# INVESTIGATION OF BRASS MICROSTRUCTURE AND MECHANICAL PROPERTIES USING METAL CASTING

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

DISEMBER 2010

**UNIVERSITI MALAYSIA PAHANG**
**FACULTY OF MECHANICAL ENGINEERING**

I certify that the project entitled 'Investigation of Brass Microstructure and Mechanical Properties Using Metal Casting' is written by Nur Hamizah Bt Minhat. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in the partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

*(MOHD AKRAMIN MOHD ROMLY)*

Examiner Signature

## SUPERVISOR DECLARATION

I hereby declare that I have read this project report and in my opinion this project report is sufficient in terms of scope and quality for the award of the Degree in Mechanical Engineering with Manufacturing.

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## STUDENT'S DECLARATION

I hereby declare that the work in this report entitled "Investigation of Brass Microstructure and Mechanical Properties Using Metal Casting is my own except for the quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for award of any other degree.

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## ACKNOWLEDGEMENTS

I am very grateful to ALLAH S.W.T for blessing me in finishing this final project (PSM) with successful and I hope this project will be benefit to all.In this opportunity I would like to convey my full appreciation thankful to my supervisor, Madam Nor Imrah Binti Yusoff for her kindness on deliver me knowledge on writing the project report and lead me for encouragement, support, critics and advise to complete this project. Without her motivation, I could not finish project study as presented here. Besides that, I also like to thank to lectures engineers from lab casting, material, lathe and cnc for guiding and supervising my project work for this whole semester. At that same time, I also like to dedicate my appreciated all assistant engineers in Faculty of Mechanical laboratory for their help and advice. Lastly, I would give my appreciation to my fellow friends that have support me a lot, help and advice to be strong and confident for doing this project.

## ABSTRACT

Brass is a alloying of cooper and zinc, alpha (α) brass are quite soft and ductile, the ductility of the α brasses actually increased zinc content. The maximum strength of brass is 538 Mpa attained at 44wt% zinc. While most brasses are not normally ranked as 'heat treatable', some brasses of very closely controlled composition are cast or hot worked in the duplex α/β state and then annealed at about 450°C to convert the microstructure to an single phase of better resistance to corrosion by dezincification in aggressive supply waters. The main object of the present work is to investigate the effect of cooling rate on microstructure and mechanical properties of brass after sand casting process. After sand casting process, the samples were heated and treated at 800˚C for 2 hours and subsequently were cooled by three different methods. For this purpose, the microhardness and microstructure of these brasses after heat treatment were examined by tensile test, optical microscopy and hardness test respectively. Experimental results have shown that the microstructure of these brasses can be changed and significantly improved by varying the cooling rate. Increase in cooling rate result in large increase in the yield strength. Thus, heat treatment, heating and cooling is used to obtain desired properties of brass such as improve the toughness, ductility or removing residual stress, etc.

# ABSTRAK

Brass adalah paduan dari tembaga dan zink, alpha (α) Brass yang cukup lembut dan ulet,kemuluran Brass meningkat dengan penambahan kandungan zink dalam Brass. Kekuatan maksimum 538 Mpa Brass,mengandungi 44wt% zink. Sementara sebahagian besar Brass tidak bertindak ke atas rawatan haba dan Brass komposisi boleh dikawal denagn dilemparkan atau panas bekerja di duplex α / β negara dan kemudian anil pada sekitar 450 ° C bagi mengubah struktur mikro untuk sebuah fasa tunggal yang lebih baik ketahanannya terhadap korosi oleh dezincification di perairan bekalan agresif. Objek utama dari penelitian ini adalah untuk mengetahui pengaruh laju pendinginan terhadap struktur mikro dan sifat mekanikal Brass selepas proses tuangan pasir. Setelah proses tuangan pasir, sampel dikenakan rawatan haba di 800 ° C selama 2 jam dan selanjutnya disejukkan oleh tiga kaedah yang berbeza. Untuk tujuan ini, microhardness dan mikro dari Brass setelah perlakuan panas diperiksa dengan uji tarik, mikroskop optik dan uji kekerasan masing-masing. Keputusan kajian menunjukkan bahawa struktur mikro kuningan ini boleh diubah dan secara signifikan memperbaiki dengan memvariasikan laju pendinginan. Kenaikan tingkat pendinginan hasil dalam peningkatan besar dalam kekuatan luluh. Dengan demikian, perlakuan panas, pemanasan dan pendinginan digunakan untuk mendapatkan cirri-ciri yang dikehendaki dari Brass seperti meningkatkan ketangguhan, kesungguhan atau stres sisa memadam dan lain-lain.

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# CHAPTER 1

# INTRODUCTION

## 1.1 PROJECT BACKGROUND

Brass is widely used in manufacturing industrial since it is usually the first-choice material for many of the components for equipment made in the general, electrical and precision engineering industries. Brass is specified because of the good combination of properties matched by no other material where a long cost-effective service life is required.

Generally, brass has excellent castability and a good combination of strength and corrosion resistance. The cast brasses are used in applications such as plumbing fixtures, fittings and low pressure valves, gears, bearings, decorative hardware and architectural trim. In this project is presented about the microstructure and mechanical properties of brass using the casting process. The types of casting process that will be using are silica sand casting process. It's consist of placing a pattern in sand to make an imprint, incorporating a gate system, removing the pattern and filling the mold cavity with molten metal, allowing the metal to cool unit it solidifies, breaking away the sand mold and removing the casting part.

The brass will be melting 900°C (cooper-zinc phase diagram, Massalski, 1990) in the induction furnace to become a liquid form, molten metal. Then it was pouring into sand casting mould to shape a tensile test specimen. After molten metal is poured into a mold, a series of event takes place during the solidification of the metal and its cooling to ambient temperature.

These events greatly influence the size, shape, uniformly, and the chemical composition of the grains formed throughout the castings, which influence its overall properties. The part will remove after solidification process.

Unfortunately, the sand casting Sand casting is typically chunky in shape, have a rough surface texture, and have a relatively low-dimensional accuracy relative to other casting methods. Post processing typically includes heat treatment to acquire desirable mechanical properties.

From that, the cooling develops and the resulting grain size influences the mechanical properties of the casting. As grain casting decreases the tendency for the casting to crack during solidification decrease.

## 1.2 PROBLEM STATEMENT

Brass is the copper zinc alloys with a wide range of engineering uses especially in automotive, machinery and jewelries because of high strength, high toughness, good machinability, and low cost. The Brass is alloying element of copper. The composition is developing by alloying, so from the soft materials it become more hardening and can be machining. The processes that choose is sand casting process which supposedly give a better mechanical properties range and microstructure view. As the better result view, quenching process is applying on the casting part in the solidification phase. Quenching is carried out in water, oils and air. The different media of quenching will give different cooling rate. By metal casting process, the relationship between properties and the structures developed during solidification. It explained these relationships in term of dendrite morphology and the concentration of alloying elements in various regions within the metal. When the alloy cooled very slowly, each dendrite develops a uniform composition. However, under the normal (faster) cooling rates encountered in practice, cored dendrites are formed. So, the further studies, able to prove the different cooling rate will contribute in developing the mechanical properties and microstructure of brass using sand casting process.

## 1.3 OBJECTIVE.

The objectives of this project as following below,

1. To investigate the effect on cooling rate of the solidification after heat process in the furnace. The cooling rate is measure in different medium of cooling.

2. To investigate the microstructure and mechanical properties of the material after sand casting.

## 1.4 SCOPE OF WORKS.

The scopes of works that involve of the project are following.

1. The green sand or CO2 sand will be used as a mould.

2. The raw material that will be used is brass ingot.

3. The microstructure and the mechanical investigations consist of hardness of the material, and tensile strength test and metallographic analysis.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

Brass is a copper-based alloy and has been utilized in a variety of applications since antiquity. Brass is non ferrous alloy that alloyed with element copper and zinc. Unalloyed copper is so soft and ductile that it is difficult to machine. Because this materials is low cost and widely use in industry application the composition is improved by alloying to become more harden. However, mechanical and corrosion resistance properties of copper can be improved by alloying. Most copper alloys cannot be hardened or strengthened by applying heat-treatment procedure (Callister, 2000). Consequently, cold working or solid-solution alloying must be utilized to improve the mechanical properties. The most common copper alloys are the brasses that the major element is zinc as a substitution impurity, is the predominant alloying element. To suit every need, there are many standard compositions for brass, with copper contents ranging from 58% to 95% and the other major part is zinc.

For many applications, brass is usually the first choice of materials for home equipments, electrical and all precision engineering industries. Brass is special because of the unique combination of properties that make it essential. This combination is matched by no other materials. The machinability of brass sets the standard by which other materials are judged. Brasses can easily be cast to shape or fabricated by extrusion, rolling, drawing, hot stamping and cold forming (Kalpakjian, 2006).

## 2.2 PROPERTIES AND BEHAVIOR OF BRASS

Brass is a nonferrous alloy that deform by alloying the copper with another element. Its stand by zinc, as a substitution impurity, is the predominant alloying element. The composition of brasses is viewed by spectrometer. The 36.8% is from the zinc content. So, brass constitutes binary alloys of copper and zinc, can have two different types of crystal structure. Alpha brasses are solid solution of copper and zinc with an FCC crystal structure (Kenneth, 1999).

There are many standard compositions of brass, with copper contents ranging from 58% to 95%. The toughness and strength of brass is increase as zinc added up less than 5% to its composition. However, the brass used in the present work contains about 29.44% Zn, 1.21% Sn, 0.11% Pb and 69.24% Cu, which falls under alpha variety. Standard brass is 65 Cu, 35 Zn. The strength is about 42 ksi, but the hardness is rapidly increasing. For this project, the brass is about 60 Cu, 40 Zn. The tensile strength is the maximum, about 46 ksi, but it must be worked hot because at room temperature it is too hard.

As may be observed for the copper-zinc phase diagram in Figure 2.1, $\alpha$ phase is stable for concentrations up to approximately 35wt% Zn. This phrase has an FCC crystal structure, and $\alpha$ brasses are relatively soft, ductile and easily cold worked. Brass alloys have a higher zinc content contain both $\alpha$ and $\beta'$ phase at room temperature. The $\beta'$ phase has an ordered BCC crystal structure and is harder and stronger than $\alpha$ phase, consequently, $\alpha + \beta$ alloys are generally hot worked. Brasses also have a low melting point, (950°C-1100°C) thus facilitating the casting process (William, 2008).

Thus, alloys are containing up about 35% zinc are single phase. Above 35% zinc, the body-centered cubic $\beta$ phase appears and the hardness increases. Alloys in this region have limited cold ductility but excellent hot workability due to the plasticity of the $\beta$ phase at high temperature. The practical limit for zinc is about 42%. Alloys containing more zinc than this are too brittle to have commercial use. For all single-phase $\alpha$ alloys solidification begins with the formation of $\alpha$ dendrites on cooling below the liquids temperature (on line AD). Some coring occurs which allows the dendritic structure to be visible in the microstructure after etching. The dendritic, as cast, structure is broken down by working and annealing to give twinned, equiaxed grains. For the two phase, or duplex α/β alloys the behavior on solidification depends on whether the zinc content lies above or below the peritectic. Up to 37.6% (point D), α continues to be the primary phase, the β being formed by the peritectic reaction which occurs in the last liquid to solidify. Above 37.6% Zn freezing occurs with the formation of β dendrites and when solidification is complete, the structure consists entirely of this phase. The freezing range is limited and so the β dendrites are almost homogeneous. On cooling, β retains less copper, as indicated by the slope of the (α +β)/ β phase boundary (line CH). At about 770°C, α begins to separate from the β and increases in quantity as the temperature falls. This reaction is diffusion controlled and may be suppressed by rapid cooling. The α is precipitated at the crystal boundaries and on certain preferred crystallographic planes (octahedral planes) of the parent phase. This form of separation within the crystal is termed a 'Widmanstätten' structure.(M. Hansen and K. Anderko, 1957)

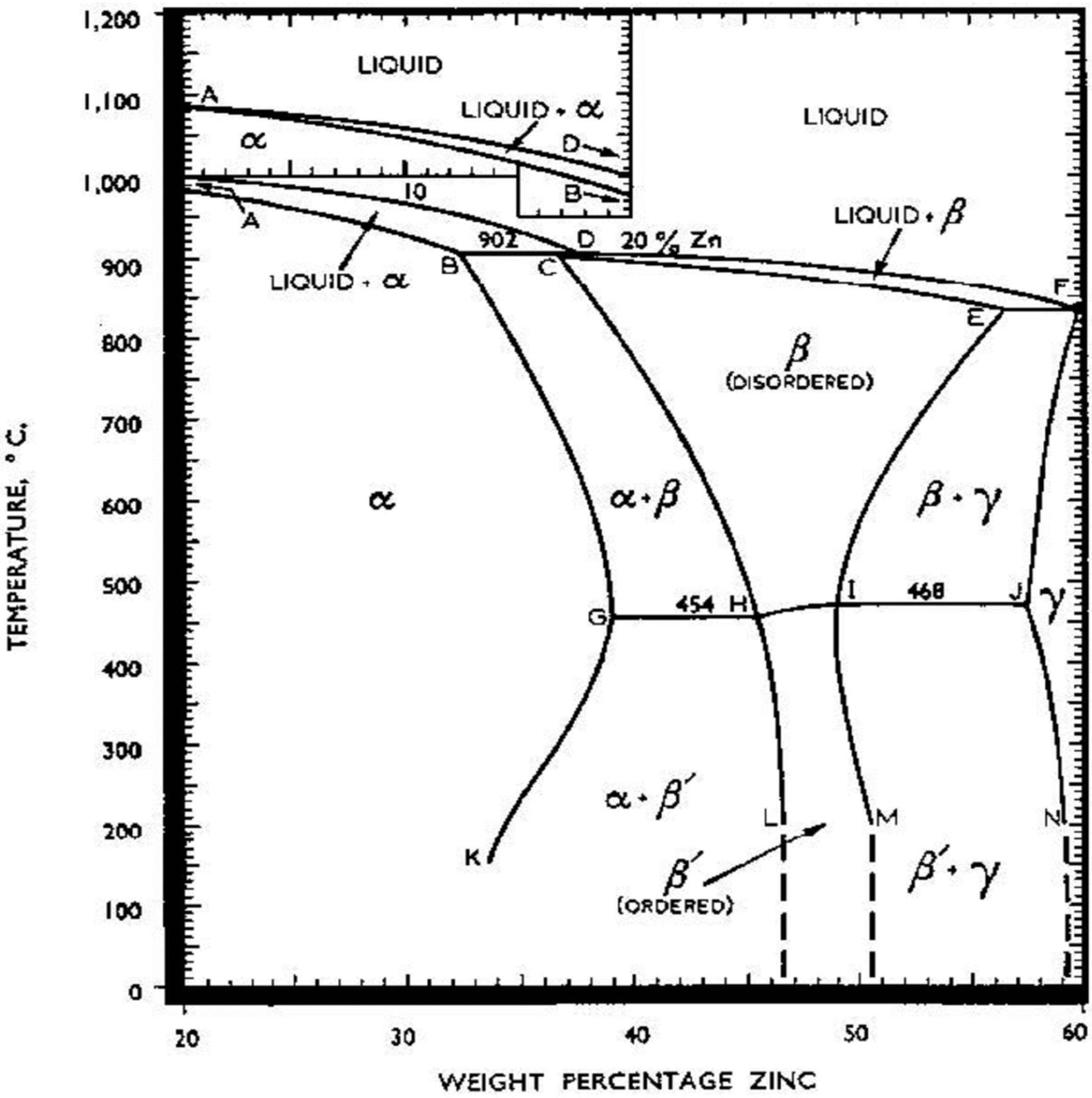


**Figure 2.1:** The copper-zinc phase diagram.

Source: Massalski 1990

The mechanical properties of materials are explained by strength, hardness, ductility and stiffness. The Table 2.1 is showed about the mechanical properties of brass that will be compared with the mechanical properties after metal casting process in the next further studies of this project.

**Table 2.1:** Comparison of the physical and mechanical properties copper alloys (depending on treatment)

| Material Shear | Density ($g/cm^3$) | Melting temperature Solidification | Modulas of elasticity,E ($kN/mm^2$) | modulas,G ($kN/mm^2$) |
|---|---|---|---|---|
| Cu-Zn (brass) | 8.3-8.8 | 895-1045 | 104-124 | 40-46 |
| Cu-Sn (bronze) | 8.8 | 910-1040 | 112-128 | 42-43 |

| Material | Thermal Conductivity at 20°C,λ (W/m.K) | Tensile strength $R_m$ ($N/mm^2$) | Fracture elongation, $A_s$ (%) | Brinell Hardness, HB |
|---|---|---|---|---|
| Cu-Zn (brass) | 8.3-8.8 | 240-610 | 12-50 | 50-190 |
| Cu-Sn (bronze) | 8.8 | 330-630 | 6-60 | 65-200 |

Source: Cahn et al, 1990.

Quenched Cu-Zn is strengthened by vacancies which are generated by the rapid disorder-to-order transformation. The quenching temperature which produces maximum strength is a function of quenching rate. The strength immediately after quenching depends on the number of trapped imperfections, where the number is proportional to the amount of ordering during the quench minus the amount of decay during the quench. The vacancies probably originate from the strong interaction between dislocations in the presence of long range order. Density change, effect of cooling rate, activation energy for decay, electrical resistivity and Clarebrough's work on internal friction are support the idea that the strength of quenched beta brass is associated with vacancies rather than anti-phase domains( N. Brown, 2003).

## 2.3 MICROSTRUCTURE OF BRASS.

In the previous study, that has been carried out from investigation on structure and properties of brass. (Haque et al., 2007) The microstructure of brass casting produced in sand mould shown in Figure 2.2 which is compared to microstructure of brass of chill mould. The dendritic grains of sand cast specimen are bigger compared to the chill mould specimen. The difference is due to the rate at which a casting cools affects its microstructure, quality and properties. The product of sand casting process often large with thick walls, generally cool slowly that may increase the metal's grain size creating a coarse microstructure as Figure 2.2(a). Coarse grain can allow elements of an alloy to separate, which also weakens the casting. Conversely, the product of metal mould process generally cool more quickly may resulting the smaller grain as Figure 2.2(b) having less alloy segregation.

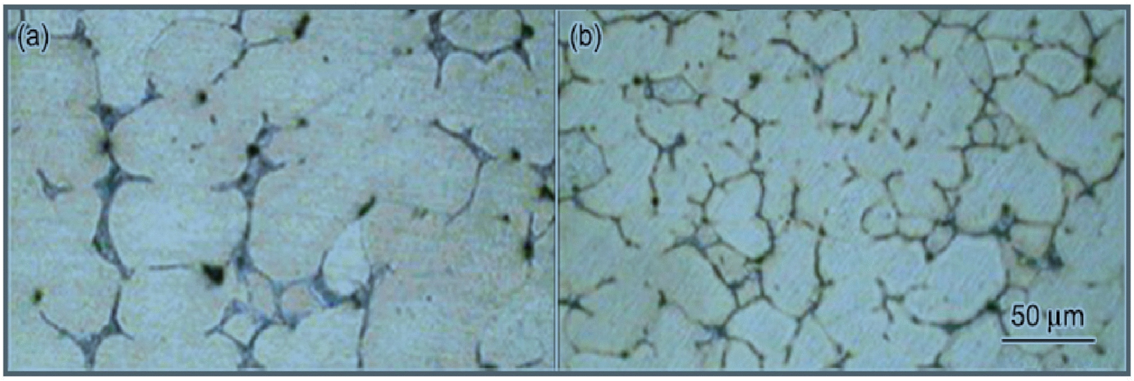


**Figure 2.2:** Microstructure of cast brass: (a) sand casting and (b) metallic chill casting.

Source: Haque et al., 2007

Microstructure of Cu-40% Zn heated to 716°C, held in 1 hour and water quenched, Figure 2.3 producing more beta phase(colored) of larger size and with less preferred orientation.(George et al.,2003).

Figure 2.4 shown microstructure of cast brass after heated 800˚C about 2 hours and furnace cooled. It's fully homogenized because only boundaries and porosity are left in the structure, but no traces of dendrite. It clearly shows that homogenizing annealing cannot completely eliminate voids but the number of voids can be reduced. According to Nivikov (1978), during homogenizing annealing, the quantity of point defects was reduced and the dislocations were redistributed but no new sub grain boundaries were formed. Structure vacancies and interstitial atoms were absorbed by the dislocation when the latter redistributed on heating. Thus, the vacancies migrated to the grain boundaries thereby reducing the vacancy concentration (Omotoyinbo et al.,2009).

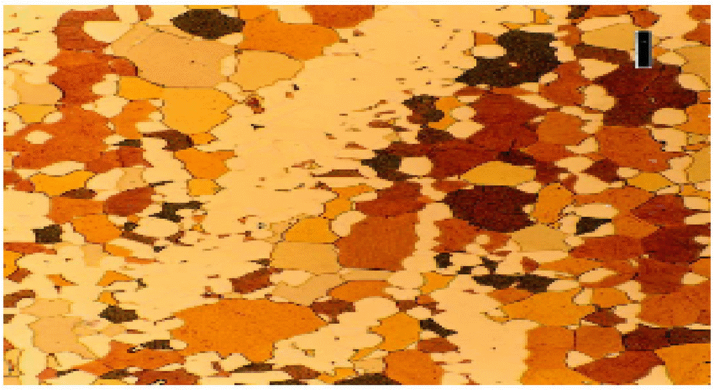

**Figure 2.3:** Microstructure of Brass,716˚C,1 h, water quenched.

Source: George et al., 2003

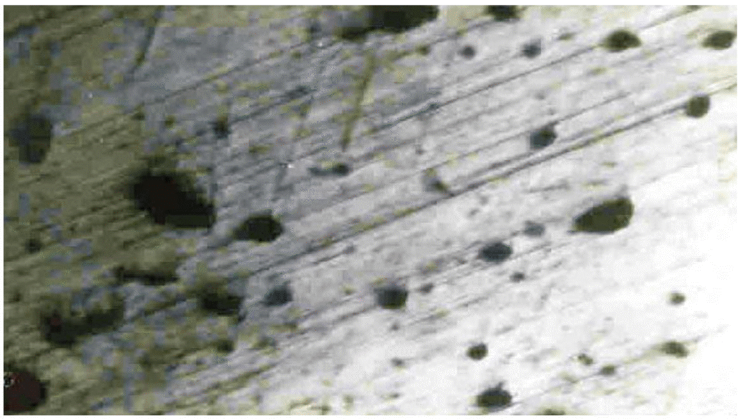

**Figure: 2.4:** Microstructure of Brass, 800˚C,2 h ,furnace cooled.

Source: Omotoyinbo et al., 2009.

## 2.4 METAL CASTING

The metal casting is the one of major manufacturing process that widely uses in industry nowadays. There are castings in locomotives, cars trucks, aircraft, office buildings, factories, schools, and homes. Metal Casting is one of the oldest materials shaping methods known. Casting means pouring molten metal into a mold with a desired cavity shape, and then the molten metal will solidify. When solidified, the desired metal object is removed out from the mold either by breaking the mold or taking the mold apart. The solidified object is called the casting. By this process, castings parts can be given a strength and rigidity frequently not obtainable by any other manufacturing process. The mold, which the place of metal is poured, is made of some heat resisting material. In the sand casting element, sand also is most often used as it resists the high temperature of the molten metal. Permanent molds of metal can also be used to cast products.

By metal casting process, the relationship between properties and the structures developed during solidification. Refer to Kalpakjian (2006), it's explained these relationships in term of dendrite morphology and the concentration of alloying elements in various regions within the metal. When the alloy cooled very slowly, each dendrite develops a uniform composition. However, under the normal (faster) cooling rates encountered in practice, cored dendrites are formed. Cored dendrites have a surface composition different from that in their centers, a difference referred to as a concentration gradient. The surface of the dendrite has a high concentration of alloying elements. A typical cast structure of a brass with an inner zone of equaled grains. This inner zone can be extended throughout the casting by adding inoculants to the alloy. The inoculants induce nucleation of the grain throughout the liquid metal (Kalpakjian, 2006).

### 2.4.1 Sand Casting.

The process of sand casting is quite differ to others casting method because it is using silica sand as a mold material. Basically, sand casting following process are first, placing a pattern in sand to make an imprint, then incorporating a gating system, removing the pattern and filling the mold cavity with molten metal, allowing the metal