



UNIVERSITI PUTRA MALAYSIA

***DEVELOPMENT OF SHIP PROPELLER USING DYNAMIC CASTING
METHOD***

ISHAK BIN MOHMAD ALI

FK 2016 30



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METHOD**

By

ISHAK BIN MOHMAD ALI

**Thesis Submitted to the School of Graduate Studies, Universiti Putra
Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of
Philosophy**

August 2016

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In the Memory of

My Father, Allahyarham Mohamad Ali bin Abdul Ghani

And

My Mother, Allahyarhamah Hjh. Hawa binti Abdul Rahman

Special Dedication to

My Wife

Riza binti Abdul Majid

And

My Childrens

Nurhafizah

Muhammad Hafiz

Muhammad Hanif

Muhammad Hathim

Nurhananiah

and Nur Husna Hanisah

Ishak bin Mohamad Ali

2016

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in
fulfillment of the requirement for the degree of Doctor of Philosophy

DEVELOPMENT OF SHIP PROPELLER USING DYNAMIC CASTING METHOD

By

ISHAK BIN MOHMAD ALI

August 2016

Chairman : Professor Shamsuddin Sulaiman, PhD
Faculty : Engineering

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 dynamics casting mold 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 and casted specimen in order to verify the projections arrangement of changes in mechanical properties. The results show that the different of used propeller and casted specimen properties is less than 5% and the arrangement can be represented for dynamics casting analysis. The dynamics mold used are Centrifugal Mold and Vibration Mold with selection of centrifugal speeds are 0, 50rpm and 150rpm and the vibration frequencies are 0, 5Hz and 9Hz,

respectively. The mechanical testing is conducted on tensile test, hardness test and scanning electron microscope investigation. The result of casting experiment showed that the mechanical properties significantly increased by the vibration frequencies up to 9Hz and the centrifugal speed up to 150rpm and led to increase in tensile strength from 4.84% to 9.68% for vibration mold and from 1.70% to 14.86% for centrifugal mold, respectively. In the vibration mold casting, the tensile strength, yield strength and elongation percentage showed the approximation of the properties values of matching the frequency of vibration is over than 9Hz on both projections but not in the centrifugal mold. It was also found that hardness improved significantly with the increased in vibration frequency and centrifugal speed. The hardness value based Rockwell superficial 15N-S scale is 6% over than without vibration. In addition, the change in microstructure and mechanical properties were successfully represented by the changes in solidification characteristics. Various vibration frequencies have reduced the lamellar spacing that changes the microstructure of the composites which as a result became more fibrous. The corresponding changes in mechanical properties indicate that the vibration casting method significantly increased the mechanical properties of casted propeller and it should be applied as a method in ship propeller manufacturing on casting process.

Abstrak tesis dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**MEMBANGUNKAN *PROPELLER* KAPAL DENGAN MENGGUNAKAN
KAEDAH ACUAN DINAMIK**

Oleh

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Ogos 2016

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Propeller kapal adalah komponen utama di dalam menghasilkan daya pendorong untuk kapal belayar. Oleh itu kestabilan dan kekuatan struktur bilah adalah diperlukan untuk memastikan keberkesanan di dalam penghasilan daya tersebut. Kajian ini dilakukan untuk mengkaji *propeller* kapal yang sedia ada dan yang dihasilkan melalui kaedah acuan dinamik tentang perubahan sifat mekaniknya. *Specimen* disediakan adalah merujuk kepada piawaian ASTM E8 2008 dan berdasarkan kepada struktur unjuran bilah iaitu unjuran Longitude dan unjuran Latitude yang merujuk kepada tindakan daya pada struktur bilah. Ujikaji terhadap sifat mekanik dijalankan ke atas *specimen* daripada potongan bilah *propeller* terpakai dan *specimen* yang diacukan di dalam menentukan kebolehpercayaan susunan unjuran *specimen* yang digunakan. Keputusan ujikaji menunjukkan bahawa perbezaan nilai properties yang kurang dari 5% dan menunjukkan bahawa susunan unjuran ini boleh digunakan di dalam analisa *dynamics casting*. Jenis acuan yang digunakan adalah *Centrifugal Mold* dengan pilihan kelajuan putaran di antara 0,

50rpm dan 150rpm dan *Mechanical Vibration Mold* pada frequency 0, 5 Hz dan 9 Hz. Ujian mekanikal yang dilakukan adalah ujian tegangan, ujian kekerasan dan penyiasatan *microscope* SEM. Keputusan ujikaji terhadap kaedah acuan telah menunjukkan peningkatan sebanyak 1.70% hingga 14.86% bagi kaedah *centrifugal* dan 4.84% hingga 9.68% bagi kaedah *vibration*. Walaubagaimanapun, kaedah getaran menunjukkan nilai sifat mekanik yang hampir sama bagi kedua-dua unjuran pada julat frequency melebihi 9 Hz dan perkara ini tidak berlaku pada kaedah *centrifugal*. Nilai *hardness* bertambah dengan bertambahnya nilai dinamik bagi kedua-dua kaedah. Berdasarkan kepada bacaan *Rockwell superficial* 15N-S adalah 6% bertambah berbanding dengan specimen yang tidak dikenakan nilai dinamik. Di samping itu, perubahan dalam mikrostruktur dan sifat-sifat mekanik telah berjaya diwakili oleh perubahan dalam ciri-ciri pemejalan. Getaran pelbagai telah mengurangkan jurang *lamellar* yang mengubah mikrostruktur bagi bahan yang menjadikannya lebih padat. Perubahan yang sama dalam sifat-sifat mekanik menunjukkan bahawa kemuluran adalah lebih dipengaruhi oleh kekerapan getaran daripada tanpa getaran dan kaedah getaran ini harus digunapakai sebagai suatu kaedah di dalam proses pembuatan propeller.

ACKNOWLEDGMENTS

In the Name of Allah, Most Gracious and the Most Merciful. Alhamdulillah, with His blessing, I have completed this research and preparation of this thesis.

I would like to express my gratitude to my parents. Without the value of life they taught, I would not have reached this achievement. I am extremely thankful to my research supervisor and the chairman of my supervisory committee Professor Dr. Shamsuddin Sulaiman and my sincere appreciations are due to the members of the supervisory committee Associate Professor Dr. B. T. Hang Tuah bin Baharudin, Associate Professor Dr. Nur Ismarrubie binti Zahari for their support in this research work and entire preparation of this doctoral thesis and I would like to convey my thanks to Mr. Ahmad Saifuddin Ismail and Mr. Ahmad Shaiful Basri , Foundry laboratories technician for his assistance during the entire period of my research project.

My acknowledgements are due to Universiti Kuala Lumpur, Malaysian Institute of Marine Engineering Technology for technical support and Majlis Amanah Rakyat (MARA) for financial support through Skim Gran Penyelidikan dan Inovasi (SGPIM).

Last but not the least many thanks to my family for their love, patience, and understanding. I believe that their patience and encouragement has given me the perseverance to achieve my ambition.

APPROVAL

I certify that a Thesis Examination Committee has met on 19 August 2016 to conduct the final examination of Ishak bin Mohmad Ali on his thesis entitled “Design and Development of Ship Propeller Using Dynamic Casting Method” in accordance with the Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The committee recommends that the student be awarded the Doctor of Philosophy.

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TABLE OF CONTENTS

	Page
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGMENTS	vii
APPROVAL	viii
DECLARATION	x
LIST OF TABLES	xix
LIST OF FIGURES	xxii
LIST OF ABBREVIATIONS	xxviii

CHAPTER

1	INTRODUCTION	
	1.1 Introduction	1
	1.2 Problem Statement	4
	1.3 Objective of the Research	10
	1.4 Scope of Research	10
	1.5 Thesis Layout	11
2	LITERATURE REVIEW	
	2.1 Introduction	12
	2.2 Ship Propeller	13
	2.2.1 Parts of Propeller	14
	2.2.1.1 Propeller Hub	15

2.2.1.2	Propeller Blade	15
2.2.2	Force in Blade	16
2.2.3	Shape and Complexity	19
2.3	Types of Propeller	20
2.3.1	Fixed Pitch Propeller (FPP)	20
2.3.2	Controllable Pitch Propeller (CPP)	21
2.3.3	Contra-rotating Propeller (CRP)	23
2.2.4	Rudder Propeller (RP)	24
2.4	Propeller Fatigue	25
2.4.1	Stress in Propeller Blade	25
2.4.2	Propeller Corrosion	25
2.4.3	Propeller Dented and Broken	27
2.4.4	Cavitation	27
2.5	Propeller Materials	30
2.5.1	Materials Composition	31
2.5.2	Nickel Aluminum Bronze	34
2.5.3	Manganese Aluminum Bronze	36
2.5.4	High Tensile Brass	37
2.6	Mechanical Properties of Standard Requirement	40
2.7	Experiment Materials selected	42
2.7.1	LM6	42
2.7.2	LM26	44
2.8	Casting Process	45
2.8.1	Sand Casting	46
2.8.2	Sand Mold Properties	51

2.8.2.1	Base Sand	52
2.8.2.2	Binder	54
2.8.2.3	Additives	55
2.8.2.4	Parting Compounds	57
2.8.3	Mold Preparation	57
2.8.3.1	Horizontal Sand Flask Molding	57
2.8.3.2	Match-plate Sand Molding	58
2.8.3.3	Mold Heating and Coating Technique	59
2.8.4	Typical Components of Sand Mold	61
2.9	Dynamic Casting Method	62
2.9.1	Centrifugal Casting	63
2.9.1.1	True Centrifugal Casting	63
2.9.1.2	Semi-centrifugal Casting	64
2.9.1.3	Centrifuge Casting	65
2.9.1.4	Centrifugal Vertical Casting	66
2.9.1.5	Centrifugal Rotation Rate	70
2.9.1.6	Rotational Speed	71
2.9.1.7	Determination of the centrifugal force on Machine	72
2.9.2	Vibration in Casting	73
2.9.2.1	Mechanical Vibrations	74
2.9.2.2	Ultrasonic Vibrations	78
2.9.3	Electromagnetic Vibration	81
2.10	Casting problems	82
2.10.1	Tolerance for the Manufacturer of Propeller	83

2.10.2	Casting Comparison	83
2.10.3	Casting Defect – Pin Holes and Porosities	84
2.11	Mechanical Testing	85
2.11.1	Standard Specimen	85
2.11.2	Rockwell Hardness Test	88
2.11.3	Tensile Test	90
2.11.4	Fatigue Test	91
2.11.5	Microscopic Techniques	92
2.11.5.1	Scanning Electron Microscopy (SEM)	93
2.11.5.2	Energy Dispersive X-Ray (EDX)	93
2.12	Summary	93
3	RESEARCH METHODOLOGY	
3.1	Introduction	95
3.2	Flow of Methodology	95
3.3	Data Analysis	100
3.4	Research Requirement	101
3.4.1	Propeller Sand Casting by Manufacturer	101
3.4.2	Mechanical Test on Used Propeller	102
3.4.2.1	Propeller Choose	103
3.4.2.2	Specimen Preparation	104
3.4.2.3	Material Test	106
3.4.3	Casted Specimen – Sand Casting	107
3.4.3.1	Specimen Arrangement	107
3.4.3.2	Specimen Description	109

3.4.3.3	Pattern and Mold Making	110
3.4.3.4	Melting of Alloys and Pouring into Mold	111
3.4.3.5	Specimen Preparation	112
3.4.3.6	Material Test	113
3.4.4	Dynamics Casting – Vibration	114
3.4.4.1	Specimen	115
3.4.4.2	Specimen Description	116
3.4.4.3	Pattern Fabrication	117
3.4.4.4	Casting Mold Preparation	117
3.4.4.5	Melting of Alloys and Pouring	119
3.4.4.6	Shakeout and Machining	120
3.4.4.7	Mechanical Testing	121
3.4.4.7.1	Hardness Test	121
3.4.4.7.2	Tensile Test	123
3.4.4.7.3	Fatigue Test	125
3.4.4.7.4	SEM and EDX Analysis	126
3.4.5	Dynamics Casting Method (Centrifugal & Vibration) – Specimen of Copper Alloys	126
3.4.5.1	Specimen Code Standard	129
3.4.5.2	Melting Alloys and Pouring	130
3.4.5.2.1	Centrifugal Mold	131
3.4.5.2.2	Vibration Mold	135
3.5	Mechanical Testing	138
3.5.1	Tensile Test	139
3.5.2	Hardness Measurement	141
3.5.3	Scanning Electron Microscope (SEM)	142

4	RESULT AND DISCUSSION	
4.1	Introduction	144
4.2	Study the existing Propeller Casting Process	145
4.2.1	Overview	145
4.2.2	Site Visit Outcome	146
4.2.2.1	Propeller Pattern	147
4.2.2.2	Mold preparation	149
4.2.2.3	Melting Process	151
4.2.2.4	Pouring Process	153
4.2.2.5	Freezing Process	154
4.2.2.6	Finishing and Refining	154
4.2.2.7	Standard Quality	156
4.2.3	Closing	157
4.3	Mechanical testing on used Ship Propeller	157
4.3.1	Overview	158
4.3.2	Specimen Preparation	159
4.3.3	Experiment Result	161
4.3.4	Closing	165
4.4	Study on specimen projection in propeller casting	165
4.4.1	Pattern Arrangement	166
4.4.2	Experiment Result	167
4.4.3	Overall Finding	170
4.5	Specimen casting with vibration mold castings	171

4.5.1	Experiment Finding	171
4.5.1.1	Tensile Test	171
4.5.1.2	Hardness Test	176
4.5.1.3	Fatigue Test	178
4.5.1.4	SEM Investigation	180
4.5.2	Overall Finding	182
4.6	Projected casting with Centrifugal Sand Casting	183
4.6.1	Tensile Test	184
4.6.2	Hardness test	186
4.6.3	Overall Finding	188
4.7	Projected Casting with Vibration Mold Casting	189
4.7.1	Tensile Test	189
4.7.2	Hardness Test	191
4.7.3	Scanning Electron microscope (SEM) Investigation	192
4.7.4	Overall Finding	194
4.8	Summary	195
5	CONCLUSIONS AND RECOMMENDATION	
5.1	Conclusions	198
5.2	Recommendation	201
	REFERENCES	202
	LIST OF PUBLICATIONS	211
	APPENDICES	215

LIST OF TABLES

Table	Page
1.1. Mechanical Properties of Copper Alloys, Cu3	7
1.2. Materials Composition of Cu3, Ni-Al Br	9
2.1. Materials composition of standard cast copper alloys for propeller (Germanisyer, 2011)	31
2.2. Chemical composition of ABS cast copper alloys for propeller (ABS, 2009)	32
2.3. ASTM Chemical requirement for centrifugal casting (ASTM, 2003)	33
2.4. Corrosion Fatigue Properties of Marine Propeller Alloys (Carlton, 2007)	34
2.5. GL Mechanical Properties of standard cast copper alloys (Germanisyer, 2011)	40
2.6. DNV Mechanical Properties for copper alloys casting (DET, 2011)	40
2.7. ABS Table properties of separately cast test coupon (ABS, 2009)	41
2.8. ASTM Mechanical properties centrifugal (ASTM, 2003)	41
2.9. Chemical Composition of LM6 (BSI, 1988)	43
2.10. Properties of LM6 (BSI, 1988)	44
2.11. Chemical Composition of LM26 (BSI, 1988)	45
2.12. Properties of LM26 (BSI, 1988)	45
2.13. Mold materials composition	60
2.14. Mechanical Property comparison of corrosion resistant steel in wrought and centrifugal cast form (Kang et al., 1994)	69
2.15. Casting Comparison for Sand Casting and Vibration Casting	84

2.16. Rockwell Hardness Test Scales (ASTM, 2008)	89
3.1. Used Propeller Specification	103
3.2. Specimen Description – cutting blade	105
3.3. Specimen Description – casted specimen	109
3.4. Description of Specimen – Aluminum Alloy	116
3.5. Description of Specimen for Centrifugal Casting Method	129
3.6. Description of Specimen for Mechanical Vibration Method	129
4.1. Chemical Composition of Standard Copper Alloys for Propeller	153
4.2. Mechanical Properties of Copper Alloys Casting	156
4.3. Specimen Description	160
4.4. Materials Composition of Sample Test of Used Propeller	162
4.5. Experiment Result of Specimen Test – Yield Strength	162
4.6. Experiment Result of Specimen Test – Tensile Strength	163
4.7. Experiment Result of Specimen Test – Elongation (%)	163
4.8. Average Result Comparison to Standard	163
4.9. Descriptions for each type of specimen	167
4.10. Experiment Result of Casted Specimen	168
4.11. The comparison of Mechanical Properties of Tested Specimen	168
4.12. The percentage of Mechanical Properties changes in Casted Specimens	169
4.13. Average values for Mechanical Properties for Specimen	172
4.14. Average Rockwell Hardness and Range Values	176
4.15. Mean and Amplitude Forces applied on Specimen	182
4.16. Expectation of Mechanical Properties changes in Copper Alloys	182
4.17. Average values for Mechanical Properties of Specimens, Centrifugal Sand Casting	184

4.18. Hardness Test Rockwell Result for Centrifugal mold casting	187
4.19. Average values for Mechanical Properties of Specimens, Vibration Sand Casting	189
4.20. Hardness Test Rockwell Result for Vibration mold casting	191



LIST OF FIGURES

Figure	Page
1.1. Circumstances in the event of blade erosion	6
1.2. Forces action and Projections of Propeller Blade	8
2.1. Ship Propeller in Propulsion System	13
2.2. Propeller parts consist of blades, bug (boss) and shaft	14
2.3. Ship Propeller Nomenclature	15
2.4. Two Forces exerted on the Blades	17
2.5. Blade Profile and Transverse View	18
2.6. Pressure Side and The Suction Side	19
2.7. Fixed Pitch Propeller (FPP)	20
2.8. Controllable Pitch Propeller (CPP)	21
2.9. Drawing of single propeller cross-sections	22
2.10. Contra Rotating Propeller (CRP)	24
2.11. Rudder Propeller (RP)	24
2.12. Corroded propeller	26
2.13. Blade Dented and Blade Broken	27
2.14. Cavitation created damaged on propeller	29
2.15. Family of Propeller Materials	30
2.16. General characteristics of a thick propeller section	31
2.17. Ni-Al-Br Propeller	36
2.18. Effect of mean tensile stress on corrosion fatigue properties	38

2.19.	Typical effect of chemical composition on mechanical properties of a copper manganese aluminum alloys	39
2.20.	High Tensile Brass 3 blade propeller	39
2.21.	Outline of metal casting processes	46
2.22.	Outline of production steps in a typical sand casting	47
2.23.	Cross sectional view of a sand casting mold	49
2.24.	Example of common defects in casting	50
2.25.	Horizontal Flask Sand Molding Principle	58
2.26.	DISAs Match-Plate Sand Molding Principle	59
2.27.	Mold parting line with complete accessories	62
2.28.	Setup for True Centrifugal Casting	65
2.29.	Centrifuge Casting Solidification Process	66
2.30.	Centrifugal Vertical Casting	66
2.31.	Product from Vertical Casting	67
2.32.	Progressive Solidification Front in Centrifugal Casting	68
2.33.	Vertical Centrifugal Casting	70
2.34.	Microscopic Photograph of Casting Surface	73
2.35.	Optical Micrographs of CHWD steel with Mechanical Vibrations	75
2.36.	SEM micrographs of CHWD steel with Mechanical Vibrations	76
2.37.	Aluminum Cooling Curve with and without Vibrations	77
2.38.	Casting microstructure with and without Vibrations	78
2.39.	Effect of Ultrasonic Treatment on Al-17%Si alloy	79
2.40.	Eutectic Si morphology without and with Vibrations	80
2.41.	Microstructure without and with ultrasonic treatment	80
2.42.	Mechanical Properties of AZ91 alloy	81

2.43.	The Pin Holes and Porosities Present at Product surface	85
2.44.	Separately Cast Sample Pieces	86
2.45.	Various Shoulder Styles and Grippers for Tensile Specimen	87
2.46.	Dumb-bell Specimen	87
2.47.	Rockwell Hardness Testing Method	89
2.48.	A Typical Stress-Strain Curve	90
2.49.	Stage of Fatigue Failure	91
2.50.	Fatigue Testing Machine	92
3.1.	Flowchart diagram of overall research methodology	96
3.2.	Industrial Site Visit Flowchart	97
3.3.	Flowchart of Used Propeller Mechanical Testing	98
3.4.	Specimen Arrangement Verification Flowchart	99
3.5.	Flowchart of the Specimen Fabrication Process	100
3.6.	Test Specimen Projection of Propeller Blade	102
3.7.	Specimen Projections on Propeller Profile	103
3.8.	Used Propeller (left) and Discrete Blade Process (right)	104
3.9.	Piece of Blade (left) and Blade Piece-Cutting (right)	105
3.10.	Dumb-bell Shape Test Specimen measurement	105
3.11.	Specimen Piece-Machining (left) and Ready Specimen (right)	106
3.12.	Mechanical Tensile Machine and Specimen Placement	106
3.13.	Spectrometer for Materials Composition Test	107
3.14.	Molten Flow in Mold Cavities	108
3.15.	Specimen arrangement and pattern	108
3.16.	Expectation molten flow	109
3.17.	Drag of the wooden pattern	110

3.18.	Complete Mold ready to use	111
3.19.	Diesel-Gas Furnace	111
3.20.	Control Panel and Infra-red Thermometer	112
3.21.	Molten Pouring and Freezing	112
3.22.	Product shakeout and chipped metal	113
3.23.	Milling process and ready specimen	113
3.24.	Mechanical Tensile Machine and Specimen Placement	114
3.25.	Spectrometer for Materials Composition	114
3.26.	Dimension of Specimen	115
3.27.	Drawing of Pattern of Second Specimen	116
3.28.	Cope and Drag of the Wooden Pattern – Vibration Mold	117
3.29.	Preparation of Sand Mold	118
3.30.	Cope for Sand Mold	118
3.31.	Induction Melting Furnace	119
3.32.	Molten Alloy Poured into Mold	120
3.33.	Shakeout and Cutting Process	120
3.34.	Machining of Specimen and Testing Samples	121
3.35.	MITUTOYO ATK-600 Hardness Test Machine	123
3.36.	INSTRON 3382 Tensile Machine	124
3.37.	Fractured Specimen after test	125
3.38.	INSTRON 8874 Fatigue Test Machine	126
3.39.	Specimen for SEM and EDX	127
3.40.	Centrifugal Workbench	128
3.41.	Mechanical Vibration Workbench	129
3.42.	Diesel-Gas Furnace	130
3.43.	Control Panel & Infra-Red Thermometer	131

3.44.	Molds Placing on Floor & Centrifugal Workbench	132
3.45.	Tachometer Reader	133
3.46.	Laser Photo and Contact RPM	133
3.47.	Application of Photo Tachometer	134
3.48.	Mold on Vibration Workbench and Pouring Process	135
3.49.	Vibrator Test Pen & Description	136
3.50.	Vibrator Test Pen Application	137
3.51.	Casted Specimen and Recovery Process	138
3.52.	INSTRON 600DXU Universal Testing Machine	140
3.53.	Specimens for Tensile Test	140
3.54.	MITUTOYO ATK-600 Hardness Testing Machine	142
3.55.	Specimen Prepared for SEM	143
4.1.	Outline of Production Steps in Typical Sand-Casting	147
4.2.	Engineering Drawing – Propeller	148
4.3.	Propeller Pattern	148
4.4.	Pattern Types	149
4.5.	The illustration of Bottom Section (drag)	150
4.6.	The illustration of Top and Bottom Mold Section	151
4.7.	Two Types of common Furnace in Foundries	152
4.8.	The illustration of Finishing and Refining work	155
4.9.	Forces action on Propeller	158
4.10.	Tension Forces Direction for Tensile Test	159
4.11.	Specimen Projection of Propeller Blade	159
4.12.	Test Specimen Projection	160
4.13.	Specimen Preparation Process	161
4.14.	Pattern arrangement (left) and Wooden Pattern (right)	166

4.15. Specimen Fabrication in Sand Casting Process	167
4.16. Graph Ultimate Tensile Strength versus Vibration Frequency	172
4.17. Graph Percentage Elongation versus Vibration Frequency	173
4.18. Young's Modulus versus Vibration Frequency	173
4.19. Average Load versus Extension for LM6	174
4.20. Average Load versus Extension for LM26	174
4.21. Rockwell Hardness versus Vibration Frequency for LM6 and LM26	177
4.22. Comparison of Fatigue Life versus Vibration Frequency	179
4.23. SEM images of Fractography for LM6 and LM26	180
4.24. Tensile Strength versus Centrifugal Speed	185
4.25. Elongation % versus Centrifugal Speed	186
4.26. Pinch Spot Hardness Test on Specimen	187
4.27. Tensile Strength versus Vibration Frequency	190
4.28. Percentage Elongation versus Vibration Frequency	190
4.29. SEM images of Fractography for Longitude and Latitude projections.	193

LIST OF ABBREVIATIONS

AA	- Aluminum Association
Al	- Aluminum
ASTM	- American Society for Testing and Materials
BS	- British Standard
C	- Carbon
CHWD	- Cast Hot Work Die Steel
CMC	- Ceramic matrix composite
CO ₂	- Carbon dioxide
CP	- Commercial purity
Cu	- Copper
EDX	- Energy Dispersive X-ray
G	- Gage length (mm)
Hz	- Heize
ISO	- International Standard Organization
kN	- kilo Newton
L	- Overall length (mm)
lbf	- Pont
LM6	- Light Metal (Type of aluminum)
m	- Mass (kg)
Mg	- Magnesium
MMC	- Metal Matrix Composite
Mn	- Manganese
MP	- Mechanical Properties

MPa	- Mega Pascal
P	- Phosphorus
PM	- Powder metallurgy
PMC	- Polymer matrix composite
R	- Radius of fillet
RMS	- Root Mean Square Value
RQI	- Rheocasting Quality Index
S	- Sulfur
SEM	- Scanning Electron Microscope
Si	- Silicon
SiC	- Silicon carbide
t	- Thickness (mm)
T	- Tone
TiC	- Titanium carbide
UTS	- Ultimate Tensile Testin
V	- Volume (cc)
W	- Watt
Zn	- Zink
μm	- micrometer
ρ	- Density (gr/cm^3)

CHAPTER 1

INTRODUCTION

1.1 Introduction

The ship propeller is a key component of the motion mechanism of the ship and its play the main part in propulsion systems. Propulsion is the act or an instance of driving or pushing forward of a body (ship), by a propeller-ship propulsion (John, 2007). Apart from that, 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 (Carlton, 2012). As for an effective propeller design, calculations of propeller strength must consider 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 (Rawson, 2001). At this point, the problems faced on the propeller are corrosion, blade breaking, fractures and distortions.

Many studies have been done on corrosion resistance and strength of the blade to select materials and appropriate size of propeller, however the other factor must be

considered and are given more attention on the manufacturing process of the propeller to make it stronger and resistant to corrosion so as to overcome mentioned above. 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 (John, 2007). Mostly, the ship propellers are manufactured by traditional sand casting method. Sand casting is one of the oldest metal forming methods used by engineers. Over 70% of all metal castings are produced via a sand casting process (Carlton, 2009). It is relatively cheaper and utilizes expendable sand molds to form complex metal parts that can be made of nearly any alloy. The sand casting process involves the use of a furnace, metal, pattern and sand mold. The molten metal from the furnace is poured into the cavity of the sand mold, which is formed by the pattern. The sand mold separates along a parting line and the solidified casting can be removed.

The competition in the ship industries has been growing rapidly in recent years. This increased competition has compelled manufacturing industries to look for better quality ship propellers. Quality products not only enhance profits but also contribute towards the growth of the company. Hence, quality ship propellers play a significant role in the success of the company. Modern approaches to improve quality in casted products involve the use of dynamics casting method and the most popular is vibration casted method and centrifugal mold casting.

Vibration has been found to play a critical role in casting by eliminating defects and enhancing quality. According to the review by Feng-Wuan and Xiao-Ling (Feng et al., 2000), the use of vibration during solidification was first studied in 1800s. A study by Shukla et al. (Shukla et al., 1980) concluded that vibration can help in promotion of nucleation and thus reduce grain size, lower susceptibility to cracking and reduce shrinkage porosities. This leads to improved features and thereby improved mechanical properties. A significant increase in mechanical properties such as tensile strength and hardness is observed. Different types of vibration such as mechanical, ultrasonic or electromagnetic vibration may be applied to the metal through various means. Vibration energy has many applications within the manufacturing and engineering fields. The centrifugal casting process utilizes inertial forces caused by rotation, to distribute the molten metal into the mold cavities (Sidpara, 2012). Different types of centrifugal such as vertical centrifugal and horizontal centrifugal may be applied to the metal through various means. This study investigates the effects of horizontal centrifugal casting on the mechanical properties in comparison with products formed without centrifugal inertial forces.

Application of dynamics casting has significant effect on grain refinement (reduce in porosity), density, hardness, ultimate tensile strength, percent elongation, degassing, shrinkage (shape complexity and dimensional accuracy), and surface finishing. In this research, the proposal of solutions will be made in relation to the appropriate manufacturing method. At the end of the achievement of this tesis, it is hoped that practical manufacturing could be introduced and then carried out to

prove its effectiveness in achieving the goal of producing propeller with strength and endurance is better than existing ones.

1.2 Problem Statement

The research is on propeller manufacturing process in producing a stronger propeller blade in terms of increased the mechanical properties without change the materials specification. The idea is to propose an alternative manufacturing process of propeller which is able to achieve the objective of this research. In the history of development of the strength blade, elimination of porosity formation has been thought of as a key factor in the propeller manufacturing. This is the main reason for the weakness blade structure and the cause of formations is due to high temperature required on melting and during casting. The others factors are pressure drop during inter-dendrite fluid molten flow, materials shrinkage during solidifications, gases bubble trapped during casting, non-uniform cooling rate and sand mold has low permeability (Kalpakjian, 2010). However, a major problem with this kind of application is the high melting temperature. The requirement of high temperature for melting as at 1100°C , cause due to they need the molten to be a liquid for casting to flowing into mold casting and to avoid pressure drop during inter-dendrite of fluid molten flow (Kalpakjian, 2010). This cause due to sand casting mold is a static casting type, where it depending on the gravity flows of molten for flowing into mold. That is why they required the liquid, so to be more liquidize, they require more temperature. The high temperature is required because of casting molten fluid must be sufficiently liquid so that the molten can permeate

into his mold cavity perfectly. To be stabilized in molten flowing into the cavity, the external force need to exerted to the molten alloy. This can be applied by created an external forces produce by dynamics mechanism such as vibration forces or centrifugal forces to the mold case.

Propeller blade surface will erode due to the friction that occurs between the surfaces of the blade with the flow of sea water while it is operating. The blade erosion would result in reduced thickness of the blade and blade surfaces are not flat and caused pitched surfaces. The illustration of blade eroded is shown in Figure 1.1. The pitched surface is caused by exposure to the porosity defects and pin holes formed in the blade body during the manufacturing due to casting process. These will be 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.

Shear stress = force / cross section area of blade; $\tau = F / A$ (Hibbler, 2004)

Where; τ is shear stress N/mm²

F is perpendicular force to surface (N)

A is cross section area (mm²)

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.

$\tau_{\text{after}} > \tau_{\text{limit}}$ = cause the blade fracture

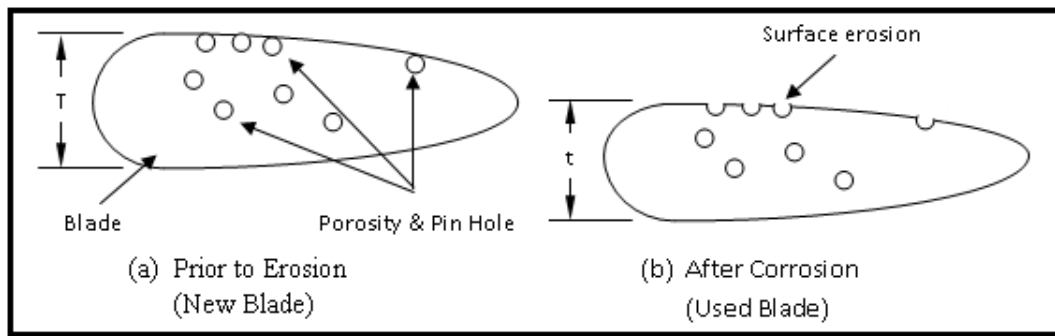


Figure 1.1: Circumstances in the event of blade erosion (Carlton, 2012)

The effect of the occurrence of extreme erosion will cause failure of the blade such as cavitations flow occurs or turbulence flows happened when the porosity or pin-hole scare exposed and resulting in strong shaking caused by unbalanced force act to the whole structure of Propeller blade and blade has a high shear stress that eventually causes the fracture. To avoid the formation of porosity and pin-holes in the blade, several factors need to be aware of such as to eliminate the porosity formation during casting process (John, 2007), selection of manufacturing compounds that can produce a mixture composite and propeller through the process of formation of an effective and accurate method of selection is required to produce.

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. 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 (Rawson, 2001). 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 Germanischer Lloyd (GL) and to meet the requirements referring to the propeller materials as shown in Table 1.1.

Table 1.1: Mechanical properties for copper alloy propeller castings (DET, 2011)

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

The mechanical properties magnitude had shown in Table 1.1 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 manufacturing methods and the illustration of these forces can be seen as in Figure 1.2(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.

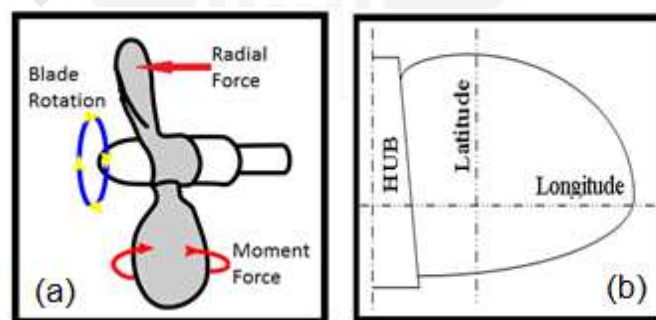


Figure 1.2: Forces action and strength required on a propeller (a) and Projection of Propeller Blade (b)

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 1.2(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 increasing of mechanical ability should be added as yield strength and tensile strength, while the elongation is reduced slightly and it will be improved the strength of the Propeller. The blade hardness also needs to be increased in terms of reduce the surface erosion rate (Kalpakjian, 2010). This will be reached if the modified manufacturing method based on the process and equipment can be performed. 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), Germanischer Lloyd (GL) and Nippon Kaiji Kyokai (NKK). The material is Copper base and the alloy is to be Nickel Aluminum Bronze (Ni-Al-Br) and the composition had been identified as shows in Table 1.2.

Table 1.2: Materials composition of Cu3, Nickel Aluminum Bronze (Ni-Al-Br)
(DET, 2011)

Casting grade	Chemical Composition (%)							
	Cu	Al	Mn	Zn	Fe	Ni	Sn	Pb
Ni-Al-bronze, 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

Referring to the problems statement and solutions needs to be done, the research is to study the methods of casting and focus in dynamics casting, as well as conducting experiments on the structure of the casting product testing on mechanical properties and investigate the microstructure grain. Hence the proposed test is Tensile Strength Test, Hardness Test and Scanning Electron Microscope Investigation. The data collection is to be handled in analysis and will be used is selecting the better method for ship propeller manufacturing process.

1.3 Objective of the Research

The research work is carried out in order to achieve the objective in provide the proposal and standardize the propeller manufacturing process in producing a better mechanical properties and good feature of the propeller in terms of stronger blades and has resistance to corrosion. Therefore, the objectives of the study are focused on the following areas, namely;

- i. To determine the mechanical properties of current propeller.
- ii. To develop the dynamic casting and compare the mechanical properties and microstructure of Copper Alloy specimens.
- iii. To propose the best casting method in propeller manufacturing process.

1.4 Scopes of Research

The scope of the research to understand the existing practice in propeller manufacturing process such as materials, design and casting technique. The propeller fractures and problems faced on the propeller coincide in the research in determining the better manufacturing process. The validation of good practices in research is continued by performing the mechanical test and microstructure investigation to the sample specimen of dynamics casting method. In the identifying of good practices of dynamics casting method, the research is performing in review on the effect of vibration in the sand casting of Copper Alloys. The specimen is casted with and without vibration to perform mechanical tests and microstructure analysis. Finally, the result is used in the selection of best method casting of propeller.

1.5 Thesis layout

The thesis has been structured into five chapters. Chapter 1 introduces the topic of sand casting and vibration used during the casting process. Chapter 2 presents a review of literature that relates to the investigation on the mechanical behavior and microstructure properties of Copper alloys with and without using mechanical vibration mold. Chapter 3 describes the research methodology and explains the processes used for the collection of data and information. Chapter 4 presents the results and discusses, analyzes and compares the effects of vibration mold casting and centrifugal mold casting on the mechanical properties of Copper alloys. Chapter 5 presents the conclusion of the research.

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