Manufacturing Processes”, 3rd edition, 2000.

3. Approximate values without the use of rapid prototyping technologies.

Table A1.5 Summary of casting processes

Type of Process	Labour cost per unit	Equipment Cost	Surface finish $\mu\text{m}$ CLA	Accuracy - mm	Minimum Section mm
Sand (green)	Medium	low	500 -1000	$\pm 2.5$	5.0
Shell	Low	medium	100 -300	$\pm 0.25$	2.5
Centrifugal	Low	medium	100 -500	$\pm 0.7$	8.0
Investment	High	medium	25 -125	$\pm 0.06$ - 25mm sect	0.6
Diecasting Gravity	Low	medium	100 -250	$\pm 0.4$ +.05 per 25mm	2.5
Diecasting Low Press	Low	high	40 -100	$\pm 0.05$ + 0.05 per 25mm	1.2
Diecasting Pressure	very low	very high	40 -100	$\pm 0.05$ + 0.05 per 25mm	0.5
Continuous	Low	high	100 -200	$\pm 0.12$ per 25mm	8.0

[72]

Table A 1.6 Some Casting summary and Processes

Proces	Typical materials cast	Weight in kg	Typical surface finish ( $\mu\text{m}$ , Ra)	Porosity*	Shape complexity*	Dimensional accuracy*	Section thickness in (mm)	Process	Typical materials cast
Sand	All	0.05	No limit	5-25	4	1-2	3	3	No limit
Shell	All	0.05	100+	1-3	4	2-3	2	2	-
Expendable mould pattern	All	0.05	No limit	5-20	4	1	2	2	No limit
Plaster mould	Non ferrous (Al, Mg, Zn, Cu)	0.05	50+	1-2	3	1-2	2	1	-
Investment	All (High melting pt.)	0.005	100+	1-3	3	1	1	1	75
Permanent mould	All	0.5	300	2-3	2-3	3-4	1	2	50
Die	Non ferrous (Al, Mg, Zn, Cu)	<0.05	50	1-2	1-2	3-4	1	0.5	12
Centrifugal	All	-	5000+	2-10	1-2	3-4	3	2	100
*Relative rating: 1 best, 5 worst									
Note: these ratings are only general; significant variations can occur, depending on the methods used.									

Table A 1.7 Types of Patterns and Moulds Used in the casting Process

**Major Casting Techniques**

<b>Die casting</b>	<b>Sand casting</b>	<b>Shell casting</b>	<b>Investment casting and lost foam casting</b>
Permanent die -ve shape	Permanent pattern +ve shape	Permanent pattern +ve shape	Permanent die (optional) -ve shape Temporary pattern +ve shape
	Temporary mould -ve shape	Temporary mould -ve shape	Temporary mould -ve shape
Final casting +ve shape	Final casting +ve shape	Final casting +ve shape	Final casting +ve shape

Adapted from [69]

Table A2.0: Survey of Various Resin Types and Their Applicability

July 2004 KV/EIPPCB/SF\_BREF\_FINAL

Harden-ing	Resin type ("commercial name")	Mould Product-ion	Core Product-ion	Curing Temp-erature	Hard-en-ing time (*)	Metal types	Size of series
Cold-setting	Furan	Medium to large	Some	10 – 30 °C	10 – 120 min	Ferrous + Nonferrous	Small to large
	Phenolic	Large	No	10 – 30 °C	10 – 180 min	Ferrous	Small to large
	Polyurethane ("Pepset/Pentex")	Small to medium	Some	10 – 30 °C	5 – 60 min	Ferrous + Nonferrous	Small to large
	Resol - ester ("Alfaset")	Small to Large	Some	10 – 30 °C	5 – 400 min	Ferrous + Nonferrous	Small to large
	Alkyd oil	Large	Some	10 – 30 °C	50 min	steel	Small
	Silicate - Water glass	Medium to large	No	10 – 30 °C	1 – 60 min	Ferrous + Nonferrous	Small to Medium
Gas-hardening	Phenolic/Furan 1 ("Hardoxy")	Small	Yes	10 – 30 °C	<60 s	Ferrous + Nonferrous	All
	Polyurethane ("Cold-box")	Small	Yes	10 – 30 °C	<60 s	Ferrous + nonferrous	All
	Resol ("Betaset")	Small	Yes	10 – 30 °C	<60 s	Ferrous + Nonferrous	All
	Acryl/Epoxy ("Isoset")	No	Yes	10 – 30 °C	<60 s	Ferrous + Nonferrous	All
	Silicate	Small	Yes	10 – 30 °C	<60 s	Ferrous + Nonferrous	All
Thermosetting	Oil	Small	Yes	180 – 240 °C	10 – 60 min	Ferrous	Small

	"Warm-box"	Seldom	Yes	150 – 220 °C	20 – 60 s	Ferrous	Medium to large
	"Hot-box"	Seldom	Yes	220 – 250 °C	20 – 60 s	Ferrous + Nonferrous	Medium to large
	"Croning"	Yes	Yes	250 – 270 °C	120 – 180 s	Ferrous + Nonferrous	Large
(*) i.e. the release time - the time in which the mould/core has gained sufficient strength to be released from the pattern							
1 Not applied for capacities <20 tonnes /day							

[Vito, 2001]

Table A2.1 Quantities of Chemicals Released in the Shell Process.

Chemical	Concentration (mg/ m <sup>3</sup> )
Sulfur dioxide	30.0
Hydrogen sulfide	0.8
Hydrogen cyanide	90.0
Ammonia	33.0
Nitrous oxides	8.5
Formaldehyde	0.3
Acrolein	0.4
Total Aldehydes	<5
Total Aromatic Amines	20
Benzene	57
Toluene	24
m-Xylene	5
o-Xylene	<1
Naphthalene	«1
Phenol	21.0
Bischloromethyl ether	<10 ppb

[43]

Table A 2.2 Quantities of Chemicals Released in the Hot Box Process.

Chemical Hot Box Binders	Concentration (mg/m <sup>3</sup> ) from Furan Hot Box	Phenolic Hot Box
Sulfur dioxide	2.8	1.2
Hydrogen sulfide	1.9	0.3
Hydrogen cyanide	110.0	39.0
Ammonia	620.0	360.0
Nitrous oxides	13.0	21.0
Formaldehyde	0.3	0.2
Acrolein	0.4	0.3
Total Aldehydes	<5	9
Total Aromatic Amines	96	42
Benzene	17	33
Toluene	<1	6
m-Xylene	<1	4
o-Xylene	<1	<1
Naphthalene	<1	<1
Phenol	0.5	6.7
Bischloromethyl ether	<10 ppb	<10 ppb

[43]

Table A2.3 Chemical Constituents of Common Foundry Binders

Chemical Binder	Constituent	Chemical Binder Emission Factor <sup>1</sup> (g / kg)
-----------------	-------------	---

	Core Oil	Shell	Alkyd Isocyanate	Sodium Silicate-Ester
Ammonia	0.038	3.86	0.037	0.038
Hydrogen Sulfide	0.057	0.094	0.007	0.197
Nitrogen Oxides	0.081	0.994	0.355	0.028
Sulfur Dioxide	0.115	3.509	0.04	0.244
Benzene	2.344	6.667	5.336	1.41
Formaldehyde	0.098	0.035	0.106	0.169
Hydrogen Cyanide	0.086	10.526	0.175	0.179
M-Xylene	0.239	0.585	2.522	0.094
Naphthalene b	0.048	0.058	0.037	0.005
O-Xylene	0.287	0.117	3.838	0.094
Phenol	0.057	2.456	0.11	0.273
Toluene	0.478	2.907	1.535	0.282
Total Aromatic Amines b	0.096	2.939	0.037	0.094

<sup>1</sup>Mosher (1994)

a Units expressed as grams of chemical released to air per kilogram of index resin.

b Add these together and list as a Polycyclic Aromatic Hydrocarbon [63]

Table A2.4 Chemical Constituents of Common Foundry Binders

Constituent of Binder	Binder Emission Factor <sup>1</sup> (g / kg)			
	Phenolic Nobake	Phenolic Urethane	Phenolic Hotbox	Green Sand
Ammonia	0.039	0.083	10.931	0.065
Hydrogen Sulfide	1.462	0.057	0.009	0.832
Nitrogen Oxides	0.029	0.044	0.638	0.562
Sulfur Dioxide	15.107	0.061	0.036	0.253
Benzene	11.209	5.351	1.002	0.611
Formaldehyde	0.01	0.022	0.006	0.004
Hydrogen Cyanide	0.029	1.053	1.184	0.118
M-Xylene	0.097	0.439	0.121	0.021
Naphthalene b	0.049	0.022	0.03	0.021
O-Xylene	0.049	0.132	0.03	0.021
Phenol	0.975	3.904	0.203	0.131
Toluene	0.694	0.833	0.182	0.063
Total Aromatic Amines b	0.049	0.351	1.275	0.021

<sup>1</sup> Mosher (1994)

a Units expressed as grams of chemical released to air per kilogram of index resin.

b Add these together and list as a Polycyclic Aromatic Hydrocarbon [63]

Table A 2.5 Chemical Constituents of Common Foundry Binders

Constituent of Binder	Chemical Binder Emission Factor (g / kg)		
	Low Nitrogen Furan	Medium Nitrogen Furan Catalyst	Furan Hotbox TSA
Ammonia	0.04	0.202	19.579
Hydrogen Sulfide	0.405	0.485	0.06
Nitrogen Oxides	0.012	0.372	0.411
Sulfur Dioxide	0.607	4.858	0.088
Benzene	0.648	4.534	0.537
Formaldehyde	0.257	0.065	0.009
Hydrogen Cyanide	0.368	0.607	3.474
M-Xylene	2.227	0.243	0.032
Naphthalene <sup>b</sup>	0.04	0.04	0.032
O-Xylene	0.729	0.04	0.032
Phenol	0.024	0.101	0.016
Toluene	0.121	8.825	0.032
Total Aromatic Amines <sup>b</sup>	0.081	0.364	3.032

<sup>a</sup> Mosher (1994)

a Units expressed as grams of chemical released to air per kilogram of index resin.

b Add these together and list as a Polycyclic Aromatic Hydrocarbon

[63]

Table A2.8 Region or Estimated world starch production (1992) (000 tonnes).

Region country	or	Maize	Sweet- potato	Cassava	Wheat	Potato	Other	Total	% Wor- ld Pro- duc- tion
North America		13,450	—	—	200	55	20	13,725	41
USA		13,200	—	—	50	50	20	13,320	40
Canada		250	—	—	150	5	—	40	5 1
Latin America		1,000	—	330	—	—	—	1,330	4
European Union		3,400	—	—	1,400	1,200	—	6,000	18
Eastern Europe		300	—	—	—	300	—	600	2
Africa		—	—	20	—	—	—	20	<1
Asia		3,020	4,165	3,442	165	400	30	11,222	34
China		—	4,000	300	—	—	—	4,300	13
Japan		2,500	120	—	150	400	—	3,1701	10
Thailand		—	—	1,800	—	—	—	1,800	5
Indonesia		—	—	800	—	—	—	800	2
India		200	—	350	—	—	—	550	2
Vietnam		—	—	90	—	—	—	90	<1
The Philippines		75	—	17	—	—	—	92	<1
Malaysia		—	—	70	—	—	—	100	<1
Taiwan		45	15	15	15	—	30	90	<1
South Korea		200	30	—	—	—	—	230	1
Australia		50	—	—	300	—	—	350	1
Total		21,220	41,165	3,792	2,065	1,955	50	33,247	100
Percent share		64%	13%	6%	6%	6%	0%	100%	

Source: Ostertag 1996

Some of the appendix materials are except from some literature. These have their references at the end of their capture.

## APPENDIX B

### REVIEW OF THEORETICAL CALCULATIONS

#### Solidification of a casting

The heat of propagation of a solid under transient conditions according to [21, pp. 27-29] which can be described under transient conditions by partial differential equation as:

$$\frac{\partial t}{\partial \tau} = a_m \frac{\partial^2 t}{\partial x^2} \quad (1)$$

Where  $t$  is temperature,  $\tau$  is time and  $a_m$  is thermal diffusivity of the mould material and  $x$  is the distance from the metal-mould interface (it is positive in the metal and negative in the mould). Also

$$a_m = \frac{\lambda_m}{c_m \rho_m} \quad (2)$$

$c_m, \lambda_m, \rho_m$  are the specific heat capacity, thermal conductivity, density of the mould material respectively.

According to the Fourier law, a unit heat flux into the interface of the mould is represented by

$$\left. \frac{q}{F_c} \right|_{x=0} = -\lambda_m \frac{\partial t}{\partial x} \quad (3)$$

Where  $q$  is the heat flux and  $F_c$  is the temperature of the surface area of the casting.

Equations (1) and (3)

$$\left. \frac{q}{F_c} \right|_{x=0} = - \sqrt{\frac{\lambda_m \rho_m c_m}{\pi \tau}} \cdot (t_c - t_s) \quad (4)$$

where  $t_c$  is the temperature of the casting interface and  $t_s$  is the temperature of the mould external surface.

Assuming  $t_c = t_s$ , then the temperature of the internal surface of the mould is a function of time,  $\tau$ , only. Under this condition the temperature of the internal surface depends on the heat evolved during solidification. Thus

$$\frac{q}{F_c} \Big|_{x=0} = -\rho_c L \frac{\partial x}{\partial \tau} \quad (5)$$

Where  $\rho_c$  is the density of the cast metal and  $L$  is the specific latent heat of solidification. This implies that the mould absorbs heat.

Equating (4) and (5) and integrating with  $x=0$  and  $\tau = 0$  gives:

$$x = \frac{2}{\sqrt{\pi}} \frac{t_c - t_s}{\rho_c L} \sqrt{\lambda_m \rho_m c_m} \sqrt{\tau} \quad (6)$$

Equation 6 gives the combined effect of the thermo physical properties of the metal and mould on solidification. The term

$$\sqrt{\lambda_m \rho_m c_m} = b_m \quad (7)$$

is a measure of heat absorption by the mould material. This parameter is often called the coefficient of heat accumulation. Also let

$$t_c - t_s = v_s \quad (8)$$

And further evaluating  $\frac{2}{\sqrt{\pi}} = 1.13$  and substituting (7) and (8) in (6) gives:

$$x = [1.13 \frac{b_m v_s}{\rho_c L}] \sqrt{\tau} \quad (9)$$

which is the thickness of the solidified metal layer in a sand mould and it varies as the square root law. Thus:

$$x \propto \sqrt{\tau}$$

Under real conditions, it is believed that when molten metal is poured into a casting mould, it is superheated above the liquidus temperature,  $t_1$ , so it is essential to consider the time required for cooling of the molten metal from the initial temperature  $t_{init}$  to  $t_1$ . G.F. Balandin has obtained the following expression for the time required for the surplus heat from the molten metal to the mould:

$$\tau = \left[ \frac{c_p \rho_c (t_{init} - t_1) R}{1.13 b_m (t_{init} - t_{init,m})} + \sqrt{\tau_p} \right]^2 \quad (10)$$

Where  $R$  is the resolved dimension of the body;  $\tau_p$  is the time of metal pouring into the mould; and  $t_{init,m}$  is the initial temperature of the mould. The initial temperature of molten metal in the mould can be found as

$$t_{in} = \frac{t_p - t_1}{2} ; t_p \text{ is the metal pouring temperature} \quad (11)$$

In cases where the temperature gradient in the metal is equal to zero and the geometrical dimensions on the body are inessential, the resolved dimension can be described as

$$R = \frac{V_c}{F_c} \quad (12)$$

where  $V_c$  is the volume of the casting and  $F_c$  is its surface area.

The time of solidification of molten metal in sand mould, considering the time of cooling is from the superheat temperature, is given by

$$\tau = \left[ \frac{L \rho_c R}{1.13 b_m v_s} + \sqrt{\tau_p} \right]^2 \quad (13)$$

With  $\tau \geq \tau_1$ , the linear solidification,  $u$ , the rate of solidification can be determined by the formula

$$u = \frac{dx}{d\tau} = \frac{b_m v_s}{L \rho_c \sqrt{\pi \tau}} \quad (14)$$

Consider an example of the solidification of a 420 kg cast iron in a sand mould as illustrated, in Figure B1, below with the casting having a box shape (table of milling machine) and the average wall thickness 30 mm. In calculation, the casting is regarded as a flat plate. After the removal of the surplus heat from the molten metal a

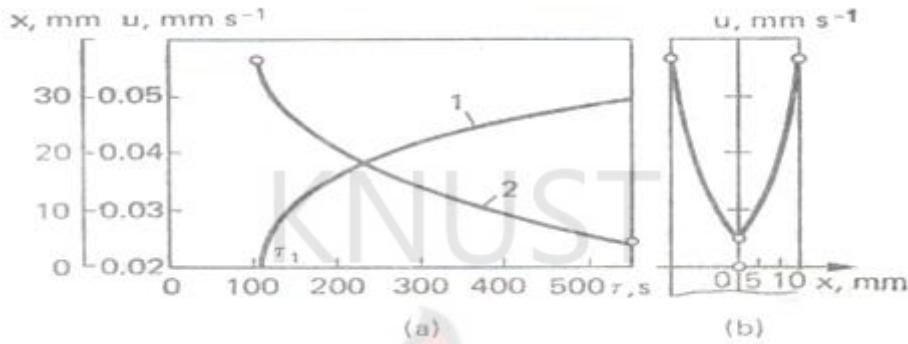


Figure B1 The solid metal thickness and solidification rate in a sand mould [21]

solid crust began to grow in accordance with the square root law (curve 1 in Figure B1a). The linear rate of solidification decreases monotonously in time (curve 2), which means that the solidification rate across the wall thickness is different in various portions of the plate, been substantially lower in the central zone (Figure B1 b).

Intricate-shaped castings can be regarded as if they consist of simpler planes, cylindrical and spherical portions each having its own resolved dimension, R. Contrary to the plane shapes in which the solidification rate decreases to the end of the process, cylindrical and spherical castings rates increase and this is associated with substantial changes in the ratio of the volume of solidified metal to the cooling surface.

By analyzing the temperature fields in mould, which depends on the quality of heat accumulated in the mould during cooling of the casting, G. F. Balandin has proposed

the following equation for calculating the time of cooling of a casting in mould to any temperature

$$\tau_c = 2 \left( \frac{c_p R}{\sqrt{2n/(n+1)b_m}} \right)^2 \left[ \left( \frac{1}{\theta} - 1 \right) (1+D) + \ln \theta \right] \quad (15)$$

Where

$$\theta = \frac{(t_{kn} - t_m)}{(t_1 - t_m)}$$

$$D = \left[ \frac{c_1 \rho_1 (t_p - t_m)}{c_s \rho_s (t_1 - t_m)} - 1 \right] + \frac{L}{c(t_1 - t_m)}$$

where  $n$  = exponent of a power function approximating the temperature distribution across the mould in the period of cooling of the solidified casting ( $n = 1.5 - 3$ ) and  $t_{kn}$  is the temperature of the casting at knockout out from the mould.

Internal stresses in casting can be relieved or practically eliminated by heat treatment, most commonly, by annealing. During holding of the metal at an elevated temperature, internal stresses in are relaxed intensively due to plastic deformation. The conditions of heat treatment are chosen depending on the composition and crack susceptibility of the metal, mass and shape of castings, and the casting process employed [21, p. 56].

## B2 Selection of the Production Process according to the given properties of Iron under Non Metallic mould

If the metal or alloy freezes in a non-metallic mould the relation between the rate  $u$ , the thermo physical properties of the materials of the mould and casting and the heat condition of casting is determined by the relation given in [66] as

$$u = \frac{dR}{dt} = 0.564 \frac{b}{\rho_1 r_1} (T_{fr} - T_{2 init}) \frac{1}{\sqrt{t-t_0}} \text{ m/s} \quad ; T_{fr} \text{ is the freezing temperature} \quad (16)$$

Where  $t_o$  is the time of flow of the metal to the mould section under examination (at moment,  $t_o$  after the beginning of pouring heat exchange commences between the metal and the mould in the given section);

*t*-the time from the beginning of charging; and

*u*-the volume rate of freezing of the metal.

According to [73], equation (16) is correct for a casting of any shape, as well as for any type or freezing of a metal or alloy (progressive or extensive), as, instead of the thickness  $\xi$  of the shell, the reduced thickness of the solid shell enters into the equation:

$$R = \frac{v}{F_1} \text{ m}$$

Where  $v$  is the volume of metal frozen at time  $t$ , in  $\text{m}^3$  and  $F_1$  is its surface area and  $R$  is the reduced size or reduced thickness or the resolved dimension.

The value  $u$  conveys the sense of the specific volume rate of freezing (per unit area of the cooling surface of the casting).

The dimension  $u$  is equal to

$$\frac{\text{m}^3}{\text{sec}} \cdot \frac{1}{\text{m}^2} = \text{m/sec}$$

In the simplest case it can be calculated that freezing of the metal commences at the time  $t_2$  of the removal of all superheat in the given section.

The value of  $t_2$  is found from (equation 195) [29]:

$$\sqrt{t_2 - t_0} = 0.886 P_1 \frac{c'_1}{b_2} \cdot \frac{T_{1 \text{ init}} - T_{fr}}{T_{1 \text{ init}} - T_{2 \text{ init}}} + \sqrt{t_1 - t_0} \text{ sec}^{\frac{1}{2}} \quad (17)$$

Where  $P_1$  is the reduced mass of the casting or its component,  $\text{kg/m}^2$

$P_1 = M_1/F_1$ ;  $M_1$  is the mass in  $\text{kg}$  and  $F_1$  is its area in  $\text{m}^2$

$T_{1 \text{ init}}$  is the initial temperature of the metal in the given section of the casting ,K.

For a flat casting

$$P_1 = X \rho_1 \text{ kg/m}^2 \quad ; \quad X \text{ is the size of casting in m and } \rho_1 \text{ is its density } \text{kg/m}^3$$

The rate at which the initial shell freezes is determined by substituting in Eqn.1 the value  $t = t_2$ , and the rate at which the metal freezes at the end of the process by substituting the values  $t = t_3$ .

the relation between the thickness of the solid shell and time (law of freezing) is determine from Eqn.198 [66];

$$R = 1.13 \frac{b_2}{\rho_1 r_1} (T_{fr} - T_{2 init}) (\sqrt{t - t_0} - \sqrt{t_2 - t_0}) \text{ m} \quad (18)$$

or

$$\sqrt{t - t_0} = 0.886 \frac{R \rho_1 r_1}{b_2 (T_{fr} - T_{2 init})} + \sqrt{t_2 - t_0} \sec^{\frac{1}{2}} \quad (19)$$

The time  $t_3$  required for complete freezing calculated from (19) by substituting  $R=R_1$ .

Using equations (16) and (18) the freezing rate  $u$  may be directly connected with the shell thickness  $R$ .

Thus

$$u = \frac{A^{\frac{1}{2}}}{\left(\frac{R}{2}\right) + A \sqrt{t_2 - t_0}} \text{ m/sec} \quad (20)$$

where

$$A = 0.564 \frac{b_2}{\rho_1 r_1} (T_{fr} - T_{2 init}) ; b_2 \text{ is the coefficient of heat accumulation which is}$$

the rate of heat absorption by the mould material

Equation (20) enables the distribution of the rate  $u$  (i.e. the rate of freezing of the metal or alloy in a non metallic mould) over the cross section of any casting to be found.

### B3 Selection of the parameters of non metallic mould

Equations (16) to (20) relate the rate of freezing of a metal in a non-metallic mould with the thermal and physical properties of the casting ( $\rho_1; r_1; c'_1$ ) and mould ( $b_2$ ), the geometric characteristics of the casting and mould ( $R; X_1; F_1; V_1$ ), the temperatures

$(T_{1\ init}; T_{fr}; T_{2\ init})$  and the pouring conditions  $(t_0; t_1; t_2)$ . In practice, the freezing rate is generally varied by varying the values of  $b_2$  (dry and wet moulds, addition of sawdust or iron fillings, etc.) and of  $T_{2\ init}$  (particularly in precision casting). These values can be found from the expressions:

$$b_2 = 1.77 \frac{\rho_1 r_1 u}{T_{fr} - T_{2\ init}} \sqrt{t - t_0} W sec^{\frac{1}{2}} / (m^2 \cdot ^\circ K) \quad (21)$$

The parameters of the non-metallic mould production process can be determined from these equations when the properties of the castings are given.

#### B4 Heat Transfer and Solidification in Insulating Moulds

##### Chvorinov's Rule

At some time,  $t$ , after pouring a pure metal into an insulating mould (sand or ceramic) at some pouring temperature  $T_p$  the temperature along a line perpendicular to the mould-metal interface would be expected to look like the Figure B2 below:

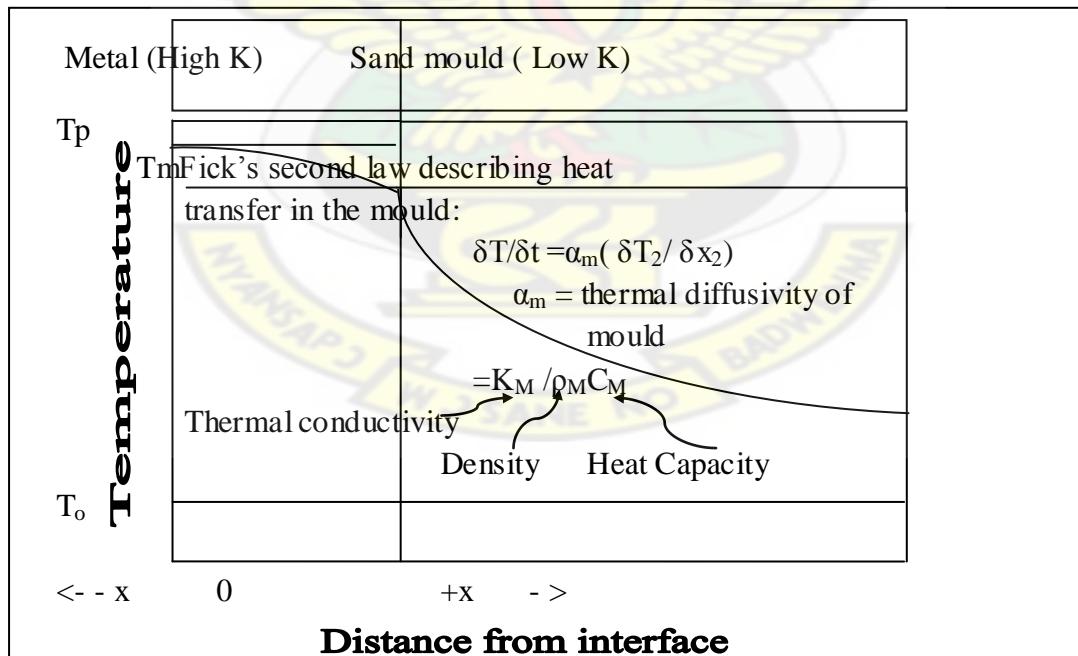


Figure B2 Heat transfer and solidification in insulating mould [74]

In this situation, the high thermal conductivity of the metal results in the temperature of the metal at the interface dropping to  $T_m$  instantly upon pouring and staying there until solidification is complete. Of course, intimate contact between the metal and mould means that the mould at the interface will also remain at  $T_m$  until solidification is complete.

The solution to the above equation subject to the boundary conditions that  $T=T_m$  at  $x=0$  and

$T=T_0$  at  $x=\infty$  for small  $t$  gives:

$$T(x,t) = T_0 + (T_m - T_0) \left\{ 1 - \operatorname{erf} \left[ \frac{x}{2\sqrt{\alpha_M t}} \right] \right\} \quad (22)$$

This equation can be used to predict the solidification time,  $t_s$ .

The flux of heat at time  $t$  is given by

$$J = -KM \left( \frac{dt}{dx} \right) \Big|_{x=0} \quad (23)$$

$$\left. \frac{dT}{dx} \right|_{x=0} = (T_m - T_0) \left. \frac{d}{dx} \left[ 1 - \operatorname{erf} \left( \frac{x}{2\sqrt{\alpha_M t}} \right) \right] \right|_{x=0} \quad (24) \text{ Expanding the erf function}$$

in the form:

$\operatorname{erf}(u) = \frac{2}{\sqrt{\pi}} \left( u - \frac{u^3}{3 \cdot 1!} + \frac{u^5}{5 \cdot 2!} - \frac{u^7}{7 \cdot 3!} + \dots \right)$  and differentiating gives at  $x=0$ , the interface,

$$J = \frac{K_M (T_m - T_0)}{\sqrt{\pi \alpha_M t}} \quad (25)$$

The total heat,  $Q$ , through the interface of area  $A$ : (the total surface area of the casting) up to the time, is given by:

$$Q = \int_0^t J dt = \frac{2AK(T_m - T_0)}{2\sqrt{\pi \alpha_M}} t^{0.5} \quad (26)$$

The total heat liberated before solidification is a sum of superheat,  $Q_S$ , and a latent heat of solidification,  $Q_F$ , where :

$$Q_F = \rho_{Metal} \Delta H_F V_{Metal} \quad (27)$$

$$Q_S = \rho_{Metal} V_{Metal} (T_p - T_m) C_{Metal} \quad (28)$$

where  $T_p$  is the pouring temperature.

The time necessary for this amount of heat to pass through corresponds to the solidification time,  $t_s$ , and therefore:

$$Q_F + Q_S = \frac{2AK_M}{\sqrt{\pi}\alpha_M} (T_m - T_0) t_s^{0.5} \quad (29)$$

and therefore:

$$t_s = \frac{\pi \alpha' \rho_{Metal}^2 V_{Metal}^2 [\Delta H(T_p - T_m)]}{4 A^2 K_M^2 (T_m - T_0)^2} \quad (30)$$

For a given metal and mould poured at temperature  $T_p$  we can separate a mould constant  $B_s$  and the V/A ratio to give the Chvorinov's Rule,

$$t_s = B_s (V/A) \quad (31)$$

The constants needed to utilize Chvorinov's Equation for a variety of materials are given in [74, p. 52].

### **B.5 Gas exchange between casting and mould**

Apart from shrinkage cavities and pores in a casting are gaseous defects or blowholes. These defects are of two kinds: endogenous which is formed when gases evolve from the metal, and exogenous which occurs when gases penetrate into a casting through its surface layers.

Since solubility of gases decreases substantially as temperature decreases, they start to evolve from the metal when they solidify and cool off. When molten metal is poured into mould it solidifies at the mould walls and solid crust prevents the gases from leaving the central portions of the casting where gas cavities may be formed. This may also cause thermal diffusion of gases to the center of the casting due to an appreciable thermal gradient across the casting section. A riser is important here to conduct the gases away. In some cases gases evolve from the supersaturated solution

across the whole casting section, which leads to the formation of gas porosity. The pressure in gas may turn out to exceed the high strength in metal and thus producing fine cracks. Blowholes in the metal may form not only by dissolved gases in the liquid but also by gases which is formed in the casting when the metal solidifies.

Gas blowholes of exogenous nature are often the cause of spoilage of casting. Gases may be entrapped by the molten metal when it is poured into moulds only when the metal flow is strongly turbulized; this can be eliminated by changing properly the design and dimensions of the gating system or the place of metal feeding.

Pouring in of molten metal should be such that it should displace the gases. Because of these, open risers, vents or vertical channels are provided in moulds. In [21, p. 49], according to Ya I. Medvedev, when hot metal comes into contact with a sand mould or core, an appreciable gas pressure creates in the contact zone see Figure.B3 below; this pressure depends primarily on temperature. With time the gas pressure in the contact zone drops down substantially, but later rises again. The initial rise of pressure is caused by a number of factors. These are (i).The expansion of air on heating. This is pronounced at where expansion takes place as in restricted volume of pores (ii). The formation of an additional quantity of gases in the mould. With poorly dried moulds and cores, the main source of gases is moisture. The pressure of gases in moulds and cores depends on two interrelated processes: gas formation and gas removal.

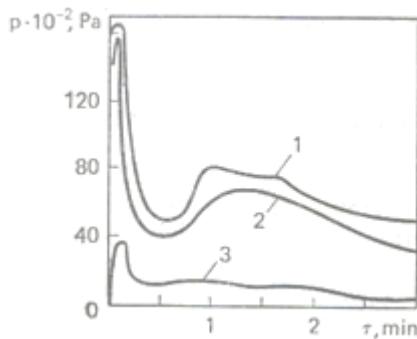


Figure B3 Time variations of pressure  $p$  of gases at the metasurface upon pouring into a sand mould [21]

1-steel; 2-cast iron; 3- aluminium

The quantity (mass)  $G$  of gases evolving from the moulding material obeys the law:

$$G = m\sqrt{\tau} \quad (32)$$

Where  $m$  is the proportionality factor and  $\tau$  is the time.

The gas generating capacity of sand and core mixture is characterized by the coefficient of gas evolution

$$E = G/Q_m \quad (33)$$

where  $Q_m$  is the quantity of heat absorbed by a mould.

The coefficient of gas evolution  $E$  is essentially the quantity (mass) of gas evolved by a mould or core when they absorb  $4.19 \times 10^3$  J of heat. The coefficient  $E$  of a gaseous mixture depends on the temperature of the metal being poured with the use of high melting alloys, practically all substances in the surface layers of a mould which can be gasified are subjected to gasification.

The ability of gases to pass through the surface of mould from the surface of casting to the outside is characterized by the gas permeability,  $K$ . Assuming Darcy's filtration law, under the condition of continuity of flow, the motion of gases in passages of a

porous mould (or core) is given by the total volume,  $V$ , of gases removed from the metal-mould interface in time,  $\tau$  is

$$V = K(P_1 - P_2)F_m \tau / l_m \quad (34)$$

where  $P_1$  and  $P_2$  are the gas pressures in the initial and final sections of a passage respectively;  $F_m$  is the cross sectional area of the mould; and  $l_m$  is the thickness of the mould wall. Equation (34) is used for experimental determination of the gas permeability coefficient  $K$  of

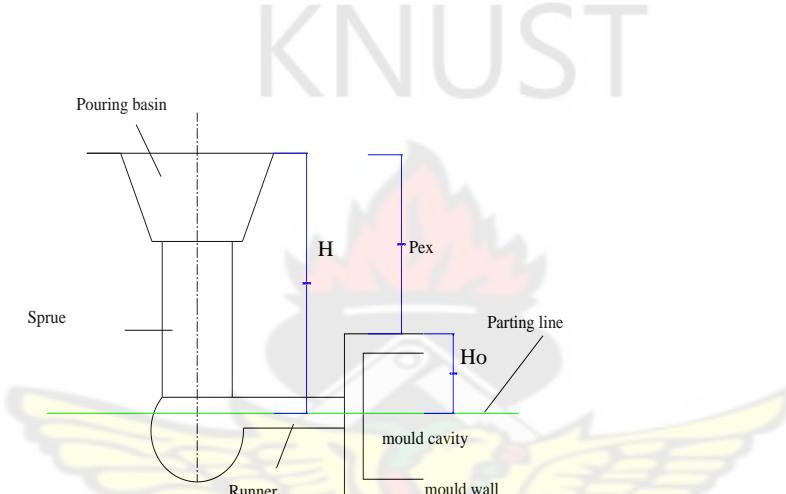


Figure B4 Pressure head during casting in relation to the static head and the external pressure

moulding sands when air is blown through a specimen prepared from the tested sand. Experimental determination of coefficients  $E$  and  $K$  makes it possible to estimate the excess gas pressure  $P_m$  at the metal-mould interface S:

$$P = \frac{2ESl_m}{3K F_m \sqrt{\tau}} \quad (35)$$

It can be realized from the equation above that the maximum excess gas pressure at the metal-mould interface builds up at the beginning of heating of the mould, i.e. at time,  $\tau \rightarrow 0$ , which has been proved experimentally, see Figure B3. The thermal diffusivity of sand moulds is quite low, so that the thickness of the mould layer involved in heat exchange with the casting increases only slowly. On the other hand,

with an appreciable porosity of a mould (30-40%), the coefficient of a gas filtration through it is rather high, so that the width of a layer carrying gases is always larger than that of a layer involved in heat exchange. At the initial moment when the metal contacts the mould a thin surface layer of the mould is heated up quickly and gases start to evolve from it practically instantaneously. As a result the gas pressure at the metal-mould interface rises to its maximum and then decreases gradually due to the fact that gas filtration becomes predominant over gas evolution.

According to equation 35 when the pressure of gases in the mould  $P_m$  attains its maximum, there is the largest probability that gases may penetrate into the casting, since the surface of casting may still have no solidified crust at that time (this corresponds to stage II of cooling of the casting).

The height of liquid metal in the pouring cup is denoted by

$$H = H_o + P_{ex} \quad (36)$$

where  $H\rho o$  is the ferrostatic head (height of mould above parting line) and  $P_{ex}$  is the external pressure, see Figure B4.

When excess pressure of gases exceeds  $H$ , gas cavities and pores can be formed. But the pressure of gases must be sufficiently high to overcome the surface tension of the molten metal. Unfavorable conditions may cause blowholes to be formed in the surface of castings. Thus, in cases where excess gas is formed in the mould at the initial moment of the casting, the evolving gas may cause ‘boiling’ of the molten metal or its splashing from the mould during pouring.

The excess pressure of gases can be controlled by varying the  $E/K$  ratio. It is also important to select the binding materials and the moisture content of sand mixture content with due account of probable gas evolution. On the other hand, the excess gas pressure can be reduced substantially by forming favorable conditions for

removal of evolving gases, for instance, by increasing the gas permeability of moulding mixtures [21, pp. 48-54].

## B6 Metal Melt Pressure on Moulds and Cores

During casting, moulds and cores are exposed to vigorous strain due to the high temperature of the melt and the pressure that the melt exerts on the surfaces of the mould and cores. To prevent a break-through, calculations of the expected pressure on the mould walls, the lifting capacity of the upper part of the mould and the buoyancy forces on cores, which are completely or partly surrounded by melt, must be performed. These calculations are the basis for different strengthening procedures such as varying compaction weighting in different parts of the mould, locking of the cores in the mould and compaction weighting on or cramping of the upper part of the mould. The wording of the laws has been adapted to the special casting applications.

The laws, which are the basis of the calculations, are given below:

**The Law of Connected Vessels.** If two or more cavities are connected to each other, the height of the melt will be equal in all of them.

**Pascal's Principle.** A pressure that is exerted on a melt in a closed cavity is transferred unchanged to all parts of the mould wall.

**Liquid Pressure and Strain.** If  $p$  is pressure,  $\rho$  is density in  $\text{kg/m}^3$ ,  $g$  is acceleration due to gravity and  $h$  is height in metres,  $m$ , then

$$p = \rho gh$$

Also  $F$  is force in newtons and  $A$  is area in  $\text{m}^2$ , then

$$F = pA$$

**The Hydrostatic Paradox.** The pressure on a surface element is universally perpendicular to the element and equal to  $\rho gh$  where  $h$  is the depth of the surface

element under the free surface of the melt, independent of the direction of the element.

The pressure on a lateral surface  $\frac{1}{4}$  the weight of a column with the surface as a basis and a height equal to the depth of its centre of mass.

**Archimedes' Principle.** An immersed body (core) seemingly loses an amount of weight equal to the weight of the melt displaced by the body.

The laws given above are valid for static systems.

During casting the melt is moving and dynamic forces have to be added. These forces are difficult to estimate. The solution of the problem is usually practical. The calculations are made as if the system was static and the resulting values are increased by 25–50 %.

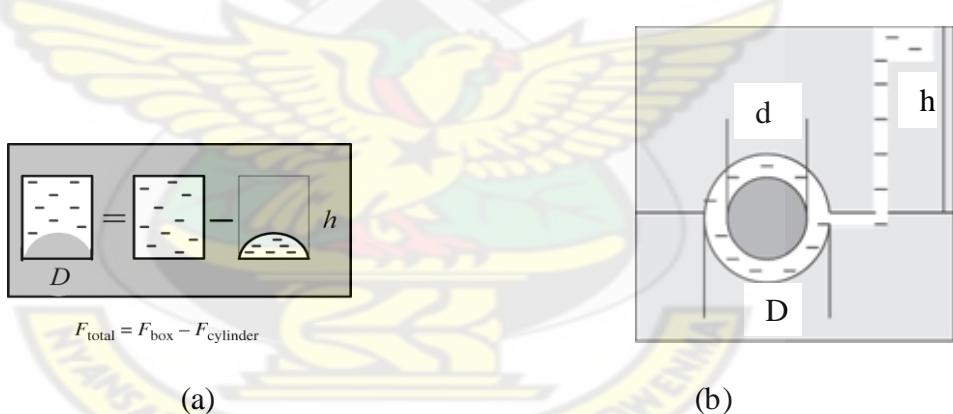


Figure B5 (a) The force exerted by a melt and (b) the buoyant force on the cope and drag as the molten metal begins to fill the mold

(a) The force exerted by the melt is given by

$$F = LD \rho_L g - \frac{1}{2} \left( \frac{\pi D^2}{4} \right) 2 - LD \rho_L g = LD \rho_L g \left( h - \frac{\pi D}{8} \right) \quad 1'$$

(b): The lifting force is equal to the weight of the melt, displaced by the sand core, minus the weight of the core. This force acts on the core prints [Figure B5 (a) and (b)]

$$F_{lift} = \frac{\rho d^2}{4} L \rho_L g - \left( \frac{\rho d^2}{4} \right) L \rho_S g = \left( \frac{\rho d^2}{4} \right) L g (\rho_L - \rho_S) \quad 2'$$

(c): The forces, directed upwards and acting on the upper part of the mould, are equal to the weight of the mass  $M$  of the melt:

$$F_{total} = LD\rho_L g \left( h - \frac{\pi D}{8} \right) + \left( \frac{\rho d^2}{4} \right) L g (\rho_L - \rho_S) \quad 3'$$

Thus

$$M = \frac{F_{total}}{g} ; \quad g \text{ is the same as } g \text{ here.}$$



## APPENDIX C

Table C3.1 Process Chart of shell Moulding Technique for sand coating

Process Chart of shell Moulding Technique for sand coating										
Material specs. .....  Purchased stock size....  Weight .....	Sand between BS Sieve ... and no. ....		Part name...  Usage.... .. Date Sup'd.... ..	Shell Coat sand		Part no. ....  Date issued...  Issued by.....	SM 201030			
				Resin coating						
	.....kg									
Profession...		MSc Student/Engineering			Grade ... .....			BSc. Mechanical Engineering		
O p er .N o.	Operation description		Dep t.	Mac hine	Set up Hr	Rate Pc/H r	Tools/ Materials	Instrument		
0 1	Weigh sand						Scale balance/	Sand used has been been sieved with BS sieve below 400 µm		
0 2	Resin: Measure phenol formaldehyde 2.5-4.5% of sand volume						Measuring scale/ cylinder	Novolac type of the resin is mostly employed. He one used is not specified.		
0 3	Catalyst: Hexamethylene tetramine (urotropin) 11-14% of resin volume		CO E				Measuring scale/ cylinder	Another alternative catalyst is ammonium chloride.		
0 4	Lubricating agent: Calcium stearate 4.5% of resin volume		CO E					Other lubricating agents are zinc stearate and carnauba wax.		
0 5	Heat sand to the coating temperature 120 – 150 oC		CO E	Oven /fire		Tray	Thermocouple/Thermometer	It can be heated on fire up to that temperature or can be put in oven at a slightly		

								higher temperature so as to attain that temperature early.
O 5	Mix sand evenly with catalyst	CO E	Mull er	40- 60 Sec.	mixer			
O 6	Charge resin and mix	CO E	Mull er	2 - 3 Min				
O 7	Add lubricating agent	CO E			Measurin g cylinder			Allow flow of air to cool
O 8	Remove the coated sand at 60-65oC	CO E				Thermomet-er		Maintain the temperature in this range for some time.
O 9	Cool the coated sand till resin sets.	CO E	Fan					The cooling effect is to prevent premature curing of binder.
1 0	Break any lump formed and sieve	CO E			BS sieve			Sieve sand while still hot at that temperature
1 1	Cool sand to room temperature.	CO E	Fan					In some instances fluidized bed cooler with cooling pipes are used.
1 2	Store coated sand	CO E			Sack			Store sand for future use.

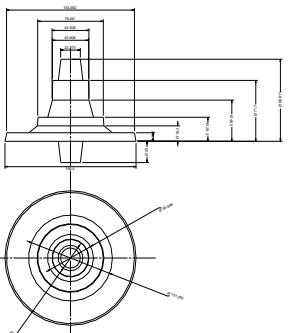
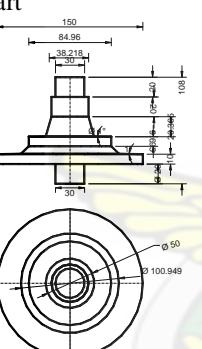
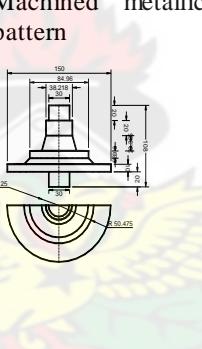
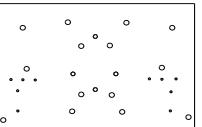
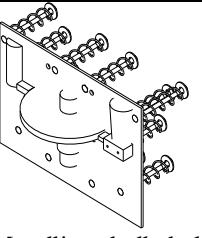
COE is College of Engineering

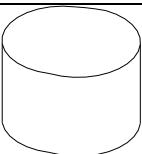
Table C3.2 The process chart for shell moulding using coated sand

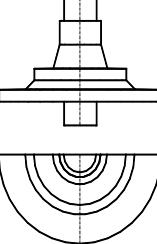
Process Chart: Shell Moulding using coated sand									
Material specs. ..... Purchased stock size.... Weight .....		Shell precoated sand	Part name..... Usage..... Date Sup'd.....	Shell moulding using coated sand.	Part no. .... Date issued. .... Issued by.....				
				For shell moulding					
Profession		MSc.Student /Engineering			Grade		BSc. Mechanical Engineering		
Op-er. No.	Operation description		Dept.	Mach ine	Set up Hr	Rate Pc/H r	Tools/ Materials	Instr-ument	Notes
01	Light charcoal / Switch oven on		College of Engineering, COE	oven			Matches/ lighter		Light fire and increase temperature by fanning. Increase temperature of oven to between 150-200 °C or to 250 °C
02	Place precoated sand in dump box		COE				Dump box		Sand place in dump box should be such that it should be able to cover the pattern should have height greater than the height of the pattern.
03	Heat Pattern		COE				Coal pot/oven	Thermocouple/Termometer	Observe pattern temperature from from 150–250 °C
04	Remove pattern from heat source		COE				Hand glove, tongs		With the hand glove on use the tong to remove from oven.
05	Increase oven temperature		COE					Thermometer	Increase oven temperature :from 300-350 °C
06	Heated pattern is to be sprayed		COE	Oven / fire			Tray		Put on nose mask. Spray pattern with silicone emulsion. Fire is generated as you spray so be careful.
07	Place pattern on dump box containing		COE			40-60 Sec.	Hand glove		Secure pattern plate well on the dump box.

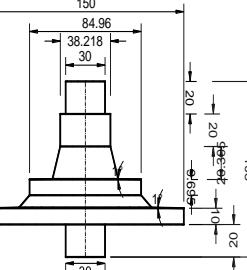
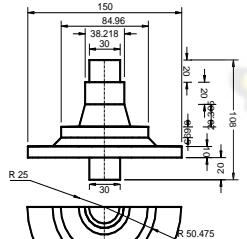
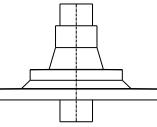
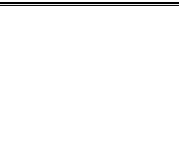
	sand						
08	Mount pattern plate On dump box	College of Engineering (COE)			Hand glove/ plier	Measuring scale/ Cylinder	Start this by timing using either stop watch, stop clock. That on mobile phone can be used.
09	Turn box through 180-360 degrees	COE		2 - 3 Min	Hand glove/No se mask		Observe timing for about 10-25 seconds.
10	Re invert box	COE			Hand glove/No se mask		Ensure that nose mask is on and use hand gloves.
11	Replace pattern together with semi-hard mould in oven	COE	Oven		Hand glove/No se mask		Observe timing for 50-60 s. higher time than this may overheat and overheat mould and cause mould to break. Gupta 2002, gives 1-2 mins.
12	Strip mould from pattern	COE			Hand glove		Eject mould from pattern with the help of ejector pins under pattern plate.
13	Mould is ready for use	COE					Place mould on shelf ready for use.
14	Repeat process for other half of shell mould using the duplicate pattern	COE					Change and use other half of pattern. If more moulds are required moulds making are repeated.
15	Halves are ready for assembly						Fit ready moulded halves with cores and glue or clamp into boxes and reinforced with metal shots or pellets or even with gravels in mould boxes ready for use.

Table3.4 Process Chart- Making shell metal pattern using Wooden Pattern and employing sand casting

Material specs. ....		Part name.....	Shell metal pattern	Part no. ....	
Purchased stock /size....	Wooden log and molten iron from a foundry.	Usage.....	For shell metal pattern making	Date issued...	
Pieces Per Purchase Size ...		Assy. No.		Date Sup'd ...	
Weight .....		Sub assy. No. .....		Issued by.....	
Batch Qty...	1	Technician profession...	Engineering	Tech'n Grade .....	BSc
Wooden Pattern		Part	Machined metallic half shell pattern	Steel plate with holes in it	Metallic shell half pattern with gating system and riser assembly
		 	 		

Set-tin-gs	Oper .. No.	Cont-ent of steps	Operation description Sketch	Dept.	Set-up/ Hr	Rate Pc/Hr	Mach-ine /Tools	Fixture	De-pth of cut mm	Feed mm/ rev or mm/ min	Cut-ting speed	Spি-nle spe-ed rev/min	Notes
		Create half wooden pattern-s						3- jaw chuck	2				Insert log in lathe and turn
A	01	Create half wooden patterns		Mac. shop			Cutti-ng mach-ine	G-clamp , 3- jaw chuck	2mm	0.06 0.22		150/200 200	This is best done by halving a circular wooden log into two halves. Flatten the surfaces and then join pieces later before turning to the required shape
	02	Create a half pattern wooden mould box		Mac. shop			Grin-der / Cutting machine		2 mm	0.06 0.22		150/200 200	Allow a minimum of 3 cm allowance around the cast piece. Fortunately, a 100 x 300 x 310 mm.
	03	Use (1) and (2) to form a hollow cavity		Fou-ndry			Cope & drag	4- jaw chuck					
	04	Repeat proce-dures (1) to (3) if workpiece is symmetrical		Fou-ndry			Cope & drag	4-jaw chuck					
	05	Create the other wooden part of the pattern if not symm-etical		Fou-ndry			Cope & drag						
	06	Add parti-ng agent and join 5 to 6		Fou-ndry			Cope & drag						Ensure that parting agent is applied to the surface before joining the other half

Sett - ings	Op er. No.	Content of steps	Operation description Sketch	De p t.	Set up Hr	Rate Pc./ Hr.	Machine /Tools	Fixture	Depth of cut	Feed	Cut-ting speed	Spindle speed rev/min	Notes
	07	Add cope, riser and gating systems and continue with the other part to form its hollow cavity and apply the mixing sand		Fou-ndry			Cope & drag						Put cope, sprue, gating systems and riser before fully filling cope ensuring that everything is at its position. Lock cope and drag
	08	Remove the cope and drag after they are used											
	09	Sepa-rate the cope and drag and remove the wood-en patterns		Fou-ndry			Cope & drag						
	10	Cast the two half -metal patte-rn seper-ately using the same process		Fou-ndry			Cope & drag						
	11	Cast their base (the base plate) separ-ately. A steel plate can also be used		Fou-ndry			Cope & drag						

Settings	Oper No.	Content of steps	Operation description Sketch	Dept .	Set-up Hr	Rate Pc/ Hr	Machine /Tools	Fixture	Depth of cut mm	Feed mm/ rev or min	Cutting speed	Spindle speed rev/min	Notes
B	12	Mach-ine parts to preci-sion		Mac hine shop					2mm	0.06 0.22		150/200 200	
	13	Mill part to half			2.5				1.5-2				The shaping machine is used to reduce the whole piece to half
	14	Polish the pattern											
	15	Make base metal plate separate					Shaper, horizontal milling mach-ine						

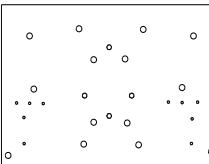
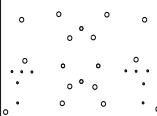
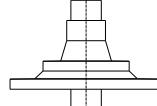
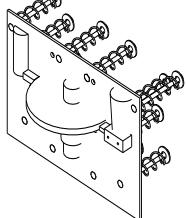
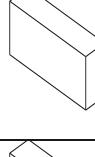
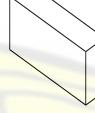
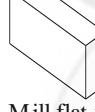
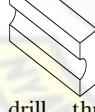
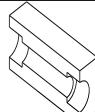
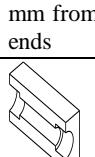
Settings	Oper No.	Cont-ent of steps	Operation description Sketch	Dept .	Set-up Hr	Rate Pc/ Hr	Machine /Tools	Fixture	Depth of cut mm	Feed mm/ rev or mm/ min	Cuttin g speed	Spindle speed rev/min	Notes
	16	Drill holes					Metal punch, press drill,						Perforated template created and holes are pierced through to mark points since the holes are to be symmetrical about the length of the plate. The template is fastened to the plate. Depressions are made with metal punches before the holes are drilled
	17	Put the half metal pattern on the metal plate and mark points for cutting of threads from the under-side of the pattern through hole.					Steel, thread cutter			0.06		150/200	Mark the underside of the pattern from the underside of the plate
	18	Cut threads at the plane back-side of pattern											Cut the threads on the marked parts of the pattern
	19	Asse-mby 13 and 16 to form a compl-ete shell pattern.											Assembly the parts according to the figure

Table C3.4 Process Chart For machining of shell metal core box from Foundry

Material specs. CAST BLANK.....		Grey Cast iron		Part name..... Usage..... Assy. No. .... Sub assy. No. .... Technician profession...	Shell core box		Part no. .... Date issued... Date Sup'd ... Issued by..... Tech'n grade.....						
Purchased stock size....					Shell core making								
Pieces. Per purchase Size.....					SB 2010								
Weight .....													
Batch Qty... .		2											
Part		Blank		1st machining		Final machining							
Oper. No.	Operation description	Sketch	Depth.	Machine	Set up / Hr	Rate Pcs /Hr	Tools	Fixture	Depth of cut (mm)	Feed	Rot. Spd. (rev/m in)		
01			cut				Cutting machine	G-clamp					
02			Grind	Grinder	3/4		Grinding machine						
03			mill	Mach	2 min	30	lathe	4-jaw chuck	2	1.5	100		
04			drill		2 min	30	Machine drill	4-jaw chuck			Normal		
05			drill through middle 20 ± 0.1	drill	1 min	60	Machine drill						
06			counter drill 30 ± 0.1 at 20 mm from both ends	Finish	Manual	1	1	Sand paper					

## **APPENDIX D**

### **D Preparing some of the unavailable chemical (calcium stearate) with local available materials:**

#### **i. Preparation of Calcium stearate with stearic acid**

Calcium stearate was prepared using two process routes. In the first process two parts of the stearic acid was charged into boiling water in an aluminum bowl. After the acid melted and boiled for some time, one part of the calcium oxide was added and boiled over highly charged fire for about two hours until calcium stearate was formed.

#### **ii. Preparation of Calcium stearate with beef tallow**

During this process, beef tallow was boiled on fire until most of the oil in it was removed. It was allowed to solidify. The above process was repeated but this time the oil was first boiled until it melted and a solution of the calcium oxide was added. The resulting products looked physically similar to the one obtained in the first process. The pH of the first was 8.2 while the second was 8.3.

Comments on these two processes were again discussed in the next chapter

## APPENDIX E

### PLATES

#### SAND CASTING-ACTIVITIES



Plate E 1: shows wooden pattern,riser, sprue, half core-boxes, chromite sand-cores from silicate-CO<sub>2</sub> process and some gating systems that were used to mould the cast, also in the picture is a tape measure.



Plate E 2: The sand for the shell mould is being seived in KNUST Civil Engineering laboratory



Plate E 3: Boniface filtering water in the water lab of the Civil Engineering Dept. of KNUST,Kumasi



Plate E 4: Filtered water tested for pH, Total Dissolved Solids (TDS) and Conductivity



Plate E 5: Mold mixture prepared with the best quality sand, some amount of charcoal and clay at Abu-Dia Company ,Suame Magazine



Plate E 6: Picture showing the pattern for the shell mould machined. On the surface shows some blow hole defects

CONSTRUCTED SAND MIXER FOR MIXING HOT SAND AND RESINS



Plate E 7: Clear view of mixer showing the mixing parts

#### FUNNING HOT PREQUOTED SAND



Plate E 10: Fanning a just precoated sand ready for shell coring



Plate E 8: Demonstrating how the spring loaded bolts work

#### SAND COATING FOR SHELL PROCESS



Plate E 11: Shell core just prepared



Plate E 9: Testing temperature of sand with thermocouple prior to the addition of resin



Plate E 12: Shell core prepared with fresh prepared coated sand

## SHELL MOULDMAKING ASSEMBLY OF MOULDS AND CORE



Plate E 14: Internal view of half mold showing sprue, gating system, mould cavity, runner and riser from right to left respectively. Hexagonal depressions are marks for spring ejector



Plate E 15: Male and female mould with shell core on display

## IMMITATING THE SHELL MOULDING PROCESS



Plate E 13: Preparing a silicate-CO<sub>2</sub> mould with shell precoated sand to imitate the shell moulding process after the collapse of sand. See a new constructed mould-dump box



Plate E 16: Moulds are painted with white adhesive FEVICOL SH – a synthetic adhesive. Care taken not to allow glue to enter into any of the mould cavities and then clamped



Plate E 17: Dried assembly of two half-mould. Also in picture is the dump-mould box used to imitate the shell mould



Plate E 18: The cast process after pouring



Picture E 19: The shell mould after being removed from cope and drag



Plate E 20: The cast during fettling.  
See the ventilated shell core