ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

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On

Investigating the effect of gas porosity on selected Mechanical properties and Machinability characteristics of Aluminium cast materials (AA6082).

By

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DECLARATION

I declare that the thesis which is being presented entitled as "Investigating the effect of gas porosity on selected Mechanical properties and Machinability characteristics of Aluminium cast materials (AA6082)" in partial fulfilment of the requirements for the award of the degree of Masters of Science (MSc.) in Manufacturing Engineering is an authentic record of my own work carried out under the supervision of Dr. Bhaskaran, program of Mechanical Design and Manufacturing Engineering at the University of Adama Science and Technology University, Ethiopia.

The matter embodied in this thesis has not previously been submitted for MSc. Degree or any other certificate at this or any other universities, and that all resources of materials used for this thesis have been duly acknowledged.

Tesfaye Haregeweyn ______________________ ____________________

Candidate Signiture Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for Examination with my approval.

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Abstract

This research paper investigates the effect of gas porosity on selected mechanical properties and machinability characteristics of aluminium alloy AA6082. The material has been casted as per predetermined specification of casting process and the products or samples allowed to pass through different machining process and destructive testing methods to check the machinability and mechanical properties of the prepared samples.

The thesis tries to address sand casting gas porosity as one of the most influential factors which affects the mechanical properties and machinability characteristics of cast aluminium (AA6082). Focus has been given specially on gas porosity (pin hole and blow holes) due to hydrogen and nitrogen gases on the mould. Brief description has been made on sand casting processes, as one of the most important manufacturing process and defects on it. In Addition to that the factors affecting machinability characteristics and mechanical properties of cast aluminium were also studied as a review of literature.

In this thesis different cast aluminium samples were considered: Defect free samples and samples with defects of different level, which intentionally made for investigation purposes. The material composition of each samples were taken as constant (AA6082) and, nature and degree of defects will be vary by varying the moisture content and venting mechanisms of the mould. The surface finishes of the machined samples, chips produced, and material removal rate (MRR) for different level defect cast aluminium sample has been studied to check machinability characteristics. Mechanical properties like hardness, impact, tensile strength, and torsional tests were conducted on the samples to understand the difference on mechanical properties of each sample specimen. The experiments and tests were conducted on turning cylindrical samples and different destructive testing machines. Various types of equipment and instruments were used for checking the samples and conducting the experiments as well. Lastly the result of the experiment shows, sand casting gas porosity have a negative effect on machinability and mechanical properties of cast aluminium alloy AA6082.

Keywords: cast aluminium, destructive testing, sand casting defects, machinability characteristics, mechanical properties.

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LIST OF ABBREVIATIONS AND ACRONYMS

AA- Aluminium Alloy

ABMI- Akaki Basic Metals Industry

AISA- American Iron and Steel Industry

AJM- Abrasive Jet Machining

Al. – Aluminium

ASTU-Adama Science and Technology University

BC-Before Christ

BHN- Brinel Hardness Number

CAD- Compuer Aided Design

Ca. – Calcium

CNC- Computer Numerical Control

EBM- Electron Beam Machining

ECM- Electrochemical Machining

EDM- Electron Discharge Machining

HMMBI- Hibret Manufacturing and Machine Building Industry

LBM- Lather Beam Machining

LJM- Lather Jet Machining

MMC- Metal Matrix Composites

MPa- Mega Pascal

MRR- Material Removal Rate

NC- Numerical Control

RPM- Rubber Plastic Moulding

rpm- revolution per minute

SDAS- Secondary Arm Spacing

USM- Ultra Sonic Machining

VHN- Vickers Hardness Number

WJM- Water Jet Machining

Zn. - Zinc

LIST OF SYMBOLS

CO_2 = Carbon dioxide

CO = Carbon monoxide

D = Diameter

d = Depth of cut

F = Force

f = Feed

G = Shear Modulus

h = Height

J = Joule

L = Load

T = Tool life

v = Speed

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Casting is one of the oldest methods to manufacture objects with cast copper components dating back to 3000 BC having been found in archaeological surveys. Cast iron was developed in China around 600 BC. Cost-effective cast aluminium alloys and magnesium alloys are all twentieth-century innovations [1]. Metal casting process begins by creating a mould, which is made from a refractory material, the 'reverse' shape of the part we need. The metal is heated in an oven until it melts, and the molten metal is poured into the mould cavity. The liquid takes the shape of cavity, which is the shape of the part we need to produce. It is cooled until it solidifies, and finally the solidified metal part is removed from the mould and fettling is accomplished. Lastly heat treatment, cleaning and finishing as well as inspection will be done as shown in figure 1.1. In doing this it is very difficult to produce defect free castings due to its dependence on many parameters.

Casting defects are the result of a single cause or a combination of causes. The castings may have one or more defects at a time. Because the remedy of one casting defect may be the cause of another casting defects [2]. Because to solve sand erosion it is possible to increase the clay content and ram it well. But it can restrict the air to escape and creates air bubble cavity. Even in completely controlled process, defect in casting are observed and hence casting process is also known as process of uncertainty which challenges explanation about the cause of casting defects. Mostly casting defects are concerned with process parameters. Hence one has to control the process parameter to achieve zero defect parts. For controlling process parameter one must have knowledge about effect of process parameters on casting and their influence on defect. [3].

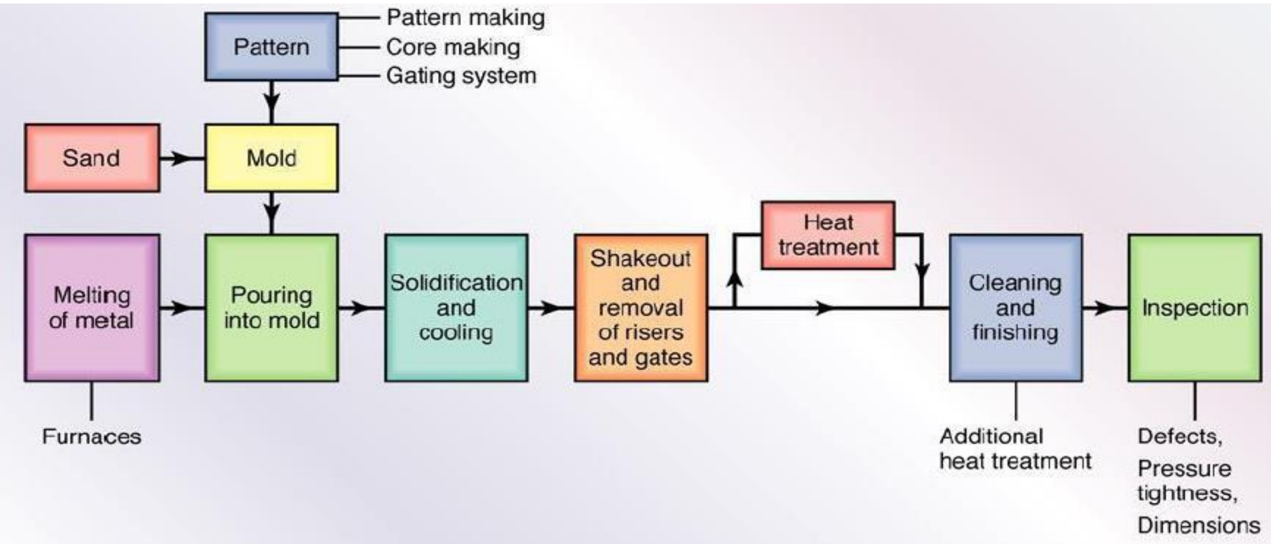


Figure1.1. General Procedures and steps for making sand casting process (sources http://www.daneprairie.com)

The history of machining goes back to the middle of the eighteenth century when there was a need for making metallic parts of the steam engine; it is noted that prior to this there were some machining operations used to craft wood. Since then, the field of machining has come a long way indeed [1]. The final and finished product with desired shape, size, and surface roughness will come using machining processes. Machining is an essential process of finishing by which work pieces are produced to the desired dimensions and surface finish by gradually removing the excess material from the preformed blank in the form of chips with the help of cutting tool as shown in figure 1.2.

The machinability characteristics and mechanical properties of cast materials are affected by different factors. Among the factors that affects mechanical properties, hence affecting machinability characteristics are presented in this paper, as casting defects.

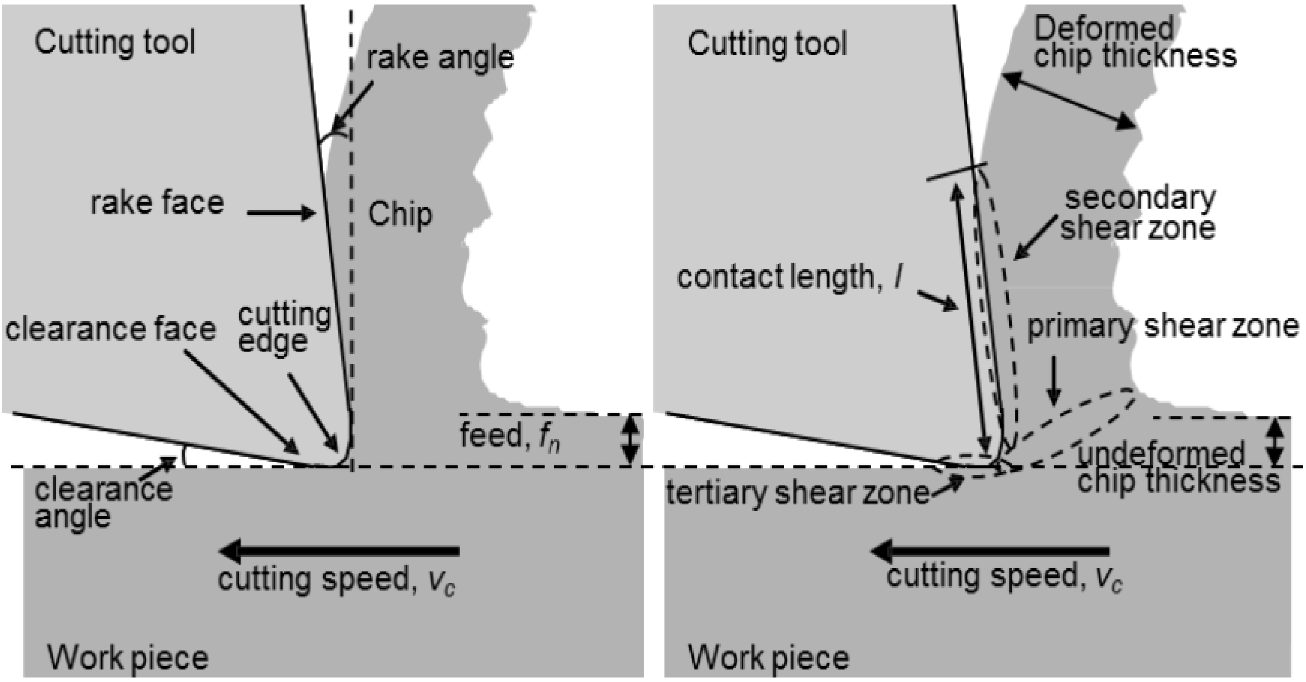


Figure 1.2. Schematic illustrations of the chip formation process and the three shear zones in metal cutting (Niclas Anmark, 2016)

Casting defects can negatively affect the bottom line of a foundry. At the simples' level, they manifest as rework costs or casting scrap costs as shown in figure 1.3. However, in many cases, the casting defects may be discovered at the machining stage, at the assembly stage or during use of the component. The resultant value added costs and warranty costs may sometimes be passed on to the foundry by their customer [5]. Casting defects result in increased unit cost and lower morale of shop floor personnel. These charges also may be significantly more than the cost of the casting itself. Castings with defects very often have to be scrapped. This is a major cost for the foundry, both in terms of productivity and, often, reputation.

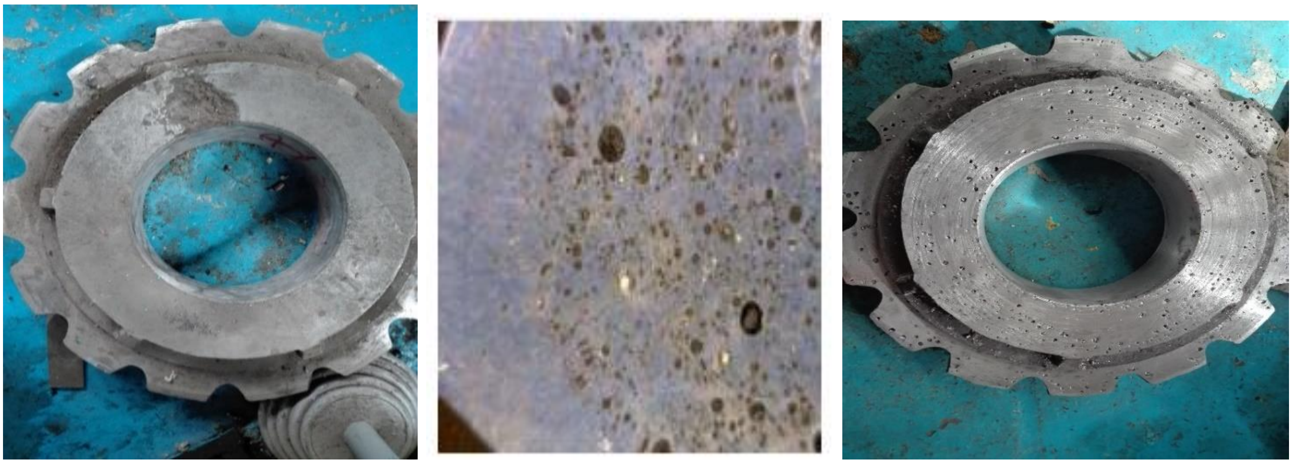
Defects that have slipped through inspection have the highest value as they may not be discovered until they reach the machining stage or, even worse, the end user [6].

Defects in castings may be of three basic types based on their effects on the foundry [5]

- Major defects, which cannot be rectified, resulting in rejection of the casting and total loss;
- Defects that can be remedied but whose cost of repair may not justify the salvage attempt;
- Minor defects, which clearly allow the castings to be economically salvaged and thereby leave a reasonable margin for profit.

The cause of defects is often a combination of several factors rather than a single one. For defect analysis, the possible causes are grouped into design, material and process parameters.
Broadly, the defects may be caused due to:

- Unsuitable or unsatisfactory raw materials used in moulding, pattern and core making or casting;
- The application of unsatisfactory moulding or casting practice by the individual worker or incorrect advice by the supervisor;
- The use of improper tools, equipment, appliances, or patterns, and
- Unprofessional management policies procedure, faulty organisation and poor work discipline, or lack of training. [5][7].



(a) sand inclusion (b) blow holes (c) gas porosity

Figure 1.3. Some types of sand casting defects [ABMI]

Similar to the foundry, casting defect impacts the mechanical properties, hence affecting machinability characteristics of cast aluminium materials. The term machinability refers to the ease or difficulty with which a work material is machined under a given set of cutting conditions. It is a term indicating how the work material responds to the cutting process [8].

Machinability is how readily a particular workpiece material can be machined by a cutting tool in a manner such that certain predetermined levels of form, size and degree of roughness of the surface can be achieved [4].

In the most general case good machinability means that material is cut with good surface finish/integrity, high metal removal rate, long tool life, low force and power requirements, well broken chips, uniform dimensional accuracy and low cost.

The different factors influencing machinability of a material are

(i) Machining operations,
(ii) Cutting conditions,
(iii) Workpiece properties,
(iv) Tool properties, and
(v) Machine tool-tool-workpiece dynamics.

For in case of machining sand cast materials, casting defects also affecting the mechanical properties and machinability characteristics of cast aluminium.

1.2. Statement of the problem

Foundry industries in developing countries suffer from poor quality and productivity due to involvement of number of process parameter, combined effect of manufacturing automation and shortage of skilled workers compared to other developed industries as compared in figure 1.4. Even in completely controlled process, defect in casting are observed and hence casting process is also known as process of uncertainty which challenges explanation about the cause of casting defects. Foundries are still using trial and error methods to solve quality problems. Global buyers demand defect-free castings and strict delivery schedule, which foundries are finding it very difficult to meet. Among these industries in Ethiopia, Akaki basic metals industry is the major government owned model industry used not only for manufacturing metallic products but also used as a training and research centre for all higher Education Engineering students and other researchers in the country. It is intended to respond the need of spare parts for textile, sugar, cement industries, other construction supplies, metal industries, transport sector and to some extent to agriculture, energy and mines sector. Most of its products are moved to Hibret manufacturing and machine building industry for finishing purposes or machining processes. A few parts are machined there and delivered to the customer directly.

In doing all the above machining activities, it is obvious to observe:

- Machining instability and listening unexpected noise repeatedly due to sudden collision (touching) of cutting tool with the defective parts like sand inclusion, blowhole, crack, and cavities of the product results in the reduction of the machinability and affecting mechanical properties, hence it affects the surface roughness, tool life, and overall productivity of the foundry and machining industries. More specifically it has been observed;
    - More defects occurred in a product and filled with welding to avoid discontinuity.
    - The defects are revealed during machining & grinding stage (poor surface finishing)
    - Nocking type of sound is created when tool touches the defect part of the product (sudden breakage of cutting tool).
    - High frequency of machine tools corresponding to the defects.

In literature many researcher investigated which is related to casting defects with machinability and mechanical properties; but there is no clear information regarding to it and which has been found as a research gap.

- To assess the relationship among casting defects with machinability and mechanical properties of cast materials especially cast aluminium ally (AA6082).
- As a starting point for researcher to look at there and further study.
- To think that effect of casting defect doesn't ended at foundry level (by rejection) but also extends its effect on machining process and reduce productivity at both levels.

Having knowledge on the effect of casting defects on the machinability characteristics and mechanical properties enables to focus in minimization of casting defects since it influences the productivity through increasing cutter damage and slow down the operation process. In point view of this study casting defects can be considered as one of the critical factors determining the mechanical properties and machinability, hence reducing productivities in both at foundry and machining levels through increasing rejections and decreasing the service year of the products.

(a) Imported shafts for sprockets made by metal forming (sources HMMBI)

(b) Locally manufactured sprockets with casting (sources HMMBI)

Figure 1.4. Comparison of defective and defect free cast materials (HMMB)

1.3. Objective of the study

1.3.1. General objective

The general objective of this thesis is to investigate, the effects of sand casting gas porosities on mechanical properties and machinability characteristics of cast aluminium alloy (AA 6082) through experiment.

1.3.2. Specific objective

The specific objective of this thesis depicted as follows.

- To cast aluminium test specimens as per the predetermined specifications.
- To perform experimental tests on major machinability characteristics such as surface finish, chip morphology, tool life and material removal rate.
- To performing experimental tests on major mechanical properties, Hardness, impact, torsional and tensile strength.
- To analysing the results which found from the experimental tests.
- To investigate the effect of gas porosity on mechanical properties and machinability characteristics

1.4. Significance of the study

The significances of this study are mentioned as follows:

- To increase the cutting tool life through reducing sudden breakage by giving attention on casting defects as a major factor for tool life.
- To improve mechanical properties and machinability characteristics of cast aluminium materials by focusing on casting process.
- Lowering process time and total unit cost through giving attention on casting process to minimize casting defect.
- To improve productivity of machining processes through eliminating defective parts at foundry level
- To increase attentions of researchers on elimination of casting defects
- To reduce material rejection and rework processes at machining level.

1.5. Benefits and beneficiaries of the study

1.5.1. Benefits of the study

The benefits of the studies are the following:

- Improving mechanical properties and machinability characteristics, hence they increase the productivity of the machining industry and reducing the total unit cost of the product.
- Increasing the competence ability in the global market of the foundry and machining industries and reducing the material wastage, rejection, and rework process at both level.

1.5.2. Beneficiaries of the study

Beneficiaries from this study are depicted as follows:

- Akaki basic metals and a like industries by gaining feedback regarding to casting defect's influence on mechanical properties of machined product and machinability characteristics supported by experimental tests.
- Machining industries by gaining information about the relationship between casting defects, and mechanical properties and machinability characteristics supported by experimental tests.
- The researchers who needs to do further on this issue and related ideas.
- The researcher for acquiring knowledge and skills in the study and for the award of the master's degree.

1.6. Scope of the study

The scope of the thesis is to study the effect of casting defects (gas porosity) and reveal it as one of the critical factors determining the mechanical properties and machinability characteristics by doing experiments on different level cast defective and defect free specimens.

1.7. Organization of the paper

After assessing casting defects and factors affecting mechanical properties and machinability characteristics in the introduction and literature review parts, experimental setups and works will be discussed in the methodology part. The experimental tests will be accomplished as per the methodologies and materials required. As per the experimental results, discussion and presentation will be done. Lastly conclusion and recommendation will be forwarded for further study depending on the discussion and presentation.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

In this chapter it will be tried to review different literatures thought about the important points regarding to manufacturing processes specifically sand casting process and defects can exist on it, mechanical properties, machinability characteristics and factors affecting them. Focuses will be given to scholastic articles, journals, and studies which directs how sand casting defects (gas porosities) affecting mechanical properties and machinability characteristics. Since cutting tool life is one of the indexes of machinability, it should be known that talking about machinability is also talking about cutting too life indirectly. It should be also think that the microstructures, inclusion distribution and location, grain size, ununiformed shape, and cracks causing unsmooth motion between the cutting tool and workpiece which can affects machinability and tool life. Mechanical properties of cast metals will be elaborated in terms of microstructure, tensile strength, impact strength and hardness supporting using international studies.

2.2. Manufacturing processes

The art of converting raw material into finished goods with application of different types of tools, equipments, machine tools, manufacturing set ups and manufacturing processes, is known as **production**. Generally there are three basic types of production system that are given as under [9].

1. **Job production** (operator or group of operators to work upon a single job and complete it before proceeding to the next similar or different job. It requires fixed type of layout for developing same products).
2. **Batch production** (products less in number say 200 to 800) with variety of similar parts with very little variation in size and shape. Whenever the production of batch is over, the same manufacturing facility is used for production of other batch product or items. The batch may be for once or of periodical type or of repeated kinds after some irregular interval. Such manufacturing concepts are leading to GT and FMS technology. Manufacturing of products in this case requires process or functional layout.
3. **Mass production** (production of large number of identical products say more than 50000 that needs line layout type of plant layout which is highly rigid type and involves automation and huge amount of investment in special purpose machines to increase the production.

Manufacturing process is that part of the production process which is directly concerned with the change of form or dimensions of the part being produced. It does not include the transportation, handling or storage of parts like production process [9]. As per [9, 10] manufacturing defined as:
The English word manufacture is several centuries old. The term manufacture comes from two Latin words, **manus** (hand) and **factus** (make) combined gives made by hand.
As per oxford English dictionary manufacture refers “to make or produce goods in large quantities, using machinery”.

Working definition of manufacturing

There are two types of working definitions available for manufacturing: as a technical process and as an economic process [10].

Technologically: Manufacturing is the application of physical and chemical processes to alter the geometry, properties and or appearance of a given starting material to make parts or product as it fulfil the design requirement or specifications as shown in figure 2.1.

Economically: Manufacturing is the transformation of materials into items of greater value by means of one or more process and or assembly operation as shown in figure 2.2.

Manufacturing processes are technological methods to change the raw material from its raw form to the final product. It is the backbone of any industrialized nation. Manufacturing and technical staff in industry must know the various manufacturing processes, materials being processed, tools and equipments for manufacturing different components. Beside above, all kinds of the future engineers must know the basic requirements of workshop activities in term of man, machine, material, methods, money (5M) and other infrastructure facilities needed in a well-planned manufacturing organization [9].

2.2.1. Classification of manufacturing processes

Manufacturing processes can be classified as processing operation and assembly operation [10].

In ***processing operation*** the work material is transformed from one state to other advanced state. Through this operation value is added to the work material by changing the geometry; shape properties, appearance etc. of the starting work material. Usually processing operations are performed on individual component. But in some cases like aerospace industry, the processing operations are performed on assembled items also.

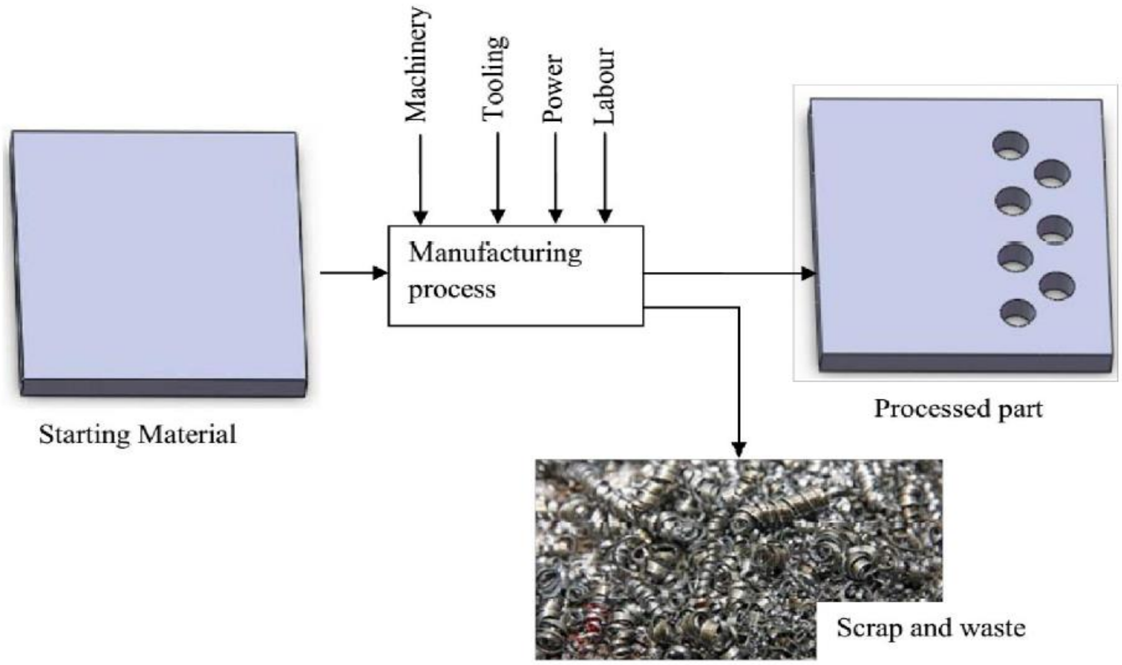


Figure2.1. Definition of manufacturing in terms of technology.
[Sources: http://nptel.ac.in/courses/107103012/module1].

In ***assembly operation*** two or more components are joined to create a new entity. The new entity is called assembly, subassembly based on its state in the product. If the entity is an intermediate state of the product, it is called subassembly. Some other terms are also referred based on the joining process. The assembly created by welding operation is called weld met.

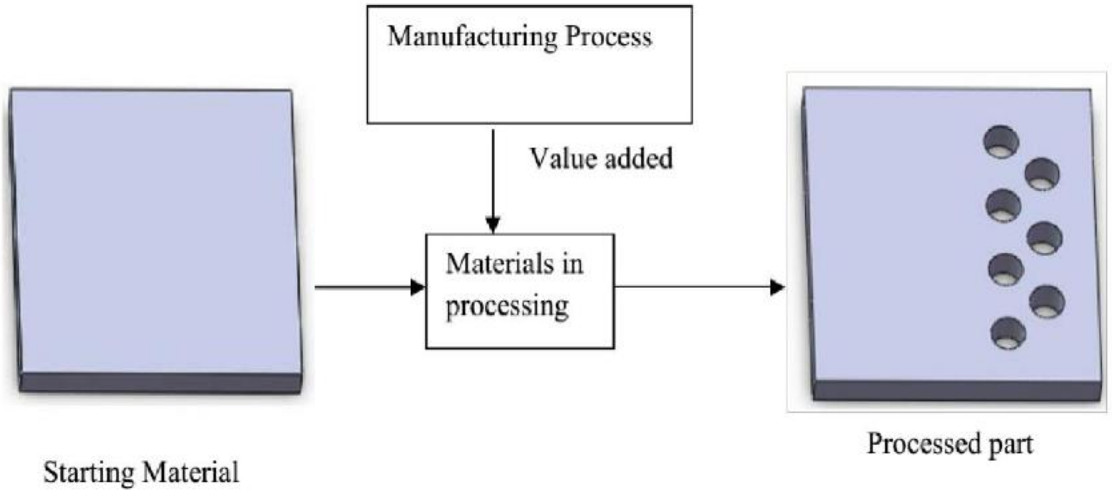


Figure 2.2. Definition of manufacturing in terms of economic value.
[Sources: http://nptel.ac.in/courses/107103012/module1].

For producing of products materials are needed. It is therefore important to know the characteristics of the available engineering materials. Raw materials used for manufacturing of products, tools, machines and equipments in factories or industries are extracted from ores. The ores are suitably converted the metal into a molten form by reducing or refining processes in foundries. This molten metal is poured into moulds for providing commercial castings, called ingots. Such ingots are then processed in rolling mills to obtain market form of material supply in form of bloom, billets, slabs and rods. These forms of material supply are further subjected to various manufacturing processes for getting usable metal products of different shapes and sizes in various manufacturing shops. All these processes used in manufacturing concern for changing the ingots into usable products may be classified as below [9].

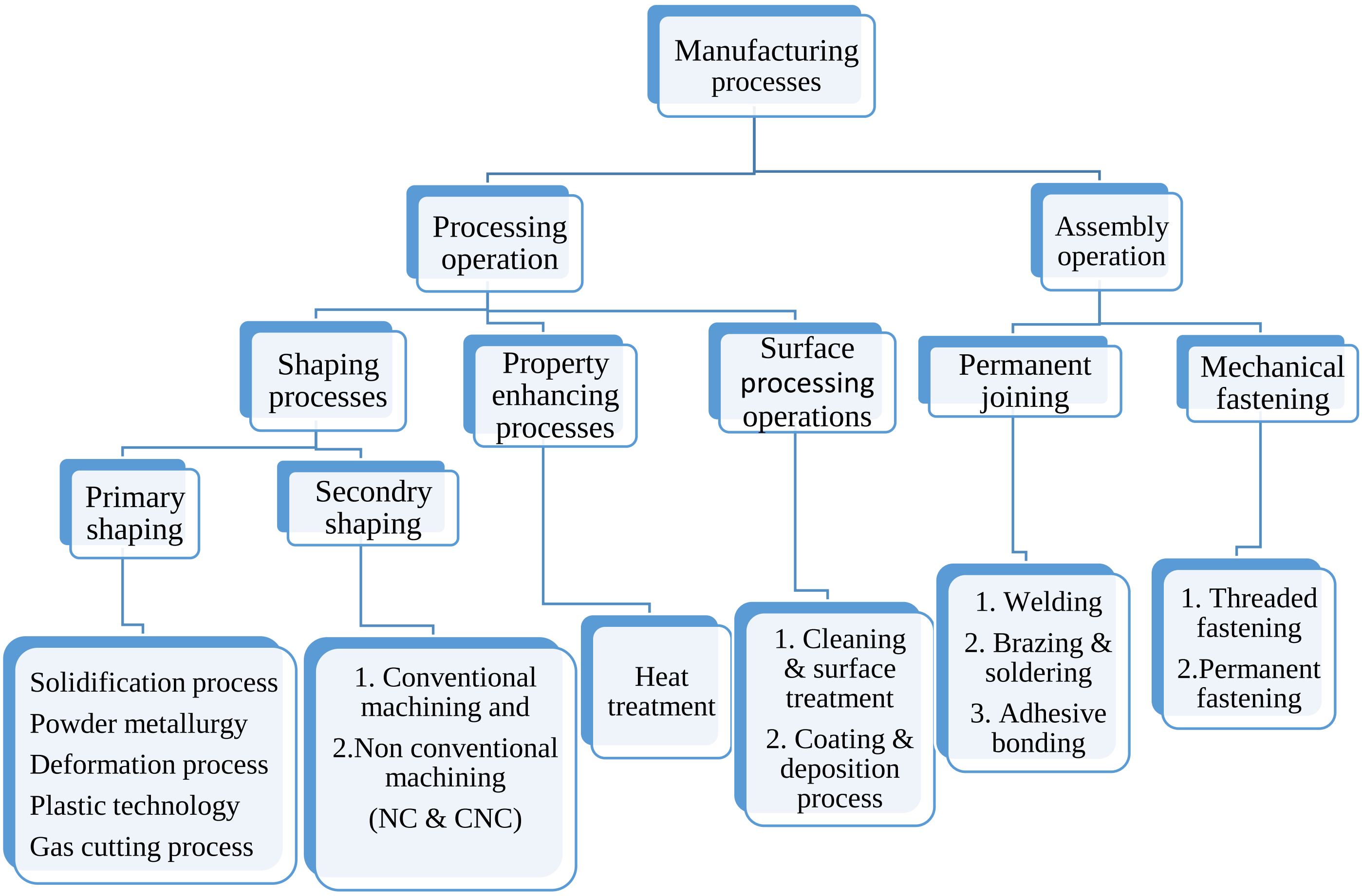


Figure. 2.3 Herarchical classification of manufacturing processes

1. **Primary shaping process**

Primary shaping processes are manufacturing of a product from an amorphous material. Some processes produces finish products or articles into its usual form whereas others do not, and require further working to finish component to the desired shape and size. Castings need re-melting of scrap and defective ingots in cupola or in some other melting furnace and then pouring of the molten metal into sand or metallic moulds to obtain the castings. Thus the intricate shapes can be manufactured. Typical examples of the products that are produced by casting process are machine beds, automobile engines, carburettors, flywheels etc. The parts produced through these processes may or may not require to undergo further operations. Some of the important primary shaping processes are:

(1) Casting, (2) Powder metallurgy, (3) Plastic technology, (4) Gas cutting, (5) Bending and (6) Forging.

2. **Secondary or Machining Processes**

As large number of components require further processing after the primary processes. These components are subjected to one or more number of machining operations in machine shops, to obtain the desired shape and dimensional accuracy on flat and cylindrical jobs. Thus, the jobs undergoing these operations are the roughly finished products received through primary shaping processes. The process of removing the undesired or unwanted material from the workpiece or job or component to produce a required shape using a cutting tool is known as machining. This can be done by a manual process or by using a machine called machine tool (traditional machines namely lathe, milling machine, drilling, shaper, planner, slotter machines). In many cases these operations are performed on rods, bars and flat surfaces in machine shops.

These secondary processes are mainly required for achieving dimensional accuracy and a very high degree of surface finish. The secondary processes require the use of one or more machine tools, various single or multi-point cutting tools (cutters), job holding devices, marking and measuring instruments, testing devices and gauges etc. for getting desired dimensional control and required degree of surface finish on the workpieces. The example of parts produced by machining processes includes hand tools machine tools instruments, automobile parts, nuts, bolts and gears etc. Lot of material is wasted as scrap in the secondary or machining process. Some of the common secondary or machining processes are:-

(1) Turning, (2) Threading, (3) Knurling, (4) Milling, (5) Drilling, (6) Boring, (7) Planning, (8) Shaping, (9) Slotting, (10) Sawing, (11) Broaching, (12) Hobbing, (13) Grinding, (14) Gear cutting, (15) Thread cutting and (16) Unconventional machining processes namely machining with Numerical Control (NC) machines tools or Computer Numerical Control (CNC) machine tools using ECM, LBM, AJM, USM setups etc.

3. Processes Effecting Change in Properties

Processes effecting change in properties are generally employed to provide certain specific properties to the metal work pieces for making them suitable for particular operations or use.

Some important material properties like hardening, softening and grain refinement are needed to jobs and hence are imparted by heat treatment. Heat treatments affect the physical properties and also make a marked change in the internal structure of the metal. Similarly the metal forming processes effect on the physical properties of work pieces. Similarly shot peening process, imparts fatigue resistance to work pieces. A few such commonly used processes are given as under:

(1) Annealing, (2) Normalising, (3) Hardening, (4) Case hardening, (5) Flame hardening,
(6) Tempering, , (7) Grain refining and (8) Age hardening.

In addition, some allied manufacturing activities are also required to produce the finished product such as measurement and assembly.

4. Surface Finishing Processes

Surface finishing processes are utilized for imparting intended surface finish on the surface of a job. By imparting a surface finishing process, dimension of part is not changed functionally; either a very negligible amount of material is removed from the certain material is added to the surface of the job. These processes should not be misunderstood as metal removing processes in any case as they are primarily intended to provide a good surface finish or a decorative or protective coating on to the metal surface. Surface cleaning process also called as a surface finishing process. Some of the commonly used surface finishing processes are:

(1) Honing, (2) Lapping, (3) Super finishing, (4) Belt grinding, (5) Polishing, (6) Tumbling,

(7) Organic finishes, (8) Sanding, (9) Electroplating, (10) Metal spraying, (11) Painting, (12) Inorganic coating, (13) Galvanizing, (14) Plastic coating, (15) Metallic coating, (16) Anodizing and (17) Sand blasting.

5. **Joining Processes**

Many products observed in day-to-day life, are commonly made by putting many parts together may be in subassembly. For example, the ball pen consists of a body, refill, barrel, cap, and refill operating mechanism. All these parts are put together to form the product as a pen.

More than 800 parts are put together to make various subassemblies and final assembly of car or aero-plane. A complete machine tool may also require to assemble more than 100 parts in various sub assemble or final assembly. The process of putting the parts together to form the product, which performs the desired function, is called assembly. An assemblage of parts may require some parts to be joined together using various joining processes. But assembly should not be confused with the joining process. Most of the products cannot be manufactured as single unit they are manufactured as different components using one or more of the above manufacturing processes, and these components are assembled to get the desired product.

Joining processes are widely used in fabrication and assembly work. In these process two or more pieces of metal parts are joined together to produce desired shape and size of the product. The joining processes are carried out by fusing, pressing, rubbing, riveting, screwing or any other means of assembling. These processes are used for assembling metal parts and in general fabrication work. Such requirements usually occur when several pieces are to be joined together to fabricate a desired structure of products. These processes are used developing steam or water-tight joints. Temporary, semi-permanent or permanent type of fastening to make a good joint is generally created by these processes. Temporary joining of components can be achieved by use of nuts, screws and bolts. Adhesives are also used to make temporary joints. Some of the important and common joining processes are:

(1) Welding (plastic or fusion), (2) Brazing, (3) Soldering, (4) Riveting, (5) Screwing,

(6) Press fitting, (7) Sintering, (8) Adhesive bonding, (9) Shrink fitting, (10) Explosive welding,

(11) Diffusion welding, (12) Keys and cotters joints, (13) Coupling and (14) Nut and bolt joints.

2.3. Metal casting processes

Casting is considered as one of the most important, the first step and ancient process of manufacturing metallic components. Metal casting process begins by creating a mould, which is the 'reverse' shape of the part we need. The mould is made from a refractory material, for example, sand. The metal is heated in an oven until it melts, and the molten metal is poured into the mould cavity. The liquid takes the shape of cavity, which is the shape of the part. It is cooled until it solidifies. Finally, the solidified metal part is removed from the mould.

A large number of metal components in designs we use every day are made by casting.

The reasons for this include [8]:

(a) Casting can produce very complex geometry parts with internal cavities and hollow sections.

(b) It can be used to make small (few hundred grams) to very large size parts (thousands of kilograms)

(c) It is economical, with very little wastage: the extra metal in each casting is re-melted and re-used

(d) Cast metal is isotropic – it has the same physical/mechanical properties along any direction.

2.3.1. Classification of metal casting processes

According to [8] casting process can be classified as follow by considering the mould materials into account.

i. Conventional sand moulding process
   a. Green sand moulding
   b. Dry sand moulding
   c. Flask less moulding
ii. Chemical sand moulding process
   a. Shell moulding
   b. Sodium silicate sand moulding
   c. No bake moulding
iii. Permanent mould casting
   a. Gravity die casting
   b. Low and high pressure die casting
iv. Special casting processess
   a. Lost wax
   b. Ceramic shell moulding
   c. Evaporative pattern casting
   d. Vaccuume sealed casting
   e. Centrifugal casting

In more general way the casting processes can be broadly classified into two [11]

a. Expendable mould casting
b. Permanent mould casting processes

2.3.1.1. Expandable mould casting process.

This method uses temporary, non-reusable moulds. After the molten metal in the mould cavity solidifies, the mould is broken to take out the solidified cast. Most of the casting process are carried out using expandable moulding processes since it is suitable for very complex shaped parts and materials with high melting point temperature. However, the rate of production is often limited by the time to make mould rather than the casting itself. Accordingly expandable mould casting is majorly classified as [11]

i. Sand Casting.

Sand casting is widely used for centuries because of the simplicity of the process. The sand casting process involves the following basic steps [11]:

(a) Place a wooden or metallic pattern in sand to create a mould
(b) Fit in the pattern and sand in a rating system
(c) Remove the pattern
(d) Fill the mould cavity with molten metal
(e) Allow the metal to cool, and
(f) Break the sand mould and remove the casting.

Sand casting uses natural or synthetic sand (lake sand) which is mostly a refractory material called silica (SiO_2) [10]. The sand grains must be small enough so that it can be packed densely; however, the grains must be large enough to allow gasses formed during the metal pouring to escape through the pores. Larger sized molds use green sand (mixture of sand, clay and some water). Sand can be re-used, and excess metal poured is cut-off and re-used also.

The sand casting process is usually economical for small batch size production. The quality of the sand casting depends on the quality and uniformity of green sand material that is used for making the mould. According to [12] various patterns are used to create cavity in the moulds wherein, pattern can be said as the replica of the final object to be made with some modifications considering different allowances. Depending on production quantities, different pattern materials namely wood, aluminium, ferrous metals are used in practice. These materials are used for low, moderate and high production quantities respectively.

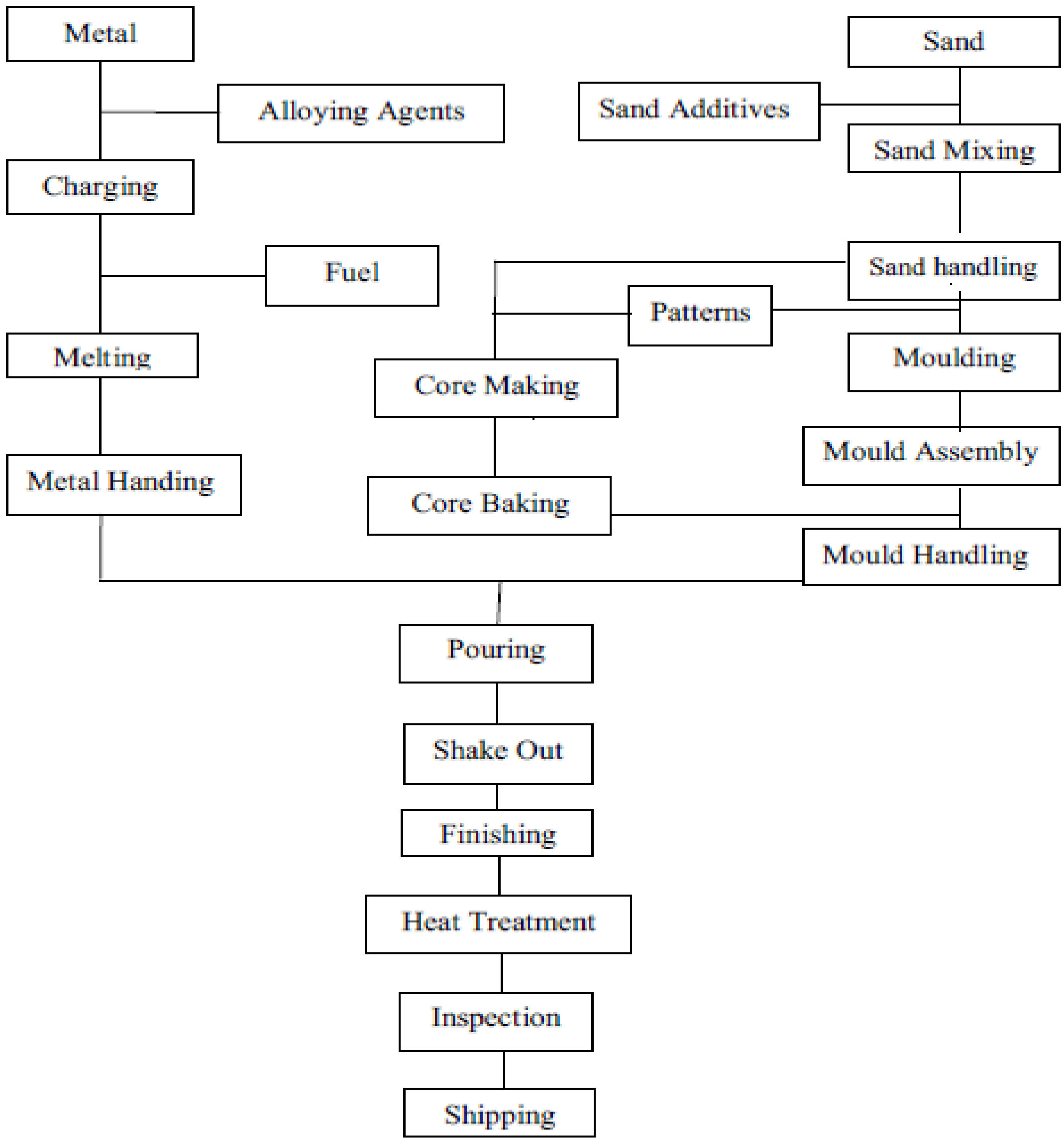


Figure 2.4. Schematic diagram for working flow of general sand casting process [9]

The below figure schematically shows a two-part sand mould, also referred to as a cope-and-drag sand mould. The molten metal is poured through the pouring cup and it fills the mould cavity after passing through down sprue, runner and gate. Core refers to loose pieces which are placed inside the mould cavity to create internal holes or open section. The riser serves as a reservoir of excess molten metal that facilitates additional filling of mould cavity to compensate for volumetric shrinkage during solidification. Sand castings process provides several advantages. It can be employed for all types of metal. The tooling cost is low and can be used to cast very complex shapes. However sand castings offer poor dimensional accuracy and surface finish.

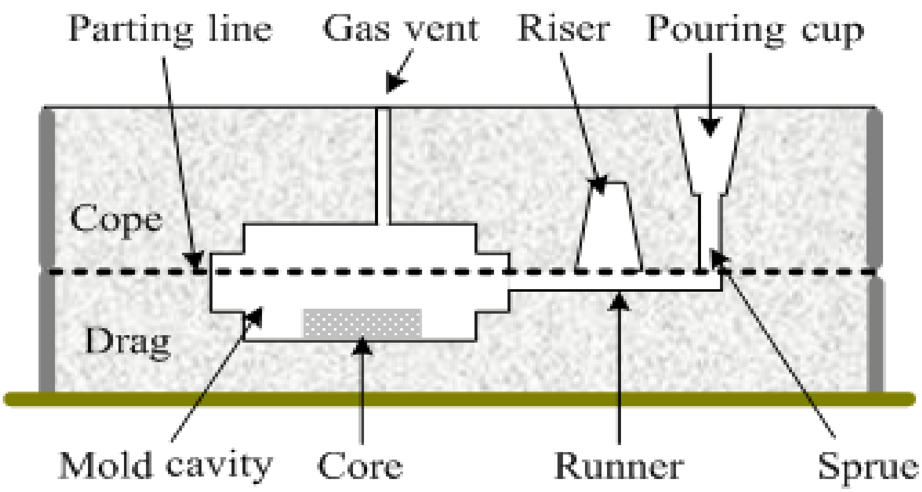


Figure 2.5 Schematic set-up of sand molding / casting process [11]

ii. Shell moulding

Shell moulding is similar to sand casting. Normally a machined pattern of grey iron or aluminium is used in this process. The pattern is heated to 250^0C to 260^0C [11] and the sand resin mixture is poured over its surface. The heated pattern melts the resin creating bonds between the sand grains. The mould cavity is now formed by a hardened shell of sand. The mould is then heated in an oven for further curing. The shell thus formed constitutes one half of the mould. Two such halves are placed over one another to make the complete mould. The sands used in shell moulding process are usually finer than the same used in sand casting. This process is ideal for complex shaped medium sized parts. This method can be employed for making an integrate shapes, thin and sharp corners small projection which are not possible in green sand mould. Subsequent machining operations are also reduced due to more dimensional accuracy.

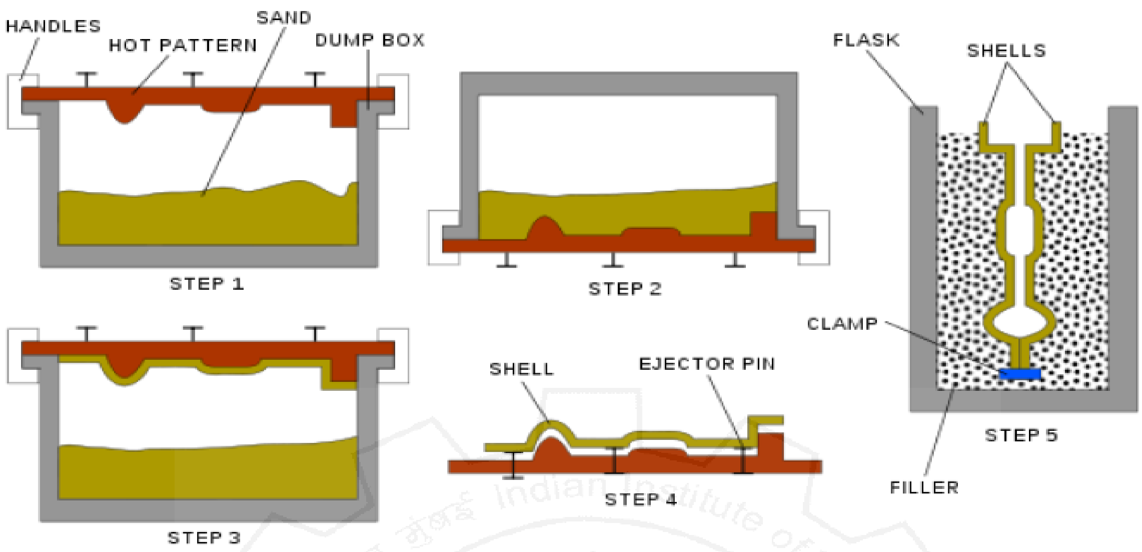


Figure 2.6 Schematic set-up of shell mould casting process [11]

iii. Investment casting

Investment casting is also referred to as lost-wax casting since the pattern is made of wax. The wax patterns are first dipped into a slurry of refractory material and subsequently, heated so that the wax melts away keeping a refractory mold. The mold is then further cured to achieve proper strength. Very high melting temperature material can be cast in *investment casting process* because of the refractory mold. The molten metal is poured into the mold and is taken out after solidification by breaking the mold. Very high dimensional accuracy and surface finish can be achieved in *investment casting* process. However, the tooling cost is usually high and hence, *investment casting* process is primarily used for large size batch production or for specific requirements of complex shape or casting of very high melting temperature material.

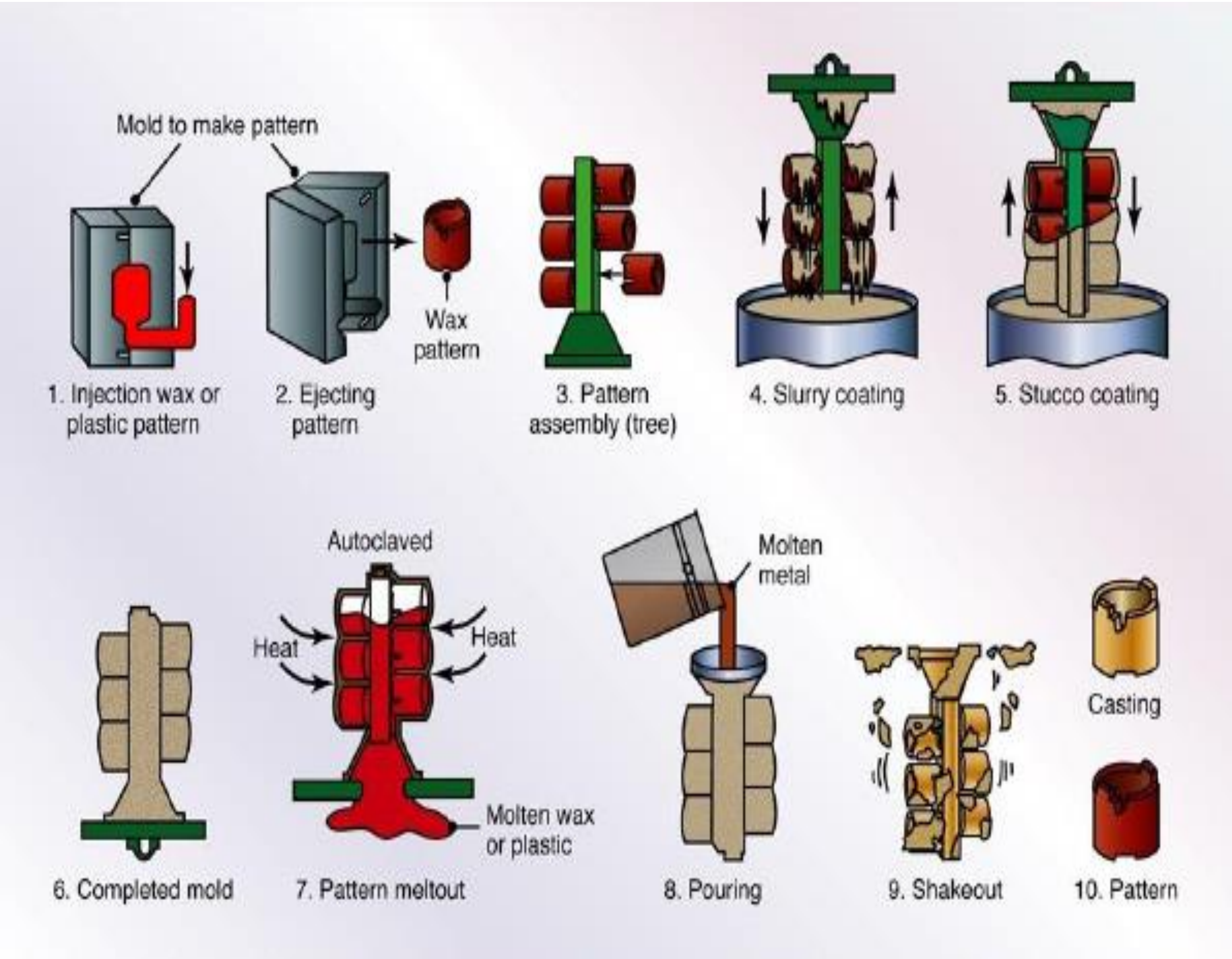


Figure 2.7. Basic steps involved in investment casting [13]

iv. Vacuum Casting

In this process, a mixture of fine sand and urethane is moulded over metal dies and cured with amino vapour. The moulted metal is drawn into the mould cavity through a gating system from the bottom of the mould. The pressure inside the mould is usually one-third of the atmospheric pressure. Because the mould cavity is filled under vacuum, the *vacuum casting* process is very suitable for thin walled, complex shapes with uniform properties.

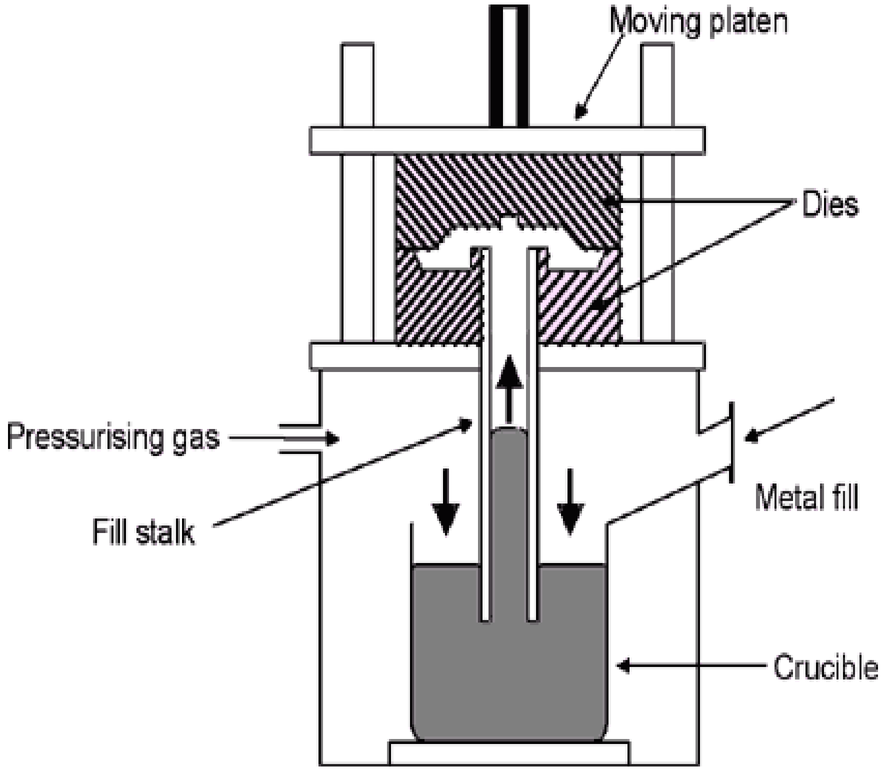


Figure 2.8 schematic set up of typical vacuum casting process [11]

v. Plaster mould casting

Plaster mould casting, also called rubber plaster moulding (RPM), is a method of producing aluminium or zinc castings by pouring liquid metal into typical plaster (gypsum) moulds. The plaster moulds used as negative moulds are created from gypsum and water. After mixing and forming the mould shape, the plaster moulds are dried and baked in an oven to remove any water remaining in the mould. Often, the moulds are made in two halves – i.e. cope and drag moulds – and the halves of the plaster moulds are clamped together with any required cores positioned appropriately in the mould. Molten metal is subsequently poured into the negative plaster mould and allowed to dry. The final part is taken out after breaking the mould. The final cast may require machining operation depending upon the requisite dimensional accuracy. This process is often used for producing prototypes of final part or component.

vi. Ceramic mould casting:

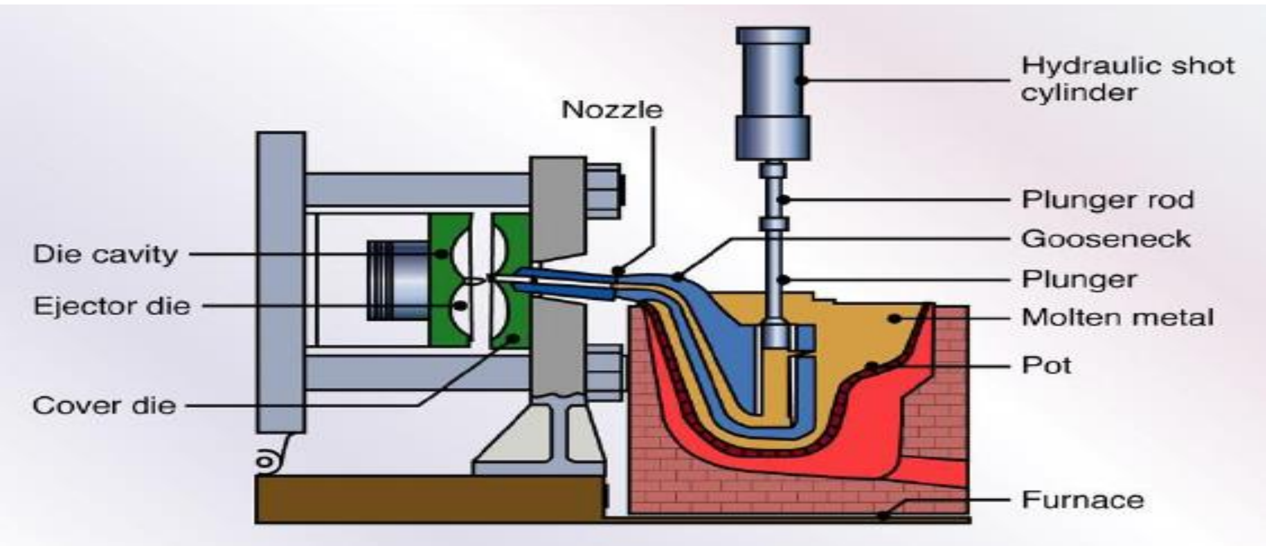
The ceramic mold casting is used to produce split molds from a quick-setting ceramic investment. Blended ceramic particles are mixed rapidly with liquid binder to form free flowing slurry that is poured quickly over a pattern. The casting does not require wax patterns and there are no limits to size or alloy. Foundry applications are large and complex impellers, valve bodies, and military hardware. The green strength of ceramic mould casting is high.

2.3.1.2. Permanent Mould Casting processes

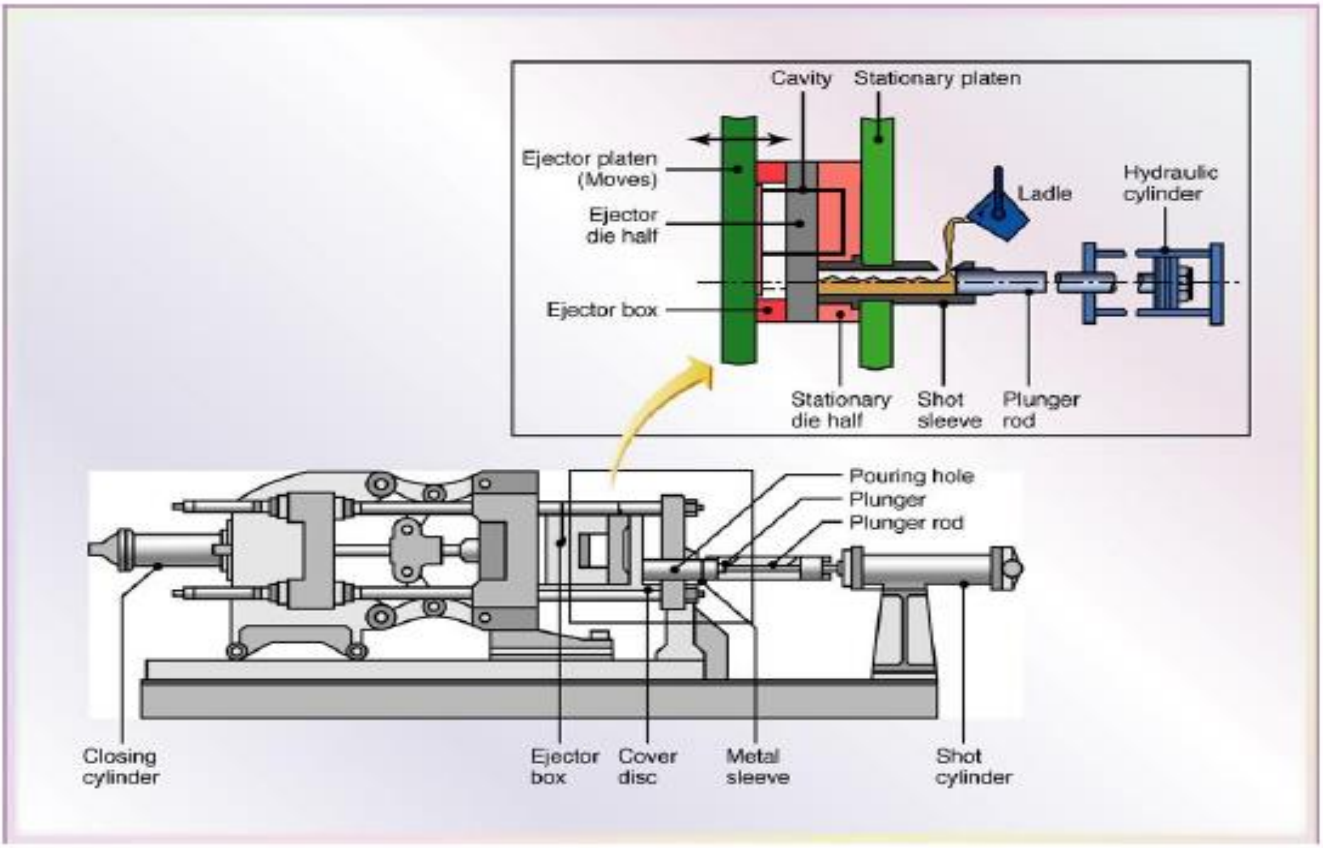
Permanent mould casting processes involve the use of metallic dies that are permanent in nature and can be used repeatedly. The metal moulds are also called dies and provide superior surface finish and close tolerance than typical sand moulds. The permanent mould casting processes can be classified as [11]

I. Pressures die casting

The *pressure die casting process* is the most common for Al, Zn and Mg castings (low melting point). The liquid metal is injected into the mold under high pressure and allowed to solidify at the high pressure. The solidified cast is then taken out of the mould or the die which is ready for the next cast. *Pressure die casting* is suitable for large batch size production. Two types of pressure die casting are generally common in the industry – (a) high pressure die casting and (b) low pressure die casting. Very high production rates can be achieved in pressure die casting process with close dimensional control of the casting. However, the process is not suitable for casting of high melting temperature materials as the die material has to withstand the melting (or superheated) temperature of the casting. Pressure die castings also contain porosity due to the entrapped air. Furthermore, the dies in the pressure die casting process are usually very costly. The figure below shows schematic representation of the hot-chamber and the cold-chamber die casting processes. In the hot-chamber die casting process, the furnace to melt material is part of the die itself and hence, this process is suitable primarily for low-melting point temperature materials such as aluminium, magnesium etc.



a) Figure 2.9. Schematic diagram of hot- chamber die casting process [14]



b) Figure 2.9. Schematic diagram of cold-chamber die casting processes [14]

II. Squeeze casting

Molten metal is poured into a metallic mould or die cavity with one-half of the die squeezing the molten metal to fill in the intended cavity under pressure as shown in Figure below.

Fibber reinforced casting with SiC or Al_2O_3 fibres mixed in metal matrix have been successfully squeeze cast and commercially used to produce automobile pistons. However, squeeze casting is limited only to shallow part or part with smaller dimensions.

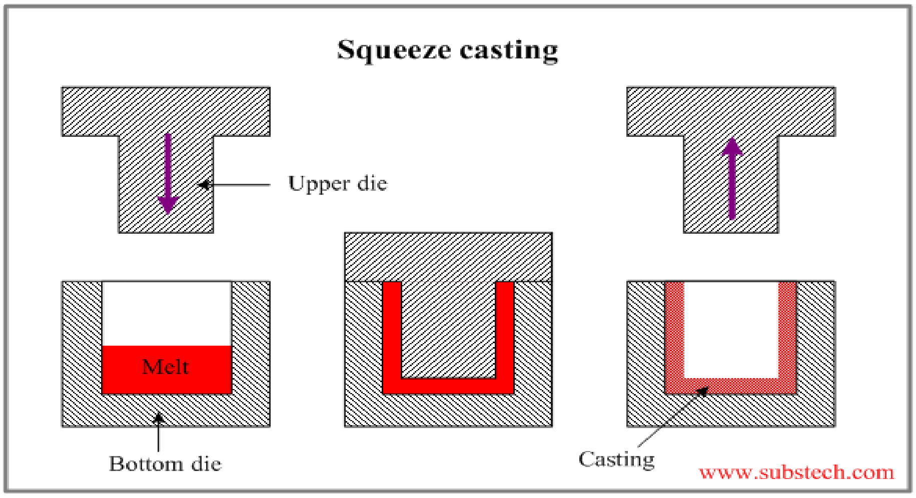


Figure 2.10. Schematic set-up of squeeze casting process [11]

III. Centrifugal casting

In centrifugal casting process, the molten metal poured at the centre of a rotating mould or die. Because of the centrifugal force, the lighter impurities are crowded towards the centre of the case. For producing a hollow part, the axis of rotation is placed at the centre of the desired casting. The speed of rotation is maintained high so as to produce a centripetal acceleration. The centrifuge action segregates the less dense non-metallic inclusions near to the centre of rotation that can be removed by machining a thin layer. No cores are therefore required in casting of hollow parts although solid parts can also be cast by this process. The centrifugal casting is very suitable for axisymmetric parts. Very high strength of the casting can be obtained. Since the molten metal is fed by the centrifugal action, the need for complex metal feeding system is eliminated. Both horizontal and vertical centrifugal castings are widely used in the industry.

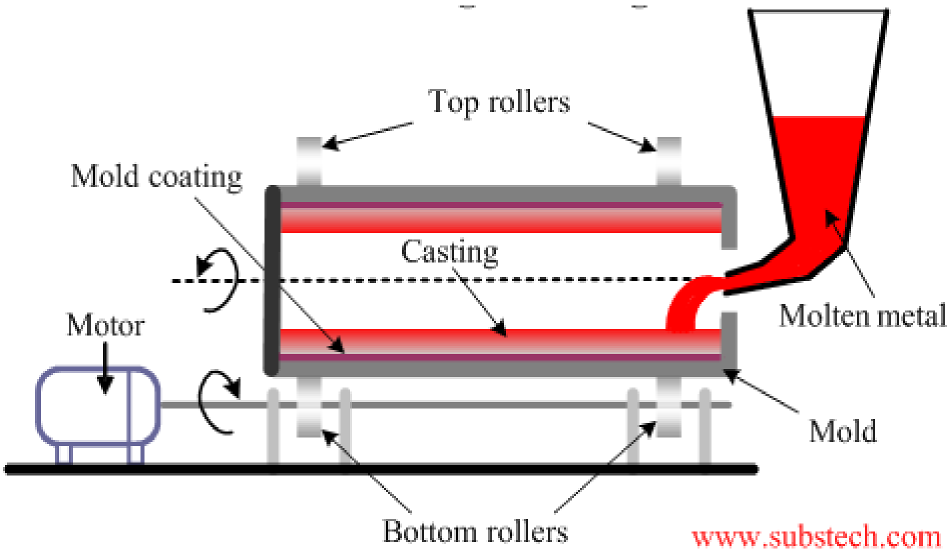


Figure 2.11. Schematic set-up for horizontal centrifugal casting process [12]

IV. Continuous casting

Continuous casting process is widely used in the steel industry. In principle, continuous casting is different from the other casting processes in the fact that there is no enclosed mold cavity. Figure below shows a set-up for continuous casting process. Molten steel coming out from the furnace is accumulated in a ladle. After undergoing requisite ladle treatments, such as alloying and degassing, and arriving at the correct temperature, the ladle is transported to the top of the continuous casting set-up. From the ladle, the hot metal is transferred via a refractory shroud (pipe) to a holding bath called a tundish. The tundish allows a reservoir of metal to feed the casting machine. Metal is then allowed to pass through an open base copper mould. The mould is water-cooled to solidify the hot metal directly in contact with it and removed from the other side of the mould. The continuous casting process is used for casting metal directly into billets or other similar shapes that can be used for rolling. The process involves continuously pouring molten metal into an externally chilled copper mould or die walls and hence, can be easily automated for large size production. Since the molten metal solidifies from the die wall and in a soft state as it comes out of the die wall such that the same can be directly guided into the rolling mill or can be sheared into a selected size of billets.

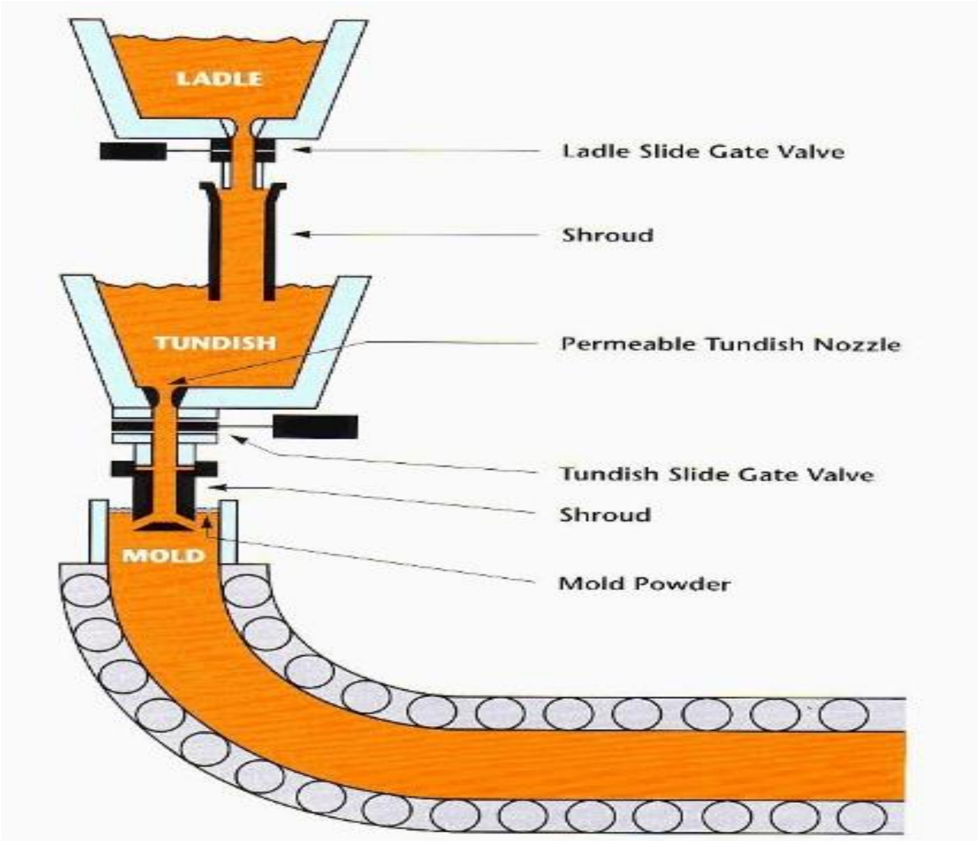


Figure 2.12. Schematic set-up of continuous casting process [12

2.4. Defects in Sand Casting Processes

Below shows various defects that are experienced during casting, in particular, sand casting processes. A brief explanation of some of the significant defects are indicated in the next to follow [3].

a) Shrinkage

Shrinkage of molten metal as it solidifies is an important issue in casting. It can reduce the 5-10% volume of the cast. Grey cast iron expands upon solidification due to phase changes. Need to design part and mould to take this amount into consideration. The thickness of the boss or pad should be less than the thickness of the section of the boss adjoins and the transition should be gradual. The radius for good shrinkage control should be from one half to one third of the section thickness. Shrinkage defect can be reduced by decreasing the number of walls and increasing the draft angle.

b) Porosity

Porosity is a phenomenon that occurs in materials, especially castings, as they change state from liquid to solid during the manufacturing process. Casting porosity has the form of surface and core imperfections which either effects the surface finish or as a leak path for gases and liquids. The poring temperature should be maintained properly to reduce porosity.

Adequate fluxing of metal and controlling the amount of gas-producing materials in the moulding and core making sand mixes can help in minimizing this defect.

c) Hot tear

Hot tears are internal or external ragged discontinuities or crack on the casting surface, caused by rapid contraction occurring immediately after the metal solidified. They may be produced when the casting is poorly designed and abrupt sectional changes take place; no proper fillets and corner radii are provided, and chills are inappropriately placed. Hot tear may be caused when the mold and core have poor collapsibility or when the mold is too hard causing the casting to undergo severe strain during cooling. Incorrect pouring temperature and improper placement of gates and risers can also create hot tears. Method to prevent hot tears may entail improving the casting design, achieving directional solidification and even rate of cooling all over, selecting proper mold and poured materials to suit the cast metal, and controlling the mold hardness in relation to other ingredients of sand.

d) Blowhole

Blowholes are smooth round holes that are clearly perceptible on the surface of the casting. To prevent blowholes, moisture content in sand must be well adjusted, sand of proper grain size should be used, ramming should not be too hard and venting should be adequate.

Figure 2.13. Gas porosities (blow holes) [sample specimens]

e) Dross

The lighter impurities are appearing on the top of the cast surface is called the dross. It can be taken care of at the pouring stage by using items such as a strainer and a skim bob.
Sometimes sand particles dropping out of the cope get embedded on the top surface of a casting. When removed, these leave small angular holes is known as dirty.

f) Wash

It is a low projection on the drag surface of a casting commencing near the gate. It is caused by the erosion of sand due to high velocity liquid metal.

g) Buckle

It refers to a long fairly shallow broad depression at the surface of a casting of a high temperature metal. Due to very high temperature of the molten metal, expansion of the thin layered of the sand at the mold face takes place. As this expansion is obstructed by the flux, the mold tends to bulge out forming a V shape.

h) Rat tail

It is a long shallow angular depression found in a thin casting. The cause is similar to buckle.

i) Shift

A shift results in a mismatch of the sections of a casting usually as a parting line. Misalignment is common cause of shift. This defect can be prevented by ensuring proper alignment of the pattern for die parts, molding boxes, and checking of pattern flux locating pins before use.

j) Warped casting

Warping is an undesirable deformation in a casting which occurs during or after solidification. Large and flat sections are particularly prone to wrap edge. Wrap edge may also be due to insufficient gating system that may not allow rapid pouring of metal or due to low green strength of the sand mold or inadequate / inappropriate draft allowance in the pattern / mold cavity.

k) Metal Penetration and Rough Surfaces

This defect appears as an uneven and rough external surface of the casting. It may be caused when the sand has too high permeability, large grain size, and low strength. Soft ramming may also cause metal penetration.

l) Fin

A thin projection of metal, not intended as a part of casting, is called a fin. Fins occur at the parting of the mould or core sections. Moulds and cores in correctly assembled will cause the fin. High metal pressures due to too large down sprue, insufficient weighing of the molds or improper clamping of flasks may again produce the fin defect.

m) Cold Shut and Mis-Run

A cold shut is a defect in which a discontinuity is formed due to the imperfect fusion of two streams of metal in the mould cavity.

The reasons for cold shut or mis-run may be too thin sections and wall thickness, improper gating system, damaged patterns, slow and intermittent pouring , poor fluidity of metal caused by low pouring temperature, improper alloy composition, etc.

2.5. Literatures on The Effects of Sand Casting defects

(Pribulová Alena et.al) quantity of defected castings and kinds of defects in the castings during the year was investigated. The attention was paid to sand inclusions and factors that can influence the sand inclusions origin. According to this investigation casting defects can negatively impact the bottom line of a foundry. At the simples' level, they manifest as rework costs or casting scrap costs. However, in many cases, **the casting defects may be discovered at the machining stage, at the assembly stage or during use of the component**. The resultant value added costs and warranty costs may sometimes be passed on to the foundry by their customer. These charges may be significantly more than the cost of the casting itself. Defects can, above all, be minimized by a clear understanding of their fundamental causes and its consequences.

One the most common defects in castings are inclusions, which can be found on the casting surface or inside the casting. Some inclusions have the shape of compact particles, while other inclusions form thin films but of large surface dimensions (ROUČKA J. 2000). Some inclusions are separate particles, whereas other inclusions agglomerate into compact clusters. Some inclusions are not bonded to the alloy microstructure and others concentrate in intergranular spaces. Depending on all this, the negative effect of inclusions can manifest itself in various ways. **Deterioration of casting surface quality** – inclusions are detrimental in that they impair the appearance of the casting surface and in that large inclusions (particularly those formed in steel re-oxidation) reach deep into the casting. Removing such defects is expensive and, moreover, it requires considerable machining allowance. As a consequence of the inclusions reacting with the mould material, both the amount of burned-on sand and the surface roughness can increase. **Deterioration of mechanical properties** – an inclusion is a foreign particle that interferes with the metal matrix. Inclusions make the mechanical properties deteriorate, in particular **ductility and fatigue strength**. Considerably reduced is mainly the low-cycle fatigue strength. Apart from the quantity of inclusions, the significance of this effect depends on the volume and the shape of inclusions. Inclusions that form films have an adverse effect. They damage large areas of the metal structure and they also cause the notch effect. A very negative effect are inclusions that form a network along the grain boundaries, inclusions that are arranged in lines, and inclusions with sharp edges.

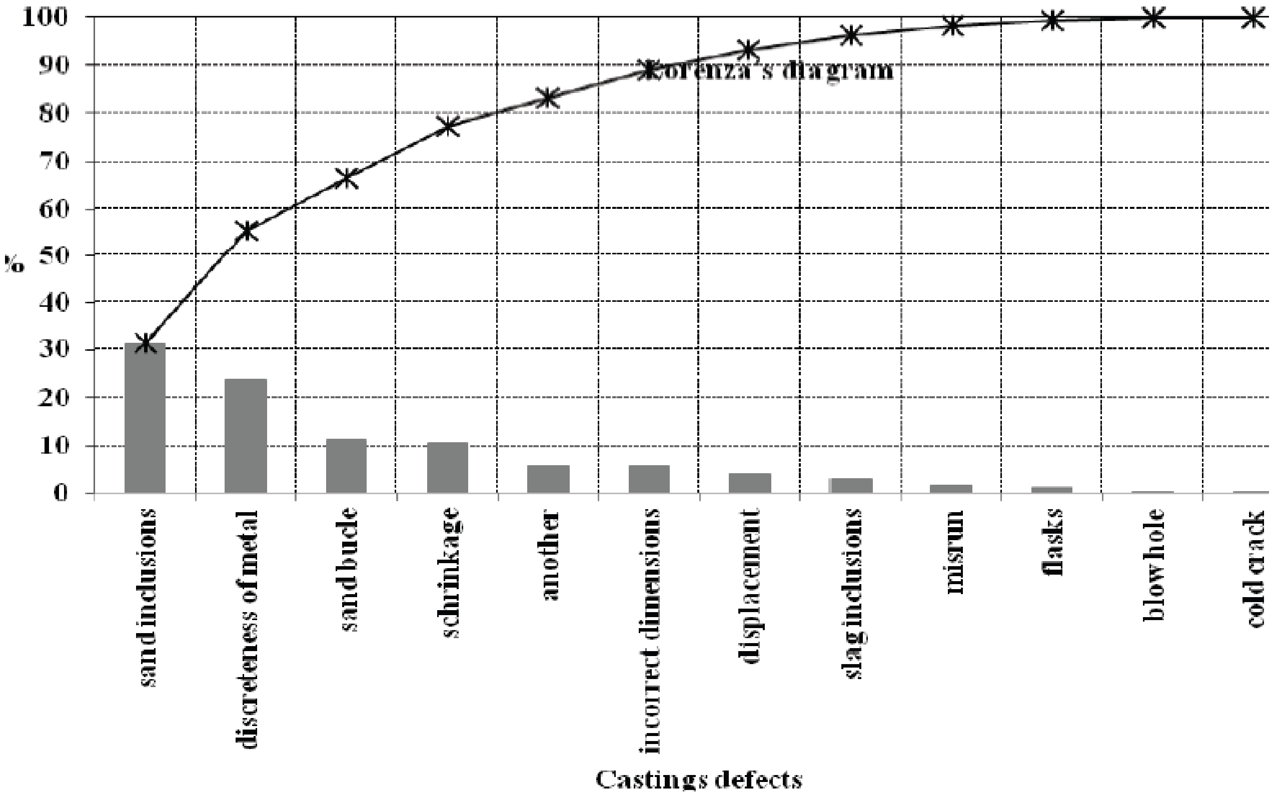


Figure 2.14 Pareto-Lorenzo diagram for chucking head (Pribulová Alena et.al)

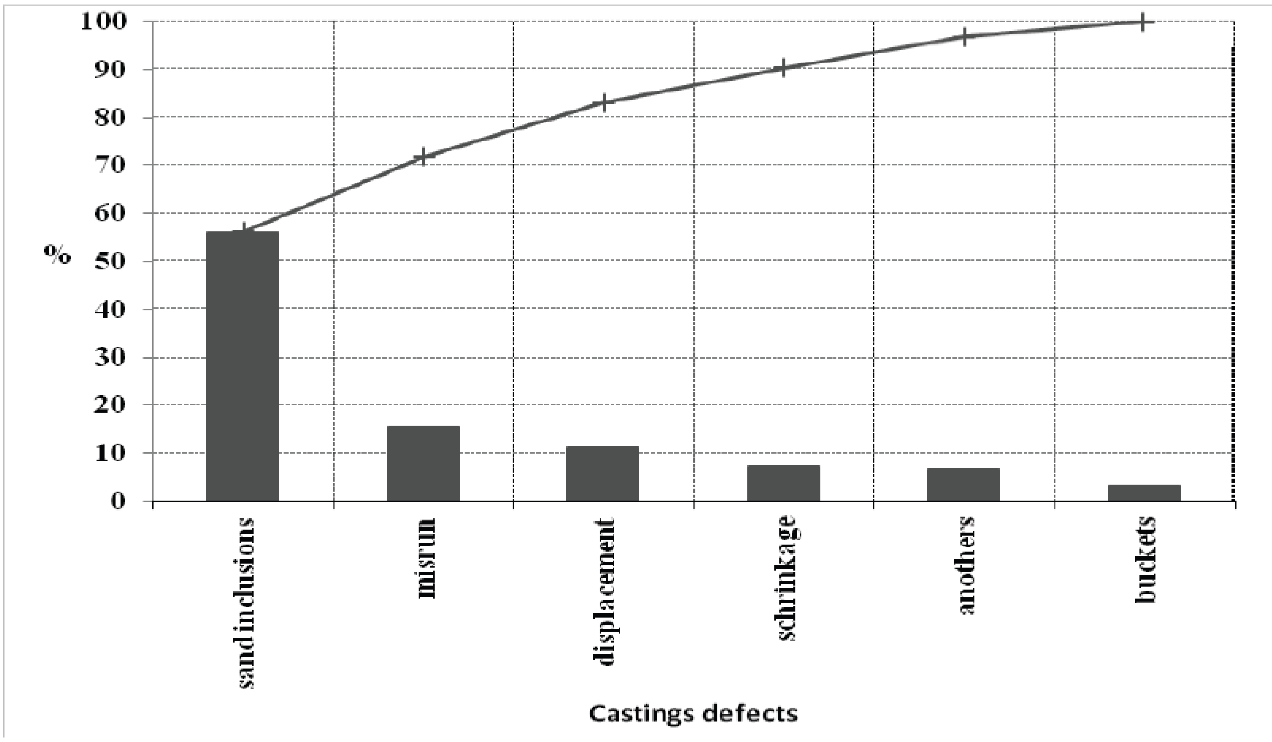


Figure 2.15. Pareto-Lorenzo diagram for cylinder (Pribulová Alena et.al)

Assessment shows, the weight of casting defect on the two products i.e. cylinder and chucking head found that, sand inclusion is the major defect. In addition it shows that this defect strongly affects machinability characteristics and mechanical properties.

(Mr. Siddalingswami et.al. 2015). This project is about new devolvement for identification of defects for 4R cylinder block which is presently having a 40% or more percent rejection in Kirloskar ferrous industrial ltd, Solapur. It presents a methodology in rejection level percent by using scientific study on casting defects such as; Product Process Search analysis (PPS) Inspection method, Design of Experiment (DOE), and by using a Casting simulation software and by finding out the cause-effect diagram. A new approach is proposed which may be helpful for foundries for controlling and reducing the defects.

It is very difficult to produce defect free castings. A defect may be the result of a single cause or a combination of causes. The castings may have one or more defects. Foundries are still using trial and error methods to solve quality problems. There are benefits of using a more disciplined approach to define, identify and determine the root cause of the defect which is an expensive and error-prone process.

(Rajesh Rajkolhe, J. G. Khan, 2014) This study aims to finding different defects in casting, analysis of defect and providing their remedies with their causes. It provide correct guideline to quality control department to find casting defects and will help them to analyse defects which are not desired. Even in completely controlled process, defect in casting are observed and hence casting process is also known as process of uncertainty which challenges explanation about the cause of casting defects.

Foundry industries in developing countries suffer from poor quality and productivity due to involvement of number of process parameter. Casting is a process which carries risk of failure occurrence during all the process of accomplishment of the finished product.

(**Q.G. Wang et.al. 2001**) The influence of casting defects on the room temperature fatigue performance of a Sr-modified A356-T6 casting alloy has been studied using un-notched polished cylindrical specimens. The numbers of cycles to failure of materials with various secondary arm spacings (SDAS) were investigated as a function of stress amplitude, stress ratio, and casting defect size. It was observed that **casting defects have a detrimental effect on fatigue life by shortening not only the crack propagation period, but also the initiation period**.

Castings with defects show at least an order of magnitude lower fatigue life compared to defect-free ones. The decrease in fatigue life is directly correlated to the increase of defect size.

(V.V.Mane1 et.al. 2014) In this work, 3-step approach to casting defect identification, analysis and rectification had been investigated. For defect analysis, the possible causes are grouped into design, material and process parameters. Based on the results and their interpretation, the optimal values of the parameters are determined to eliminate the defects.

Foundry industry suffers from poor quality and productivity due to the large number of process parameters, combined with lower penetration of manufacturing automation and shortage of skilled workers compared to other industries. Global buyers demand defect-free castings and strict delivery schedule, which foundries are finding it very difficult to meet. Casting defects result in increased unit cost and lower morale of shop floor personnel.

Unfortunately, this is not an easy task, since casting process involves complex interactions among various parameters and operations related to metal composition, methods design, molding, melting, pouring, shake-out, fettling and machining.

For casting defect analysis, the possible causes are grouped into design, material and process parameters. Most of the previous work is focused on finding process-related causes for individual defects, and optimizing the parameter values to reduce the defects.

This is not sufficient for completely eliminating the defects, since parameters related to part, tooling and methods design also affect casting quality, and these are not considered in conventional defect analysis approaches.

(**Niclas Ånmark Stockholm 2016**) The machinability of a case hardening steel is improved by M-treatment (additions of Ca). Also, the improved machinability of the M-steels offers an attractive potential to save money which makes it possible to reduce the tooling costs with up to 50%. The cutting tool life is one of the most common machinability indexes, because it is closely related to production economy. Non-metallic inclusions and their characteristics which needs to be considered in order to control the mechanical strength and machinability of high performance steel grades. The fatigue strength and impact toughness of steel are strongly related to the maximum size and the size distribution of non-metallic inclusions.

(L. Pejryd, et.al.) In machining, vibration may be detrimental both to the quality of the workpiece, the performance and life of the cutting tool or the life of the machine tool. Regenerative chatter occurs from the difference in vibration phase between the current cut and the previous cut through the waviness of the surface to be machined.

Chatter starts as a self-excited phenomenon in the closed loop of dynamically flexible machining structure and the machining process. Vibrations change the cutting forces and oscillatory cutting forces create vibrations between the tool and the workpiece.

Vibrations between the tool and the workpiece damages the surface finish, increase cutting forces dramatically and ultimately lead to tool breakage and damages to the machine tool.

(Prof. Dr.Ahmet Aran, 2017) machinability is actually a relative measure of how easily a material can be machined when compared to 160 brinell of AlSl B1112 free machining low carbon steel. B1112 represents a 100 % rating; materials with a rating less than this level would be more difficult to machine, these that exceeds 100% would be easier to machine.

Table 2. 1 Machinability rating of some materials.

Material	Hardness	Machinability Rating
B1112 Steel	160 BHN	100%
6061-T 7075-T Aluminum Alloys	-	190%
Aluminum	-	120%
416 Stainless Steel	200 BHN	90%
1120 Steel	160 BHN	80%
1020 Steel	148 BHN	65%
8620 Steel	194 BHN	60%
304 Stainless Steel	160 BHN	40%

According to Ahmet and other scholars, things should be considered in rating machinability are cutting speed, surface finish and tool life attained

(Ahmad RazlanYusoff et.al) Chatter produces a poor surface finish, high tool wear, and can even damage machine tools because of the regenerative effect, the loss of contact effect, and the mode coupling effect.

Chatter is a self-excited type of vibration that occurs in metal cutting if the chip width is too large with respect to the dynamic stiffness of the system, especially when machining with a high material removal rate.

(Sunday Joshua Ojolo et.al 2014) Among the parameters which affect the process quality, spindle speed has an inverse influence on tool life and it was more dominant than the effect of feed rate. Work-piece microstructure has a correlation with the life of a cutting tool.

(**M. Pradeep Kumar et.al 2015**) any machining process involves three basic elements viz., chip, cutting tool and work piece, in which the cutting tool is one of the major considerable factors. Tool life is the ability of the cutting tool to shear the unwanted material form the work piece. It is not only meant for the shearing the metal but also to achieve the required accuracy. These tasks can be performed efficiently when the cutting tool severs for a long period of time, which determines the rate of production and in turn governed by the number of times that a tool must re-grinded or reconditioned. The efficiency of the cutting tool not only enhances the productivity but also minimizes the cost of reconditioning of tool.

Generally the ways of expressing the tool life are:

1) Time period in minutes between two successive grinding
2) Cutting speed for a given time to failure
3) Number of components machined between two successive grindings.
4) In terms of volume of material removed between two successive grindings

There are various factors that affect the tool life some of them are

1) Geometry of cutting tool
2) Speed feed depth of cut
3) Cutting tool material
4) Work piece material
5) Use of cutting fluids

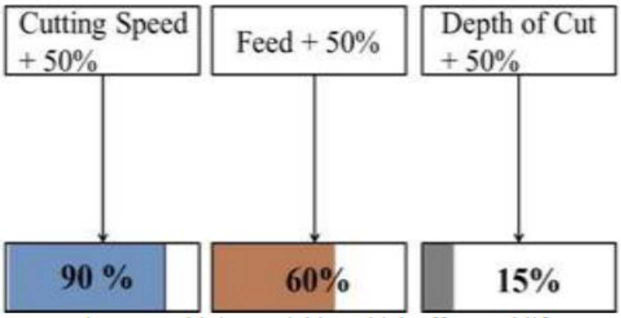


Fig 2.16 machining variables which affect tool life (M. Pradeep Kumar, 2015)

Taylor thought that there is an optimum cutting speed for the best productivity. At low cutting speeds, the tools have higher life but productivity is low and at higher speeds the case is reverse. Based on his experimental work he proposed a formula for the cutting tool life i.e.

$$VcT^{n} = C$$

Where Vc is cutting speed, T is tool life, and n and C are constants found by experimentation; they are properties of tool material, workpiece, and feed rate.

Among all the variables, cutting speed has the maximum effect on tool life. Tool life varies inversely with the cutting speed. That is higher the cutting speed the smaller the tool life. So, proper cutting speed is the most critical factor that needs to be considered when establishing optimum cutting conditions.

Effect of work piece material on tool life: The microstructural properties of the work piece material have a significant effect on the life of the cutting tool. The increase carbide cutting temperature and power consumption vary directly as the hardness of the work piece material. Due to the tendency of pure metals to stick on to tool face of cutting tool, these would adversely affect the tool life. The properties of the work material that tends to increase the tool life include the following

- Softness

- Absence of abrasive constituents
- Lack of work hardening tendency

Effect of workpiece properties on machinability:

The workpiece properties have a profound effect on machinability. The microstructure, chemical composition and physical properties are important.

Microstructure: Metals of similar microstructure generally have similar machining properties, but small changes in microstructure can greatly affect machinability.

Chemical Composition: The structure and mechanical properties of any alloy are determined basically by its chemical composition. Alloying elements have a strong influence on machinability

Physical Properties: the major physical properties affecting machinability are its hardness and work hardening properties.

Fabrication: whether a metal has been hot rolled, cold rolled, cold drawn, cast, or forged will affect its grain size, ductility, strength, hardness, structure and therefore its machinability.

(Wasiu Ajibola et.al 2012) the effect of using CO_2 process, metal mould, cement-bonded sand mould and naturally-bonded sand mould on the hardness, tensile and impact strengths of as-cast 6063 Aluminum alloy is presented. The results show that there is significant increase in hardness of the alloy when naturally-bonded sand mould is used for its production over that of metal, CO_2 and cement moulds. The stress-strain curves behaviour of the samples also indicated that sample from naturally bonded sand has highest tensile strength with superior ductility. The alloy shows highest impact strength when metal mould is used for sample preparation in comparison with other moulds.

(S. N. Aqida et.al, 2004) effects of porosity on mechanical properties of metal matrix composite has been investigated. As a result he conclude that increasing content of porosity will decrease the mechanical properties of MMC such as tensile strength, Young's modulus, Poisson ratio, and damping capacity. He presented that the presence of porosity decreased the mechanical properties of cast MMC as the failure process is initiated from the voids formed.

(Pierre Osmond. Et.al, 2017) Effect of porosity on the fatigue strength of cast aluminium alloys has been investigated. Clear link between certain microstructural features and the average fatigue strength has been established. According to pierre, the fatigue strength of cast aluminium alloys is known to be greatly affected by different defect types related to the manufacturing process, particularly micro shrinkage pores created during the solidification phase of the casting process. The test has been carried out in the case of a real structure submitted to high cycle fatigue damage: engine cylinder heads, used in the automotive industry using classical approach of Murakami. Indeed, both fatigue tests and microstructural characterizations are carried out on cylindrical specimens and real structures. The specimens are subjected to uniaxial and multiaxial loading conditions. Systematic analyses of fatigue failure surface are conducted to obtain the statistics of critical defects at the origin of the failures for both specimens and structures. In parallel, critical regions and the associated local loading mode in the structure are characterized by an appropriate high cycle fatigue analysis. Finally, based on the joint analyses of the average critical defect size in the specimens and the structure, a relevant fatigue design procedure accounting for size effect is proposed.

(**Mrs. V. S. Deshmukh &** Dr**. S. S. Sarda** Volu, Sep 2015**)**

Sand inclusion is an important defect in Cast Iron castings. On an average this defect is almost thirty to forty percent of the total defects occurring in a foundry. Sand inclusion is undesirable since it results in reduction in the strength of the casting and bad finish of the casting surface. More than hundred parameters are responsible for sand inclusion and hence it is difficult to control defect during casting. A detailed Literature review of the previous work mostly on sand inclusion for almost last fifty years is done in this paper to find appropriate parameters for defect formation of sand inclusion. From the literature review it is found that the exact remedy for sand inclusion is not easy. The papers describing different techniques like Quality Function Deployment, cause and effect diagram, Design of Experiments etc. are also referred for finding the appropriate parameters responsible for sand inclusion. Corrective action should be taken on responsible parameters to eliminate the defect and improve quality of ferrous castings.

CHAPTER THREE

3. MATERIALS AND METHODOLOGIES

3.1. Introduction

In this chapter materials to be used for the research and the methods to be followed to achieve the specific objective of the research will be described. Basically aluminium scrap will be used to produce the sample tests since it is easily available in the workshop and the test will be accomplish here. After producing the samples as per the required level of defects, different test will be done to check the machinability and mechanical properties of those produced sample workpieces. The set-up of the machines, required equipments and materials will be addressed well as it to be clear to be done. Care will be taken starting from the foundry to the machining process in order to get better results. This also must be achieved by using clear methods and proper materials for the research. The data to be used here will be both qualitative and quantitative data in order to assure the research both in terms of quality and quantity. The source of these dada will be acquired from primary sources (workshop observation, the result of the tests, and observing materials on services) and secondary sources (literatures, books, and scientific journals).

3.2. Machines and equipment's needed for the thesis

The experimental facilities used for foundry processes, assessing the casting defects, machinability, and mechanical properties of aluminium sample workpiece will be discussed. The details of the machines or equipment, work materials, and cutting tool used have been described. The list of machines, equipment and tools needed are mentioned as below:

Wood work shop: is the shop where patterns has been made for mould preparation. The necessary materials, equipment and tools are listed below:

- Wood work lathe
- Australian wood blank (45mmx45mm)
- Wood cutter
- Chisel
- Calliper
- Hack saw
- Wood bench vice
- Different grades of sand paper

Expected outputs from wood workshop:- Desired patterns, Desired sprue, and Desired riser

Foundry shop: is the shop where casting process has been done. Necessary materials, equipment and tools are listed below:

- Aluminium scraps to be melted.
- Direct fuel fired furnace.
- Sand and sand filter sieves
- Ladle
- Flasks and gating systems

- Preformed patterns made up of wood
- Binding materials (bonding clay
- Venting rod
- Sand rammer
- Air blower
- Water for binding the mold
- Strike off bar
- Draw spike
- Slicks

Expected output from foundry shop: - Desired mould, and desired aluminium cast

Machine shop: in this shop where machining of samples to observe the effect of porosity on the chip formation, surface finish, and cutting tool life has been accomplished**.**

- Lathe machines with full accessory to turn the samples of stepped shaft to the required sample size and shape for tensile strength, and torsional test and check the machinability of the sample workpiece i.e surface finish, chips produced and material removal rate (MRR)
- On bench grinding and cut off machine for fettling purposes of the riser and sprue.
- Callipers, rulers and other measuring devices.
- HSS cutting tools used for turning, cut off, facing and other operations.
- Milling cutters and other miscellaneous equipments.
- Milling machines with full accessory to prepare the samples of the required size and shape for impact and hardness tests.
- Lathe and milling chalk to clamp the work piece

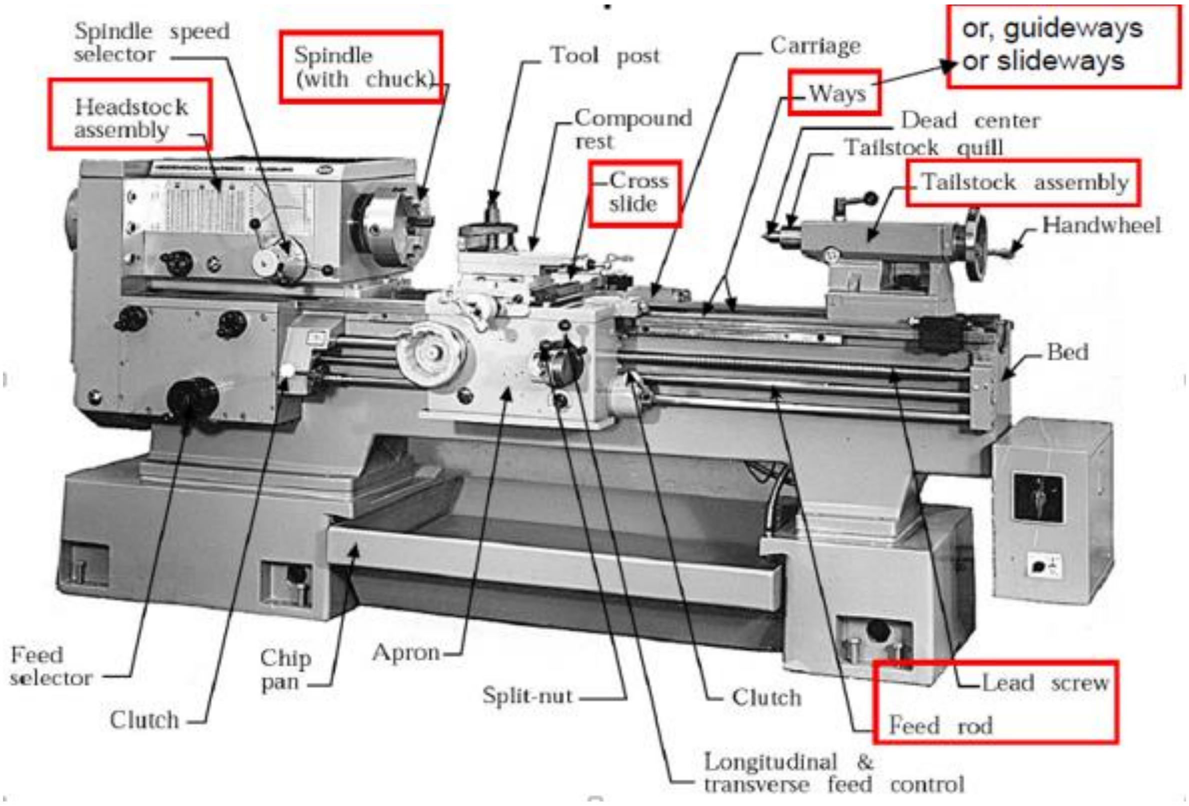


Figure 3.1. Basic parts of universal lathe machine

Figure 3.2. The two basic machines used for machining of sample casts [ASTU]

Quality assurance shop: is the shop where the quality of the cast samples checked whether it satisfy the pre-set specification or not. In addition to this it is used to check whether the objective of the practical work meet or not.

- Destructive testing machines.
- Comparator, or surface roughness tester.
- Scanning electron microscope.
- Tensile strength testing machine.
- Hardness testing machine.
- Torsional testing machine.
- Impact testing machine.
- Other miscellaneous equipments.

3.3. Methods of the study

3.3.1. Pattern, sprue and riser design

Blank material: *Australian wood with 40x40x210mm to be change in to desire patterns.*

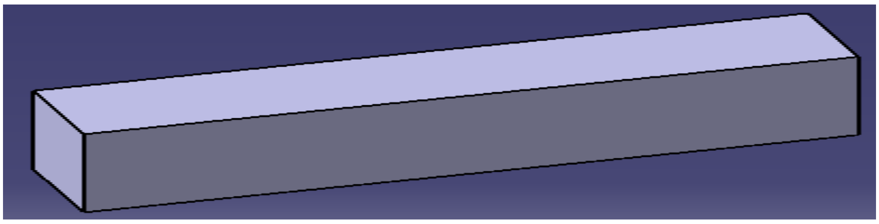


Figure 3.3. Wood materials from which sprue, pattern and riser made

Design of pattern, sprue and riser

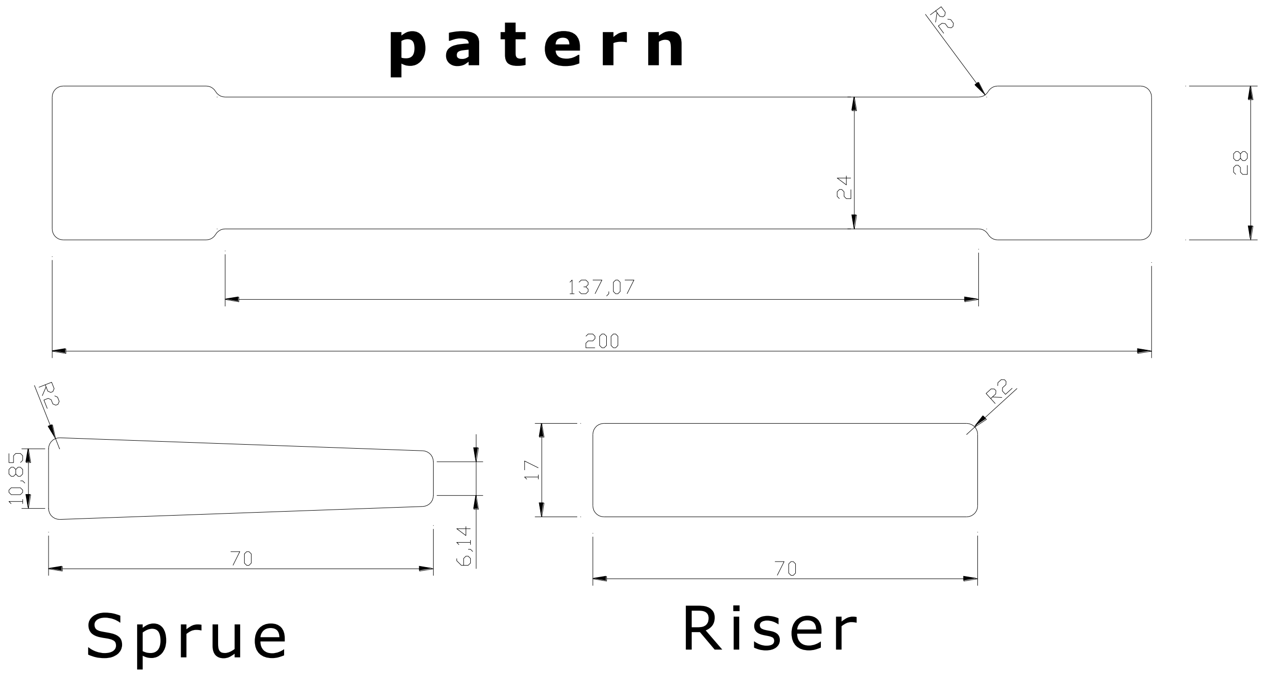


Figure 3.4. AutoCAD 2-D design of pattern, sprue, and riser

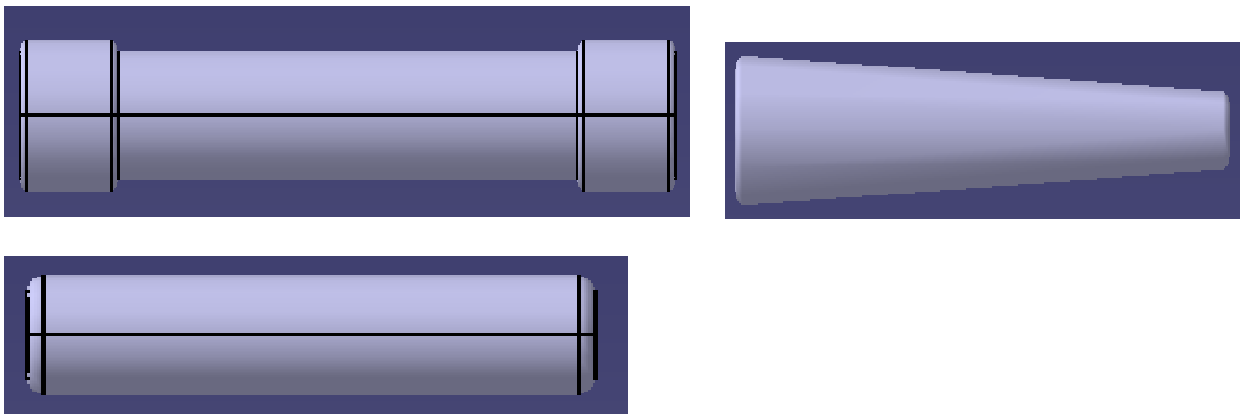


Figure 3.5. CATIA 3-D design of pattern, sprue, and riser

3.3.2. Foundry technology procedures.

The whole process of producing castings may be classified into five stages:

1. Pattern making
2. Moulding and core making
3. Melting and casting
4. Fettling
5. Testing and Inspection

There are different types of patterns used in foundry shop made up of different materials. The common materials used for making patterns are wood, metal, plastic, plaster and wax. The pattern type may be among of the following:

1. One piece or solid pattern
2. Two piece or split pattern
3. Cope and drag pattern
4. Three-piece or multi-piece pattern
5. Loose piece pattern
6. Match plate pattern
7. Follow board pattern
8. Gated pattern
9. Sweep pattern
10. Skeleton pattern

The type of pattern used for this thesis is two piece or split pattern for the reason of

- ✓ This is the most widely used type of pattern for intricate castings.
- ✓ Used when the contour of the casting makes its withdrawal from the mould difficult, or when the depth of the castings is too high.

The working is in such a way that the pattern is split into two parts so that one part is the drag and the other in the cope. The split surface of the pattern is same as the parting plane of the mould. The two halves of the pattern should be aligned properly by making use of the dowel pins which are fitted to the cope half. These dowel pins match with the precisely made holes in the drag half of the pattern and thus align the two halves properly as seen in the fig below.

3.3.2.1. Split pattern and riser preparation

Before any product is produced through casting process, a model, which is an exact replica of the product to be produced, known as ‘‘pattern’’ is prepared.
A pattern is a model or the replica of the object (to be casted). It is embedded in moulding sand and suitable ramming of moulding sand around the pattern is made. The pattern is then withdrawn for generating cavity (known as mould) in moulding sand.

Pattern materials

The selection of pattern materials depends on factors such as:

- Service requirements, e.g. quantity, quality and intricacy of castings, minimum thickness desired, degree of accuracy and finish required;
- Possibility of design changes;
- Type of production of castings, and type of molding method and equipment to be used; and
- Possibility of repeat orders.

To be suitable for use, pattern material should be:

- Easily worked, shaped, and joined;
- Light in weight for facility in handling and working;

- Strong, hard, and durable (i.e. of high strength-to-weight ratio);
- Resistant to wear and abrasion, to corrosion, and to chemical action;
- Dimensionally stable and unaffected by variation in temperature and humidity;
- Available at low cost;
- Having ability to take a good surface finish.

The common materials used for making patterns are wood, metal, plastic, plaster and wax.
For this thesis wood pattern is recommendable, since it is applicable for one times and the product produced also go for further finishing processes for the purpose of further investigation.
The detail preparation methods are shown blow supported by photos of activities in wood shop.

Figure 3.6. Preparation of split pattern, and sprue.

3.3.2.2. Selection and preparation of moulding sand.

In sand casting process it is possible to use different types of moulding sands as per the type of the material to be casted. For instance to cast metals with high melting point it is recommendable to use moulding sands which can resist such high heat energy imparted on the moulding sands. For the purpose of this thesis silica sand has been used due to its availability in the foundry shop as well as its preference for general purpose casting applications.

Silica sand

Silica sand in form of granular quarts is the main constituent of molding sand having enough refractoriness which can impart strength, stability and permeability to molding and core sand.
But along with silica small amounts of iron oxide, alumina, lime stone, magnesia, soda and potash are present as impurities. The chemical composition of silica sand gives an idea of the impurities like lime, magnesia, alkalis etc. present. The presence of excessive amounts of iron oxide, alkali oxides and lime can lower the fusion point to a considerable extent which is undesirable. The silica sand can be specified according to the size (small, medium and large silica sand grain) and the shape (angular, sub-angular and rounded).

Effect of grain shape and size of silica sand: The shape and size of sand grains has a significant effect on the different properties of molding and core sands. The shape of the sand grains in the mold or core sand determines the possibility of its application in various types of foundry practice. The shape of foundry sand grains varies from round to angular. Some sands consist almost entirely of grains of one shape, whereas others have a mixture of various shapes. According to shape, foundry sands are classified as rounded, sub-angular, angular and compound. Use of angular grains (obtained during crushing of rocks hard sand stones) is avoided as these grains have a large surface area. Molding sands composed of angular grains will need higher amount of binder and moisture content for the greater specific surface area of sand grain. However, a higher percentage of binder is required to bring in the desired strength in the molding sand and core sand. For good molding purposes, a smooth surfaced sand grains are preferred. The smooth surfaced grain has a higher sinter point, and the smooth surface secures a mixture of greater permeability and plasticity while requiring a higher percentage of blind material. Rounded shape silica sand grain sands are best suited for making permeable molding sand. These grains contribute to higher bond strength in comparison to angular grain. However, rounded silica sand grains sands have higher thermal expandability than angular silica grain sands.
Silica sand with rounded silica sand grains gives much better compact ability under the same conditions than the sands with angular silica grains. This is connected with the fact that the silica sand with rounded grains having the greatest degree of close packing of particles while sand with angular grains the worst. The green strength increases as the grains become more rounded. On the other hand, the grade of compact ability of silica sands with rounded sand grains is higher, and other, the contact surfaces between the individual grains are greater on rounded grains than on angular grains. As already mentioned above, the compact ability increases with rounded grains. The permeability or porosity property of molding sand and core sand therefore, should increase with rounded grains and decrease with angular grains. Thus the round silica sand grain size greatly influences the properties of molding sand.
The characteristics of sub-angular sand grains lie in between the characteristics of sand grains of angular and rounded kind. Compound grains are cemented together such that they fail to get separated when screened through a sieve. They may consist of round, sub-angular, or angular sub-angular sand grains. Compound grains require higher amounts of binder and moisture content also. These grains are least desirable in sand mixtures because they have a tendency to disintegrate at high temperatures. Moreover the compound grains are cemented together and they fail to separate when screened.
Grain sizes and their distribution in molding sand influence greatly the properties of the sand. The size and shape of the silica sand grains have a large bearing upon its strength and other general characteristics.

The sand with wide range of particle size has higher compact ability than sand with narrow distribution. The broadening of the size distribution may be done either to the fine or the coarse side of the distribution or in both directions simultaneously, and a sand of higher density will result. Broadening to the coarse side has a greater effect on density than broadening the distribution to the fine sand. Wide size distributions favour green strength, while narrow grain distributions reduce it. The grain size distribution has a significant effect on permeability. Silica sand containing finer and a wide range of particle sizes will have low permeability as compared to those containing grains of average fineness but of the same size i.e. narrow distribution. The compactability is expressed by the green density obtained by three ram strokes. Finer the sand, the lower is the compact ability and vice versa. This results from the fact that the specific surface increases as the grain size decreases. As a result, the number of points of contact per unit of volume increases and this in turn raises the resistance to compacting. The green strength has a certain tendency, admittedly not very pronounced, towards a maximum with a grain size which corresponds approximately to the medium grain size. As the silica sand grains become finer, the film of bentonite becomes thinner, although the percentage of bentonite remains the same. Due to reducing the thickness of binder film, the green strength is reduced. With very coarse grains, however, the number of grains and, therefore, the number of points of contact per unit of volume decreases so sharply that the green strength is again reduced. The sands with grains equal but coarser in size have greater void space and have, therefore greater permeability than the finer silica sands. This is more pronounced if sand grains are equal in size.

For the purpose of this thesis round shaped with medium size silica grain sand has been used. This is because of its availability in our foundry shop as well as it is the most preferable type of sand for green sand moulding processes. All the sand that is expected to be backed has been allowed to pass through the No 30, 20, and 12 sieves manually. A set of eleven sieves having U.S. Bureau of standard meshes 6, 12, 20, 30, 40, 50, 70, 100, 140, 200 and 270 are mounted on a mechanical shaker to filter sand grain sizes.

Lastly the sand has been divided in to three equal amounts for the three flasks to be moulded with high level defect, medium level defect, and sound casting moulds. To produce the difference in the casting product's quality amount of clay and moisture content with in the mould were varied.

Figure 3.7. Sand proclamation and preparation for moulding

3.3.2.3. Moulding process

Steps involved in making a sand mould [40]

1. Initially a suitable size of molding box for creating suitable wall thickness is selected for a two piece pattern. Sufficient care should also be taken in such that sense that the molding box must adjust mold cavity, riser and the gating system (sprue, runner and gates etc.).
2. Next, place the drag portion of the pattern with the parting surface down on the bottom (ram-up) board as shown in Fig. below (a).
3. The facing sand is then sprinkled carefully all around the pattern so that the pattern does not stick with molding sand during withdrawn of the pattern.
4. The drag is then filled with loose prepared molding sand and ramming of the molding sand is done uniformly in the molding box around the pattern. Fill the molding sand once again and then perform ramming. Repeat the process three four times,
5. The excess amount of sand is then removed using strike off bar to bring molding sand at the same level of the molding flask height to completes the drag.
6. The drag is then rolled over and the parting sand is sprinkled over on the top of the drag [Fig. below (b)].
7. Now the cope pattern is placed on the drag pattern and alignment is done using dowel pins.
8. Then cope (flask) is placed over the rammed drag and the parting sand is sprinkled all around the cope pattern.
9. Sprue and riser pins are placed in vertically position at suitable locations using support of molding sand. It will help to form suitable sized cavities for pouring molten metal etc. [Fig. below (c)].
10. The gaggers in the cope are set at suitable locations if necessary. They should not be located too close to the pattern or mold cavity otherwise they may chill the casting and fill the cope with molding sand and ram uniformly.
11. Strike off the excess sand from the top of the cope.
12. Remove sprue and riser pins and create vent holes in the cope with a vent wire. The basic purpose of vent creating vent holes in cope is to permit the escape of gases generated during pouring and solidification of the casting.
13. Sprinkle parting sand over the top of the cope surface and roll over the cope on the bottom board.
14. Rap and remove both the cope and drag patterns and repair the mold suitably if needed and dressing is applied
15. The gate is then cut connecting the lower base of sprue basin with runner and then the mold cavity.
16. Apply mold coating with a swab and bake the mold in case of a dry sand mold.
17. Set the cores in the mold, if needed and close the mold by inverting cope over drag.
18. The cope is then clamped with drag and the mold is ready for pouring, [Figure below (d)].

Things done during preparation of moulds to satisfy the desired casing samples.

Basically the samples are intentionally made for practical testing applications. Accordingly the following samples will be prepared with the required moulding and casting parameters. Since things are done manually slight difference may occur on ramming forces and other pouring parameters.

1. Sample test A:

As per the assumption of this thesis sample test A represents for the sound cast

Required parameters on sand preparation:

- ✓ Moulding sand – natural silica sand (88%)
- ✓ Bonding material – clay (7%)
- ✓ Binding materials – water (5%)

Other parameters considered to create a visible difference on the casting samples.

- ✓ Ramming force – rammed three rounds per mould
- ✓ Venting mechanism – venting is done to easily escape air gases from the mould during pouring.
- ✓ The mould is dried for 7 hours before pouring process takes place.

2. Sample test B:

As per the assumption of this thesis sample test B represents for the medium level defect casting.

Required parameters on sand preparation:

- ✓ Moulding sand – natural silica sand (86%)
- ✓ Bonding material – clay (7%)
- ✓ Binding materials – water (7%)

Other parameters considered to create a visible difference on the casting samples.

- ✓ Ramming force – rammed four rounds per mould
- ✓ Venting mechanism – no venting process takes place
- ✓ The mould is dried for 2 hours before pouring process takes place.

3. Sample test C:

As per the assumption of this thesis sample test C represents for the high level defect casting.

Required parameters on sand preparation:

- ✓ Moulding sand – natural silica sand (84%)
- ✓ Bonding material – clay (7%)
- ✓ Binding materials – water (9%)

Other parameters considered to create a visible difference on the casting samples.

- ✓ Ramming force – rammed five rounds per mould
- ✓ Venting mechanism – no venting process takes place
- ✓ The mould is poured immediately after moulding process is finished.

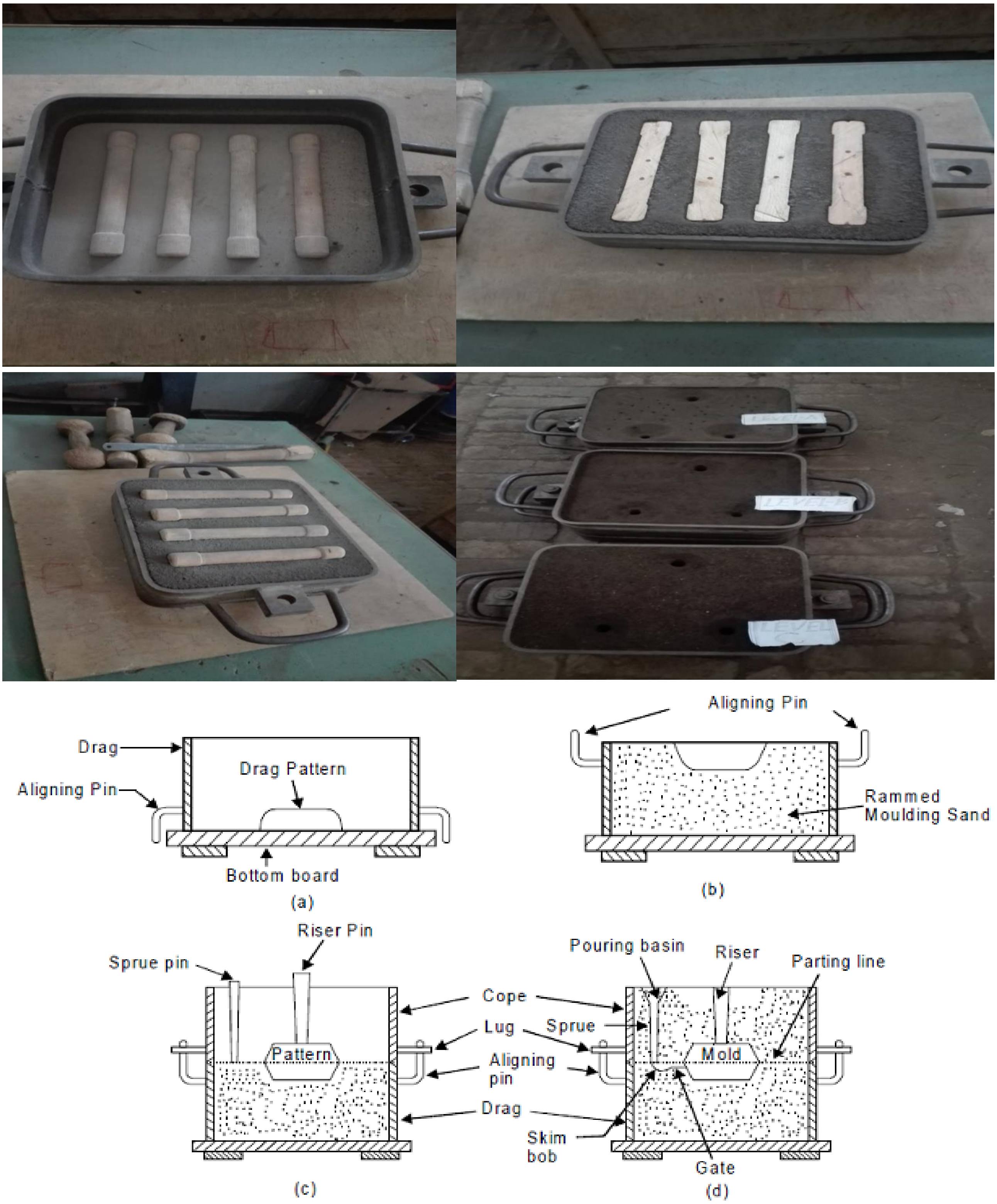


Figure 3.8. Practical and theoretical mould preparation at foundry shop

3.3.2.4. Melting and pouring process

Before pouring into the mould, the metal to be casted has to be in the molten or liquid state.
Furnace is used for carrying out not only the basic ore refining process but mainly utilized to melt the metal also. A blast furnace performs basic melting (of iron ore) operation to get pig iron, cupola furnace is used for getting cast iron and an electric arc furnace is used for re-melting steel. Different furnaces are employed for melting and re-melting ferrous and nonferrous materials. The following are the factors which are responsible for the selection of furnace.

- Considerations of initial cost and cost of its operation.
- Relative average cost of repair and maintenance.
- Availability and relative cost of various fuels in the particular locality.
- Melting efficiency, in particular speed of melting.
- Composition and melting temperature of the metal.
- Degree of quality control required in respect of metal purification of refining,
- Cleanliness and noise level in operation.
- Personnel choice or sales influence.

Heat in a melting furnace is created by combustion of fuel, electric arc, electric resistance, etc. A furnace contains a high temperature zone or region surrounded by a refractory wall structure which withstands high temperatures and being insulating minimizes heat losses to the surroundings. For refining and melting the ferrous and nonferrous materials, various furnaces are used.
Various types of furnaces are in use in foundry shops for melting ferrous and non-ferrous metals and alloys.

1. Crucible furnace (for ferrous and non-ferrous castings)
   a. Coke-fired crucible furnace
   b. Oil- fired crucible furnace
2. Cupola furnace (for manufacture of cast iron from pig iron)
3. Electric furnaces (for steel castings)
   a. Direct arc furnace
   b. Indirect arc furnace
   c. Electric induction furnace

The above considerations are generally used to install furnaces in foundry shop for production purposes. But for in case of this thesis it was used the available type of furnaces in the foundry shop for teaching purposes. The furnace is designed to melt only for nonferrous metals and which is limiting the study on nonferrous metals AA6061-T6. The assumption here taken is the principle is same for ferrous and nonferrous metals and also taken as a limitation of the study.

Some foundry industries was assessed and asked to use to prepare some samples of medium carbon steel for the study. But they were not voluntary to prepare as per the requirement of the study, rather they allow to use what they melt for general purposes. This is also will not meet the specifications what the study needs. Lastly focus was made on the available resources in our foundry shops.
The furnace used for melting aluminium scraps here is gas fuel furnace and the scrap has been melted within 25 minutes by properly adjusting the ratio of the fuel and the gas at optimum proportions.

After melting the slag has been removed using slag cleaning ladles. By following the proper steps and procedures pouring process has been done

Figure 3.9. melting and pouring process

3.3.2.5. Casting process

Casting process is one of the earliest metal shaping techniques known to human being. It means pouring molten metal into a refractory mould cavity and allows it to solidify. The solidified object is taken out from the mould either by breaking or taking the mould apart. The solidified object is called casting and the technique followed in method is known as casting process.

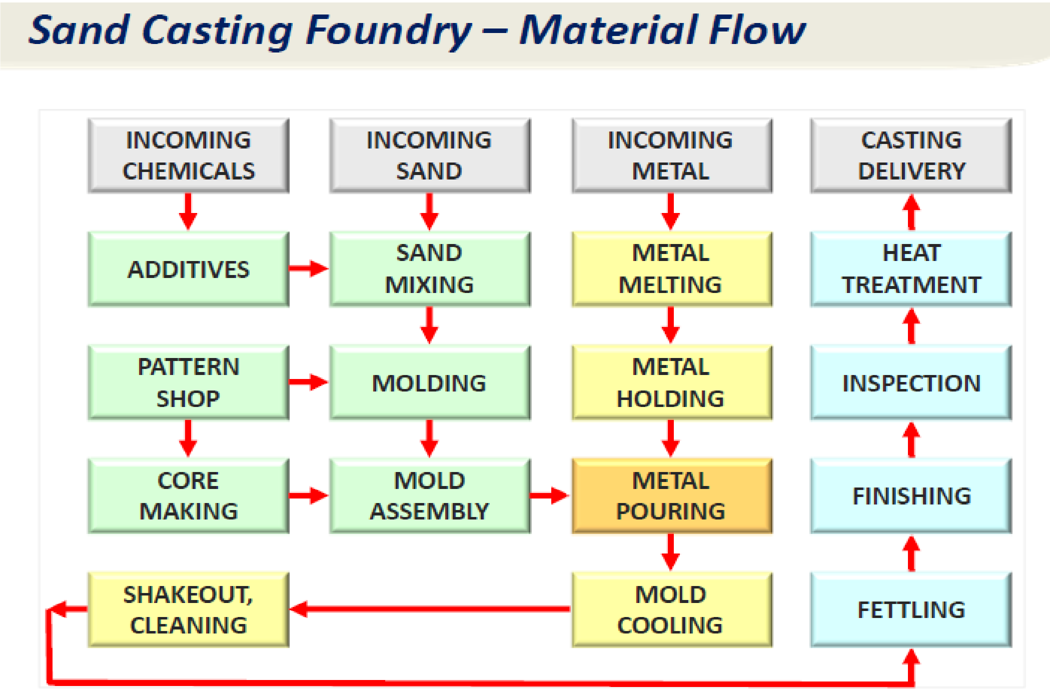


Figure 3.10. Material flow in sand casting process [15]

Materials used for casting [16]

Aluminium alloy 6082 is a medium strength alloy with excellent corrosion resistance. It has the highest strength of the 6000 series alloys. Alloy 6082 is known as a structural alloy. In plate form, Aluminium alloy 6082 is the alloy most commonly used for machining. As a relatively new alloy, the higher strength of Aluminium alloy 6082 has seen it replace 6061 in many applications. The addition of a large amount of manganese controls the grain structure which in turn results in a stronger alloy. The tighter chemical band ensures more consistent anodising between batches.

Applications

Aluminium alloy 6082 is typically used in:

- ✓ High stress applications
- ✓ Ore skips
- ✓ Trusses
- ✓ Beer barrels
- ✓ Bridges
- ✓ Milk churns
- ✓ Cranes
- ✓ Transport applications

Table 3.1. Characteristics of aluminium cast AA6082 – T6

Typical Chemical Composition

Element	% Present
Si	0.7 – 1.3
Fe	0.0 – 0.5
Cu	0.0 – 0.1
Mn	0.4 – 1.0
Mg	0.6 – 1.2
Zn	0.0 – 0.2
Ti	0.0 – 0.1
Cr	0.0 – 0.25
Al	Balance

Typical Mechanical Properties

Temper	O	T4	T6 / T651
Proof Stress 0.2% (MPa)	60	170	310
Tensile Strength (MPa)	130	260	340
Shear Strength (MPa)	85	170	210
Elongation A5 (%)	27	19	11
Hardness Vickers (HV)	35	75	100

Typical Physical Properties

Property	Value
Density	2700 km/m3
Melting Point	555 °C
Modulus of Elasticity	70 GPa
Electrical Resistivity	0.038×10^{-6} ohm.m
Thermal Conductivity	180 W/m.K
Thermal Expansion	24×10^{-6} /K

Typical Fabrication Response

Process	Rating
Workability - Cold	Good
Machinability	Good
Weldability – Gas	Good
Weldability – Arc	Good
Weldability – Resistance	Good
Brazability	Good
Solderability	Good

Figure 3.11. Casted samples with 3 - level of deffect

Figure 3.12. As cast of sample tests

3.3.2.6. Fettling.

The castings as obtained unwanted metal attached in the form of:

- ✓ gates,
- ✓ risers, etc.
- ✓ sand particles also tend to adhere to the surface of the castings.

The unnecessary projections are cut off, the adhering sand removed, and the entire surface made clean and uniform. This process is called fettling process.

Cause of Porosity on the sample specimens

Porosity is the name given to small voids in a casting. This problem can arise due to solidification shrinkage, air entrapy, and chemical compusition of nitrogen or hydrogen or carbon with oxigen. Alternatively, gas porosity is caused when gas bubbles are evolved during solidification and become trapped to form small, smooth, round voids or pinholes inside the casting. Gases such as hydrogen and nitrogen can dissolve easily in liquid metals. Bubbles form because the solubility of gases in the solid metal is much less than that in the liquid phase. Bubbles can also form by chemical reaction, such as dissolved oxygen in steel combining with carbon to create carbon monoxide bubbles. Dissolved gases can be harmful even when they do not form bubbles, since they can react to form inclusions, in the case of oxygen and nitrogen, or cause embrittlement of some alloys, in the case of hydrogen.

Dissolved gases can be prevented by protecting the metal from contact with air or moisture (which creates hydrogen). Gases can be removed by lowering the liquid temperature or by vacuum degassing the liquid metal. This involves holding the ladle of molten metal under a vacuum and / or injecting an inert gas such as Argon to rapidly stir the liquid and promote removal of unwanted Hydrogen, Nitrogen, and Sulfur from the top surface. When the bubbles cannot escape, pinhole porosity is produced, particularly in cast iron, aluminum, and copper. To encourage the escape of trapped air and gas, vents (vertical holes) are sometimes added to sand castings. Gas bubbles can also be prevented by alloy additions that form solid precipitates instead. For example, Al or Si is added to steel to combine with the excess oxygen and prevent the formation of CO gas bubbles. Unfortunately, the precipitate particles (SiO_2 or Al_2O_3 in this example) sometimes act as detrimental inclusions, unless they can float out into the slag.

During subsequent deformation processes, defects such as internal porosity and internal cracks often can be squeezed together and completely healed. If these defects reach the metal surface and are exposed to the environment, however, they will oxidize and become permanent.

As we observe from the cast samples, around 5 small gas porosities (pin holes) are occurred on the sample test specimen A, 9 on specimen B, and 9 blow holes and 20 pin holes on sample specimenC. This shows that proper venting and proportional mixing of sand, clay and water is the basic criteria for the occurance or not of thus defects.

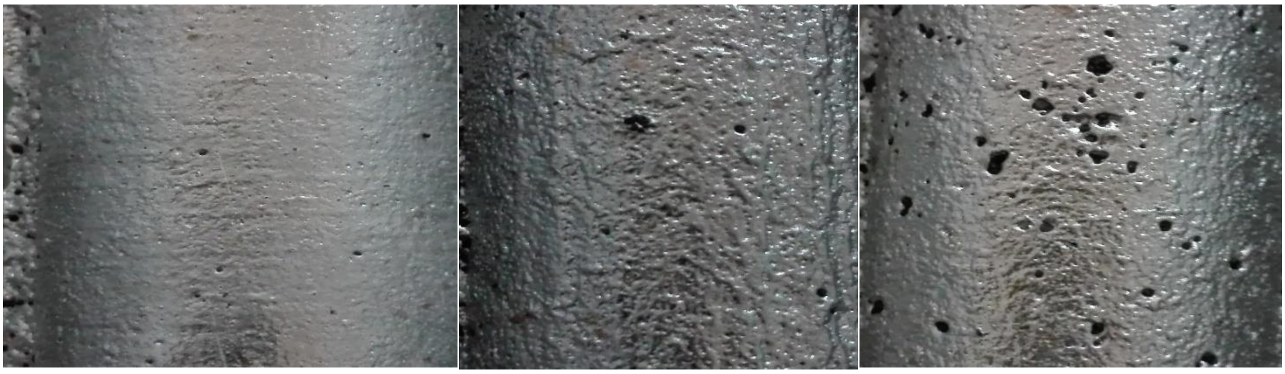


Figure 3.13. visible differences on casted samples before machining

Figure 3.14. Casting samples after fettling process

3.3.2.7. Inspection and testing of casting

Two basic objectives of inspection generally are:

- To reject castings that fail to meet the customer's requirement, and
- To serve as a means of maintaining the quality of workmanship and materials used in the foundry.

In this case inspection is needed to check the cast product whether it pass to the next step machining or not and rough observation has been made to look the difference on the samples.

'' Inspection '' broadly covers a large number of methods and techniques used to check the quality of castings. These methods may be classified into five categories:

1. Visual inspection.
2. Dimensional inspection.
3. Mechanical testing.
4. Flow detection by non-destructive methods; and metallurgical inspection.

For in case of this thesis mechanical testing (destructive testing) will be apply to check the mechanical properties of the casted samples. The other mechanisms used in this thesis are visual and dimensional inspections to check whether the casted products are done in a way that satisfying the samples requirement or not.

The latter mechanisms of inspections are done for the purpose of simple comparison among the casted sample products. Because the sample products will go for further investigations of their mechanical properties and machinability characteristics.

General observation on samples casted:

Defects observed on the samples casted

- ✓ pin holes
- ✓ misalignments
- ✓ blow holes
- ✓ flashes

Causes of defects:

- ✓ Pin holes and blow holes – the defect has been done intentionally on medium and high level defective casted samples (for investigation purpose). On the sound cast also some pin holes are observed due to moulding errors and due to dependency on many casting parameters, but not as much as of on the samples intentionally made.

- ✓ Misalignments – has been observed in some casted sample tests regardless of their degree of defect. The cause for this defects are either misalignment of the dowel pin on the cope and made holes on the drag or un proper fitting of these two parts. The other cause for misalignment is unproportioned size of the dowel pin and the whole, which causes/allows free movement of cope over the drag.
- ✓ Flashes – flashes has been occurred in almost all parting lines of the casting samples even its degree is different. The cause is normally related with mould corner destruction during patter withdraw and improper knocking of pattern during separating it from the mould cavity. The other reason for the creation of flash is avoiding split pattern corners during its preparation.

Successes on casting of aluminium samples:

- ✓ The level of gas porosity was happened as of the expectations of the study.
- ✓ Reduction of sand casting defects other than these intentionally made i.e. shrinkage defects, sand inclusion, sand plastering, mould erosion, etc.

Causes of success:

- ✓ Appropriate proportions of mixture; sand, clay, and water.
- ✓ Appropriate venting mechanisms applied.
- ✓ Type of moulds used; dry mould for defect free and green sand mould for the remaining once.
- ✓ Appropriate ramming mechanism applied; the ramming force increased with their level of defects even though it is manually done.

3.3.2.8. Sample size.

Twelve sample workpieces has been prepared to test the general objective of the thesis. These sample workpieces are prepared at foundry shop with three level of defects; highly defect, medium defect, and sound casting, intentionally done to check their effects on machinability and mechanical properties at service.

3.3.3. Machining process.

In an industry, metal components are made into different shapes and dimensions by using various metal working processes. Metal working processes are classified into two major groups; they are:

- ✓ Non-cutting shaping or chips less or metal forming process - forging, rolling, pressing, extrusion, drawing etc.
- ✓ Cutting shaping or metal cutting or chip forming process - turning, drilling, milling, boring, facing etc.

Metal cutting process: - is an essential process of finishing by which work pieces are produced to the desired dimensions and surface finish by gradually removing the excess material from the preformed blank in the form of chips with the help of cutting tool.

A family of shaping operations, the common feature of which is removal of material from a starting work part so the remaining part has the desired geometry

- ✓ Machining – material removal by a sharp cutting tool, e.g., turning, milling, drilling, boring etc.
- ✓ Abrasive processes – material removal by hard, abrasive particles, e.g., grinding
- ✓ Non-traditional processes - various energy forms other than sharp cutting tool to remove material, e.g. LJM, EBM, WJM, AJM, USM, ECM, etc.

After casting process has been accomplished turning activity has been done on the machine shop using universal lathe machine. During machining process different observations and data has been taken to check the machinability characteristics of the work material and the cutting tool as well. The chip formation, types of chips produced, amount of chips collected (MRR) all are taken on the lathe operation for study purposes.

3.3.3.1. Basic working principles of machining.

Machining is manufacturing process that involves removing materials using cutting tools for getting rid of the unwanted materials from some workpiece and converting it into the shape you desire. The three principal machining processes are classified as turning, drilling and milling. Other operations falling into miscellaneous categories include shaping, planning, boring, broaching and sawing etc. [41].

Machining operation can be classified as traditional machining process or non-traditional machining processes depending on the technologies they use. In case were traditional machining process everything is done manually and controlled by human beings. Were as in case of non-traditional machining operation intelligent machines will feed the required data in the form of type, or feed with flash, or CD. The machine by itself understand the data and process the job as per the order of the pre-set data. Thus machines are called NC or CNC machines.

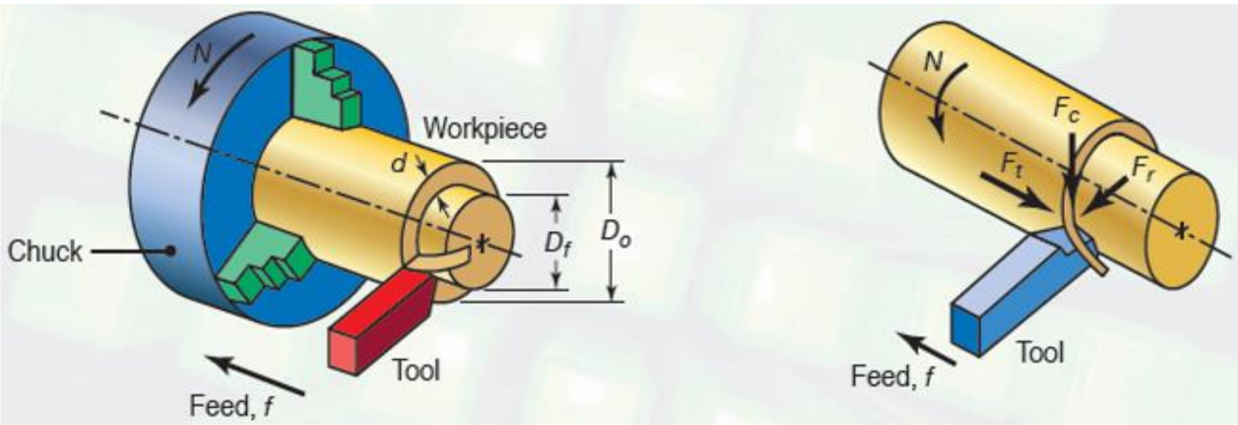


Figure 3.15. Basic working principles of machining process

3.3.3.2. Basic elements of machining process.

The basic elements of machining operations are the machine, the tool, and the workpiece. The machine tool can be lathe, milling, drilling, shaping etc. depending on the type of operation needed to perform. The cutting tool also selected depending on the type of operation, type of material to be cut and extra. The workpiece is the material that will be changed to the required shape and size for applications.

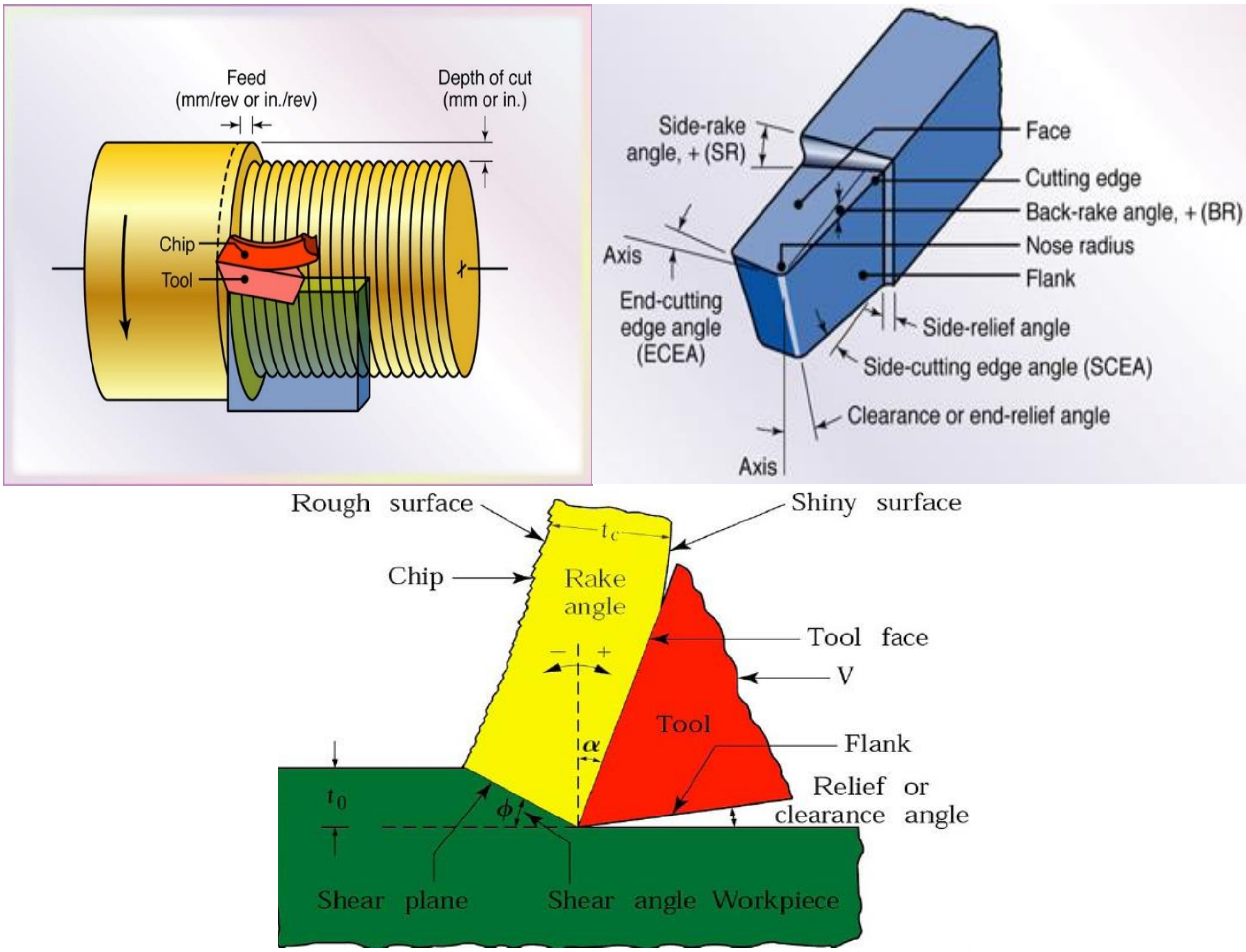


Figure 3.16. Tool-Work correlations.

3.3.3.3. Cutting conditions

The three cutting conditions of a machining process are:

- ✓ Cutting speed (v) – primary motion
- ✓ Feed (f) – secondary motion
- ✓ Depth of cut (d) – penetration of tool below original work surface

For certain operations, material removal rate can be computed as

$$MRR = v\ f\ d$$

Where v = cutting speed; f = feed; d = depth of cut.

For the case of this thesis all cutting conditions such as cutting speed, feed, and depth of cut are taken as constant or the same. Because the difference on the result are expected to come with gas porosity.

Table 3.2. Tool-workpiece motions in metal cutting

operation	Workpiece motion	Tool motion
Turning	Rotary	Translation
Drilling	Stationary	Rotary and Translation
Milling	Translation	Rotary
Shaping	Translation	Translation
Planning	Translation	Translation
Boring	Stationary	Rotary and Translation

In case of this thesis only lathe facing, turning and face milling operations has been accomplished to investigate the mechanical properties and machinability characteristics of cast aluminium AA6082.

Turning operation: Single point cutting tool removes material from a rotating workpiece to generate a cylinder performed on a machine tool called a lathe as shown in figure 3.17.

Turning operation on the lathe machine has been takes place for preparing testing samples for tensile strength and torsional test purposes. According to the plan eight sample specimens are prepared and two of them has been rejected due to failure. The failed one are high defect work specimens intentionally made during casting process.

Figure 3.17. Machined surfaces on the lathe machine

Milling operation:
Wear as face milling is used to prepare testing samples for impact and hardness tests.

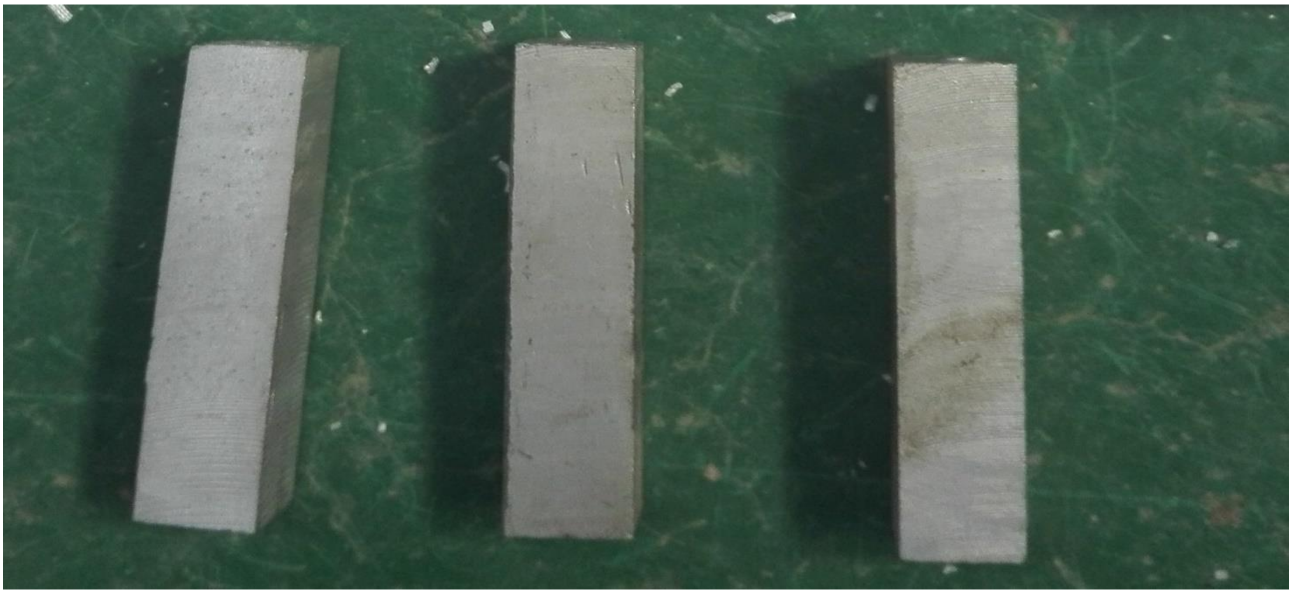


Figure 3.18. Milled sample tests for hardness and impact tests

Things done during machining operation to satisfy the desired casing samples.

- ✓ Constant cutting speed is applied for all sample work piece types: i.e 800 rpm
- ✓ Constant depth of cut is applied for all sample work piece types specially at the layers it is expected for study of chip formation and types of chips produced: i.e 1 mm
- ✓ Tried to apply or provide constant feed manually since the lathe machine is not working automatic feed.
- ✓ Tool grinding has been done especially when information required related with the study such as chip types and formation, and surface finish.
- ✓ In the above all activities especial care has been taken during collecting chips and observing the formation of it, and consequences happened on the cutting tool.

Observed problems and successes during machining

Success:-

- ✓ The required amount of testing samples are prepared successfully.
- ✓ The required data, and evidences has been collected.
- ✓ Safe work has been done (no accident on the operator, machine tool and others)

Problems observed:-

- ✓ Brake down of cutting tools.
- ✓ Brake down of sample tests during machining.
- ✓ Manual feed may not accurate.

CHAPTER-4
Result and Discussion

4.1. Introduction:

In this chapter the scientific approach of experimental tests will be depicted. Theoretical and practical procedures following to test the sample's machinability characteristics and mechanical properties will be mentioned. Additionally, results of the experimental tests will be revealed and detail explanation of each result will be made. In doing so, care will be taken on whether the result is answering the specific objectives or research questions or not. Both the result and the discussion will be elaborated consecutively as one topics. The result will focus on experimental procedures, steps, and data recorded on the experimental tests. Lastly the recorded data will be converted in to valuable or meaningful information through discussion to conclude and recommend on the issue.

4.2. Machinability characteristics of the sample specimens

4.2.1. Machinability Tests

The term "machinability" is a relative measure of how easily a material can be machined when compared to 160 Brinell AISI B 1112 free machining low carbon steel. The American Iron and Steel Institute (AISI) ran turning tests of this material at 180 surface feet and compared their results for B 1112 against several other materials. If B 1112 represents a 100% rating, then materials with a rating less than this level would be decidedly more difficult to machine, while those that exceed 100% would be easier to machine.

The machinability rating of a metal takes the normal cutting speed, surface finish and tool life attained into consideration. These factors are weighted and combined to arrive at a final machinability rating. A range of machinability tests have been developed, often to assess specific cutting conditions, while others are used for more general machining assessment. Sometimes machinability data is expressed in the form of a single index such as a "standard" material being ranked as 100% with others having values relative to it [2].

Aluminium is a soft, machinable metal and the limitations on speeds are governed by the capacity of the machine and good safe practices. Chips are of the continuous type and frequently they are a limiting safety factor because they tend to bunch up. Aluminium has been machined at such high speeds that the chip becomes an oxide powder. To increase its strength and hardness, aluminium is alloyed with silicon, iron, manganese, nickel, chromium, and other metals. These materials should be machined with positive cutting geometries [17].

Aluminium alloys are among the most commonly used lightweight metallic materials as they offer a number of different interesting mechanical and thermal properties. Aluminium alloy as a class are considered as the family of materials offering the highest level of machinability as compared to other families of lightweight metals such as titanium and magnisium alloys. Thus machinability quantifies the machining performance, and may be defined for the specific applications by various criteria, such as tool life, surface finish, chip evaluation, material removal rate, and machine tool power[18].

a. Type of chips and formation:

Chips are separated from the workpiece to impart the required size and shape to the workpiece. The type of chips edge formed is basically a function of the work material and cutting conditions. The chips that are formed during metal cutting operations can be classified into four types:

1. Discontinuous or segmental chips.
2. Continuous chips.
3. Continuous chips with built-up edge.
4. Non homogenous chips.

From the below figure we can observe that the first three type of chips are continuous and the remaining once are discontinuous. For the case of this thesis the chip formed for the three specimens are depicted as follow. In sample specimen A the chip formed is infinite helix, in sample specimen B it seems like between infinite helix and snarling chips; whereas for sample specimen C the chip formed is a combination of straight, snarling and half turn chips. This is because of the materials property produced intentionally during casting process. In case of samples machined with high pin and blow holes the chips will try to break at the point of porosity, since it causes as a sources of crack initiation and propagation. Whereas in case of sound cast the chip formed is continuously formed till it winds with each other or chip breakers to clean and make the turning process safer.

Sample specimen A **Sample specimen B** **Sample specimen C**

Figure 4.1. Chip morphology of sample tests

There have been machinability ratings based on the type of chip that is formed during the machining operation. The machinability might be judged by the ease of handling and disposing of chips. A material that produces long stringy chips would receive a low rating, as would one, which produces fine powdery chips. Materials, which inherently form nicely broken, chips, a half or full turn of the normal chip helix, would receive top rating. Chip handling and disposal can be quite expensive. Stringy chips are a menace to the operator and to the finish on the freshly machined surface. However, chip formation is a function of the machine variables as well as the workpiece material, and the ratings obtained by this method could be changed by provision of a suitable chip breaker.

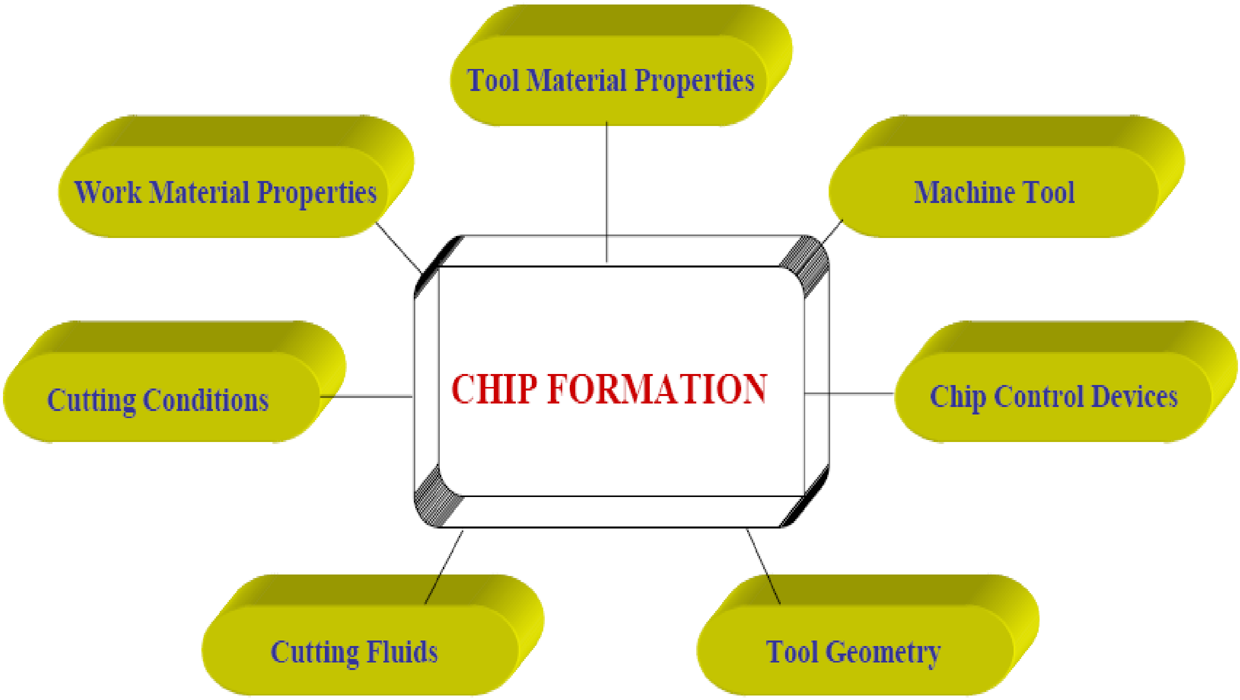


Figure 4.2. Influencing factors of chip formation

b. Cutting force during machining of aluminium alloy

While cutting force during machining of aluminium alloy is relatively low, they can nevertheless provide a good indicator for a comparison of different alloys under the same machining conditions [39]. The use of tool forces or power consumption as a criterion of machinability of the workpiece material comes about for two reasons. First, the concept of machinability as the ease with which a metal is cut implies that a metal through which a tool is easily pushed should have a good machinability rating. Second, the more practical concept of machinability in terms of minimum cost per part machined, relates to forces and power consumption, and the overhead cost of a machine of proper capacity.

When using tool forces as a machinability rating, either the cutting force or the thrust force (feeding force) may be used. The cutting force is the more popular of the two since it is the force that pushes the tool through the workpiece and determines the power consumed. Although machinability ratings could be listed according to the cutting forces under a set of standard machining conditions, the data are usually presented in terms of specific energy. Workpiece materials having a high specific energy of metal removal are said to be less machinable than those with a lower specific energy.

The use of net power consumption during machining as an index of the machinability of the workpiece is similar to the use of cutting force. Again, the data are most useful in terms of specific energy. One advantage of using specific energy of metal removal as an indication of machinability, is that it is mainly a property of the workpiece material itself and is quite insensitive to tool material. By contrast, tool life is strongly dependent on tool material.

c. **Surface finish of the machined product**

The quality of the surface finish left on the workpiece during a cutting operation is sometimes useful in determining the machinability rating of a metal. Some workpieces will not `take a good finish' as well as others. The fundamental reason for surface roughness is the formation and sloughing off of parts of the built-up edge on the tool. Soft, ductile materials tend to form a built-up edge rather easily. Stainless steels, gas turbine alloy and other metals with high strain hardening ability also tend to machine with built-up edges. Materials which machine with high shear zone angles tend to minimize built-up edge effects. These include the aluminum alloys, cold worked steels, free-machining steels, brass and titanium alloys. If surface finish alone were the chosen index of machinability, these latter metals would rate higher than those in the first group.

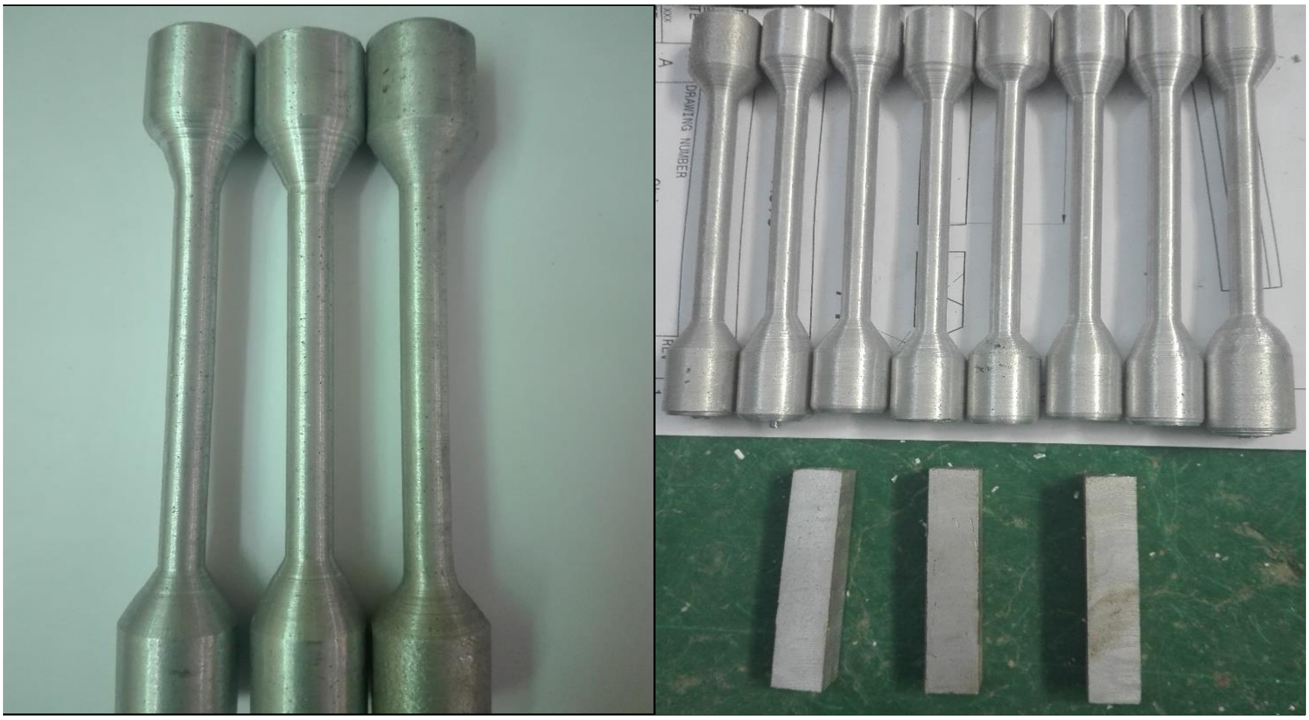


Figure 4.3. Surface finish of machined surface

Figure 4.4. Grain structures of specimens (a) specimen A, (b) specimen B, (c) specimen C

In case of this thesis the surface finish of the test samples have been observed and for in case of the high level defect sample specimens the pin holes are revealed more after the upper layer of the cast has been removed. Even though they are quite small they distributed throughout the surface of the machined specimen. Even the degree of existence is varied the problem also observed on medium level defect samples. Generally the one with higher gas porosity have high surface roughness and vies versa.

d. Tool Life:

Metals that can be cut without rapid tool wear are generally thought of as being quite machinable, and vice versa. A workpiece material with many small hard inclusions may appear to have the same mechanical properties as a less abrasive metal. It may require no greater power consumption during cutting. Yet, the machinability of this material would be lower because its abrasive properties are responsible for rapid wear on the tool, resulting in higher machining costs.

One problem arising from the use of tool life as a machinability index is its sensitivity to the other machining variables. Of particular importance is the effect of tool material. Machinability ratings based on tool life cannot be compared if a high-speed steel tool is used in one case and a sintered carbide tool in another. The superior life of the carbide tool would cause the machinability of the metal cut with the steel tool to appear unfavourable. Even if identical types of tool materials are used in evaluating the workpiece materials, meaningless ratings may still result. For example, cast iron cutting grades of carbide will not hold up when cutting steel because of excessive cratering, and steel cutting grades of carbide are not hard enough to give sufficient abrasion resistance when cutting cast iron.

Tool life may be defined as the period of time that the cutting tool performs efficiently. Many variables such as material to be machined, cutting tool material, cutting tool geometry, machine condition, cutting tool clamping, cutting speed, feed, and depth of cut, make cutting tool life determination very difficult.

The first comprehensive tool life data were reported by EW. Taylor in 1907, and his work has been the basis for later studies. Taylor showed that the relationship between cutting speed and tool life can be expressed empirically by: $VT = C$
where: V = cutting speed, in feet per minute
t = tool life, in minutes
C= a constant depending on work material, and other machine variables.

The tool has been grinded so many times as machining operation have been done for the sample specimens. Even though the material is easy to machine it was degraded sonly, since it is HSS tool. But it was very high during machining of high level defect specimens.

To generalize the tool gets an impact force as the tool tip jumped from one edge of porosity to the next edge. This also causes the tool to be harmed easily and fail earlier to its life span. Especially if the sand plastering and large cavity produced during casting process, it might cause teenage failure and it needs to be grinded faster than the normal time.

e. Material removal rate (MRR)

The metal removal factor is the reciprocal of the specific energy and can be used directly as a machinability rating if forces or power consumption are used to define machinability. That is, metals with a high metal removal factor could be said to have high machinability.

Material Removal Rate (MRR) = Volume Removed/Time

$$MRR = vfd$$

Where 'v' spindle speed, 'f 'feed, and'd' depth of cut.

Accordingly it is easy to judge to say MRR is very high during machining sound casts other than medium and high level defect specimens. In this thesis it were observed that 20 gram of chip was collected in specimen

4.3. Mechanical properties of sample specimens

4.3.1. Impact test.

A metal may be very hard and therefore very strong and yet be unsuitable for applications in which it is subjected to sudden loads in service. Materials behave quite differently when they are loaded suddenly than when they are loaded more slowly as in tensile testing. Because of this fact, impact test is considered to be one of the basic mechanical tests (especially for ferrous metals).
The term brittle fracture is used to describe rapid propagation of cracks without any excessive plastic deformation at a stress level below the yield stress of the material. Metals that show ductile behaviour usually can, under certain circumstances, behave in a brittle fashion. The stress needed to cause yield rises as the temperature falls. At very low temperatures, fracture occurs before yielding.
Impact tests are used not also to measure the energy absorbing capacity of the material subjected to sudden loading; but also to determine the transition temperature from ductile to brittle behaviour.

THEORY:

Experimental set up:

In this test the specimen is positioned across the lowest point in the path of a striker mounted at the end of a pendulum as shown in Figure below. The striker, having been initially lifted to a specific height h1, and then released, swings against the specimen and breaks it. The striker continues its swing to the other side of the specimen to a height h2. Clearly the difference between the two heights multiplied by the weight of the striker corresponds to the amount of energy that is absorbed in fracture.

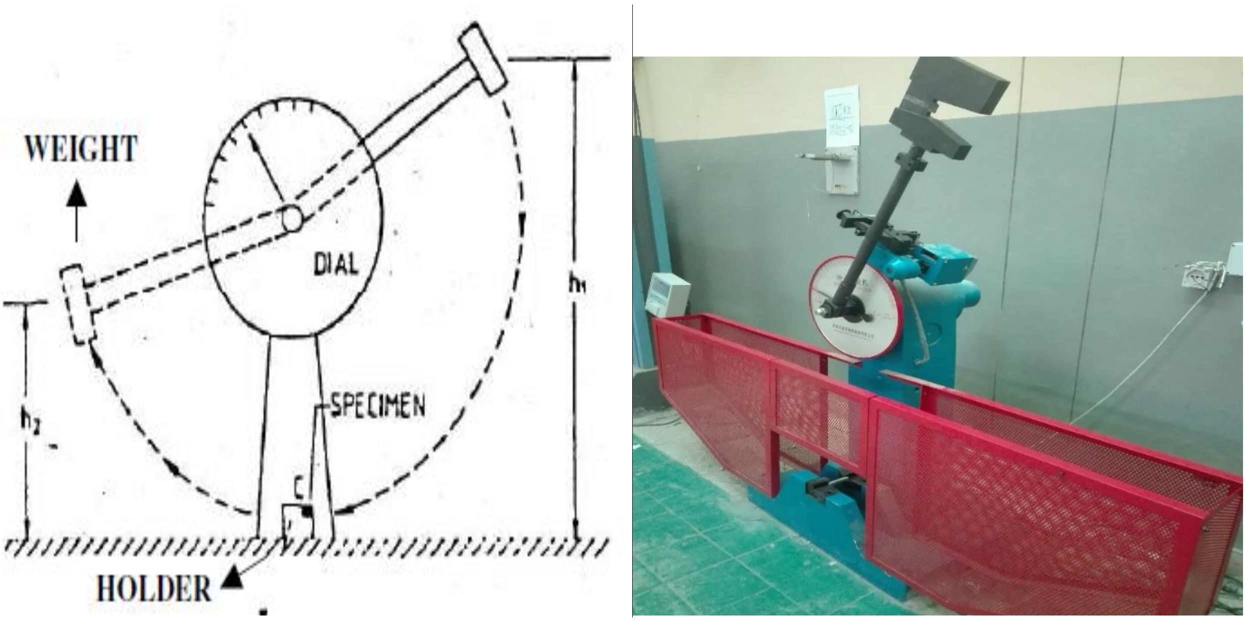


Figure 4.5. Working principles and machines of impact tester.

In pendulum impact test sample specimens has been positioned on the holder and load L is allowed to drop from a height of h1 and swing over it to break the specimen. After the test the final height has been measured by touching the tail pointer of the load to the reading dial gauge tail. The ability of the material absorbing the energy can be measure either directly from the dial gauge as shown below or by multiplying the load applied with the height difference. In doing so slight difference might be observed due to human error.

Sample A Sample B Sample C

Figure 4.6. Readings of the dial gauge for the three sample from Impact tests (a) sound cast (b) medium level defective casts and (c) high level defective parts.

Table 4.1. Results of impact test

Sample test A (Sound cast)	**Actual reading on dial gauge**	**Height of the load before (h1) and after (h2) application on the smple specimens (mm)**	
		H1	H2
	= 5 joule	=1687mm	=1640mm
Sample test B (Medium level defective cast)	**=4.2 joule**	=1687mm	=1652mm
Sample test C (High level defective cast)	**=3.8 joule**	=1687mm	=1657mm

Discussion on the result of impact test:

From the above result the amount of energy that can be absorbed by the material can be read directly as above or can be calculated as follow to compare the three sample specimens. The stricker load used for the experiment is 12.5 kg load including the systems which are attached to the stricker.

Table 4.2. Calculated results of impact test

	Difference (h1-h2)	
Specimen A	=47mm	E=mxg(h1-h2) =12.5kgx9.8x0.047 **=5.7575 joule**
Specimen B	=35mm	E=mxg(h1-h2) =12.5kgx9.8x0.035 **=4.2875 joule**
Specimen C	=30mm	E=mxg(h1-h2) =12.5kgx9.8x0.030 **=3.675 joule**

From the results above we can obseve that the three sample specimens have visible differences in absorbing impact energy during sudden drop of the stricker. Based on the experimental results, sample specimen A (with the assumption of sound cast) has the highst load absorbing ability than the remaining once. Relatively sample specimen B has also better load absorbing ability than that of C.

4.3.2. Hardness test

Hardness has already been defined as the resistance of a material to indentation or abrasion by another hard body (good hardness generally means that the material is resistant to scratching and wear). It is by indentation that most hardness tests are performed. A hard indenter is pressed into the specimen by a standard load, and the magnitude of the indentation (either area or depth) is taken as a measure of hardness.

Hardness tests are commonly used for assessing material properties because they are quick and convenient. However, a variety of testing methods is appropriate due to differences in hardness among different materials. The most well-known hardness tests are Brinell, vickers and Rockwell.

Hardness is a measure of the material’s resistance to localized plastic deformation (e.g. dent or scratch)

The Vickers hardness test

Vickers hardness test uses a square-base diamond pyramid as the indenter with the included angle between opposite faces of the pyramid of 136°. The Vickers hardness number (VHN) is defined as the load divided by the surface area of the indentation. This test is preferable to the Brinell test where hard materials are concerned, as it uses a diamond indenter. (Diamond is the hardest material known approximately 6000 HB). Standard loads are 5, 10, 20, 30, 50 and 1 00 kg.
It is necessary to state the load when specifying a Vickers hardness number.
For example, if the hardness number is found to be 200 when using a 50 kg load, then the hardness number is written as HV (50) = 200.

Experimental set up

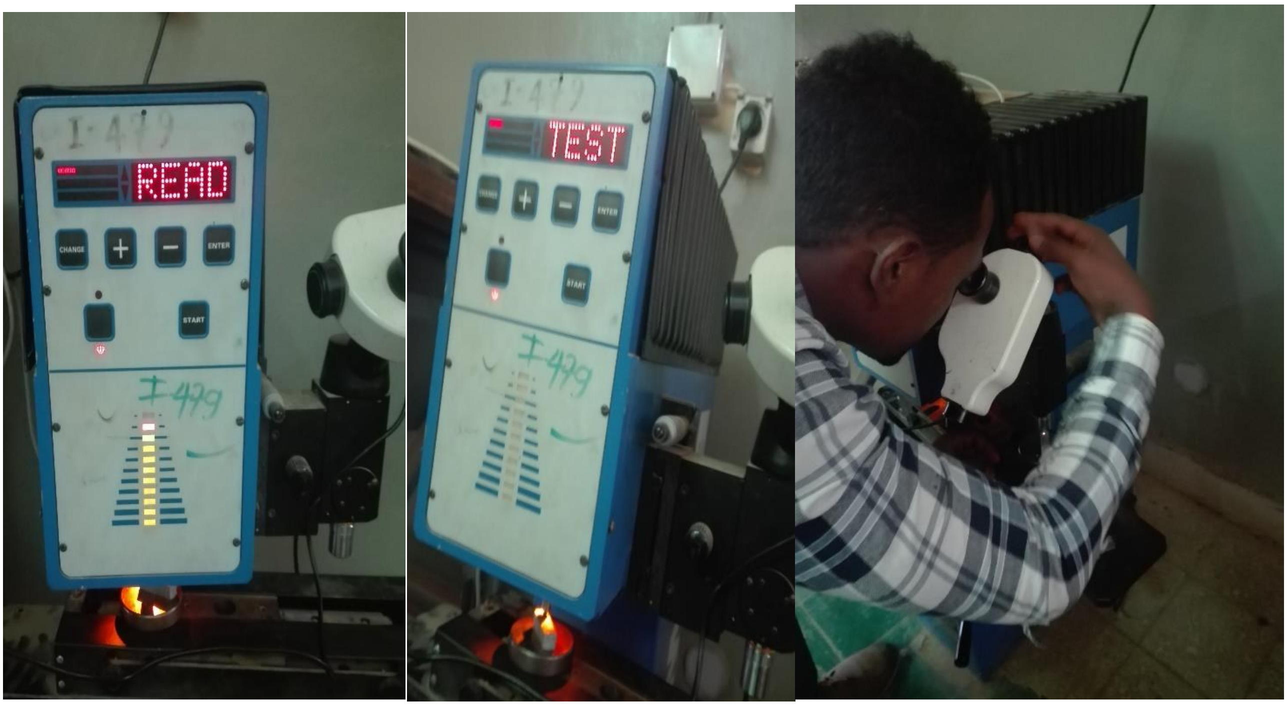


Figure 4.7. Vickers hardness tests

Table 4.3. Results from the reading of hardness tests after applying 100kg load for 15 sec.

Sample	Indent 1 (mm)		Indent 2 (mm)		Indent 3 (mm)	
	D1	**D2**	**D1**	**D2**	**D1**	**D2**
Sample test A (Sound cast)	0.6698	0.6048	0.7223	0.6512	0.6595	0.6025
Sample test B (medium level defective cast)	0.6520	0.7356	0.7339	0.6276	0.6336	0.6559
Sample test C (high level defective cast)	0.7327	0.6857	0.7327	0.7366	0.5290	0.7047

Discussion on hardness test

The HV number is then determined by the ratio *F/A*, where *F* is the force applied to the diamond in kilograms-force and *A* is the surface area of the resulting indentation in square millimetres. *A* can be determined by the formula. Hence, [35]

$$A = \frac{d^2}{2\sin(136^\circ/2)} \qquad A \approx \frac{d^2}{1.8544},$$

Where *d* is the average length of the diagonal left by the indenter in millimetres.

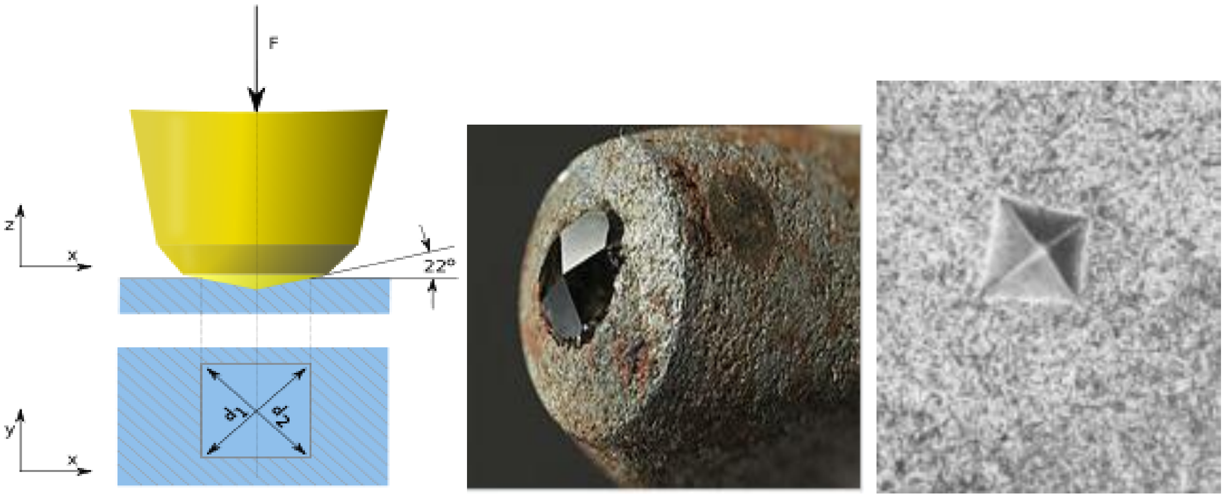


Figure 4.8. Principles and indenter tips of Vickers hardness machine

HV=F/A

$$HV = \frac{2F\sin\frac{136^o}{2}}{d^2}$$

or

$$VHN = \frac{2P\sin(\frac{\theta}{2})}{d^2} = \frac{1.854\,P}{d^2}$$

$$HV = \frac{F}{A} \approx \frac{1.8544F}{d^2} \quad [\mathrm{kgf/mm^2}],$$

Where *F or p* is in kgf and *d* is in millimetres.

The corresponding units of HV are then kilograms-force per square millimetre (kgf/mm^2). To calculate Vickers hardness number using SI units one needs to convert the force applied from newton to kilogram-force by dividing by 9.806 65 (standard gravity). This leads to the following equation [36]

$$HV \approx 0.1891\frac{F}{d^2} \quad [\mathrm{N/mm^2}],$$

Where *F* is in N and *d* is in millimetres. A common error is that the above formula to calculate the HV number does not result in a number with the unit Newton per square millimetre (N/mm2), but results

directly in the Vickers hardness number (usually given without units), which is in fact kilograms-force per square millimetre (kgf/mm²).
To convert the Vickers hardness number to SI units the hardness number in kilograms-force per square millimetre (kgf/mm²) has to be multiplied with the standard gravity (9.806 65) to get the hardness in MPa (N/mm²).

Vickers hardness numbers are reported as **xxxHVyy**, e.g. **440HV30**, or **xxxHVyy/zz** if duration of force differs from 10 s to 15 s, e.g. 440HV30/20, where:

- **440** is the hardness number,
- **HV** gives the hardness scale (Vickers),
- **30** indicates the load used in kgf.
- **20** indicates the loading time if it differs from 10 s to 15 s

Vickers values are generally independent of the test force: they will come out the same for 500 gf and 50 kgf, as long as the force is at least 200 gf.

Table 4.4. Results of Vickers hardness tests

Sample test A (Sound cast)	**Indent 1**		**Indent 2**		**Indent 3**		**Average diametre**
	D11	**D21**	**D12**	**D22**	**D13**	**D23**	
	0.6698	0.6048	0.7223	0.6512	0.6595	0.6025	0.65168
Sample test B (medium level defective cast)	0.6520	0.7356	0.7339	0.6276	0.6336	0.6559	0.6731
Sample test C (high level defective cast)	0.7327	0.6857	0.7327	0.7366	0.5290	0.7047	0.6868

Sample A (sound casting): HV = 1.854 F /d^2 , where d is average diameter of the three indents on sample specimen A and F is the force kilogram of the machine i.e. 30 kg.

$$= 1.854*30kg/0.65168^2$$
$$= 130.967HV/30$$

Sample B (Medium level defect casting): HV = 1.854 F /d^2 , where d is average diameter of the three indents on sample specimen B and F is the force kilogram of the machine i.e. 30 kg .

$$= 1.854*30kg/0.6731^2$$
$$= 122.764HV/30$$

Sample C (High level defect casting): HV = 1.854 F /d^2, where d is average diameter of the three indents on sample specimen C and F is the force kilogram of the machine i.e. 30 kg.

$$= 1.854*30kg/0.6868^2$$
$$= 117.915HV/30$$

From the results above it can be observed that sample specimen A can withstand HV of 130, which is superior of the other sample specimens. Sample specimen B and C are also can resist indentations of 122 and 117 respectively.
The other thing that can be compared is with the HV of the material state by the suppliers as of 100HV.

4.3.3. Tensile test:

TENSILE TESTS are performed for several reasons. The results of tensile tests are used in selecting materials for engineering applications. Tensile properties frequently are included in material specifications to ensure quality. Tensile properties often are measured during development of new materials and processes, so that different materials and processes can be compared.

Finally, tensile properties often are used to predict the behaviour of a material under forms of loading other than uniaxial tension. The strength of a material often is the primary concern. The strength of interest may be measured in terms of either the stress necessary to cause appreciable plastic deformation or the maximum stress that the material can withstand. These measures of strength are used, with appropriate caution (in the form of safety factors), in engineering design. Also of interest is the material's ductility, which is a measure of how much it can be deformed before it fractures. Rarely is ductility incorporated directly in design; rather, it is included in material specifications to ensure quality and toughness. Low ductility in a tensile test often is accompanied by low resistance to fracture under other forms of loading. Elastic properties also may be of interest, but special techniques must be used to measure these properties during tensile testing, and more accurate measurements can be made by ultrasonic techniques [19].

A brief overview of some of the more important topics associated with tensile testing includes:

- Tensile specimens and test machines
- Test methodology and data analysis

Tensile specimens and test machines

Tensile Specimens. Consider the typical tensile specimen shown in Figure 4.10 below. It has enlarged ends or shoulders for gripping. The important part of the specimen is the gage section. The cross-sectional area of the gage section is reduced relative to that of the remainder of the specimen so that deformation and failure will be localized in this region. The gage length is the region over which measurements are made and is centred within the reduced section. The distances between the ends of the gage section and the shoulders should be great enough so that the larger ends do not constrain deformation within the gage section, and the gage length should be great relative to its diameter. Otherwise, the stress state will be more complex than simple tension.
There are various ways of gripping the specimen. The most important concern in the selection of a gripping method is to ensure that the specimen can be held at the maximum load without slippage or failure in the grip section.

Testing Machines. The most common testing machines are universal testers, which test materials in tension, compression, or bending. Testing machines are either electromechanical or hydraulic. The principal difference is the method by which the load is applied.

Electromechanical machines are based on a variable-speed electric motor; a gear reduction system; and one, two, or four screws that move the crosshead up or down. This motion loads the specimen in tension or compression. Crosshead speeds can be changed by changing the speed of the motor. A microprocessor-based closed-loop servo system can be implemented to accurately control the speed of the crosshead.

Hydraulic testing machines are based on either a single or dual-acting piston that moves the crosshead up or down. However, most static hydraulic testing machines have a single acting piston or ram. In a manually operated machine, the operator adjusts the orifice of a pressure-compensated needle valve to control the rate of loading. In a closed-loop hydraulic servo system, the needle valve is replaced by an electrically operated servo valve for precise control.

In general, electromechanical machines are capable of a wider range of test speeds and longer crosshead displacements, whereas hydraulic machines are more cost-effective for generating higher forces.

Figure 4.9. Tensile test machine set up

Figure 4.10. Sample specimens for tensile test

Table 4.5. Direct results from the reading of the tensile tester machine

Sample test A (Sound cast)	**Tensile break force**	**Tensile strength (F/A)**
	5518.07 N	125 MPa
Sample test B (medium level defective cast)	5413..24 N	122.6 MPa
Sample test C (high level defective cast)	5268.52 N	119 MPa

Discussion on tensile tests

Sample A (sound casting): the tensile strength is given as: $\sigma A = F/A$

$= F/(\pi r^2)$

$= 5518.07N/(\pi * 0.00375^2)$,

$= 124.966$ MPa

≈ 125 MPa

Sample B (Medium level defect casting): the tensile strength is given as: $\sigma A = F/A$

$$= F/(\pi r^2)$$

$$= 5413.24N/(\pi * 0.00375^2),$$

$$= 122.592 \text{ MPa}$$

$$\approx 122.6 \text{ MPa}$$

Sample C (High level defect casting): the tensile strength is given as: $\sigma A = F/A$

$$= F/(\pi r^2)$$

$$= 5268.52N/(\pi * 0.00375^2),$$

$$= 119.32 \text{ MPa}$$

$$\approx 119 \text{ MPa}$$

By comparing the three results it is clear to understand the effect of gas porosity on tensile strength of the aluminium cast AA6082 materials**.** From the discussion we can understand that even the difference is small it have a negative effect on the tensile strength as gas porosity increased on the casted specimens.

4.3.4. Torsional test

Components that are subjected to rotary movements are twisted. This twisting is referred to as torsion. The torsional stiffness determined in the torsion test serves as orientation for the load capacity of the material. This method is applied in shafts, axles, wires and springs and to assess the impact behaviour of tool steels.

In the torsion test, a specimen is clamped at one end and subjected to the load of a steadily increasing moment, known as the twisting moment or torsional moment. The twisting moment causes shear stresses in the cross section of the specimen and a stress state that leads to deformation and ultimately to fracture.

Each test will be conducted until failure i.e., it will end in the buckling of the hollow specimen or fracture for the solid specimen. Thus, this experiment will also allow observing the different modes of failure for solid circular shafts made of aluminium cast specimen AA6082. Torsion loading results in twisting of one section of a body with respect to a contiguous section. During the test the angle of twist θ and the applied torque T are measured as the test proceeds. For a circular cross-section, in the absence of the other loads, pure shear stress state exists at each point. Torsional elastic shear stresses vary linearly from zero at the axis of twist to a maximum at the extreme fibres.

The assumptions made in this experiment include but are not limited to the following:

1. The torque is applied along the centre of axis of the shaft.
2. The material is tested at steady state (absence of strain rate effects).
3. Plane sections remain plane after twisting (the circular section conforms to this condition).

Test Procedure (for solid shafts):

1. Measure the diameter of the test specimen using the calliper (take an average of 5 measurements).
2. Slide the shaft into the troptometer and tighten down the two fastening screws to the shaft.
3. Clean the clamps used to hold the shaft in place.
4. Insert the shaft into the right clamps' chucks in the testing machine. Tighten the clamp ensuring that the grip is very tight.
5. Slide the other clamp over the other end of the shaft, and tighten down tightly as well.
6. Adjust the troptometer to the correct position from both ends (i.e. do not let it contact with any part of the testing machine.).
7. Measure the length between the troptometer clamps Lt using the tape measure. This length will be used in calculations later.
8. Next, measure the length between the torsion machine's clamps, Lc.
10. Make zero the torque indicator by aligning the red needle with the black one on the torque indicator. Also, use the zero lever to make sure that the needles point to zero.
11. Make zero the troptometer indicator by hand.
12. Turn the crank manually forwards (counter-clockwise) and observe the troptometer indicator. You want to increase the angle of twist by 1° increments up to12°.
13. At each interval as describe in the above step, read the measurement (using the red needle) displayed by the torque gage.
14. Also take the reading off the scale on the right (rotating) clamp housing. This should be done at every even degree that is reached by the troptometer. (i.e. at 2°, 4°, 6° etc.)

Torsion test machine set up

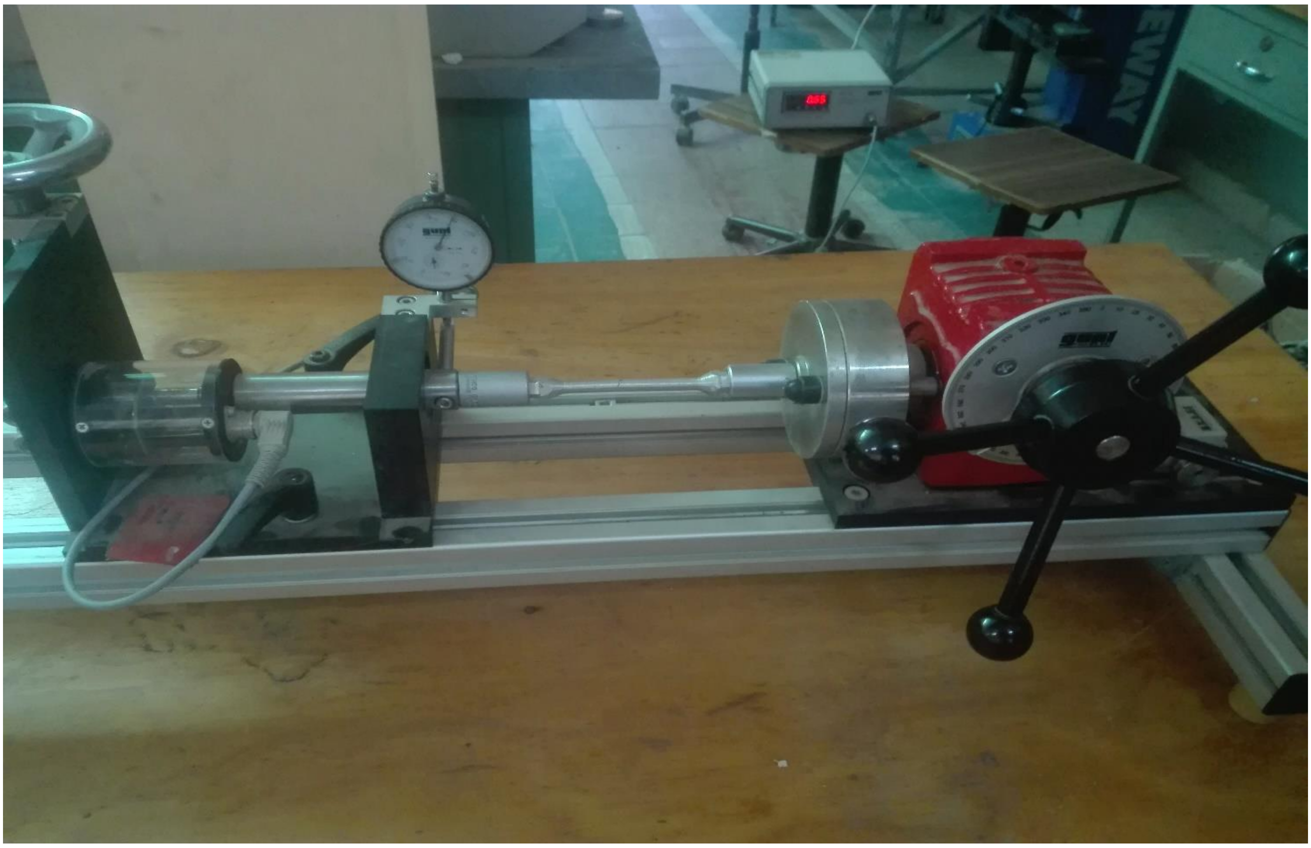
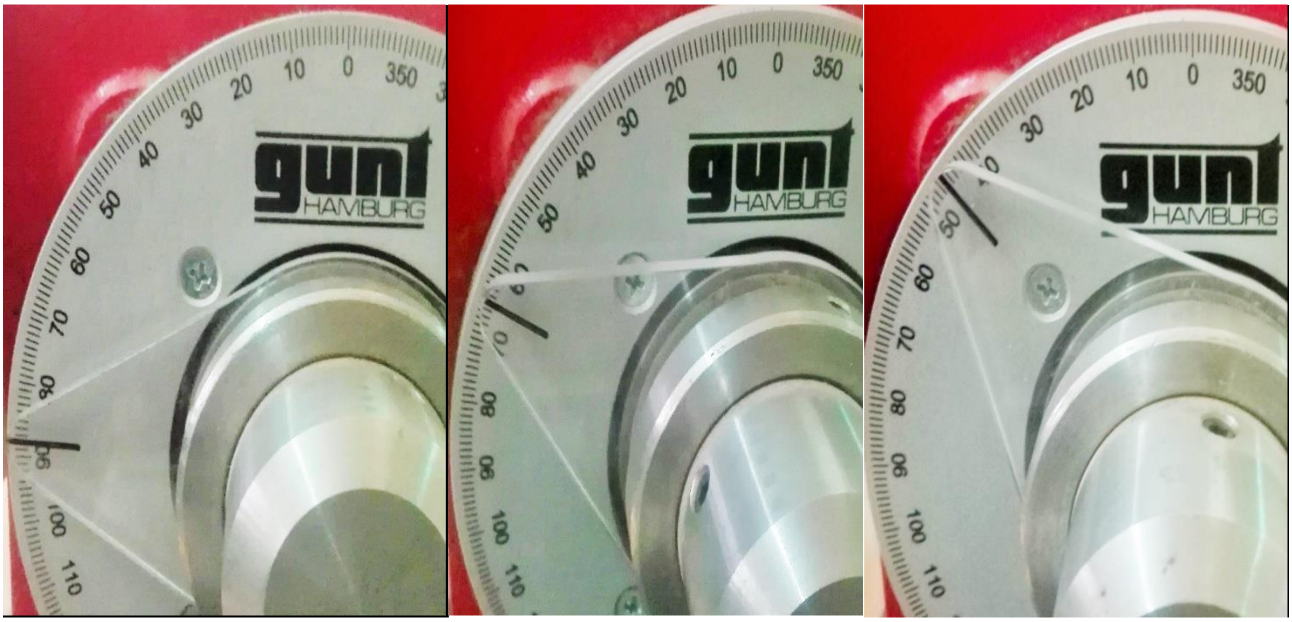


Figure 4.11. Torsion test set up

Results from the experiment

a



b

Figure 4.12. Result of the experiment from the testing machine (a) torque (b) twist angle

Table 4.6. Torsion test results from the experiment

Sample test A (Sound cast)	**Torque**	**Twist angle**
	12.00 N-m	88^{o}
Sample test B (medium level defective cast)	10.75 N-m	65^{o}
Sample test C (high level defective cast)	8.30 N-m	45^{o}

Discussion on torsion test

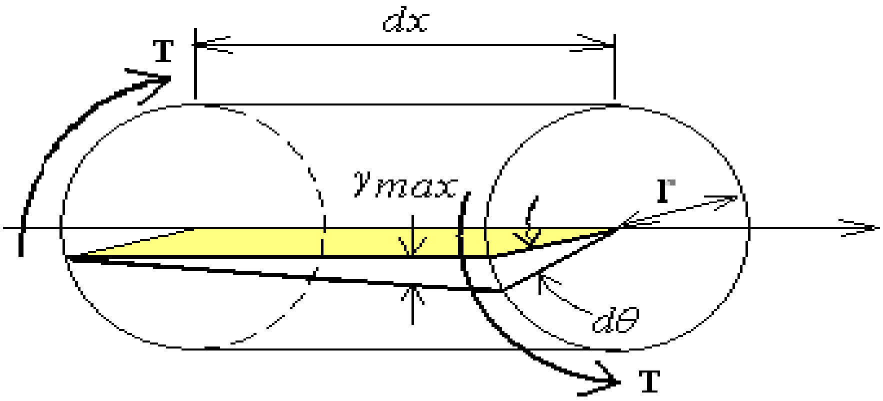


Figure 4.13. Torsional tests of circular specimen http://www.gunt.de/static/s4883_1.ph

The maximum shear stress, τmax, is computed by: $\tau max = \frac{Tr}{J}$, where J is the polar moment of inertia of circular cross section shaft, and given as $J = \frac{\pi d^4}{16}$

So maximum shear stress is given as $\tau max = \frac{16\ T}{\pi d^3}$

Maximum shear stress for specimen A, τmaxA = $\frac{16\ X12}{\pi d^3} = \frac{16\ X12}{\pi(\frac{7.5}{1000})^3} = 144.94$ MPa

Maximum shear stress for specimen B, τmaxB = $\frac{16\ X10.75}{\pi d^3} = \frac{16\ X10.75}{\pi(\frac{7.5}{1000})^3} = 129.78$ MPa

Maximum shear stress for specimen C, τmaxC = $\frac{16\ X8.3}{\pi d^3} = \frac{16\ X8.3}{\pi(\frac{7.5}{1000})^3} = 100.20$ MPa

Maximum shear strain, is computed by: $\gamma max = \frac{\theta r}{dx}$, where θ = angle of twist in radian,

dx = segment length.

r = radius of the specimen.

Maximum shear strain for specimen A, γmaxA = $\frac{88x2\pi/360}{dx} = \frac{2\pi X0.24444}{75} = 0.0205$

Maximum shear strain for specimen B, γmaxB = $\frac{65x2\pi/360}{dx} = \frac{2\pi X0.181}{75} = 0.0151$

Maximum shear strain for specimen C, γmaxC = $\frac{45x2\pi/360}{dx} = \frac{2\pi X0.125}{75} = 0.0105$

Shear modulus, *G*, is computed as, dividing shear stress by shear strains. $\boldsymbol{G} = \frac{\boldsymbol{\tau max}}{\boldsymbol{\gamma max}}$

Shear modulus, G, for specimen **A,** $G_A = \frac{144.94\ MPa}{0.0205} = 7.07$ GPa.

Shear modulus, G, for specimen **B,** $G_B = \frac{129.78\ MPa}{0.0151} = 8.60$ GPa.

Shear modulus, G, for specimen **A,** $G_A = \frac{100.20\ MPa}{0.0105} = 9.54$ GPa.

From the result recorded, it is possible to investigate the effect of the gas porosity on the torsional strength of the material. Accordingly the torsional force and strength, twist angle, and shear strain of the material are inversely proportional to the existence of the gas porosity and directly proportional to the shear modulus of the material which comes due to improper moulding sand and other casting parameters.

The experiment reveals that specimen A, which is relatively sound cast can resist more twisting force before fracture, have high shear stress and lower shear modulus. On the other side specimen C, which is relatively with high degree of defect can fracture earlier than of the other specimens, have medium shear modulus and lower shear stress. Specimen B, which is medium level defect cast have medium performance in resisting twist force, shear stress and higher shear modulus.

Table 4.7**.** Summarized results of the destructive test

Sample specimen	Tensile strength	Torsional strength	Hardness	Impact	Remark
Specimen C	119 MPa	7.07 GPa	117.915HV/30	3.675 joule	
Specimen B	122.6 MPa	8.60 GPa	122.764HV/30	4.2875 joule	
Specimen A	125 MPa	9.54 GPa	130.967HV/30	5.7575 joule	
Original material	260 MPa		75 BH		

CHAPTER-5

CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION:

As it can be observed from the thesis, casting is a major manufacturing process used for all types of materials, as it is cost effective, reusable, used for more intricate shapes, and due to its ability to cast high melting point materials in refractory materials. Beside thus advantages it needs its own requirements to perform the casting process as per the need of the customers. To meet the customers need it is important to produce defect free castings or products at tolerable level of defects. It is known that most gas porosities (pin holes and blow holes) are occur from the upper layer of the cast to underneath of the products. Thus defects are revealed more, either during machining process or during using cast products (at service). This thesis is designed to investigate the effect of these gas porosities on selected machinability characteristics and mechanical properties of aluminium cast AA6082 specimens.

The experiments has been done by following scientific approaches starting from the preparation of specimens for testing up to the end. To investigate the effect of gas porosity on machinability characteristics and mechanical properties the defects are allowed to introduce into the specimens intentionally. In doing this things was not easy since the degree of the defect is not expected to be equal to all sample specimens. The samples were prepared in three types; sound cast, medium level defect cast, and high level defect cast. So all the things such as sample preparation, machining process, and mechanical testing (destructive) method has been done. From the result and the discussion made earlier the following conclusion have been forwarded.

- Gas porosities are greatly affected by the amount of moistures used during mould preparation, ramming of moulds, and venting mechanisms, but not limited.
- Machinability characteristics greatly affected by the gas porosities during machining of cast products. In this thesis things has been done clearly how the gas porosity especially blow holes influencing the cutting tool life, chips produced, surface finish, power consumptions and material removal rates. Thus all have inverse relation with the existence of gas porosities.
- The torsional strength of the material is greatly affected by gas porosity than the other types of mechanical properties, as it is depicted in the result and discussion. This is due to that the porosities are used as crack initiation and propagation during twisting.
- All mechanical properties investigated in this thesis are negatively affected by the gas porosity as the result shows in the experimental activities. Slight difference is observed between specimen A and specimen B, whereas great difference is observed with specimen C.
- The fairness of casting loss is decrease, as the cast materials failure approaching to the final stage or during using materials. If cast products are fail at machining level the cost may be doubled, since we invest more energy and time on it than at casting level only. If the products are failed at the beginning of using of products the loss may be tripled.
- 88:7:5 of sand, clay, and moisture mix ratio and vented mould provided better cast product of aluminium AA6082.

Generally it is possible to conclude that the gas porosity (pin holes and blow holes) are negatively affecting the machinability characteristics and mechanical properties of cast aluminium AA6082.

5.2. RECOMMENDATION

As we all know sand casting process is the most versatile and widely applicable manufacturing methods in earlier as well as in modern centuries. But its dependence on many casting parameters make it difficult to produce defect free castings. The effect of these defects are costly and even can cause total rejections at foundry as well as machining levels. This is also affects the bottom line of the foundry. So to overcome the problem and making fair the effect of defects, it is important to identify were the problem is it? What will be the consequences? Up to what it will be extend? And what care should be taken are answered through scientific approaches. Based on the study made here the followings are forwarded as recommendations.

- Since the effect of casting defect will not end at foundry level great care should be given during casting process.
- The quality assurance departments in foundry industry shall be use non-destructive testing methods to assure the quality of the castings. Because most gas porosities are revealed during machining process or grinding.
- It is recommendable to study the casting parameters independently to differentiate their effects on the cast products**.**
- As the amount of the moisture increased in sand mould, the amount of gas porosity is increased in cast products. So it is better to use proper proportionate of moisture, sand, and clay amounts in moulding process.

Generally Attention must be given in casting process of ferrous and non-ferrous metals to reduce rejection cost at casting level as well as at machining level. If products are fail at machining level the cost may be doubled, since we invest energy at casting as well as at machining level. If the products are failed during using of products the loss may be tripled. So considering thus all in to account advancing the casting process we can reduce costs incurred for rejection, re melt, cutting tool, powers and energies during casting process and machining process. This implies that care should be given in mould preparation and casting processes.

5.3. Limitation and future works of the study

In doing something it is difficult to do hundred percent correct. Some limitations will occur either with the human error and machine error or environmental confirmations. But minimizing thus errors to the lowest limit is possible with a great care made on each steps and procedures, using the correct material, equipment and tools for their respective functions and soon. Similarly, in this thesis have its own limitations forwarded as follow:

- During machining process the lathe machine were not provide automatic feed and manual feed were used. Manual feed may not accurate as of automatic feed even great care were given. But assumptions were made as equal feed were given during machining for investigating machinability.
- Tensile testing machines used for testing was a latest machine, but the person who operate the machine wasn't have sufficient knowledge on it. Due to this one work piece were rejected during testing. And all information that can be performed by the machine were not processed. i.e. graphs, yield points, pick points etc. due to this manual calculation of stress had been made.
- It was better to study on steel alloys, but the resources which available in our campus limiting the study on cast aluminium AA6082. Because foundries in our country melts and cast steel than aluminium. Thus foundry shops in Akaki and others were not interested to allow sample preparation for specific purposes i.e thesis. Rather they allow to use what they cast on the shop. This may not fruitful for the study purpose. For research it is recommendable to prepare specimens as per the specification, moulding for that purpose, using additives etc.
- In sample preparation for tensile and torsion, equal diameter of gauge length and shoulder was used and this leads to the two specimen to fail near to the grip.

Generally the above are some among the more limitations observed and identified as weakness of the study. In the future it is better to overcome the above limitations and focus will be given to non-destructive testing methods to make more scientific. Future works may also focus on investigating the effect of sand plastering on mechanical properties of cast products.

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