Cavitation Failure of Local Made Propellers and Suggestion for Improvement

by

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

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Mechanical Engineering Programme
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Approved by,

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JULY 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Mohamad Faiz bin Mat Nasir

ABSTRACT

Cavitation is a normal phenomenon for a propeller and its presence indicates the loss of its usefulness. For the failed propeller, effect of cavitation is due the poor material in term of its hardness and strength. The local foundries produced α-phase brass to cast the propeller. Compare to the α+β phase brass, the α-phase brass has less tensile strength and hardness. The α+β brass can be produced by having a chemical composition of 60 wt% Cu and 40 wt% Zn. The investigation shows that the chemical composition for the failed propeller contains only 31.38 wt% Zn. The hardness value for the failed propeller and new developed material are found to be 97.06HV and 178.64HV, respectively. In improving the material properties with respect to the effect of cavitation on propeller the local foundries is suggested to cast α+β phase brass

ACKNOWLEDGEMENTS

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I am also indebted to many individuals during my project where their presences are the essence to make this successful. First and the foremost, to my beloved parents which always give me full support for what I have done to become an engineer. Specifically, my utmost appreciation goes to all laboratory technicians of Mechanical Engineering, especially in material laboratory at Building 17 who have contributed an endless amount of assistance, guidance, advice and support along the project period.

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

Propeller is a set of thin angled blades attached to a central hub. When the hub spins, the angled blades push air backwards which forces the aircraft or boat forward. it have two or more twisted blades that is designed to propel a vessel through the water when spun rapidly by the engine. It is a type of fan which transmits power by converting rotational motion into thrust for propulsion of a vehicle such as an aircraft, ship, or submarine through a fluid such as water or air, by rotating two or more twisted blades about a central shaft, in a manner analogous to rotating a screw through a solid [2]. The typical propeller that normally used by the local fishing boat is shown in Figure 1.1

Figure 1.1: Typical propeller used by fisherman boat

Cavitation is a general term used to describe the behavior of voids or bubbles in a liquid. Cavitation referred to as "ventilation" and either term will satisfy. Under cavitation the propeller loses its bite and much or all of it's propulsive force at the same time. Cavitation occurs when the propeller pulls air into the circle in which it is operating and ventilates or aerates the water. The resulting water is called "soft" water and the propeller cannot function in soft water. This project will focus on investigating of the cavitation failure of the propeller due to material properties [1].

1.2 PROBLEM STATEMENT

Local made propellers are produced from brass, like the imported product. However, the chemical composition of the propeller material cannot be controlled due to melting of brass from scrap. Therefore, the quality of the local made propellers appears to be low compared to the foreign made product. Such complains of poor quality are made by customers in terms of frequent needs for replacement of new propellers compared to the imported products.

1.3 OBJECTIVE AND SCOPE OF WORK

The objectives of this research are:

- To investigate the cavitation failure of the local made propellers due to material properties.
- To perform analysis on the mechanical, physical and chemical properties of the failed propeller and new developed propeller material from the foundry

The scope of work for this project is to carry out a study on the physical, mechanical and chemical properties on failed propeller and new developed material.

CHAPTER 2
LITERATURE REVIEW

Malaysia is a country that surrounded by the sea, like Straits of Malacca and South China Sea. Therefore, maritime industry played the important role for the country. Among the maritime activities are transportation and fishing purpose. To make boats or ships can move, it needs propellers to do that. Because of it importance, the requirement for it maintenance and replacement is a necessity.

In this country, the propellers can be obtained from local made foundries or imported from overseas. Obviously, local made propeller is less quality compare with the imported products. This is because local made prone to cavitation failure compare to imported product. It is understood that the local foundries do not produce a high standard quality propeller compared to the imported products.

2.1 IMPORTANCE OF PROPELLER

Propeller is very important, not only to the Malaysians, but to the rest of the world. For this case, the author means for boat or marine propeller because there are many other propeller which use for aeroplane. Boat or marine propeller is very important because it plays many roles in industries like fishing and cargo ships. For the fishing industry, propellers are used to propel the boat to the open sea. It is very important because seafood are among the main food and protein source for almost every single country in the world. Propeller is very important to cargo ship because cargo ship is the main key to the transport goods from one country to another country. It is multi billion dollars industry all over the world.

2.2 FAILURE OF MATERIAL

Among the cause of material's is due to cavitation. Cavitation is the appearance of vapor cavities inside and initially homogeneous liquid medium. It can also occur in many different situations. It can be present various features, according to the flow configuration and the physical properties of the liquid. It is also can be defined as the breakdown of a liquid medium under very low pressures [4].

The main reason that leads to material failure is not using the right material to produce the propeller. May be the company which produces the propeller does not refer to the standards and research papers while doing their business.

2.3 WHAT IS THE RIGHT MATERIAL?

There are several types of material which suitable to make propellers. One of them is stainless steel. Stainless steel is defined as a steel alloy with a minimum of 11.5 wt% chromium content by mass. Stainless steel does not stain, corrode or rust as easily as ordinary steel (it "stains less"), but it is not stain-proof. It is also called corrosion resistant steel when the alloy type and grade are not detailed, particularly in the aviation industry. There are different grades and surface finishes of stainless steel to suit the environment to which the material will be subjected in its lifetime. Common uses of stainless steel are cutlery and watch straps.

Stainless steel differs from carbon steel by amount of chromium present. Carbon steel rusts when exposed to air and moisture. This iron oxide film is active and accelerates corrosion by forming more iron oxide. Stainless steels have sufficient amount of chromium present so that a passive film of chromium oxide forms which prevents further corrosion [7].

Other material is titanium. Titanium is a chemical element with the symbol Ti and atomic number 22. It is a light, strong, lustrous, corrosion-resistant (including to sea water and chlorine) transition metal with a grayish color. Titanium can be alloyed with iron, aluminium, vanadium, molybdenum, among other elements, to produce strong lightweight alloys for aerospace (jet engines, missiles, and spacecraft), military, industrial process (chemicals and petro-chemicals, desalination plants, pulp, and paper), automotive, agri-food, medical prostheses, orthopaedic implants, dental endodontic instruments and files, dental implants, sporting goods, jewelry, mobile phones, and other applications. But this material is quite expensive [6].

Aluminium bronze is a type of bronze in which aluminium is the main alloying metal added to copper. A variety of aluminium bronzes of differing compositions have found industrial use, with most ranging from 5% to 11% aluminium by weight, the remaining mass being copper; other alloying agents such as iron, nickel, manganese, and silicon are also sometimes added to aluminium bronzes [8].

2.4 WHY TO CHOOSE BRASS?

Brass is also suitable to make propeller. Brass is any alloy of copper and zinc; the proportions of zinc and copper can be varied to create a range of brasses with varying properties. In comparison, bronze is principally an alloy of copper and tin. Despite this distinction, some types of brasses are called bronzes. Brass is a substitutional alloy. It is used for decoration for its bright gold-like appearance; for applications where low friction is required such as locks, gears, bearings, ammunition, and valves; for plumbing and electrical applications; and extensively in musical instruments such as horns and bells for its acoustic properties [5]. Aluminium bronze and manganese bronze are also type of copper alloy.

Brass is easy to cast comparing to the other material. This is because brass has low melting point temperature. So, it will be melted in lower temperature than other material, thus need less energy than others to melt.

Brass also has good properties. Brass has higher malleability than copper or zinc. The relatively low melting point of brass (900 to 940°C, depending on composition) and its flow characteristics make it a relatively easy material to cast. By varying the proportions of copper and zinc, the properties of the brass can be changed, allowing hard and soft brasses. The density of brass is approximately 8.4 g/cm^3. Brass is good resistance of corrosion. It also have high tensile and hardness than others.

CHAPTER 3
METHODOLOGY

3.1 PROJECT IDENTIFICATION

For the first part of this project, it was working on Gantt chart. The purpose of Gantt chart is to prepare and plan for activity of Final Year Project that would be followed by the author in this semester. Process of designing an experiment is made up of three main phases that are the planning phase, the conducting phase and the analysis/interpretation phase.

The second part of this project is to do update the literature review on this project. It is including literature survey carry out on journals, online search, conference proceedings, text books and reports.

The third phase is to conduct the experimental analyses. There are several methods that have been carried out for the experimental analyses. These are metallographic, scanning electron microscope (SEM), hardness test, and chemical analysis. .

The final phase is to interpret analyzed data. This is followed by the suggestions improvement on the propellers.

3.2 METALLOGRAPHIC

Metallographic is the process of preparing a metal surface to reveal microstructural information. Sample can provide information about chemical composition, heat treatment, processing, phase diagram and grain boundaries [9].

Metallography Methodology

- Sectioning
- Mounting of sample
- Grinding
- Polishing
- Etching
- Microscopy
- Image recording

3.2.1 Sectioning

Sectioning is a process removal of representative sample, noting of section relative to prominent features. In failure cases like cavitation, specimens are taken from regions immediately adjacent to failure surface. Abrasive cutter, quite commonly
found in metallographic laboratories are abrasive cutoff machines where it is used to sectioning the sample. It may produce deformation damage as much as 1mm, can be minimized by using thin cutting disks. A hard wheel is usually better for cutting softer materials; a soft wheel is better for cutting hard materials all abrasive-wheel sectioning should be done wet. An ample flow of coolant should be directed onto cut. The abrasive cutter that have been used shown in Figure 3.1

Figure 3.1: Abrasive cutter

3.2.2 Sample Mounting

The purpose of sample mounting are ;

- For ease of handling of difficult shapes and sizes of

Samples.

- For edge retention and/or protection
- To accommodate automated metallographic preparation equipment
- Also allow easy labeling and identification of samples

Samples with different chemical compositions should be mounted in separate mounts. It can be either be cold or hot mounts

• Mounting media must be relatively inert, but sometimes need to be conductive (for electro-etching or SEM use)

Hot Mounting

Thermosetting polymeric powder is placed in a mould with the sample to which heat and pressure is applied

• Usually Bakelite or epoxy

3.2.3 Grinding

Grinder was used to minimize thickness of damaged layer from the sectioning process. Typically, it was done using rotating discs covered with SiC paper and using water as lubricant. Various available grades of grinder are:

- 180,
- 240,
- 320,
- 400,
- 600,
- 800,
- and 1200 grit (grains per square inch).

Initial abrasive size establish a flat sample surface and remove damaged layer due to sectioning. Subsequent abrasive sizes remove damaged due to previous grinding steps. The grinder which have been used shown in Figure 3.3

Light pressure should be applied at the centre of the sample. Grind until all the blemishes from previous steps have been removed. Ensure the flatness of sample surface is maintained throughout the grinding steps. Before proceeding to the next grinding steps, we need to ensure the scratches from the current step are in a single orientation. The rolling and abrasive sectioning direction is shown in Figure 3.2.

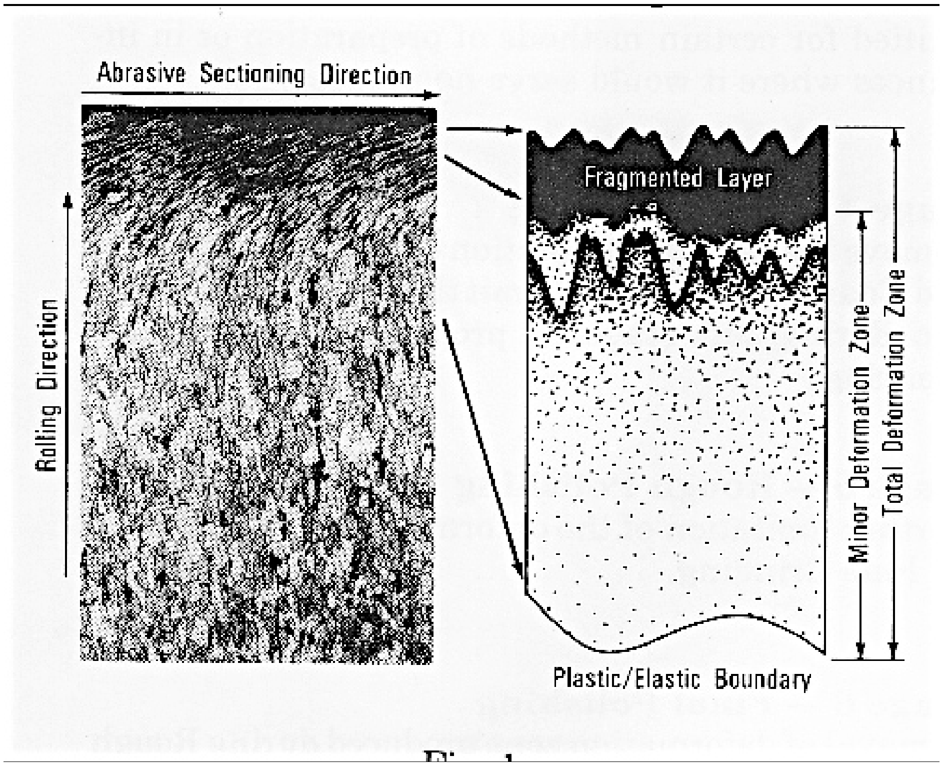


Figure 3.2: Rolling and Abrasive Sectioning Direction[9]

Figure 3.3 : Grinder machine

3.2.4 Polishing

Consist of rotating discs covered with soft cloth impregnated with micro-particles of diamond or other media and lubricant. For my project, I use 6μm and 1μm. Among the typical "rough" polishing are 9, 6, and 3μm. Typical "final" polishing are 1, 0.25μm diamond, or 0.06μm. In this project, the author was used for 6μm and 1μm. The polishing machine shown in Figure 3.4.

Polishing will be done after at least a 400 grit grinding. But for this project, the author did until 1200 grit grinding. Polishing should produce a scratch-free mirror-like finish on the sample. Polishing and grinding process shown in Figure 3.5.

Figure 3.4 : Polishing machine

Figure 3.5 : Grinding and Polishing Process

3.2.5 Etching

Etching has two-fold purpose:

- remove final thin layer of deformation
- preferentially attack particular sites on the sample surface with the "highest energy", leading to various features to be distinguished in reflected light microscopy

Etching usually refers to chemical etching, which is a dilute chemical solution to selectively corrode certain microstructural feature. A polished sample is etched by swabbing a cotton tip dipped in etchant, by immersing or spraying the sample with the etchant. It should always be done in stages, beginning with light attack, an examination in the microscope and further etching only if required. An over-etched sample requires a repeat of the polishing procedure [9]. For my project, I use ferric chloride as an etchant.

3.3 Microscopic

Microscopic examination

Microscopic examination for this project has been divided into 3 type of examination with 2 different samples as previous testing. The samples involve in these examination are cross section coating layer mounted , and labeled as sample 1 (cavitation propeller) and 2 (right material for propeller). The 2 type of microscopic examination adapted in this project are optical microscope observation and Scanning Electron Microscope (SEM) analysis.

The scanning electron microscope (SEM) is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity.

The types of signals produced by an SEM include secondary electrons, back scattered electrons (BSE), characteristic x-rays, light (cathodoluminescence), specimen current and transmitted electrons. These types of signal all require specialized detectors for their detection that are not usually all present on a single machine. The signals result from interactions of the electron beam with atoms at or near the surface of the sample. In the most common or standard detection mode, secondary electron imaging or SEI, the SEM can produce very high-resolution images of a sample surface, revealing details about 1 to 5 nm in size. Due to the way these images are created, SEM micrographs have a very large depth of field yielding a characteristic three-dimensional appearance useful for understanding the surface structure of a sample. A wide range of magnifications is possible, ranging from about x 25 (about equivalent to that of a powerful hand-lens) to about x 250,000, about 250 times the magnification limit of the best light microscopes. Back-scattered electrons (BSE) are beam electrons that are reflected from the sample by elastic scattering. BSE are often used in analytical SEM along with the spectra made from the characteristic x-rays. Because the intensity of the BSE signal is strongly related to the atomic number (Z) of the specimen, BSE images can provide information about the distribution of different elements in the sample. For the same reason BSE imaging can image colloidal gold immuno-labels of 5 or 10 nm diameter, that would otherwise be difficult or impossible to detect in secondary electron images in biological specimens. Characteristic X-rays are emitted when the electron beam removes an inner shell electron from the sample, causing a higher energy electron to fill the shell and release energy. These characteristic x-rays are used to identify the composition and measure the abundance of elements in the sample [18].

3.4 HARDNESS TEST

Microhardness is the hardness of a material as determined by forcing an indenter such as a Vickers or Knoop indenter into the surface of the material under 15 to 1000 gf load; usually, the indentations are so small that they must be measured with a microscope. Capable of determining hardness of different microconstituents within a structure, or measuring steep hardness gradients such as those encountered in casehardening. Conversions from microhardness values to tensile strength and other hardness scales (e.g. Vickers) are available for many metals and alloys [14].

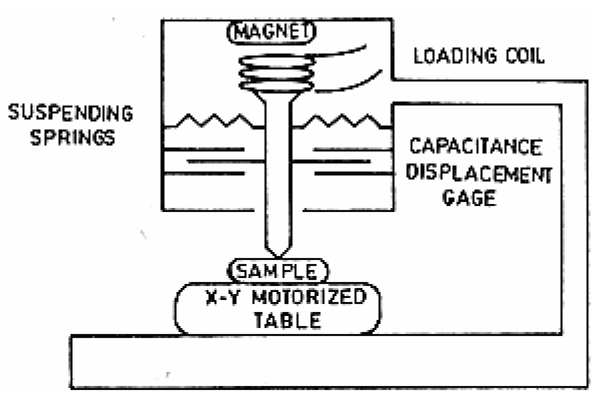


Figure 3.6 **:** Nano-indentation machine [15]

3.4.1 Vickers Hardness Test

It is the standard method for measuring the hardness of metals, particularly those with extremely hard surfaces: the surface is subjected to a standard pressure for a standard length of time by means of a pyramid-shaped diamond.

Vickers hardness is a measure of the hardness of a material, calculated from the size of an impression produced under load by a pyramid-shaped diamond indenter. The indenter employed in the Vickers test is a square-based pyramid whose opposite sides meet at the apex at an angle of 136º. The diamond is pressed into the surface of the material at loads ranging up to approximately 120 kilograms-force, and the size of the impression (usually no more than 0.5 mm) is measured with the aid of a calibrated microscope. The Vickers number (HV) is calculated using the following formula: [17]

$$= 0{\cdot}102 \times 2F\left(\sin\frac{136^{\circ}}{2}\right) \Big/ d^{2}$$

with F being the applied load (measured in kilograms-force) and D2 the area of the indentation (measured in square millimetres). The applied load is usually specified when HV is cited.

The Vickers indenter is a 136 degrees square-based diamond cone, the diamond material of the indenter has an advantage over other indenters because it does not deform over time and use. The impression left by the Vickers penetrator is a dark square on a light background. The Vickers number is determined by dividing the load by the surface area of the indentation (H = P/A). The load varies from 1 to 120 kilograms. For this experiment, the author had chosen load 100 kgf. To perform the Vickers test, the specimen is placed on an anvil that has a screw threaded base. The anvil is turned raising it by the screw threads until it is close to the point of the indenter. With start lever activated, the load is slowly applied to the indenter. The load is released and the anvil with the specimen is lowered. The operation of applying and removing the load is controlled automatically.

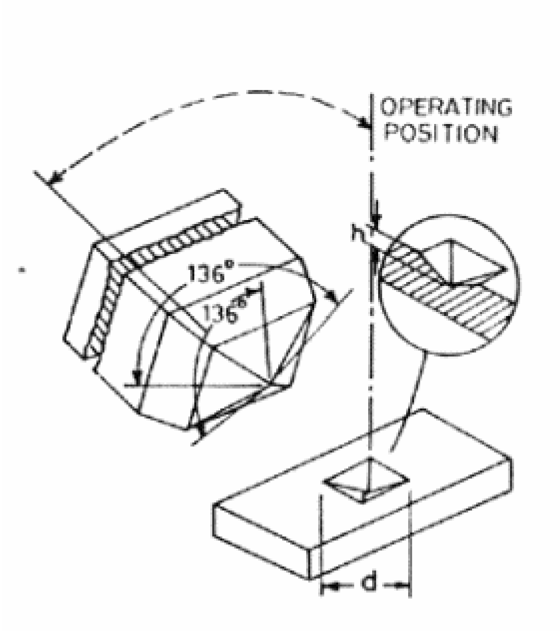


Figure 3.7: Vickers hardness test principle [15]

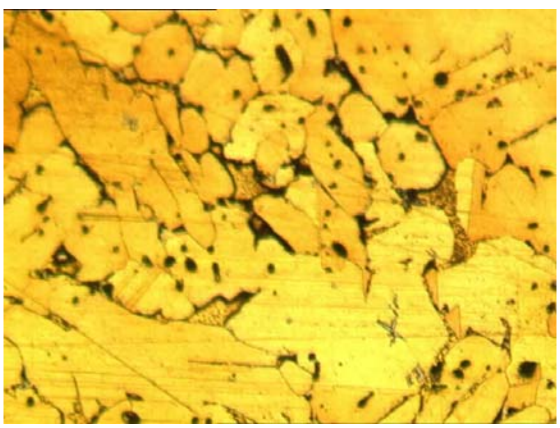
Several loadings give practically identical hardness numbers on uniform material, which is much better than the arbitrary changing of scale with the other hardness machines. A filar microscope is swung over the specimen to measure the square indentation to a tolerance of plus or minus 1/1000 of a millimeter. Measurements taken across the diagonals to determine the area, are averaged. The correct Vickers designation is the number followed "HV" (Hardness Vickers). The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments [16].

CHAPTER 4

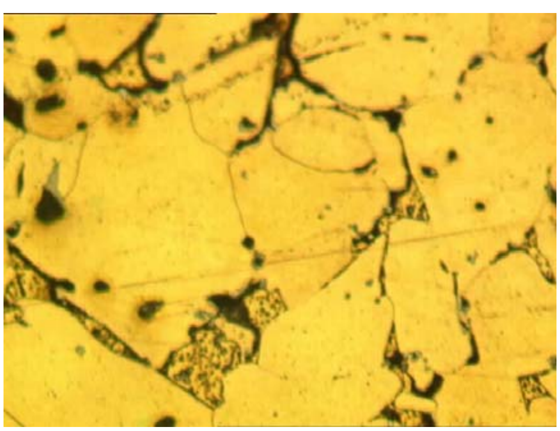
RESULT & DISCUSSION

4.1 Microscopic examination

The objective of conducting the microscopic analysis via optical microscope and SEM is to investigate metal microstructure changes of failed propeller and sample for new developed propeller material.



(a) Micrograph image for failed propeller (100X)



(b) Micrograph image of failed propeller (200X)

Figure 4.1: Optical microscope photograph of failed propeller

The microstructure of failed propeller was observed using optical microscope and it is shown in Figure 4.1(a) and 4.2(b). The micrograph shows typical microstructure for brass. This indicates the presence of α-phase which contains less than 38wt % Zn and as shown in Figure 4.8(a). The tensile strength at this composition is lower than at the α+β phase. The tensile strength and hardness are related. The higher the tensile strength, the higher the hardness is. This shows that the chemical composition is not complied with the standard [10]. In the standard, it specified that the composition should in the range of 35-46% or with the microstructure of α+β phase [3].

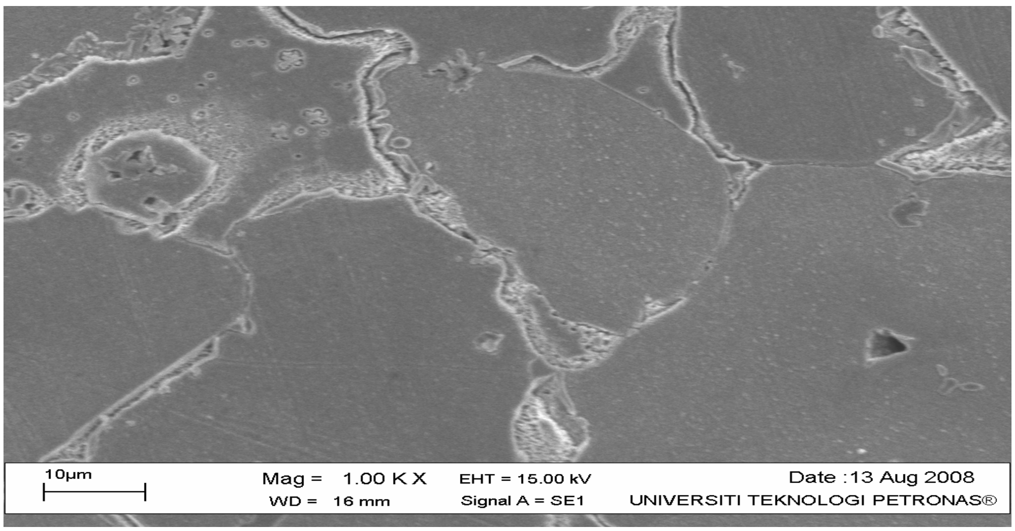


Figure 4.2: SEM photograph of failed propeller (100X)

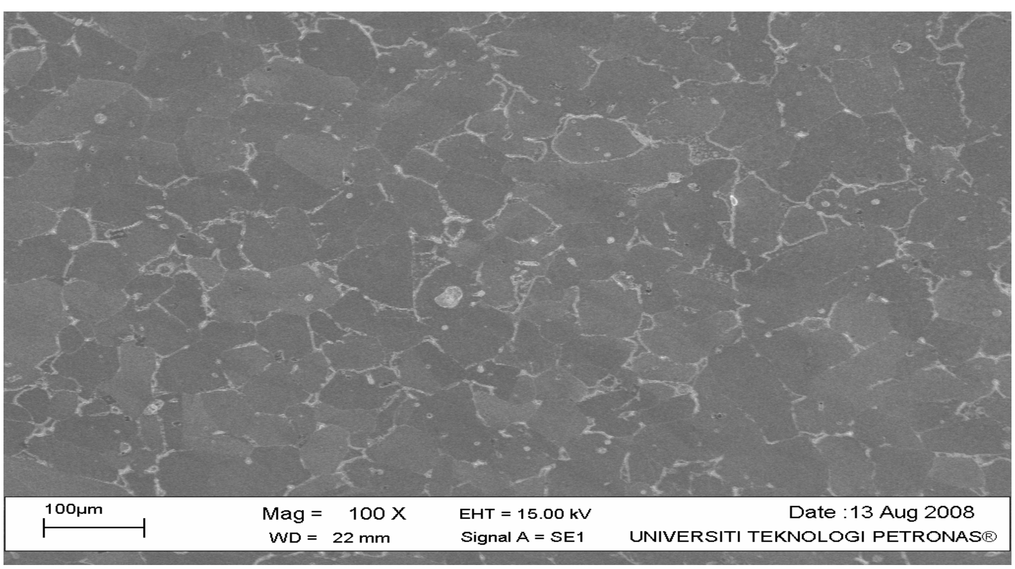


Figure 4.3: SEM photograph of failed propeller (1000X)

SEM was also conducted to observed the microstructure of the failed sample. Similarly, it shows the presence of α-phase and this is shown in Figure 4.2 and 4.3. The presence of grain boundaries can also be seen in this figure and it is a single phase microstructure.

The α-phase has inferior properties compare to α+β phase as indicates in this analysis.

<u>New developed propeller's material</u>

The microstructure of new developed propeller material was also observed using optical microscope and it is shown in Figure 4.4(a) and 4.4(b). The micrograph shows the presence of α+β phase. The composition of α+β phase contains composition of zinc in the range of 35-46.6% and shown in Figure 4.8(a). The tensile strength at this composition is higher than α-phase. At this composition, the chemical composition is comply with the standard [10]. In the standard, it specified that the composition should in the range of 35-46.6% or with microstructure of α+β phase [3].

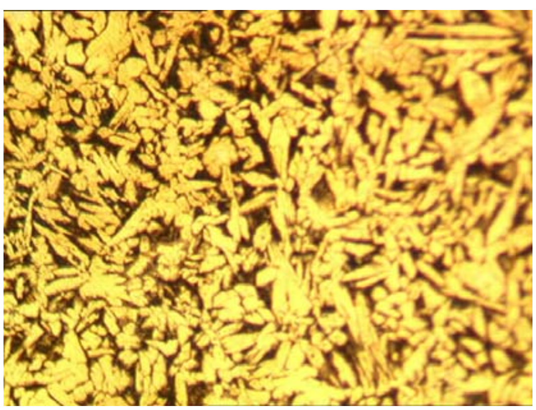


Figure 4.4(a) Micrograph image for new developed propeller material (100X)

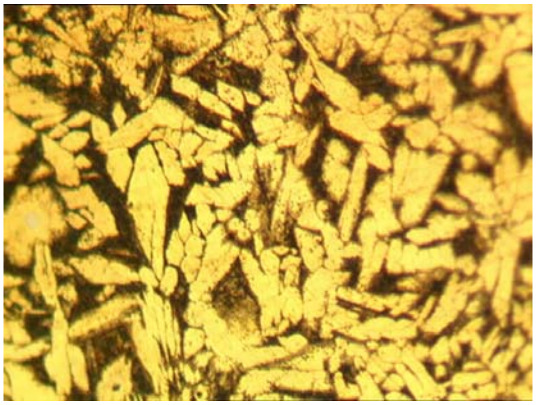


Figure 4.4 (b) : Micrograph image for new developed propeller material (200X)

Similar on the failed material, SEM was also conducted on this sample to observe the microstructure of the new developed propeller material. It shows the presence of α+β phase and this is shown in Figure 4.5. The presence α and β solid solution grains can also be seen in this figure. At this composition, it is stronger than α-phase due to the higher strength of α+β phase. Strength of brass increases with the increasing amount of α+β phase. On other hand, α+β brasses have poor ductility [11].

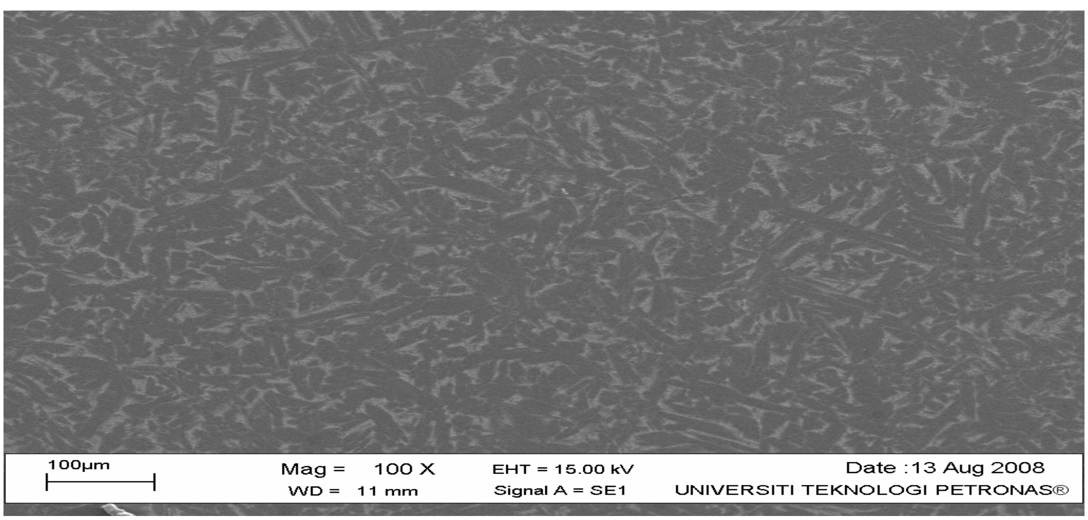


Figure 4.5: SEM micrograph of new developed propeller's material

4.2 Chemical analysis

Chemical examination by Scanning Electron Microscope (SEM) Energy Dispersive X-Ray Spectrometer (EDS) revealed the chemical content on both of the samples. The results obtains from chemical analysis will be used as the basic supporting data in understanding the structure of the materials and its properties.

a) Chemical Analysis on failed propeller

Table 4.1: Qualitative analysis of failed propeller

Element	Weight%	Atomic%
C K	6.18	25.96
Fe K	1.13	1.02
Ni K	0.96	0.83
Cu K	60.35	47.95
Zn K	31.38	24.24
Totals	100.00	

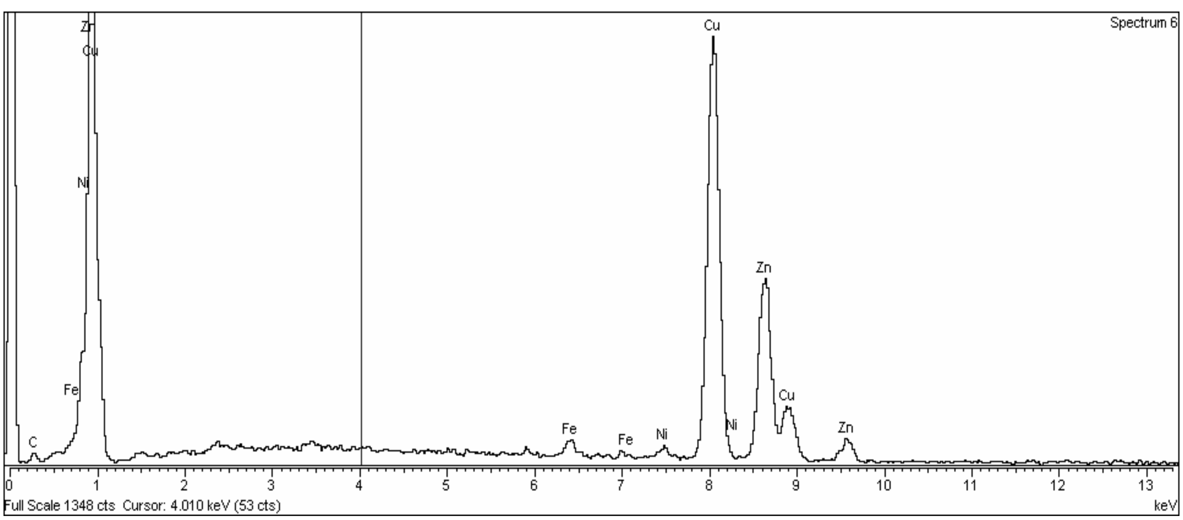


Figure 4.6: Qualitative analysis showing the elements present in failed propeller

Table 4.1 shows the quantitative analysis of failed propeller. The composition of zinc in this material is 31.38%. Refers to the equilibrium diagram of brass, since the percentage (%) of zinc is 31.38%, it is not in α + β phase. The α+β phase structure can be achieved when the composition of zinc is in the range of 35-46.6%.

b) Chemical Analysis on new developed propeller material

Table 4.2: Quantitative analysis of new developed propeller's material

Element	Weight%	Atomic%
Al K	2.26	5.22
Fe K	1.01	1.13
Cu K	58.05	56.84
Zn K	38.67	36.81
Totals	100.00	

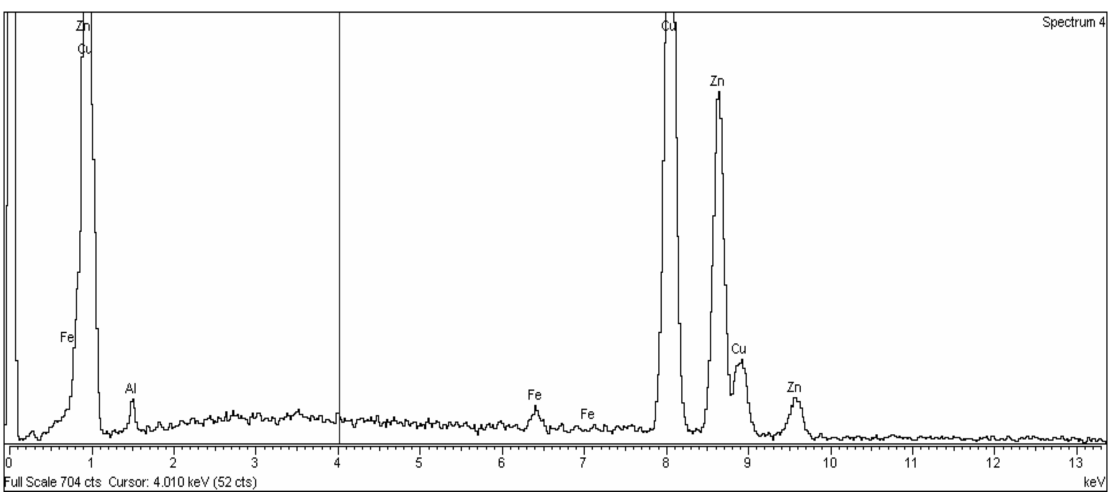


Figure 4.7: Qualitative analysis showing the elements present in new developed propeller's material

From the table above, the weight percent of Zn in the new developed propeller's material is 38.67%. Refers to the Figure 4.8(a), it is in α+β phase. The percentage of Fe, Al and Cu are 2.26%, 1.01%, 58.05% respectively.

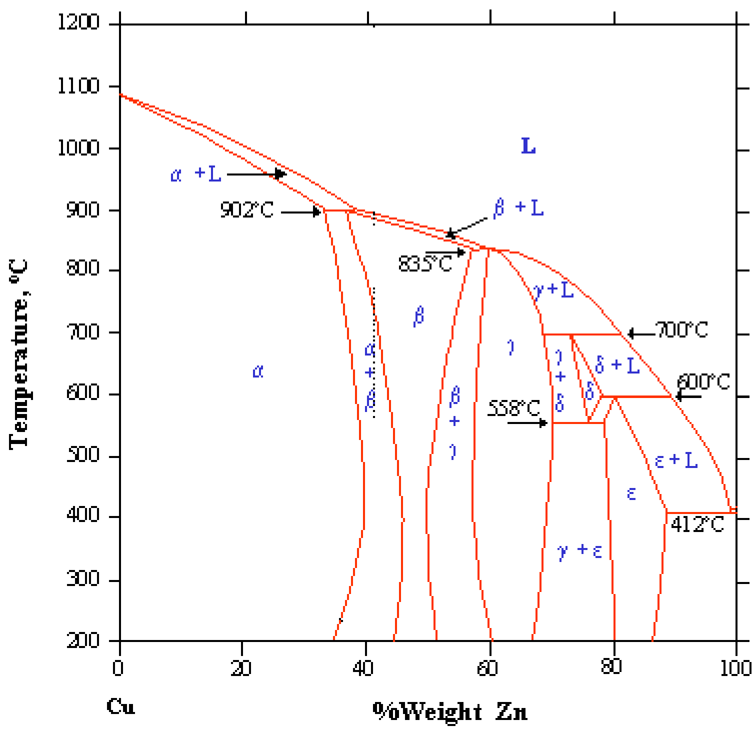


Figure 4.8(a): Equilibrium diagram of brass [15]

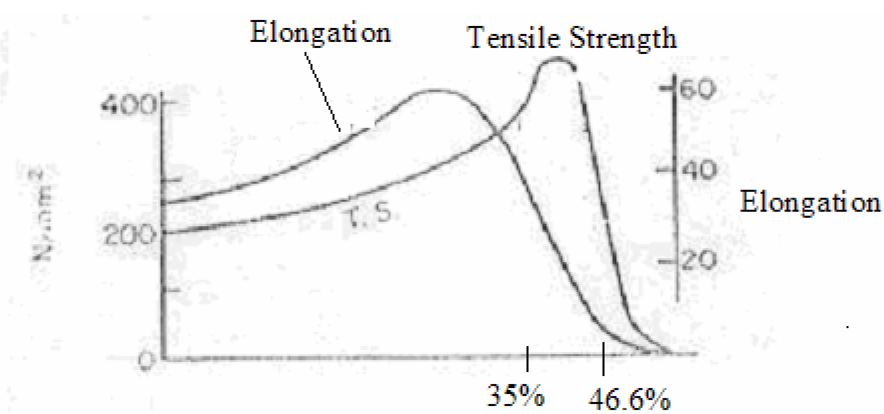


Figure 4.8(b): mechanical properties of brass [10]

4.3 Hardness Test

In order to prove that $\alpha+\beta$ phase has better mechanical properties than α- phase, the hardness was conducted. The author choose Vickers test with load 100kgf for this experiment. The result was shown in the Table 4.3 and Table 4.4.

Hardness Test (Vickers) (load of 100kgf)

Cavitation Propeller

Table 4.3 : Hardness test for failed propeller

Reading	HV-100kgf
1	96.7
2	97.4
3	92.4
4	96.4
5	102.4
Average	97.06

The table 4.3 shows the result of hardness test for failed material that have alpha phase. From the experiment, the average reading that the author had for this sample is 97.06 HV. This is quite low compared to the new developed propeller's material. The harder the hardness, the better material resistance against cavitation.

New Developed propeller's Material

Table 4.4: Hardness for new developed propeller's material

Reading	α- phase (HV-100kgf)	β –phase (HV-100kgf)
1	182.9	208.6
2	185.6	200.1
3	165.5	203.6
4	178.4	207.5
5	180.8	208
Average	178.64	205.56

Table 4.4 shows the hardness test result for new developed propeller material that has α+ β phase. For the α-phase, the average reading is 178.64 HV. For β-phase, the average reading is 205.56 HV. This is about two times higher than the hardness reading of failed material. This is because at this composition, the material had higher tensile strength than α-phase.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

From equilibrium diagram and mechanical properties of brass, α+β phase structure can be achieved when the composition of zinc is in the range of 35-46.6%. At this composition, the mechanical properties are at the optimum and this can be seen in the same that figure. In α-phase, the tensile and elongation increase and maximum ductility can be obtained at 30% Zn content. Elongation decreases when β-phase appeared. However, the tensile strength is at its maximum value when the material is in the range of α and β phase. Adding Zn more than 45% wt, the ductility seems to decrease significantly and the alloy becomes hard and brittle. Hence, the selection of material is based on α+β phase where the hardness and the tensile strength are related to each other. In preparing the propeller material, the important mechanical properties are the tensile strength, high hardness value and elongation of about 20%.

Conclusion can be deduced that the failure of the propeller is due to physical and mechanical properties which have been illustrated by its microstructure of α-phase and the hardness value. This phase shows that it has lower tensile strength compare to new developed propeller's material by the foundry. The hardness of the failed propeller is 97.06 HV which is lower than the new developed propeller's material. The average hardness for α-phase is 178.64 HV and β-phase is 205.56 HV.

5.2 Recommendation

There are recommendations should be made by local foundry in order to improve the quality of the propeller's material :

- Make propeller in form of $\alpha+\beta$ phase brass

Local foundry should make propeller from $\alpha+\beta$ phase brass because of higher hardness and tensile strength to overcome the effect of cavitation

- Refer to The Standard

Local foundry also should refer to standard to produce better propeller

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