



**UNIVERSITI PUTRA MALAYSIA**

**WEAR PERFORMANCE OF CONCRETE MIXTURE PADDLES  
WITH HARDENED SURFACES.**

**CHIONG KUNG KWONG**

**FK 2003 46**



**WEAR PERFORMANCE OF CONCRETE MIXTURE PADDLES WITH  
HARDENED SURFACES.**

**By**

**CHIONG KUNG KWONG**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,  
in Fulfillment of the Requirements for the Degree of Master of Science**

**August 2003**



Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

**WEAR PERFORMANCE OF CONCRETE MIXTURE PADDLES WITH HARDENED SURFACES.**

By

**Chiong Kung Kwong**

**August 2003**

**Chairman : Associate Professor Yousif A. Khalid, PhD.**

**Faculty : Engineering.**

Throughout this investigation, paddles from the SIMEM concrete mixer plant were selected as the subject for this wear analysis. The numbers of paddles studied are twenty. The performance and wear progress of the paddles were monitored periodically. In this project, six types of hard facing alloy were welded onto the same base metal, cast manganese materials. Hard surfacing is an effective method of modifying the surface properties without changing the whole materials of the paddle. These hard-facing alloys (severe wear resistant and moderate impact resistance characteristics) were welded onto the surfaces and edges of each paddle respectively (each hard facing alloys on three paddles). These welds were as cross lines of 20 mm apart all over the top surface of each paddle and full weld on the front side edges for maximum wear protection. Each weld bead deposited is 3 to 4mm thick and 5 to 6mm wide.



Two paddles were selected without any hard facing protective layers in this analysis as a reference purpose. Hard facing alloys used in this research are high Chromium high Carbon alloys (Paddles A1, A2, A3, A4, A5, A6, A7, A9, A11), Complex Chromium Carbide alloys with Boron (Paddles B1, B2, B3, B4, B5 and B6) and Tungsten Carbide material on paddle B7, B9 and B11. The main parameters measured were the side dimensions loss, thickness loss, volume loss and mass loss. Data collection was collected on a monthly basis in order to obtain higher accuracy. Two sets of paddles were used for each type of hard facing. As one set is in the measuring stage, the next set is fitted in the concrete mixer.

The results of the project show that cast manganese materials can be surfaced with various hard facing alloys to modify the surface layers characteristics. The results show that the front dimension loss is the determining factors which decide on the usability of the paddle. Other parameters such as mass loss, volume loss and thickness loss did not have any direct influence on the usability of the paddles. The results obtained from side dimension loss show that there is an increase in the service life of the mixer paddle by 1.45 times of paddle A3, 1.40 times of paddle A4 and 1.43 times of paddle A9 as compare to the reference paddle A10. On the other hand, the increase of service life of the mixer paddle B3 was 2.00 times, paddle B4 was 1.46 times and paddle B9 was 1.01 times when compare with reference paddle B10.

The finding on the front edge materials loss show that tungsten carbide hard facing alloys have lowest performance compared to other hard facing alloy. The main reason is that tungsten carbide is too brittle to be applied on the side edges of the mixer paddle. On the other hand, complex chromium carbide alloys with boron

have double service life of the paddle as compared to the reference paddle. Chromium carbides hard facing alloy have 40 to 45% of service life improvement.

The overall result shows that hardest hard facing alloy is not the most suitable protective layer for the front edge but it has good abrasion resistance property when applied on the paddle surface. The chromium carbide hard facing alloys show better wear resistance property for front edge protection compared to tungsten carbide alloys but not on paddle surface. Complex chromium carbide alloys gave the best desirable performance in this analysis.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia  
sebagai memenuhi keperluan untuk Ijazah Master Sains

**TINGKAH LAKU PENDAYUNG KONKRIT DENGAN Pengerasan  
PERMUKAAN**

**Oleh**

**Chiong Kung Kwong**

**Ogos 2003**

**Pengerusi : Profesor Madya Yousif A. Khalid, PhD**

**Fakulti : Kejuruteraan**

Dalam siasatan ini, pendayung konkrit dari kilang pembancuh SIMEM telah dipilih sebagai subjek dalam analisis kehausan. Jumlah pendayung yang dikaji adalah dua puluh keping. Tingkah laku dan perkembangan kehausan pendayung telah diikuti dari semasa ke semasa. Dalam projek ini, enam jenis keluli keras muka telah dikimpal keatas asas logam yang sama iaitu mangan acuan. Kimpalan keluli keras muka adalah cara berkesan untuk mengubah ciri-ciri sesuatu permukaan tanpa menukar keseluruhan bahan pendayung tersebut. Keluli keras muka ini (dengan sifat-sifat tahan kehausan yang tinggi dan tahan hentaman yang sederhana) telah dikimpal keatas permukaan and tepi setiap pendayung masing-masing (setiap jenis keluli keras muka dikimpal keatas tiga pendayung. Kimpalan ini adalah berbentuk petak dengan jarak di antara setiap baris kimpalan sebanyak 20mm dan kimpalan penuh pada tepi pendayung untuk perlindungan maksimum. Setiap garis kimpalan yang dikimpal adalah berbentuk 3 ke 4 mm tinggi dan 5 ke 6 mm lebar.

Dua pendayung tanpa sebarang perlindungan keluli keras muka telah dipilih sebagai pendayung rujukan untuk tujuan perbandingan. Jenis keluli keras muka yang digunakan dalam penyelidikan ini adalah dari jenis kromium tinggi karbon tinggi (pendayung A1, A2, A3, A4, A5, A6, A7, A9 dan A10), kromium kompleks dengan tambahan boron pada pendayung B1, B2, B3, B4, B5 dan B6 dan jenis tungsten karbid pada pendayung B7, B9 dan B11. Parameter-parameter utama yang diukur adalah kecutan dimensi sisi, kekurangan ketebalan, kehilangan isipadu dan kehilangan jisim. Untuk memperolehi kejituan data, data-data dikumpul pada selang masa setiap bulan. Dua set pendayung telah dipilih untuk keluli muka keras supaya semasa satu set dalam process pengukuran, satu set yang lain dipasang dalam pencampur konkrit.

Projek ini menunjukkan bahawa mangan acuan boleh dikimpal dengan pelbagai keluli keras muka untuk mengubah cirri-ciri permukaannya. Data yang dikumpul dianalisis dan keputusan menunjukkan kehausan dimensi sisi depan adalah factor utama yang menentukan kebolehan-gunaan pendayung. Parameter lain seperti kehilangan jisim, kehilangan isipadu dan kehilangan ketebalan tidak memberi kesan secara langsung keatas kebolehan-gunaan pendayung. Keputusan yang diperolehi dari kehilangan dimensi sisi menunjukkan penokokan kitar servis sebanyak 1.45 kali untuk pendayung A3, 1.40 kali untuk pendayung A4 dan sebanyak 1.43 kali untuk pendayung A9. Sementara kitar servis menambah sehingga 2.00 kali untuk pendayung B3, 1.46 kali untuk pendayung B4 dan 1.01 untuk pendayung B9.

Keputusan dari kehilangan sisi hadapan menunjukkan bahawa keluli muka keras jenis tungsten karbid mempunyai tingkah laku paling lemah berbanding

dengan keluli keras muka yang lain. Sebab utama adalah tungsten karbid terlalu rapuh untuk digunakan pada sisi depan pendayung. Sementara itu, kromium kompleks dengan boron menunjukkan penambahan sebanyak 2 kali ganda berbanding dengan pendayung rujukan. Dan pendayung yang dikimpal dengan keluli keras muka kromium karbid menunjukkan penambahan kitar servis antara 40% hingga 45%.

Keputusan keseluruhan menunjukkan bahawa keluli keras muka yang terkeras adalah tidak sesuai untuk digunakan sebagai perlindungan sisi depan tetapi menunjukkan kebolehan menegurangkan kehausan yang baik pada permukaan pendayung. Sementara itu, keluli keras muka jenis kromium karbid menunjukkan kebolehan menghalang kehausan dimensi sisi depan yang baik berbanding dengan keluli tungsten karbid. Keseluruhannya, kromium karbid Kompleks menyebarkan tingkah laku yang paling memuaskan dalam analisis ini.



## **ACKNOWLEDGEMENT**

First of all, I would like express my special appreciation to the chairman of the supervisory committee Associate Professor Dr. Yousif A. Khalid for his invaluable supervision, constructive guidance, advice, comments, ideas and patients throughout the duration of my project. I also like to thank you the members of the supervisory committee, Professor Ir. Dr. Barkawi Bin Sahari and Dr. Wong Shaw Voon for their guidance and comments.

I also like to express my appreciation to the staff from the Mechanical Engineering Department, UPM especially Haji Shaarani, Mr. Mohd Rashid and Mrs. Mahayon for their assistance on the borrowing of lab measuring tools.

I also wish to thank Mr. Ng Kok Chin (Deputy General Manager) from Buildcon Concrete Sdn Bhd who has given the permission to conduct this investigation in his batching plant. I am also grateful to the technical staffs from Buildcon Concrete who extent their assistance in the assemble and disassemble of the mixer paddle periodically throughout the investigation.

Last but not least, I also like to thank the management and staff of KTS Trading Sdn Bhd, VAUTID-VERSCHLEISS-TECHNIK GmbH & Co, Germany and Thermadyne S.E.A. Sdn Bhd for their information on the wear resistance products and its application. Finally, I wish to thank those who have been given me direct and indirect assistance and advice to make this thesis possible.



# TABLE OF CONTENTS

	<b>Page</b>
ABSTRACT	ii
ABSTRAK	v
ACKNOWLEDGEMENTS	viii
APPROVAL	ix
APPROVAL	x
DECLARATION	xi
LIST OF TABLES	xv
LIST OF FIGURES	xvi

## CHAPTER.

<b>1</b>	<b>INTRODUCTION.</b>	
1.1	General.	1
1.2	Existing Wear Problems.	2
1.3	Objectives.	2
1.4	Thesis Layout.	3
<b>2</b>	<b>LITERATURE REVIEW.</b>	
2.1	Introduction.	4
2.2	Wear Definition and Wear Processes Classification.	4
2.3	Types of Wear.	5
2.3.1	Abrasive Wear.	6
2.3.2	Erosive Wear.	10
2.3.3	Adhesive Wear.	13
2.3.4	Impact Wear.	14
2.3.5	Fatigue Wear.	15
2.3.6	Corrosive Wear.	17
2.3.7	Cavitation Wear.	19
2.3.8	Other Types of Wear.	20
2.4	Wear Variables and Control.	21
2.4.1	Effect of Wear Rate by Wear Variables.	22
2.4.2	Particle Properties.	26
2.5	Quantitative Analysis of Wear.	33
2.6	Methods to Resist Wear.	36
2.6.1	Carburising.	37
2.6.2	Nitriding.	37
2.6.3	Tufftriding.	38
2.6.4	Cyaniding and Carbonitriding.	38
2.6.5	Siliconising.	39
2.6.6	Boronising.	39
2.6.7	Electroplating.	39
2.6.8	Anodizing.	40
2.6.9	Metal Spraying.	40
2.6.10	Induction Hardening.	41
2.6.11	Flame Hardening.	41



2.6.12	Hard Facing.	42
2.7	Hard Facing Materials and Application.	43
2.7.1	Hard Facing Mis-conception.	43
2.7.2	Type of Hard facing Materials.	45
2.7.3	Hard facing Welding Process.	46
2.7.4	Preparation for Hard Facing Depositions.	49
2.8	Discussion.	50
<b>3.</b>	<b>METHODOLOGY.</b>	
3.1	Introduction.	52
3.2	Methodology Sequence Flow.	55
3.3	Problems Analysis.	57
3.3.1	Wear Media.	57
3.3.2	Center Paddle Wear Condition.	57
3.3.3	Paddle Preparation.	59
3.3.4	Hard facing alloys Selection.	59
3.3.5	Paddles Arrangement and Numbering.	60
3.3.6	Wear Protection Pattern Design.	62
3.4	Data Collection.	64
3.4.1	Measurement Point of the Paddle.	64
3.4.2	Data Collection Measuring Tools.	67
3.4.3	Data Collection Procedures.	68
3.4.4	Data Collection Table.	69
3.4.5	Data Collection Schedule.	69
3.4.6	Data Collection Points.	70
3.5	Discussion.	71
<b>4.</b>	<b>EXPERIMENTAL WORK.</b>	
4.1	Introduction.	72
4.2	Experimental set-up.	72
4.3	Hard facing alloys Welding procedure.	77
4.3.1	Surface Preparation.	78
4.3.2	Preheat and Interpass Temperature.	79
4.3.3	Critical Heat Input for Austenite Manganese Steel.	79
4.3.4	Welding of Hard facing alloys.	80
4.3.5	Welding Current Effect on Weld Deposit and Base Metal.	80
4.3.6	Cooling Rate Control.	81
4.3.7	Welds Surface Finishing.	81
4.4	Paddle Installation and Handling.	81
4.5	Discussion.	82
<b>5.</b>	<b>RESULTS AND DISCUSSION.</b>	
5.1	Introduction.	83
5.2	Effect of Paddle Location.	83
5.3	Side Dimension Loss.	88
5.4	Thickness Loss.	102
5.5	Mass Loss.	108
5.6	Volume Loss.	111
5.7	Hard facing Materials Type Effects.	113
5.7.1	Similar Hard facing Materials Type.	114

5.7.2	Different Hard facing Materials Effect.	115
5.8	Discussion.	118
<b>6.</b>	<b>CONCLUSION AND RECOMMENDATIONS</b>	
6.1	Introduction.	121
6.2	Mass Loss.	122
6.3	Volume Loss.	122
6.4	Dimensions Loss.	123
6.5	Overall Conclusions.	123
6.6	Recommendation for Further Study.	125
	<b>REFERENCES/BIBLIOGRAPHY.</b>	126
	<b>APPENDICES.</b>	129
	A Thickness loss on line C (mm).	130
	B Side dimensions loss (mm).	143
	<b>BIODATA OF THE AUTHOR.</b>	156

## LIST OF TABLES

TABLE		Page
Table 2.1	Wear Variables.	21
Table 2.2	Type of hard coating processes and their respective surface characteristics.	36
Table 3.1	Chemical composition of hard facing alloys.	60
Table 3.2	Classification of paddle. (Group A and Group B).	62
Table 3.3	Data collection table.	65
Table 3.4	Thickness measurement point on each line. (Line A to Line F).	66
Table 3.5	Side dimension measuring point on each dimension (FP, LP and RP).	66
Table 3.6	Schedule for data collection.	70
Table 5.1	Average side dimension loss (mm)for paddle A3, A4, A9, A10, B3, B4, B9 and B10.	98
Table 5.2	Life cycle comparison with reference paddle (Group A and Group B).	100
Table 6.1	Life cycle different for each individual paddle.	124

## LIST OF FIGURES

FIGURES		Page
Fig 2.1	Illustration of the differences between (a) two-body abrasive wear and (b) three-body abrasive wear.	6
Fig 2.2	Mechanisms of abrasive wear: micro-cutting, fracture, fatigue and grain pull-out.	7
Fig 2.3	Relative wear resistance (proportional to 1/wear rate) for pure metals (open circles) and heat-treated and work-hardened steels (solid circles) under conditions of two-body abrasion, plotted against indentation hardness.	8
Fig 2.4	Abrasive wear model for brittle material.	9
Fig 2.5	Relationship between abrasive wear resistance and fracture toughness of Ytria-doped zirconium oxide.	9
Fig 2.6	(a) Illustration of erosive wear (b) forces act on particle contact with solid surface.	10
Fig 2.7	Possible mechanisms of erosion; a) abrasion at low impact angles, b) surface fatigue during low speed, high impingement angle impact, c) brittle fracture or multiple plastic deformation during medium speed, large impingement angle impact, d) surface melting at high impact speeds, e) macroscopic erosion with secondary effects, f) crystal lattice degradation from impact by atoms.	11
Fig 2.8	Impingement angle of a particle causing erosion of surface.	12
Fig 2.9	Schematic representation of the effect of impingement angle on wear rates of ductile and brittle materials.	12
Fig 2.10	Metal surfaces after erosion by hard particles: (a) mild Steel eroded at 308 impact angle and 55 ms <sup>-1</sup> by angular silicon carbide particles; (b) aluminium eroded at 908 by spherical glass beads at 60 ms <sup>-1</sup> .	13
Fig 2.11	Enlarged view of two rubbing surfaces.	14
Fig 2.12	Schematic illustration of the mechanisms of impact wear.	15
Fig 2.13	Appearance of typical surface fatigue failures in their early stage. (a) Surface crack; (b) Subsurface crack.	15

Fig 2.14	Schematic diagram showing mechanism of crack propagation in fatigue wear.	16
Fig 2.15	Models of interaction between a corrosive agent and a worn surface.	18
Fig 2.16	Cavitation mechanism.	20
Fig 2.17	Relative volume wear rate plotted against the ratio of the hardness of the abrasive to that of the surface ( $H_a/H_s$ ) for the range of metallic and ceramic materials and abrasive particles, for two-body abrasion.	28
Fig 2.18	Illustration of contact between a grit particle under normal load and a plane surface. (a) If $H_a$ is greater than $\sim 1.2 H_s$ , the particle will indent the surface; (b) if $H_a$ is less than $\sim 1.2 H_s$ , plastic flow will occur in the particle, which will be blunted.	28
Fig 2.19	Comparison of indentation hardness (measured by the Vickers or Knoop method) with Mohs hardness number for ten standard minerals.	29
Fig 2.20	Effect of abrasive particle hardness on wear of steel.	29
Fig 2.21	SEM micrographs of silica particles; (a) rounded and (b) angular.	31
Fig 2.22	Wear rates of copper under conditions of two-body and three-body abrasion and erosion due to silicon carbide particles of different sizes.	32
Fig 2.23	Hardness compare to wear resistance.	44
Fig 2.24	Comparison of hard surfacing deposits : Hardness vs. Abrasion Resistance. (Microschematic cross sections).	45
Fig 2.25	An example of how to produce sweating.	47
Fig 2.26	Schematic representation of Shield Metal Arc Welding.	48
Fig 2.27	Schematic representation of Flux Cored Arc Welding.	48
Fig 3.1	The concrete mixer external view.	53
Fig 3.2	The concrete mixer internal projection view.	54
Fig 3.3	Schematic plan view of the paddle layout inside concrete mixer.	54
Fig 3.4	Methodology flow chart.	56

Fig 3.5	The centre paddle profile (a) before wear and (b) after wear.	58
Fig 3.6	Wear resistance weld pattern layout on center paddle.	63
Fig 3.7	Measuring point layout on center paddle.	64
Fig 3.8	Measurement tools for data collection.(a) caliper dial gauge, (b) weighting machine (c) measurement cylinder.	67
Fig 4.1	Wear resistance weld pattern template (a) Horizontal layout (b) Vertical layout.	73
Fig 4.2	Metal Stand.	74
Fig 4.3	Template for thickness measurement.	75
Fig 4.4	Side dimension measuring rigs.	75
Fig 4.5	Volume measurement tools; (a) measuring container (b) measuring cylinder.	76
Fig 4.6	Time/temperature reaction of Manganese Steel.	77
Fig 5.1	Schematic layout of paddle location inside the concrete mixer.	84
Fig 5.2	Weight loss (kg) for paddle A1 to A6 on shaft no. 1.	84
Fig 5.3	Weight loss (kg) for paddle A7, A9, A10 and A11 on shaft no. 2.	85
Fig 5.4	Volume loss (cm) for paddle A1 to A6 on shaft no. 1.	87
Fig 5.5	Volume loss (cm) for paddle A7, A9, A10 and A11 on shaft no. 2.	87
Fig 5.6	Location of re-arrange side dimension point number 1 to 64.	89
Fig 5.7	Side dimension loss (mm) for paddle A3.	90
Fig 5.8	Side dimension loss (mm) for paddle A4.	91
Fig 5.9	Side dimension loss (mm) for paddle A9.	92
Fig 5.10	Side dimension loss (mm) for paddle A10.	93
Fig 5.11	Side dimension loss (mm) for paddle B3.	94



Fig 5.12	Side dimension loss (mm) for paddle B4.	95
Fig 5.13	Side dimension loss (mm) for paddle B9.	96
Fig 5.14	Side dimension loss (mm) for paddle B10.	97
Fig 5.15	Side dimension average loss (mm) against various product output for paddle A3, A4, A9, A10, B3, B4, B9 and B10.	99
Fig 5.16	Predicted life cycle of each paddles.	100
Fig 5.17	Distribution of thickness measurement point on paddle according to line and point number.	102
Fig 5.18	Line C (point 2-19) thickness loss (mm) for paddle A3.	103
Fig 5.19	Line C (point 2-19) thickness loss (mm) for paddle A4.	103
Fig 5.20	Line C (point 2-19) thickness loss (mm) for paddle A9.	104
Fig 5.21	Line C (point 2-19) thickness loss (mm) for paddle A10.	104
Fig 5.22	Line C (point 2-19) thickness loss (mm) for paddle B3.	105
Fig 5.23	Line C (point 2-19) thickness loss (mm) for paddle B4.	105
Fig 5.24	Line C (point 2-19) thickness loss (mm) for paddle B9.	106
Fig 5.25	Line C (point 2-19) thickness loss (mm) for paddle B10.	106
Fig 5.26	Weight loss (kg) for various paddle of group A.	109
Fig 5.27	Weight loss (kg) for various paddle of group B.	109
Fig 5.28	Weight loss (kg) for various paddle of group A and group B.	110
Fig 5.29	Volume loss (cm) for various paddle of group A and group B.	111
Fig 5.30	Volume loss (cm) for various paddle of group A.	112
Fig 5.31	Volume loss (cm) for various paddle of group B.	112
Fig 5.32	The wear profile of paddle A3, A4, A9 and A10 for various output.	113
Fig 5.33	The wear profile of paddle B3, B4, B9 and B10 for various output.	116

# CHAPTER 1

## INTRODUCTION

### 1.1 General.

Wear occur whenever there is undesirable materials loss on any surfaces. Results from the undesirable materials loss may be due to different types of wear mechanisms. These wears are preventable if the cause of the wear is studied and analysed carefully. Each year a huge amount of resources are wasted due to improper wear prevention measurement and seriousness in reducing possible wear mechanisms. The selection of suitable hard facing materials is very important in order to achieve the desire service life cycle of a wear components.

Wear exist in various industries and the concentration in this investigation is on a SIMEM concrete batching plant. Common wears presence in the batching plant are erosion and abrasion type of wear. Components that are facing the wear problems for example are the shovel bucket, conveying belt and roller, measuring bin, inlet chute, center mixer paddle, end scrapping paddle, mixer wall liner, discharge chute etc. This research concentrated on evaluating the wear of the center mixer paddles. The wear rate of these mixer paddles was observed and the paddles were found to be replaced every 25,000m<sup>3</sup> to 30,000m<sup>3</sup> of the production output. This practice leads to frequent replacement of mixer paddles every 2 to 3 months.

## **1.2 Existing Wear Problems.**

The thought is prevalent that it is easier to replace the part when it wears rather than to provide adequate solution to prolonging the service life of these wear components. The paddles at the center of the mixer have been selected for investigation due to the wear rate on these mixer paddles are the highest among the others. The proposed investigation is to conduct a scientific analysis to determine the wear performance of mixer paddles clad with various hard facing alloys. In this investigation, various parameters are determined to enable the adequate wear data can be collected from time to time. Six hard facing alloys are selected for analysis in the investigation.

## **1.3 Objectives.**

The main objectives of this investigation are outline as follows;-

1. To investigate the effective service life of each paddles clad with various hard facing alloys.
2. To determine the most suitable type of hard facing alloys which provide the optimum protecting layers for the mixer paddles.
3. To compare the results obtain for each individual mixer paddles with hard facing cladding with the reference paddle without hard facing cladding.

#### **1.4 Thesis Layout.**

The thesis is divided into six chapters. In this thesis, a review of literatures is presented in chapter 2 which discussed about the previous research work and theories development on wear resistance alloys. In chapter 3, methodology used for this experimental (i.e. measuring rigs, selection of parameters for analysis and table for recording data) are discussed. Chapter 4 is about the experimental work (i.e. rigs design and welding procedures for hard facing alloys are outlined in this chapter). While chapter 5 discussed about the results obtained from this experimental work and are interpreted into useful graphs and statements. Finally, chapter 6 is about the conclusion of this research and recommendation for future study.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction.

In this chapter, literature related to type of wears, wear mechanisms, wear variables, effect of wear rate by wear variables, wear particles, methods to resist wear and hard facing methodology will be discussed. In the first section, types of wear and their mechanisms is explored. Then, the wear variables and their effect on wear rate and the properties of wear particles is discussed. It will then be followed by the discussion on methodology to resist wear. The final discussion is concentrated on the hard facing materials and their application to resist wear.

#### 2.2 Wear Definition and Wear Processes Classification.

Several research has been carried out to define wear and its processes. Wear is generally defined as “unwanted removal of material by chemical or mechanical action”[1]. Another factor that affecting the wear is the temperature of the wear component. Such definition is not precise since plastic flow may occur, clearances become larger, and, for all practical purposes, wear has occurred even though no material has been removed. However, the point of view that all definitions are approximations could be adopted, and some inaccuracies will occur. With this point of view in mind, the latter definition appears to be adequate. [1]

There have been many attempts to classify wear processes. The conventional method is called as the “process” descriptions where the classification is based upon a physical description of the process: abrasion, adhesion, deformation, fretting, thermal, etc. On the other hand, wear can also be classified by the type of materials, that is, metal versus nonmetal or abrasive, metal versus metal, or metal versus liquid or vapor. In addition, the distinction is made between lubricated or non-lubricated wear [1].

The advantage of this classification is that it confirms to the definition of wear as a removal process. Even more important, it allows the establishment of the fundamental quantities to each wear process. The difficulty with this classification is that it is cumbersome from a practical point of view.

### **2.3 Types of Wear.**

Different types of wear has been described and categorized by various investigators throughout the years [1,2,3,4,5,10,14]. It is generally held that the most common types of wear are (1) adhesive, (2) abrasive, (3) corrosive, (4) erosive, (5) cavitation, (6) fatigue (7) fretting and (8) impact [2]. It is important, however, to recognize that, in wear, material is removed from surfaces permanently. The form of that removal can take place in different manners according to the mechanisms operating in the system. Of the aforementioned wear mechanisms, one or more wear factors may be operating in one particular mechanical system [3].