

A COMPUTER – AIDED DESIGN (CAD)

OF

SAND CASTING OPERATIONS

BY

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CERTIFICATION

We, the undersigned hereby certify that this research thesis has been carried out by ADEJUYIGBE, Samuel Babatope for the partial fulfilment of the requirements for the award of Doctor of Philosophy (Ph.D) in Production Engineering, Federal University of Technology, Akure, and that the work has not been submitted elsewhere for the award of a degree.



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(Supervisor)



DEDICATION

"Great is thy faithfulness O! God my father" Lam. 3:23.

"Great is the Lord, and greatly to be praised in the city of our God" Psalm 48:1.

"My lips shall greatly rejoice as I am singing unto thee; and for my soul, which thou has redeemed" Psalm 71:23.

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"Mark the perfect man, and behold the upright: for the end of that man is peace" Ps 37:37.

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ABSTRACT

The development of Computer – Aided Design (CAD) model and programs to be used in sand casting operations was carried out in this project. The model incorporates standard shape changes which are required to effect feeding as a result of thermal contraction and solidification during the casting process. It also incorporates the cost of the sand casting product designed in this project (boss and flange) which can also be used for any other sand casting products.

A suitable CAD software program was developed using Visual Basic Language. The program generates automatically drawings of parts to be cast (CADD) for boss and flange in 2D and 3D; and also parts to be cast in position in the moulding box ready for pouring for both flange and boss in 2D exploded view from a feature based development.

The Visual Basic program and model are developed to generate automatically the necessary parameters needed to cast a non-defective casting for example: volume of the mould; volume of sand; volume of mould cavity; volume of molten metal needed; pouring time; thermal contraction; feeding efficiency; machining allowance; total weight; yield of casting; solidification time; practical value of linear shrinkage; and conductive heat flow.

Three types of materials were used to achieve different results (Aluminium, Cast Iron, and Brass) for flange and boss, making six samples in all – 3 samples for boss and 3 samples for flange.

The computer program and model for costing called Computer-Aided Costing (CAC) of sand casting products were developed. Three types of materials were used to test the models and resulting softwares.

The CAD, CADD, Manufacturing and CAC results obtained have an average of 99.9% correlation, emphasizing that the models and the Computer-Aided Integrated programs developed are reliable and can be used in producing a good and sound sand casting products; aided by its costing implications that use different types of materials.

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CHAPTER ONE

1.0 INTRODUCTION

For any meaningful technological, or industrial design, or manufacturing breakthrough in developing countries like Nigeria, it is time to abandon the old traditional ways of manual preparation, in favour of more consistent and faster tool as computer-aided design/drafting/manufacturing (CAD/CADD/CAM), so that fast accurate data, drawings, and manufactured products can be correctly obtained in good time.

Inuwa (1995) observed that, foundry is the oldest engineering industry in Nigeria, starting over twenty centuries ago. Foundry was known to have been practised in the middle belt of Nigeria over 2,000 years ago by iron- melting termed the Nok-culture. Iron smelting was also known to be in Kano city over 1,000 years ago. Bronze castings were practiced on the South-Western plain's of Benin, Ife and Igbokwu for over 1000 years. These ancient foundry practices provided the means by which the fore-fathers produced their domestic and agricultural tools and implements and preserved their artistic cultural values. Foundry processes are an integral part of Nigeria's culture.

Inuwa (1995) lamented that, it is unfortunate that despite this early start of the foundry in Nigeria, it is still very much lagging behind. This can be attributed to the lack of political will and the collective zeal of our governments and the individual entrepreneurs to start up and support the main class of foundries, that is, the production group that really determines the level of industrial development, which has not been established. This group comprises the highly mechanised foundries requiring the production of large numbers of a given kind of castings; for the automobile, ship building, aircraft, machine tool, railway industries. In Nigeria, foundry

occupies a special and irreplaceable position in the economy. This is because the machines which the other industries must use in their factories all have their origin in the foundry.

In the developed countries, the foundries have only recently recognised that they must transform their operations to meet the present day technological advancements. This can be accomplished only by infusing the microprocessor-based computer systems into the basic fabric of their business. Accurate data are required for every variable that affects quality and cost of production (Lindberg, 1990)

1.1 OBJECTIVES OF THE RESEARCH PROJECT

The objectives of this study are as follows:

- a. To model the manufacturing processes of sand casting operations, pattern making, gating, feeding, fluid flow, thermal contraction, and solidification.
- b. To develop a suitable model which will utilize drawings obtained from Computer Aided Design (CAD) input automatically, thus improving the sand casting operations and method.
- c. To investigate the conductive heat flow of the molten metal to ensure the reduction of thermal stresses which may cause defective castings.
- d. To validate the results of CAD model through its incorporation into actual sand casting processes on practical components produced in a foundry industry.
- e. To computerize the cost estimation and final costing of any sand casting product.

1.2 EXPECTED CONTRIBUTION TO KNOWLEDGE

The outcome of this work will:

- a. assist production engineers, and foundry engineers, in their day-to-day running of the foundry thus helping in cutting and drastically reducing process time on the various types of preparatory activities.
- b. lead to the production of improved casting through maintenance of consistently high degree of production quality of the cast product using CAD results to generate data.
- c. aid costing of the casting products before they are produced and also in the reduction of production cost of the product.
- d. encourage rapid modernization of foundry in Nigeria through application of CAD methodology.

1.3 RESEARCH METHODOLOGY

Detailed knowledge of the contribution on sand casting process, through the use of literature survey, visitation and field work at Nigerian Machine Tools, Osogbo was acquired. The documentation of acquired data for the purpose of building suitable sand casting process model using CAD for use in Nigeria was carried out.

The computer software which automatically generates patterns in 2 dimensions (2D) and 3 dimensions (3D) which allows for machine allowance and metal shrinkage was developed. The process model for pattern development, moulding and feeding of molten metal to ensure thermal contraction, solidification and withdrawal of metal leading to non-defective casting was developed.

Mathematical and empirical models for prescribing optimal casting parameters such as volume and melting temperature of molten metal required, pouring time, etc to ensure non-defective casting was developed and tested. The cost estimation and final costing of sand cast materials using Activity-Based Costing (ABC) programming method, computer models and programmes were done.

The validation of the models (CAD software) was tested using typical castings (CAM) at a typical foundry industry (Nigerian Machine Tools, Osogbo) in Nigeria was done and found to work perfectly having 99.9% correlation.

CHAPTER TWO

2.0 LITERATURE REVIEW

Developments in the computer industry are having a profound impact on the manufacturing industries from design to machine processing as well as the management and marketing components (Brown, 1990). In both the developed and developing countries, most of the technological processes can be characterized by the rapid development and widespread application of CAD/CAM systems.

Although Nigeria has a lot of raw materials, the country has remained undeveloped because it lacks technology and machineries to convert the raw materials to consumer and industrial goods. Comparing India with Nigeria, it is obvious that India has left Nigeria behind technologically. While India has about 10,000 foundries today, producing more than 2,350,000 tonnes of grey cast iron, 6,900 tonnes of special grades iron, 21,000 tonnes of non-ferrous metals, Nigeria has about 100 foundries processing 5,000 tonnes of grey and malleable cast iron, 1,500 tonnes of special cast materials (Inuwa, 1995).

Adejuyigbe and Aderoba (2000) conducted an appraisal of Foundry Technology Development in Nigeria, and concluded that the majority of the foundry industry in Nigeria are sand casting Job shops. They used wood pattern and very little of metal pattern; and have the required manpower needed to man various operations.

The area of foundry operations had been thought too difficult to computerize. However, the advantages to be gained by the application of methods of computer-aided engineering can no longer be ignored. Plants that have made use of CAD/CAM in foundry have, along with other benefits, found computer technology important in monitoring solidification temperatures and thereby the quality of the castings (Lindberg, 1990). Foundry is a basis for sustainable

development. It is the basis of a great deal of the replaceable parts necessary for continuous functioning of industrial machinery. Monitoring solidification temperatures and quality of the castings were done but lack the sand casting process integration. Hence the essence of this study.

Modelling castings is intended to give an insight into the casting process we cannot be observed directly and to enable the prediction of the quality of castings before manufacture. Effort to use modelling to enhance understanding the physical phenomena that occur on the micro-scale must continue (Stoehr, 1998).

2.1 COMPUTER-AIDED DESIGN / DRAFTING / MANUFACTURING (CAD/CADD/CAM)

CAD/CADD/CAM are terms which mean computer-aided design, computer-aided design and drafting, and computer-aided manufacturing respectively. It is the technology concerned with the use of digital computers to perform certain functions in design and production (Groover and Zimmers, 1984). This technology is moving in the direction of greater integration of design, drafting and production.

2.1.1 COMPUTER

Computer can be defined as a machine that handles information with amazing speed. It handles information in form of numbers. It solves problems dealing with words by changing them into problem dealing with numbers. The fastest computers can solve problems in a few seconds (Adejuyigbe, 1997; Gbotoso, 1997; Brown, 1990).

Computers are universally recognized as the most powerful and effective tool for improving productivity in industry, which is the single most important concern of every manufacturing manager (Lindberg, 1990)

Computer excels in three areas of manufacture; namely:

- collecting information;
- reaching a decision; and
- issuing an order.

2.1.2 COMPUTER - AIDED DESIGN (CAD)

CAD refers to Computer-Aided Design and is defined as the use of computer systems to assist in the creation, modification, analysis, or optimization of design (Groover and Zimmers, 1984).

Computer-based systems are used for creating, modifying, and communicating a plan or product design (Wright, 1990). Activities performed by CAD include;

- Engineering design
- Design analysis; and
- Design presentation.

CAD systems have become more intelligent. Many potential customers are focusing less on geometry creation and more on integration (Hirschtick, 1996). The problem is that solid

modelling are not interchangeable in the same way as word processors are. Windows obviously provides a common interface and common platform for CAD.

The CAD software consists of the computer programs to implement computer graphics on the system plus application program to facilitate the engineering functions of the user company. The process design is characterized by an iterative procedure which consists of identifiable steps or phases thus:

- Recognition of need- that a problem exists
- Definition of problem- specification
- Synthesis- conceptualised the component
- Analysis and optimisation-Analysis
- Evaluation- measuring the design against specification
- Presentation- documentation e.g. drawing e.t.c

Fig. 2.1. Shows the various design related tasks which performed by modern computer - aided design system which can be grouped into four functional areas;

- Geometric modeling- computer compatible mathematical description of the geometry of an object
- Engineering analysis- it may be stress-strain analysis, heat transfer computations, or differential equation e.t.c.
- Design review and evaluation- checking accuracy, dimensioning and tolerancing routines.

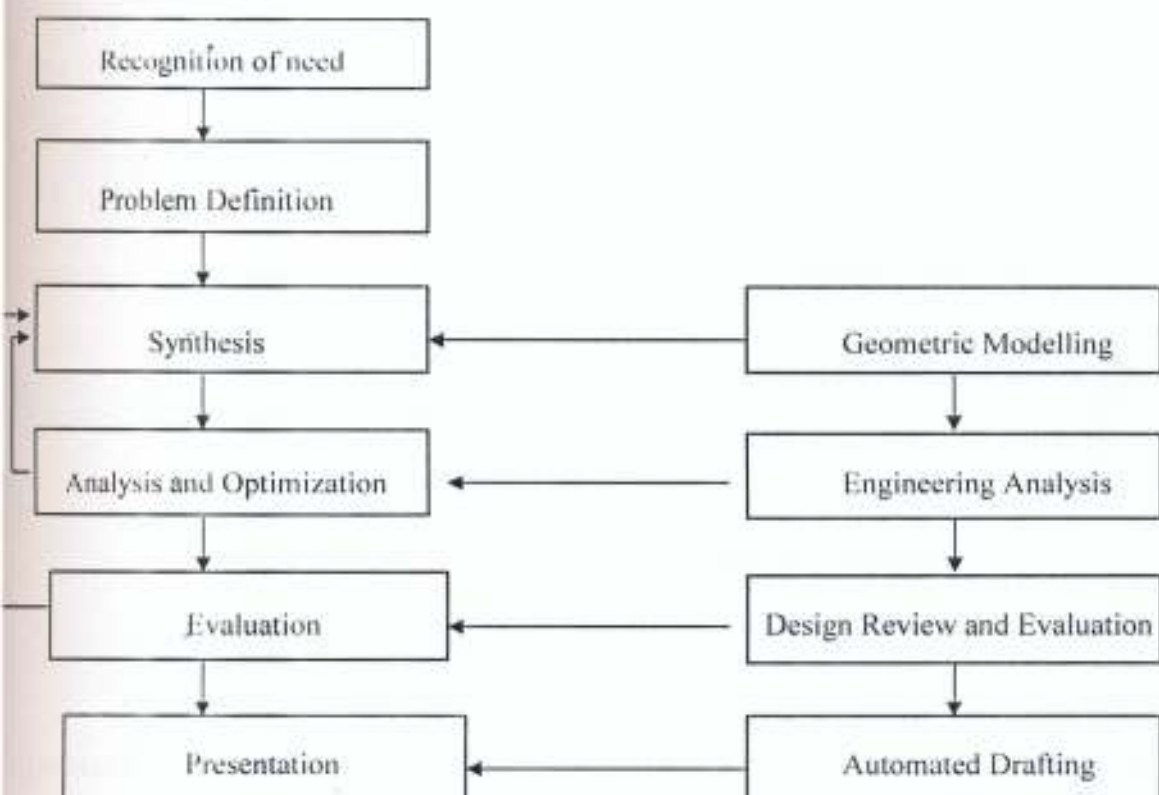


Fig.2.1: Application of computers to the design process.

Source: Groover and Zimmers (1984).

- Automated drafting- creation of hard-copy engineering drawings directly from the CAD data base

Some of the benefits of computer - aided design are;

- improved quality;
- more pertinent and usable information; and
- improved control.

Voisonet (1987) and Brown (1990) enumerated the benefits derived from the use of CAD system thus:

- Reduction of drafting labour;
- Reduction of turn around time;
- Production of the number of drawings required;
- Direct cost savings;
- High accuracy (to-one-millionth of a unit)
- Improvement in the general flow of information through a company;
- Provision of more reliability in design work by having relevant information;
- Evaluation of alternative designs;
- Use of standard libraries for rapid "copy repeats";
- Elimination of tedious calculations by designers and drafters
- Generation of notations, bills of materials, and symbols to be placed on drawings, saving valuable time.

The benefits and productivity gained by using a CAD system lies in many areas. (Brown, 1990).

The areas are summarized thus;

- (i) **Drawing Speed:** Research has indicated that skilled CAD users are up to three times faster than drafters using traditional tools.
- (ii) **Quality:** Quality gained using CAD includes line quality and accuracy. Another key to quality is the precision of the drawing.
- (iii) **Modifications:** A full range of CAD editing functions make modification quick and easy.
- (iv) **Communications:** Application of computers in the production process has increased communication among departments of a company.

(v) **Analysis Tools:** Application programs can use the drawing data created by the CAD system to study many aspects including durability, strength, and potential failures of the product. The end result is a better quality product without having to build expensive prototype models for destructive testing.

The CAD has moved from its present stage of non-utilization to 'Design for All' which embraces the concept of designing products and workplaces so as not to exclude significant sections of the total user population. Case et. al., (2000) worked in the area of computer modelling techniques which are used to create a three-dimensional geometric model of the workplace/product and evaluation is achieved using a human model that can be varied to represent the individuals within the sample. But the research of this project looked at CAD for sand casting operation and developed model and programmes which can be utilized to quickly solve the time wastages in the preparatory activities of the sand casting processes.

2.1.3 COMPUTER-AIDED DESIGN AND DRAFTING (CADD)

(Automatic Drawing Approach)

Engineering drawing has been an integral part of industry for many years. It is the link between engineering design and manufacturing. Design information is quickly communicated to manufacturing in the form of drawings prepared according to prescribed drafting standards.

The popular alternative now is to prepare the drawing with the aid of a computer. A CAD system is a tool of the drafter. The combination of equipment to operate a CAD system is referred to as the workstation (Brown, 1990). It includes a computer, CAD software, display screen, input devices, and hard copy devices.

The new method of drawing is known as Computer-Aided Drafting (CAD), or Computer-Aided Design and Drawing (CADD) (Groover and Zimmer, 1984). It has rapidly replaced the manual drawing. Other names include:

- Computer-assisted drafting;
- Computer-augmented drafting; and
- Computer-automated drafting.

The computer-aided design for foundry begins with the customer's specification for a given part. The best result in working out a new design are usually obtained when joint efforts are made involving the foundry engineers and manufacturing engineers. The foundry design committee reviews the request, and with aid of CAD, a wire frame or a solid model is developed. The part is rapidly designed and can be easily modified on the CRT screen. Also, changes can be documented for future reference. The part can be rotated and viewed from different angles so that dimensional tolerances, location, interferences, and clearances can be checked carefully when components are assembled. Three-dimensional solid from drawings require special software. All surfaces can be accurately defined, including hidden lines, impossible to conceive, that were formerly left to be worked out as wooden models (Lindberg, 1990).

It is, however, noted that plants or industries that have made use of computer-aided design (CAD) and computer -aided manufacture (CAM) in the foundry, have along with other benefits, found computer technology important in monitoring solidification temperatures and thereby the quality of the casting (Lindberg, 1990).

2.1.4 COMPUTER-AIDED MANUFACTURE (CAM)

Groover and Zimmer (1984) defined Computer-Aided Manufacturing (CAM) as the use of computer systems to plan, manage, and control the operations of manufacturing plant through either direct or indirect computer interface with the plant's production resources.

The Computer-Aided Manufacturing (CAM) facility is a natural extension of the technology of CAD. CAM can also be defined as a plan for utilizing numerically controlled machines such as mills, lathes, drills, punches, and other programmable production equipment controlled by computer. Computers are also used in a CAM facility to control production scheduling and quality control, as well as the business functions of manufacturing such as purchasing, financial planning and marketing (Brown, 1990).

CAM is the use of computer technology in the management and control of manufacturing of operations. CAM operation is concerned within or both of the following;

- (i) Computer process control; and
- (ii) Manufacturing support.

CAM uses a computer to assist in monitoring and controlling either or both components of manufacturing operations (Wright, 1990).

The use of computers is seen through the manufacturing process. Mechanical CADD is part of a much broader concept, of computer-aided manufacturing (CAM). At first, computer-aided design systems are used to define the geometry of the object. This geometry is then converted to numerical code (NC) by an NC processor. The code is read by a controller, connected to a milling machine or lathe, to direct the speed and direction of the machine tool. CAM speeds up the manufacturing process since the same information used to create the design is used by machinery to machine the part. Before being sent to a machine, the numerical code can

be used for machine to simulate using the program develop, the computer displays the tool path on the screen. Errors in tool movement can be detected before the part is machined. If the tool moves too fast or too deep, the designer can edit the tool path (Brown, 1990).

2.1.5 AN INTEGRATED CAD/CAM

Computer-Aided Design / Computer-Aided Manufacturing (CAD/CAM) refers to the integration of computers into the design and production process to improve productivity (Lindberg, 1990).

CAD/CAM is a term which means Computer-Aided Design and Computer-Aided Manufacturing. It is the technology concerned with the use of digital computers to perform certain functions in design and production. This technology is moving in the direction of greater integration of design and manufacturing, two activities which have traditionally been treated as distinct and separate function in production form. Ultimately, CAD/CAM will provide the technology base for the computer-integrated factory of the future (Groover and Zimmers, 1984).

The scope of CAD/CAM in the operations of a manufacturing firm and the product cycle is presented in Fig. 2.2. Except for engineering changes which typically follow the product through its life cycle, this completes the design activities. The impact of CAD/CAM is manifest in all of the different activities in the product cycle. This can be effectively utilized when casting product cycle activities is being done.



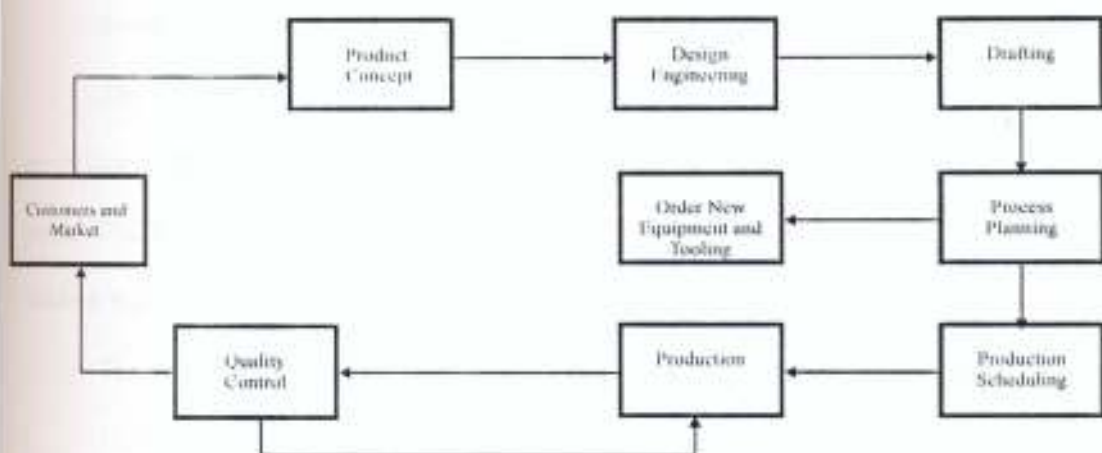


Fig. 2.2: Product Cycle (design and manufacturing)

Source: Groover and Zimmer (1984)

2.2 PROCESS MODELLING

Models can be defined as the representation or abstraction of reality and simplifies a complete version of real object but lack reality that makes real object function (Levin, 1989; Jain, 1992a).

Process modelling is rapidly becoming cost-effective for several manufacturing processes, especially casting and solidification processes. Under increasing pressure to improve quality and reduce expenses, many foundries are turning to advanced software packages to model solidification in castings. These software packages help foundry engineers reduce or eliminate the need for trial and error prototyping since it is possible to model casting variables and identify rigging and mould designs that are likely to cause shrinkages, cold shuts, and other defects before any tooling is built, much less any metal poured. Process modelling techniques

have grown in efficiency and cost-effectiveness. (Case et. al., 1999).

Some of the advanced research work already done on modelling are enumerated thus:

The computer-aided design for foundry begins with the customer's specification for a given part to be produced and the designer will develop a CAD wireframe or solid model of such parts. There are three types of CAD models that are useful for component design, wire frame models; surface models and solid models.

There are three basic techniques for generating solid models. Nan-Shing et. al., (1997)

- i. Constructive Solid Geometry (CSG) – Where various geometric patterns such as cylinders, spheres and cones are combined by Boolean algebra to create appropriate design.
- ii. Boundary Representation (B-Rep)–A profile of the part is defined and then swept either linearly or radially, and the enclosed area represents the solid form. This representation is used to store bounding faces, and makes the Boolean operations much easier and more economical. Instead of recognizing only surfaces, the computer “thinks” of the object as solid materials. Solid models are created in computer using small elements, called primitives.
- iii. Analytical Solid Modelling – It can use both CSG packages and B – Rep techniques. Which is the combination of (i) and (ii).

Other representations include Pure Primitive Instancing (PPI); Spatial Occupancy Enumeration (SOE); Cell Decomposition (CD); and Sweeping (Nan – Shing et. al., 1997).

Early packages of solid modeling required laborious Boolean operations but new approaches have now simplified the process of solid modeling (Hanratty, 1994). they involve;

- * Piece-by-piece application of Boolean operation; to
- * Inflexibly defined application of solid primitive; or

* The equally laborious construction of trimmed-to-true-intersection surface enclosures. The new method is called parametric solid modeling and the industry is now moving towards calling it dimensions – driven variational modeling. What sets the new approaches apart from traditional solid modeling is that they permit the user to work with the mathematical and topological relationships underlaying the model instead of just defining a set of rigid spatial locations.

Puttre (1994 a , b, c, d), in his analysis enumerated that solid models convey information that surface or wireframe geometry do not, such as topology, volume, and mass properties. Both B – rep and CSG methods are incomplete because they store only list of mathematical definitions of surfaces or primitives and do not convey design intents very well. Recently, pen based computers can serve as attractive alternatives to traditional desktop systems and paper drawings for engineers who prefer to sketch geometry right on the screen. A light pen or stylus connected to a computer transforms the screen into precise vector geometry, as if the object had been created using a mouse or keyboard. The relatively inexpensive design and manufacturing software systems enable individuals and partnerships to produce work on a par with that of large engineering firms. The very metaphor of design has changed from pen strokes to mouse clicks.

Hounsell and Case (1999) reported that conventional CAD systems have promoted the marriage of an efficient Geometric Solid Modeling (GSM) system, such as Boundary Representation (B – rep), Constructive Solid Geometry (CSG) or a hybrid approach (Zerd,1991) with user – friendly graphical interfaces composing successful system to help the detailed design activity. Further integration of conventional CAD systems with other activities such as computer aided engineering (CAE), process planning (CAPP), manufacturing (CAM), and production and control (CAPC), has been shown to be a difficult task because conventional CAD systems are

incapable of capturing non-geometric aspects of the designer's intent such as tolerances, past relationships, surface finish, etc (Nnaji et. al., 1993; Stroud, 1993; Morefat, 1993).

The research works on geometric analysis of components from a CAD database are related to process planning. They start by identifying the features of the components from the CAD database and then generating a process plan to aid in manufacturing these features. The same concept can also be applied to the analysis of design for assembly Nan – Shing et. al, 1997).

Meyer (1982) developed a LISP program for the automatic analysis of manual handling of parts in a mechanical assembly. The analysis is performed on a 3-D solid model CAD database to obtain the part's size and rotational symmetry. The programs determines the required information automatically from a CAD database using point data, mass properties, the polygonal representation of the part, and the CAD system's functions.

Swift (1987) described his work on knowledge – based system that provides estimated costs for automatic assembly and proposed design modifications for components designed at CAD workstations. The system can determine the relevant properties of a design automatically by analyzing its engineering drawing. These properties are defined in terms of the co-ordinate ring.

Goldbogen et. al. 1988) demonstrated the feasibility of applying expert system technology to the problem of extracting manufacturing features from CAD/CAM drawings. After the part drawing is finished, a CAD file filter is invoked to process CAD database to produce a file of geometric primitives that can be read by the expert system. The expert system will list the manufacturing features and their location in the part, identified by the points and CAD co-ordinates that were used to draw the point.

Henderson and Musti (1988) have developed software to identify the form features from a solid model of a part and then generate a group technology code for the part. Using logic

programming, the software consists of facts, describing the part, which must be searched to satisfy rules defining the form features.

Sanchez and Priest (1992) described a design for predictability approach, which is based on a feature-based method for reviewing design for productivity. Every part geometry, which is made up of a number of definable features, is automatically extracted from a CAD file containing the candidate design. Rules are then applied to determine the manufacturability of the individual feature.

De Fazio and Edsall (1993) developed a prototype software system that identifies information important to design for assembly (DFA) tasks, and how the information could be captured using feature based design and explored the use of the information.

Mahajan et. al. (1993) reported that design for manufacturability tools have been developed for stamped components and are being integrated into a feature – based design system. The part is designed in terms of features. A manufacturing evaluator converts this representation based on design with features into a representation base manufacturing features, which is then used to derive methodology for taking a CAD model of a part and extracting a set of machinable interpretations of the part. Besides extracting a variety of features, the approach also considers accessibility constraints for these features, and modifies features recognized to account for available tooling for manufacturability analysis.

Nanda et. al. (1994) used the heuristic – based computer system, which was produced under a strong conceptual design with two major steps;

- i. Identification of features; and
- ii. Estimation of process design parameters.

22.1 IDENTIFICATION OF FEATURES

The casting process designer divides a complex process into various logical regions based on functionality. These regions are then labeled "features" (Nanda, et. al.,1994).

Hounsell and Case (1999) reported that future CAD technology is likely to be based on feature-based modeling (Mantyla, 1996).

Features provide alternative component representation that is suitable for a wide range of activities, thus bridging the gap between design and manufacturing (Case and Harun, 1999). Because of this potential, features have been used in many CAD/CAM applications (Pratt, 1993), such as design (Case and Gao, 1993), process planning (Krause et al., 1991; Gindy et al., 1993) casting (Corbet and Woodward, 1991), injection moulding (Al – Ashaab and Young, 1995), design for assembly (De Fazio, 1990), assembly planning (Wang and Li, 1991), inspection planning (El Maraghy and El Maraghy, 1994) and manufacturing cost analysis (Niemi and Tuomi, 1991).

Many existing CAD/CAM packages can be classified as geometric modelers with data structures designed to manipulate individual parts. However in most engineering design the product of interest is a composition of parts formed into an assembly and there is a need for system that allows designer to create individual parts, assemble them and then form the necessary analysis of the assembly. Modeling and representing assemblies generating assembly sequences and analyzing assembly are all relevant issues for geometric modeling and CAD/CAM technology (Case and Harun, 1999).

After identifying the features, the importance of each is determined using a variety of heuristics. A mental picture of the casting, with relative locations, approximate dimensions, and the importance of various features is generated.

Feature-based modeling (FBM) systems enhance traditional computer aided design (CAD) environments, making them more meaningful and easier to use, and facilitate their integration with other computer aided system within the manufacturing context because they subsume extra non-geometric semantics (Hounsell and Case, 1999).

One way of implementing feature-based CAD systems is the design-by-features (DbF) approach which offers the designer a library of features that can be used to represent components. DbF systems are distinct from the alternative feature recognition (FeR) approach, where features are 'discovered' after a session using traditional CAD systems. Current thinking is that these elements of traditional CAD systems, DbF and FeR can be combined into a DbF-like system producing a useful, powerful and flexible system.

2.3 SAND CASTING PROCESS

Casting is the fastest way to go from a raw material to a simple or complex shape that is hollow or non uniform in cross-section. More than 85% of all metal castings are produced in sand moulds, the balance are made in ceramic shell or metal moulds (Niebel et al., 1989).

UNIDO (1982) said that production of sand castings involves the following steps (Fig 2.3);

- (i) Component Design/Casting Design
- (ii) Production of pattern: This step translates the idea of the designer into a pattern.

The pattern make must take into account the physical-chemical and metallurgical characteristics of the raw material, of the refractory materials, and of the processes of casting;

- (iii) Production of the mould;
- (iv) Preparation of sand and bonding elements forming the mould;

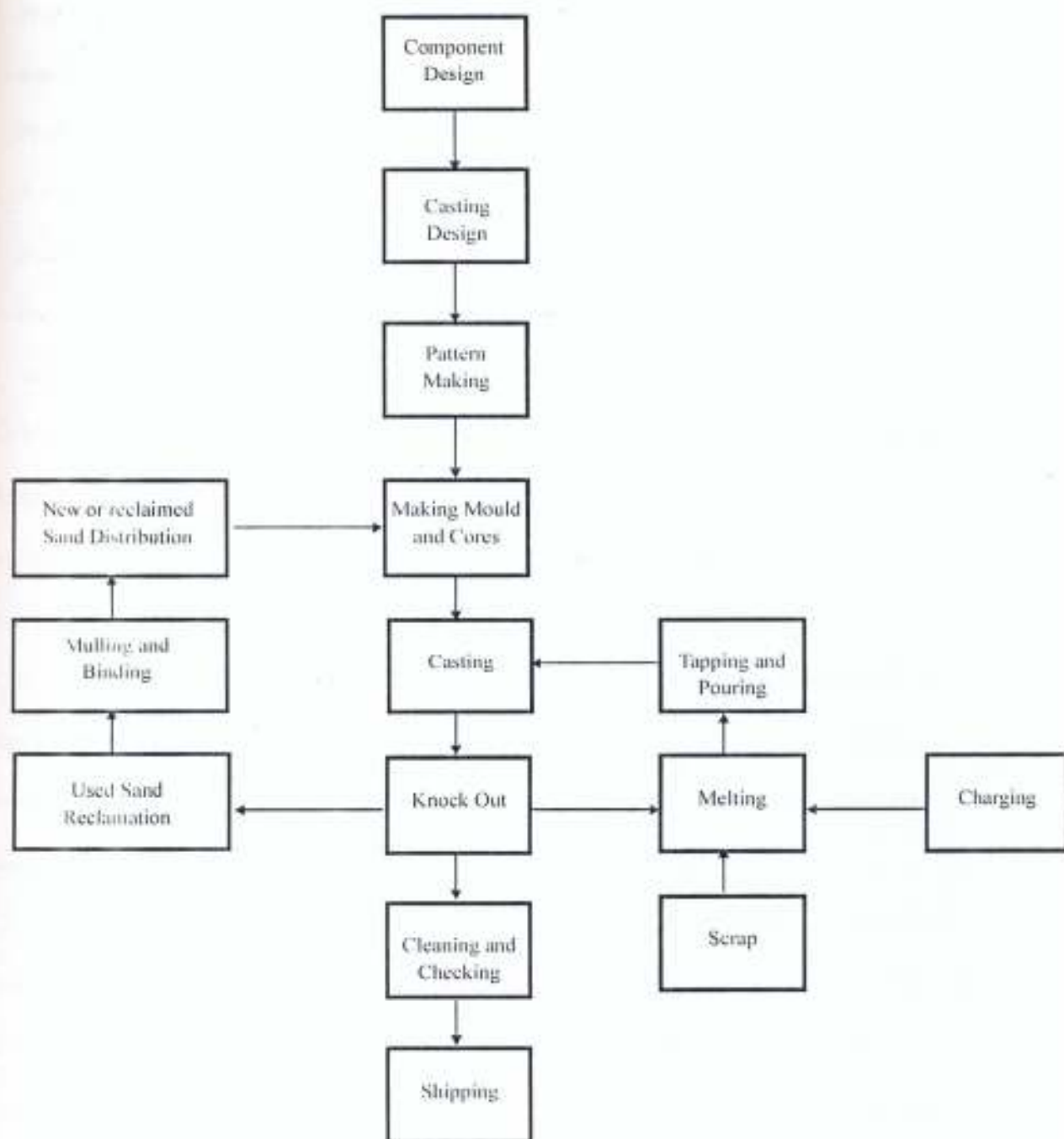


Fig. 2.3: Process Sequence of the main steps of the Foundry Processes
Source: (UNIDO), 1982

- (v) Preparation of cores. Cores are required for the casting that is hollow. The template shaping the core is called a "core box".
- (vi) Preparation of metal. This involves melting and also proper control of composition;
- (vii) Assembling the cores and clamping the moulds;
- (viii) Introducing liquid metal into the mould;
- (ix) Removing the solidified casting from the sand (Knock-out)

Sand casting is versatile and is capable of making parts ranging from small knob to huge radio telescope bases weighing more than 100,000 kg (100 tonnes). The only disadvantage of sand casting is that the process requires a high investment in plant facilities and sand-handling equipment to make sure production rates as described above are possible.

The new innovable development in foundry can be recorded thus;

Bombelli (1994) enumerated the Implant Machine Fonderia (IMF) complex at Luino developed AUTOMA which offers foundries a tool to solve an endless series of problems by rationalizing work, boosting productivity and improving safety standard AUTOMA, a remote controlled manipulation whose design takes account not only of today's trend but even of future ones, is certainly part and parcel of technologies for the year 2000. Nothing is ergonomically closer to a human arm than is the AUTOMA. Its control system reproduces the movements, the complete manufacturing job. The operator sits inside a protected, sound-proofed and air conditioned control cab from where all pickup, transfer and machining operations are monitored with just one hand, in completely safe conditions. AUTOMA replaces the operator in all shake-out, riser removal, casting handling, shot blast loading and forge parts feeding operations as well as finishing. Equipped with special tooling, it can perform chipping, felting, riser cutting and many other functions.

A complete plant that produces moulds with No-bake process (furan) has been recently commissioned. This is an old foundry which has completely restructured all its plants in recent years. It is a jobbing foundry producing castings of 1500kg Max weight in grey iron, modular iron and in-hard and in resist alloyed iron. IMF moulding plant was designed to produce about 15 complete moulds/hour. It consist of a classic fast loop moulding carrousel with 8 patterns in circulation, 4 cope and 4 drags, fed by a 25-30t/h double arm mixer. Mould stripping is done by a roll over-stripping machine in automatic cycle, while painting is done in a painting station where the moulds are held by a handler. After drying and coring, the moulds are closed by a hydraulic guided, handler-closer. The mould are then automatically conveyed to the pouring and cooling lines by means of a transfer car with line pushers on board controlled by an electronic programm. Shake-out and casting separation are done in a sound proof enclosed shake-out unit able to guarantee reduction of noise, fumes and dust according to the environmental standards. This machine, on a mobile car, collects the castings and positions, then into baskets, and it is controlled by an operator inside an air conditioned cabin. The sand coming from the shake-out is mechanically reclaimed in a 10-12t/h unit (Ingegnol, 1994).

A highly sophisticated mid Western foundry producing thin walled stainless steel castings in the converter gravity casting process has been developed. Moulds are produced in a gas cured phenolic urethane binder system at a rate of 60 moulds/hours. One, two, three or four pattern sets with different jobs transfer through an IMF fast loop moulding system. The moulds can be produced in new sand, mechanically reclaimed sand or any combination of both sands. Iron oxide can also be used as an additive for reclaimed sands (Blendin and Morlotti, 1994a).

The modern Wisconsin foundry produces a variety of heat and wear resistant castings in No Bake phenolic urethane resin bounded sand system. Mould process and production operations are controlled by a production management system installed on an IBM PC, coupled with the

system PLC. Information such as sand type (new, mechanical and/or thermally reclaimed sand), sand amount per mould half, binder level, strip time, as well as the number that need to be produced are programmed in the system via the PC and PLC. As soon as an empty flask, reaches the filling position the mixer automatically begins to deliver a prest quantity of sand mixer according to one of the fire available programmes. After filling, a compaction table provides single direction linear vibration with a manual mechanically adjustable variable amplitude system to optimize mould then transfers to an automatic mould strike off system to remove excess sand from the top of the pattern frame (Blendin and Morlotti, 1994b).

2.3.1 PATTERN MAKING

Foundry pattern is very essential to the production of high-quality casting. The accuracy of the pattern determines the accuracy of the casting. For usable castings to be produced consistently, a thorough knowledge of pattern design is essential to the foundry worker (Little, 1977).

Pattern making is the first step in the casting of a job. The pattern is a model of the job and is made of a suitable material, commonly wood or metal, and is used to make the mould. The success of a casting process depends a lot on the quality and design of the pattern.

Different types of patterns are available. Little (1977), and UNIDO (1982) in Tables 2.2, 2.3 and 2.4 describe various types of patterns summarized below;

- (i) One Piece or Solid Patterns;
- (ii) Two Pieces or Split Patterns;
- (iii) Multipieces or Loose Pattern;
- (iv) Match Plate Pattern;
- (v) Cope and Drag Pattern;

- (vi) Follow Board Pattern;
- (vii) Gated Pattern;
- (viii) Sweep Pattern;
- (ix) Skeleton Pattern; and
- (x) Segmented or Part Pattern

The selection of particular material for pattern-making, depends on the following factors which must be taken into consideration;

- (i) Number of castings to be made or produced;
- (ii) Mould material used;
- (iii) Type of moulding process;
- (iv) Degree of accuracy and surface finish required,
- (v) Minimum thickness required; and
- (vi) Physical characteristics of the pattern design.

Some of the more common material used in the construction of pattern are;

- | | | |
|--------------------|---|--|
| (i) Wood | - | Pine Wood, Teak Wood, and Mahogany; |
| (ii) Metal | - | Cast iron, Brass, Bronze, and Aluminium; |
| (iii) Plastic | - | Thermosetting resins; |
| (iv) Plaster | - | Belong to gypsum family; and |
| (v) Wax or Mercury | - | Pattern making in investment casting. |

Table 2.1 below gives the properties of the various pattern materials on comparative basis

Table 2.1 Properties of Various Pattern Materials

Properties	<i>Wood</i>	<i>Mild steel</i>	<i>Aluminium</i>	<i>Plastics</i>
Machinability	Superior	Good	Good	Good
Wear resistance	Poor	Superior	Good	Average
Strength	Average	Superior	Good	Good
Weight	Superior	Poor	Good	Good
Corrosion due to moisture	Superior	Poor	Superior	Superior
Swelling due to moisture	Poor	Superior	Superior	Superior
Repairability	Superior	Good	Poor	Average

Source: Little, (1977)

Table 2.2 Pattern Colour Code

Colour	Identification
Black	Surface as-cast
Red	Machined finish
Yellow	Core prints and seats
Yellow/Red diagonal stripes	Loose pieces
Yellow/Black diagonal stripes	Stop-offs

Source; Little, (1977)

Table 2.2 above shows pattern colour code for loose patterns with their core prints and core boxes, for easy identification in many foundries. This colour coding establishes a basis for communication between the various individuals involved in the construction and use of patterns.

Table 2.3 shows the characteristics of various pattern-making techniques. The table prescribes that pattern with special equipment like skeleton pattern, sweep pattern and template pattern and that of expandable pattern using polystyrene foam for full mould process is not suitable for use in developing countries like Nigeria. These are however the type of foundry pattern that can bring industrial growth to Nigeria.

Table 2.3 Characteristics of Various Pattern-Making Techniques

Material and for pattern	No. of moulding produced	Moulding	Level of Technical required	Relative Cost	Relative costing size	Auxiliary tools use	Comments	Appropriate for developing countries
INTERMEDIATE								
Wood or Plastic	Up to 40 (wood) Up to 100 (Plastics)	By hand	Medium	Very low		Hand tools (pneumatic rammers)		Appropriate for a few simple parts
Wood or Plastic	Up to 40 (wood) Up to 100 (plastics)	By hand	Low to medium	Very low to low		Hand tools (pneumatic rammers)	Generally for first parts of a series	
PATTERN								
Wood, plastic or metal	Up to 300 (Wood) 500-1000 (plastic) 1000-5000 (metal)	By machine	Low	Low to medium	Medium	Precision flashers, moulding machines	Use of metal for pattern is infrequent	
Wood, plastic or metal	150-400 (wood) 500-1000 (plastic) 1000-5000 (metal)	By hand, machine or mixer	Medium to High	Medium to very high	Medium	Mixer or blowing machine	Good surface precision	Appropriate if mixers or blowing machines are available
FAST								
Wood	Few	By hand	Medium to high	Minimal	Large	Hand tools and slinger machines for filling		
Wood	Few	By hand	Medium to high	Minimal	Large			
Wood	Few	By hand	Medium to high	Minimal	Large			
FAST								
Polystyrene foam	One (not reusable)	By hand or mixer	Low to medium	Minimal	Medium and Large	Self-hardening material needed		

Source: United Nations Industrial Development Organization (UNIDO) -1982

23.2 MOULD MAKING

Mould can be defined as a soft, fine, loose earth, and moulding as the act of shaping or line of ornamental plaster, carved wood-work (Hornsby, 1980).

The preparation of moulds entirely by hand is slow and costly. In most modern foundries, moulds of small and medium sizes are prepared by machines, for mass production, match-plate patterns are normally used (Lindberg, 1990).

Moulding can be classified in a number of ways, but broadly they are classified either on the basis of the method used or on the basis of the material used thus;

- Classification based on the method used;

- (i) Bench moulding;
- (ii) Floor moulding;
- (iii) Pit moulding; and
- (iv) Machine moulding.

- Classification based on the material used;

- (i) Sand Moulding
 - (a) Green sand mould;
 - (b) Dry sand mould;
 - (c) Skin dried mould;
 - (d) Core sand mould;
 - (e) Cement bonded sand mould;
 - (f) Loam mould;
 - (g) Carbon-dioxide mould; and
 - (h) Shell mould.

- (ii) Plaster moulding; and

(iii) Metallic moulding.

Mould materials used in castings can be metallic as non-metallic under the metallic group, the following are common:

- (i) Cast iron;
- (ii) Mild steel;
- (iii) Alloy steel; and
- (iv) Anodized aluminum.

The non-metallic group includes the following materials;

- (i) Moulding sands;
- (ii) Plaster of Paris;
- (iii) Graphite;
- (iv) Silicon Carbide; and
- (v) Ceramics.

However of all these, moulding sand is the most common mould materials.

The basic requirement of a proper moulding sand are; Refractoriness; Permeability, Dry strength, Green strength, Flowability, Collapsibility, and Reusability.

The main constituents of moulding sand can be listed as follows;

- (i) Sand;
- (ii) Binder; and
- (iii) Additives.

Table 2.4 shows the general characteristics of the main methods for castings. For casting less than 10g, the Jolt-squeeze machine is an inexpensive and very versatile machine. Hand moulding requires experienced personnel. It is surprising to see that the mechanized sequence and the flaskless mould mechanized lines which is the type that bring continuity to casting production

is not recommended for developing countries like Nigeria, hence the old ways or traditional ways of casting persist in the developing countries. The precise and accurate parts produced by this types of process eluded the developing countries.

Table 2.4 Characteristics of Moulding Methods

Method	Techniques used	Run length and Comments	Product Quality	Manpower skill needed	Equipment	Relative Productivity (Number)	Equipment investment costs	Adaptability in developing countries
Green sand	Use green or dry moulding sand in a unit or as facing sand backing sands	Short run, generally large simple pattern	Low to very low	Medium	Loose pattern or wood splitted pattern	1 to 2	Low	Only for small foundries
Baked sand	Generally uses baked sand unit	Short run and limited size castings	Low	Medium	Loose pattern or wood splitted pattern	1	Low	Only for small foundries
Lost foam		Short run large castings	Very low	High	Loose pattern even reduced (profile skeleton)	1	Low	
Machine mould	Uses compression plate, multiple rammers, etc.	Simple shapes size, complex profile	Medium	Low	Plastic or wood bound pattern	15	Medium	Only for thin casting
Jolt	Uses different type of Jolt	Pattern of limited size, complex profiles	Medium	Medium	Plastic or wood pattern	10	Medium	Long run, with output of 20 moulds per hour
Jolt core		Castings with sizes generally smaller than 1000mm	Medium	Medium	Plastic or wood bound pattern	15	Medium to high	Medium run with output of 30 mould per hour
Automatic compression	Metal is blow or shot into mould	Long runs, for size, smaller than 1000mm	High	Medium	In preference metal types	20	Medium to high	Good productivity but high pattern cost
Advanced cores		Very long runs, for sizes generally smaller than 200mm	Very high	High	Metal type every precise and accurate	Greater than 100	Very high	Absolutely not suitable
Flaskless moulding techniques	Horizontal or vertical parting line	Simple, precise (possibly coreless) very long run castings	Very high	High	Very precise and accurate metal type	Greater than 100	High	Absolutely not recommended

Source: United Nations Industrial Development Organisation (1982)

2.3.3 GATING SYSTEM

The process of metal casting requires that molten metal be transferred from some type of container to the mould cavity. The gating system is the plumbing that determines the direction of flow and the amount of metal to reach the mould cavity. If the mould cavity is open on one side, uneven cooling of the metal will take place. Consequently, the mould cavity should not be open and only a few gates, or entrances, should be exposed to the atmosphere (Little, 1977).

The term 'gating' or 'gating system' includes all the passage ways through which molten metals enters the mould cavity. The gating system is made up of the following parts: pouring basin, sprue, runner, and gates (Fig.2.4).

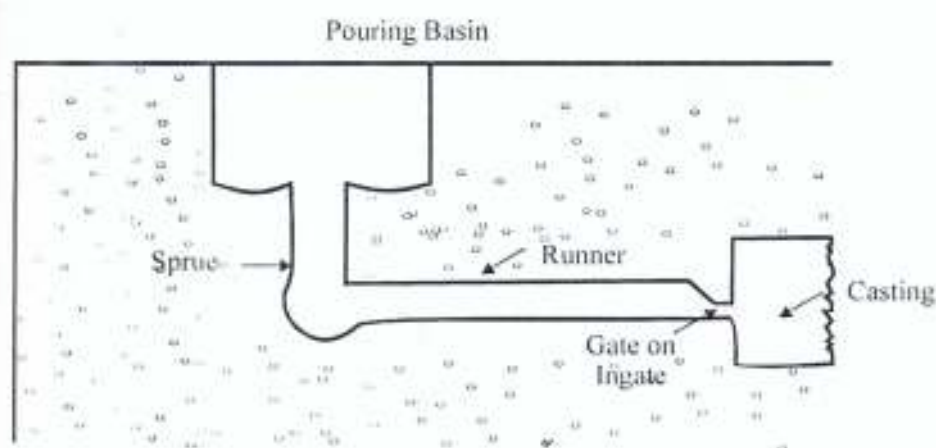


Fig. 2.4: Various parts of Gating System

Little (1977) categorized pouring basins into four types;

- (i) concentric basin;
- (ii) dam basin;
- (iii) the skimmer/dam basin; and
- (iv) the strainer core basin

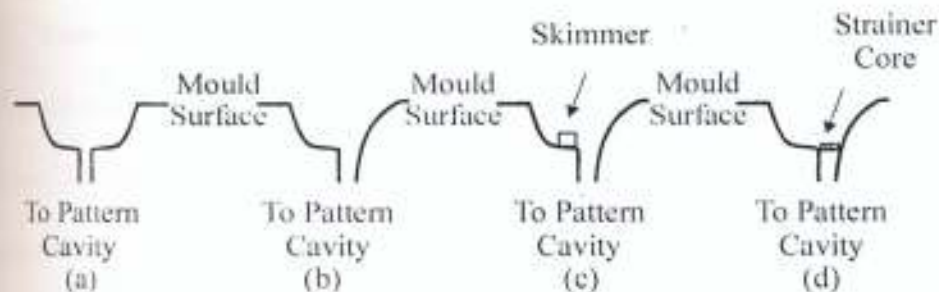


Fig. 2.5: Pouring Basins (a) Concentric (b) Dam (c)Skimmer/Dam (d) Strainer Core

Little (1977) shows different types of sprue shown in figure below

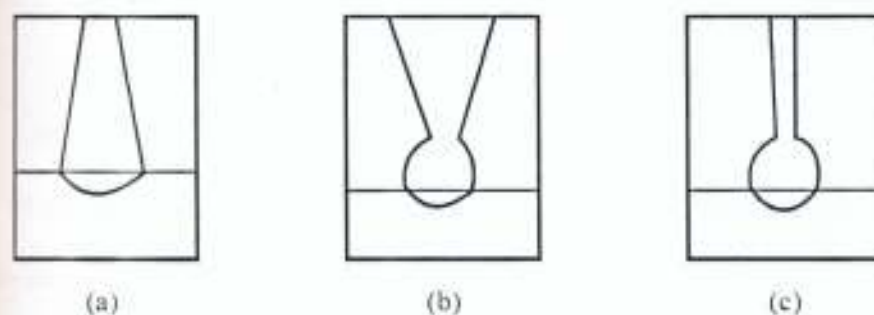


Fig. 2.6: Sprue Types: (a) Reverse taper
(b) Positive taper
(c) Straight-no taper

23.4 FEEDING SYSTEM

The gating and feeding system of a mould is essentially a combination of passages and elements of the mould cavity, filling the later, and feeding up the metal during solidification (Mikhailor,1989). It can be sub-divided as ;

- Filling mould cavity- Gating System
- Feeding the metal during solidification- feeding system (Risers).

From the clarification done above, feeding system is the same as the problem encountered during the design of risers. Riser is used to feed metal to the casting as it solidifies. Risers are designed and placed so as to ensure filling the cavity during solidification. The volume of metal in the riser should be sufficient to retain heat long enough to feed the shrinkage cavity and to equalize the temperature in the mould. avoiding casting strains (Little, 1977; Lindberg, 1990)

Riser serves a dual function;

- (i) they compensate for solidification shrinkage; and
- (ii) they are also a heat source, so that they freeze last and promote gradients from a remote chilled area to the riser (Niebel et al.,1989).

Little (1977) shows the major shapes used in making risers to include the cylindrical shape with a positive taper, the cylindrical shape with a reverse taper, and the straight and bulbous shapes (Fig.2.7).

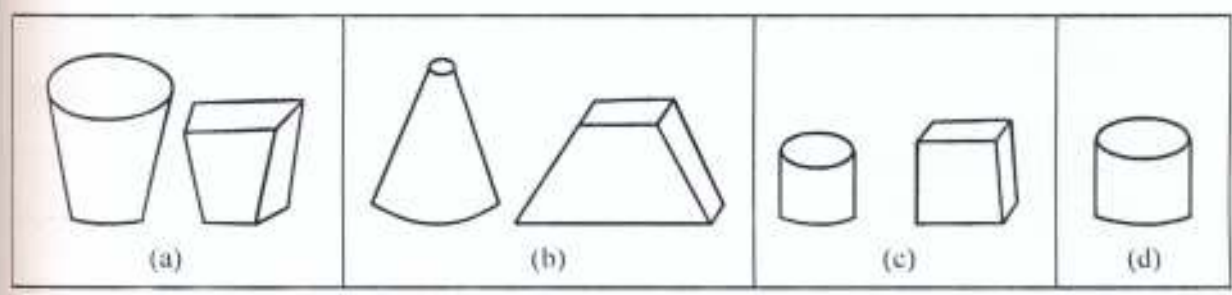


Fig. 2.7 Risers shapes

- (a) Positive taper;
- (b) Reverse taper;
- (c) Straight; and
- (d) Bulbous.



The world class foundry operations requires the best equipment. (Martinez, 1994). Two types of automatic pouring or mould filling tagged controller RSE 1000 and controller RSE 400 has been developed by societe D'Etude Et Realisations Techniques (SERT). It increases productivity; cut the scrap losses; improve working condition and have 7 to 10 months payback.

2.3.5 THERMAL CONTRACTION

Thermal can be defined as the number of units of heat needed to raise the temperature of a body by one degree, and contract as making/becoming smaller, or shorter (Hornsby, 1980). Thermal contraction is the volume reduction as a result in drop in temperature of the material.

Inpractice, it is found that all common cast metals shrink a significant amount when they are cooled from the molten state. The total contraction in volume is divided into the following parts: liquid contraction; contraction on cooling; and solid contraction.

Table 2.5: Contraction Allowances for Metals and Alloys

Metals and Alloys	Contraction Allowance (mm/metre)
Cast Iron	10
Brass	16
Aluminum	15
Steel	21
Lead	24

Source: Little (1977)

The contraction allowance differs between metals (Table 2.5 above)

Although no absolute rules exist for determining the exact amount of excess material to allow for shrinkage, there are estimates that have been established. The size of the pattern is never kept the same as that of the desired casting. This is because of the fact that during cooling the casting is subjected to various effects and hence to compensate for these effects corresponding allowances are given in the pattern. These allowances comprise; Machining allowance; Draft or Taper Allowance; Rapping or Shake Allowance; Distortion Allowance; Allowance for Mould Wall Movement; and Thermal Properties.

2.3.6 SOLIDIFICATION

Many properties of castings are directly related to their final structures developed after the casting operation. The final structure of a casting, however, depends on its solidification history.

A foundry man is always interested in producing sound castings free from defects such as porosity, shrinkage, crack, segregation, etc. To produce a casting free from such defects, it is necessary to understand the phenomena of the solidification of casting and the various variables causing the defects during solidification.

Solidification of casting should be approached from the crystallization process of such metals or material used for casting. Consider the cooling curve of a liquid metal from the melt, the undercooling curve is large for liquid metal but small for solid (Fig. 2.8)

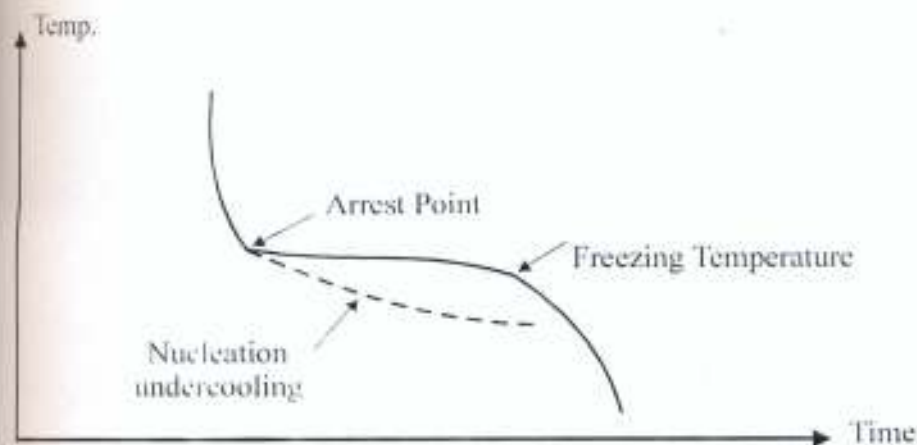


Fig. 2.8 Cooling curve of a liquid metal from melt.

As molten metal is poured, it acquires the shape of the latter and continues to cool. On cooling to the solids temperature, the metal in the mould starts to change from the liquid to the solid state. The rate of solidification of the metal is determined by the rate of heat removal and characterizes the increase of the solid-phase fraction in time (Mikhailor, 1989).

The solidification of most alloys is accompanied by appreciable volume contraction. Measures adopted for the feeding of castings frequently use the principle of directional cooling is controlled by designing the mould and the utilising the intrinsic design of the casting, so that freezing begins in those parts of the mould furthest from the feeder heads and continues through the casting towards the feeder heads which are designed to solidify last so as to supply liquid metal throughout freezing. No two alloys have identical feeding characteristics but it is possible to distinguish three groupings based upon the major contracts in solidification behaviour. These groupings are:

- (i) Short freezing range alloys such as low carbon Steel, brasses, aluminum, bronze, etc.

- (ii) Long freezing range alloys such as medium and high carbon steels, nickel based alloys, phosphor bronzes, etc.
- (iii) Expansion stage such as Gray cast iron,

The factors affecting fluidity are;

- (i) Temperature - Fluidity of an alloy is related to the superheat above the liquids. Fluidity therefore is dissipation of superheat before flow stops.
- (ii) Composition - High fluidity is associated with metal or alloy of eutectic composition with short freezing range. Low fluidity is associated with alloy of long freezing range. In short freezing range alloy, flow stops by gradual narrowing down of the flow front until the tube closes entirely

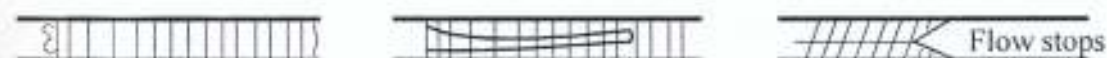


Fig. 2.9 Fluid Flow

In the long freezing range alloy solidification occurs with formation of suitable nuclei within the melt. These grow until flow stops by the interaction of the grains (Fig. 2.9). The superheat also increase for the after the eutectoid or eutectic temperature.

Modelling of solidification is becoming increasingly feasible, even in manufacturing certain critical features of solidification can be modelled very accurately and used to predict casting results, including defects. The advent of faster computers and continuing software development bid well for the future of modelling in foundry operations (Overfelt, 1992).

Solidification in casting involves two things; Nucleation and Growth. After casting and when cooling has started, nucleation first takes place at the moulds walls of the thinner sections. Grain forms may be dendrite, columnar, or equiaxed, depending on the cooling rate and alloy

structure in dendritic structures, some of the arms break off during the normal conditions of growth, thus furnishing nuclei for central, inner portions of the castings. New dendrite grow from these fragmented parts to form the equiaxed central zone (Fig. 2.10).

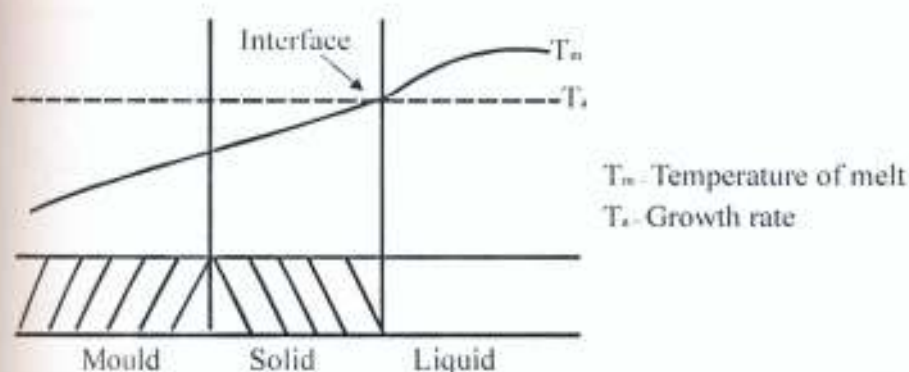
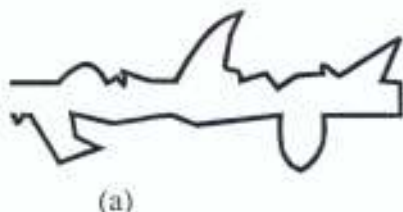
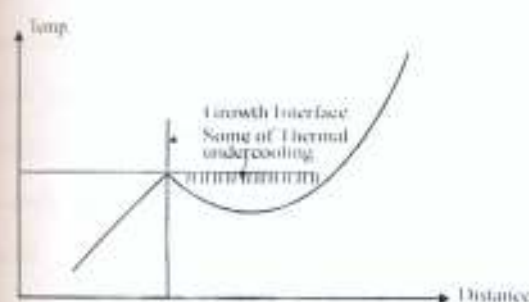


Fig. 2.10: Thermal conditions for planar growth or interface from solid to liquid.

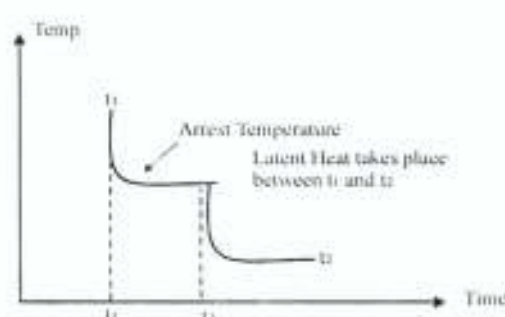
The dendrite growth is where local evolution of latent heat is sufficient to reverse the temperature gradient at the interface (Fig. 2.11). The condition for dendrite growth are;

- (i) there must be undercooling either constitutional or thermal in pure metals.
- (ii) Lower temperature not at the interface
- (iii) spike like structure growth towards the cool region.





(b)



(c)

Fig. 2.11 (a), (b), and (c) Condition for Dendritic Growth.

Fleetwood (1987) researched into rapid solidification processes and explained that the increasing solidification rate which is a thousand fold above that of typical conventional casting refines grain size and segregation; a million-fold increase extends solid solubility, forms metastable phases and, in certain alloys entirely subdues segregation and crystallisation, creating amorphous alloys. Used to improve strength, modulus, corrosion resistance and magnetic properties, rapid solidification (RS) has been achieved by quenching droplets or thin metal streams by gas liquid, or a solid surface.

Purvis et. al. (1994) worked on the modelling characteristics for solidification in single-crystal, investment-cast superalloys. The macroscopic traits of solidification such as thermal gradient, solidification rate, and other criteria functions were extracted from computer modelling data of a single-crystal investment cast superalloy. The thermal history were used to predict the presence or absence of grains defects in the shaped castings.

Overfelt (1992) researched into the area of the manufacturing significance of solidification modelling, modelling of solidification is becoming increasingly feasible even in manufacturing scale processes. Certain critical features of solidification can be modelled very accurately and used to predict casting results including defects.

Beckermann and Wang (1994) wrote on incorporating interfacial phenomena in solidification models. A general methodology is available for the incorporation of microscopic

interfacial phenomena in macroscopic solidification models that include diffusion and convection. An example is shown in (Figure 2.12), which considers the various physical scales associated with dendritic alloy solidification. In the magnified views of the solid, mushy, and pure liquid regions, one finds a myriad of microscopic structures, all of which are characterized by different scales, physical phenomena, and growth dynamics. These micro-scopic structures are closely coupled with the heat flow, melt convection, and species redistribution on the system scale.

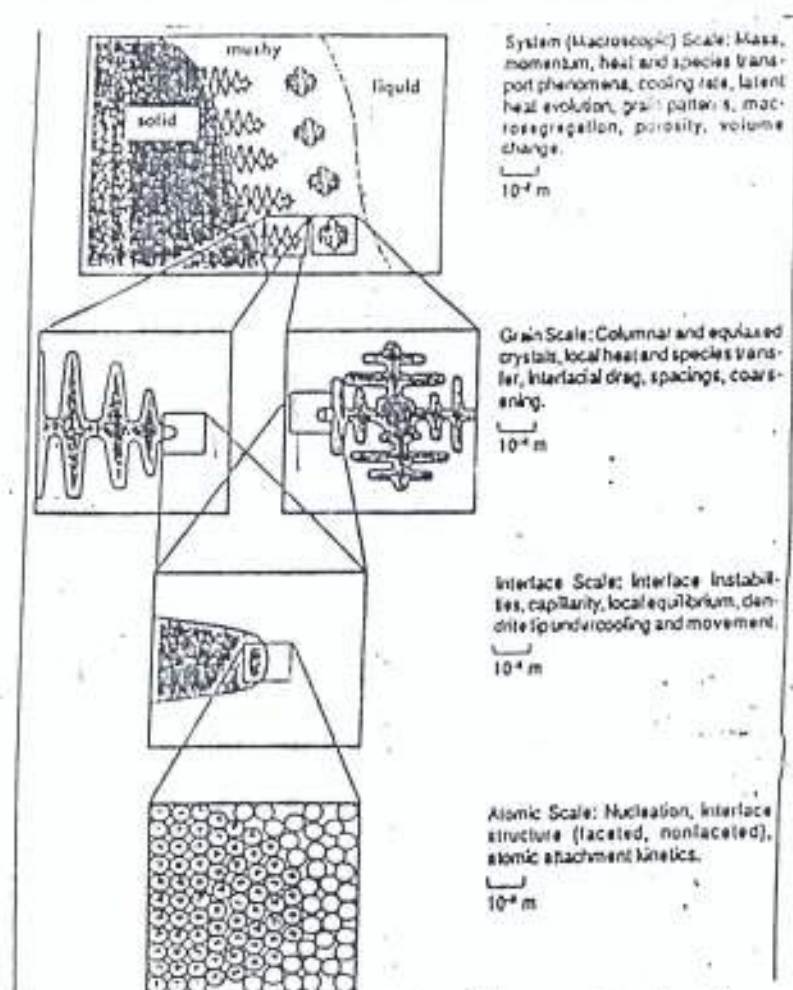


Fig. 2.12 An illustration of the physical scales and phenomena in dendritic solidification

Source: Beckermann and Wang (1994)

Beckermann and Wang (1994) also shows the development of structural zone and segregation patterns in the hypothetical casting in figure 2.13 below:

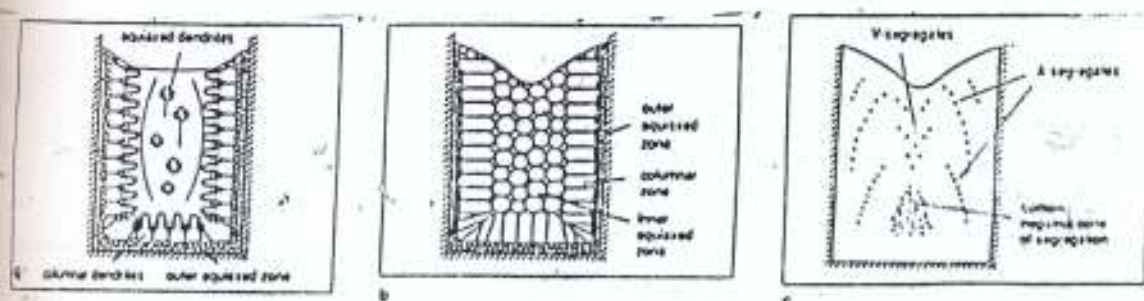


Fig. 2.13 An illustration of the structural zone and macrosegregation patterns in a casting (a) intermediate stage (b) structure (c) macrosegregation.

Source: Beckermann and Wang (1994)

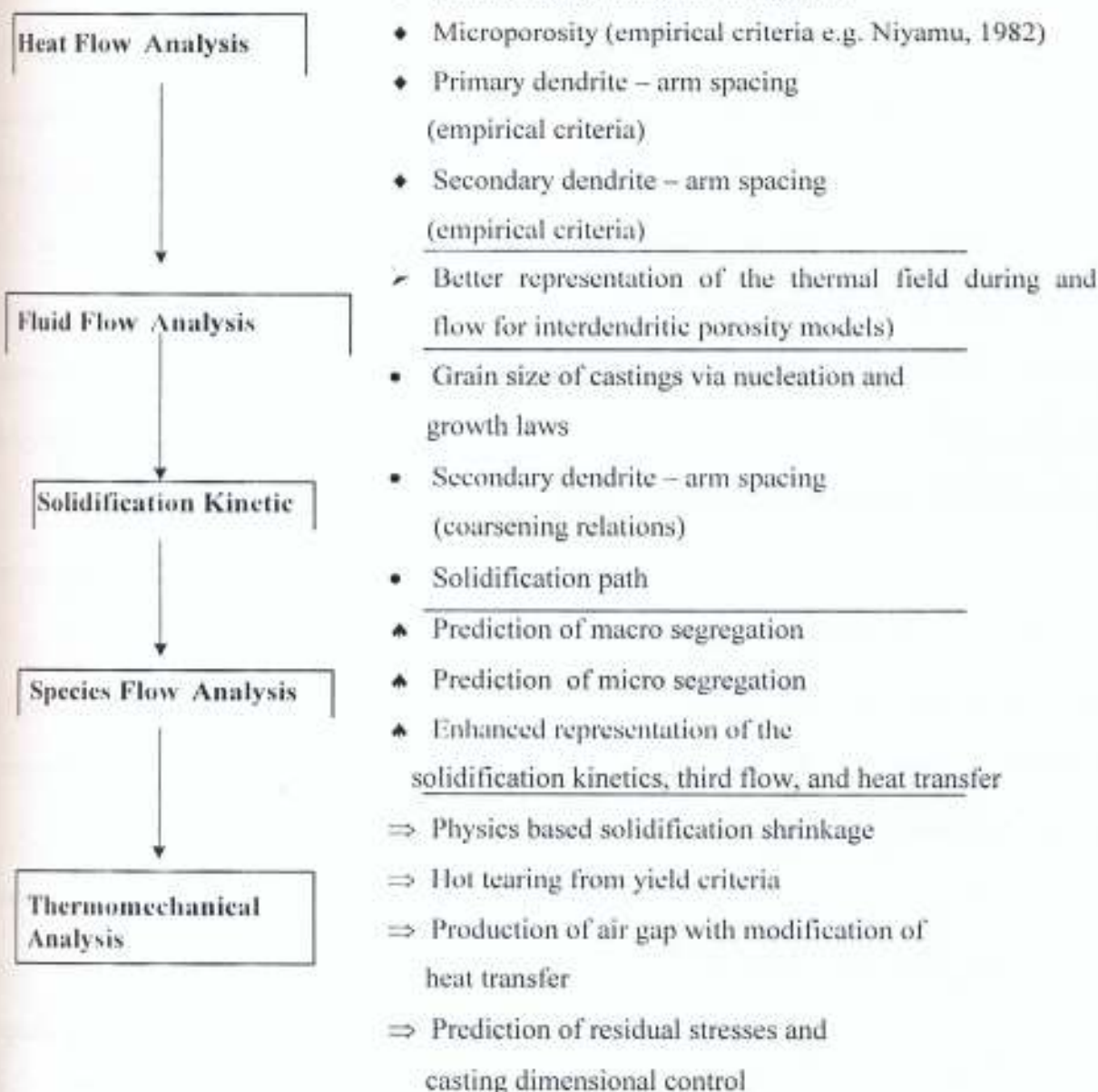


Fig. 2.14: The Types of Analysis Available for Solidification Modeling and Their Benefits

Source: Overfelt (1992)

Figure 2.14 is a representation of the types of analyses required to completely describe casting processes. The primary and most obvious phenomenon controlling casting is the transfer of heat from the cooling metal to the mould. The early models of castings cooling were straightforward heat conduction analysis. However, the mechanics fluid flow are important for both mould filling effects and physics based models of interdendritic porosity. Buoyancy effects after the mould is full exert varying degrees of influence during the cooling cycle depending on the thickness of the casting being produced. In addition, the analysis of flows of various chemical species is very important for electronic crystal growth, and many thermo fluid models today incorporate species flow.

Solidification kinetics including phase selection, nucleation and growth are now being investigated in several laboratories.

Finally, the coupling of mechanical analysis with thermal analysis enable the prediction of residual stresses and distortions in castings. When compared to the appropriate high-temperature constitute models, tendencies for castings to exhibit hot tear will also be predictable.

Voller (1998) has modeled the solidification of an alloy and enumerated two central numerical problems;

- i. The calculation of thermal and species transport fields which satisfy the conservation equations and are also consistent with the underlying thermodynamics.
- ii. The treatment of local scale solute diffusion.

2.3.6.2 Conductive Heat Flow

The simplest models analyze the cooling of a casting assuming conductive heat flow only and incorporate the effects of the latent heat release using one of several techniques. The solutions proceed by specifying the material properties, geometry, boundary conditions and

initial conditions. Then the following, well known unsteady heat conduction equations is integrated over time and space to determine the thermal history of all points within the casting (Overfelt, 1992);

$$\frac{\partial T}{\partial t} = \nabla(\delta, \nabla T) + \frac{q_s}{\rho c_p} \quad \text{Eqn. 2.1}$$

Where;

ρ	=	Density	(kg/m ³)
c_p	=	Specific heat	(kJ/kg K)
q_s	=	Latent heat	(kJ/kg K)
t	=	Time	(s)
δ_t	=	Thermal diffusivity	(M ² /S)
T	=	Temperature	(K)



Since these simple models do not account for mould filling effects, the initial temperature throughout the casting is usually assumed to be uniformly with the pouring temperature.

Once the thermal history of the interior of the casting can be predicted, tendencies for shrinkage porosity can be evaluated using straightforward empirically derived criteria. It is clear that isolated hot spots containing liquid will form porosity. Analysis of the directional progression of the freezing isotherms during the transient analysis then leads directly to determining the likelihood of porosity for a given casting geometry.

However, eliminating the isolated hot spots often does not ensure the absence of interdendritic porosity in long – freezing range alloys, such as Al – 4.5% Cu. In these cases empirical criteria are required.

Pellini and Bishop (1950) reasoned that a minimum temperature gradient, G_{min} , must be required to feed the solidification shrinkage sufficiently to achieve a minimum radiographic standard for steel castings.

On the other hand, Niyamu (1982) felt that the time available for feeding the shrinkage would also be important and advanced the concept of the modified thermal gradient.

$$G_{min} = (G/\sqrt{R}) \quad \text{Eqn. 2.2}$$

Where: G_{min} = minimum temperature gradient
 R = is the cooling rate during solidification
 G = thermal gradient at the freezing zone

More recently Lee et al (1990) have shown a more complex thermal parameter.

$$\text{Where: } G_{min} = (G/V_s) t^{2/3} \quad \text{Eqn. 2.3}$$

V_s = the solidification front velocity (m/s)
 t = the solidification time (s)

This gives excellent correlation with plate castings of an aluminium alloy.

23.6.3 Microstructural Predictions

Bamberger et.al., (1987) reported that dendritic arm spacing exerts a marked influence on the mechanical properties and homogenization kinetics of cast materials. It is known that these two sets of data improve as the dendritic arm spacing is reduced.

According to Kurz and Fisher (1986), the primary dendrite arm spacing,

$$\lambda_i = K V_{gr}^{-0.25} G_i^{-0.5}$$

Eqn. 2.4

Where;

K = an alloy dependent materials constant

V_{gr} = solidification growth velocity (m/s) and

G_i = thermal gradient at the freezing zone, $\text{sec}^\theta/\text{C}$

The development of micro-structural in cast components thus depends directly on the solidification growth velocity (v), the thermal gradient at the freezing zone (G), and an alloy – dependent parameter. Micro structural length scales are proportional to the processing parameters $(V_{gr}^{-0.25} G_i^{-0.5})$.

Also, Bamberger et.al., (1987) in their research work formulated the dendrite arm spacing (λ) to be

$$\lambda = \bar{c} t_f^n$$

Eqn. 2.5

Where;

λ = dendrite arm spacing (mm)

$\bar{c}$ = constant

t_f = local solidification time (sec)

n = constant, ≈ 0.5 for primary arm spacing

Also, Kurz and Fisher (1986) reported that the secondary dendrite arm spacing

(λ_2) is largely determined by annealing and coarsening processes occurring in the solidified metal. Experimentally,

$$\lambda_2 = C(GV)^n \quad \text{Eqn. 2.6}$$

Where;

C = is the alloy – dependent constant

n = is the exponent in the range of $1/3$ to $1/2$.

The proportionality constant and the actual exponent can be experimentally determined for an alloy system of interest. Predicting λ_2 from the computer determined values of G and V is then a straight forward matter.

Stafanescu et.al., (1990) in the United States pioneered the prediction of grain sizes in equiaxed castings, while Rappa and his colleagues in Europe also predicted the grain sizes in equiaxed castings (Overfelt, 1992). Predictions for equiaxed castings are much more complicated than for simple columnar structures because the theories of nucleation and growth have to be incorporated into the basis heat transfer calculations.

The nucleation rate of a solidifying alloy can be represented by a simple Dirac delta function as;

$$\frac{dN}{dT} = N_0 \delta(T - T_n) \quad \text{Eqn. 2.7}$$

Where;

N = is the number of nuclei;

N_s = is the number of active substrates;

T = is the temperature ($^{\circ}\text{C}$) and

T_N = is the critical nucleation temperature for active substrates ($^{\circ}\text{C}$).

If more than one type of inoculants is active at slightly different temperatures, then the combined nucleation rate can be found by superposition. Stefanescu et al (1990) show that experimental data for N_s can be described by the following parabolic equation;

$$N_s = K_3 + K_4 \left(\frac{dT}{dt} \right)^2 \quad \text{Eqn. 2.8}$$

Where the constant K_3 and K_4 and the critical nucleation temperature, T_N can be determined experimentally for a given alloy using a variety of cooling rates. The growth rate (V) of the nucleated grain's is proportional to the square of undercooling, that is;

$$V = \mu (\Delta T)^2 \quad \text{Eqn. 2.9}$$

Where the proportionality constant μ is dependent on the alloy. This equation describes the case for either eutectic grains or dendritic grains, the evolution of the grains internal volume fraction solid must be determined.

Stefanescu and Pang (1998) explained that the traditional method of predicting microstructure in castings relies on experimental measurements of some process parameters such

as cooling rate ($\dot{T}$), temperature gradient (G), or liquid/solid interface velocity (V) in the casting. Then these process parameters are correlated with microstructure length scale and composition (fraction of phases). The microstructure length scale includes phase spacing as a function of cooling rates $\bar{d} = f(\dot{T})$, or as a function of thermal gradient and solidification velocity $\bar{d} = f(GV)$; it also includes grain density as a function of nuclear efficiency, and cooling rate, $N = f(\dot{T})$. As computer technology evolved, classic macro-transport solidification models were used to generate a spatio temporal description of the movement of the liquid/solid interface. From this description, local T , V , and G as well as empirically derived microstructural features, can be mapped throughout the casting.

According to Rappaz et.al.(1989), the change in solidification with time $[\Delta f_s(t)]$ can be determined from

$$\Delta f_s(t) = n(t) \left[4\pi r^3(t) \Delta r(t) \right] f_i(t) + \frac{4}{3} \pi r^3(t) \Delta f_i(t) \quad \text{Eqn. 2.10}$$

Where;

$n(t)$ = is the grain density; (kg/m^3)

$r(t)$ = is the radius of the spherical envelope of the equiaxed grain, (m) and

$f_i(t)$ = is the percent of internal solid fraction.

Rappaz et al (1999), has proposed another new criterion for the appearance of hot tears in metallic alloys. During solidification, a metal experiences temperature differences which induce convection in the liquid region and deformation in the solid. The first phenomenon involves very

large displacements but low stresses, whereas, the opposite occurs for the second one. This drastically different behaviour is due to the very large change of viscosity of a metal when it undergoes the liquid-to-solid transition. The transition is made more complicated for an alloy because the presence of the mushy zone somehow 'mixes' the two behaviours; the deformation of the dendritic network strongly depends on its coherency state and the flow of liquid now occurs in a porous solid phase.

Two major defects related to a lack of feeding can be encountered in alloys; porosity and hot tears.

First defect is associated with a hydrostatic depression in the mushy zone combined with aggregation of gaseous solute elements (hydrogen, nitrogen and carbon monoxide).

This depression is associated with the suction of the liquid in the porous dendritic region due to shrinkage.

13.6.4 Fluid and Solute Flow

Fluid flow influences the development of porosity and microstructure in castings at several levels. Fluid flow affects temperature distribution, and thus modifies the progression of solidification (Stoeckhert, 1998).

Fluid flow effects must be included to describe the all important mould-filling during casting as well as predict porosity from more fundamental models instead of empirical criterion

functions as described in this report including fluid flow causes modification of the $(u \cdot \nabla T)$ for convective heat transfer:

$$\frac{\partial T}{\partial t} + u \cdot \nabla T = \nabla \cdot (u T \nabla T) + \frac{q_s}{\rho c_p} \quad \text{Eqn. 2.11}$$

Where; u = the velocity of the fluid (m/s)

In addition the equation of continuity and momentum turn must also be solved. They are respectively

$$\Delta \cdot I = 0 \quad \text{Eqn. 2.12}$$

$$\nabla \cdot J = 0 \quad \text{Eqn. 2.13}$$

and

$$\rho \left[\frac{\partial u}{\partial t} + (u \cdot \nabla) u \right] = -\nabla p + \rho g [1 - \beta(T - T_\beta)] + \mu \nabla^2 u \quad \text{Eqn. 2.14}$$

Where;

ρ = the density (kg/m^3)

p = the pressure (N/m^2)

g = the acceleration due to gravity; (m/s^2)

β = the volumetric expansion coefficient; and

μ = the viscosity (N Sec/m^2)

The inclusion of fluid flow effects enables the calculations of the transient temperature distribution during mould filling, rather than having to rely on an arbitrarily assumed temperature distribution to begin the cooling simulation. Thus, heat losses incurred during mould filling can be determined and the design of gating and risering system is possible. With this designers will not have to rely exclusively on empirical rules of thumb to achieve smooth filling plus minimal gas and dross entrapment.

23.7 FINISHING

After the castings have solidified and cooled, they are placed on a shakeout table or gating on which the sand mould is broken up leaving the casting free to be picked where the gates and risers are removed (Lindberg, 1990)

Castings, when taken out from the mould, are not in the same condition in which they are desired because of the following facts;

- (i) Lot of sand and fused particles are clinging to the surface of the casting;
- (ii) Gates, runners, risers are attached with the main casting which are finally not required.

Hence, the castings used cleaning and trimming operations to be done on them before they can be finally brought to the final shape. This operation of cleaning, which is also known as fettling, consists of mainly three operations given below;

- (i) Removal of dry-sand cores
- (ii) Removal of extra parts like sprues, gates, risers, fins, etc.
- (iii) Cleaning of the casting surface

24 OTHER CASTING PROCESSES

There are other casting processes apart from sand casting earlier treated in this write-up. Other casting processes include diecasting, investment casting, shell moulding, etc (Adejuyigbe and Akinlosore, 1987).

25 COSTING OF SAND CASTED MATERIAL

Klimowicz (1994) said that one of the most important, but usually unrecognised and undiscussed, design "pro parties" of a material is cost. It is ironic that many people working on new materials are apparently oblivious to this fact. Yet, once a potential user has completed the technical evaluation and field trials of a new material, inevitably the final decision to use the material will be critically dependent on cost. Only if the additional cost of the new material is justified by the improved performance will the materials be utilized.

Therefore, Alean Aluminum Ltd, USA known as Duratean developed cost of costing in the area of green sand, bonded sand, permanent mould, plaster mould, investment lost foam, die, and centrifugal casting. The current casting research focuses on optimizing the casting process for the specific final application in order to reduce finished part cost. High tolerance casting is important in reducing cost because it reduces composite material cost, machining costs, and material losses during machining. Clearly, the traditional trade offs between near-net-shape casting and machining costs for unreinforced materials are quite different when material costs are of concern.

UNIDO (1982) enumerated some detailed cost estimate used to cost the establishment, and the running of a sand casting foundry shop and its products. The foundry unit used consists of an iron foundry, a small non-ferrous foundry, a machine tool and maintenance department and

a pattern-making shop. The plant consists of a costing unit producing mainly grey and modular iron with a small shop for non-ferrous casting. It is estimated that full production (about 80% of the capacity) will be reached within five years, with some production beginning during the second year of operation. Table 2.6 below summarizes the estimated cost of these items as at 1982.

Table 2.6: Summary of Estimated Capital Costs for the Foundry Equipment

Item	Costs (N 000)
Iron foundry facilities	1235
Non-ferrous facilities	138
Utilities and material handling	640
Inspection and laboratory testing	115
Pattern-shop	195
Machine and maintenance shop	780
Building and site development	1000
Total	4,103

a. Including freight, foundations, erection and installation

Source: UNIDO (1982).

An economic model was built both to simulate and predict the most economical way of costing casted product. Other work by the other people are very useful when building up the model such work as Aderoba (1994) who built an economic model for simulation of the most economical mobile power system for a given farm.

Sule (1988) built up a yield and cost models when a product is defective, Ariet and Schweger (1970) looked at various cost estimation and control system.

The basic cost elements include according to Amrine et. al., (1975); Haslehurst, (1980) and Lockyer et. al., (1988):

- Material cost
- Direct labour cost
- Overhead cost and
- Fixed cost

UNIDO (1978) in their analysis said that the investment costs for castings depend very largely on

- (i) geographical conditions;
- (ii) layout of the plant;
- (iii) product range;
- (iv) tariffs;
- (v) economic policies of the country;
- (vi) local market costs;
- (vii) freight; and
- (viii) labour costs etc.

CHAPTER THREE

3.0 CAD MODEL DEVELOPMENT FOR SAND CASTING OPERATIONS

The study covers "Computer-Aided Design (CAD) of sand casting operations".

In this chapter, a CAD system for sand casting is developed.

CAD/CAM is the technology of using digital computers to perform certain functions in design and production. The resulting software is intended to control various kinds of manufacturing activities, such as product planning and so on. The software package will also improve productivity and cost effectiveness by integrating many activities of sand casting; part design, NC/CNC machines, process planning, documentation/costing, which encompass the entire manufacturing planning and operational control aspects of manufacturing enterprise.

This model will consider among others, the following:

- * CAD flowchart for sand casting operations;
- * Geometric description and drawing for the cast part using its features;
- * Design of pattern, mould boxes, gating, feeding, sand, riser optimal design (Technological Design Module);
- * Specification for pouring and solidification;
- * The development of database for CAD having independent modular build up;
- * Costing of cast products development.

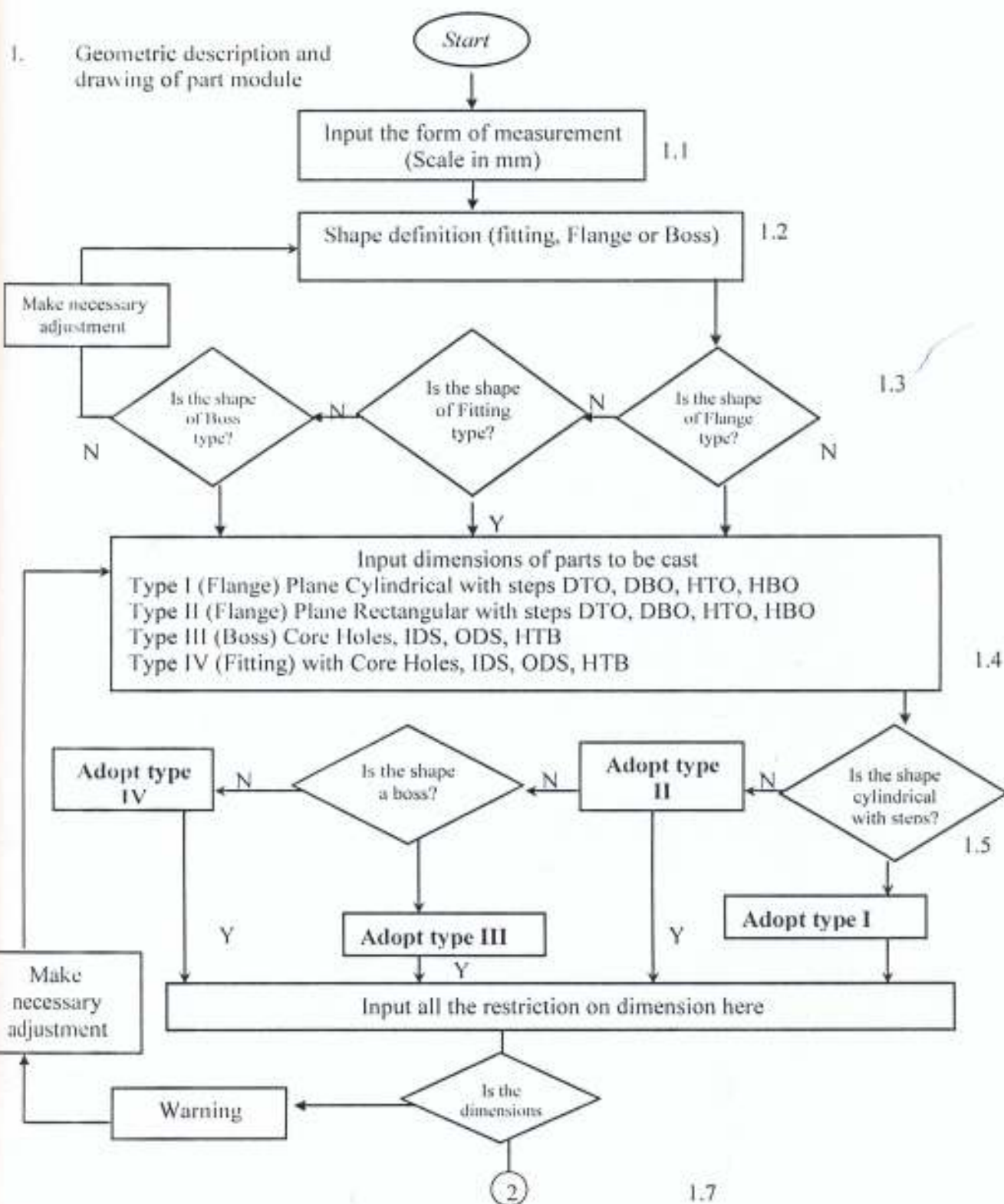


Fig 3.1 Flow chart of CAD/Manufacturing for Sand Casting Process

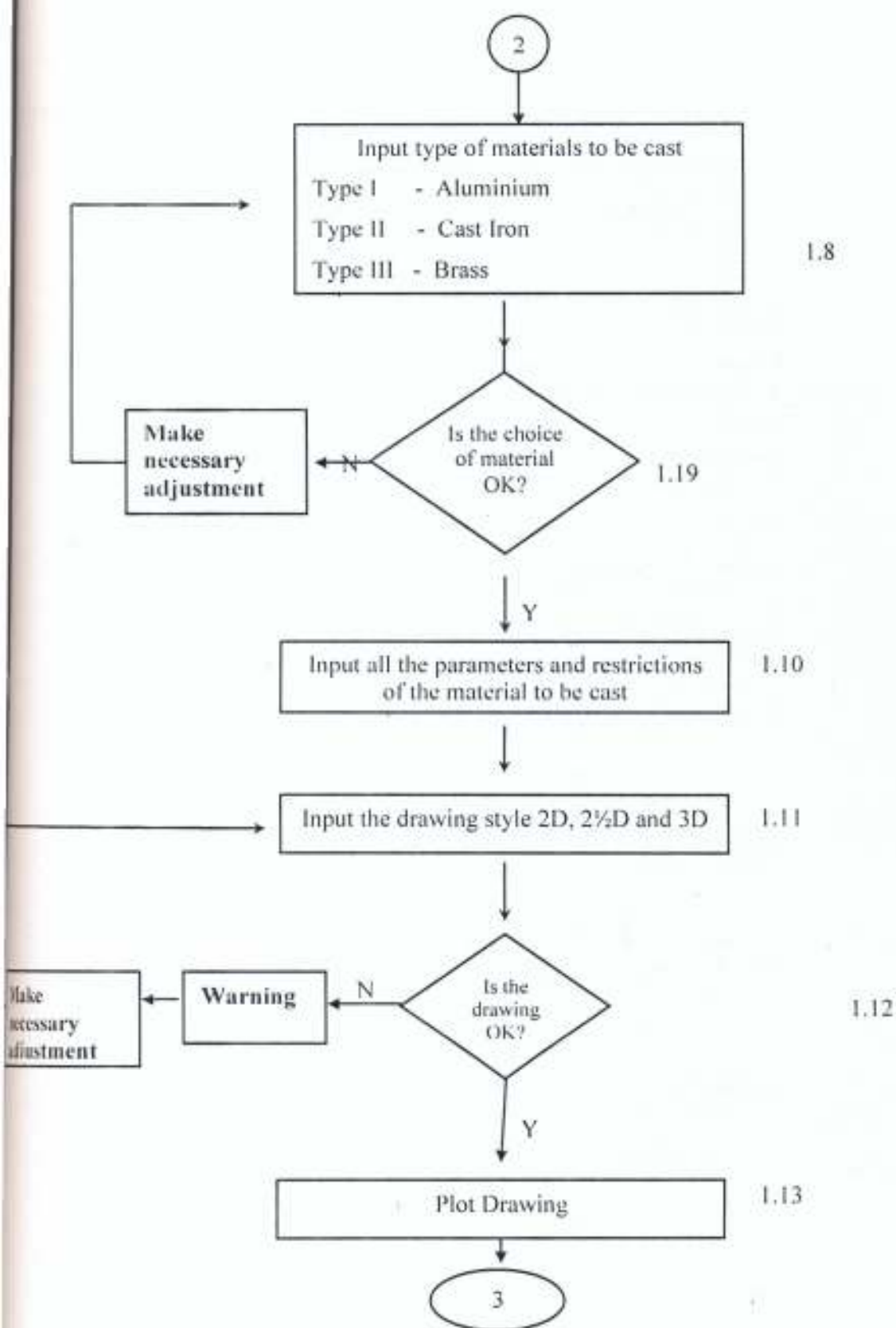


Fig 3.1 Flow chart of CAD/Manufacturing for Sand casting Process (contd.)

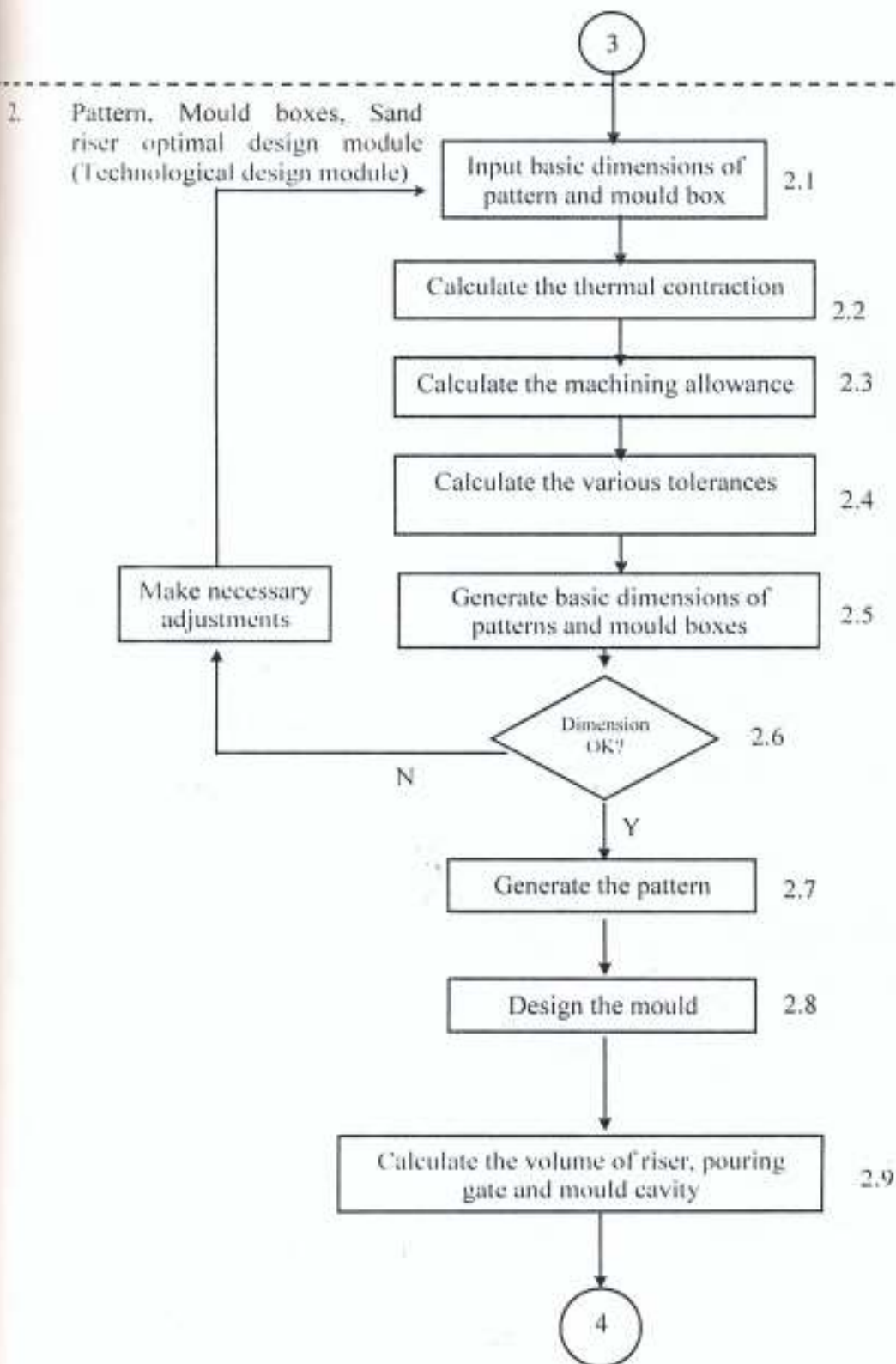


Fig 3.1 Flow chart of CAD/Manufacturing for Sand Casting Process (contd.)

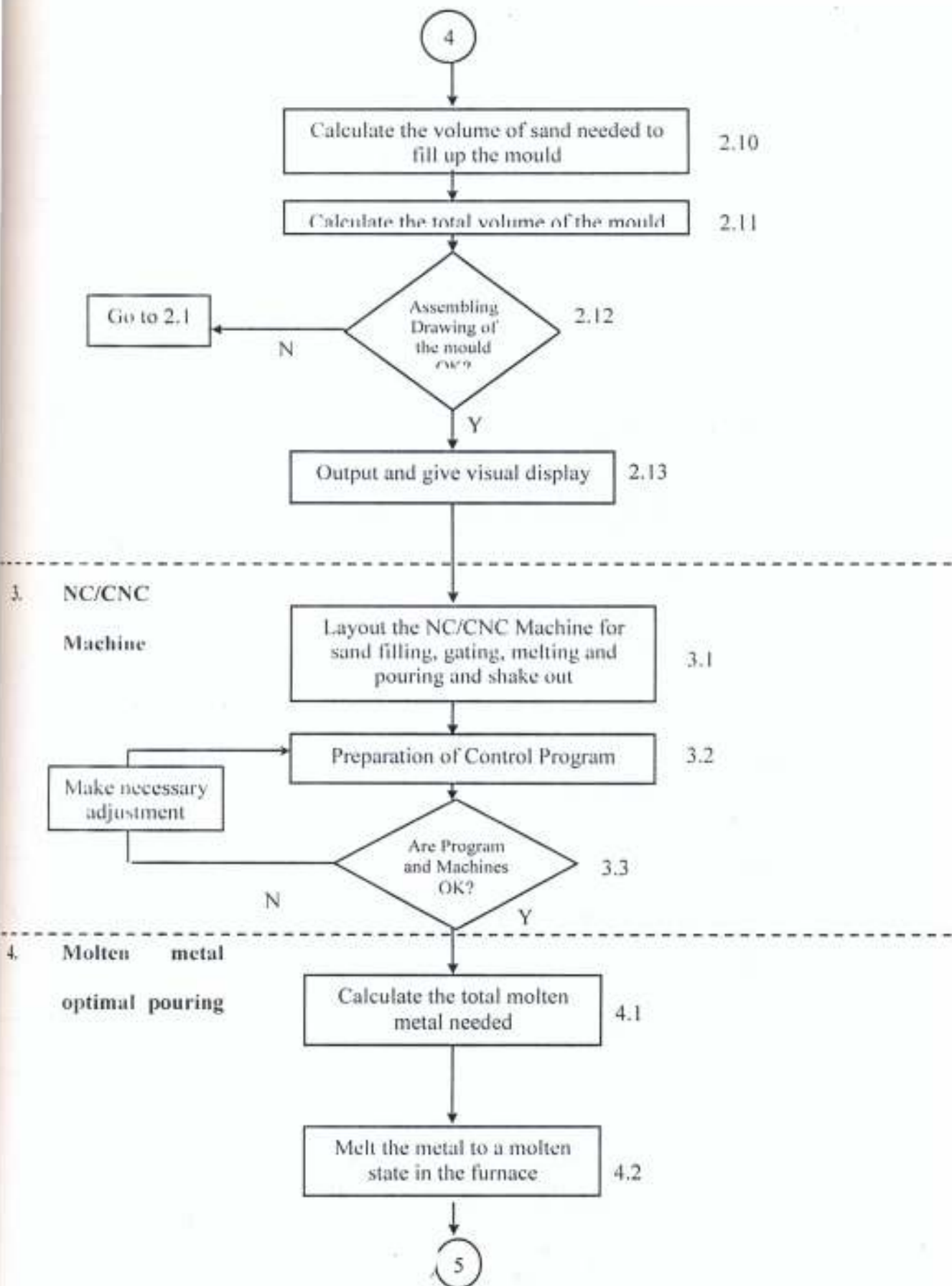


Fig 3.1 Flow chart of CAD/Manufacturing for Sand Casting Process (contd.)

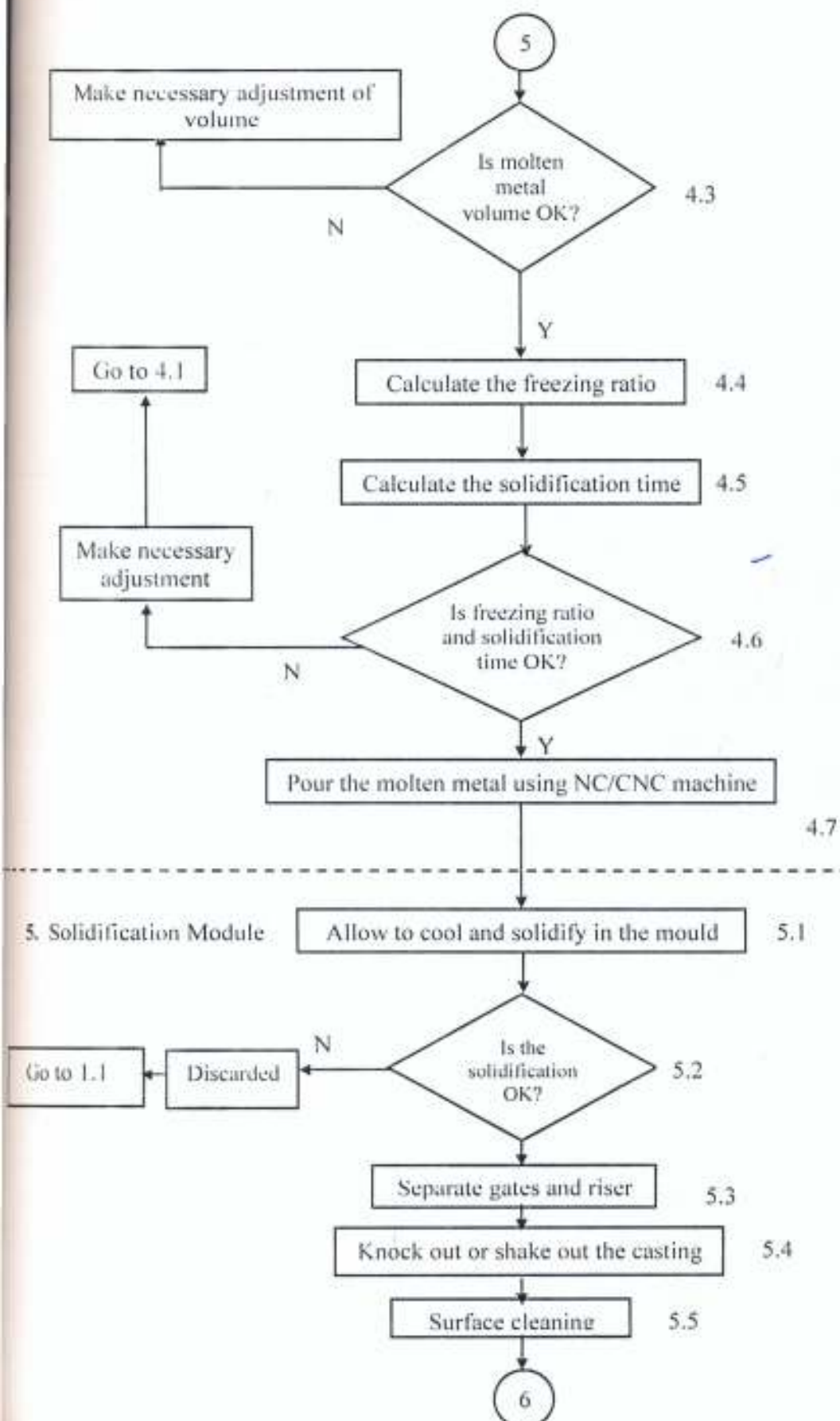


Fig 3.1 Flow chart of CAD/Manufacturing for Sand Casting Process (contd.)

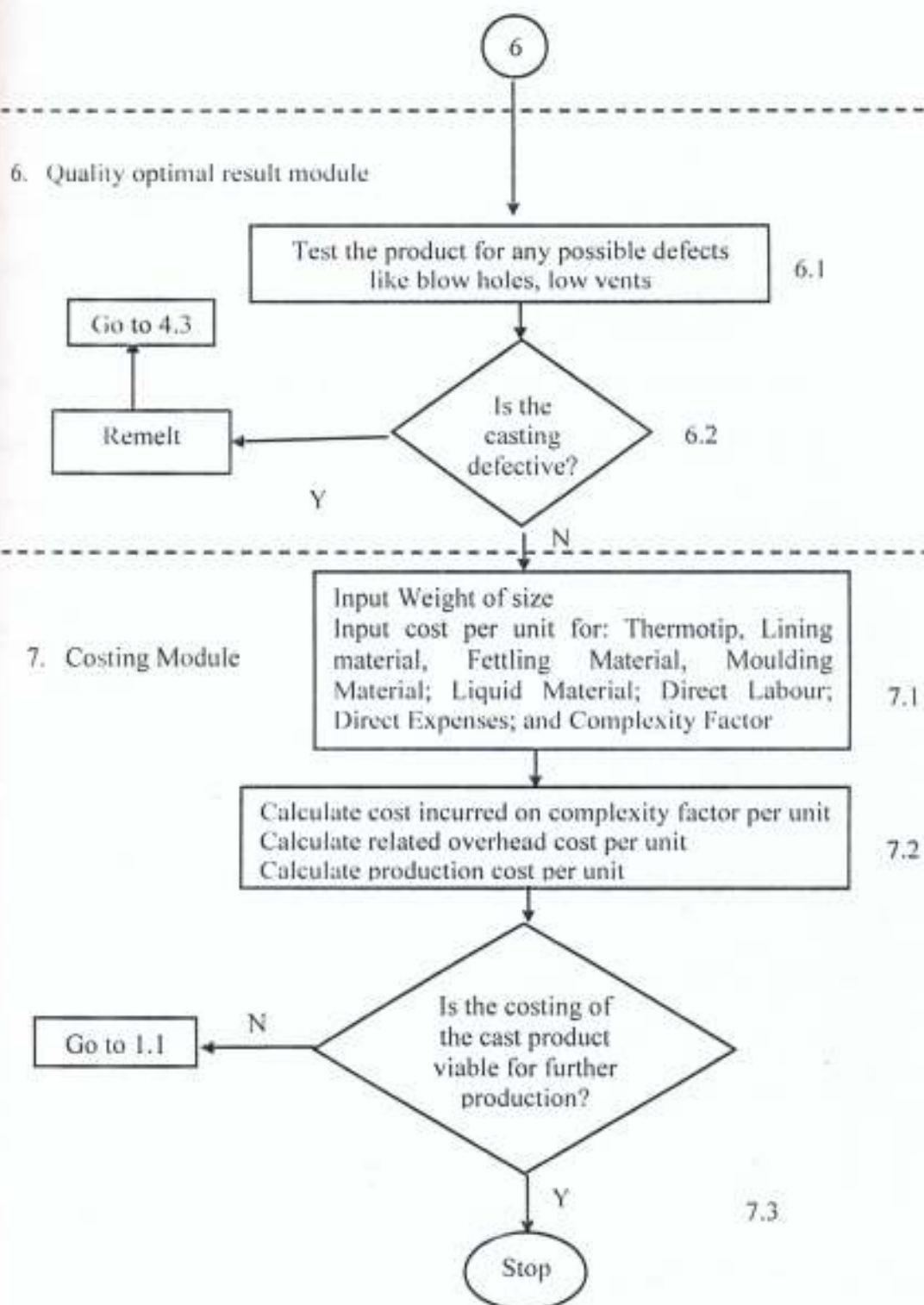


Fig. 3.1 - Flow Chart for CAD/Manufacturing for Sand Casting Process.

3.1 CAD FLOWCHART FOR SAND CASTING PROCESS

CAD flowchart describing the casting process was developed. This is shown in Fig. 3.1. The flowchart developed is divided into seven modules and it takes into account the use of temporary moulding system of sand casting.

Characteristics and parameters of three types of materials, viz; Aluminium, Cast Iron and Brass were built into the ensuring program of the flowchart, with a view to adapting it for other materials such as steel. Each of the modules in the flowchart is described below thus;

3.2 GEOMETRIC DESCRIPTION AND DRAWING FOR THE CAST PART MODULE

This is the area where the following operations were carried out in this module;

- * Input of the dimensions of parts to be cast.
- * The shape of the cast material is configured as flanges, bosses or combination of both.
- * The development of CAD software programs using Visual Basic for 2½D schematic cross-sectional and 3D solid model was done.
- * Drawings are presented as 2½D schematic and 3D solid model.

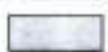
3.2.1 COMPONENT DESIGN OF PART TO BE CAST

The aim of this geometric description program of the part to be cast is to provide the total and unambiguous geometric input of components as simply as possible. The component layout in this project is the strong conceptual design using the heuristic –

based computer system. Features were identified by dividing a complex casting component into their various logical regions.

Nanda et al (1994) used mounting flange as features which had a shape of rectangular box (Table 3.1); and Boss/fitting as features which had a hollow cylinder (Table 3.1), in their research on casting process design.

TABLE 3.1: FEATURE ATTRIBUTES VALUES FOR THE TEST CASTING

Features	General	Surrounding	Stress Level	Feature Type	Shape	Dimension (cm)
Mounting flange 1	1.5875	0.3175	Primary		Rectangular Box	121.92(l) x 1.5875(b) x 1.5875(h)
Mounting flange 2	1.5875	0.3175	Primary		Rectangular Box	121.92(l) x 1.5875(b) x 1.5875(h)
Boss 1	1.27	0.4699	Secondary		Hollow Cylinder	3.4925(h) x 7.62(a) x 5.08(l)
Boss 2	1.27	0.4699	Secondary		Hollow Cylinder	3.4925(h) x 7.62(a) x 5.08(l)
Fitting	2.54	0.635	Primary		Hollow Cylinder	8.5725(h) x 12.7(o) x 7.62(l)

L = Length; b = base; h = height; O = outside diameter I = inside diameter

Source: Nanda et al.(1994)



According to Nanda et. al. (1994),

- * In a plate configuration, features originate from a thin disk-like shape. In a box configuration, the features are organized in such a way that the casting can be imagined as a rectangular shape.
- * Second attribute, grade, represents the final quality requirements set in the part design.
- * The third attribute, wall thickness, divides a casting into different categories based on rules of thumb. In aluminium foundry, for example, castings are classified into three categories – thin (0.238 – 0.318), medium (0.318 – 2.54cm) or thick (2.54 – 10.16cm).

Adejuyigbe (1997) used shapes which represented features as rectangular box and hollow cylinder in his earlier research in sand casting.

Case et. al. (1994) used protrusions which he also called boss; depressions and surfaces which can be (hole, slot, step, face). They used it to describe the machining features in CAD/CAM integration.

Therefore, from the foregoing, the use of this two classifications was justified – boss and flange which this research used in describing the part to be cast (Figs. 3.2 and 3.3)

Since the components are in box configuration, the features are organised in such a way that can be imagined as a rectangular shape as shown in Fig. 3.2. Two projects will be considered having two types of configurations as shown in Figs. 3.2 and 3.3. The computer aided design for foundry begins with the customer's specification for a given part to be produced called the component layout. Then the development of CAD wireframe 2D or solid model 3D is developed. The component layouts used are shown

In Fig 3.2 and 3.3

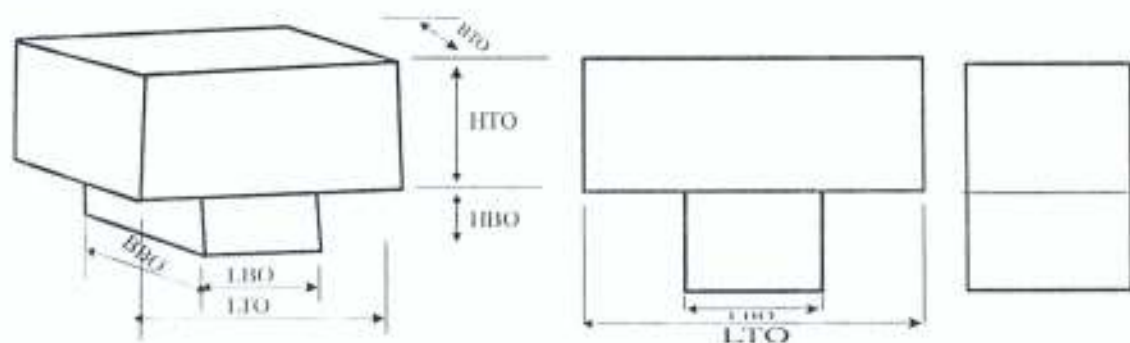


Fig. 3.2 Mounting Flange 2 with Stress level - Primary

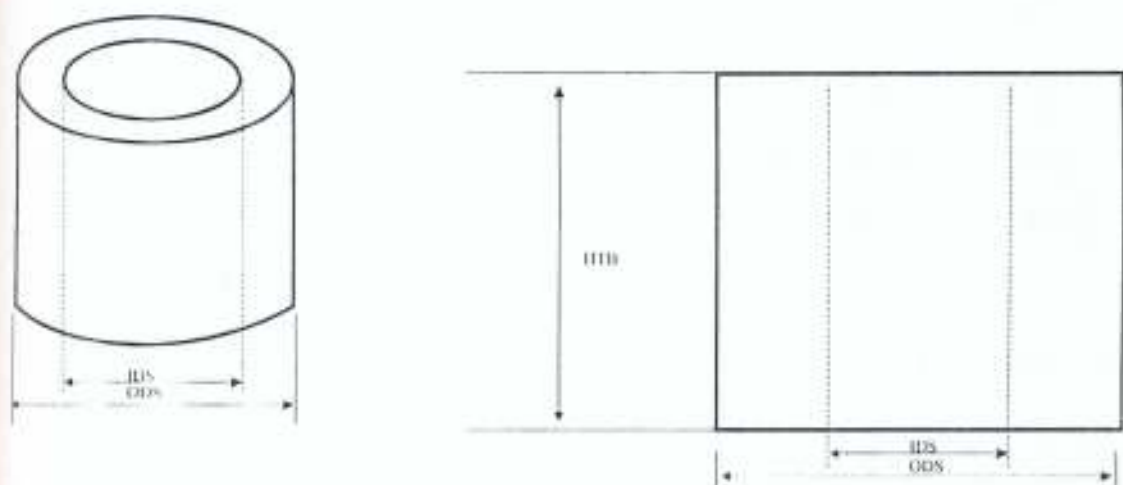


Fig. 3.3 Boss with Stress level - Secondary

Where;

- LTO = Length of object top
- LBO = Length of object base
- HTO = Height of object top

HBO	=	Height of object base
HTB	=	Height of Boss
INS	=	Inside diameter boss
ODS	=	Outside diameter boss
BBO	=	Breadth of object base
BTO	=	Breadth of object top
BBO	=	Breadth of object base
BTO	=	Breadth of object top

3.2.2 SOFTWARE DEVELOPMENT

The development of the CAD software programs has been done which will adequately cater for the production of the part cast automatically having the result in;

- i. 2D or 2½ schematic cross sectional view of the component (Figs, 4.1 & 4.2) in chapter four.
- ii. 3D or solid modeling in three dimensional x.y.z. (Figs, 4.1 & 4.2) in chapter four.

The dimensions shown above can be varied to get various sizes of object automatically from CAD automated drafting. In order to achieve an economic use of the CAD technique from the very first installation, the application program was developed to aid the design engineer and the casting engineers in their day to day activities. The combination of in-house developed application programs with the interactive CAD functions is expected to generate a very efficient result.

The program to run this module was developed and shown in Appendix I using visual basic tagged CAD PROG. 1. Other languages available which can also be

developed to run the module are:

- i. Quick Basic (q Basic);
- ii. FORTRAN;
- iii. C Language and others.
- iv. MATLAB

The justification for the use of this software package stem from the fact that:

- i. Visual Basic is a new software package presently in vogue in developed countries;
- ii. It can handle complex situations like;
 - * Mathematics and Computation;
 - * Algorithm development;
 - * Modeling, Simulation, and Prototyping
 - * Data analysis, exploration, and visualization
 - * Scientific and Engineering Graphics
 - * Application development, including graphical user interface building.

3.3 TECHNOLOGICAL DESIGN MODULE (PATTERN, MOULD, BOXES, SAND, RISER OPTIMAL DESIGN MODULE)

The following operations were carried out;

- * Allowance for various tolerances to establish shapes of patterns,
- * Input of the dimensions of the patterns, sand and the cavity of the casting riser and pouring gate;
- * Specifications of the sand
- * Determination of riser location, volume of the mould cavity and pouring gates
- * Assembling the top and bottom mould
- * Determination of molten metal needed and the suitable raw material, and control of solidification processes.
- * Calculation of sand casting mould volume, thermal contraction, machining allowance, total molten metal needed, and the decision whether the molten metal volume was too big or too small, was carried out.
- * The calculation of pouring time, feeding efficiency, and the calculation of the solidification time was carried out.

The technological design module is regarded as one of the important modules which can also be applied both in conventional and NC/CNC manufacturing.

All the data and calculations needed for the above are presented below.

3.3.1 PATTERN DESIGN

In building the mould for the pattern design for sand casting processes, there are some basic requirements of a good pattern used in this research. Some are:

- * Patterns are designed in such a way as to allow directional solidification, so as to

avoid internal micro shrinkage entrapped gas and large voids. For example, a bad pattern can be re-designed to produce uniform wall thickness and allow for directional solidification. (Fig 3.4)

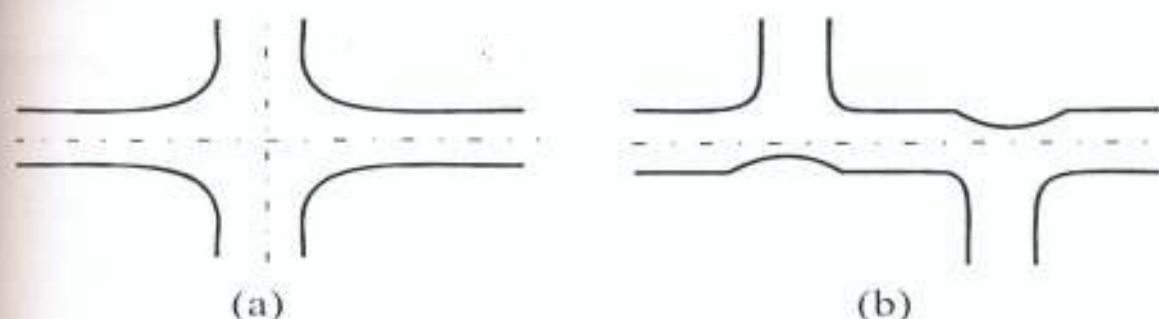


Fig. 3.4: Pattern Design

a. Original

b. Improved

* The basic forms of ribs, junctions and the fillet used when designing the pattern in casting processes are done in such a way as not to cause hot spot at sharp corners, (Fig 3.5)

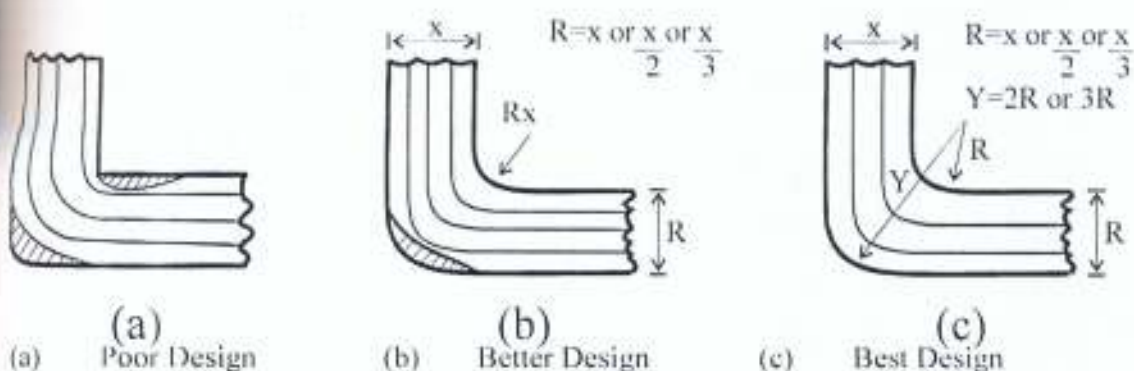


Fig. 3.5: Basic form of Ribs

The intersection of surfaces in castings must be smooth and form no sharp angles.

Figs. 3.4 and 3.5 shows the basic forms of ribs, junctions and the fillet used. Filletting eliminates internal corners of castings and rounding do away with external corners. Whenever a sharp corner forms in a pattern by virtue of its construction, a smooth fillet

should be provided.

The standard dimension of fillet radii established for cast parts are 1, 2, 3, 4, 8, 10, 15, 20, 25 and 40mm. The radius of fillets should be taken within $\frac{1}{3}$ – $\frac{1}{3}$ of arithmetical mean of the two wall thicknesses (a and b) forming the angle;

$$R = \left(\frac{1}{3} \text{ to } \frac{1}{5} \right) \frac{a+b}{2} \quad \text{Eqn. 3.7}$$

$$R = \left(\frac{1}{3} \text{ to } \frac{1}{5} \right) \text{ of } \frac{a+b}{2} \quad \text{Eqn. 3.8}$$

Radii 1, 2 and 3mm are chiefly used for metallic patterns.

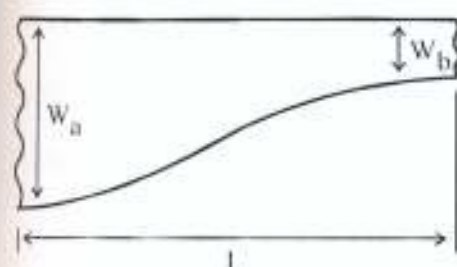
Table 3.2 gives the values of moulding tapers for external surfaces of patterns and core boxes.

TABLE 3.2: FOUNDRY TAPERS FOR PATTERN AND BOXES

	Sand Mould			
	Metallic Patterns		Wood Patterns	
Height of Pattern mm	Machine	Moulding	Manual	Machine
Up to 0	1°	30°	3°	3°
20 - 50	1°		1°30'	1°30'
50 - 100	0°	45°	1°15'	1°15'
100 - 200	0°	30°	0°45'	0°45'
200 - 300	0°	30°	0°30'	0°30'
300 - 800	0°	20°	0°30'	0°30'
800 - 2000	-		0°30'	0°30'
More than 2000	-		30°	-

Source:- Mukherje (1979)

The tapering or the change in sectional width, if too abrupt, will lead to turbulence, aspiration, and hot spots. Therefore, the change in thickness should be gradual slope, a wedge shape, to control the solidification process. The properties of the wedge shape, length to width, should not exceed a ratio of 1:4.



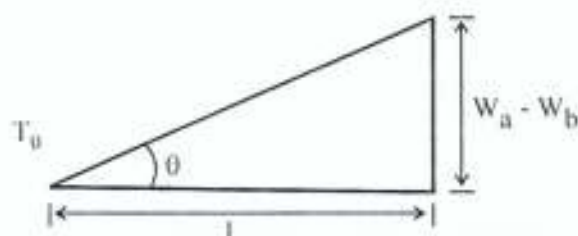
Where:

l = length

W_a = Original width

W_b = Reduced width

(a)



$$T_{\theta} = \tan \theta = \frac{W_a - W_b}{l} \dots\dots\dots \text{Eqn.3.3}$$

(b)

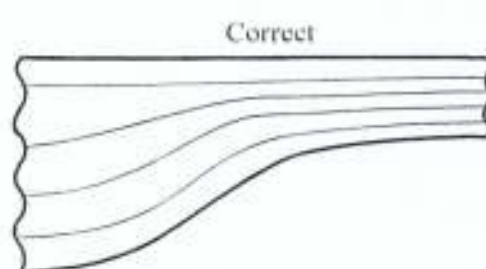
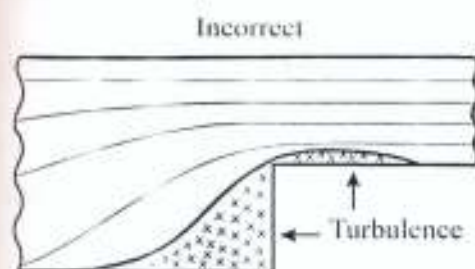


Fig. 3.6: Tapering of Pattern Design (c)

- Formula
- Taper in degrees
- Isothermic considerations

All the above points were properly accounted for in pattern design used in this research.

3.3.2 MOULD DESIGN

Trovant and Argyropoulos (1998) worked on the formation of the air gap at the mould/metal interface during casting and said that this is responsible for considerable changes in local cooling rates. Often, boundary conditions input a mathematical model have routinely been guessed at (often inaccurately) or have been determined experimentally, both of which can introduce difficulties in predicting solidification history.

Masuku and Mileham (2000, 1997a, 1997b and 1996) have worked on various mould design. The design of the mould in industry typically involves a combination of expert knowledge and trial and error methods which are often not cost effective. Research into computer-aided mould design in the past decade has focused mainly on two categories; mathematical modeling using finite element method and computer advice using artificial intelligence techniques (Al-Ashaab et al., 1995).

Masuku and Mileham (2000) apply intelligence techniques for developing an intelligent system for mould design. Previous parts of the work (Masuku and Mileham, 1996, 1997a and 1997b) have elicited expert rules for each element of mould design and formalized them into usable heuristics, for box-type, cylindrical and solid Block moulding, taking into account other mould elements.

These heuristics are considered to be the foremost important decision to be taken in mould design. The system architecture is shown in Figure 3.7.

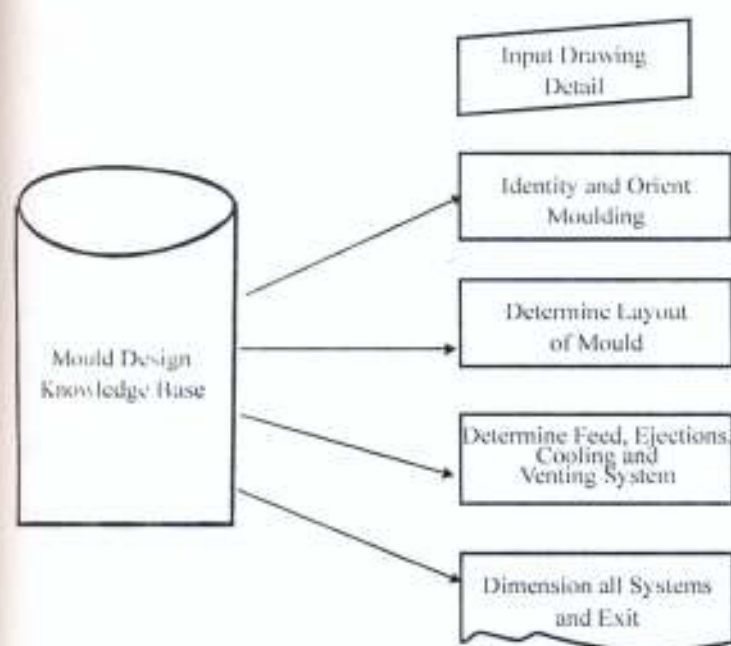


Fig 3.7: System architecture for mould design

Source: Masuku and Mileham (2000)

The mathematical relationship developed by Nanda et al (1994) using conceptual design and Adejuyigbe (1997) 2D schematic cross-sectional view of the mould and Masuku and Mileham (2000, 1997 (a), (1997 (b) and 1996) make it possible to assume a box-type mould to develop a mould design model used in this research as follows;

$$\begin{aligned}
 \text{i. For rectangular box} &= \text{length (l) x breadth (b) x height (h)} \\
 &= l \times b \times h
 \end{aligned}
 \tag{Eqn. 3.4}$$

with a feature of mounting flange as shown in Table 3.1

$$\begin{aligned}
 \text{ii. For hollow cylinder} &= \text{Height (h) x Outside diameter (o) x Inside diameter (l)} \\
 &= h \times o \times l
 \end{aligned}
 \tag{Eqn. 3.5}$$

This has a feature of either boss or fitting as shown in Table 3.1.

3.3.3 GATING DESIGN

The gating design includes the design of the following parts;

- i. Pouring basin;
- ii. Sprue;
- iii. Runner and
- iv. Gates.

There are three main design elements in a gating system namely; the sprue, runner and ingates;

3.3.3.1 Pouring Basin and Sprue

The calculation that gives a close approximation to the amount of taper necessary in sprue is;

$$\frac{A_1}{A_2} = \sqrt{\frac{Z_2}{Z_1}} \quad \text{Eqn. 3.6}$$

where;

A_1 = Area of sprue entrance

A_2 = Area of sprue base

Z_1 = Depth of metal level in pouring

Z_2 = Distance from metal level in pouring basin to base of sprue

Bernoulli's theorem for calculating velocities in an idealized gating system helps a foundry worker predict the success of the gating system design. The theorem can be

modified to take into account the energy loss that is not considered in the standard equation, however, sufficient data are available for all gating systems. At any rate, Bernoulli's theorem can still be used as the best estimate as long as it is recognized that there may be differences between the idealized and the actual system. Bernoulli's theorem states;

$$\frac{V_1^2}{2g} + \frac{P_1}{\rho_{xy}} + h_1 = \frac{V_2^2}{2g} + \frac{P_2}{\rho_{xy}} + h_2 \quad \text{Eqn. 3.7}$$

Where:

- V = Metal velocity (m/s)
- g = Acceleration due to gravity, (m/s²)
- P = Static pressure (N/m²)
- ρ_{xy} = Density of metal (kg /m³)
- h = Height of liquid (m)

Another law of fluid mechanisms guiding the design of gating system is the law of continuity, which show the metal flow rates. The equation for obtaining metal flow that states the quantity of fluid flowing per second, passing all points in a full channel to be the same, irrespective of local changes in cross-sectional area and velocity is as stated below thus:

$$Q = A_1 V_1 = A_2 V_2 = \text{Constant} \quad \text{Eqn. 3.8}$$

Where

- Q = Flow rate or volume of metal passing per unit time, m³/s

A_c = Cross sectional area, m^2

V_f = Velocity of flow m/s

The law of continuity can also be used to estimate velocities within a gating system when the channels are changed as shown below;

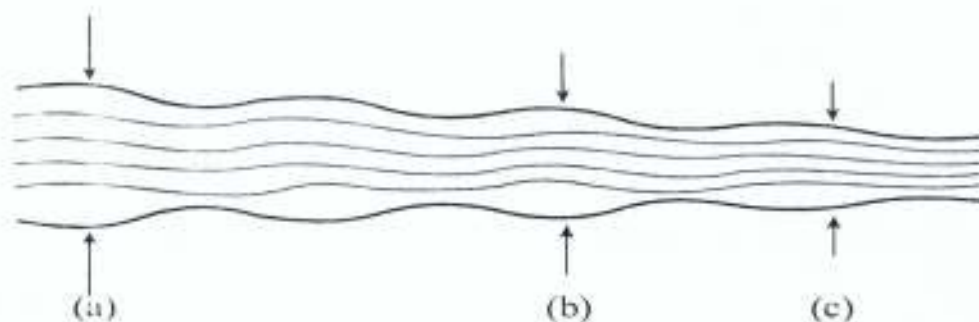
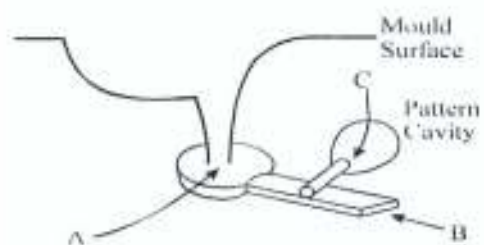


Fig. 3.8: The law of continuity when the channels changed

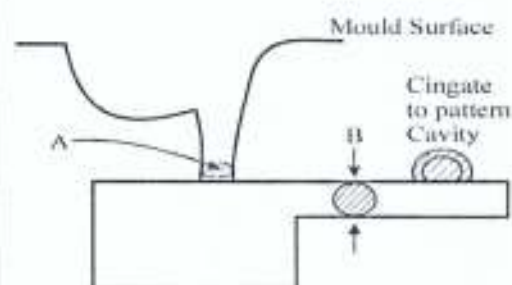
3.3.3.2 Runners and In-Gates Design

The runners and in-gates, pipe the metal from the sprue base to the mould cavity. The combination of the sprue, sprue base, runners and in-gates completes the total pouring system of any casting. There are two types of gating;

- i. Pressure gating, and
- ii. No-pressure gating



$A > B > C$ A = Sprue area at the exist
 $A : B : C$
 $1 : 0.75 : 0.5$ B = Runner area
 $4 : 3 : 2$ C = In-gate area



$A < B < C$
 $A : B : C$
 $1 : 2 : 4$

Fig. 3.9a Pressure gating systems used on heavy metals

Fig. 3.9b Non-pressure gating used on all light-metals

TABLE 3.3: SUGGESTED GATING SYSTEM RATIOS

Metal	Ratio
Aluminium	1:2:1, 1:2:3, 1:2:4, 2:2:1
Brass	1:1:1, 1:1:3
Ductile iron	10:9:8, 4:8:3
Grey cast iron	1:4:4
Steel	1:3:3, 1:2:2, 1:1:4

Source: Little (1977)

Another formulae that can be used for calculating the gating ratio according to Little (1977) is:

$$W = KA\sqrt{H} \quad \text{Eqn. 3.9}$$

where

W = Orifice coefficient of the sprue

A_m = Minimum sprue area (m^2)

H_s = Sprue height (m)

K is defined as a ratio of sprue and ingate areas

$$K \approx \frac{A_s}{A_g} \quad \text{Eqn. 3.10}$$

where

A_s = Sprue area (m^2)

A_g = Ingate area (m^2)

The sequence for calculating gating system are;

- i. Calculate the weight of casting from the drawing
- ii. Choose the location and design of gating system

- iii. Find pouring time
- iv. Calculate the choke area

The choke area can be calculated using; (Little, 1977).

$$A = \frac{G}{\delta t \alpha \sqrt{2gH_p}} = \frac{G \times 1000}{\delta t \alpha \sqrt{2gH_p}} = \frac{G}{t} \times \frac{1000}{8} \times \frac{1}{C} \times \frac{1}{\sqrt{H_p}} \quad \text{Eqn. 3.11}$$

where

- G = Casting weight + gating + riser in kg
 δ = Density of molten metal gm/cc
 H_p = Effective height of metal head, cm;
 α = Discharge coefficient;
 t = Pouring time, sec
 g = Acceleration due to gravity cm/sec²
 A = Choke area, sq.m
 C = a $\sqrt{2g}$ is known as nozzle or orifice coefficient



The factor to be considered also in a gating system is the cross sectional area and not only the function or the mass, but also of the pouring time T_p . Thus the total cross-sectional area of the gates can be determined according to Little (1977) and Nwajagu (1994) from the expression;

$$A_g = \frac{M_0}{\mu \beta T_p \sqrt{H_u}} \quad \text{Eqn. 3.12}$$

where

- A_g = Area of gate in cm²
 M_0 = Mass of rough casting in kg

- μ = a coefficient that accounts for friction
- β = Force coefficient dependent on the types of cast alloy
- H_{st} = Effective static head in cm
- T_p = Optimum pouring time

The force coefficient, β is calculated from; (Nwajagu, 1994 and Little, 1977)

$$\beta = \rho \sqrt{g} \quad \text{Eqn. 3.13}$$

where

- ρ = Metal density (kg/cm^3)
- g = Acceleration due to gravity, cm/s^2

3.4 NC/CNC POST PROCESSOR MODULE

Applying the results of geometric and technological design module, this module aims at working out the control programs for NC/CNC post processor machines used for manufacturing or casting the parts (i.e. sand filling, gating, melting, pouring and shaking). The data on the machines and the tools available in the databank are used for the optimal use for the production of the cast part.

3.5 OPERATION MODULE

(Mould filling, Molten-metal optimal Pouring and Solidification)

This module is where all the operations concerning the production of the cast part is carried out, like

- Mould filling, and the creation of the gating system;

- Selection of standard furnace ladle, measurement heat transfer in the mould and the control of thermal contraction;
- Solidification control; and
- Finishing operation.

3.5.1 FEEDING SYSTEM DESIGN

The feeding system is the same as the problem encountered during the design of risers. Riser design includes

3.5.1.1 Feeders and Risers

The supply or design of feeding or risering of different types of materials varies considerably, depending on the characteristics of each material used.

I. Aluminium Alloy Castings

- * Solidification shrinkage is 6.6% from liquid to the solid state.
- * Difficulty of eliminating micro shrinkage. The gross shrinkage can be avoided using Cain's principle. According to Jain (1992) and Khanna (1996) the Cain's formulate for the relative freezing time, F_r is given by

$$F = \frac{a}{V - b} + c \quad \text{Eqn. 3.14}$$

Where

$$F = \text{Freezing ratio} = \frac{(\text{Area/Volume}) \text{ casting}}{(\text{Area/Volume}) \text{ riser}}$$

$$V_r = \text{Volume ratio} = \frac{\text{Riser volume}}{\text{Casting volume}}$$

- a. = is freezing characteristics constant
- b. = liquid solid solidification contraction
- c. = relative freezing rate of riser and casting

For aluminium castings we have

$$F = \frac{0.10}{V - 0.06} + 1.08 \quad \text{Eqn. 3.5}$$

The values for a, b, and c can be obtained from the table shown below thus;

Table 3.4: The Values of Freezing Characteristic Constant, Liquid Solidification and Relative Freezing Rate.

Cast metal	a	B	C
Aluminium	0.10	1.08	0.06
Gray cast iron	0.33	1.0	0.03
Steel	1.2	1.0	0.05

Source: Jain (1992)

3.5.1.2 Riser Shape and Size

(a) Riser Shape

The metal in the riser should remain in the molten condition for a longer time than in the mould cavity. The heat loss from the riser should therefore, be kept to a minimum. This in turn can be achieved by having a minimum surface area of the riser for a given volume. It is, therefore, evident that the spherical feeder is the most effective, with the cylindrical feeder a bad second. Because of the difficulty of moulding spherical risers, cylindrical riser is usually used. The diameter of cylindrical riser must be larger than that

of casting, otherwise, it would solidify before the casting.

Brigg as stated in Mikhailor (1989) revealed that the height of cylindrical feeders should be $1\frac{1}{2}$ x diameter keeping the height more than this is not advantageous from economic point of view.

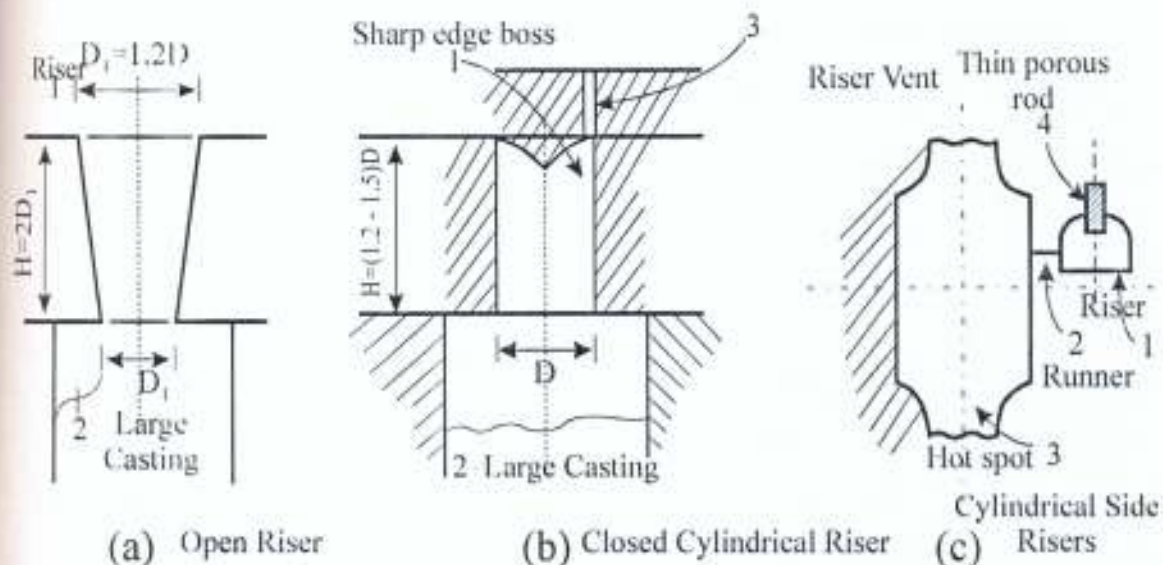


Fig. 3.10: Riser Shapes

Sources: Mikhailor, (1989)

Open risers are used when making large castings (labelled 2 in Fig3.10). It is possible to add more hot metal to them or introduce exothermic mixtures for metal heating.

Closed cylindrical risers are applicable with castings labelled 2 are produced by methods of machine moulding. Gases evolving from the moulds on metal pouring are let to escape through the riser vents 3. The top of a riser is provided with a sharp edge boss 1 or thin porous rod 4. When the metal starts to solidify, the well heated boss or rod prevent the formation of solid metal crust at this point.

Cylindrical side risers are used for feeding hot spots in the sides or bottom of castings. Connecting necked up runners 2 solidifies later than riser 1 and hot spot 3, so that the latter is fed up properly. Side risers require little work for chipping and cleaning. Since it is possible that the risers can be cut off easily at the connecting runner.

All the above mentioned types of the riser may have different shapes (spherical, annular, rectangular, elliptical, e.t.c.) depending on the shape of the casting or hot spot.

In this research, the open riser Fig 3.10(a) was utilized for the design in the model developed.

(b) Riser Size

The volume and size of risers are determined by analytical and empirical formulae

Top risering is extensively used in aluminium castings. Micro shrinkage can be minimized by using more than one riser at close diameter. Hence the use of top risering in the CAD/CAM model developed.

ii. STEEL CASTINGS

Caine's principle can also be used here (Eqn. 3.14). The centre top riser in a plate casting is more effective than at the side. Therefore, the Cain's principle used for Aluminium alloy castings can also be used in building the model.

iii. GREY CAST IRON CASTINGS

The feeding of grey-iron requires special attention because of its solidification history. From iron-graphite diagram in Fig. 3.11, solidification of a 3% carbon grey iron occurs in two steps;

- a. Liquids to eutectic temperature 1133°C in which austenitic dendrites separate from the liquid.
- b. At the eutectic temperature where duplex precipitation of graphite and austenite takes place.

Since austenite is a denser phase than liquid iron, contraction takes place while cooling from liquids to the eutectic temperature and therefore, feed metal is required from a riser during this interval. During the eutectic solidification, however, expansion takes place, since the density of solid eutectic structure (austenite + graphite) is less than that of liquid phase. At the eutectic temperature, therefore, metal flows back from the casting to the riser. This process is known as “purging”. If in the grey iron casting, the riser is small and had frozen at the top, due to purging, great pressure will be developed in the casting and its walls will bow outwards. Hence care should be taken to keep the riser open to the atmosphere so that pressure in the casting is easily relieved without any distortion. Therefore, in developing the model, open riser in 3.10(a) was used to eliminate all the problems associated with Grey iron casting enumerated above.

The desirability of preferring one allotropic form of iron – austenite, ferrite or cementite in casting is very important. Hence, the establishment of the composition of the material used when casting is desirable. The specification of the composition for each casting is desirable.

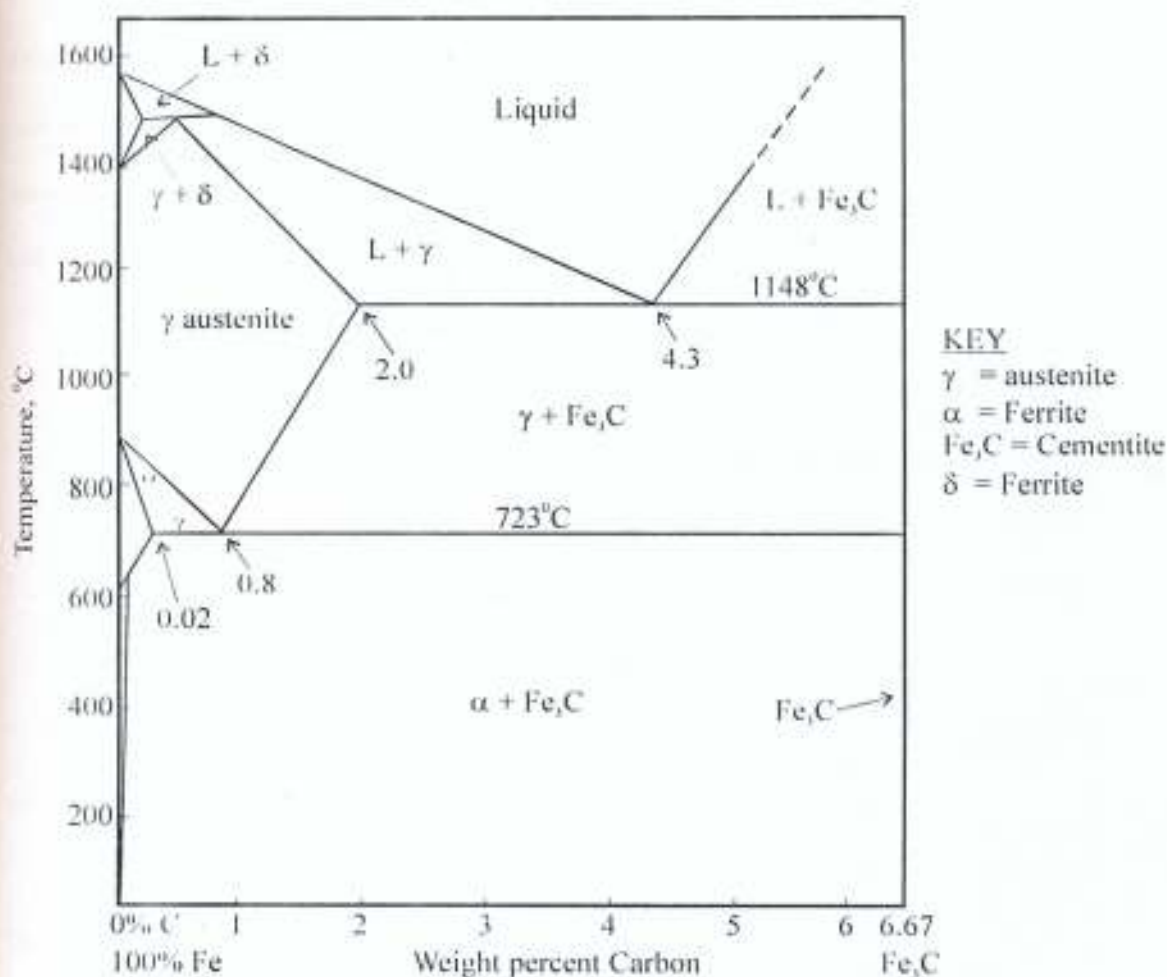


Fig. 3.11: Iron-Graphite Equilibrium Diagram

3.5.1.3 Feeding Efficiency

For economic reasons, the weight of the feeders must be kept as low as is consistent with adequate feeding. Jain (1992), and Khanna (1996) established that the feed efficiency can be calculated using the following formulae;

$$\text{Feeding Efficiency} = \frac{\text{Weight of Feed Metal}}{\text{Weight of Riser before Feeding}} \quad \text{Eqn.3.16}$$

Adejuyigbe (1977b), Nwajagu (1994), Jain (1992), and Khanna (1996) established that the feeding efficiency can be calculated as follows; Consider a simple case in which a casting is fed to soundness by a riser i.e shrinkage does not take place in the casting but instead in the riser.

Let

V_{rb} = Volume of the riser before feeding;

W_{rb} = Weight of the riser before feeding;

W_{ra} = Weight of the riser after feeding i.e. after complete solidification

V_{fm} = Volume of the feed-metal supplied by the riser;

W_{fm} = Weight of the riser feed metal;

V_{ra} = Volume of riser after feeding.

$$W_{ra} = W_{rb} - W_{fm} \quad \text{Eqn. 3.17}$$

Or

$$V_{ra} = V_{rb} - V_{fm} \quad \text{Eqn. 3.18}$$

Therefore,

$$\text{Feeding Efficiency, } Fe = \frac{W_{fm}}{W_{rb}} = \frac{V_{fm}}{V_{rb}} \quad \text{Eqn. 3.19}$$

This equation 3.21 for feeding efficiency was applied in the model developed.

3.5.1.4 Riser Location

A riser should be located in a position that will cause directional solidification from the casting towards it. Top risering is advisable for light metals as it develops feeding pressure due to metalostatic pressure in the riser.

Sometimes more than one riser have to be used to secure soundness in the casting. No matter how complex, any casting can be reduced to a series of geometrical shapes that consists of two heavier sections joined by a thinner one. Each heavier section needs its own riser.

If the thinner section is not tapered to become larger toward the heavier sections, centre line shrinkage is probable. Chills at the thinner section may prevent such shrinkage but promote directional solidification can also be brought about by using internal and external chills. Drawings of casting are checked for the probability of formation of shrinkage defects by the method of inscribed circles, which should freely roll out, as it was formed, from lower sections of a casting into the upper ones and further into the riser.

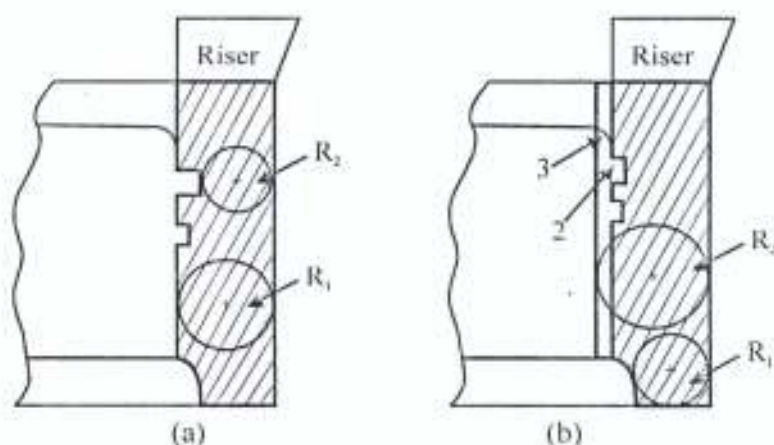


Fig. 3.12: Probability of shrinkage defects using inscribed circles.

Source: Niebel et al (1989)

For casting shown in Fig. 3.12(a) this condition is not satisfied ($R_1 > R_2$) and therefore, shrinkage cavity 1 is likely to appear in the hot spot. After marking the machining allowances, draft 2 and filler 3 in the drawing, Fig 3.12(b), the inscribed

circles will roll out freely ($R_1 < R_2$) from the bottom of the casting upwards into the riser which will ensure the directional solidification, and therefore, the absence of shrinkage cavity in the casting.

Past research (Little, 1977; Adejuyigbe, 1997a; Niebel et al., 1989; Khanna, 1996) has shown that an adequate riser can provide soundness for a distance of:

- (i) $4.5t$ for a plate casting;
Where t = thickness of the material used
- (ii) $2t$ is the riser contribution; and
- (iii) $2.5t$ is from the edge effect

The maximum distance between risers is;

- (i) $4t$ for plates and
- (ii) $1t$ to $4t$ for bars

Chills increase the feeding distance for plates to a total of;

- (i) $4.5t + 5\text{cm (2in)}$, for a plate; and to
- (ii) $6\sqrt{t} + t$ for a bar

Thus, the maximum spacing between risers if chills are used midway between them is;

- (i) $9t + 10\text{cm (4in)}$, for a plate; and
- (ii) $12\sqrt{t} + 2t$ for bars

It should be noted that the distances are from the outside edge, not the centre line, of the riser (Fig 3.13)

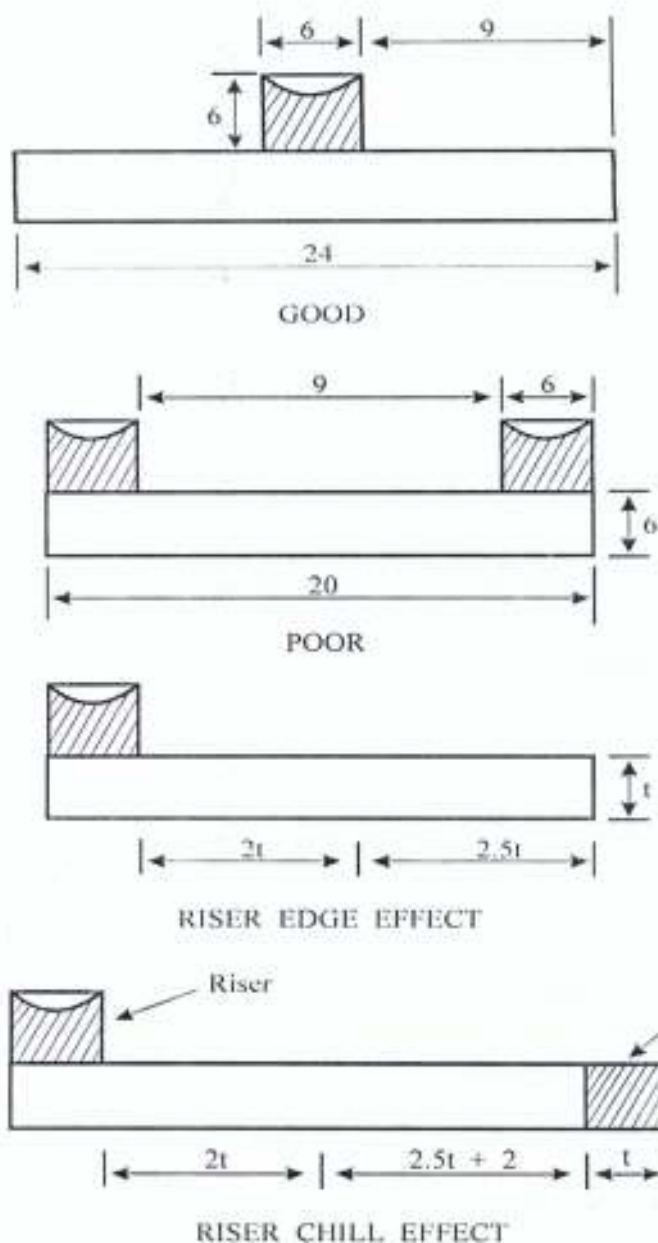


Fig. 3.13: Feeding Distance of Risers For Steel Plates

Source: Niebel et al (1989)

Possibly the most important study of risering a casting is that carried out by Chrorinov's study who provided a useful working basis for feeding design. [Mikhailor

(1989), Jain (1992), and Khanna (1996)]. In its original form, the Chvorinov's equation can be expressed as:

$$T = \left(\frac{V}{AK} \right)^2 \quad \text{Eqn. 3.20}$$

- T_s = Solidification time of a casting
 V_c = Volume of the casting
 A_{sa} = Surface area of the casting; and
 K = Constant = 2.09

3.5.1.5 Proper Connection of the Riser to the Casting

The riser connection to the casting warrants considerable care because it determines how well the riser feeds, and secondly, how readily a riser can be removed. The basic requirements of riser-casting connections are that;

- The feeder should not be joined to the casting by a narrow neck; which may solidify before the casting; and
- They should be so designed that the feeder is easily removable from the casting.

The above requirements can be achieved in a way that feeder may be attached to a narrow neck and yet be able to perform its function by the use of a wash burn or knock-off core to form a very short neck. To aid in top riser removal, it is wise to consider placing an annular core similar to a large washer in the riser neck. The thin section of core sand soon becomes hot, so that little chilling occurs and feeding takes place through the centre hole. The connection length for a riser should not exceed $D/3$ to $D/2$, where D is the diameter of the riser and the inner hole should be about 1.2 times the connection length.

3.5.2 THERMAL CONTRACTION

The shrinkage or contraction must always be allowed by making the pattern proportionately larger in every dimension. This is due to the fact that all metals contract on cooling and solidification. The amount however, varies with different metals. Cast iron for instance contracts approximately 2.5mm in 300mm, a length of 300mm on a pattern mould contracts to 297.5mm in the casting. This is a contraction of 1 in 120 and a rule for making patterns for castings made of iron would be marked contraction 1/120 (Tables 3.5 and 3.6).

Table 3.5: Contraction Allowances for Cast Iron

Type of Cast Iron	Contraction Percentage	
	Soft Mould (Green Sand)	Hard Mould (Dry Sand)
a. Grey Iron Casting:		
Small/Medium	0.9	1.0
Medium/Big	0.8	0.9
Very Hard	0.7	0.8
b. Special Cylinder Casting:		
Linear	0.8	0.9
Diameter	0.5	0.7
c. Malleable Castt Iron:		
White heart	0.8 – 1.7	1.6 – 2.0
Black heart		Up to 1.2

Source: Mikhailor (1989)

Table 3.6: Contraction Allowances for Other Materials

S/N	Type of Material	Contraction	Expansion
1	Other ferrous metals apart from cast iron	-	2.5 to 4%
2	Pure aluminium	6.6%	
3	Copper	4.9%	
4	Lead	7.7% in volume at its phase change	

Source: Adejuyigbe (1997)

Trovant and Argyropoulus (1996) classified shrinkage into three thus:

1. Liquid contraction
2. Solidification contraction and
3. Solid contraction, as earlier done in the literature review. They also looked at shrinkage in casting metals using three boundary conditions;
 - i. Displacement boundary conditions – Thermal contraction
 - ii. Temperature boundary conditions – Heat transfer (Energy equation) that change for shrinkage (Liquid contraction and solidification contraction)
 - iii. Velocity boundary conditions – Fluid flow (momentum equation and continuity equation);

They further predicted using the algorithm on Fig. 3.14 the possible location of shrinkages and how such could be controlled or compensated.

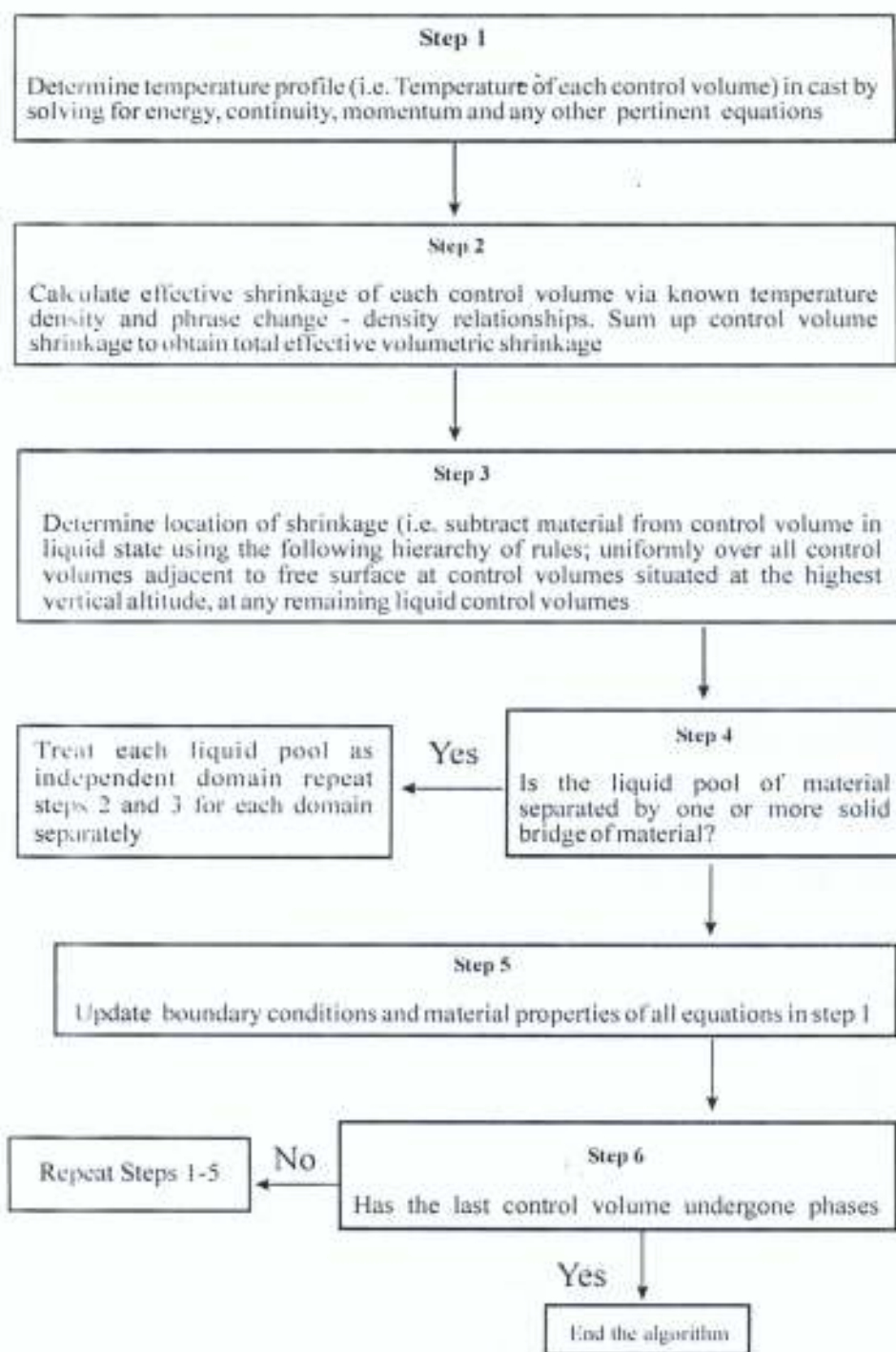


Fig. 3.14: The Shrinkage Algorithm
Source: Trovant and Argyropoulos (1996)

Linear shrinkage is the contraction of linear sizes of a casting during its cooling in the mould. The practical value of shrinkage is determined according to Khanna, (1996), Mikhailor (1989) as;

$$E_{pr} = \frac{l_{pattern} - l_{cast}}{l_{cast}} \times 100\% \quad \text{Eqn. 3.21}$$

Where;

E_{pr}	=	The practical value of shrinkage
$l_{pattern}$	=	Length of pattern
l_{cast}	=	Length of cast

3.5.2.1 Thermal Aspects of Moulding Sands and Chipping Power of Mould

Heat abstracted from a casting during its pouring, solidification and cooling to shake out is largely diffused into the moulding media. The main factor determining the heat abstraction is the heat diffusivity. The thermal conductivity of sand and chipping power of the mould (b_2) (Khanna, 1996, Adejuyigbe, 1997, and Mikhailor, 1989) is given by;

$$b_2 = \sqrt{K\rho C} \quad \text{Eqn. 3.22}$$

Where;

K	=	Thermal conductivity of the moulding media;
C	=	Specific heat of the moulding media
ρ	=	Density of the moulding media

Pouring hot metal into a mould causes extreme thermal shock to the mould

surface. Resistances of a bonded sand to thermal shock (R_s) can be expressed by the relations (Mikhailov, 1989, and Khanna, 1996);

$$R_s = \frac{KY_T(1-\mu)}{E\alpha} \quad \text{Eqn. 3.23}$$

Where;

Y_T = Tensile strength of the material (sand)

μ_p = Poisson's ratio of sand

E = Modulus of elasticity of sand

α = Thermal expansion of sand

Generally, for a foundry sand, Y_T and μ are very small, while the thermal expansion, accommodates the shock. When a molten metal is poured into cavity and begin to solidify, the metal pulls away from the cavity walls. Each metal, pure or alloyed has its own characteristics amount of shrinkage and rate of contraction. Consequently when a pattern is designed, several factors determine the amount of extra size to build unto the pattern to allow for shrinkage. These factors are;

- i. The metal or alloy being used;
- ii. The optimum pouring temperature of the particular work;
- iii. The chilling effect of the moulding material; and
- iv. The size of the mould and the core mass; if any, inside the mould cavity.

3.5.3 ALLOWANCE FOR MACHINING

Allowances for plain machining surfaces is given because (Khanna, 1996);

- i. Castings get oxidized in the mould and during heat treatment and scales etc. thus formed need to be removed.
- ii. It is intended to remove surface roughness and other imperfections from the castings.
- iii. It is required to achieve exact casting dimensions.
- iv. Surface finish is required on the casting.

The above factors necessitate the provision of extra metal on the castings or the machining/finishing allowance. He further enumerated the appropriate machining allowances for various metals and alloys which can be used when building the CAD/CAM models for sand casting thus;

Table 3.7: Various Metals and Appropriate Machining Allowances

Metal/Alloy	Machining Allowance (mm) (on surface)
-Cast Iron	
Medium Casting	3mm
Large Casting	10mm
-Cast Steel	
Medium Casting	4.5mm
Large Casting	Up to 12mm
-Non-ferrous (Brass, Bronze, Aluminium etc)	
Medium Casting	1.5mm
Large Casting	3mm

Source: Khanna (1996)

It is to be noted that machining allowance should be allowed. The recommended

machining maximum allowance (British) in mm for steel casting in sand moulds according to Mikhailor (1989) is given by;

$$a = 4 + \frac{6D}{100} \quad \text{Eqn. 3.24}$$

$$b = 4.5 + \frac{5D}{100} \quad \text{Eqn. 3.25}$$

$$c = 5 + \frac{4D}{100} \quad \text{Eqn. 3.26}$$

Where;

- a = is for castings having greatest dimension (D) less than 250mm
- b = between 250 and 1000mm
- c = above 1000mm thrice respectively

Minimum allowance normally used in all cases is 3mm.

Khanna (1996) also enumerated draft or taper allowance which is given to all surfaces perpendicular to the parting line, so as to allow the pattern to be easily removed from the moulding material tightly packed round it without damaging the mould cavity.

- Taper on external surfaces – 10 to 25mm/metre
- Taper on internal surfaces – 40 to 65mm/metre

He further said that distortion allowance may vary from 2 to 20mm depending upon the size, shape and material of the casting.

3.5.4 SOLIDIFICATION

When a molten metal is poured in the mould and allowed to cool, the process of freezing starts. A mathematical study of heat flow is most helpful in following what is happening in the mould. Heat flow in dies and permanent moulds is more difficult to analyze than in sand moulds, and the mathematical solutions are more complex because the solidifying metal, mould – metal interface and the mould may each contribute to the flow of heat.

3.5.4.1 Time of Pouring

Time for pouring of a casting depends on many factors, some of which are;

- i. Rheological properties of the melt;
- ii. The mass of casting
- iii. The thickness of webs; ribs, and anchor elements;
- iv. The shape of the casting; and
- v. The type of metal being cast.

Asuquo and Bobo Jama (1991) enumerated the pour out time T_p as;

$$T_p = K.M_o \quad \text{Eqn. 3.27}$$

Where;

T_p = Time in seconds within which to pour out

K = A force coefficient which varies according to range of wall thickness (Table 3.8).

M_o = Mass of the casting in Kg and this includes the gates and risers

Table 3.8: Typical Values Assigned to Force Coefficient (K)

Wall Thickness (mm)	K Value
3 – 4	1.63
5 – 8	1.85
8 – 15	2.20

Source: Asuquo and Bobo Jama (1991)

In an earlier study, Adejuyigbe (1997) concluded that most of the experimental evidence is based on “pour out” method. In this method, molten metal is poured in the mould and allowed to solidify. Time of pouring is a function of;

- * Area of mould (A_m)
- * Area of gate (A_g)
- * Height of the sprue (h_t)
- * Height of the mould (h_m)

The above enumerated points is shown in Fig. 3.15 below used in moulding process.

a. Time of Pouring for Side Gating

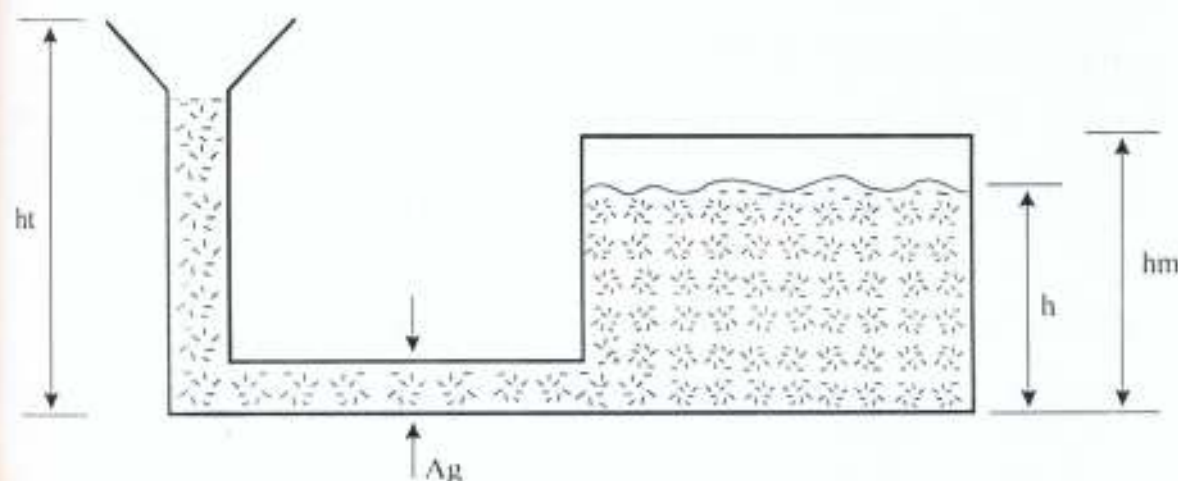


Fig. 3.15 Side Gating System

Adejuyigbe (1997), Mikhailor (1989) and Niebel et al (1989) in their early study had derived the formulae for time of pouring for side gating as;

$$t_f = \frac{2A_m}{A_g \sqrt{2g}} [\sqrt{ht} - \sqrt{ht - hm}] \quad \text{Eqn. 3.28}$$

This can further be broken down as

$$t_f = \frac{A_m}{A_g} \sqrt{\frac{2}{g}} [\sqrt{ht} - \sqrt{ht - hm}] \quad \text{Eqn. 3.29}$$

b. **Time of Pouring for Top Gating**

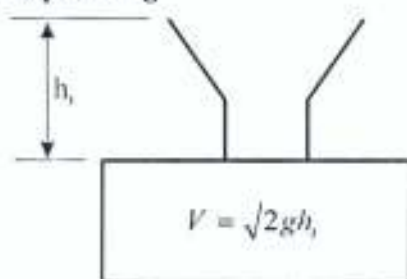


Fig. 3.18 Top Gating

Fig. 3.16: Top Gating

Also, Adejuyigbe, (1997), Mikhailor (1989) and Niebel et al (1989) in their early study derived the formulae for time of pouring for top gating as;

$$t_f = \frac{A_m hm}{A_g \sqrt{2ght}} \quad \text{Eqn. 3.30}$$

In practice, t_f must not be too long to prevent premature solidification occurring before mould h is completely filled up; t_f used to be short. If the rate of pouring is too fast, turbulence may occur and this may lead to mould erosion and inclusion in the casting.

In Nigerian Machine Tools, (NMT) Osogbo, the pouring time (t) is calculated using the following formulae:

$$\text{Pouring Time (t)} = \left(1.41 + \frac{T}{14.59} \right) \sqrt{W} \quad \text{Eqn. 3.31}$$

Where;

T = Minimum section thickness for the casting

W = Weight of the casting

Jain (1992) also suggested a similar empirical formulae for pouring time (t) like that of NMT, Osogbo thus;

$$R = \frac{W^p}{\left(1.34 + \frac{t}{13.77} \right)} \quad \text{Eqn. 3.32}$$

Where R = Pouring rate in kg per second

W = Weight of the casting in kg

t = the critical casting thickness in mm

p = the quotient whose value depends on the weight of the

casting

The value of p for different castings is as follows;

Weight of casting	Value of p
Up to 500kg	0.50
500 – 5000kg	0.67
5000 – 1500kg	0.70

Hence the adoption of the pouring formulae used by NMT, Osogbo which I learnt

was obtained from their casting manual.

3.6 COSTING MODULE

In the costing module, the following operation were carried out;

- * Inputing all the parameters needed to cost the sand casted products like weight of the material, Thermotip, lining material, Fettling & Moulding materials, Liquid material, Direct labour, Direct Expenses, and complexity factor.
- * Calculation of the following were carried out
 - Cost incurred on complexity factor per unit;
 - Overhead cost per unit
 - Total production cost per unit
- * Determination of whether the casting is viable for production



3.6.1 COSTING OF CAST PRODUCTS MODEL DEVELOPMENT

An economic model was built both to simulate and predict the most economical way of costing casting products. Other work by other people are very useful when building up the model such work as: Aderoba (2001) who built a generalized cost-

estimation model for jobshops; Aderoba (1994) who built economic model for simulating and predicting the most economical mobile power system for a given farm. Sule (1988) built up a yield and cost models when a product is defective.

Ariet and Schweger (1970) looked at various cost estimation and control system. Ulrich and Eppinger (1995) wrote on estimating the manufacturing costs.

All the above are very useful, but failed to address the peculiar problems in costing of sand casting products hence this research.

In estimating and building costing model for a sand casting products, it must be noted that the product is of a custom type, that is, one off, witnessed in a jobshop. Therefore, the mixture of Activity-Based Costing (ABC) method (Cooper and Kaplan, 1988; Aderoba, 2001; and Brimson, 1991) and direct cost per unit of component produced will be used. In the ABC system, the cost of a product equals the cost of all the activities required to produce it. The ABC system is based on activity resources rather than machine cost.

3.6.2 Estimating the Production Costs of Sand Casting Products

The estimate of the final costs for the production of sand casting products can be done by adding up the costs of:

- | | | |
|-----|---|-------|
| i. | Direct materials' cost per unit of size j | a_j |
| ii. | Direct labour cost per unit of size j | b_j |

iii.	Direct expenses per unit of size j	c_j
iv.	Heat Treatment charge per unit of size j	d_j
v.	Cost incurred on complexity factor per unit of size j	e_j
vi.	Related overhead cost per unit of size j	f_j
vii.	Total Production Cost per unit of size j	Pc_j

In developing this model, Nigerian Machine Tools (NMT), Osogbo was used as a case study. All their approaches for costing is being put into consideration.

The model is hereby developed below thus;

3.6.3 Direct materials (a_j)

In sand casting, activities i on the direct material cost per unit of size j (a_j), the activity is divided into two thus;

* Partial Direct Material Cost (PDMc) gives;

$$(PDMc) = (B_{ij} + d_{ij} + F_{ij} + K_{ij} + h_{ij}) \quad \text{Eqn 3.33}$$

where;

B_{ij} = Lining material cost in activity i for size j

d_{ij} = Moulding material cost in activity i for size j

F_{ij} = Fettling Cost in activity i for size j

K_{ij} = Liquid metal Cost in activity i for size j

h_{ij} = Heat treatment Cost (Thermotip) in activity i for size j

* Pattern Cost (PTc) gives;

$$PTc = 0.3 (PDMc + c_j + b_j^l) \quad \text{Eqn. 3.34}$$

Where;

$PDMc$ = Partial direct material cost

c_j = Direct expenses per unit size j

b_j^l = Direct labour cost per unit size j

Therefore the total direct material cost (a_{1j}) gives;

$$(a_{1j}) = [(\beta_{ij} + d_{ij} + F_{ij} + K_{ij} + h_{ij}) + 0.3 (PDMc + c_j + b_j^l)] X_{ij} \quad \text{Eqn 3.35}$$

where;

X_{ij} = Production limit > 0 for $d//j = 1 \ i = 1$

3.6.4 Direct Labour Cost (b_j^l)

The direct labour activity (i) cost per unit of size (j) involved the amount incurred

on salaries and allowances of the operatives of the sand casting industries and their allowances. In developing the activity model in this areas, the labour rates L_{ik} gives;

$$L_{ik} = S_i / (h_i n_i \varepsilon_i) \quad \text{Eqn 3.36}$$

where;

- L_{ik} = the labour rates for all the activity i at work centre k
- S_i = the total salaries and allowances for labour in activity;
- H_i = the hours available work per period in activity;
- n_i = The number of workers in activity i
- ε_i = the labour efficiency factor in activity i

It can also be discovered that in a sand casting operations the direct labour cost (b^1_j), is a function of total salaries and allowances for labour in activity i (S_i), which can further be broken down to involve the following activities;

$$S_i = (t_i + MM_i + MO_i + P_i + F_i) \quad \text{Eqn 3.37}$$

Where

- t_i = Costs of labour on pattern making in activity i
- MM_i = Costs of labour on mould making and preparation in activity i
- MO_i = Costs of the operation(s) of the moulding machines in activity i
- P_i = Costs of labour on pouring in activity i
- F_i = Costs of labour on fettling in activity i

Therefore, the direct labour cost (b^1_j) which is the labour rate L_{ik} gives;

$$b^1_j = (t_i + MM_i + MO_i + P_i + F_i) / (h_i n_i \varepsilon_i) \quad \text{Eqn 3.38}$$

3.6.5 Direct Expenses (C_j)

The direct expenses (C_j) per unit of size j incurred in this nature is the cost incurred as a result of consumption of;

$$C_j = 2E_i + W_i + 0.5 D_i \quad \text{Eqn 3.39}$$

Where;

C_j = The direct expenses per unit of size j

E_i = Electricity expenses in activity i

W_i = Water expenses in activity i

D_i = Diesel expenses in activity i

3.6.6 Heat Treatment Charge (d_j)

The heat treatment charge is the amount incurred for improving the properties of the components. The development of model done here is with reference to 2 tons furnace.

It is however to be noted that different materials will present different charge needed to improve it.

It has the following breakdown

Grey Cast Iron

- Cast Iron Scraps (C_i) = 98.63%
- Carburiser (C_a) = 0.78%
- Fe Si = 0.59%

The mathematical relationship is

$$0.986 C_1 + 0.0078 C_2 + 0.0059 \text{ FeSi} \leq 10.23 \quad \text{Eqn 3.40}$$

For 1kg of Grey cast iron charge, it cost ₦10.23

White Cast Iron

- Steel Scraps (Sc)	-	8%
- Cast Iron Scraps (Cs)	-	92%
1 kg of white Cast Iron	=	₦7.26

The mathematical relationship model gives;

$$0.08Sc + 0.92Cs \leq 7.26 \quad \text{Eqn 3.41}$$

Mn-Steel

- Mn-Steel Scraps (Mn-s)	-	94.6%
- Carburiser (C ₂)	-	0.7%
- Fe-Si	-	0.56%
- Fe-Mn	-	4.4%

1kg of Mn-Steel = ₦29.20

The mathematical relationship model gives;

$$0.946 \text{ Mn-s} + 0.007 C_2 + 0.0056 \text{ Fe-Si} + 0.04 \text{ Fe-Mn} \leq 29.20 \quad \text{Eqn 3.42}$$

In addition to the above cost, Thermotip cost is also added to heat treatment charge. Thermotip is used along with immersion pyrometer to measure the temperature of molten metal. Thermotips are consumables, because it can only be used two or three times before disuse. It serves as a sensor which transfer signal to pyrometer which display the temperature reading, Nigerian Machine Tools (NMT), Osogbo used ₦0.7 cost

of 1kg of the material.

$$\text{Thermotip Cost (₦/kg)} = 0.7$$

3.6.7 Complexity Factor e_j

Complexity factor is defined as the rate of the degree of difficulty incurred in executing the job. The cost incurred on complexity factor per unit of size j .

$$e_j = \alpha_j (a_j + b^1_j + c_j + d_j) \quad \text{Eqn 3.43}$$

and $0.05 \leq \alpha_j \leq 0.4$; with α_j being the complexity factor of size j

where;

$$a_j = \text{direct materials' cost per unit of size } j$$

$$b^1_j = \text{direct labour cost per unit of size } j$$

$$c_j = \text{direct expenses per unit of size } j$$

$$d_j = \text{heat treatment change per unit of size } j$$

3.6.8 Related Overhead Cost (f_j)

The related overhead cost per unit size j comprises of services rendered by other departments to enhance production activities. Usually f_j

$$\begin{aligned} f_j &= 0.05 (a_j + b^1_j + c_j + d_j + e_j) \\ &= 0.05 [a_j + b^1_j + c_j + d_j + \alpha_j (a_j + b^1_j + c_j + d_j)] \\ &= 0.05 [1 + \alpha_j] (a_j + b^1_j + c_j + d_j) \end{aligned} \quad \text{Eqn 3.44}$$

where;

$$\alpha_j = \text{complexity factor per unit of size } j$$

- a_j = direct materials' cost per unit of size j
- b_j^l = direct labour cost per unit of size j
- c_j = direct expenses per unit of size j
- d_j = heat treatment change per unit of size j

3.6.9 Production Cost (PC_j)

The production cost (PC_j) per unit of size j comprises of the summation of all the cost associated with the production of sand casting products.

$$PC_j = a_j + b_j^l + c_j + d_j + e_j + f_j \quad \text{Eqn 3.45}$$

Where;

- PC_j = production cost per unit of size j
- α_j = complexity factor per unit of size j
- a_j = direct materials' cost per unit of size j
- b_j^l = direct labour cost per unit of size j
- c_j = direct expenses per unit of size j
- d_j = heat treatment change per unit of size j
- e_j = cost incurred on complexity factor per unit of size j
- f_j = related overhead cost per unit of size j

3.7 THE DEVELOPMENT OF DATABASE MODULAR CAD FOR SAND CASTING OPERATIONS

A database handling system is developed, having modular build up principle, where the basic requirements of the elements are of the following types;

- each module should be applicable independently;
- at the same time they should integrate with the total system and should contain the necessary input/output connection points.

The database for the CAD software illustrated in Fig. 3.17 having the following modules;

- Geometric Description Module
- Technological Design Module;
- NC/CNC Post Processor Module;
- Operation Module; and
- Costing Module

Case et al (1994) researched into the second which is the determination of a part representation scheme which is capable of acting as a carrier of information. A single representation is sought that serves the purposes of computer aided design (CAD) and computer aided manufacture (CAM) (within the domain of mechanical components) as an effective way of unifying the information needs of CAD. This approach is what is exploited in this research (Fig. 3.17) and Fig. 3.18 shown above.

A major objective of modern manufacturing planning methods is to reduce substantially the lead time for product conception to product introduction through the adoption of a concurrent rather than serial approach to the various design and planning activities. (Case et. al., 1994; Hounsell and Case, 1994).

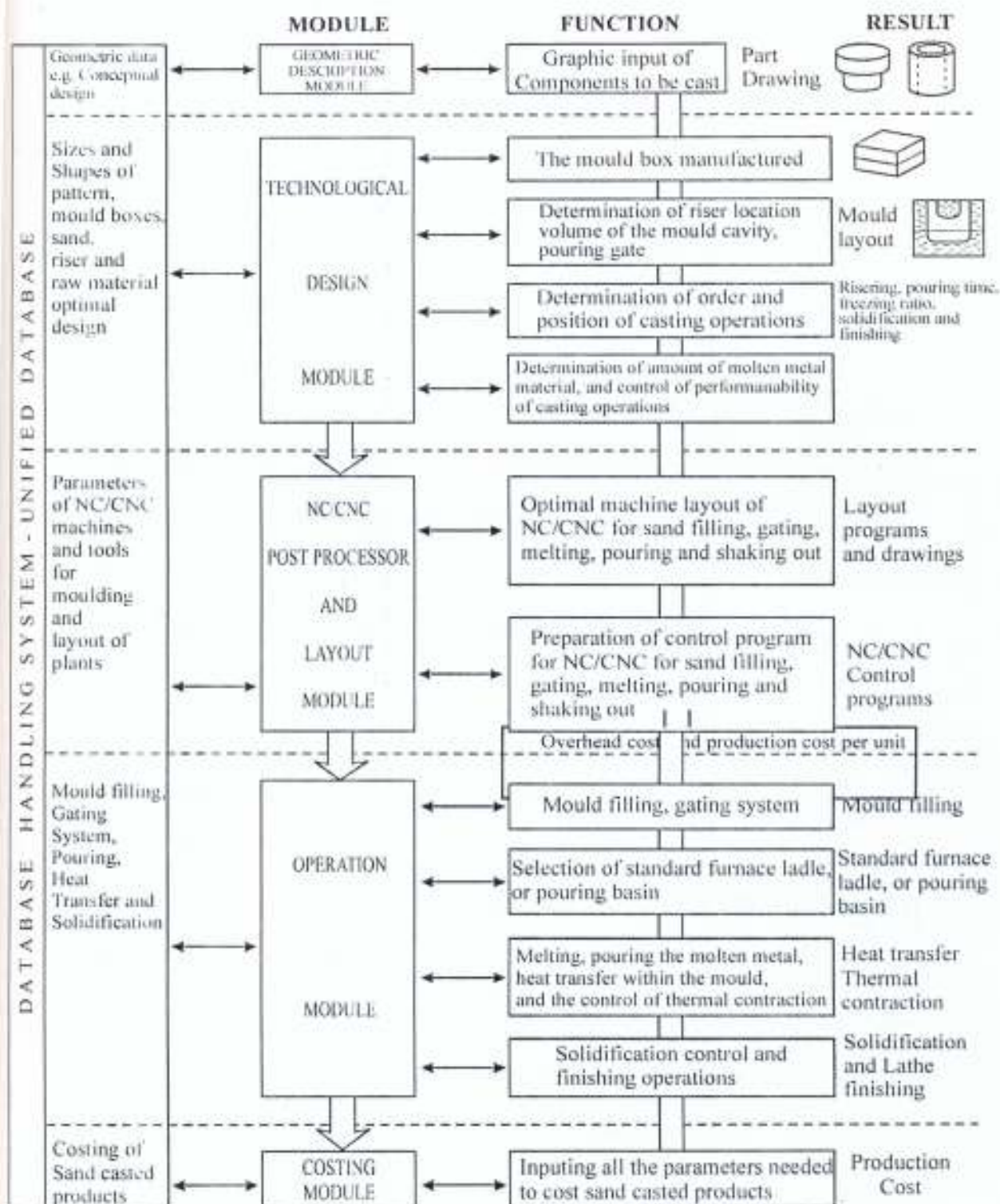


Fig. 3.17: General Scheme of integrated CAD Systems Database for Sand Casting Operations.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

The results findings of this project work, make use of the practical case study, to test the validity of the models and computer programs developed. It is divided into five main components.

- i. The development of computer program (Appendix I) using Visual Basic Language tagged CAD Prog. I, which automatically generate drawings in 2 dimensions (2D) and 3 dimensions (3D)
- ii. The development of computer program (Appendix II) using Visual Basic tagged CAD Prog. II which can generate automatically the necessary parameters needed to cast a non-defective casting
- iii. Real component production was done at Nigerian Machine Tools, Osogbo to confirm the authenticity of both the computer programs and models developed tagged (Manufacturing).
- iv. Validation of Computer-Aided Design and Manufacturing (CAD/Manufacturing) results using manual calculation
- v. The development of computer program (Appendix III using Visual Basic tagged CAD Prog. III for costing called Computer –Aided Costing (CAC) of sand casting products. It automatically calculate the cost of producing a sand casting products.

4.1 THE DEVELOPMENT OF COMPUTER-AIDED DRAFTING (CADD) PROGRAM (CAD PROG I) TO AUTOMATICALLY GENERATE DRAWINGS IN 2 DIMENSIONS AND 3 DIMENSIONS

4.1.1 Hardware Requirement

The CAD programme requires an IBM – compatible microcomputer with the following minimum hardware configuration for good performance.

- * Intel Pentium 120 MHZ processor
- * 32MB RAM
- * 10MB Free Hard Disk Space
- * 3.5" Floppy Disk Drive
- * 14" VGA Colour Monitor
- * Standard Serial Mouse
- * A Laser or Desk Jet Printer

4.1.2 Software Requirement

Microsoft Windows Professional 95, 98, 2000 Built on NT Technology.

4.1.3 DETAILS OF THE USE OF SOFTWARE OR APPLICATION – CASE STUDY

CAD using Visual Basic Language CAD PROG I allows you to design basically two types of objects, namely: flange and boss. It can also draw the cavity of the object in position and the mould ready for pouring.

It can display any of the two objects in three different views, 3 Dimension (3D); 2-Dimension (2D); and cross-sectional exploded view of the mould for both the flange and boss. The default is 3-Dimension (i.e. after specifying the parameters of an object, it automatically drawn in 3D and 2D.

4.1.3.1. Getting Started with CAD

CAD starts with a splash screen with the software logo for a few seconds, as shown in fig. 4.1 below.

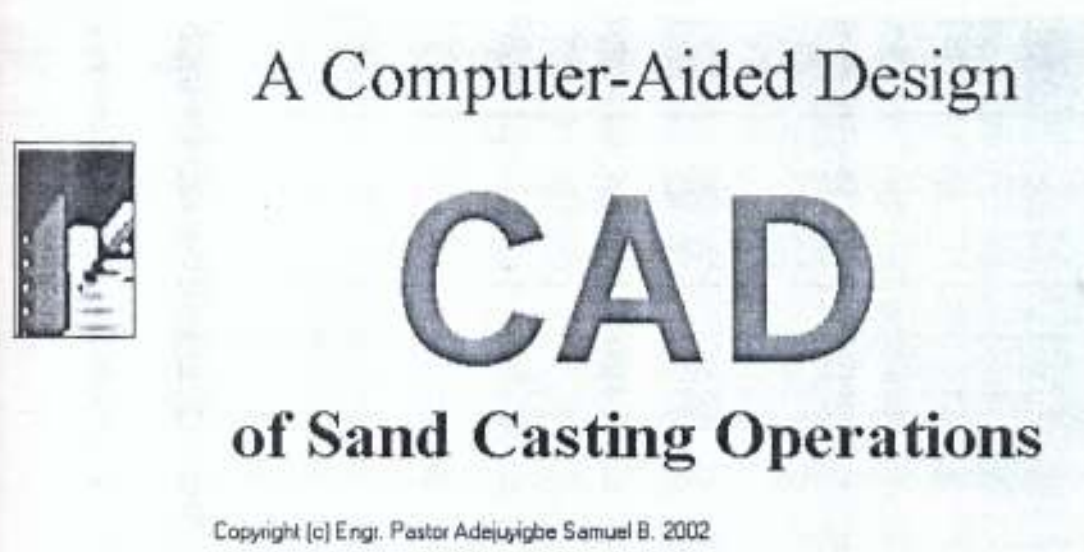


Fig. 4.1: Splash Screen

Then, the programme takes the user to the main menu, from where all the features of the program can be accessed as shown in fig. 4.2

A Computer-Aided Design (CAD) of Sand Casting Operations

File About

MOULD	BOSS	FLANGE	SECTION
Mould Length	Boss Height	Top Height	Section Length
Mould Height	Outer Diameter	Top Width	Section Diameter
Mould Width	Inner Diameter	Top Length	Draw Boss Draw Flange Draw Mould Compute result
Riser Length	Gate Length	Bottom Height	
Riser Diameter	Gate Diameter	Bottom Width	
		Bottom Length	

Fig. 4.2: The Main Menu

4.1.3.2 Designing Boss

From the menu,

1. Enter the parameters of the Boss; outside diameter, inside diameter, and height.
2. Click Draw Boss

It will automatically draw the Boss in 3-dimensional and 2-dimensional views (Fig. 4.3).

The dimensions for the production of the boss in this research are as follows;

- Outside diameter of boss - 160
- Inside diameter of boss - 80

- Height of the boss - 80

4.1.3.3 Designing Flange

From the main menu,

1. Return to main screen or menu
2. Enter the parameters of the flange (Length of the top object; breadth of the base object; and height of the base object).
3. Click Draw flange

It will automatically draw the flange in 3-dimensional and 2-dimensional views (Fig. 4.2).

The dimensions for the production of the flange in this research are as follows;

- Length of the top object - 160
- Breadth of the top object - 100
- Height of the top object - 100
- Length of the base object - 100
- Breadth of the base object - 56
- Height of the base object - 58

4.1.3.4 Designing the Moulding Box

From the main menu:

1. Return to main screen or menu
2. Enter the parameters of the moulding box (parameters for flange, boss, runner, riser and section thickness).
3. Click Draw mould

It will automatically draw the moulding box in 2-dimensional, cross-sectional exploded view, of the object in the mould ready for pouring (Fig. 4.5).

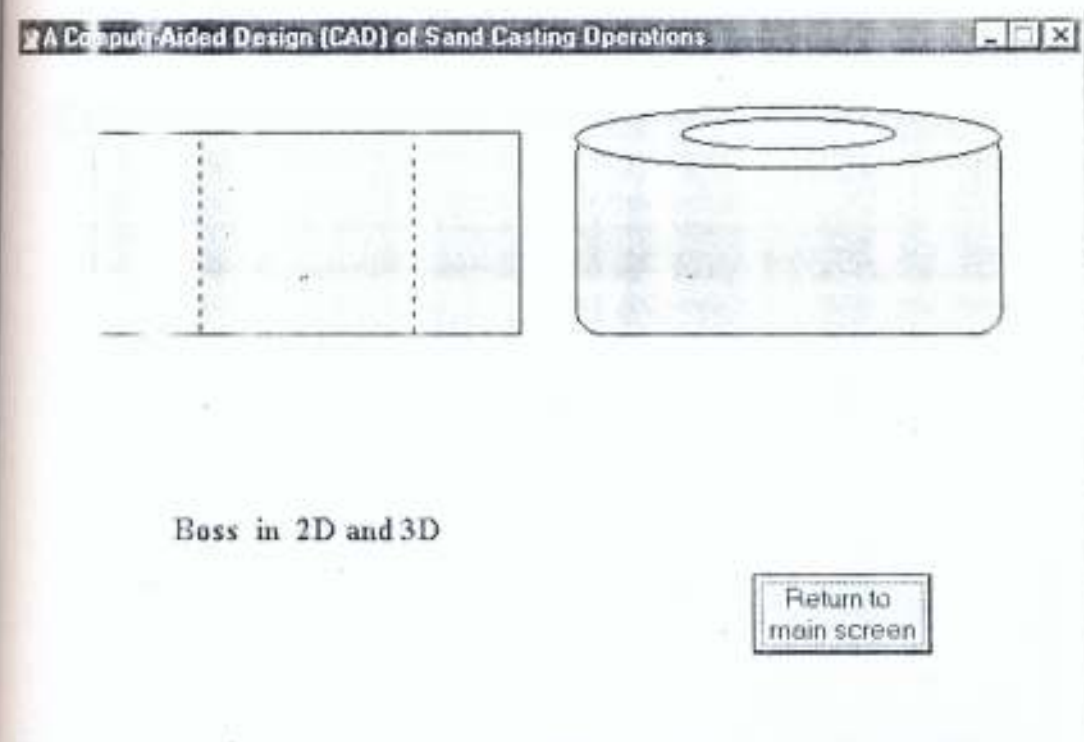


Fig. 4.3: CADD for Boss in 2D and 3D

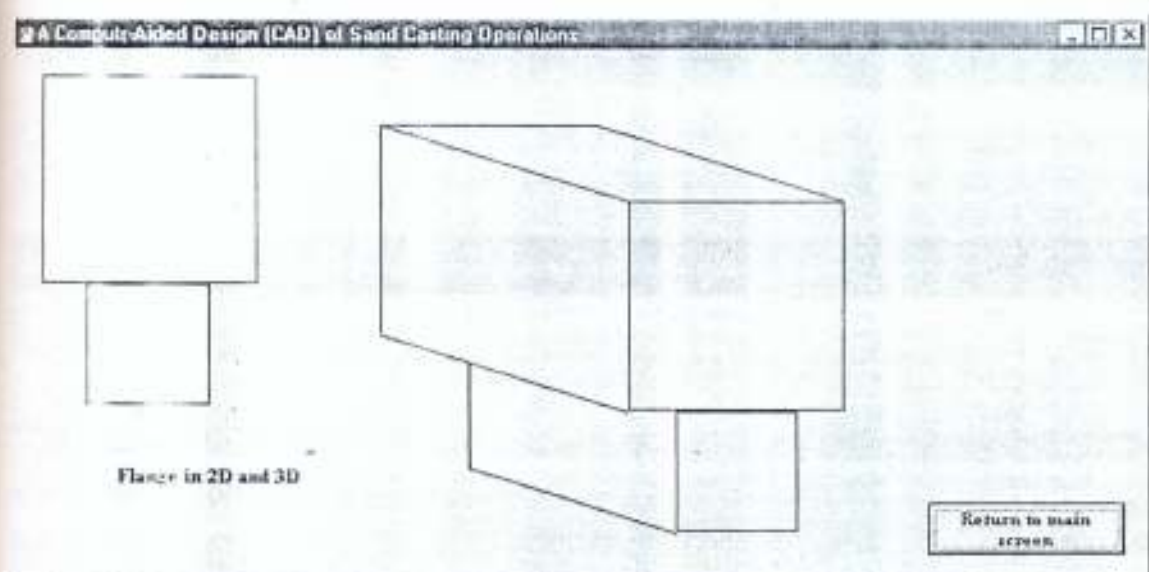
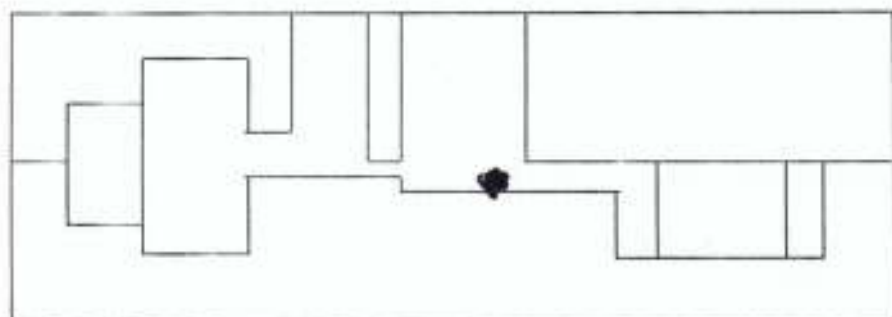


Fig. 4.4: CADD for Flange in 2D and 3D



Moulding Box for Boss and Flange in two-dimensional sectional exploded view

Return to main screen

Fig. 4.5 CADD for Moulding Box for Boss and Flange in 2D sectional exploded view of the computer output.

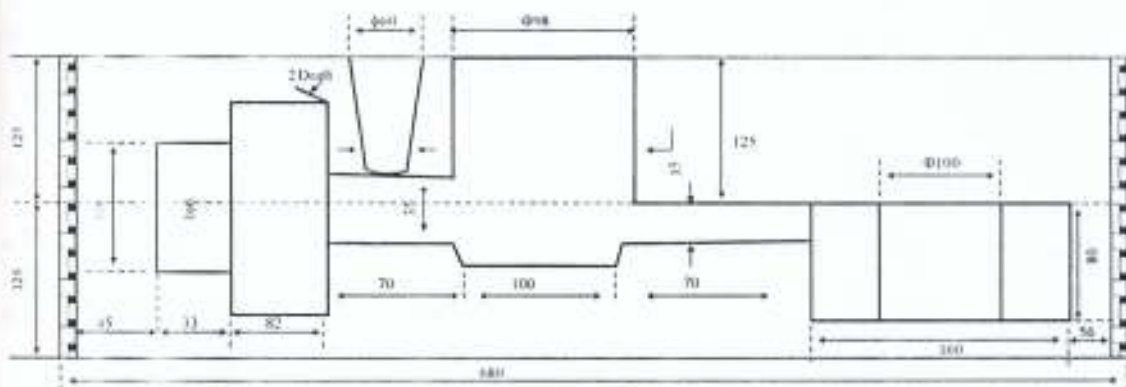


Fig. 4.6 Exploded view of the casting assembly in the mould in 2D using CorelDRAW and AutoCAD with full dimensions in mm

4.2 COMPUTER-AIDED DESIGN (CAD) CALCULATION OF THE PARAMETERS NEEDED TO CAST A NON-DEFECTIVE CASTING

The CAD Program to calculate the parameters needed to cast a non-defective casting has been done.

The program developed will generate automatically the following parameters needed to cast a non-defective sand casting products:

- i. Volume of the mould;
- ii. Volume of the mould cavity;
- iii. Volume of sand to fill up the mould;
- iv. Volume of molten metal needed to fill the mould;
- v. Total weight of the casting
- vi. Pouring time
- vii. Feeding efficiency;
- viii. Yield of the casting
- ix. Solidification time;
- x. Machining allowance;
- xi. Thermal contraction;
- xii. Conductive heat flow; and
- xiii. Practical value for linear shrinkage

The program developed used three different types of materials;

- i. Aluminium;
- ii. Cast Iron; and
- iii. Brass

The program is written in such a way that numerous data from different materials can be used to automatically give varied outputs and results. This is based on the mathematical model developed in Chapter Three which has already been inputted into the computer to carry out the calculation.

The result of the output of the component on the three materials used for this study is shown in Table 4.1.

The result in Table 4.1 was achieved after inputting the following dimensions:

(All dimensions are in mm).

i. Dimension of the mould

-	Length	680.00
-	Breadth	480.00
-	Height	250.00

ii. Dimension of the products/components to be cast using its features

A. **FLANGE**

-	Length of top object	160.00
-	Breadth of top object	100.00
-	Height of top object	82.00
-	Length of bottom object	100.00
-	Breadth of bottom object	56.00
-	Height of bottom object	58.00

B. BOSS

- Length of boss 80.00
- Outside diameter of boss 160.00
- Inside diameter of boss 80.00

iii. The dimensions of gating system

- Length of riser 130.00
- Diameter of riser 98.00
- Length of gate 120.00
- Diameter of gate 60.00
- Length of section thickness 70.00
- Diameter of section thickness 35.00

The display of the results of the computations can be obtained for the 3 different materials, Aluminium, Cast Iron and Brass from Fig. 4.7 shown below.

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RESULT FOR

Mould Volume	0	Cavity Volume	0	Feeding Efficiency	0
Sand Volume	0	Metal Volume	0	Solidification Time	0
Thermal allowance	0	Machine Allowance	0	Yield	0
Metal Weight	0	Pour Time	0	Heat Flow	0
		Linear Shrink	0		

Aluminum Result
Brass Result
Iron Result
Return to Main Screen

Fig. 4.7: The display of result form for the 3 different materials, Aluminium, Cast Iron and Brass.

The summary of the computer-aided design results for the three materials; Aluminium, Cast Iron, and Brass are shown in Table 4.1. The results are explained under 4.5 comparison and discussion of CAD and manual calculated results.

TABLE 4.1: SUMMARY OF THE COMPUTER-AIDED DESIGN (CAD) CALCULATED PARAMETERS NEEDED TO CAST A NON-DEFECTIVE CASTING

TYPE OF PRODUCT: FLANGE AND BOSS

Types of Materials	Total Vol. Of the mould (mm ³)	Total Vol. of the mould cavity (mm ³)	Volume of Sand (mm ³)	Total Vol. of molten metal (mm ³)	Thermal contraction (mm ²)	Machining Allowance (mm ³)	Total Weight (kg)	Pouring Time (sec)	Feeding Efficiency %	Yield of Casting %	Solidification Time (sec)	Conductive Heat Flow °C	Practical values of linear shrinkage %
Aluminium	81,600,000	4230396.793	77369603.207	4283276.753	52879.960	147916.381	11.993	21.4984	98.338	74.355	76.9128	459.558	2.10040
Cast Iron	81,600,000	4230396.793	77369603.207	4272700.761	42303.968	300071.723	30.849	34.4793	98.872	74.355	76.9128	152.297	-1.03175
Brass	81,600,000	4230396.793	77369603.207	4293852.745	63455.952	147916.381	36.498	37.5035	98.381	74.355	76.9128	673.653	1.76713

Source: From data calculated using computer programming tagged CAD/PROG II for the flange and boss components used in the study.

4.3 PRACTICAL CASE STUDY MANUFACTURING – NMT, OSOGBO

The practical case study to relate the computer-aided integrated model developed to manufacturing was carried out at the Nigeria Machine Tools (NMT) Limited, Osogbo's foundry.

NMT's jobshop foundry consists of the following facilities

- * Melting Section: This possesses the capacity for ferrous and non-ferrous castings, and in use are two 2,000kg/250Hz coreless induction furnaces (for melting from iron and plain carbon steel, a 250kg/250kW/1,000Hz capacity induction furnace (for various ranges of steel), four 200kg capacity oil-fired crucible furnace (for brass, bronze and aluminium), one 3,000kg rotary furnace and two die-casting machines (for the production of casting in lead, zinc, tin and aluminium).
- * Moulding/Core Making/Sand preparation section
- * Pattern Shop: Designed for the production and repair of patterns, pattern plates and core boxes.
- * Quality Control Session
- * Metallurgical laboratory

The facilities are backed up with two 1,250KVA power generating sets apart from the regular power from National Grid.

4.3.1 THE PATTERN DEVELOPMENT

The pattern was developed using the machines and the facilities of the NMT, Osogbo pattern shop. There are two components to be produced namely;

- Boss type; and
- Flange type

Boss Type Required

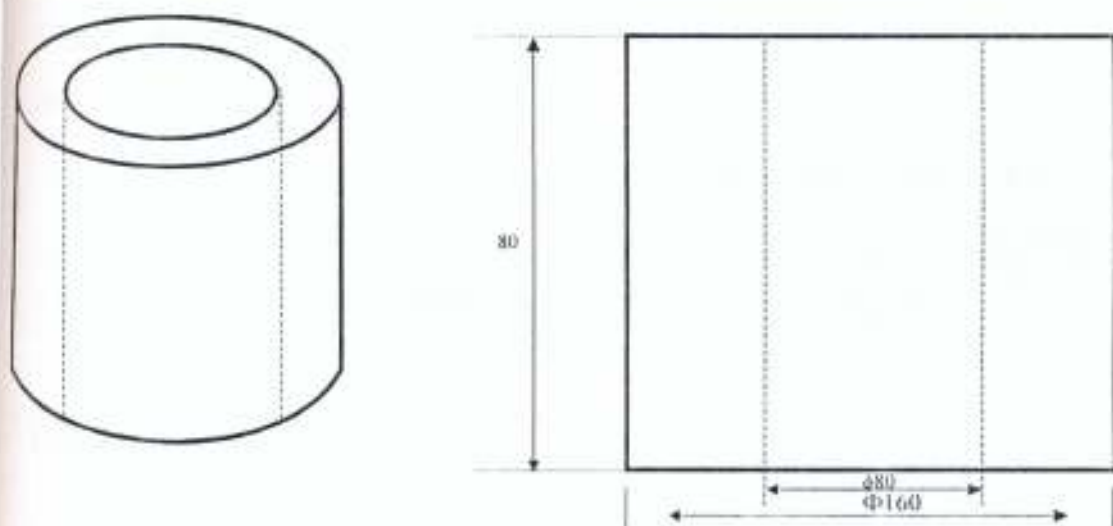


Fig. 4.8 Boss Type required for development

Flange Type Required

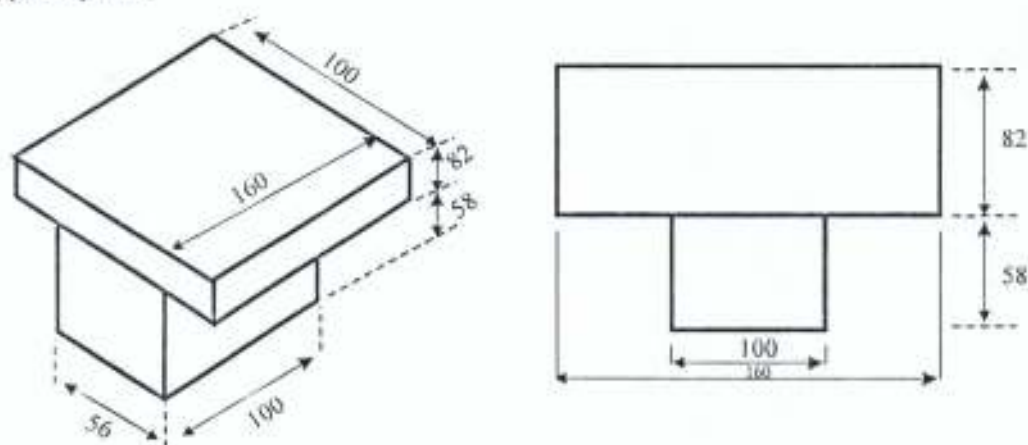


Fig. 4.9: Flange type required for development

The pattern is a mounted split patterns or cope and drag pattern plates, used in machine moulding. It has the top and bottom type plate as shown in plate 4.1 and 4.2. The runner and gates are also attached to it.

The mould is packed full of sand with the mould cavity already created. Then the assembly of the cope and drag together for pouring on the moulding machine is shown in plates 4.3 and 4.4.

The pouring of the molten metal with a crane ladle is shown in plate 4.5.

The dimensions of the pattern developed and shapes is shown in fig. 4.10 and 4.11 below. The draft taper of 2° was used.

Boss Pattern Developed

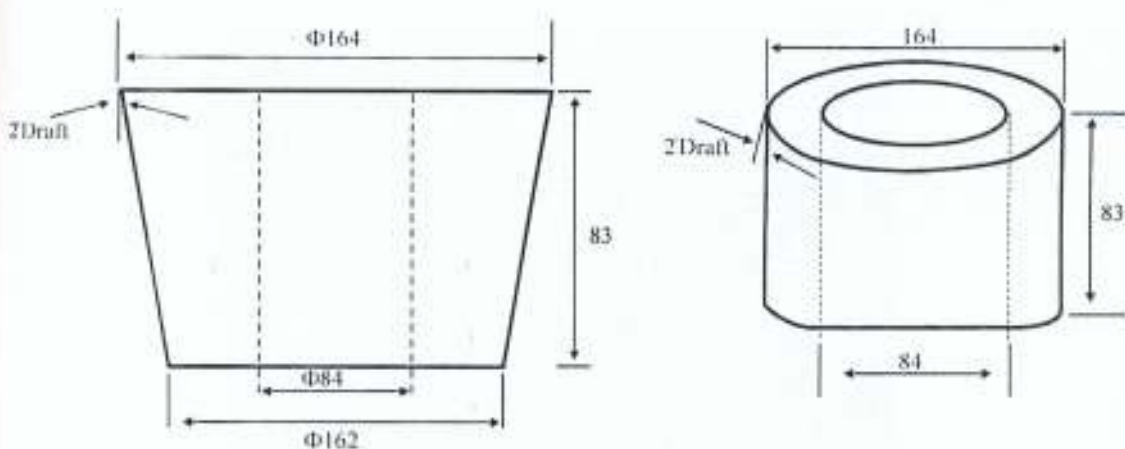


Fig. 4.10: Pattern for Boss developed

Flange Pattern Developed

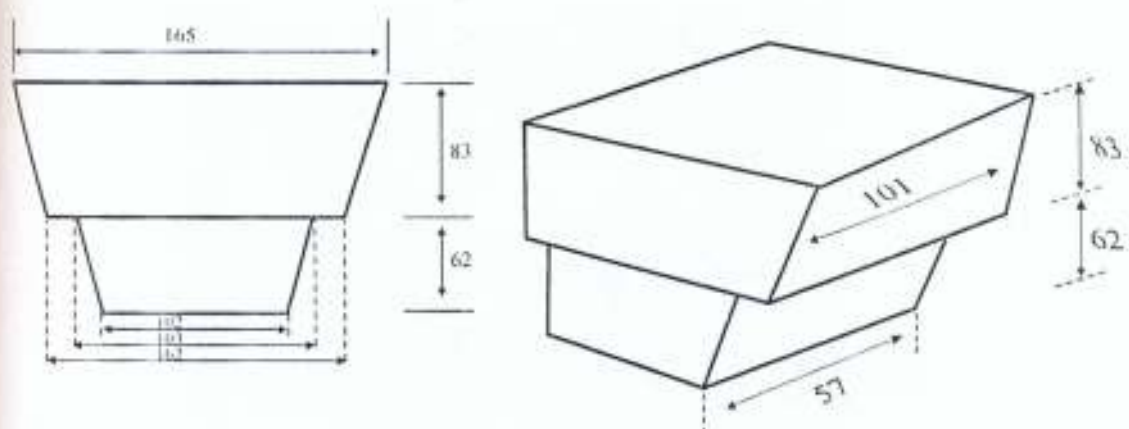


Fig. 4.11: Pattern for Flange developed



Plate 4.1: Top Pattern Developed



Plate 4.2: Bottom Pattern Developed



Plate 4.3: The Top Moulding Box filled up with sand and pattern impression



Plate 4.4: Bottom Moulding Box filled up with sand and pattern impression



Plate 4.5: The pouring of the molten metal

iii.	Mould Strength	-	90N/mm ²
iv.	Humidity (Mixture content)	-	3.0%
v.	Clay Content	-	1.5%
vi.	Shatter index	-	85
vii.	Green Compression Strength	-	112kN/m ²
viii.	Green Shear Strength	-	38kN/m ²
ix.	Dry Compression Strength	-	660kN/m ²
x.	Dry Shear Strength	-	370kN/m ²
xi.	Silica Content	-	98%
xii.	Alumina	-	1.0%
xiii.	Iron Oxide	-	1.0%
xiv.	Calcium and Magnesium Oxide	-	1.0%
xv.	Alkaline	-	0.5%
xvi.	Sintering temperature	-	1710°C

B. Composition of moulding sand used are;

Silica sand	-	83%
Bentonite	-	9%
Coal dust	-	6%
Water	-	2%

The moulding box used is made of metal steel type of 680mm length x 480mm breadth x 250mm height. See plate 4.3 and 4.4.

4.3.2.2 The Manufacturing Practical Results on the Three Materials Used – Aluminium, Cast Iron, and Brass

There are 3 major results obtained from the Manufacturing Practical carried out on the three types of materials used - Aluminium, Cast Iron, and Brass, as enumerated in Table 4.2. Other certified laboratory test on chemical composition analysis of the material used are enumerated thus;

- Aluminium

The certified laboratory test results on chemical composition analysis of aluminium used gives;

Aluminium (Al)	-	89.45%
Copper (Cu)	-	3.0%
Magnesium (Mg)	-	0.15%
Silicon (Si)	-	5.0%
Iron (Fe)	-	0.8%
Manganese (Mn)	-	0.4%
Nickel (Ni)	-	0.3%
Zinc (Zn)	-	0.5%
Lead (Pb)	-	0.1%
Tin (Sn)	-	0.1%
Titanium (Ti)	-	0.2%

Plate 4.6 shows the completed aluminium casting with the runner and riser attached. It presented the neatest casting and most accurate of all the 3 materials used. It is very light in terms of weight which prove that the CAD, Manufacturing and Manually

calculated parameters to cast a non-defective casting to be true. It presented the least of the weight 11.8kg.



Plate 4.6: Completed Aluminium Casting

- **Cast Iron**

The certified laboratory test result on chemical composition analysis of cast iron used gives;

Iron (Fe)	-	92.5%
Carbon	-	3.8%
Manganese (Mn)	-	0.5%
Silicon (Si)	-	2.4%
Phosphorus (P)	-	0.012%
Sulphur (S)	-	0.001%
Chromium (Cr)	-	0.2%
Nickel	-	0.06%
Copper (Cu)	-	0.134
Molybdenum (Mo)	-	0.101%

Vanadium (V)	-	0.005%
Titanium	-	0.008%
Aluminium (Al)	-	0.05%
Magnesium (Mg)	-	0.008%
Tin (Sn)	-	0.03%



Plate 4.7: Completed Cast Iron Casting

Plate 4.7 shows the completed cast iron casting with the runner and riser attached. It presented the roughest casting with very poor dimensional accuracy out of the 3 materials used. Its weight is closer to that of brass, but not as heavy. Heavier than that of aluminium. It has a weight of 30.5kg. The result obtained above is in line with what is obtainable from the literature about the characteristics and solidification characteristics of cast iron. It can be observed by visual inspection that there are some sand attached to the

casting products which make the surface extremely coarse. The surface finish cannot be compared with that of aluminium nor brass which presented very neat surface finish.

Brass

The certified laboratory test results on chemical composition analysis of brass used gives;

Copper (Cu)	-	88.97%
Tin (Sn)	-	10.0%
Zinc (Zn)	-	0.05%
Lead (Pb)	-	0.25%
Phosphorus (P)	-	0.50%
Nickel (Ni)	-	0.1%
Aluminium (Al)	-	0.01%
Iron (Fe)	-	0.10%
Silicon (Si)	-	0.02%

Plate 4.8 shows the completed brass casting with the runner and riser attached. It presented a neat and accurate casting but not up to that of aluminium. It has the highest weight out of the three materials used. It has a weight of 37.2kg.



Plate 4.8: Completed Brass Casting

TABLE 4.2: SUMMARY OF THE MANUFACTURING PRACTICAL CASE STUDY RESULT AT NMT, OSOGBO, NIGERIA
TYPES OF PRODUCT; FLANGE AND BOSS

Types of Materials	Total Vol. of the mould (mm ³)	Total Vol. of the mould cavity (mm ³)	Volume of Sand (mm ³)	Total Vol. of molten metal (mm ³)	Thermal contraction (mm ³)	Machining Allowance (mm ³)	Total Weight (kg)	Pouring Time (sec)	Feeding Efficiency %	Yield of Casting %	Solidification Time (sec)	Conductive Heat Flow °C	Practical values of linear shrinkage %	Solidification Temp. °C	Tempr. °C	Pouring Temp. °C
Aluminium	81,600,000	4,200,000	77,400,000	4,253,112.5	53112.5	147916.3	11.8	22	98.36	74.35	77	460.1	2.31	610	740	690
Cast Iron	81,600,000	4,200,000	77,400,000	4,242,490	42490	300071.7	30.5	30.2	98.87	74.35	77	150.3	-1.03	1200	1400	1350
Brass	81,600,000	4,200,000	77,400,000	4,283,733	63733	147916.3	37.2	33.6	98.20	74.35	77	670.6	1.76	910	1130	1030

Source: From the data collected during the practical test at NMT, Osogbo

TABLE 4.3: SUMMARY OF MANUAL CALCULATED PARAMETERS NEEDED TO CAST A NON-DEFECTIVE CASTING
TYPE OF PRODUCT: FLANGE AND BOSS

Types of Materials	Total Vol. Of the mould (mm ³)	Total Vol. of the mould cavity (mm ³)	Volume of Sand (mm ³)	Total Vol. of molten metal (mm ³)	Thermal contraction (mm ³)	Machining Allowance (mm ³)	Total Weight (kg)	Pouring Time (sec)	Feeding Efficiency %	Yield of Casting %	Solidification Time (sec)	Conductive Heat Flow °C	Practical values of linear shrinkage %
Aluminium	81,600,000	4230396.786	77369603.21	4283276.745	52879.96	147916.37	11.6534	21.19	98.36	74.348	77.012	460.095	2.3096%
Cast Iron	81,600,000	4230396.786	77369603.21	4272700.754	42303.97	300071.712	30.0568	34.033	98.36	74.35	77.012	150.2505	-1.031%
Brass	81,600,000	4230396.786	77369603.21	4293852.738	63455.95	147916.37	35.3857	36.92	98.20	74.35	77.012	670.567	1.763%

Source: From data calculated using manual (hand calculated) for flange and boss components used in the study

The summary of the computer-aided Manufacturing Practical case study results done at Nigerian Machine Tools, Osogbo is shown in Table 4.2. The practical case study obtained additional results, the solidification temperature, tapping temperature and pouring temperature, which is not in other hand or computer-aided calculated results. The results are explained under 4.5 comparison and discussion of CAD/Manufacturing and Manual calculated results.

4.4 VALIDATION OF COMPUTER-AIDED DESIGN AND MANUFACTURING (CAD/MANUFACTURING) RESULTS USING MANUAL CALCULATION

The use of manual to validate the parameters needed to cast a non-defective casting has been undertaken. The dimensions and parameters of the molten-metal used are of the three materials used in the study – Aluminium, Cast Iron and Brass. (Appendix II).

The summary of the manual calculated parameters is shown in Table 4.3. The discussion of the results obtained is done at 4.4.1 under comparison and discussion of CAD, Manufacturing and manual calculated results.

4.4.1 COMPARISON AND VALIDATION OF CAD, MANUFACTURED, AND MANUALLY CALCULATED RESULTS

In comparing and validating of the results obtained from this research, four major areas were tested thus;

- i. CADD and Manual drawing;

- ii. CAD and Manufacturing on the THREE materials used;
- iii. CAD and Manually calculated results on the THREE materials used; and
- iv. CAC and Manually calculated costing results.

The following FOUR Null hypothesis were tested in relation to the four major areas enumerated above thus;

Hypothesis I

Null hypothesis (Ho) -That the quality of the drawing used in casting industries for the production of component parts and the mould when manually drawn cannot be compared with that of computer-aided design and drafting (CADD).

Hypothesis II

Null hypothesis (Ho) -There is no significant difference between the computer-aided design (CAD) results and the manufactured results of the three materials used to cast a non-defective casting.

Hypothesis III

Null hypothesis (Ho) -There is no significant difference between the CAD results obtained and the manually calculated results of the three materials used to cast a non-defective casting.

Hypothesis IV

Null hypothesis (Ho) -There is no significant difference between the computer-aided costing and the Manually calculated costing for costing the casting products.

In discussing the results, three approaches were adopted;

- i. The use of bar chart and line graphs;
- ii. The use of manual calculation to get the correlation (r) and the coefficient of determination (r^2), from the regression analysis.
- iii. The use of computer-aided correlation (r) analysis, to estimate the functional relationship between variables. The computer program used is Microsoft frontier version 3.1 in Excel was used to analyse the results. The computer results of the correlation (r) (Table 4.4) shows a better result than the manual calculated result since the computer approximate all the decimal numbers (Table 4.5).

4.4.2 COMPARISON OF CADD AND MANUAL DRAWING

In testing the Null hypothesis 1, the production drawings of the products; flange, boss and the mould of the assembly ready for pouring the molten metal has been done using CADD programming tagged CAD PROG I in Appendix I.

The quality of the CADD drawing is better than the manual drawings used in the time past. It offers the following advantages over manual ones;

- i. The preparation of the drawings quickly and accurately (Figs. 4.1, 4.2 and 4.3);
- ii. The elimination of human errors during the use of lead, ink, vellum or maylar;
- iii. It reduces the drafting labour and cost;
- iv. It allows the evaluation of alternative designs; and
- v. It can make use of standard libraries for rapid "copy repeat".

This is in absolute agreement with our postulation in Null Hypothesis I (H_0) that the quality of the drawings used in casting industries for the production of component

parts and the mould when manually drawn cannot be compared with that of computer-aided design and drafting (CADD).

4.4.3 COMPARISON OF CAD AND MANUFACTURED RESULTS

In testing the Null hypothesis II – There is no significant difference between the CAD results of the three materials used to cast a non-defective casting. The manually calculated results on the three materials used: Aluminium, Cast iron and Brass is done (Appendix IV).

Result of Computer-Aided Manufacturing practical case study, and the computer-aided calculated parameters needed to cast a non-defective casting were compared and tabulated (Appendix IV).

The summary of the calculated CAD versus Manufacturing correlation (r) and the coefficient of determination (r^2) is as shown

- CAD versus Manufacturing results for Aluminium $r = 0.9937$ $r^2 = 0.9874$
 $= 98.74\%$
- CAD versus Manufacturing results for Cast Iron $r = 0.99981$ $r^2 = 0.9996$
 $= 99.96\%$
- CAD versus Manufacturing results for Brass $r = 0.9995$ $r^2 = 0.99904$
 $= 99.9\%$

The above result is in absolute agreement with our postulation with Null hypothesis II (H_0), that there is no significant difference between the CAD and Manufactured results of the three materials used to cast a non-defective casting. Therefore the Null hypothesis is accepted.

4.4.4 COMPARISON OF CAD AND MANUALLY CALCULATED RESULTS

In testing the Null hypothesis III – There is no significant difference between the CAD results and the manually calculated results of the three materials used to cast a non-defective casting. The manually calculated results on the three materials used: Aluminium, Cast iron and Brass is done;

Result of manually calculated parameters needed to cast a non-defective casting, and the computer-aided calculated parameters needed to cast a non-defective casting were compared and tabulated (Appendix IV).

The summary of the calculated CAD versus manually calculated results correlation (r) and the coefficient of determination (r^2) is as shown.

CAD versus manually calculated results for Aluminium	$r = 0.98567$ $r^2 = 0.97172$ $= 97.17\%$
CAD versus manually calculated results for Cast Iron	$r = 0.9981$ $r^2 = 0.9962$ $= 99.62\%$
CAD versus manually calculated results for Brass	$r = 0.9990$ $r^2 = 0.9981$ $= 99.8\%$

The above result is in absolute agreement with our postulation with Null hypothesis III (Ho) – that there is no significant difference between the CAD results and the long-hand calculated results of the three materials used to cast a non-defective casting. Therefore, from the above results of 97.17%, 99.62%, and 99.8% it has a super fit and so, the Null hypothesis is accepted

4.4.5 COMPARISON OF CAD, MANUFACTURED AND MANUALLY CALCULATED RESULTS – USING COMPUTER CORRELATION (r) MATRIX AND LINE GRAPHS

In order to further study the relationship among the variables, and to confirm the manually calculated correlation (r) used to measure the linear correlation, and the coefficient of determination (r^2), a correlation matrix is used. This is developed with the aid of computer, using Microsoft Frontier Version 3.1 in Excel to generate the correlation matrix in Table 4.5. It indicates the coefficient of correlation between each pair of variables. Table 4.4 shows the summary of CAD, Manufacturing and manually calculated results parameters used to generate the correlation matrix for CAD, Manufacturing and manual calculated shown in Table 4.5. The computer calculated results is as shown below thus;

- i. CAD versus Manufactured results for Aluminium $r = 1$

$$r^2 = 1 = 100\%$$

- ii. CAD versus Manufactured results for Cast Iron $r = 0.999999$

$$r^2 = 0.999999 = 99.99\%$$

iii. CAD versus Manufactured results for Brass $r = 1$

$$r^2 = 1 = 100\%$$

iv. CAD versus Manual calculated results for Aluminium $r = 1$

$$r^2 = 1 = 100\%$$

v. CAD versus Manual calculated results for Cast Iron $r = 0.99999$

$$r^2 = 0.999999 = 99.99\%$$

vi. CAD versus Manual calculated results for Brass $r = 1$

$$r^2 = 1 = 100\%$$

Table 4.4: Summary of the CAD, Manufactured and Manually Calculated Results

CAD			MANUFACTURED			MANUALLY CALCULATED		
Alumini.	Cast Iron	Brass	Alumini.	Cast Iron	Brass	Alumini.	Cast Iron	Brass
8160000	81600000	81600000	81600000	81600000	81600000	81600000	81600000	81600000
4230397	4230397	4230397	4200000	4200000	4200000	4230397	4230397	4230397
77369603	77369603	77369603	77400000	77400000	77400000	77369603	77369603	77369603
4272701	4272701	4293853	4253113	4242490	4263735	4283277	4272701	4293853
63455.95	42303.97	63455.95	53112.5	42490	63735	52879.96	42303.97	63455.95
147916.4	300071.7	147916.4	147916.4	300071.7	147916.4	147916.4	300071.7	147916.4
30.849	30.849	36.498	11.8	30.5	37.2	11.6534	30.0568	35.3857
34.4793	34.4793	37.5035	22	30.2	33.6	21.019	34.033	36.92
98.872	98.872	98.381	98.36	98.87	98.2	98.36	98.36	98.2
74.355	74.355	74.355	74.35	74.35	74.35	74.348	74.35	74.35
76.9128	76.9128	76.9128	77	77	77	77.012	77.012	77.012
152.279	152.279	673.653	460.1	150.3	670.6	460.095	150.2505	670.567
-1.03175	-1.03175	1.76713	2.31	-1.03	1.76	2.3039	-1.031	1.763



Table 4.5: Summary of the CAD, Manufactured and Manually Calculated Computer-aided Correlation (r) Matrix

	CAD			MANUFACTURED			MANUALLY CALCULATED		
	Alumini.	Cast Iron	Brass	Alumini.	Cast Iron	Brass	Alumini.	Cast Iron	Brass
Alumini.	1								
Cast Iron	0.999999	1							
Brass	1	0.999999	1						
Alumini.	1	0.999999	1	1					
Cast Iron	0.999999	1	0.999999	0.999999	1				
Brass	1	0.999999	1	1	0.999999	1			
Alumini.	1	0.999999	1	1	0.999999	1	1		
Cast Iron	0.999999	1	0.999999	0.999999	1	0.999999	0.999999	1	
Brass	1	0.999999	1	1	0.999999	1	1	0.999999	1

Table 4.6: Manual Cost Estimation for Boss using Manually Calculated Approach

Type of Product	Material	Weight (kg)	PDMc (₦ /kg)	PTc (₦ /kg)	TDMc (₦ /kg)	CFc (₦ /kg)	PC _{ij} (₦ /kg)	PC _{ij} (₦ /Unit)
BOSS	Aluminium	3.3778	136.40	46.05	182.45	9.98	220.00	743.12
	Cast Iron	8.71	23.41	12.15	35.56	2.633	58.06	505.70
	Brass	10.254	136.95	46.22	183.17	10.01	220.08	2,264.08
	Total	22.342	296.75	104.42	401.18	22.623	498.14	3,512.9

Source: From data calculated using manually calculated for boss component used in the study.

Table 4.7: Summary of Manually Cost Estimation (Production Cost) for Flange using Three Different Materials

Type of Product	Material	Weight (kg)	PDMc (₦ /kg)	PTc (₦ /kg)	TDMc (₦ /kg)	CFc (₦ /kg)	PC _{ij} (₦ /kg)	PC _{ij} (₦ /Unit)
FLANGE	Aluminium	4.08	136.40	46.05	182.45	9.98	220.00	897.60
	Cast Iron	11.818	23.41	12.15	35.56	2.633	58.06	686.15
	Brass	13.9128	136.95	46.22	183.17	10.01	220.80	3,071.95
	Total	29.8109	296.75	104.42	401.18	22.623	498.86	4,655.7

4.5 COMPARISON OF MANUALLY CALCULATED COSTING WITH COMPUTER-AIDED CALCULATED COSTING

In analysing the results of the research findings on computer-aided costing (CAC) of sand casting products, two approaches were used.

- Manual calculated approach – (Manual costing of sand casting products)

- ii. Computer-aided calculated approach – Using the model developed in Chapter three.

Three types of materials, Aluminium, Cast Iron and Brass were used for the cost estimation of Boss and Flange each. Making six samples in all (i.e 3 samples for Boss and 3 samples for Flange) (Appendix V).

4.5.1 MANUAL COST-ESTIMATION FOR BOSS AND FLANGE

The summary of the manual cost-estimation for Boss (Table 4.6) and Flange (Table 4.7) using Manual calculated approach was done (Appendix V).

The detailed comparison of the result with that of Computer-Aided-Costing (CAC) was done in 4.5.3.

The dimensions and parameters of the molten metal used are of the three materials used in the study – Aluminium, Cast Iron and Brass.

4.5.2 COMPUTER-AIDED COSTING (CAC) OF SAND CASTING PRODUCTS (BOSS AND FLANGE)

The use of computer-aided costing (CAC) tagged CAD, PROG III Appendix III is done to calculate the parameters needed to cost sand casting products.

The dimensions and parameters of the molten metal used are of the three materials used in the study – Aluminium, Cast Iron and Brass. After inputting the following dimensions for each of the material Flange and Boss, it will calculate the production cost of each of item thus;

- Weight of Brass for Boss

- Lining material cost/kg (N/kg)
- Moulding material cost/kg (N/kg)
- Fettling material cost/kg (N/kg)
- Liquid Charge cost/kg (N/kg)
- Thermotip cost/kg (N/kg)
- Direct expenses cost/kg (N/kg)
- Direct labour cost/kg (N/kg)

It will automatically calculate the following

- Partial Direct Material Cost (PDMc)
- Pattern Cost (PTc)
- Total Direct Material Cost (TDMc)
- Complexity Cost (CFc)
- Production Cost

The output of the computer-aided costing table for sand casting products (Boss and Flange) is as shown in Table 4.8.

**Table 4.8:- OUTPUT FOR COMPUTER AIDED COSTING OF SAND CASTING
PRODUCTS (BOSS AND FLANGE)**

	Boss Aluminium	Boss Cast Iron	Boss Brass	Flange Aluminium	Flange Cast Iron	Flange Brass
Weight (kg)	3.37780	8.71000	10.25400	4.08000	11.81800	13.91280
Lining (N/kg)	0.80000	0.80000	0.80000	0.80000	0.80000	0.80000
Mould (N/kg)	12.02000	12.02000	12.02000	12.02000	12.02000	12.02000
Liquid Charge (N/kg)	120.25000	7.26000	120.80000	120.25000	7.26000	120.80000
Dir. Exp. (N/kg)	3.50000	3.50000	3.50000	3.50000	3.50000	3.50000
Fettling (N/kg)	2.63000	2.63000	2.63000	2.63000	2.63000	2.63000
Dir. Labour (N/kg)	13.60000	13.60000	13.60000	13.60000	13.60000	13.60000
Pattern (N/kg)	46.05000	12.15300	46.21500	46.05000	12.15300	46.21500
Dir. Material (N/kg)	182.45000	35.56300	183.16500	182.45000	35.56300	183.16500
Production Cost/Unit (N/kg)	743.12909	505.71094	2,264.00283	897.61581	686.16440	3,071.83720

Source: From data calculated using Computer-aided for Boss and Flange of the component used in the study.

4.5.3 COMPARISON OF CAC AND MANUAL CALCULATED RESULTS

In testing the Null hypothesis IV – “There is no significant difference between the computer-aided costing and the manual hand calculated costing for costing the casting products” the long-hand calculated results on the three materials used; Aluminium, Cast Iron, and Brass has been done.

Results of Manual Cost Estimation of Sand Casting Products (Boss and Flange) Method, and the Computer Aided Costing of Sand Casting Products (Boss and Flange) Method results were compared and tabulated as follows.

Table 4.9: Summary of Manual and Computer Costing for Boss and Flange

Type of Product	Weight (kg)	Manual Cost (Production ₦ /Unit)	Computer Aided Cost Result (Production ₦/Unit)	Difference
Boss Aluminium	3.37780	743.12000	743.12909	0.00909
Boss Cast Iron	8.71000	505.70000	505.71094	0.01094
Boss Brass	10.25400	2,264.08000	2,264.00283	0.07717
Flange Aluminium	4.08000	897.60000	897.61581	0.01581
Flange Cast Iron	11.81800	686.15000	686.16440	0.01440
Flange Brass	13.91280	3,071.95000	3,071.83720	0.11280

Source: From data calculated using manual and computer-aided for flange and boss component used in the study.

From the Table 4.9, it is observed that the differences in the manual costing method and that of computer-aided costing method developed is very negligible; hence one can rely on computer-aided costing developed for costing the casting products totally and that the Null hypothesis is accepted.

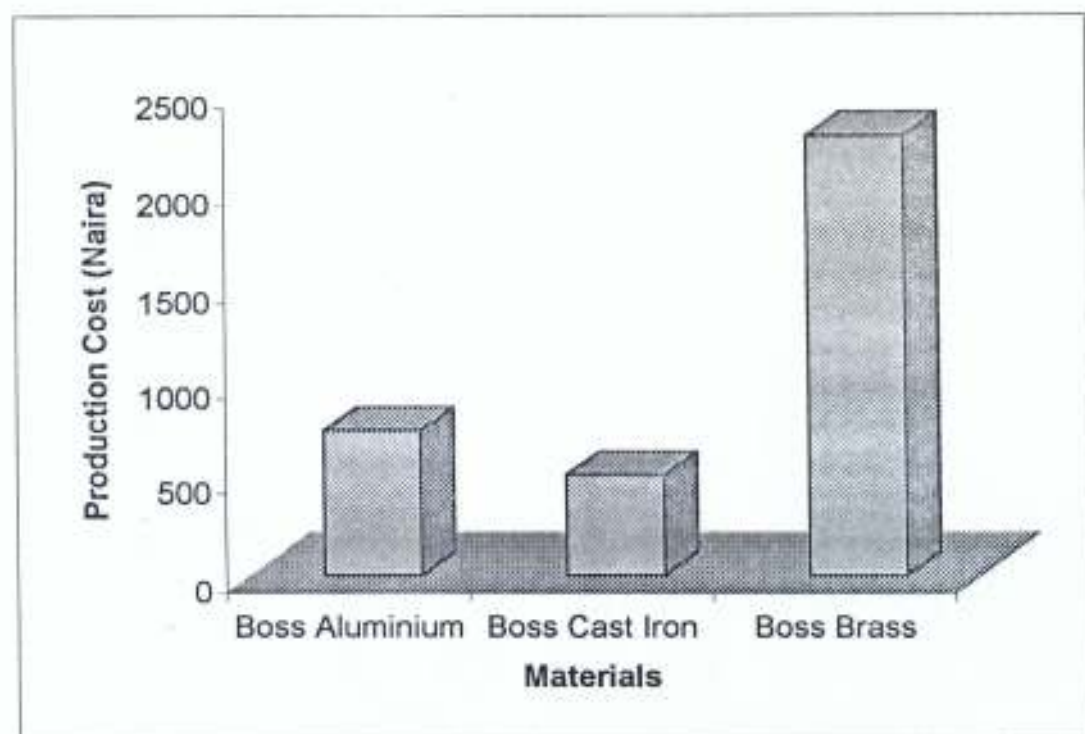


Fig. 4.13: Relationship Between Production Cost For Boss Materials

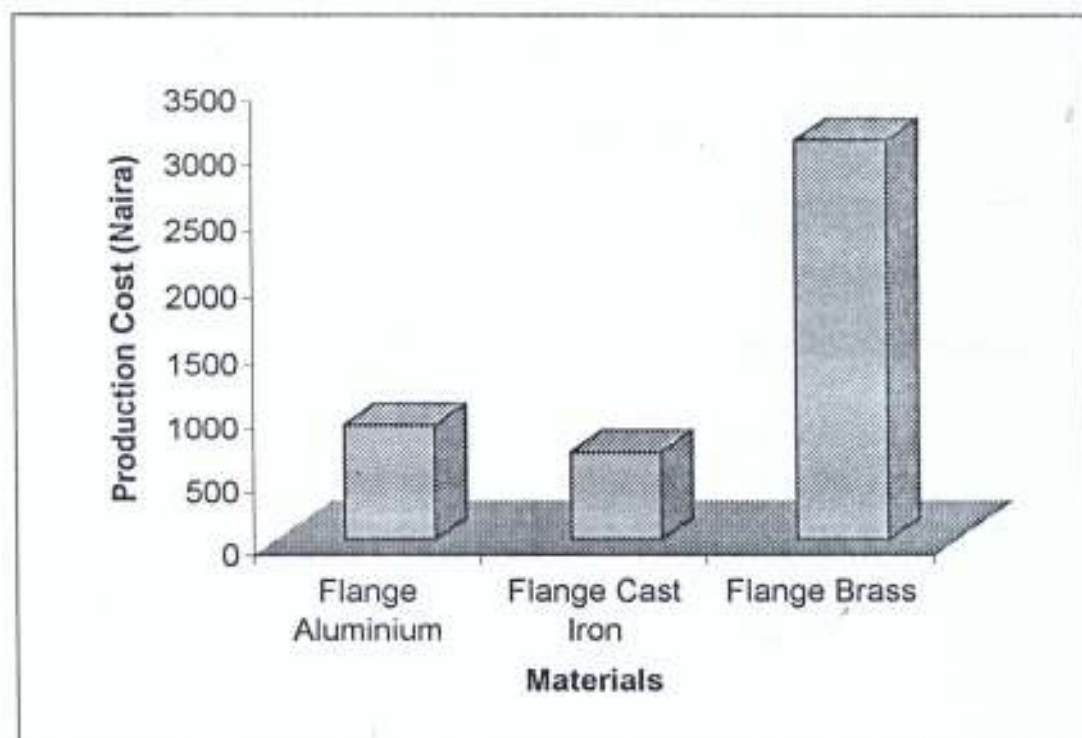


Fig. 4.14: Relationship Between Production Cost For Flange Materials

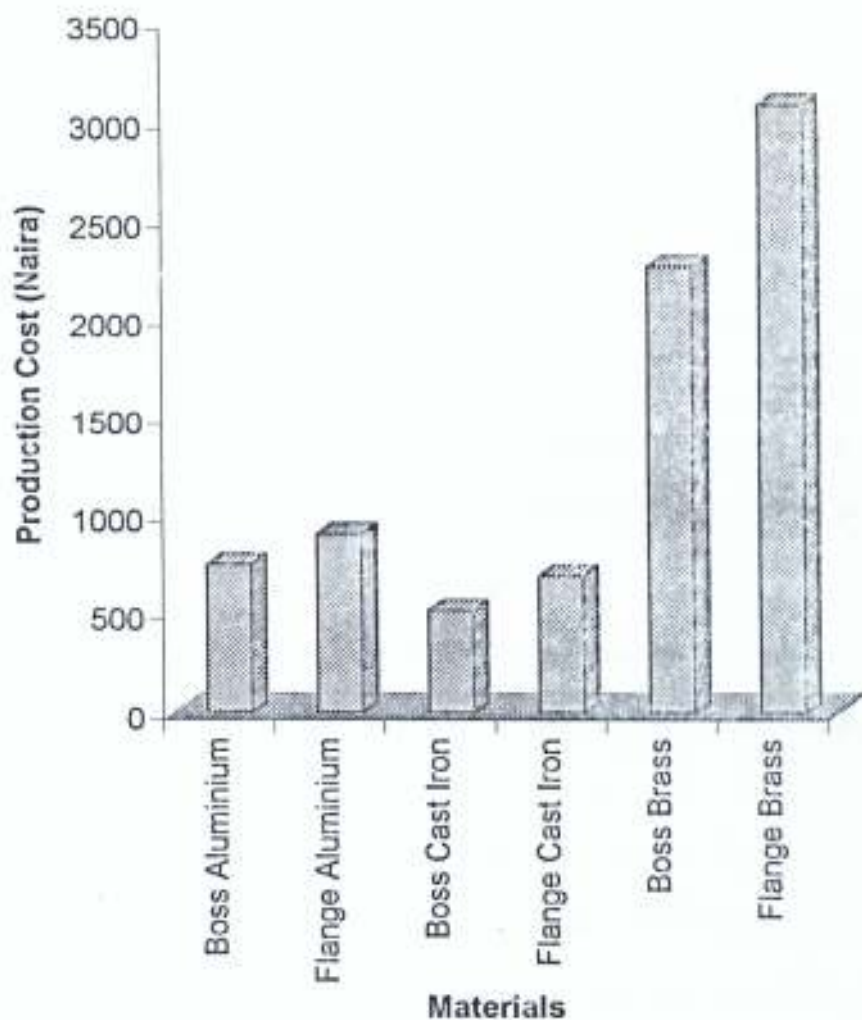


Fig. 4.15: Relationship Between Production Cost For Boss and Flange Materials

Also the calculation of the correlation coefficient (r) which is 0.999996 and the coefficient determination (r^2), which is 0.999996, show that it has 99.9%. (Appendix v).

The model and the program developed agreed with what is obtainable in the industry and it is reliable. Therefore, it is recommended for costing any cast finished products.

Fig. 4.13 shows the relationship between the production cost for the three materials used for boss. Aluminium has ₦743.12 which is 21.15%, Cast Iron ₦505.70 with 14.395%; and Brass ₦2,264.08 which represented 64.45%.

Fig. 4.14 shows the relationship between the production cost for the three materials used for flange. Aluminium has ₦897.62 which is 19.28%; Cast Iron ₦686.16 with 14.738%; and Brass ₦3,071.84 which represented 65.97%

Fig. 4.15 shows the relationship between the production cost for the three materials producing both boss and flange; Aluminium has ₦1,640.74 which is 20.08% of the total cost; Cast Iron has ₦1,191.88 with 14.59% of the total cost; and brass has the highest cost with ₦5,335.84 which is 65.32%.

It is a consistent tool which enable the Production Planning Manager to know the cost of a material before production starts.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The purpose of this research project is aimed at modelling An Integrated CAD/Manufacturing process of sand casting and costing the cast products. The shape changes that are required to effect feeding which occurs due to thermal contraction and solidification during casting process need to be standardized.

In this research project, a suitable program tagged CAD/PROG 1 (Appendix 1) was developed using Visual Basic Language, which automatically generate drawings in 2 dimensions and 3 dimensions of both;

- The part to be cast (CADD) for;
Boss in 2D and 3D
Flange in 2D and 3D
- The part to be cast in position in the moulding box ready for pouring (Manufacturing) for; flange and boss in 2D exploded view.

The drawings produced by computer called Computer-Aided Design and Drafting (CADD); obtained a better result than the manually prepared drawing used in the time past, thus improving the way things are done. Therefore, the program developed is aimed at enabling casting drawings to be produced automatically from CAD inputs.

A CAD Flowchart (Fig. 3.1) and general scheme of Integrated CAD systems Database for sand casting (Fig. 3.17) were also developed which dictated the computer sequence of operation to generate automatically the necessary parameters needed to cast a

non-defective casting such as; volume of the mould; volume of sand; volume of mould cavity; volume of molten metal, pouring time; thermal contraction; feeding efficiency; machining allowance; freezing ratio; solidification time; the practical value of linear shrinkage; conductive heat flow; and the yield of casting for the three materials used; Aluminium, Cast Iron; and Brass.

A model and computer program tagged CAD/PROG III for costing, called computer-aided costing (CAC) of sand caste products, which automatically calculate the cost of producing a sand casting products was developed.

Real component production was carried out at the Nigerian Machine Tools, Osogbo to validate both the computer programs and models developed for production process and costing of sand cast products.

From the results of the research findings obtained so far, therefore; the Computer-Aided Design (CAD) models and programs used for process planning of the three different materials used for casting non-defective casting are effective. The actual production of real components and the Computer-Aided Costing models, and programs developed; can be used effectively in the sand casting industries; higher institutions; developing and developed countries as an integrated CAD tool for sand casting operations.

The tool developed provides;

- i. A standardized method of producing products devoid of defects;
- ii. A material that will have less failure when put into use; allowing the production of durable materials.

- iii. The CAD integration programs and flowchart adaptable to various production processes, so that automatic drawings can be produced for the products.
- iv. Quick and faster production of products, thereby reducing capital often tied up in inventories and work in progress. This is achieved by the reduction in the preparatory activities time prior to actual casting.
- v. A valuable and consistent tool for design, drafting, and manufacture for foundry engineers to facilitate their design of various production processes.
- vi. The preparation of the drawings quickly and accurately.
- vii. Supply of automatic result on the material needed; thermal contraction; pouring time; solidification time; volume of molten metal needed; volume of sand needed; volume of mould cavity; feeding efficiency; practical value of linear shrinkage; conductive heat flow and the yield of casting on the three materials used; Aluminium, Cast Iron, and Brass and any other materials, when the data of such material is inserted into the program.
- viii. The availability of production cost of a product automatically using the weight of the material as a base, which enable the process planning personnel to have a quick and automatic value of the worth of their products before the production begins.
- ix. A less expensive method (cost saving), and a systematic approach to problem solving in casting industry. The use of computer saves time and overhead cost and drudgery of manual calculations used in the time past.

Finally, the research project is an improvement on the images of casting industries in developing countries like Nigeria and a challenge for a better improvement of the present level of development of casting industries by the introduction of micro processor

computer into their day-to-day activities, which is not yet common in the casting industry in Nigeria; most especially the production of sand casting products.

5.2 RECOMMENDATIONS AND SUGGESTION FOR FURTHER WORK

Based on the findings from this research, certain recommendations become imperative. It is hoped that the implementation of these recommendation will assist Nigeria's foundry industries; design and drafting engineers; metallurgical and foundry engineers; manufacturing and production engineers and process engineers in their skill and the development of Nigeria. There are some limitations encountered when carrying out the research. This will form the basis of the recommendation stated below.

It is hereby recommended that;

- i. Further research should still be conducted into the area of micro-structural predictions. There is no machine which can be used to monitor the solidification process. Only the temperature can be measured.
- ii. Further research should be conducted in the area of heat transfer and reaction between the solid mould surface and the molten metal poured into the mould (either metal mould or sand mould). The development or purchase of the necessary equipment and machine to measure the reaction of the heat transfer will eliminate completely the inability of the researcher to go deep into this area of study.
- iii. The limitation in the area of testing the finished cast products can also be further investigated. The only two available means, which of course, is part of inspection procedures are; (i) visual inspection or examination of defect. Defects or the surface quality on the surfaces of the castings (ii) the second type of inspection carried out is the

dimensional inspection. The others like physical, metallurgical and chemical tests; and testing of mechanical properties (destructive and semi-destructive tests) and non-destructive tests could not be carried out to allow for physical inspection of the casting material during the project defence.

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```

REM APPENDIX I CAD PROG I
REM COMPUTER-AIDED DESIGN (CAD) OF SAND CASTING OPERATIONS USED
REM TO GENERATE THE PART TO BE CAST IN POSITION IN THE MOULDING BOX
REM FOR FLANGE AND BOSS IN 2D AND 3D

```

```

Rem SUBROUTINE TO DRAW

```

```

Private Sub About_Click()

```

```

MsgBox ("This program was designed by Engineer S. B. Adejuyigbe and developed by Engineer  
K. E. Alowolodu, AKEF Systems, Box 3224, Tel. 034-243078, 243328 Akure. Nigeria")

```

```

End Sub

```

```

Private Sub Boss_Click()

```

```

Form2.Show

```

```

Form2.Shape1.Height = 20 * Val(Form1.hboss.Text)

```

```

Form2.Shape1.Width = 20 * Val(Form1.outboss.Text)

```

```

Form2.Shape2.Height = 20 * Val(Form1.hboss.Text)

```

```

Form2.Shape2.Width = 20 * Val(Form1.inboss.Text)

```

```

a = Form2.Shape1.Left

```

```

Form2.Shape2.Left = a + 20 * (Val(Form1.outboss.Text) - Val(Form1.inboss.Text)) / 2

```

```

Form2.Shape3.Height = 20 * Val(Form1.hboss.Text)

```

```

Form2.Shape3.Width = 20 * Val(Form1.outboss.Text)

```

```

Form2.Shape4.Width = 20 * Val(Form1.outboss.Text)

```

```

Form2.Shape3.Top = Form2.Shape2.Top

```

```

Form2.Shape4.Top = Form2.Shape3.Top - Form2.Shape4.Height / 2.5

```

```

Form2.Shape3.Left = a + Form2.Shape1.Width + 400

```

```

Form2.Shape4.Left = Form2.Shape3.Left

```

```

Form2.Shape5.Width = 20 * Val(Form1.inboss.Text)

```

```

Form2.Shape5.Left = Form2.Shape3.Left + (Form2.Shape3.Width - Form2.Shape2.Width) / 2

```

```

Form2.Shape5.Top = Form2.Shape3.Top - Form2.Shape5.Height / 2.5

```

```

End Sub

```

```

Private Sub close_Click()

```

```

End

```

```

End Sub

```

```

Private Sub Command1_Click()

```

```

Form2.Show

```

```

Form2.Shape1.Height = 20 * Val(Form1.hboss.Text)

```

```

Form2.Shape1.Width = 20 * Val(Form1.outboss.Text)

```

```

Form2.Shape2.Height = 20 * Val(Form1.hboss.Text)

```

```

Form2.Shape2.Width = 20 * Val(Form1.inboss.Text)

```

```

a = Form2.Shape1.Left

```

```

Form2.Shape2.Left = a + 20 * (Val(Form1.outboss.Text) - Val(Form1.inboss.Text)) / 2

```

```

Form2.Shape3.Height = 20 * Val(Form1.hboss.Text)

```

```

Form2.Shape3.Width = 20 * Val(Form1.outboss.Text)

```

```

Form2.Shape4.Width = 20 * Val(Form1.outboss.Text)

```

```

Form2.Shape3.Top = Form2.Shape2.Top

```

```

Form2.Shape4.Top = Form2.Shape3.Top - Form2.Shape4.Height / 2.5

```

```

Form2.Shape3.Left = a + Form2.Shape1.Width + 400

```

```

Form2.Shape4.Left = Form2.Shape3.Left

```

```

Form2.Shape5.Width = 20 * Val(Form1.inboss.Text)
Form2.Shape5.Left = Form2.Shape3.Left + (Form2.Shape3.Width - Form2.Shape2.Width) / 2

Form2.Shape5.Top = Form2.Shape3.Top - Form2.Shape5.Height / 2.5

End Sub

Private Sub Command2_Click()
Form3.Show
Form3.Shape3.Height = Val(htop.Text) * 20
Form3.Shape3.Width = Val(wtop.Text) * 20
Form3.Shape2.Height = Val(hbottom.Text) * 20
Form3.Shape2.Width = Val(wbottom.Text) * 20
d = Form3.Shape3.Left
e = Form3.Shape3.Top
Form3.Shape2.Top = e + Form3.Shape3.Height
Form3.Shape2.Left = (Form3.Shape3.Width - Form3.Shape2.Width) / 2 + d
Form3.Shape1.Height = Val(htop.Text) * 20
Form3.Shape1.Width = Val(wtop.Text) * 20
a = Form3.Shape1.Top
b = Form3.Shape1.Left
Form3.line2.X1 = b
Form3.line2.Y1 = a
Form3.line2.Y2 = Form3.line2.Y1 + Val(Form1.ltop.Text) * 20 * Sin(60)
Form3.line2.X2 = Form3.line2.X1 + Val(Form1.ltop.Text) * 20 * Cos(60)
Form3.line1.X1 = Form3.line2.X2
Form3.line1.Y1 = Form3.line2.Y2
Form3.line1.X2 = Form3.line1.X1 + Form3.Shape1.Width
Form3.line1.Y2 = Form3.line1.Y1
Form3.line3.X1 = Form3.line1.X2
Form3.line3.Y1 = Form3.line1.Y2
Form3.line3.X2 = b + Form3.Shape1.Width
Form3.line3.Y2 = a
Form3.Line5.X1 = Form3.line1.X1
Form3.Line5.Y1 = Form3.line1.Y1
Form3.Line5.X2 = Form3.Line5.X1
Form3.Line5.Y2 = Form3.Line5.Y1 + Form3.Shape1.Height
Form3.Line4.X1 = Form3.Line5.X2
Form3.Line4.Y1 = Form3.Line5.Y2
Form3.Line4.X2 = b
Form3.Line4.Y2 = a + Val(Form1.htop.Text) * 20
d = Form3.Shape1.Left
e = Form3.Shape1.Top
Form3.Shape4.Height = Val(hbottom.Text) * 20
Form3.Shape4.Width = Val(wbottom.Text) * 20
Form3.Shape4.Top = e + Form3.Shape1.Height
Form3.Shape4.Left = (Form3.Shape1.Width - Form3.Shape4.Width) / 2 + d
a = Form3.Shape4.Left
b = Form3.Shape4.Top + Form3.Shape4.Height
Form3.Line6.X1 = a
Form3.Line6.Y1 = b

```

```

Form3.Line6.Y2 = b + Val(Form1.lbottom.Text) * 20 * Sin(60)
Form3.Line6.X2 = a + Val(Form1.lbottom.Text) * 20 * Cos(60)
Form3.Line7.X1 = Form3.Line6.X2
Form3.Line7.Y1 = Form3.Line6.Y2
Form3.Line7.X2 = Form3.Line7.X1
Form3.Line7.Y2 = Form3.Line7.Y1 - Form3.Shape4.Height + (Form3.Shape1.Width -
Form3.Shape4.Width) / 2 * Tan(60)
Form3.Line7.ZOrder 1
l = Val(ltop.Text) * 20
h = Val(htop.Text) * 20
w = Val(wtop.Text) * 20

```

```
End Sub
```

```

Private Sub Command3_Click()
Form5.Show
End Sub

```

```

Private Sub Command4_Click()
Form4.Show
End Sub

```

```

Private Sub Flange_Click()
Form3.Show
End Sub

```

```

Private Sub Form_Load()
splash.Show
d = Timer
Do While Timer < d + 5
DoEvents
Loop
Form1.Show
Unload splash

```

```
End Sub
```

```

Private Sub Mould_Click()
Form5.Show

End Sub

```

```

Private Sub Result_Click()
Form4.Show
End Sub

```

Rem APPENDIX II: CAD PROG II

Rem COMPUTER AIDED DESIGN (CAD) PROGRAM TO CALCULATE THE PARAMETERS NEEDED TO CAST

Rem A NON-DEFECTIVE CASTING FOR BOSS AND FLANGE USING ALUMINIUM, BRASS AND CAST IRON

Sub calculat()

lm = Val(Form1.lmould.Text)

hm = Val(Form1.hmould.Text)

wm = Val(Form1.wmould.Text)

mouldv = lm * hm * wm

mouldvolume = mouldv

ht = Val(Form1.htop.Text)

lt = Val(Form1.ltop.Text)

wt = Val(Form1.wtop.Text)

topflange = ht * lt * wt

irontopflange = (ht + 3) * (lt + 3) * (wt + 3)

alumentopflange = (ht + 1.5) * (lt + 1.5) * (wt + 1.5)

hb = Val(Form1.hbottom.Text)

lb = Val(Form1.lbottom.Text)

wb = Val(Form1.wbottom.Text)

bflange = hb * lb * wb

ironbflange = (hb + 3) * (lb + 3) * (wb + 3)

alumbflange = (hb + 1.5) * (lb + 1.5) * (wb + 1.5)

flangev = topflange + bflange

flangevolume = flangev

ironvflange = irontopflange + ironbflange

alumnvflange = alumentopflange + alumbflange

bossv = 22 / 7 * Val(Form1.hboss.Text) * ((Val(Form1.outboss.Text)) ^ 2 -

-(Val(Form1.inboss.Text)) ^ 2) / 4

bossvolume = bossv

ironvboss = 22 / 7 * Val(Form1.hboss.Text + 3) * ((Val(Form1.outboss.Text + 3)) ^ 2 -

-(Val(Form1.inboss.Text + 3)) ^ 2) / 4

alumnvboss = 22 / 7 * Val(Form1.hboss.Text + 1.5) * ((Val(Form1.outboss.Text + 1.5)) ^ 2 -

-(Val(Form1.inboss.Text + 1.5)) ^ 2) / 4

riserv = 22 / (4 * 7) * Val(Form1.lriser.Text) * Val(Form1.driser.Text) ^ 2

riservvolume = riserv

gatev = 22 / (4 * 7) * Val(Form1.lgate.Text) * Val(Form1.dgate.Text) ^ 2

gatevolume = gatev

sectionvolume = 22 / (4 * 7) * Val(Form1.lsection.Text) * Val(Form1.dsection.Text) ^ 2

cavityv = flangev + bossv + riserv + gatev + sectionv

cavityvolume = cavityv

ironmachine = (ironvflange + ironvboss - flangev - bossv)

alummachine = (alumnvflange + alumnvboss - flangev - bossv)

brassmachine = alummachine

ironthermal = (ironvflange + ironvboss + riserv + gatev + sectionv - ironmachine) * 0.01

alumthermal = (alumnvflange + alumnvboss + riserv + gatev + sectionv - alummachine) * 0.0125

brassthermal = (alumnvflange + alumnvboss + riserv + gatev + sectionv - brassmachine) * 0.015

sandv = mouldv - cavityv

sandvolume = sandv

ironvmetal = cavityv + ironthermal

alumvmetal = cavityv + alumthermal

brassvmetal = cavityv + brassthermal

irondensity = 0.00000722

alumdensity = 0.0000028

brassdensity = 0.0000085

```

ironmass = irondensity * ironvmetal
alummass = alumdensity * alumvmetal
brassmass = brassdensity * brassvmetal
sect = Val(Form1.lsection.Text)
lsection = Val(Form1.lsection.Text) * 22 / 7 * (Val(Form1.dsection.Text))
lsectionvolume = vsection
irontime = (1.41 + lsection / 14.59) * Sqr(ironmass)
alvertime = (1.11 + lsection / 14.59) * Sqr(alummass)
brassime = (1.41 + lsection / 14.59) * Sqr(brassmass)
ironriserweight = riserv * irondensity
alumriserweight = riserv * alumdensity
brassriserweight = riserv * brassdensity
ironefficiency = 7 / ironriserweight
alumefficiency = 2.7 / alumriserweight
brassefficiency = 8.7 / ironriserweight
yield = (flangev + bossv) / (flangev + bossv + riserv)
ironspecific = 1.22
alumspecific = 2.287
brassspecific = 0.0909
ironlatent = 65
alumlatent = 92.7
brasslatent = 43
irondiffuse = 0.0825
alumdifffuse = 0.645
brassdiffuse = 0.6
ironpour = 1350
alumpour = 690
brasspour = 1030
ironheat = irondiffuse * ironpour + ironlatent / (irondensity * 10 ^ 6 * ironspecific)
alumheat = alumdifffuse * alumpour + alumlatent / (alumdensity * 10 ^ 6 * alumspecific)
brassheat = brassdiffuse * brasspour + brasslatent / (brassdensity * 10 ^ 6 * brassspecific)
ironconduct = 0.901
alumconduct = 0.612
brassconduct = 0.41
ipatfop = 165
ipatfbot = 103
ipatboss = 83
lcastfironfop = 165
lcastfironfbot = 105
lcastfalumfop = 162
lcastfalumfbot = 101
lcastfbrassfop = 162
lcastfbrassfbot = 102
lcastbiron = 84
lcastbalum = 81
lcastbbrass = 11
ironshrink = ((lpatfop - lcastfironfop) / lcastfironfop _
+ (lpatfbot - lcastfironfbot) / lcastfironfbot _
+ (lpatboss - lcastbiron) / lcastbiron) / 3
alumshrink = ((lpatfop - lcastfalumfop) / lcastfalumfop _
+ (lpatfbot - lcastfalumfbot) / lcastfalumfbot _
+ (lpatboss - lcastbalum) / lcastbalum) / 3
brassshrink = ((lpatfop - lcastfbrassfop) / lcastfbrassfop _
+ (lpatfbot - lcastfbrassfbot) / lcastfbrassfbot _
+ (lpatboss - lcastbbrass) / lcastbbrass) / 3
totalarea = 2 * it * wt + 2 * ht + wt + 2 * lt * ht + 2 * hb * wb + 2 * lb * hb + 2 * lb * wb _

```

```

+22 / 7 * outbo * (hbo + outbo / 2) - 22 / 7 * inbo * (hbo + inbo / 2) + 22 / 7 * dg * (lg + dg / 2) _
+22 / 7 * dr * (lr + dr / 2)
solidtime = (cavityv / (totalarea * 2.09)) ^ 2
End Sub
Rem APPENDIX I CAD/CAM PROG I
Rem COMPUTER AIDED DRAFTING (CADD) PROGRAM USED TO GENERATE THE PART
Rem TO BE CAST, AND THE PART TO BE CAST IN POSITION IN THE MOULDING
Rem BOX FOR FLANGE AND BOSS IN 2D AND 3D
Rem THIS SUBROUTINE DISPLAYS THE HEADER FOR ALUMINIUM
Private Sub Command1_Click()
metal.Caption = "ALUMINIUM"
calculat
End Sub
Rem THIS SUBROUTINE DISPLAYS THE HEADER FOR BRASS
Private Sub Command2_Click()
Unload Form4
Form6.Show
metal.Caption = "BRASS"
calculat
End Sub
Rem THIS SUBROUTINE DISPLAYS THE HEADER FOR IRON
Private Sub Command3_Click()
Unload Form4
metal.Caption = "IRON"
calculat
Form7.Show
End Sub
Rem RETURN TO MAIN FORM
Private Sub Command4_Click()
Unload Form4
Form1.Show
End Sub

```

APPENDIX III

CAD PROG III

COMPUTER AIDED COSTING OF SAND CASTING PRODUCTS USING DIFFERENT MATERIALS

```
Begin VB.Form Form1
  Caption           =   "COMPUTER AIDED COSTING OF SAND
CASTING"
  ClientHeight      =   3960
  ClientLeft        =   1605
  ClientTop         =   1560
  ClientWidth       =   6720
  Height            =   4365
  Left              =   1545
  LinkTopic         =   "Form1"
  ScaleHeight       =   3960
  ScaleWidth        =   6720
  Top               =   1215
  Width             =   6840
Begin VB.CommandButton Command1
  Caption           =   "Compute Cost"
  Height            =   375
  Left              =   5040
  TabIndex          =   26
  Top               =   3360
  Width             =   1215
End
Begin VB.TextBox shape
  Height            =   285
  Left              =   4320
  TabIndex          =   25
  Top               =   360
  Width             =   735
End
Begin VB.TextBox Material
  Height            =   285
  Left              =   1800
  TabIndex          =   24
  Top               =   360
  Width             =   1455
End
Begin VB.TextBox alpha
  Alignment         =   1 'Right Justify
  Height            =   285
```

```

Left           = 3240
TabIndex      = 21
Top           = 3360
Width         = 1095
End
Begin VB.TextBox h
  Alignment    = 1 'Right Justify
  Height       = 285
  Left         = 4680
  TabIndex     = 19
  Top         = 2760
  Width        = 1095
End
Begin VB.TextBox bprime
  Alignment    = 1 'Right Justify
  Height       = 285
  Left         = 4680
  TabIndex     = 17
  Top         = 2280
  Width        = 1095
End
Begin VB.TextBox thermo
  Alignment    = 1 'Right Justify
  Height       = 285
  Left         = 4680
  TabIndex     = 15
  Top         = 1800
  Width        = 1095
End
Begin VB.TextBox c
  Alignment    = 1 'Right Justify
  Height       = 285
  Left         = 4680
  TabIndex     = 13
  Top         = 1320
  Width        = 1095
End
Begin VB.TextBox d
  Alignment    = 1 'Right Justify
  Height       = 285
  Left         = 4680
  TabIndex     = 11
  Top         = 840
  Width        = 1095
End
Begin VB.TextBox k
  Alignment    = 1 'Right Justify

```

```

Height           = 285
Left             = 1800
TabIndex        = 9
Top             = 2760
Width           = 1095
End
Begin VB.TextBox weight
Alignment        = 1 'Right Justify
Height          = 285
Left            = 1800
TabIndex        = 7
Top            = 2280
Width          = 1095
End
Begin VB.TextBox fetting
Alignment        = 1 'Right Justify
Height          = 285
Left            = 1800
TabIndex        = 5
Top            = 1800
Width          = 1095
End
Begin VB.TextBox gama
Alignment        = 1 'Right Justify
Height          = 285
Left            = 1800
TabIndex        = 3
Top            = 1320
Width          = 1095
End
Begin VB.TextBox beta
Alignment        = 1 'Right Justify
Height          = 285
Left            = 1800
TabIndex        = 1
Top            = 840
Width          = 1095
End
Begin VB.Label Label13
Caption          = "Shape"
Height          = 255
Left            = 3720
TabIndex        = 23
Top            = 360
Width          = 615
End
Begin VB.Label Label12

```

```

Caption      = "Material"
Height       = 255
Left         = 960
TabIndex     = 22
Top          = 360
Width        = 855
End
Begin VB.Label Label11
    Alignment  = 1 'Right Justify
    Caption    = "Complexity Factor"
    Height     = 375
    Left       = 2040
    TabIndex   = 20
    Top        = 3360
    Width      = 1095
End
Begin VB.Label Label10
    Alignment  = 1 'Right Justify
    Caption    = "Heat Treatment Time Per Unit"
    Height     = 375
    Left       = 3360
    TabIndex   = 18
    Top        = 2760
    Width      = 1215
End
Begin VB.Label Label9
    Alignment  = 1 'Right Justify
    Caption    = "Direct labour Cost Per Unit"
    Height     = 375
    Left       = 3480
    TabIndex   = 16
    Top        = 2280
    Width      = 1095
End
Begin VB.Label Label8
    Alignment  = 1 'Right Justify
    Caption    = "Thermotip Cost Per Unit"
    Height     = 375
    Left       = 3480
    TabIndex   = 14
    Top        = 1800
    Width      = 1095
End
Begin VB.Label Label7
    Alignment  = 1 'Right Justify
    Caption    = "Direct Expense Cost Per Unit"
    Height     = 375

```

```

Left           = 3480
TabIndex      = 12
Top           = 1320
Width         = 1095
End
Begin VB.Label Label6
Alignment     = 1 'Right Justify
Caption       = "Heat Treatment Cost Per Unit"
Height       = 375
Left         = 3360
TabIndex     = 10
Top          = 840
Width        = 1215
End
Begin VB.Label Label5
Alignment     = 1 'Right Justify
Caption       = "Liquid Material Cost Per Unit"
Height       = 375
Left         = 600
TabIndex     = 8
Top          = 2760
Width        = 1095
End
Begin VB.Label Label4
Alignment     = 1 'Right Justify
Caption       = "Weight Cost per Unit"
Height       = 375
Left         = 600
TabIndex     = 6
Top          = 2280
Width        = 1095
End
Begin VB.Label Label3
Alignment     = 1 'Right Justify
Caption       = "Fettling cost per Unit"
Height       = 375
Left         = 600
TabIndex     = 4
Top          = 1800
Width        = 1095
End
Begin VB.Label Label2
Alignment     = 1 'Right Justify
Caption       = "Moulding Cost per Unit"
Height       = 375
Left         = 600
TabIndex     = 2

```

```

Top          = 1320
Width        = 1095
End
Begin VB.Label Label1
    Alignment   = 1 'Right Justify
    Caption     = "Lining Cost Per Unit"
    Height      = 375
    Left        = 600
    TabIndex    = 0
    Top         = 840
    Width       = 1095
End
End

Attribute VB_Name = "Form1"
Attribute VB_Creatable = False
Attribute VB_Exposed = False
Private Sub Command1_Click()
    lin = Val(beta.Text)
    mou = Val(gama.Text)
    fet = Val(fetting.Text)
    wei = Val(weight.Text)
    liq = Val(k.Text)
    comp = Val(alpha.Text)
    hea = Val(d.Text)
    expe = Val(c.Text)
    the = Val(thermo.Text)
    lab = Val(bprime.Text)
    heat = Val(h.Text)
    a = liq + heat + mou + lin + fet + the
    patter = 30 / 100 * (a + lab + expe)
    directmaterial = a + patter
    a = directmaterial
    a = comp * (a + lab + expe + hea)
    f = 0.05 * (1 + comp) * (a + lab + expe + hea)
    pc = 1.05 * (1 + comp) * (a + lab + expe + hea)
    pc = pc * wei
    Print #1, tab2; UCase(Material.Text); UCase(shape.Text);
    tab(20); pc

Form1.Hide
Form3.Show

End Sub

Private Sub Form_Load()
Open "adejuyi.txt" For Output As #1

```

```
Print #1, "output for computer aided costing of sand  
casting products-boss and flange"  
Print #1,  
  
Print #1, Tab(2); "Material"; Tab(20); "Total cost of  
Production"  
  
End Sub
```

APPENDIX IV

MANUALLY CALCULATED RESULTS FOR CASTING A

NON-DEFECTIVE CASTING

The use of manual to calculate the parameters needed to cast a non-defective casting has been undertaken. The dimensions and parameters of the molten-metal used are of the three materials used in the study – Aluminium, Cast iron and Brass.

The following formulae were used to cast a non-defective castings:

i. The volume of the mould

$$- \text{Length (L) x Breadth (B) x Height (H)}$$

where; $\text{Length} = 680\text{mm}$

$$\text{Breadth} = 480\text{mm}$$

$$\text{Height} = 250\text{mm}$$

$$\text{Therefore, the volume} = 680 \times 480 \times 250$$

$$= 81,600,000\text{mm}^3$$

ii. Total volume of the mould cavity

$$- \text{Volume of the flange} + \text{Volume of Boss} + \text{Volume of the riser, Volume of the pouring gate, Volume of section thickness.}$$

* To calculate the volume of the flange

$$- \text{Object of top volume} = L \times B \times H = 160 \times 100 \times 82$$

$$= 1312000\text{mm}^3$$

$$- \text{Object of base volume} = L \times B \times H = 100 \times 56 \times 58$$

$$\begin{aligned} \text{Total volume of flange} &= 324800\text{mm}^3 \\ &= 1636800\text{mm}^3 \end{aligned}$$

* To calculate the volume of Boss

$$\begin{aligned} \text{Volume of Boss} &= \frac{\pi}{4}(D^2 - d^2) \times L = \frac{\pi}{4}(160^2 - 80^2) \times 80 \\ &= 1206371.59\text{mm}^2 \end{aligned}$$

* To calculate the volume of Riser

$$\begin{aligned} \text{Volume of Riser} &= \frac{\pi D^2 l}{4} = \frac{\pi}{4}(98)^2 \times 130 \\ &= 980585.316\text{mm}^2 \end{aligned}$$

* To calculate the volume of the Runner/Pouring gate

$$\begin{aligned} \frac{\pi D^2 l}{4} &= \frac{\pi}{4}(60)^2 \times 120 \\ &= 339292.0066\text{mm}^2 \end{aligned}$$

To calculate the volume of section thickness of the two castings

$$\begin{aligned} \frac{\pi D^2 l}{4} &= \frac{\pi}{4}(35)^2 \times 70 \\ &= 67347.8925\text{mm}^2 \end{aligned}$$

Total volume of the mould cavity

$$\begin{aligned} &1636800 + 1206371.59 + 980585.316 + 339292.0066 + 67347.8923 \\ &= 4230396.786\text{mm}^3 \end{aligned}$$

iii. Volume of Sand

$$\begin{aligned}
 - \quad & \text{Total volume of mould} - \text{Total volume of mould cavity} \\
 &= 81,600,000 - 4,230,396.786 \\
 &= 77369603.21 \text{mm}^3
 \end{aligned}$$

iv. Total volume of the molten metal to fill up the mould cavity

- Total volume of mould cavity + Shrinkage or Thermal contraction allowance (Cast iron 1%, Aluminium 1.25%, Bronze 1.5%) of the total volume of molten metal needed to fill up the mould cavity.

$$\begin{aligned}
 \text{Aluminium} \quad - \quad & 4230396.786 + 52879.957 \\
 &= 4,283,276.745 \text{mm}^3
 \end{aligned}$$

$$\begin{aligned}
 \text{Cast Iron} \quad - \quad & 4230396.786 + 42303.9678 \\
 &= 4,272,700.754 \text{mm}^3
 \end{aligned}$$

$$\begin{aligned}
 \text{Brass} \quad - \quad & 4230396.786 + 63455.95 \\
 &= 4,293,852.738 \text{mm}^3
 \end{aligned}$$

v. Thermal Contraction or Shrinkage Allowance

$$\begin{aligned}
 - \quad & 1.25\% \text{ Aluminium} = 52879.959 \text{ mm}^3 \\
 - \quad & 1\% \text{ Cast Iron} = 42303.9678 \text{ mm}^3 \\
 - \quad & 1.5\% \text{ Brass} = 63455.95 \text{ mm}^3
 \end{aligned}$$

vi. Machining Allowance = Machining Allowance for cast iron is 3mm all round the dimensions, while aluminium and brass is 1.5mm.

Aluminium and Brass - (New volume of the flange + New volume of the boss) - (Original volume of the flange + Original volume of the boss)

New Volume of Flange

$$A = 161.5 \times 101.5 \times 83.5$$

$$= 1368752.875$$

$$B = 101.5 \times 57.5 \times 59.5$$

$$= 347256.875$$

$$\text{Total for Flange} = A + B$$

$$= 1716009.75$$

New Volume of Boss

$$\frac{\pi}{4} (D^2 - d^2) \times l$$

$$\frac{\pi}{4} (161.5^2 - 78.5^2) \times 81.5$$

$$\frac{\pi}{4} (1584360)$$

$$= 12750.78.21$$

Machining allowance for Aluminium and Brass

$$= (1716009.75 + 12750.78.21) - (1636800 + 1206371.59)$$

$$= 2991087.96 - 2843171.59$$

$$= 147916.37\text{mm}^2$$

Cast Iron

New Volume of Flange

New Volume of Boss

$$A = 163 \times 103 \times 85$$

$$= 1427065$$

$$\frac{\pi}{4}(D^2 - d^2) \times l$$

$$B = 103 \times 59 \times 61$$

$$= 370697$$

$$\frac{\pi}{4}(163^2 - 77^2) \times 83$$

$$1345481.302$$

$$\text{Total for flange} = A + B$$

$$= 1797762$$

Machining allowance for Cast Iron

$$(1797762 + 1345481.302) - (1636800 + 1206371.59)$$

$$= 300071.712 \text{ mm}^3$$

Total Weight of the Materials Used = Volume of the material x Density of the material

Flange

$$\text{Cast Iron} = 1636800 \times 7.22 \times 10^{-6} \text{ kg}$$

$$= 11.818 \text{ kg}$$

$$\text{Aluminium} = 1636800 \times 2.8 \times 10^{-6}$$

$$= 4.58 \text{ kg}$$

$$\text{Brass} = 1636800 \times 8.5 \times 10^{-6}$$

$$= 13.9128$$

Boss

Aluminium	=	$1206371.579 \times 2.8 \times 10^{-6}$
	=	3.3778kg
Cast Iron	=	$1206371.579 \times 7.22 \times 10^{-6}$ kg
	=	8.71kg
Brass	=	$1206371.579 \times 8.5 \times 10^{-6}$
	=	10.254kg

Sprue

Aluminium	=	$339292.0066 \times 2.8 \times 10^{-6}$
	=	0.95kg
Cast Iron	=	$339292.0066 \times 7.22 \times 10^{-6}$ kg
	=	2.449kg
Brass	=	$339292.0066 \times 8.5 \times 10^{-6}$
	=	2.8839kg

Riser

Aluminium	=	$980585.316 \times 2.8 \times 10^{-6}$
	=	2.7456kg
Cast Iron	=	$980585.316 \times 7.22 \times 10^{-6}$ kg
	=	7.0798kg
Brass	=	$980585.316 \times 8.5 \times 10^{-6}$
	=	8.335kg

Total weight for the castings

$$\begin{aligned}\text{Cast Iron} &= 11.818 + 8.71 + 7.0798 + 2.449 \\ &= 30.0565\text{kg}\end{aligned}$$

$$\begin{aligned}\text{Aluminium} &= 4.58 + 3.3778 + 2.74556 + 0.95 \\ &= 11.6534\text{kg}\end{aligned}$$

viii. Calculation of Pouring Time

The formulae used for calculating pouring time

$$\text{Pouring time (t)} = \left(1.41 + \frac{T}{14.59}\right) \sqrt{W}$$

Where T = section thickness of the casting

W = weight of the casting

- Aluminium

$$\begin{aligned}\text{Pouring time (t)} &= \left(1.41 + \frac{T}{14.59}\right) \sqrt{W} \\ &= \left(1.41 + \frac{70}{14.59}\right) \sqrt{11.6534} \\ &= 6.2078 \times 5.482 \\ &= 21.19\text{secs}\end{aligned}$$

- Cast Iron

$$\text{Pouring time (t)} = \left(1.41 + \frac{T}{14.59}\right) \sqrt{W}$$

$$\begin{aligned}
 &= \left(1.41 + \frac{70}{14.59}\right) \sqrt{30.0568} \\
 &= 6.2078 \times 5.482 \\
 &= 34.033 \text{secs}
 \end{aligned}$$

- Brass

$$\begin{aligned}
 \text{Pouring time (t)} &= \left(1.41 + \frac{T}{14.54}\right) \sqrt{W} \\
 &= \left(1.41 + \frac{70}{14.54}\right) \sqrt{35.3857} \\
 &= 6.2078 \times 5.948 \\
 &= 36.92 \text{secs}
 \end{aligned}$$

NOTE: To calculate for minimum section thickness (T) for the casting gives;

Flange

$$\begin{aligned}
 \text{A. } \frac{160 + 82}{2} &= 121 & \frac{200}{2} &= 100 \\
 \text{B. } \frac{58 + 100}{2} &= 79
 \end{aligned}$$

Boss

$$\frac{160 - 80}{2} = 40$$

$$\begin{aligned}
 \text{Section thickness (T) for the 2 castings} &= \frac{100 + 40}{2} \\
 &= 70 \text{mm}
 \end{aligned}$$

$$\text{ix. Feeding Efficiency} = \frac{\text{Weight of feed metal}}{\text{Weight of riser before feeding}}$$

The weight of feed metal are

Cast iron - 7.9g per cm³

Aluminium - 2.7g per cm³

Brass - 8.2g per cm³

Therefore, feeding efficiency for

$$\text{i. Cast Iron} - \frac{7.0}{7.0798} \times 100 = 98.87\%$$

$$\text{ii. Aluminium} - \frac{2.7}{2.745} \times 100 = 98.36\%$$

$$\text{iii. Brass} - \frac{8.2}{8.35} \times 100 = 98.20\%$$

x. Calculations on Yield of Casting

Aluminium

$$\begin{aligned} \text{Yield of the Casting} &= \frac{\text{mass of casting}}{\text{mass of casting} + \text{Riser}} \times 100 \\ &= \frac{7.9578}{7.9578 + 2.7456} \times 100 \\ &= 74.348\% \end{aligned}$$

Cast Iron

$$\text{Yield of the Casting} = \frac{\text{mass of casting}}{\text{mass of casting} + \text{Riser}} \times 100$$

$$\begin{aligned}
 &= \frac{W_c}{W_c + W_{in}} \times 100 \\
 &= \frac{20.529}{20.529 + 7.0798} \times 100 \\
 &= 74.35\%
 \end{aligned}$$

Brass

$$\begin{aligned}
 \text{Yield of the Casting} &= \frac{\text{mass of casting}}{\text{mass of casting} + \text{Riser}} \times 100 \\
 &= \frac{24.1668}{24.1668 + 8.335} \times 100 \\
 &= 74.35\%
 \end{aligned}$$

NOTE: Usually the yield during casting of carbon steel is 50 – 60% while during casting of high alloy steels it is between 40 – 50% (Nwajugu, 1994). Therefore the yield result obtained above for the production of this materials under study is very high.

ix. Solidification Time (T)

The formulae for calculating the Solidification Time (T)

$$T = \left(\frac{V}{AK} \right)^2$$

where

- T = Solidification time of a casting (sec)
- V = Volume of the casting
- A = Surface area of casting; and
- K = Constant ≈ 2.09

- Total volume for the casting

Volume of flange + Volume of boss + Volume of riser + Volume of runner +
section thickness volume

$$= 1636800 + 1206371.579 + 980585.316 + 339292.006 + 67347.8925]$$

$$= 4230396.794\text{mm}$$

- Total surface area of the casting

$$\text{Flange A} = 2(lb + lh + bh)$$

Where;

$$l = \text{length}$$

$$b = \text{breadth}$$

$$h = \text{height}$$

$$= 2(160 \times 100 + 160 \times 82) + 100 \times 82)$$

$$= 74640$$

$$B = 2(lb + lh + bh)$$

$$= 2(100 \times 56 + 100 \times 58 + 56 \times 58)$$

$$= 29296$$

Boss

$$\frac{\pi \times D(h+D)}{2} + \frac{\pi \times d(h+D)}{2}$$

where

D = Larger Diameter

d = Smaller Diameter

=

= 60318.57895 + 20106.19298

= 80424.77193

Riser

=

=

= 35097.87313

Sprue

=

=

= 16964.60033

Area of section thickness

=

=

= 5772.67650

Total surface area

= Area of Flange A and B + Boss + Riser + Flange – Section thickness

$$\begin{aligned}
&= 74640 + 29296 + 80424.77193 + 35097.8731 + 16964.60033 - 5772.67650 \\
&= 236423.2454 - 5772.67650 \\
&= 230650.5689
\end{aligned}$$

$$\begin{aligned}
\text{Solidification Time (t)} &= \left[\frac{V}{Ak} \right]^2 \\
&= \left(\frac{4230396.794}{230650.5689 \times 2.09} \right)^2 \\
&= (8.7756)^2 \\
&= 77.012 \text{ sec}
\end{aligned}$$

xii. Conductive Heat Flow

The formulae for calculating the conductive heat flow is:

$$\frac{\partial T}{\partial t} = \nabla(\partial, \nabla T) + \frac{q_s}{C_p}$$

where

ρ	=	density
C_p	=	Specific heat
q_s	=	latent heat
t	=	time
∂t	=	thermal diffusivity
T	=	temperature

Aluminium

$$\frac{\partial T}{\partial t} = \nabla(\partial, \nabla T) + \frac{q_s}{C_p}$$

$$\rho = 2.7 \text{ gm cm}^3$$

$$C_p = 2.282^\circ\text{C}$$

$$q_s = 92.7^\circ\text{C}$$

$$t = 22.0 \text{ secs}$$

$$\partial t = 0.645$$

$$T = 690^\circ\text{C}$$

$$\Rightarrow \nabla(0.645 \times 690) + \frac{92.7}{2.7 \times 2.282}$$

$$= 460.09528^\circ\text{C}$$

Cast Iron

$$\frac{\partial T}{\partial t} = \nabla(\partial, \nabla T) + \frac{q_s}{C_p}$$

$$\rho = 7.60 \text{ gm cm}^3$$

$$C_p = 0.22^\circ\text{C}$$

$$q_s = 65.0^\circ\text{C}$$

$$t = 30.2 \text{ secs}$$

$$\partial t = 0.0825$$

$$T = 1350^\circ\text{C}$$

$$\nabla(0.0825 \times 1350) + \frac{65}{7.60 \times 0.22}$$

$$= 150.250598^{\circ}\text{C}$$

Brass

$$\frac{\partial T}{\partial t} = \nabla(\partial, \nabla T) + \frac{q_s}{C_p}$$

$$\rho = 9.0 \text{ gm/cm}^3$$

$$C_p = 0.090922$$

$$q_s = 43.0$$

$$t = 33.2 \text{ secs}$$

$$\partial t = 0.6$$

$$T = 1030^{\circ}\text{C}$$

$$\nabla(0.6 \times 1030) + \frac{43}{9 \times 0.0909}$$

$$= 670.567^{\circ}\text{C}$$

xiv. The Practical Value of Linear Shrinkage

$$\frac{l_{\text{pattern}} - l_{\text{cast}}}{l_{\text{cast}}} \times 100\%$$

For Cast Iron

Flange	Boss
l pattern (flange) – 165 (Big) l pattern (flange) – 103 (Small) l cast (flange) – 165 (Big) l cast (flange) – 105 (Small) $\frac{103 - 105}{105} \times 100 = -1.904\%$ $\frac{165 - 165}{165} \times 100 = 0\%$	l pattern (Boss) - 83 l cast (Boss) - 84 $\frac{83 - 84}{84} \times 100$ $= -1.190\%$
For Aluminium l pattern (flange) – 165 (Big) l pattern (flange) – 103 (Small) l cast (flange) – 162 (Big) l cast (flange) – 101 (Small) $\frac{165 - 161}{161} \times 100 = 2.48\%$ $\frac{103 - 101}{101} \times 100 = 1.980\%$	l pattern (Boss) - 83 l cast (Boss) - 81 $\frac{83 - 81}{81} \times 100$ 2.469%
For Bronze l pattern (flange) – 165 (Big) l pattern (flange) – 103 (Small) l cast (flange) – 162 (Big) l cast (flange) – 102 (Small) $\frac{165 - 162}{162} \times 100 = 1.85\%$ $\frac{103 - 102}{102} \times 100 = 0.98\%$	l pattern (Boss) - 83 l cast (Boss) - 81 $\frac{83 - 81}{81} \times 100$ 2.46%

Total shrinkage allowance for each metal

- **Cast Iron**

$$= -1.904 + 0 + -1.190$$

$$= -3.094 \div 3$$

$$= -1.031\%$$

- **For Aluminium**

$$= 2.48 + 1.980 + 2.469$$

$$= 6.929 \div 3$$

$$= 2.3096\%$$

- **For Bronze**

$$= 1.85 + 0.98 + 2.46$$

$$= 5.29 \div 3$$

$$= 1.763\%$$

The summary of manual parameters needed to cast a non-defective casting is shown in Table 4.3. The discussion of the results obtained is done at 4.5 under comparison and discussion of CAD, CAM and long-hand calculated results.

For Aluminium

Table A.1: CAD Versus Manufacturing Results for Aluminium

	Manufacturing result	Computer-aided Cal. Parameter's result	Difference
Total Vol. of the mould (mm ³)	81,600,000	81,600,000	0.000
Total vol. of the mould cavity (mm ³)	4,200,000	4230396.793	30396.793
Volume of Sand (mm ³)	77,400,000	77369603.207	30396.8
Total vol. of molten metal (mm ³)	4,253,112.5	4283276.753	30164.253
Thermal Contraction (mm ³)	53112.5	52879.960	232.54
Machining allowance (mm ³)	147916.3	147916.381	0.081
Total Weight (kg)	11.845	11.993	0.148
Pouring Time (Sec)	22	21.4984	0.5016
Feeding Efficiency (%)	98.36	98.338	0.022
Yield of casting (%)	74.348	74.355	0.007
Solidification Time (Sec)	77	76.9128	0.0872
Conductive heat flow (°C)	460.095	459.558	0.537
Practical value of linear shrinkage (%)	2.3	2.3	0.000

Source: The results obtained from the study

Table A.2: CAD Versus Manufacturing Results using Regression Analysis

	Manufacturing Result (xi)	Computer-aided parameter's result (yi)	$(X - \bar{X})$	$(Y - \bar{Y})$	$(X - \bar{X})(Y - \bar{Y})$	$(X - \bar{X})^2$	$(Y - \bar{Y})^2$
Volume of mold (m ³)	81,600,000	81,600,000	68703470.22	68701167.84	4.7200086×10^{13}	4.7201668×10^{13}	4.7198504×10^{13}
Volume of mold (m ³)	4,200,000	4230396.793	-8696529.785	-8668435.367	7.5385306×10^{13}	7.562963×10^{13}	7.5141771×10^{13}
Volume of sand (m ³)	77,400,000	77369603.207	64503470.22	64470771.04	4.1585884×10^{13}	4.1606976×10^{13}	4.1564803×10^{13}
Volume of sand (m ³)	4,253,112.5	4283276.758	-8643417.285	-8615555.407	7.446784×10^{13}	7.4708662×10^{13}	7.4227794×10^{13}
Normal contact (m ³)	53112.5	52879.960	-12843417.28	-12845952.2	1.6498562×10^{14}	1.6495336×10^{14}	1.6501848×10^{14}
Volume of sand (m ³)	147916.3	147916.381	-12748613.48	-12750915.78	1.6255649×10^{14}	1.6252714×10^{14}	1.6258585×10^{14}
Volume of sand (m ³)	11.845	11.993	-12896517.94	-12898820.17	1.6634986×10^{14}	1.6632017×10^{14}	1.6637956×10^{14}
Volume of sand (m ³)	22	21.4984	-12896507.78	-12898810.66	1.6634961×10^{14}	1.6631991×10^{14}	1.6637931×10^{14}
Volume of sand (m ³)	98.36	98.338	-12896431.42	-12898733.82	1.6634763×10^{14}	1.6631794×10^{14}	1.6637733×10^{14}
Volume of sand (m ³)	74.348	74.355	-12896455.44	-12898757.81	1.6634825×10^{14}	1.6631856×10^{14}	1.6637795×10^{14}
Volume of sand (m ³)	77	76.9128	-12896452.78	-12898755.25	1.6634818×10^{14}	1.663184×10^{14}	1.6637788×10^{14}
Volume of sand (m ³)	460.095	459.558	-12896069.69	-12898372.6	1.6633831×10^{14}	1.6630861×10^{14}	1.6636801×10^{14}
Volume of sand (m ³)	2.3	2.3	-12896527.48	-12898829.86	1.6635011×10^{14}	1.6632042×10^{14}	1.6637981×10^{14}
Volume of sand (m ³)	167654887.2	167684818	0.075	-0.044-0.044	$1.05204240 \times 10^{16}$	1.0656586×10^{16}	1.0517944×10^{16}

$$\begin{aligned}\bar{X} &= \frac{\sum Xi}{n} \\ &= \frac{167654887.2}{13} \\ &= 12896529.78\end{aligned}$$

$$\begin{aligned}\bar{Y} &= \frac{\sum Yi}{n} \\ &= \frac{167684818}{13} \\ &= 12898832.16\end{aligned}$$

Recall from above

$$\begin{aligned}(r) &= \frac{\sum (X - \bar{X})(Y - \bar{Y})}{\sqrt{\left(\sum (X - \bar{X})^2\right) \left(\sum (Y - \bar{Y})^2\right)}} \\ &= (r) = \frac{1.0520424 \times 10^{16}}{\sqrt{(1.0656586 \times 10^{16})(1.0517944 \times 10^{16})}} \\ &= \frac{1.0520424 \times 10^{16}}{1.0587038 \times 10^{16}} \\ \therefore (r) &= 0.9937 \\ (r^2) &= 0.9874 \\ &= 98.74\%\end{aligned}$$

FOR CAST IRON

Table A.3: CAD versus Manufacturing Results for Cast Iron

	Manufacturing Calculated Results	Computer-aided Cal. Parameter's result	Difference
Total Vol. of the mould (mm ³)	81,600,000	81,600,000	0.000
Total vol. of the mould cavity (mm ³)	4,200,000	4230396.793	30396.793
Volume of Sand (mm ³)	77,400,000	77369603.207	30396.8
Total vol. of molten metal (mm ³)	4,242,490	4272700.761	30210.761
Thermal Contraction (mm ³)	42490	42303.968	186.032
Machining allowance (mm ³)	300071.7	300071.723	0.023
Total Weight (kg)	30.543	30.849	0.306
Pouring Time (Sec)	30.2	34.4793	4.279
Feeding Efficiency (%)	98.87	98.872	0.002
Yield of casting (%)	74.35	74.355	0.005
Solidification Time (Sec)	77	76.9128	0.0872
Conductive heat flow (°C)	150.25	152.297	2.047
Practical value of linear shrinkage (%)	-1.03	-1.03175	0.00175

Source: The results obtained from the study

Table A.4: CAD versus Manufacturing Results for Cast Iron using Regression Analysis

	Manufacturing Results (Xi)	Computer-aided Cal. Parameter's result (Yi)	$(X - \bar{X})$	$(Y - \bar{Y})$	$(X - \bar{X})(Y - \bar{Y})$	$(X - \bar{X})^2$	$(Y - \bar{Y})^2$
Total Vol. Of the mould (mm ³)	81,600,000	81,600,000	68693422.16	68691112.06	4.7186275 x 10 ¹⁵	4.7187829 x 10 ¹⁵	4.7184688 x 10 ¹⁵
Total vol. Of the mould cavity (mm ³)	4,200,000	4230396.793	-8706577.84	-8678491.147	7.5559958 x 10 ¹³	7.5804917 x 10 ¹³	7.5316208 x 10 ¹³
Volume of Sand (mm ³)	77,400,000	77369603.207	64493422.16	64460715.26	4.1572921 x 10 ¹⁵	4.1593983 x 10 ¹⁵	4.1551838 x 10 ¹⁵
Total vol. of molten metal (mm ³)	4,242,490	4272700.761	-8664087.84	-8636187.179	7.4824684 x 10 ¹³	7.5066835 x 10 ¹³	7.4583728 x 10 ¹³
Thermal Contraction (mm ³)	42490	42303.968	-12864087.84	-12866583.97	1.6551686 x 10 ¹⁴	1.6548537 x 10 ¹⁴	1.6554898 x 10 ¹⁴
Machining allowance (mm ³)	300071.7	300071.723	-12606506.14	-12608816.22	1.5895311 x 10 ¹⁴	1.589246 x 10 ¹⁴	1.5898224 x 10 ¹⁴
Total Weight (kg)	30.543	30.849	-12906547.3	-12908857.09	1.6660877 x 10 ¹⁴	1.6657958 x 10 ¹⁴	1.6663859 x 10 ¹⁴
Pouring Time (Sec)	30.2	34.4793	-12906547.64	-12908853.46	1.6660873 x 10 ¹⁴	1.6657959 x 10 ¹⁴	1.6663849 x 10 ¹⁴
Feeding Efficiency (%)	98.87	98.872	-12906478.97	-12908789.07	1.6660701 x 10 ¹⁴	1.6657782 x 10 ¹⁴	1.6663683 x 10 ¹⁴
Yield of casting (%)	74.35	74.355	-12906503.45	-12908813.59	1.6660764 x 10 ¹⁴	1.6657845 x 10 ¹⁴	1.6663746 x 10 ¹⁴
Solidification Time (Sec)	77	76.9128	-12906500.84	-12908811.03	1.6660758 x 10 ¹⁴	1.6657838 x 10 ¹⁴	1.666374 x 10 ¹⁴
Conductive heat flow (°C)	150.25	152.297	-12906427.59	-12908735.64	1.6660566 x 10 ¹⁴	1.6656849 x 10 ¹⁴	1.6663545 x 10 ¹⁴
Practical value of linear shrinkage (%)	-1.03	-1.03175	-12906578.87	-12908888.97	1.6660959 x 10 ¹⁴	1.6658031 x 10 ¹⁴	1.6663941 x 10 ¹⁴
	167785512.0	167815543.2	0.00	-0.046	1.0517029 x 10 ¹⁶	1.0519505 x 10 ¹⁶	1.0518547 x 10 ¹⁶

Source: The results obtained from the study

$$\begin{aligned}\bar{X} &= \frac{\sum Xi}{n} \\ &= \frac{167785512.0}{13}\end{aligned}$$

$$\bar{X} = 12906577.84$$

$$\begin{aligned}\bar{Y} &= \frac{\sum Yi}{n} \\ &= \frac{167815543.2}{13} \\ &= 12908887.94\end{aligned}$$

Recall from above,

$$\begin{aligned}(r) &= \frac{\sum (X - \bar{X})(Y - \bar{Y})}{\sqrt{\left(\sum (X - \bar{X})^2\right) \left(\sum (Y - \bar{Y})^2\right)}} \\ &= \frac{1.0517029 \times 10^{16}}{\sqrt{(1.0519505 \times 10^{16})(1.0518547 \times 10^{16})}} \\ (r) &= \frac{1.0517029 \times 10^{16}}{1.0519025 \times 10^{16}} \\ &= 0.99981 \\ (r^2) &= 0.9996 \\ &= 99.96\%\end{aligned}$$

For Brass

Table A.5: CAD versus Manufacturing Results for Brass

	Manufacturing Results	CAD result	Difference
Total Vol. of the mould (mm ³)	81,600,000	81,600,000	0.000
Total vol. of the mould cavity (mm ³)	4,200,000	4230396.793	30396.793
Volume of Sand (mm ³)	77,400,000	77369603.207	30396.8
Total vol. of molten metal (mm ³)	4,263,735	4293852.745	30117.745
Thermal Contraction (mm ³)	63735	63455.952	279.048
Machining allowance (mm ³)	147916.3	147916.381	0.081
Total Weight (kg)	37.225	36.498	0.727
Pouring Time (Sec)	33.6	37.5035	3.9035
Feeding Efficiency (%)	98.20	98.381	0.181
Yield of casting (%)	74.35	74.355	0.005
Solidification Time (Sec)	77	76.9128	0.0872
Conductive heat flow (°C)	670.567	673.653	3.086
Practical value of linear shrinkage (%)	1.76	1.76713	0.00713

Source: The results obtained from the study

Table A.6: CAD versus Manufacturing Results for Brass using Regression Analysis

	Manufacturing Results (Xi)	Computer-aided Cal. Parameter's result (Yi)	$(x - \bar{x})$	$(y - \bar{y})$	$(x - \bar{x})(y - \bar{y})$	$(x - \bar{x})^2$	$(y - \bar{y})^2$
Total Vol. Of the mould (mm ³)	81,600,000	81,600,000	68701817	68699521.22	4.7197819×10^{15}	4.7199396×10^{15}	4.7196242×10^{15}
Total vol. Of the mould cavity (mm ³)	4,200,000	4230396.793	-8698183	-8670081.987	7.5413959×10^{13}	7.5658387×10^{13}	7.5170321×10^{13}
Volume of Sand (mm ³)	77,400,000	77369603.207	64501817	64469124.42	4.1583756×10^{15}	4.1604843×10^{15}	4.156268×10^{15}
Total vol. of molten metal (mm ³)	4,263,735	4293852.775	-8634448	-8606626.035	7.4313464×10^{13}	7.4553692×10^{13}	7.4074011×10^{13}
Thermal Contraction (mm ³)	63735	63455.952	-12834448	-12837022.83	1.647561×10^{14}	1.6472305×10^{14}	1.6478915×10^{14}
Machining allowance (mm ³)	147916.3	147916.381	-12750266.7	-12752562.4	1.6259857×10^{14}	1.625693×10^{14}	1.6262784×10^{14}
Total Weight (kg)	37.225	36.498	-12898145.78	-12900442.28	1.6639178×10^{14}	1.6636216×10^{14}	1.6642141×10^{14}
Pouring Time (Sec)	33.6	37.5035	-12898149.4	-12900441.28	1.6639181×10^{14}	1.6636225×10^{14}	1.6642138×10^{14}
Feeding Efficiency (%)	98.20	98.381	-12898084.8	-1290380.4	1.663902×10^{14}	1.6636059×10^{14}	1.6641981×10^{14}
Yield of casting (%)	74.35	74.355	-1289810.6	-12900404.43	1.6639081×10^{14}	1.663612×10^{14}	1.6642043×10^{14}
Solidification Time (Sec)	77	76.9128	-12898106	-12900401.87	1.6639075×10^{14}	1.6636113×10^{14}	1.6642036×10^{14}
Conductive heat flow (°C)	670.567	673.653	-12897512.43	-12899805.13	1.6637539×10^{14}	1.6634582×10^{14}	1.6640497×10^{14}
Partial value of linear shrinkage (%)	1.76	1.76713	-12898181.24	-12900477.01	1.6639269×10^{14}	1.6636307×10^{14}	1.664223×10^{14}
Σ	167676379	167706224.1	0.00	-0.012	1.0519963×10^{15}	1.0522444×10^{15}	1.0527484×10^{15}

Source: The results obtained from the study

$$\begin{aligned}\bar{X} &= \frac{\sum X_i}{n} \\ &= \frac{167676379}{13} \\ &= 12898183\end{aligned}$$

$$\begin{aligned}\bar{Y} &= \frac{\sum Y_i}{n} \\ &= \frac{167706224.1}{13} \\ &= 12900478.78\end{aligned}$$

Recall from above,

$$\begin{aligned}(r) &= \frac{\sum (X - \bar{X})(Y - \bar{Y})}{\sqrt{\left(\sum (X - \bar{X})^2\right) \cdot \left(\sum (Y - \bar{Y})^2\right)}} \\ &= \frac{1.0519963 \times 10^{16}}{\sqrt{(1.0522444 \times 10^{16})(1.0527484 \times 10^{16})}} \\ &= \frac{1.0519963 \times 10^{16}}{1.0524963 \times 10^{16}}\end{aligned}$$

$$\therefore (r) = 0.9995$$

$$(r^2) = 0.99904$$

$$= 99.9\%$$

FOR ALUMINIUM

Table A.7: CAD versus Manually calculated results for Aluminium

	Manually Calculated result	Computer-aided calculated parameters result	Percentage Difference (%)
Total Vol. of the mould (mm ³)	81,600,000	81,600,000	0.000
Total vol. of the mould cavity (mm ³)	4230396.786	4230396.793	0.0070
Volume of Sand (mm ³)	77369603.21	77369603.207	0.003
Total vol. of molten metal (mm ³)	4,283,276.745	4283276.753	0.008
Thermal Contraction (mm ³)	52879.96	52879.960	0.000
Machining allowance (mm ³)	147916.37	147916.381	0.011
Total Weight (kg)	11.6534	11.993	0.3396
Pouring Time (Sec)	21.19	21.4984	0.3084
Feeding Efficiency (%)	98.36	98.338	0.022
Yield of casting (%)	74.348	74.355	0.007
Solidification Time (Sec)	77.012	76.9128	0.0992
Conductive heat flow (°C)	460.095	459.558	0.537
Practical value of linear shrinkage (%)	2.3096	2.3	0.0096

Source: The results obtained from the study

Table A.8: CAD versus Manually Calculated results for Aluminium using Regression Analysis

	Manufacturing Results (Xi)	Computer-aided Cal. Parameter's result (Yi)	$(X - \bar{X})$	$(Y - \bar{Y})$	$(X - \bar{X})(Y - \bar{Y})$	$(X - \bar{X})^2$	$(Y - \bar{Y})^2$
Total Vol. Of the mould (mm ³)	81,600,000	81,600,000	68701167.84	68701167.84	4.7198504 x 10 ¹³	4.7198504 x 10 ¹³	4.7198504 x 10 ¹³
Total vol. Of the mould cavity (mm ³)	4230396.786	4230396.793	-8668435.371	-8668435.364	7.5141771 x 10 ¹¹	7.5141771 x 10 ¹¹	7.5141771 x 10 ¹¹
Volume of Sand (mm ³)	77369603.21	77369603.207	64470771.05	64470771.04	4.1564803 x 10 ¹³	4.1564803 x 10 ¹³	4.1564803 x 10 ¹³
Total vol. of molten metal (mm ³)	4,283,276.745	4283276.753	-8615555.412	-8615555.404	7.4227794 x 10 ¹³	7.4227795 x 10 ¹³	7.4227794 x 10 ¹³
Thermal Contraction (mm ³)	52879.96	52879.960	-12845952.2	-12845952.2	1.6501848 x 10 ¹⁴	1.6501848 x 10 ¹⁴	1.6501848 x 10 ¹⁴
Machining allowance (mm ³)	147916.37	147916.381	-12750915.78	-12750915.78	1.6258585 x 10 ¹⁴	1.6258585 x 10 ¹⁴	1.6258585 x 10 ¹⁴
Total Weight (kg)	11.6534	11.993	-12898820.16	-12898820.16	1.6637956 x 10 ¹⁴	1.6637957 x 10 ¹⁴	1.6637956 x 10 ¹⁴
Pouring Time (Sec)	21.19	21.4984	-12898810.66	-12898810.66	1.6624125 x 10 ¹³	1.6637932 x 10 ¹⁴	1.6637931 x 10 ¹⁴
Feeding Efficiency (%)	98.36	98.338	-12898733.82	-12898733.82	1.6637733 x 10 ¹⁴	1.6637733 x 10 ¹⁴	1.6637733 x 10 ¹⁴
Yield of casting (%)	74.348	74.355	-12898757.8	-12898757.8	1.6637795 x 10 ¹⁴	1.6637795 x 10 ¹⁴	1.6637795 x 10 ¹⁴
Solidification Time (Sec)	77.021	76.9128	-12898755.24	-12898755.24	1.6637788 x 10 ¹⁴	1.6637788 x 10 ¹⁴	1.6637788 x 10 ¹⁴
Conductive heat flow (°C)	460.095	459.558	-12898372.6	-12898372.6	1.66368 x 10 ¹⁴	1.66368 x 10 ¹⁴	1.6636801 x 10 ¹⁴
Partial value of linear shrinkage (%)	2.3096	2.3	-12898829.86	-12898829.86	1.6637981 x 10 ¹⁴	1.6637981 x 10 ¹⁴	1.6637981 x 10 ¹⁴
Σ	167684818	167684818	-0.023	-0.005	1.0368189 x 10 ¹⁶	1.0517944 x 10 ¹⁶	1.0517944 x 10 ¹⁶

Source: The results obtained from the study

$$\begin{aligned}\bar{X} &= \frac{\sum X_i}{n} \\ &= \frac{167684818}{13} \\ &= 12898832.16\end{aligned}$$

$$\begin{aligned}\bar{Y} &= \frac{\sum Y_i}{n} \\ &= \frac{167684818}{13} \\ &= 12898832.16\end{aligned}$$

Recall from above

$$\begin{aligned}(r) &= \frac{\sum (X - \bar{X})(Y - \bar{Y})}{\sqrt{\left(\sum (X - \bar{X})^2\right)\left(\sum (Y - \bar{Y})^2\right)}} \\ &= \frac{1.0368189 \times 10^{16}}{\sqrt{(1.0517944 \times 10^{16})(1.0517944 \times 10^{16})}} \\ &= \frac{1.0368189 \times 10^{16}}{1.0517944 \times 10^{16}} \\ r &= 0.98576 \\ r^2 &= 0.97172 \\ r^2 &= 97.17\%\end{aligned}$$

FOR CAST IRON

Table A.9: CAD versus Manually calculated results for Cast Iron

	Manually Calculated result	Computer-aided calculated parameters result	Difference
Total Vol. of the mould (mm ³)	81,600,000	81,600,000	0.000
Total vol. of the mould cavity (mm ³)	4230396.786	4230396.793	0.0070
Volume of Sand (mm ³)	77369603.21	77369603.207	0.003
Total vol. of molten metal (mm ³)	4,272,700.754	4272700.761	0.007
Thermal Contraction (mm ³)	42303.97	42303.968	0.002
Machining allowance (mm ³)	300071.712	300071.723	0.011
Total Weight (kg)	30.0568	30.845	0.792
Pouring Time (Sec)	34.033	34.4793	0.446
Feeding Efficiency (%)	98.36	98.872	0.512
Yield of casting (%)	74.35	74.355	0.005
Solidification Time (Sec)	77.012	76.9128	0.099
Conductive heat flow (°C)	150.2505	152.297	2.047
Practical value of linear shrinkage (%)	-1.031	-1.031	0.000

Source; The result obtained from the study

Table A.10: CAD versus Manually Calculated results for Cast Iron using Regression Analysis

	Manufacturing Results (Xi)	Computer-aided Cal. Parameter's result (Yi)	$(X - \bar{X})$	$(Y - \bar{Y})$	$(X - \bar{X})(Y - \bar{Y})$	$(X - \bar{X})^2$	$(Y - \bar{Y})^2$
Total Vol. Of the mould (mm ³)	81,600,000	81,600,000	6869112.35	6869112.06	4.7184688 x 10 ¹⁵	4.7184689 x 10 ¹⁵	4.7184688 x 10 ¹⁵
Total vol. Of the mould cavity (mm ³)	4230396.786	4230396.793	-8678490.865	-8678491.44	7.5316206 x 10 ¹⁵	7.5316203 x 10 ¹⁵	7.5316208 x 10 ¹⁵
Total vol. of molten metal (mm ³)	4,272,700.754	4272700.761	-8636186.897	-8636187.177	7.4583726 x 10 ¹³	7.4583724 x 10 ¹³	7.4583728 x 10 ¹³
Thermal Contraction (mm ³)	42303.97	42303.968	-12866583.68	-12866583.97	1.6554897 x 10 ¹⁴	1.6554897 x 10 ¹⁴	1.6554898 x 10 ¹⁴
Machining allowance (mm ³)	300071.712	300071.723	-12608815.94	-12608816.21	1.5898224 x 10 ¹⁴	1.5898223 x 10 ¹⁴	1.5898224 x 10 ¹⁴
Total Weight (kg)	30.0568	30.849	-12908857.59	-12908857.09	1.6663859 x 10 ¹⁴	1.666386 x 10 ¹⁴	1.6663859 x 10 ¹⁴
Pouring Time (Sec)	34.033	34.4793	-12908853.62	-12908853.46	1.6663849 x 10 ¹⁴	1.666385 x 10 ¹⁴	1.6663849 x 10 ¹⁴
Feeding Efficiency (%)	98.36	98.872	-12908789.29	-12908789.06	1.6663683 x 10 ¹⁴	1.6663684 x 10 ¹⁴	1.6663683 x 10 ¹⁴
Yield of casting (%)	74.35	74.355	-12908813.3	-12908813.58	1.6663746 x 10 ¹⁴	1.6663746 x 10 ¹⁴	1.6663746 x 10 ¹⁴
Solidification Time (Sec)	77.021	76.9128	-12908810.64	-12908811.02	1.6663739 x 10 ¹⁴	1.6663739 x 10 ¹⁴	1.666374 x 10 ¹⁴
Vol. of Sand (mm ³)	77369603.21	77369603.207	64460715.56	64460715.26	4.1551838 x 10 ¹⁵	4.1551838 x 10 ¹⁵	4.1551838 x 10 ¹⁵
Conductive heat flow (°C)	150.2505	152.297	-12908737.4	-12908735.64	1.6663547 x 10 ¹⁴	1.666355 x 10 ¹⁴	1.6663545 x 10 ¹⁴
Partial value of linear shrinkage (%)	-1.031	-1.03	-12908888.68	-12908888.97	1.6663941 x 10 ¹⁴	1.666394 x 10 ¹⁴	1.6663941 x 10 ¹⁴
Σ	167815539.5	167815543.2	-0.0059	0.0021	1.0514547 x 10 ¹⁶	1.0514547 x 10 ¹⁶	1.0554547 x 10 ¹⁶

Source: The results obtained from the study

$$\begin{aligned}\bar{X} &= \frac{\sum Xi}{n} \\ &= \frac{167815539,5}{13} \\ &= 12908887.65\end{aligned}$$

$$\begin{aligned}\bar{Y} &= \frac{\sum Yi}{n} \\ &= \frac{167815543,2}{13} \\ &= 128908887.94\end{aligned}$$

Recall from above

$$\begin{aligned}r &= \frac{\sum (X - \bar{X})(Y - \bar{Y})}{\sqrt{\left(\sum (X - \bar{X})^2\right)\left(\sum (Y - \bar{Y})^2\right)}} \\ &= \frac{1.0514547 \times 10^{16}}{\sqrt{(1.0514547 \times 10^{16})(1.0514547 \times 10^{16})}} \\ &= \frac{1.0514547 \times 10^{16}}{1.0534528 \times 10^{16}} \\ r &= 0.9981 \\ r^2 &= 0.9962 \\ &= 99.62\%\end{aligned}$$

FOR BRASS

Table A.11: CAD versus Manually Calculated results for Brass

	Manually Calculated result	Computer-aided calculated parameters result	Difference
Total Vol. of the mould (mm ³)	81,600,000	81,600,000	0.000
Total vol. of the mould cavity (mm ³)	4230396.786	4230396.793	0.0070
Volume of Sand (mm ³)	77369603.21	77369603.207	0.003
Total vol. of molten metal (mm ³)	4,293,852.738	4293852.745	0.007
Thermal Contraction (mm ³)	63455.95	63455.952	0.002
Machining allowance (mm ³)	147916.37	147916.381	0.011
Total Weight (kg)	35.3857	35.958	0.5723
Pouring Time (Sec)	36.92	36.498	0.422
Feeding Efficiency (%)	98.20	98.381	0.181
Yield of casting (%)	74.35	74.355	0.005
Solidification Time (Sec)	77.012	76.9128	0.099
Conductive heat flow (°C)	670.567	673.653	3.086
Practical value of linear shrinkage (%)	1.763	1.763	0.003

Source: The result obtained from the study

Table A.12: CAD versus Manual Calculated results for Cast Iron using Regression Analysis

	Hand Cal. Results (Xi)	Computer-aided Cal. Parameter's result (Yi)	$(X - \bar{X})$	$(Y - \bar{Y})$	$(X - \bar{X})(Y - \bar{Y})$	$(X - \bar{X})^2$	$(Y - \bar{Y})^2$
Total Vol. Of the mould (mm ³)	81,600,000	81,600,000	68699523.67	68699521.34	4.7196243 x10 ¹⁵	4.7196245 x10 ¹⁵	4.7196243 x10 ¹⁵
Total vol. Of the mould cavity (mm ³)	4230396.786	4230396.793	-8670079.541	-8670081.868	7.5170299 x10 ¹⁴	7.5170279 x10 ¹⁴	7.5170319 x10 ¹⁴
Vol. of Sand (mm ³)	77369603.21	77369603.207	64469126.88	64469124.54	4.1562681 x10 ¹⁵	4.1562683 x10 ¹⁵	4.156268 x10 ¹⁵
Total vol. of molten metal (mm ³)	4,293,852.738	4293852.745	-8606623.589	-8606625.916	7.4073989 x10 ¹⁵	7.4073969 x10 ¹⁵	7.4074009 x10 ¹⁵
Thermal Contraction (mm ³)	63455.95	63455.952	-12837020.38	-12837022.71	1.6478912 x10 ¹⁴	1.6478909 x10 ¹⁴	1.6478915 x10 ¹⁴
Machining allowance (mm ³)	147916.37	147916.381	-12752559.96	-12752562.28	1.6262781 x10 ¹⁴	1.6262778 x10 ¹⁴	1.6262784 x10 ¹⁴
Total Weight (kg)	35.3857	35.958	-12900440.94	-12900442.7	1.6642139 x10 ¹⁴	1.6642137 x10 ¹⁴	1.6642142 x10 ¹⁴
Pouring Time (Sec)	36.92	36.498	-12900439.41	-12900442.16	1.6642137 x10 ¹⁴	1.6642133 x10 ¹⁴	1.664214 x10 ¹⁴
Feeding Efficiency (%)	98.20	98.381	-12900378.13	-12900380.28	1.6641978 x10 ¹⁴	1.6641975 x10 ¹⁴	1.6641981 x10 ¹⁴
Yield of casting (%)	74.35	74.355	-12900401.98	-12900404.31	1.664204 x10 ¹⁴	1.6642037 x10 ¹⁴	1.6642043 x10 ¹⁴
Solidification Time (Sec)	77.012	76.9128	-12900399.32	-12900401.75	1.6642033 x10 ¹⁴	1.664203 x10 ¹⁴	1.6642036 x10 ¹⁴
Conductive heat flow (°C)	670.567	673.653	-12899805.76	-12899805.01	1.6640497x10 ¹⁴	1.6640498 x10 ¹⁴	1.6640496 x10 ¹⁴
Partial value of linear shrinkage (%)	1.763	1.76	-12900474.56	-12900476.9	1.6642227 x10 ¹⁴	1.6642224 x10 ¹⁴	1.664223 x10 ¹⁴
Σ	167706192.3	167706222.6	26.98	0.005	1.0517484 x 10 ¹⁶	1.0517484 x10 ¹⁶	1.0537484 x 10 ¹⁶

Source: The results obtained from the study

$$\begin{aligned}\bar{X} &= \frac{\sum X_i}{n} \\ &= \frac{167706192.3}{13} \\ &= 12900476.33\end{aligned}$$

$$\begin{aligned}\bar{Y} &= \frac{\sum Y_i}{n} \\ &= \frac{167706222.6}{13} \\ &= 12900478.66\end{aligned}$$

Recall from above

$$\begin{aligned}(r) &= \frac{\sum (X - \bar{X})(Y - \bar{Y})}{\sqrt{\left(\sum (X - \bar{X})^2\right)\left(\sum (Y - \bar{Y})^2\right)}} \\ &= \frac{1.0517484 \times 10^{16}}{\sqrt{(1.0517484 \times 10^{16})(1.0517484 \times 10^{16})}} \\ &= \frac{1.0517484 \times 10^{16}}{1.0527479 \times 10^{16}} \\ (r) &= 0.9990 \\ r^2 &= 0.9981 \\ r &= 99.8\%\end{aligned}$$

APPENDIX V

4.5.1 MANUAL COST ESTIMATION FOR BOSS AND FLANGE

FOR BOSS

ALUMINIUM MATERIAL

Weight of Aluminium for Boss = 3.3778kg

Linning material cost/kg (₦/kg) = 0.8

Moulding material cost/kg (₦/kg) = 12.02

Fettling material cost/kg (₦/kg) = 2.63

Liquid Charge cost/kg (₦/kg) = 120.25

Thermotip cost/kg (₦/kg) = 0.7

Direct expenses cost/kg (₦/kg) = 3.5

Direct labour cost/kg (₦/kg) = 13.6

I. Partial Direct Material Cost (PDMc) = Linning + Moulding + Fettling +
Liquid + Thermotip

$$= 0.8 + 12.02 + 2.63 + 120.25 + 0.7$$

₦136.40

II. Pattern Cost (PTc) = 30% (PDMc + Direct Expenses Cost + Direct
labour cost)

$$30\% (136.40 + 3.5 + 13.6)$$

= ₦46.05

$$\begin{aligned}
 \text{III. Total Direct Material Cost (TDMc)} &= \text{PTc} + \text{PDMc} \\
 &= 136.40 + 46.05 \\
 &= \text{₦}182.45
 \end{aligned}$$

$$\begin{aligned}
 \text{IV. Complexity Cost (CFc)} &= \text{Complexity Factor (CF) (TDMc + Direct} \\
 &\text{Labour Cost + Direct Expenses Cost)} \\
 &= 0.05 (182.45 + 13.6 + 3.5) \\
 &= \text{₦}9.98
 \end{aligned}$$

$$\begin{aligned}
 \text{V. Production Cost (Pc}_{ij}) &= 1.05 (1 + 0.05) \times (182.45 + 13.6 + 3.5) \\
 (\text{Pc}_{ij})/\text{kg} &= \text{₦}220.00 \\
 \text{For 3.3778kg} &= 220.00 \times 3.3778 \\
 &= \text{₦}743.116 \\
 (\text{Pc}_{ij})/\text{Unit} &= \text{₦}743.116 \\
 &\sim \text{₦}743.12
 \end{aligned}$$

- CAST IRON MATERIAL

$$\begin{aligned}
 \text{Weight of Cast Iron for Boss} &= 8.71\text{kg} \\
 \text{Linning material cost/kg (₦/kg)} &= 0.8 \\
 \text{Moulding material cost/kg (₦/kg)} &= 12.02 \\
 \text{Fettling material cost/kg (₦/kg)} &= 2.63
 \end{aligned}$$

$$\text{Liquid Charge cost/kg (₦/kg)} = 7.26$$

$$\text{Thermotip cost/kg (₦/kg)} = 0.7$$

$$\text{Direct expenses cost/kg (₦/kg)} = 3.5$$

$$\text{Direct labour cost/kg (₦/kg)} = 13.6$$

$$\text{I. Partial Direct Material Cost (PDMc)} = \text{Linning} + \text{Moulding} + \text{Fettling} + \text{Liquid} + \text{Thermotip}$$

$$= 0.8 + 12.02 + 2.63 + 7.26 + 0.7$$

$$\text{₦23.41}$$

$$\text{II. Pattern Cost (PTc)} = 30\% (\text{PDMc} + \text{Direct Expenses Cost} + \text{Direct labour cost})$$

$$= 30\% (23.41 + 3.5 + 13.6)$$

$$= \text{₦12.15}$$

$$\text{III. Total Direct Material Cost (TDMc)} = \text{PTc} + \text{PDMc}$$

$$= 12.15 + 23.41$$

$$= \text{₦35.56}$$

$$\text{IV. Complexity Cost (CFc)} = \text{Complexity Factor (CF) (TDMc} + \text{Direct Labour Cost} + \text{Direct Expenses Cost)]}$$

$$= 0.05 (35.56 + 13.6 + 3.5)$$

$$= \text{₦2.633}$$

$$V. \quad \text{Production Cost (Pc}_{ij}) = 1.05 (1 + 0.05) \times (182.45 + 13.6 + 3.5)$$

$$(Pc_{ij})/\text{kg} = \text{₦}58.06$$

$$\text{For } 8.71\text{kg} = 58.06 \times 8.71$$

$$= \text{₦}505.7026$$

$$(Pc_{ij})/\text{Unit} = \text{₦}505.70$$

BRASS MATERIAL

$$\text{Weight of Brass for Boss} = 10.254\text{kg}$$

$$\text{Linning material cost/kg (₦/kg)} = 0.8$$

$$\text{Moulding material cost/kg (₦/kg)} = 12.02$$

$$\text{Fettling material cost/kg (₦/kg)} = 2.63$$

$$\text{Liquid Charge cost/kg (₦/kg)} = 120.80$$

$$\text{Thermotip cost/kg (₦/kg)} = 0.7$$

$$\text{Direct expenses cost/kg (₦/kg)} = 3.5$$

$$\text{Direct labour cost/kg (₦/kg)} = 13.6$$

$$I. \quad \text{Partial Direct Material Cost (PDMc)} = \text{Linning} + \text{Moulding} + \text{Fettling} + \text{Liquid} + \text{Thermotip}$$

$$= 0.8 + 12.02 + 2.63 + 120.80 + 0.7$$

$$\text{₦}136.95$$

$$\text{II. Pattern Cost (PTc)} = 30\% (\text{PDMc} + \text{Direct Expenses Cost} + \text{Direct labour cost})$$

$$30\% (136.95 + 3.5 + 13.6)$$

$$= \text{₹}46.22$$

$$\text{III. Total Direct Material Cost (TDMc)} = \text{PTc} + \text{PDMc}$$

$$= 46.22 + 136.40$$

$$= \text{₹}183.17$$

$$\text{IV. Complexity Cost (CFc)} = \text{Complexity Factor (CF) (TDMc} + \text{Direct Labour Cost} + \text{Direct Expenses Cost})]$$

$$= 0.05 (183.17 + 13.6 + 3.5)$$

$$= \text{₹}10.01$$

$$\text{V. Production Cost (Pc}_{ij}) = 1.05 (1 + 0.05) \times (183.17 + 13.6 + 3.5)$$

$$(\text{Pc}_{ij})/\text{kg} = \text{₹}220.80$$

$$\text{For } 10.254\text{kg} = 220.80 \times 10.254$$

$$= 2,264.0832$$

$$(\text{Pc}_{ij})/\text{Unit} = \text{₹}2,264.08$$

MANUAL COST ESTIMATION FOR FLANGE (CALCULATED APPROACH)

- ALUMINIUM MATERIAL

Weight of Aluminium for Flange = 4.08kg

Linning material cost/kg (₦/kg) = 0.8

Moulding material cost/kg (₦/kg) = 12.02

Fettling material cost/kg (₦/kg) = 2.63

Liquid Charge cost/kg (₦/kg) = 120.25

Thermotip cost/kg (₦/kg) = 0.7

Direct expenses cost/kg (₦/kg) = 3.5

Direct labour cost/kg (₦/kg) = 13.6

I. Partial Direct Material Cost (PDMc) = Linning + Moulding + Fettling +
Liquid + Thermotip

$$= 0.8 + 12.02 + 2.63 + 120.25 + 0.7$$

$$₦136.40$$

II. Pattern Cost (PTc) = 30% (PDMc + Direct Expenses Cost + Direct
labour cost)

$$30\% (136.40 + 3.5 + 13.6)$$

$$= ₦46.05$$

III. Total Direct Material Cost (TDMc) = PTc + PDMc

$$= 136.40 + 46.05$$

$$= ₦182.45$$

$$\text{IV. Complexity Cost (CFe)} = \text{Complexity Factor (CF) (TDMc + Direct Labour Cost + Direct Expenses Cost)]}$$

$$= 0.05 (182.45 + 13.6 + 3.5)$$

$$= \text{₦}9.98$$

$$\text{V. Production Cost (Pc}_{ij}) = 1.05 (1 + 0.05) \times (182.45 + 13.6 + 3.5)$$

$$(Pc_{ij})/\text{kg} = \text{₦}220.00$$

$$\text{For 4.08kg} = 220.00 \times 4.08$$

$$= \text{₦}897.60$$

$$(Pc_{ij})/\text{Unit} = \text{₦}897.60$$

- CAST IRON MATERIAL

$$\text{Weight of Cast Iron for Flange} = 11.818\text{kg}$$

$$\text{Linning material cost/kg (₦/kg)} = 0.8$$

$$\text{Moulding material cost/kg (₦/kg)} = 12.02$$

$$\text{Fettling material cost/kg (₦/kg)} = 2.63$$

$$\text{Liquid Charge cost/kg (₦/kg)} = 7.26$$

$$\text{Thermotip cost/kg (₦/kg)} = 0.7$$

$$\text{Direct expenses cost/kg (₦/kg)} = 3.5$$

$$\text{Direct labour cost/kg (₦/kg)} = 13.6$$

$$\text{I. Partial Direct Material Cost (PDMc)} = \text{Linning} + \text{Moulding} + \text{Fettling} + \text{Liquid} + \text{Thermotip}$$

$$= 0.8 + 12.02 + 2.63 + 7.26 + 0.7$$

$$= \text{₺}23.41$$

$$\text{II. Pattern Cost (PTc)} = 30\% (\text{PDMc} + \text{Direct Expenses Cost} + \text{Direct labour cost})$$

$$= 30\% (23.41 + 3.5 + 13.6)$$

$$= \text{₺}12.15$$

$$\text{III. Total Direct Material Cost (TDMc)} = \text{PTc} + \text{PDMc}$$

$$= 12.15 + 23.41$$

$$= \text{₺}35.56$$

$$\text{IV. Complexity Cost (CFc)} = \text{Complexity Factor (CF)} (\text{TDMc} + \text{Direct Labour Cost} + \text{Direct Expenses Cost})$$

$$= 0.05 (35.56 + 13.6 + 3.5)$$

$$= \text{₺}2.633$$

$$\text{V. Production Cost (Pc}_{00}) = 1.05 (1 + 0.05) \times (182.45 + 13.6 + 3.5)$$

$$(\text{Pc}_{00})/\text{kg} = \text{₺}58.06$$

$$\text{For } 11.818\text{kg} = 58.06 \times 11.818$$

$$= \text{₦}686.1530$$

$$(Pc_{(1)})/\text{Unit} = \text{₦}686.15$$

- BRASS MATERIAL

$$\text{Weight of Brass for Boss} = 13.9128\text{kg}$$

$$\text{Linning material cost/kg (₦/kg)} = 0.8$$

$$\text{Moulding material cost/kg (₦/kg)} = 12.02$$

$$\text{Fettling material cost/kg (₦/kg)} = 2.63$$

$$\text{Liquid Charge cost/kg (₦/kg)} = 120.80$$

$$\text{Thermotip cost/kg (₦/kg)} = 0.7$$

$$\text{Direct expenses cost/kg (₦/kg)} = 3.5$$

$$\text{Direct labour cost/kg (₦/kg)} = 13.6$$

$$\text{I. Partial Direct Material Cost (PDMc)} = \text{Linning} + \text{Moulding} + \text{Fettling} + \text{Liquid} + \text{Thermotip}$$

$$= 0.8 + 12.02 + 2.63 + 120.80 + 0.7$$

$$= \text{₦}136.95$$

$$\text{II. Pattern Cost (PTc)} = 30\% (\text{PDMc} + \text{Direct Expenses Cost} + \text{Direct labour cost})$$

$$30\% (136.95 + 3.5 + 13.6)$$

$$= \text{₦}46.22$$

$$\begin{aligned}
 \text{III. Total Direct Material Cost (TDMc)} &= P_{Tc} + P_{DMc} \\
 &= 46.22 + 136.95 \\
 &= \text{₦}183.17
 \end{aligned}$$

$$\begin{aligned}
 \text{IV. Complexity Cost (Cfc)} &= \text{Complexity Factor (CF) (TDMc + Direct} \\
 &\text{Labour Cost + Direct Expenses Cost)]} \\
 &= 0.05 (183.17 + 13.6 + 3.5) \\
 &= \text{₦}10.01
 \end{aligned}$$

$$\begin{aligned}
 \text{V. Production Cost (Pc}_{(i)}) &= 1.05 (1 + 0.05) \times (183.17 + 13.6 + 3.5) \\
 (Pc_{(i)})/\text{kg} &= \text{₦}220.80
 \end{aligned}$$

$$\text{For } 13.9128\text{kg} = 220.80 \times 13.9128$$

$$= 2,264.0832$$

$$(Pc_{(i)})/\text{Unit} = \text{₦}3,071.95$$

APPENDIX VI

NIGERIA MACHINE TOOLS LIMITED OSOGBO

FOUNDRY JOB COST ESTIMATE SHEET

CUSTOMER:.....
 JOB DESCRIPTION:.....
 MATERIAL SPECIFICATION:.....
 QUANTITY ORDERED:.....
 TOTAL WEIGHT (OUTPUT):.....(KG)

(A) DIRECT MATERIALS

S/N	DESCRIPTION	QUANTITY (KG)	UNIT PRICE (N)	COST (N)
1.	Lining materials			
2.	Liquid metal			
3.	Moulding materials			
4.	Pettling materials			
5.	Thermo tip			
6.	Pattern			
TOTAL MATERIAL COST				

(B) DIRECT LABOUR

Labour Cost

(C) DIRECT EXPENSES

S/N	DESCRIPTION	AMOUNT (N)
1.	Electricity	
2.	Water	
3.	Diesel	
TOTAL DIRECT EXPENSES		

(D) HEAT TREATMENT

DESCRIPTION	AMOUNT (N)
TOTAL HEAT-TREATMENT	

COST SUMMARY N

(A) Materials cost:..
 (B) Direct Labour:....
 (C) Direct Expenses:..
 (D) Heat Treatment:.....
 (E) Complexity Factor:.....
 TOTAL COST:.....

(E) COMPLEXITY FACTOR

AMOUNT (K)
 1. PREPARED BY:..
 2. CHECKED BY: (MANAGER, FOUNDRY)
 3. APPROVED BY: (COST & MANAGEMENT)
 4. APPROVED BY: (AGM COMMERCE)

Cost of Machining (if any).....
 Related over head:
 Cost of production:.....
 Profit Margin:.....
 VAT:.....
 Selling price:.....
 Selling price/piece:...

GERIA MACHINE TOOLS LIMITED



1, Ikirun Road,
B. 4343,
Ogbo,
Ile-Ife,
Oyo State,
Nigeria.
Phone: 035-242500-3

FAX: 035-240002
NMT@Infoweb Abs. Net

Cable: NIGERTOOLS

The Head of Department
Dept. of Mech. / Prod. Eng.
Federal University of Technology
Akure.

Our ref:

Date:

Your ref:

Date:

PD/4.0

1ST February, 2001

Attn: Engr. Dr. O.P. Fapetu

Dear Sir,

RE: REQUEST FOR ASSISTANCE TO USE YOUR FACILITY

Your letter dated 18th January 2001 in respect of the above subject matter refers.

Please be informed that approval has been granted to Engr. Pastor S.B. Adejuyigbe as requested but within available facility and without extra cost to the company.

You may wish to convey this approval to him to enable him take necessary steps.

Yours faithfully,

For: NIGERIA MACHINE TOOLS LTD.

Elder J.O. Akinrinade
Assistant General Manager,
(Personnel / Admin.)