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RESEARCH ON THE SHIP PROPELLER BLADE TO DETERMINE CHANGES IN THE MECHANICAL PROPERTIES BASED ON THE FORCES PROJECTION

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ABSTRACT

The ship propeller is a key component in producing the propulsion force of the ship motion. Therefore the stability of structure strength is required to ensure the effectiveness of propulsion force generation. This research examines the existing ship propeller and the effects of casted specimen on the changes of mechanical properties of the propeller structure. The specimen prepared is referred to ASTM E8 2008 standard and including two projections is Longitude and Latitude projected, according to the forces analysis exerted on blade structure. The experiments perform on the used propeller by cutting into pieces of specimen and casted specimen of copper alloy of Nickel Aluminium Bronze (Ni-Al-Br). The mechanical testing is conducted on tensile test, tensile strength and hardness test. The results show strong influence of the mechanical properties of existing propeller are lower from the standard requirement and different in each specimen projection of Yield Strength is 23.67% to 31.84% and the Tensile Strength is 12.20% to 20.17%, and the elongation percentage is 28.19% to 35%, respectively. The latitude projection shows greater compared to longitude projection. An experimental result for the casted specimen showed a reading of mechanical properties is 3% to 5% difference compared to the cutting specimen. From the results of these experiments have found that fixing projections in this study are reasonable and can be used in subsequent studies and mechanical properties of the material are not homogenous across the blade structure. Therefore, a comprehensive study should be undertaken to overcome this problem in the future.

Keywords: mechanical properties, specimen, projection, strength, and experiments.

INTRODUCTION

The ship propeller is a key component of the motion mechanism of the ship and its play the main part in propulsion systems. The efficiency of a propeller takes important roles in the design process, because its efficiency and stabilities directly related. In most condition, propellers are designed to absorb as minimal power as possible and to give maximum efficiency with less cavitation and hull vibration characteristics [1]. The stress point accepted must allow for the cyclic variations in loads due to the wake and the increased forces due to ship motions [2]. The manufacturing challenges are interpreting the complex hydrodynamic design into physical reality at the same time ensuring that the manufacturing process does not give rise to defect which could bring about the premature failure of the ship propeller [3]. The competition in the ship industries has been growing rapidly in recent years and has compelled manufacturing industries to look for better quality ship propellers. Hence, quality ship propellers play a significant role in the success of the company.

The rotation of propeller will create the thrust force for ship motion. This is the main reason for the weakness blade structure such as blade surface erode, reduced thickness of the blade and pitched surfaces. These created the high cavitation flow occurred on the blade surface and the potential of unbalanced forced developed at the end of propulsion. The illustration of the lack of ability to prevent failures due to unbalanced force acting in the operations of Propulsion can be explained by means of a mechanical shear stress [4].

Shear stress = force / cross section area of blade;

$$\tau = F / A \tag{1}$$

Where; τ is shear stress N/mm^2
F is perpendicular force to surface (N)
A is cross section area (mm^2)

When the blade surface eroded heavily and caused the blade thickness reduced, then the shear stress is over the limit and in this condition the blade will be fractured. The circumstance in the event of blade erosion is shown in Figure-1.

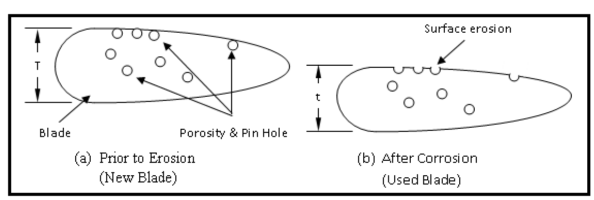

Figure-1. Circumstances in the event of blade erosion [5].

Referring to the problems statement and the data requirement, the research is to study the properties of the existing propeller and focus in mechanical properties, as well as conducting experiments on the structure of the cutting specimen on mechanical properties. Hence the proposed test is Tensile Strength Test and Hardness Test. The data collection is to be handled in analysis and will be used as reference in ship propeller manufacturing process.

The research work is carried out in order to achieve the objective in reviewing the mechanical properties of the existing propeller. Therefore, the objectives of the study are;

- To determine the detail mechanical properties of current propeller.
- To compare the experiment result and standard requirement of the propeller.

To produce the final result of the finding as a references.

LITERATURE REVIEW

As for a stronger propeller design, calculations of propeller strength must consider the torque and the bending moments acting at the blades roots. The stress point accepted must allow for the cyclic variations in loads due to the wake and the increased forces due to ship motions [2]. The forces are related to the strength of the propeller structure and this will comply with standard mechanical properties. These properties are referred to the ship classification society such as Det Norske Veritas (DNV), Lyod Register (LR), American Bureau of Shipping (ABS) and Germanisyer Lyod (GL) and to meet the requirements referring to the propeller materials as shown in Table-1.

Table-1. Mechanical properties for copper alloy propeller castings [6].

Alloy Type	Yield Strength $R_{p0.2}$ [N/mm²]	Tensile Strength R_m [N/mm²] min.	Elongation A [%] min.
Ni-Al-Br, Cu3	245	590	16

The mechanical properties magnitude had shown in Table-1 is a guide line as a standard requirement produced by International Ship Classification for ship propeller manufacturer. In this research, the main emphasis is given to respond to the structure of the propeller to the forces exerted externally. This led to a research of propeller mechanical properties and the illustration of these forces can be seen as in Figure-2(a). The two forces acting known as a Centrifugal Force or Radial Force and Twist Force or Moment Force and they will affect the blade structure in term of blade bending and blade fracture.

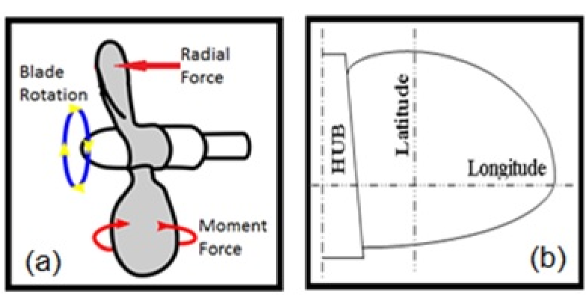

Figure-2. Forces action and strength required on a propeller (a) and projection of propeller blade (b).

The Radial Force caused the projection blade is loaded in bending sense. The Moment Force is load distribution in blade twist affect. According to the expectations of its effect on the structural strength of the propeller, the propeller blade projection can be set as shown in Figure-2(b), where the projection Longitude is represent a projection of the Radial Force direction, which extends in a circle diameter propeller and the Latitude projection is represent a projection of the Moment Force direction, which extending the propeller hub line. The two projections of blade will be used in this research and to ensure the analysis of mechanical properties is more precise and knowing the method will affect the strength of the casting propeller.

The propeller selection of this research had been classified by ship classification bodies such as Bureau Veritas (BV), Ship Classification of Malaysia (SCM), American Bureau of Shipping (ABS), Lloyd's Register (LR), Germnisyer Lyod (GL) and Nippon Kaiji Kyokai (NKK). The material is Copper base and the alloy is to be Nickel Aluminium Bronze (Ni-Al-Br) and the composition had been identified as shows in Table-2.

Table-2. Materials composition of nickel aluminium bronze (Ni-Al-Br) [6].

Casting grade	Chemical Composition (%)							
	Cu	Al	Mn	Zn	Fe	Ni	Sn	Pb
Ni-Al-Br,Cu3	77-82	7.0-11.0	0.5-4.0	<1.0	2.0-6.0	3.0-6.0	<0.1	< 0.03

Materials used in this research project are copper alloys which represented by Nickel-Aluminium Bronze where this material commonly used as foundry alloys because they offer many advantages such as good thermal conductivity, excellent cast ability, high strength to weight ratio, wear and corrosion resistance, pressure tightness and good weld ability. The copper alloys are well suited to marine components such as ship propeller and counter bearing race [7].

A standard specimen is prepared in a round or a square section along the gauge length, depending on the standard used. Both ends of the specimens should have sufficient length and a surface condition such that they are firmly gripped during testing [8]. Figure-3 shows the standard specimen dimension according to ASTM E8 / E8M – 2008.

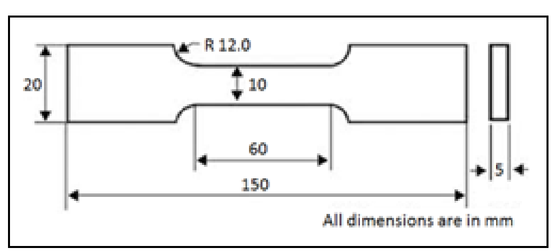

Figure-3. Dumb-bell specimen [9].

The study also revealed that the evaluation standard requirements of propeller properties are measured at random and do not lead to projections of propeller blade structure. Propeller blade required a homogenous structural strength and comprehensive in all blade parts [12]. In addition, a variety of testing methods and the establishment of revised projections specimen is needed to represent the structure of the propeller blades.

METHODOLOGY

This research is started by the study of used propeller in changes of mechanical properties and the process flow is shown in Figure-4. In this research, the questions 'how' and 'why' the defects occur are revealed and the mechanical properties to be analysed.

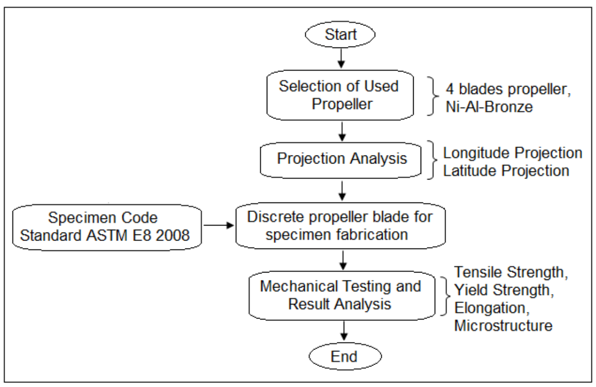

Figure-4. Flowchart of used propeller mechanical testing.

Then the specimen pattern is developed according to the forces study and blade structure projections analysis. In this stage, the casting specimen performed accordance to the pattern and to be analyzed by mechanical testing. The result will be verified by the comparison of the cutting specimen experiment result. The specimen verification on arrangement process is shows in Figure-5.

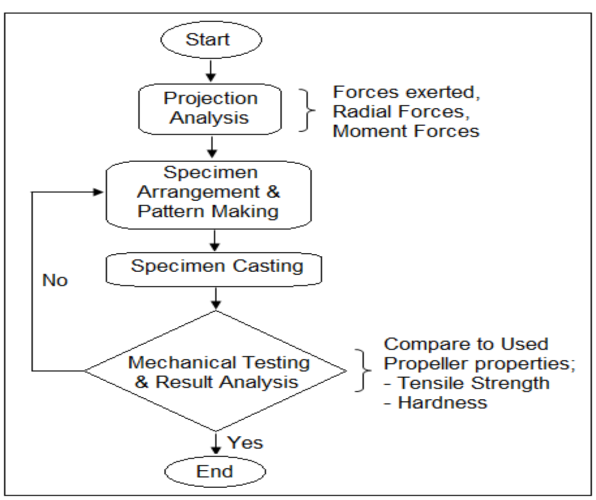

Figure-5. Specimen arrangement verification.

The specimen arrangement is represented to the propeller projections in terms of Longitude Projection and Latitude Projection. This specimen pattern arrangement is shows in Figure-6. The justification of this specimen arrangement was referring to the layout of propeller blades projection and the impact of the forces acting on the blades structure. This is important because the casting is done by pouring the molten alloys into the mold from the center of the mold and let it flow into the mold cavity by gravity action [10].

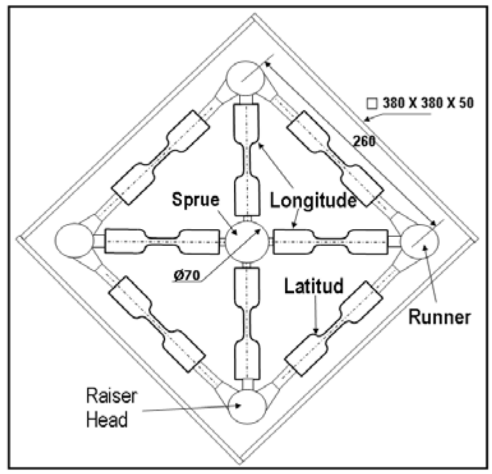

Figure-6. Specimen arrangement and pattern.

The value of tensile strength and tensile yield of casting specimen is expect equal to the cutting blade propeller specimen of existing ones. Based on this information, it can be stated that the specimen arrangement as shown in Figure-6 can be used in this study.

The process of recovery had been shown in Figure-7. The specimen will be sent to laboratory for testing and analyse the tensile strength, product hardness and microstructure investigation. All information is recorded for the experimental results are analysed to obtain the findings of this study.

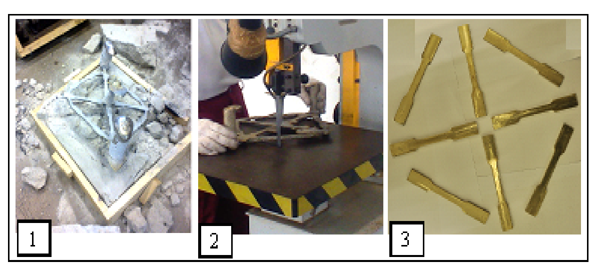

Figure-7. Casted specimen recovery process, shakeout-(1) machining-(2) finishing-(3).

To determine the mechanical properties of specimen, two mechanical tests had been performed namely tensile test and hardness test. The experiment results are described in the following sections.

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RESULT & DISCUSSION

The study is to determine the mechanical properties of used propeller in studying the validity of the specification according to the standard. The specimen is prepared from the cutting pieces of used propeller blade and performing the mechanical test. The result finding is described in the following sections.

Specimen from used propeller

The specimen preparation begins from serving marked according to the projection of longitude and latitude. The plot of specimen mark able on the blades is shown in Figure-8.

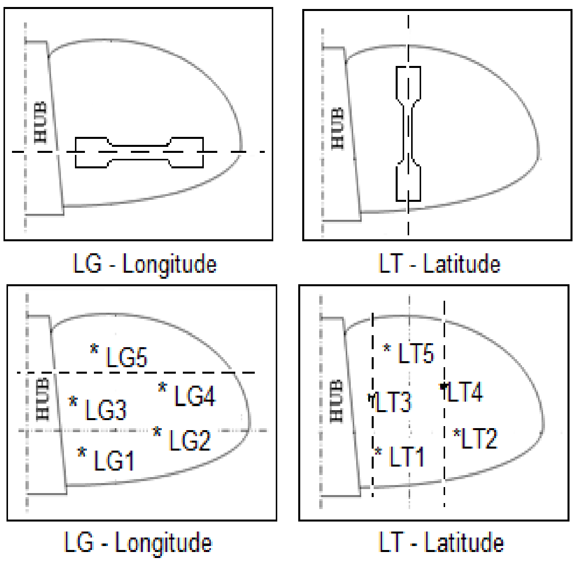

Figure-8. Test specimen projection (longitude and latitude).

A total of five pieces of specimen on each projection and the descriptions shown in Table-3.

Table-3. Specimen description.

Specimen	Total (piece)
Longitude	5
Latitude	5

The sequence of specimen preparation is shows in Figure-9, where the process begins with propeller blade separated from the hub and blade plate is marked according to the projections. Two blades are required where each blade represents each projection that is longitude projection and latitude projection. Then the blade is cut into pieces according to specimen specification.

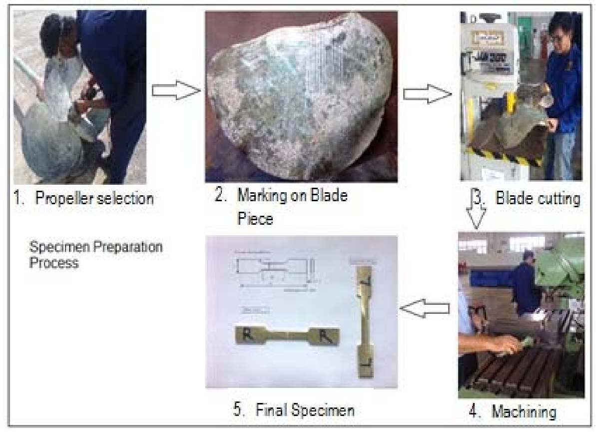

Figure-9. Specimen preparation process.

The experimental results show of two sections of data on materials composition and the experimental results on the mechanical properties. The result for materials composition is shown in Table-4.

Table-4. Materials composition of sample test of the used propeller.

Used Propeller	Chemical Composition (%)							
	Cu	Al	Mn	Zn	Fe	Ni	Sn	Pb
Standard, Cu 3	77-82	7.0-11.0	0.5-4.0	< 1.0	2.0-6.0	3.0-6.0	< 0.1	< 0.03
RESULT TestSpec*	74.1	2.8	3.46	0.04	8.0	4.52	0.04	0.06

Note *: Average value from 5 specimens

From the results, and refer to Table-2,the propeller is made from copper bronze with grade CU3 alloy and the specification of materials is Nickel Aluminum Bronze (Ni-Al-Br). The mechanical test carried out to analyze the properties of the specimen by performing the tensile strength test. The experiment result of Yield Strength has shown in Table-5.

Table-5. Experiment result of specimen test - yield strength [N/mm^2].

Specimen	# 1	# 2	# 3	# 4	# 5	Average
Longitude	165	169	162	171	167	166.8
Latitude	185	191	184	188	189	187.4

The experiment result of Tensile Strength has shown in Table-6.

Table-6. Experiment result of specimen test - tensile strength [N/mm^2].

Specimen	# 1	# 2	# 3	# 4	# 5	Average
Longitude	467	475	465	474	473	470.8
Latitude	516	521	514	521	519	518.2

The experiment result of percentage elongation has shown in Table-7.

Table-7. Experiment result of specimen – elongation [%].

Specimen	# 1	# 2	# 3	# 4	# 5	Avg.
Longitude	11.4	11.6	11.4	11.6	11.6	11.49
Latitude	10.4	10.4	10.4	10.4	10.4	10.40

Table-8 is shows the average of the experiment results compared to the standard requirement.

Table-8. Average result compared to standard.

Test Spec. Projection	Yield Strength $R_{p\ 0.2}$ [N/mm^2]	Tensile Strength R_m[N/mm^2]	Elong'n A [%]
Standard, Cu3	245	590	16
Longitude*	167	471	11.49
Latitude*	187	518	10.40

*Average reading of 5 pieces of specimen

Referring to the result from Table-8, the mechanical properties of specimen is compared to the CU3 standard requirement as shown in Table-1. Based on the experimental results, the properties of tested specimen is lower than the referred standard in average of 27%. The projected specimen shows the latitude projection is higher value compared to longitude projection by 11.97% of Yield Strength and 9.98% of Tensile Strength, respectively. The elongation percentage also shows the difference value compared for both projections.

Both projections should have the same magnitude, because it is on the same blade, however, the comparison with standard strength is significant differences, where the strength is much lower than the standard value of 12.20% ~ 20:17% for Tensile Strength and 23.67% ~ 31.84% of Yield Strength. These percentage differences allowed should be less than 5%, according to the industrial standard of manufacturing [11]. The result of elongation percentage decreased of 28.18 ~ 35% compared to the standard. This shows that the propeller is less ductile from the standard.

Therefore, the result shows that the actual blades are not complied with the standard in mechanical properties. This is due to the standard set by the authority is generally random in specimens test result and to be used as a standard range in the materials requirement. The others probability is inhomogeneous internal structure because of imbalance of temperature changes, during the freezing process or some other factor, such as chemical reactions or life force of the propeller by a long operation. These differences also reflect a change in blades shape possibilities can occur, especially to Rake Angle [13], when a high force applied and affected the rigidity of the blade structure and reduced the performance of ship propulsion.

Specimen from casting pattern

The pattern and mold had been fabricated accordingly and the casting performed in specimen fabrication to be used in determines the mechanical properties. The arrangement of specimen pattern is shows in Figure-6. Sand mold is prepared in accordance with the specification pattern that has been made. A total of eight pieces of specimen provided for each projection and marked for identification forecast for laboratory testing. Specimen description is shows in Table-9.

Table-9. Descriptions for each type of specimen.

Specimen Description	Quantity
Longitude Projection	8
Latitude Projection	8
Total	16

The casting process of specimen fabrication has shown in Figure-10.

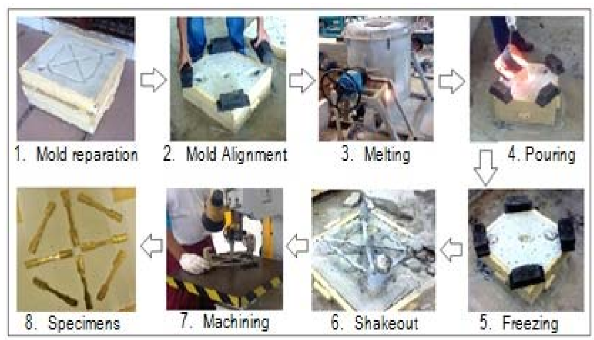

Figure-10. Specimen fabrication in sand casting process.

The experimental results are the average result for all the tested parameters in mechanical testing such as Yield Strength, Tensile Strength and Elongation Percentage. The mechanical test carried out to determine the properties of the specimen by performing the tensile test. The experiment result is shown in Table-10.

Table-10. Experiment result of casted specimen.

Test Spec. Projection	Strength [N/mm^2]		Elongation A [%]
	Yield $R_{p\ 0.2}$	Tensile R_m	
Longitude*	175	487	10.79
Latitude*	197	545	9.37

*Average reading of 8 pieces of specimen

Referring to the result as shown in Table-10, the magnitude of mechanical properties is different for both projections. The result shows that the latitude projection created higher magnitude compared to longitude projection. The difference of the parameters of Yield Strength and Tensile Strength shows that the mechanical properties of specimens are not homogenous. The elongation percentage of latitude projection is lower than longitude projection and this shows that the specimens are different in their ductile ability than others. The comparison between the results of experiment with cutting blade and standard mechanical properties are indicated in Table-11.

Table-11. The comparison of mechanical properties of tested specimens.

Specimen Type	Test Spec. Projection	Strength [N/mm^2]		Elongation A [%]
		Yield $R_{p0.2}$	Tensile R_m	
Standard, Cu3	Standard, Cu3	245	590	16
Cutting Blade	Longitude	167	471	11.49
	Latitude	187	518	10.37
Casted Specimen	Longitude	175	487	10.79
	Latitude	197	545	9.40

Referring to the comparison of specimen tested as shown in Table-11, it is found that the casted specimen has the lower mechanical properties than the standard. However, it shows higher reading than the cutting specimen. The percentage difference of the magnitude of the mechanical properties of casted specimen compared to cutting blade specimen is shown in Table-12.

Table-12. The percentage of mechanical properties changes in casted specimens compared to cutting blade specimen.

Specimen Type	Test Spec. Projection	Strength [N/mm^2]		Elongation A [%]
		Yield $R_{p0.2}$	Tensile R_m	
Casted Specimen	Longitude	4.57%	3.28%	6.49%
	Latitude	5.12%	4.95%	10.32%

The difference of 3% to 5% for Yield Strength and Tensile Strength as shown in this table is significant and specimen produced by this method can be certified as successful representative sample in the next experiment. The magnitude of mechanical properties of the casted specimen is higher than the cutting specimens is due to several factors that are likely to occur such as the size of the specimen pattern arrangement is smaller than the actual size of the tested propeller, the inhomogeneous internal structure because of imbalance of temperature changes during the freezing process, chemical reactions or service life of the propeller by a long operation. Therefore, if required the similar results for both of the tested specimen, the specimen arrangement and the pattern should be the same size as the original propeller, the melting temperature and pouring temperature should be the same during the manufacturing process of the original propeller and obtain a new original propeller for its intended use in this study.

CONCLUSIONS

This study has demonstrated that there are significant differences in the strength of the product compared to the strength of the materials in theoretically evaluated. Differences also involved in the projections of the blade structure and this need to be researched to overcome these issues. The propeller strength difference compared to the standard requirement is less than 20%, shows that the occurrence is not due to mere life, but other genes have an impingement on the operation of the propeller if it is reproduced. Among the other components required are as propeller manufacturing process, imbalances forces and the inner structure of propeller blades. Thus, the propeller is not appropriate to apply for re-use, except if they have undergone treatment structures, where it will be costly. Therefore, the projection of blade structure is playing an important parameter in study the properties of the propeller structure. The continuous study on the blade projection is to develop the pattern arrangement in specimen preparations for sand casting process. The experiment results showed differences in the mechanical properties for the casted specimen for the two projections of which has been specified. The results of these experiments show that there are differences 3% to 5% compared to the used propeller properties for each projections specimen. The overall result showed that the projected latitude is exceeded to longitude projections. The difference in value has been proved that the projected structure plays an important role in this study. Thus, the experiments on casted specimen with a composition of the projections were successful and the arrangement of specimen pattern in projection position can be used as a reference for subsequent studies. Therefore, this study has met the objectives requirements. In term of increase and to get the homogenous the strength of blade structure, the existing casting method should be review. Thus, the experiment of casted specimen with selection method is needed to test to determine the properties profile.

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