INTRODUCTION

1.1 The History of Casting and Aluminium

Casting may be defined as “metal object obtained by allowing molten metal to solidify in a mould” the shape of the object being determined by the shape of the mould cavity. So the process begins by melting the metal, blending the alloy, and finishes after pouring it into moulds. It can be recognized from the definition that casting is a simple, inexpensive, and versatile method of metal forming process. This process is more than 500 years old but even today this process continues to be the most widely used method of metal forming. A lot of technological advancement has been made so far, but the principle remains the same.

Although it is not known who made the first casting, or exactly where, most historians believe that this great step was made in ancient Mesopotamia today’s modern Iraq in the period of 4000-3000 BC. The oldest casting in existence is believed to be a copper frog cast in Mesopotamia probably around 3200 BC, and its complexity indicates clearly that it was preceded by simpler objects. It was also claimed that cast gold objects were found in royal tombs of the first dynasty of Egypt dating back to 4000 BC [1].

Gold was the first metal used by prehistoric men because of its shiny appearance and ease of manufacturing. Then silver was found and treated similarly. Later mankind found copper appearing in the ashes of camp fires from copper-bearing ore that lined the fire pits. It was found that copper was harder than gold and silver and couldn’t be bent easily. Copper products were used as tools and weaponry.

Pottery made from clay was found earlier than metal. Man learned how to make pottery by shaping clay into bowls and hardening by fire. Food was cooked in these pots. Man learned that gold could be melted in clay pots and copper could also be melted too. These were the beginnings of the “Casting Industry” [2].

In Eurasia, copper and bronze tools, decorations and weapons became common around 3,000 B.C. Bronze refers to a broad range of copper alloys, with tin as the main material which makes it stronger and tougher than copper. In that period bronze was used as important material for
most of the activities of day to day life. So, the period was named as “The Bronze Age”. The Bronze Age might have started around 3,500 B.C. in the Near East area, or around modern Turkey and around the Middle East. The Indian Bronze Age began around 3,300 B.C. while China’s Bronze Age has started around 2,100 B.C. There were many areas in the world where Bronze Ages started in different periods [3].

The Iron Age was the last period of the three-age system for classifying prehistoric societies (Stone Age, Bronze Age and Iron Age). The Iron Age corresponds to the stage at which iron production was the most advanced form of metal working. The first use of iron probably came from the Sumerians and Egyptians around 4,000 B.C. [4]. China started to have iron castings around 1,000 B.C. India made steel around 500 B.C. [2]. The casting technology went to Europe from India and the Middle East through Portuguese explorers in the 14th century [5].

Progress in casting technology was necessarily slow. From pure copper, early man moved to bronze. In the years following 3000 B.C, the metal casting process was a vital element in both art and the production of military hardware. Shortly after 1000 BC the first production of cast iron is attributed to China. Developments in metal casting came swiftly in the 14th and 15th centuries after all the improvements in molding practices. Clearly sand casting had largely displaced earlier clumsier methods of obtaining a metal shape. The available casting techniques were constantly improved upon as the industrial revolution gained momentum [1].

The development of casting practices for aluminium and its alloys is a relatively recent accomplishment. Aluminium alloys were not available in any substantial quantity for casting purposes until 1886 of the electrolytic process of reduction of aluminium oxide by Charles Martin Hall in USA and Paul Heroult in France [6]. Although Hall’s invention provided aluminium at a greatly reduced cost, the full value of aluminium as a casting material was not established until alloys suitable for the foundry process were developed. Since about 1915, a combination of circumstances - gradually decreasing cost, the expansion of air transportation, development of specific casting alloys, improved properties, and the impetus provided by two world wars - has resulted in an ever-increasing use of aluminium castings [7].
1.2 Benefits and disadvantages of casting

Casting process can simplify the production by casting a single complex shape object instead of manufacturing different parts and assembling them. Mass production of products can be done by casting either a large number of products in a single mold or in other cases by reusing the mold. Very large heavy objects can be cast which would be extremely difficult or economically impossible to produce by other methods. Some engineering properties in casting are better than objects produced by other methods. For example, uniform properties throughout the casting can be achieved if properly cast. Casting can give an economic advantage resulting from one or more of the advantages shown which may help in the competition against other types of manufacturing. [8]

There are situations where other shaping methods are more suitable. For example, machining can achieve better surface finish and dimensional accuracy which is not achievable by casting; welding can join metal objects which may be produced by wrought or casting into more complex structures, stamping produces light weight sheet metal parts; and forging helps improve the strength and toughness of steel, etc. An engineer with knowledge of the possibilities of each shaping method may select a method or a combination of methods which best suits his or her work achieving high quality, low priced products [8]

1.3 Types and Methods of Casting

There are many processes for producing a casting depending on size, type of metal, complexity, dimensional allowance, quality and whatsoever. One of the oldest methods is sand casting. Sand is mixed with binders and water so the sand grains hold shape, compacted in a flask which can be separated into two or more pieces with a pattern in the middle. This pattern will have approximately the same shape and size (or may be slightly different depending on the dimensional tolerance, shrinkage/expansion of the metal or machining allowances) of the desired casting. The mold is then parted, the pattern is removed and the compacted sand will have a negative shape of the pattern. The mold may be assembled with cores to give the casting hollow areas and the gating and feeding system including runners, ingates, risers, sprues, etc., will be made in the mold. The liquid metal would then be poured into the mold. After the casting cooled
down, the mold is broken to remove the casting. The casting’s gating system and risers would be broken off, the casting cleaned and then machined into the desired product.

Sand casting may be separated into green-sand mold casting, no-bake sand mold casting and shell-mold casting. Green-sand mold casting is silica sand and clay mixed with water, no-bake sand mold is silica sand mixed with resin that hardens within minutes after shaping and shell-mold casting is silica sand mixed with resin, shaped and baked to form the wanted mold shape [10].

Sand casting may be classified as Expendable Mold/Reusable Pattern process. Other Expendable Mold/Reusable Pattern process casting methods are the plaster-mold casting process, and ceramic-mold casting process [10].

The lost wax casting method or investment casting process was used by Asian Indians to make sculptures of gods and goddesses for hundreds of years. The wax models were carved and carefully pasted over and covered with natural clay obtained from river banks, after wetting with water. After being sun dried for 3 to 4 weeks, the wax was melted with heat, forming a hollow mold. Molten metal was poured into the mold to make the casting [5]. The modern lost wax casting method is called investment casting. Wax is injected into a metal mold to make patterns, which are connected to a common sprue to form a tree. The tree is repeatedly dipped in ceramic slurry and dried. The wax is removed by heat leaving a mold. The ceramic shell is preheated and filled with molten metal, then broken after the casting has cooled down. This method is suitable for casting any metal with small to medium intricate shapes and thin walls.

Full mold casting or evaporative-foam casting is done by packing loose silica sand around an expanded polystyrene (EPS) pattern. Molten metal is then poured into the mold through the gating system, burning out the foam pattern as it fills the mold. It is called full mold casting because the pattern is not removed, hence the name full mold. This method is suitable for even intricate castings and requires less labour and skill compared to sand casting. A mold must be used to make the EPS patterns and the mold should properly vent out the gases generated from burning the foam. The replicast process is a method similar to wax investment casting except EPS is used instead of wax. Another variation is vacuum casting, which also uses loose sand but
held between two thin plastic sheets by vacuum applied to a pattern with a number of vent holes [5].

Investment casting and evaporative-foam casting can be classified as Expendable Mold/Expendable Patterns Process. Another classification of casting process is Permanent Mold/No Patterns Process. The casting processes in this classification are permanent mold casting, die casting and centrifugal casting [9].

Gravity die casting (also called the permanent mold process) is a method which molten metal is poured into a cast iron mold coated with a ceramic mold wash. Cores can be made from sand or metal. After the casting has cooled down, the mold is parted and the casting is removed. This method is suitable for non-ferrous metals with medium sizes and moderate complexity and thickness [5].

Pressure die casting is a process which molten metal is injected into a hardened steel die under pressure. Usually this type of die is water-cooled and metal cores must be used instead of sand cores. The casting is removed by parting one half of the die and the casting is removed by ejector pins. This process is suitable for non-ferrous castings with small to medium size, varying complexity and thin walls [5].

Centrifugal casting is a process which molten metal is poured into a horizontal rotating mold where the centrifugal force would push the molten metal to the mold wall. This method can produce pipes of tubes without using cores [5] and the thickness of the casting wall depends on the amount of molten metal poured into the mold [9]. An alternative to this process is the semi-centrifugal casting process which axis-symmetrical castings, like pulleys, gears and rotors can be produced while rotating about a vertical axis rotating mold. Another variation called the centrifuge casting is a process which mold cavities are arranged around a central axis. This method uses the rotation of the mold to get better filling characteristics [5].

Squeeze casting or semi-solid casting is a process which semi-solid metal is forced under pressure into a metal mold. This method would give a casting fine microstructure free from dendrites. The mechanical properties of these castings are close to those of forgings. This method
is useful for non-ferrous metals and composites and is also applied for aerospace and automotive parts [5].

1.4 The Casting Process

The casting process starts only after receiving an confirmed order from a customer which may include the design, dimension, physical properties, etc., then the foundry starts planning for production. Supervisors select the appropriate method is to be used and then produce a prototype of the same product. Modification will be done if any defects are there. After confirming the prototype final casting is produced. Then the same final product is to be sent to the customer. Figure 1.1 shows the main procedures of a casting process, but the procedures in each casting facility may differ in detail.
Figure 1.1: Main steps of casting process
1.4.1 New Casting Development

From Figure 1.1, the area in the shaded box could be called the development of a new casting, which in detail, might be separated into three stages, product design, tooling development and foundry trials [5].

1.4.1.1 Product Design

This first stage is the most essential because it virtually influences all other decisions and activities in the product life cycle, and eventually the technical and economical value of the product.

This stage consists of three types of requirements. First is the functional requirement, driven by geometry, dimensions, relative location and orientation. The next type of requirements is property requirements, including thermal-physical properties, mechanical, and chemical properties of the product. These properties are mainly driven by the material composition and structure. The third type is production and quality requirements, which include surface finish, tolerance, internal soundness, order quantity and lead time, etc.

The above requirements are developed through three steps of the product design, which are conceptual design which focuses on the geometries of the product to achieve the required functions, detailed design involves selecting the material(s), defining the geometry and its tolerances and prototyping which basically is producing a prototype to test the form, fit and function of the product. Iterations may be done to these production design steps to achieve optimality of functional requirements, quality and cost [5].

1.4.1.2 Tooling Development

Tooling consists of patterns and core boxes for sand casting or dies for die casting or investment casting. It can also be further classified as design of cavity or the pattern for producing the cavity or cavities and its accessories.

This stage involves setting the best orientation of the casting and the determination of the parting line or parting lines if there has to be more than two segments of molds to produce the casting. Also, some castings might have multiple-cavities instead of just one. It also involves the internal
cavities such as holes and undercuts produced by cores. This require identification of core features, design of cores, which also includes their supports, called prints in sand casting, and core boxes for producing the cores.

Proper allowances must be incorporated in the mold cavity and cores considering part shrinkage, distortion and machining which may be done later in the process. The cores or dies must be easy to remove from the part. Other cavities include feeders or risers (number, location, shape, and dimensions), sprues, runners, the gating system which leads the molten metal into the mold. Other accessories include cooling, guiding and ejection systems (for die casting). The method for manufacturing the tooling depends on its material, complexity, quality and time/cost considerations [5].

1.4.1.3 Foundry Trials

Trial castings are made to observe the flaws and defects that might happen in a casting which may occur from the two previous stages. Castings are inspected using destructive and non-destructive methods for finding external and internal defects. The most common destructive method is to section the casting in the places of interest and find if defects are present. Macroporosities and shrinkages may be seen by the naked eye while micro-porosities and micro-structural defects would require seeing through a microscope. Non-destructive methods include radiography, ultrasound, magnetic particle, dye penetrant, and eddy current testing. Based on the results, the tooling, usually the gating and riser system may be modified, and the process parameters, usually the pouring temperature, pouring time (and pressure variation in the case of die casting), etc., may also be modified to improve the casting to a desirable level of quality. If the defects cannot be eliminated by modifying the process parameters or tooling design, it is necessary that the product design be modified, which is very expensive and time consuming at this late stage. Figure 1.2 shows the relationships of management time spent, the ability to influence the production process, the cost of rectifying mistakes in the process and the accumulated costs to each product development phase [5].
Figure 1.2 Cost and impact of product development phases [5].