GENERATING CAVITATION EROSION DATA FOR SHIP PROPELLER MATERIALS

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To
The Head,
Bureau of Research and Consultancy
ITM, Shah Alam,
Selangor, D.E., Malaysia.

Kind Attention: Dr.Khafilah Din, Co-ordinator, Science and Technology

Madam,

GENERATING DATA ON THE CAVITATION EROSION FOR SHIP PROPELLER MATERIALS

The above Research Project has been completed. We enclose herewith 4 copies of the final project report to BRC for your records and reference.

Thanking You,

Yours Sincerely,

(ABDUL GHANI BIN UJANG)
CHIEF RESEARCHER

MEMBERS OF THE RESEARCH TEAM

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Dr. SOLOMON DARIUS GNANARAJ
(RESEARCHER)

(Signature)

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ABSTRACT

This work deals with the cavitation erosion of ship propeller materials. The occurrence of the cavitation erosion phenomenon and the effects due to this are explained. Different types of cavitation and the conditions under which a particular type of cavitation would occur are reported. The properties of four different propeller materials are briefly given.

The experimental work performed in Nottingham University is taken as a basis for doing this work. The details of the cavitation erosion apparatus and the cavitation Erosion test rig are reported. With the help of the cavitation erosion test rig, it is possible to find the damage of a ship propeller material due to cavitation erosion, in a short time. This work reports how a computer model of the cavitation could be made and the method to simulate the flow conditions under different pressures leading to different cavitation numbers.

A CFD software, 'FLUENT' was used in visualising the flow and to find the pressure acting over the propeller material specimen. A failure analysis model is employed to find theoretically the material removal rate (MRR) based on the results from the flow analysis. The failure analysis model requires the critical normal fracture stress developed in the specimen due to the action of water jet over the specimen surface. To find this stress, Stress analysis is performed on the ship propeller material specimen using a finite element analysis program - ANSYS.

The material removal rate (MRR) calculated through the theoretical method is compared with that obtained through the experimental method and we see a good correlation between the two. This model can be used to predict the MRR of any new ship propeller material. Using the model, MRR is predicted for the following propeller materials: Nickel Aluminium Bronze, High Strength Yellow Brass, Stainless Steel and Cast Iron.

The theoretical values of the material removal rate (MRR) are required to be verified experimentally. For this purpose, we are developing the required facilities in ITM, Shah Alam which will be similar to that available in Nottingham University. Though we have procured most of the components of the test rig, few components could not be procured due to non-availability. We are working on an alternative design based on the available components to fabricate the testing facility for conducting experimental verification of the theoretical values of MRR of the propeller materials.

TABLE OF CONTENTS

CONTENTS	PAGE
ACKNOWLEDGEMENT	**i**
ABSTRACT	**ii**
TABLE OF CONTENTS	iv
CHAPTER 1	
INTRODUCTION	
1.0 Introduction	1
1.1 Objective	2
1.2 Present Work Procedure (FLUENT-ANSYS-MRR)	3
1.2.1 FLUENT (Simulation)	4
1.2.2 ANSYS (Analysis)	4
1.2.3 Material Removal Rate (MRR)	4
CHAPTER 2	
CAVITATION EROSION	
2.0 Cavitation	5
2.1 Definition of Cavitation	5
2.2 Types of Cavitation	6
2.2.1 Travelling Cavitation	6
2.2.2 Fixed Cavitation	7
2.2.3 Vortex Cavitation	7
2.2.4 Vibratory Cavitation	8
2.3 The Effect and Significance of Cavitation	11
2.4 Liquid Impingement Erosion	11

CHAPTER 3

PROPELLER MATERIALS

3.0 Introduction 14

3.1 General Properties of Propeller Materials 17

3.2 Properties of Propeller Materials 18

3.2.1 High Tensile Brass 18

3.2.2 Nickel Aluminium Bronze 18

3.2.3 Martensitic Stainless Steel 19

3.2.4 Cast Iron 19

CHAPTER 4

EXPERIMENTAL STUDIES

4.0 Introduction 21

4.1 Cavitation Erosion Apparatus 21

4.2 The Cavitation Erosion Test Rig 21

4.3 Experimental Results 22

CHAPTER 5

FLOW SIMULATION

5.0 Introduction 29

5.1 Construction of the computer Model 29

5.2 Results 29

CHAPTER 6

FAILURE ANALYSIS

6.0 Introduction 48

6.1 Stress Analysis 48

6.2 Failure Analysis 48

CHAPTER 7

RESULTS AND DISCUSSION

7.0 Introduction 54

7.1 Flow Analysis 54

7.2 Failure Analysis 58

7.3 Sample Calculations for MRR 63

7.4 Comparison of MRR from Experiment with Theory 68

7.5 Predicton of MRR of Ship Propeller Materials 68

7.6 Testing Facility Development 72

CHAPTER 8

CONCLUSIONS

8.0 Conclusions 73

8.1 Work to be continued(Experimental) 73

REFERENCES 74

CHAPTER - 1

INTRODUCTION

INTRODUCTION

1.0 Introduction

Cavitation is a general fluid mechanics phenomenon which can occur whenever a liquid is used in a machine which induces pressure and velocity fluctuations in the fluid. Consequently, pumps, turbines, propellers and bearing are all examples of machines where the destructive consequences of cavitation may occur.

Erosion of a solid surface can take place in a liquid medium even without the presence of solid, abrasive particle in that medium. One mechanism of liquid erosion involves the formation and subsequent collapse of bubbles within the liquid, which is known as cavitation. The process by which material is removed from a surface is called cavitation erosion and the resulting damage is cavitation damage. When liquid droplets collide with a solid surface at high speed, a form of liquid erosion called liquid impingement erosion occurs.

Cavitation damage has been observed on ship propellers and hydrofoils on dams, spillways, gates, tunnels and other hydraulics structures and in hydraulics pumps and turbines. High speed flow liquid in this devices causes local hydrodynamics pressures to vary widely and rapidly. Liquid erosion involves the progressive removal of material from a surface by repeated impulse loading at microscopically small areas.

The process of liquid erosion is less well understood than most other failure processes. It is difficult to define the hydrodynamic conditions that produce erosion and to define the metallurgical processes by which particles are detached from the surface. In any event, the appearance of damage surfaces and the relative resistance of materials to damage are similar for both liquid impingement and cavitation erosion.

1.1 Objective

The objectives of this project are:

1. Generate cavitation erosion data by using different propeller materials.
2. Stress analysis in the propeller material specimen by using ANSYS software (FEA).
3. To analyse the effect of stand off distance of the nozzle.
4. Prediction of Material Removal Rate (MRR) due to cavitation erosion.
5. To compare the theoretical Material Removal Rate (MRR) with experimental results of MRR for validation.

In this project we used ANSYS (FEA) to simulate the propeller material specimen to find the stress distribution and critical stress. FEA gives the position of elements subjected to maximum and minimum stresses. The procedure followed in using the ANSYS software to generate the required output are reported in Chapter six.

All data used in this analysis were collected from FLUENT simulation. The cavitation pressure acting on the specimen was the input in this analysis. For these studies, five material were use in this analysis. The materials are:-

1. Pure Aluminium.
2. High Strength Yellow Brass.
3. Nickel Aluminium Bronze.
4. Martensitic Stainless Steel.
5. Cast Iron

1.2 Present Work Procedure (FLUENT-ANSYS-MRR)

For these present work procedure, there are three steps how the material removal rate (MRR) was calculated. Figure 1.0 shows the correlation between FLUENT, ANSYS and MRR.

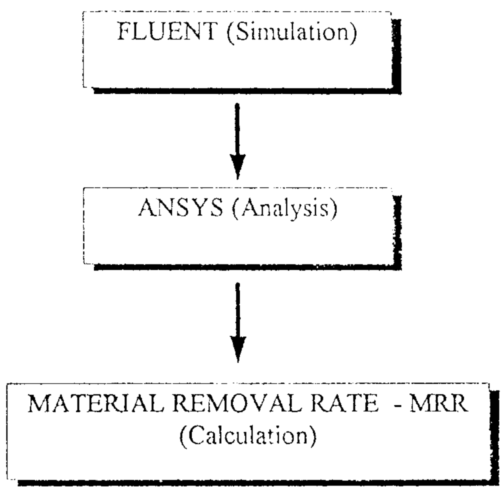

Figure 1.0 Work procedure

1.2.1 FLUENT (Simulation)

From FLUENT simulation, the pressure and velocity distribution will be used in ANSYS analysis. These simulation done for five different stand off distances; 5mm, 10mm, 15mm, 20mm and 25mm. The results of the FLUENT simulation are presented in Chapter-5.

1.2.2 ANSYS (Analysis)

To find the stress distribution and critical stress in the propeller materials specimen. The pressure and velocity (from FLUENT simulation) acting on the specimen were the input in this analysis. The value of critical stress will be used in calculation of material removal rate (MRR). The results of the ANSYS analysis are presented in chapter-7 .

1.2.3 MATERIAL REMOVAL RATE (MRR)

Prediction of material removal rate (MRR) due to cavitation erosion. The MRR of the materials are calculated by using the results from FLUENT and ANSYS. The steps and sample calculation are shown in Chapter-7.

CHAPTER - 2

CAVITATION EROSION

CAVITATION EROSION

2.0 Cavitation

The phenomenon which are commonly now termed as cavitation has been known as long as during the time of Galileo. The term "cavitation" itself was coined by Froude. Sir Charles Parsons were experiencing problems with the propellers of his "Turbinia" due to the formation of cavities around the propellers. Recognising this fact he undertook some studies of cavitation in order that he could redesign the propulsion. The problem of cavitation then is not new one. However it is essential that some fundamental concepts and practices are reviewed before proceeding further in order to appreciate the relevance of the phenomenon

2.1 Definition of cavitation.

When a body of liquid is subjected to heat under constant pressure or to pressure reduction at essentially constant temperature it will form cavities. These cavities are frequently also termed as bubbles. These cavities are filled with either vapour or a mixture of both vapour and gases which has been dissolved in the liquid. The condition is known as "boiling" if it is the result of the addition of heat. Otherwise it is known as "cavitation" if it is caused by dynamic pressure reduction. We shall now confine ourselves to cavitation brought about by localised hydrodynamic pressure reduction. For a vapour filled cavity with negligible gas content the collapse occur implosively. The effect of gaseous content is to somewhat retard the implosion. When cavitation occurs close to a solid boundary or surface it causes damages to it by mechanically pitting or eroding the boundary or surface. Although other factors such as chemical corrosive effects are also important the major factor that gives rise to cavitation damage is purely mechanical. This factor is always present.

2.2 Types of cavitation experienced by propellers

Cavitation can be classified in a number of ways. One ways is to classify it according to the conditions under which it takes place and according to its principal characteristics. Classifying it this way cavitation then fall into the following groups :

2.2.1 Travelling cavitation

Travelling cavitation (Figure 2.1) is composed of individual transient cavities which form in liquid and moving with it as they expand, shrink and then collapse. Such transient *travelling* cavities may appear at the low pressure points along a solid boundary or in the liquid interior either at the core of moving vortices or in the high-turbulence region in a turbulent shear field.

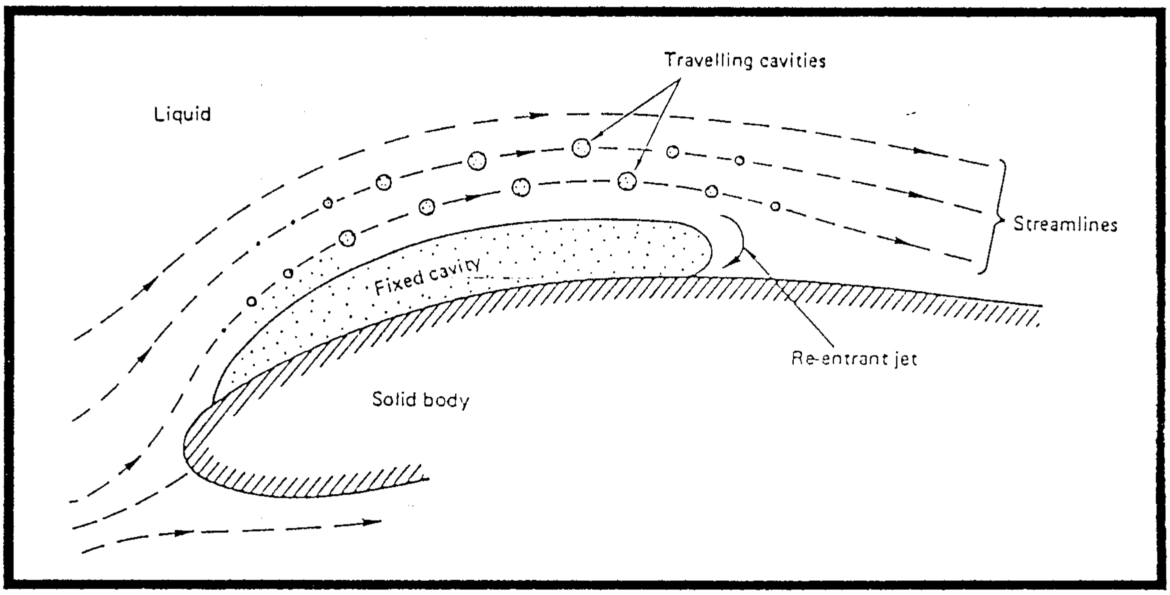

Figure 2.1 Fixed in travelling cavities

2.2.2 Fixed cavitation

Fixed cavitation (Figure 2.1) refers to the situation sometimes develops after inception, in which the liquid flow detaches from the rigid boundary of an immersed body or a flow passage to form a pocket or cavity attached or fixed to the boundary.

2.2.3 Vortex cavitation

In the case of *vortex cavitation* the cavities are found in the *cores of vortices* which form in zones of high shear. They may appear as travelling cavities or as a fixed cavity. Vortex cavitation occurs on the tips of the propeller blades of ships. It also occurs in the flow around the baffle piers downstream of spillway chutes. This type of cavitation may also be found on the boundary surfaces of *submerged jets*. The development of this vortex depends on the existence of a sufficiently high shear rate region which allows the formation of vortices wherein the absolute pressure in the core drops to a critical pressure usually approximately the vapour pressure. Their inherent characteristics appear to indicate that the rates of collapse and consequently the collapse pressure are low.

It can be seen clearly that on the basis of this description vortex cavitation will cause damage only if the collapse of the bubbles occurs on or very close to the adjacent surfaces. An important example which is supported by much field evidence is the damage caused by tip clearance cavitation on the blade ends of propeller turbines or pumps.

2.2.4 Vibratory cavitation

In the case of the fourth type cavitation called *vibratory cavitation* this feature is absent. The velocity of flow that sometimes accompany it is so low that a given element of liquid is exposed to several cycles of cavitation instead of just one. The forces that causes cavities to form and collapse are due to a continuous series of high-amplitude, high frequency pressure pulsation's in the liquid. These pulsation are generated by a submerged surface which vibrates normal to its face and sets up pressure waves in the liquid. No cavities will form unless the amplitude of pressure variation is great enough to cause the pressure to drop to or below vapour pressure of the liquid.

The three types of cavitation described above occur in a flowing stream. The fourth type of cavitation is a type associated with a condition where there is no major flow. Instead now a solid body moves in a stationary liquid. Essentially there is no difference between cavitation in a flowing stream and that of cavitation where the fluid remains to a great extent stationary.

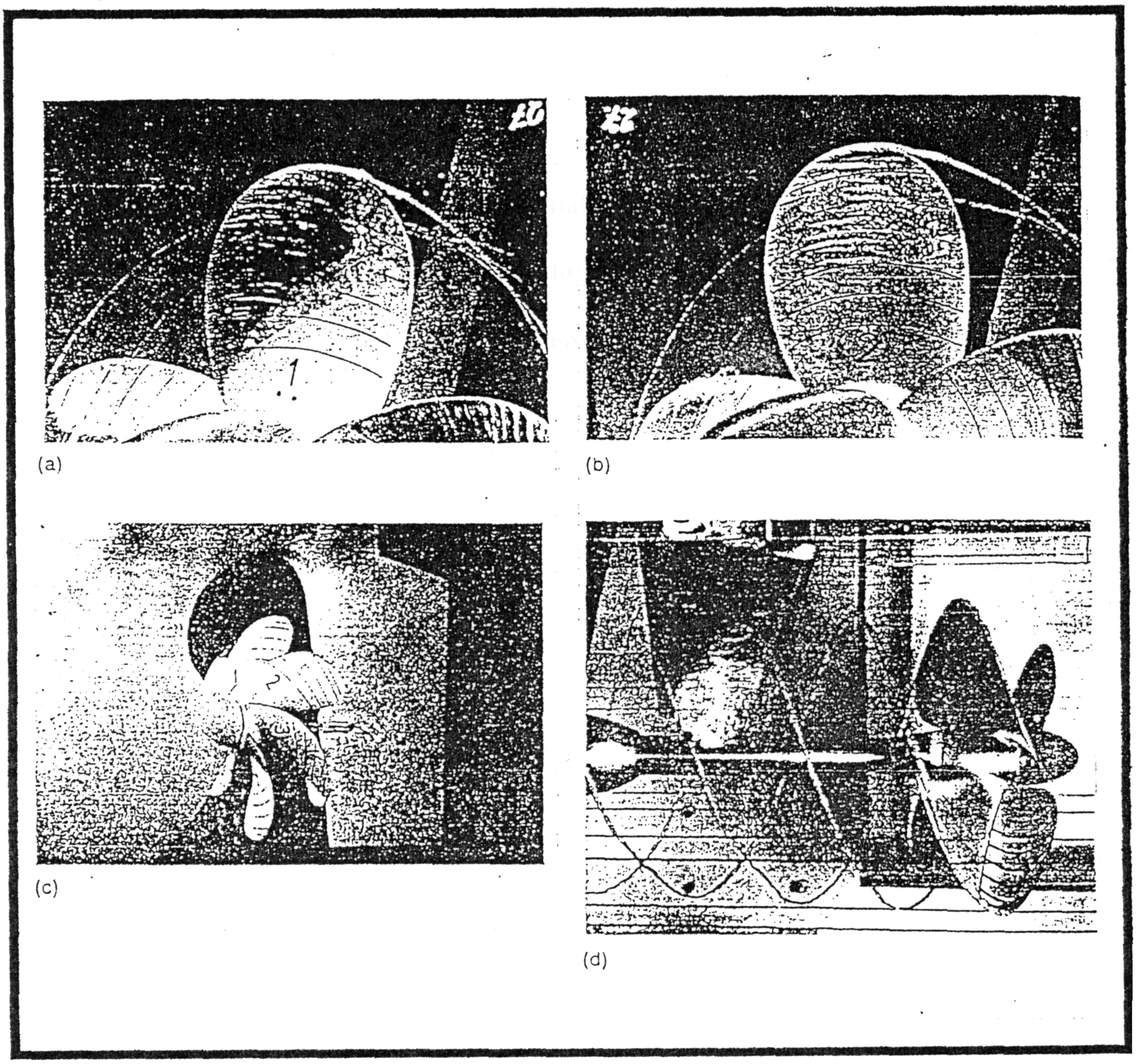

Figure 2.2 Types of cavitation on propellers (Marine)

a) sheet and cloud cavitation together with a tip vortex
b) mid chord bubble cavitation together with a tip vortex and some leading edge streak cavitation
c) hub vortex cavitation
d) tip vortex cavitation

2.3 The effects and significance of cavitation

The significance of cavitation is as a consequence of its effects. When cavitation occurs the following effects are produced:-

1. pitting and erosion when the collapse occur near to or in contact with a surface. This is by far the most important effect of cavitation.
2. noise which is rather high pitched. This high pitched noise tends to a dull roar when the cavitation is fully developed. This noise is generated by the collapsing of the bubbles
3. vibration of the surface affected by it, and
4. changes in the hydrodynamics of the flow of the liquid

2.4 Liquid Impingement Erosion

The high velocity impact of a drop of liquid against a solid surface produces two effects that result in damage to the surface:-

1. high pressure which is generated at the point of impact.
2. liquid flow along the surface at high speed radially from the point of impact which occurs as the initial pressure pulse subsides.

Although there is not as yet any fully accepted theory for the pressure distribution in a solid upon impact with a spherical drop of liquid, a qualitative understanding is being developed through both analytical and experimental studies. There is a simple evidence that the maximum pressure is developed not at the central point of impact but in a ring around it. That maximum pressure is close to twice the theoretical pressure for a flat impact.

Liquid impingement erosion is believed to occur by the process illustrated in Figure 2.3 (next page). Upon impact, the impact pressure can produce circumferential cracks in the area of impact (Figure 2.3a), depending on the properties of the surface material and the energy of impact. (For very ductile materials, the initial damage may be in the form of shallow craters surrounded by a circular ridge of deformed metal.) Following impact, the liquids flow away radially at high velocity. When the spreading liquid hits a nearby surface asperity, the force of this impact stresses the asperity at its base and may produced a crack (Figure 2.3b). Subsequent impacts by other drops may widen the crack or detach the asperity entirely as shown in Figure 2.3c. Direct hits on existing cracks, pits or other deep depressions can produce accelerated damage by a microjet impingement mechanism, as illustrated in Figure 2.3d. Eventually, the pits and secondary cracks intersect, and larger pieces of the surface become detached.