VARIATION OF TWO BODY ABRASIVE WEAR AND THREE BODY ABRASIVE WEAR IN AL (6063)

A Dissertation submitted
In partial fulfillment of the requirement For the Degree

MASTER OF TECHNOLOGY

In

MECHANICAL ENGINEERING

With specialization
In
"Production and Industrial Engineering"
By

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July, 2022

CERTIFICATE

It is certified that **RIYAN AHMAD** (Enrollment No. 2000100820) has carried out the research work presented in this dissertation entitled "**VARIATION OF TWO BODY ABRASIVE WEAR AND THREE BODY ABRASIVE WEAR IN AL (6063)"** for the award of **Master of Technology** from **Integral University, Lucknow** under our supervision. The dissertation embodies result of original work and studies are carried out by the student himself and the contents of the thesis do not form the basis for the award of any degree to the candidate or to any body else from this or any other university/Institution.

Dr. Mohd. Shadab Khan

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Date:

DECLARATION

I hereby declare that the dissertation titled "**VARIATION OF TWO BODY ABRASIVE WEAR AND THREE BODY ABRASIVE WEAR IN AL (6063)**" is an authentic record of the research work carriedout by me under the supervision of Dr. Mohd. Shadab Khan, Department of Mechanical Engineering, for the period from 2020 to 2022 at Integral University, Lucknow. No part of this dissertation has been presented elsewhere for any other degree or diploma earlier.

I declare that I have faithfully acknowledged and referred to the works of other researchers wherever their published works have been cited in the dissertation. I further certify that I have not willfully taken other's work, paragraph, text, data, results, tables, figures etc. reported in the journals, books, magazines, reports, dissertations, thesis,etc. or available at websites without their permission, and have not included those in this M.Tech. dissertation citing as my own work.

Date -

Signature -

Name -RIYAN AHMAD

Enrollment No-2000100820

ACKNOWLEDGEMENT

At this moment of accomplishment, I wish to pay my heartfelt gratitude and sincerest thanks homage to my guide, Dr. Mohd. Shadab Khan (Associate Professor),department of mechanical engineering, Integral University, Lucknow. This work would not have been possible without his able guidance, support, and encouragement. Under his guidance, I have successfully over come many difficulties and learned a lot. He used to review my work progress, give his valuable suggestions, and made correction. His unflinching courage and conviction will always inspire me, and I hope to continue to work on his noble thought.

I am also extremely indebted to Dr. P.K.Bharti (HOD), Mechanical Engineering Department, Integral University, Lucknow for providing necessary infrastructure and resources to accomplish research work. I warmly thank to Er. Faizan Hasan and Er.Abhishek Dwivedi for their valuable advice and encouraging me at regular interval. I would also like to thank Mr. Thomas, workshop instructor for his support during my entire work.

Last but not the least, it goes without saying that I am indebted to a number of friends and well-wisher specially who have extended their co-operation and help during the work.

RIYAN AHMAD

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ABSTRACT

This study aims to correlate the abrasive wear performance with mechanical properties, considering AA6063 Al-Mg-Si alloy as the model material. The selected alloy specimens are subjected to artificial ageing at 150 °C for an ageing duration ranging from 1 to 672 h, covering severely under-aged (SUA) to peak-aged (PA) to severely over-aged (SOA) states. Apart from the hardness and tensile properties, two-body abrasive wear properties are also evaluated for differently aged alloys in terms of wear rate, coefficient of friction, and roughness of the abraded surfaces. Furthermore, the generated wear debris, surface, and sub- surface of the abraded specimens are critically examined to reveal the micro-mechanisms of abrasion. The lowest amount of wear rate is observed for a PA alloy with maximum hardness, while the OA alloy exhibits a slightly lower wear rate than the UA alloy at a similar level of hardness. Statistical analyses of wear rate and various mechanical properties of all heat-treated alloys establish a strong negative linear correlation between the wear rate and hardness, yield strength, tensile strength, and strength coefficient; whereas, a positive linear correlation with the strain hardening exponent. Relationships between wear rate and different roughness parameters are also discussed. Under the investigated wear condition, the aged alloys endure significant plastic deformation; micro-plowing, micro-cutting, and delamination are found to be the predominant mechanisms during abrasion.

CHAPTER-1

INTRODUCTION

1. Introduction

The emission of greenhouse gases and global warming are the potential threats to the sustainable development of the human race. Hence, from the last few decades, continuous efforts are being made to cut down the fuel consumption and the emission rate of greenhouse gases in transportation sectors; this has led to the emergence of light alloys, *e.g.*, aluminium, magnesium, and titanium alloys, for structural and rotating components in automobile and aerospace industries [1–4]. Age-hardenable aluminium alloys are the most preferred ones in this field due to their excellent ageing response, high specific strength, and good corrosion resistance [5–8]. Al-Mg-Si alloys, especially the low Cu content members, are currently the economical ones employed for these applications [9]. The progress of age-hardening depends on the amount of added trace elements which can precipitate as per the kinetics of the alloy [10,11]. Additionally, Al-Mg-Si alloys undergo several microstructural alterations during the process of ageing; such microstructural changes have profound effects on the mechanical properties [12].

One of the significant drawbacks of Al alloys in the transportation sectors is their poor wear performance [13,14]. Several investigators [15–20] have attempted to understand the wear behavior of age-hardenable Al-alloys. Reports related to the wear of Al-alloys are primarily directed at understanding the adhesive wear behavior [15,16], although the frequently encountered mode of wear during industrial applications is abrasion. Wear causes damage to the material surface when it comes in contact with other materials like solid, liquid, and gas [21]. Abrasive wear removes the material on the surface in the form of debris when a hard surface slides against a softer surface under normal loading conditions [22]. Earlier investigations related to the abrasive wear behavior of Al-Mg-Si are primarily focused on the effect of Si content [17] and the temperature of ageing [16]. Kaushik et al. [23,24] have investigated the influence of applied pressure and the abrasive grit size on the high-stress abrasive wear resistance of hybrid 6082 Al-Mg-Si composites and compared them with the unreinforced alloy in both as-cast as well as in T6 conditions. The authors have observed that the abrasive wear resistance is the highest under lower applied pressures and grit size and gradually decreases with increasing the same for both as-cast and the aged conditions. At the same time, comparatively, the aged specimen has shown higher abrasion resistance at any particular applied pressure and grit sizes.

However, from the tribological perspective, besides understanding the type of wear encountered, wear behavior, and their mechanisms, studying the correlation between the wear and mechanical properties are also equally important in enhancing the entire life cycle of mechanical components by defining the abrasive wear losses [5]. Few earlier researchers have attempted to correlate the abrasive wear performance with mechanical properties of materials. Baldoni et al. [25] have examined the abrasive wear resistance of three different classes of cutting tool materials (brittle, brittle-ductile, and ductile) in correlation with the hardness and fracture toughness. Wear by fracture is dominant for the brittle materials, which indicates the abrasive wear resistance depends on the fracture toughness of the material. For brittle-ductile material like cemented carbide, wear can cause a large amount of plastic deformation, which is less prone to fracture toughness; whereas, for ductile metals, low hardness and fracture toughness results in less abrasive wear resistance. Jha et al. [26] have studied the correlation between the hardness, microstructure, and tensile properties of high-strength low alloy steel. These researchers have optimized the microstructural features and other mechanical properties to achieve superior wear characteristics and suggested that apart from hardness, ductility is also equally important in defining the abrasive wear performance of the steel. In a different study, Das et al. [27] have investigated the wear resistance of the aluminium alloys and hard particle composites. This research group has established an equation to define the wear rate as a function of hardness, strength, and young's modulus and has suggested that the wear resistance is being entirely dependent on hardness, even though other mechanical properties like strength and elongation have a minor influence on it.

One can find a gap in the existing literature regarding the correlation between the abrasive wear characteristics and the mechanical properties of materials in contact. This study focuses on understanding two-body abrasive wear behavior and its correlation with the mechanical properties of artificially aged

AA6063 alloy. Apart from establishing the hardness and tensile properties, the two-body abrasive wear behavior is examined in terms of wear rate, coefficient of friction, and roughness of the abraded surfaces. The operative wear mechanisms are identified by characterizing the abrasive paper, generated debris, surfaces, and sub-surfaces of abraded specimens using SEM and EDS apart from surface topography using a 3D optical profilometer. Finally, an attempt to correlate the wear rate with mechanical properties and some roughness parameters is made for Al-Mg-Si alloy specimens subjected to different ageing conditions.

CHAPTER-2
REVIEW OF LITERATURE

REVIEW OF LITERATURE

- **Saurabh Kumar [1**] published three body abrasive wear behaviour on six aluminium alloys (AA1050, AA2014-T6, AA3003, AA5052, AA6061-T6 and AA6351-T6).Research shows abrasive wear increases with increase in load. Interaction of abrasive wear rate with hardness, ultimate strength and percentage elongation at break are reported. Wear mechanisms involved in material removal process were studied with the aid of optical microscope and scanning electron microscope (SEM).

- **Monil Salot [2]** This study focuses on the evaluation of abrasive wear resistance of Al-Si alloys with and without chromium oxide coating. It states that the wear resistance of Al-Si alloys increases with the increase in the amount of Si in the alloy.

- **Tadashi Ohtani [3]** Two-body wear and three-body abrasive wear test of katsura wood were carried out using abrasive paper and moving abrasive grains. it is reported that two-body abrasive wear is more affected by yield stress and surface microstructure, and three-body abrasive wear is more affected by the cutting action of moving abrasive grains.

- **A.P. Harsha [4**] Investigates the three-body abrasive wear behavior of polyaryletherketone composites.It includes the study the effect of reinforcement fibres, solid lubricants, mass of abrasives and load in three-body abrasive wear situations on various polyaryletherketone (PAEK) matrix. He inspected that fibre reinforcement is detrimental to the abrasive wear resistance of neat PAEK matrix. Scanning electron microscopy was used to detect worn surfaces and to know the functioning involved in it.

- **Mohd Shadab Khan [5]** conducted a research on Abrasive wear behavior of Silicon Polyethylene vinyl Acetate copolymer using a pin-on-disc arrangement. Load and angular speed are the two parameters which are taken into consideration .Results showed that the wear increases as the load and angular speed(rpm).

- **Mohd shadab Khan** [6] inspected the Abrasive wear behavior of Organopolysiloxane and concluded that the wear varies with applied load and and mechanical parameters .The wear increases with increasing load and angular speed.

- **N. Mohan [7**] investigates the Two-Body Abrasive Wear Behavior of Silicon Carbide Filled Glass Fabric-Epoxy Composites. The effect of silicon carbide (SiC) fillers inclusion on two-body abrasive wear behaviour of Glass Fabric - Epoxy (GE) composites was observed and results are examined. He states that the appreciably decrement in wear loss and specific wear rates were observed after introducing of SiC filler into GE composites.

- **Gaoqi Wang [8**] examined the Two-Body and Three-Body Wear Behavior of a Dental Fluorapatite Glass-Ceramic. Results obtained that good mechanical properties of fluorapatite glass-ceramic can be achieved by the sintering process. In both two-body and three-body modes, the fluorapatite glass-ceramic had a smaller friction coefficient and wear rate and caused less damage on antagonistic teeth than the feldspathic glass-ceramic.

- **Vishwas Mahesh [9]** performed research on two-body and three-body abrasive wear behavior of jute-natural rubber flexible green composite. The wear trend of the composites follows a similar pattern in the case of two- and three-body wear, the mechanisms governing the wear are found to be different. The morphology of the worn surface is studied with the aid of a scanning electron microscope.

- **M Singh, D. P Mondal , O. P Modi, A. K Jha[10]** "Two-body abrasive wear behaviour of aluminium alloy–sillimanite particle reinforced composite", In the present paper two-body abrasive wear behaviour of the cast aluminium alloy and aluminium alloy–10wt.% sillimanite particle composite has been studied at different applied loads and abrasive sizes for different sliding distances. It was noted that the wear rate decreased with sliding distance and approached to a stable value and increased with increase in abrasive size and applied load irrespective of the materials. It was interesting to note that at 25µm abrasive size, composite showed superior wear resistance to that of alloy but at 200µm abrasive size, the former one suffered from inferior wear resistance than the later one irrespective of applied load. In the intermediate abrasive size (100µm) the composite exhibited superior wear resistance than that of alloy at lower applied load, whereas at higher applied load the trend is reversed. These facts have been studied through wear surface, subsurface and wear debris analysis.

CHAPTER-3

EXPERIMENTAL PROCEDURE

EXPERIMENTAL PROCEDURES

Material

Experimentation

In this chapter, details of material used in the present investigation and its preparation has been described and the details of the experimentation on wear studies in the material of present investigation have been given.

In order to carry out the experimental work, the procedure is as follows.

(i) Fabrication of Pin on Disc
(ii) Specimen‘s Materials
(iii) Wear characterization

Fabrication of Pin on Disc

Numerous researches have been done in the field of abrasive wear. This work is also an experimental design in the field of abrasive wear Pin on Discvia a newly designed wear Pin on Disc. In view of the objective a set-up was needed to be designed which can calculate wear rate at different speed (rpm) of work piece with respect to the main frame (horizontal position).

The wear machine used for Pin on Disc wear properties was designed by **Prof. (Dr.) Zahir Hasan** and fabricated by **Dr. Mohd Shadab Khan.** A pin on disc wear test technique was adopted to test the wear behavior of specimens.

Wear rate and wear mass were Pin on Disc at different orientation of the specimen. The tests were conducted for seven different orientations namely **100 rpm , 150 rpm, 200 rpm .** The wear mass of above said specimen Pin on Disc test at a constant time of **2min (120 sec).**

The set-up has following different parts-:

(1)Controller (2)D.C Motor (3)Flange Coupling (4)Bearing (5)Main Frame (6)Frame(Angular) (7)Acrylic Sheet (8) Grinding Wheel (9) Specimen (10) Screw Jack (11) Load Cell (12) Angular Lever.

The designed setup is shown in the fig. 4.1 and 4.2

Experimental Setup of Wear Pin on Disc

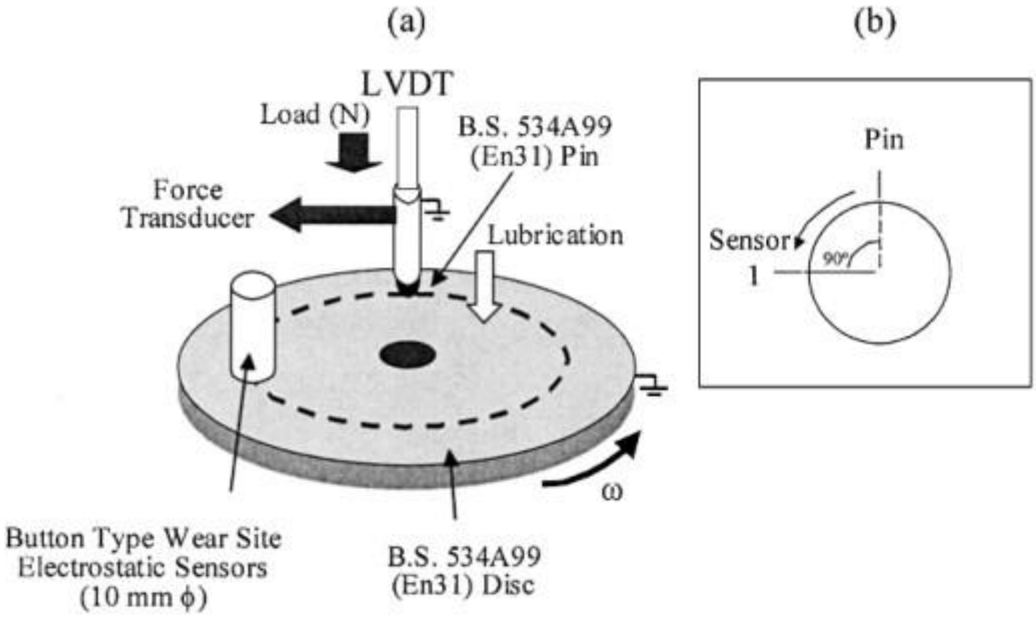


Fig- 4.1 Experimental Setup (Front View)

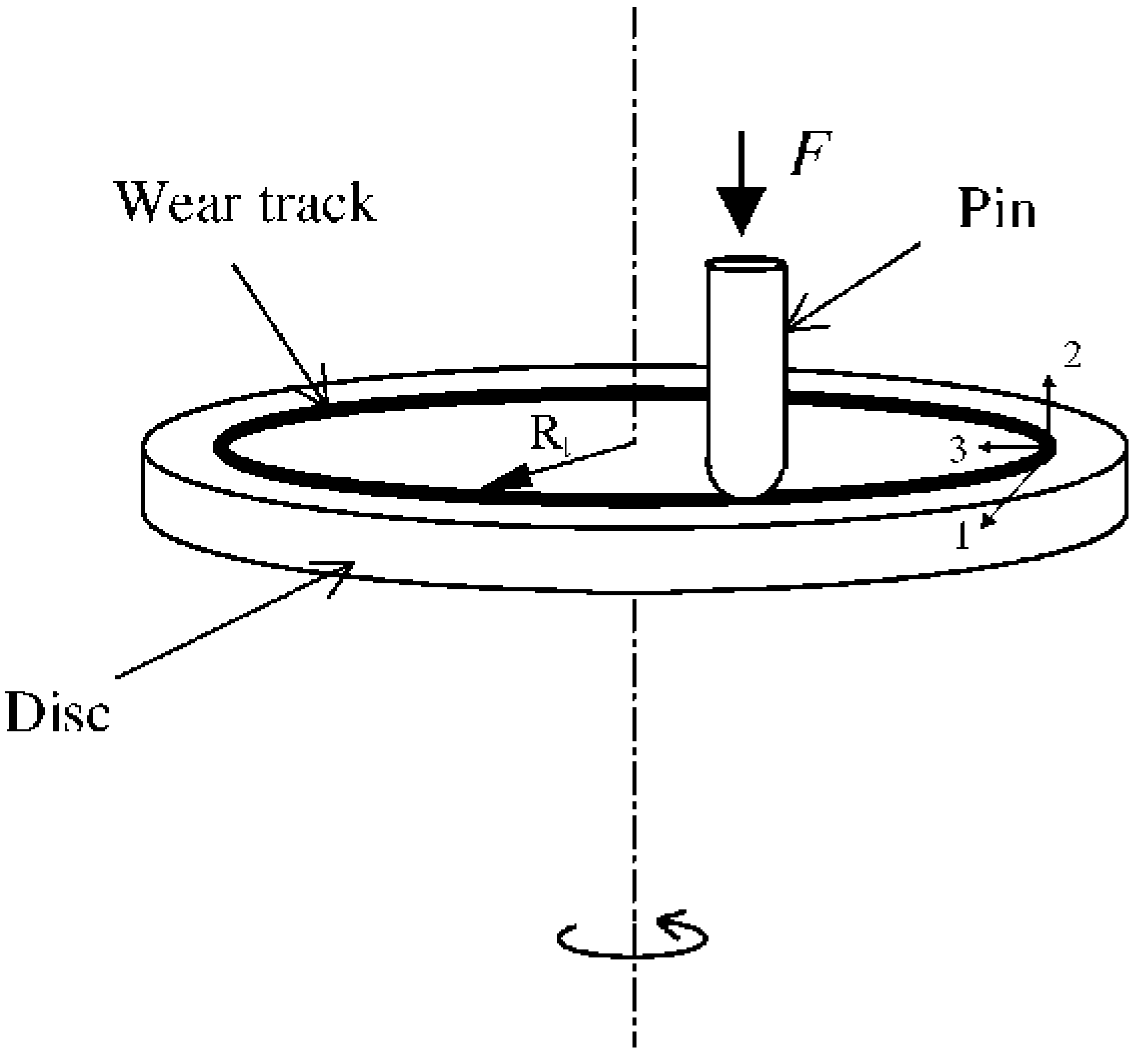


Fig- 4.1 Experimental Setup (Top View)

Working of Set-Up

The pin-on-disc sliding tests were conducted in the following manner. The pins, measuring 5 mm in diameter and 5 mm in length, were made of hardened bearing steel (AISI 52100) and polished to a surface roughness of Ra 0.05 micron. The disc measured 35 mm in diameter and 2.5 mm in thickness and was made of carburized steel. The three pins were secured to prevent them from rotating and were pressed against the toric sliding surface of the rotating disc at a position that was 20 mm in diameter from the center of the disc. Contact at the sliding interfaces was in the shape of lines under high Hertzian pressure of 700 MPa due to a normal force of 500 N, Lubrication was provided by an oil bath heated to 353 K. The sliding speed was varied in a range of 0 to 1 ms^{-1} for the tribological experiments and the sliding time was 60 minutes..

Description of the Parts of the Wear Pin on Disc

DC Motor

The D.C. Motor having following specifications:

Power – 1 H.P, Rotation – 1 rpm to 3000 rpm

Regulator of a direct current motor is used to regulate and control the speed of motor. It has ammeter to measure current and voltmeter to measure volt attached to it. The characteristic features of regulator are:

Regulated Voltage – 0-260 V , Least Count – 2V The technical parameters of Ammeter are:
Current Range: 0 – 10 ampere
Least Count: o.4 ampere
The technical parameters of Voltmeter are: Voltage Range : o – 300V , Least Count: 20 V

Frame

The main frame is just like chassis to the engine ,it hold all the parts such as motor , shaft , coupling , screw jack and all its related attachment. The dimensions of the main frame are as follows:

Length – 105 cm , Width – 21 cm Dimensions of angular frame are as follows :

Length – 115 cm Width – 35 cm

Acrylic Disc

The acrylic disc is used as a fixture of specimen holder. The disc is drilled with multiple holes at different radius. This is done so that every specimen gets fresh abrasive surface. This makes synchronization in the calculation of wear rate of the entire specimen. The dimensions of the acrylic disc are as follows:

Diameter – 26 cm

Radius of the first hole (r1) = 8 cm Radius of the second hole (r2) = 16 cm Radius of the third hole (r3) = 24 cm

Grinding Wheel

A grinding wheel used in the design as an abrasive media to produce abrasive wear on the specimen selected. The dimensions of the grinding disc are as follows:

Diameter – 20 cm

Speed Of Grinding Wheel

Generally all the abrasive processes are performed with the wheel speed in between the range of 300 to 2000 rpm with the maximum work speed from 0 to 60 m/min.

Shaft

Two shafts were used , the first shaft connects motor to the abrasive disc and second shaft connects accrylic disc to screw jack. Load is applied with help of second shaft , it pushes the specimen against the rotating abrasive disc.

The dimensions of the shaft are as follows :

Diameter – 25mm Length (First) – 20 cm Length (Second) – 30 cm

Screw Jack

The screw jack is used to apply the load gradually turn wise. The screw jack is connected to the shaft, which is further connected to the acrylic disc and specimen fixture.As the screw jack unfolds, it pushes the shaft and acrylic sheet which holds the specimen against the abrasive disc.

Weighing Machine

The weighing machine used in the design to calculate mass loss (wear) of the specimen. The weighing machine used had following parameters:

Least Count – 0.001gm Max. Capacity – 5 Kg

Diagram of Experimental Setup

Fig-4.2 Experimental Setup –With Controller

Fig-4.3 Experimental setup (Front View)

Fig-4.4 Experimental set up (Top View)

Fig-4.6 Specimen

CHAPTER-4

RESULT AND DISCUSSION

RESULTS AND DISCUSSION

Table 1: Variation in Two-body and Three Abrasive Wear of Aluminiumalloy(6063) at 5N Load

SET NO.1(100rpm,5N)					
TEST NO.	MASS BEFORE TEST (gm)	MASS AFTER TEST (TWO BODY test) (gm)	Wear by mass (Two BODY WEAR) gm	Mass after three body test (gm)	Wear by Mass(three Body wear
1.	54.921	54.458	0.463	54.344	0.114
2.	55.139	54.711	0.428	54.529	0.182
3.	53.673	53.215	0.458	53.020	0.195
4.	54.116	53.787	0.329	53.568	0.219
5.	53.545	53.326	0.219	53.200	0.126
MEAN			0.379		0.167

Table 2:

SET NO.2(150rpm,5N)					
TEST NO.	MASS BEFORE TEST(gm)	MASS AFTER	Wear by mass gm	Mass after three body	Wear by mass

		TEST (TWO BODY test) (gm)		test	
1.	54.344	53.600	0.744	53.335	0.265
2.	54.529	53.955	0.574	53.670	0.285
3.	53.020	52.530	0.490	52.200	0.330
4.	53.568	52.830	0.738	52.535	0.295
5.	53.200	52.650	0.550	52.355	0.295
MEAN			0.619		0.294

Table 3:

SET NO.3(200RPM,5N)

TEST NO. MASS BEFORE TEST mass after test WEAR BY MASSmass after three (gm) (two body test) (gm) body test(gm)					Wear by mass
1.	53.300	52.575	0.725	52.100	0.475
2.	53.655	52.800	0.855	52.350	0.450
3.	52.200	51.455	0.745	50.970	0.485
4.	52.530	51.700	0.830	51.235	0.465
5.	52.355	51.600	0.755	51.225	0.375
mean			0.782		0.450

SET NO.4(100RPM,10N)

TEST NO. MASS BEFORE TEST mass after test WEAR BY MASSmass after (gm) (two body test)(gm) (two body wear)gm three body test					Wear by mass
1.	52.100	51.525	0.575	51.155	0.370

2.	52.350	51.856	0.494	51.375	0.481
3.	50.970	50.235	0.735	49.800	0.435
4.	51.235	50.560	0.675	50.145	0.415
5.	51.200	50.620	0.580	50.130	0.490
mean			0.611		0.438

SET NO.5(150RPM,10N)

TEST NO. MASS BEFORE TEST mass after test WEAR BY MASSmass after three (gm) (two body test)(gm) (gm) body test(gm)					Wear by mass
1.	51.155	50.550	0.605	50.200	0.350
2.	51.375	50.700	0.675	50.235	0.465
3.	49.800	49.224	0.576	48.835	0.389
4.	50.145	49.450	0.695	49.100	0.350
5.	50.130	49.635	0.495	49.225	0.410
mean			0.609		0.392

SET NO.6(200RPM,10N)

TEST NO. MASS BEFORE TEST mass after test WEAR BY MASs mass after (gm) (two body test)(gm) (gm) three body(gm					Wear by mas
1.	50.200	49.337	0.863	48.900	0.437
2.	50.350	49.755	0.595	49.225	0.530
3.	48.835	48.105	0.730	47.554	0.551
4.	49.100	48.322	0.778	47.883	0.439
5.	49.225	48.445	0.780	47.900	0.545
mean			0.749		0.500

SET NO.7(100RPM,15N)

TEST NO. MASS BEFORE TEST mass after WEAR BY MASS mass after (gm) (two body test)(gm) (gm) three body test					Wear by mass
1.	48.900	48.230	0.670	47.620	0.610
2.	49.225	48.665	0.560	48.223	0.442
3.	47.554	46.882	0.672	46.260	0.622
4.	47.883	47.120	0.763	46.570	0.550
5.	47.900	47.220	0.680	46.600	0.620
mean			0.669		0.568

SET NO.8(150RPM,15N)

TEST NO. MASS BEFORE TEST mass after WEAR BY MASS mass after (gm) (two body test)(gm) (two body wear)gm three body test					Wear by mas
1.	47.620	46.800	0.820	46.210	0.590
2.	47.950	47.177	0.773	46.450	0.727
3.	46.260	45.445	0.815	44.910	0.535
4.	46.570	45.653	0.917	44.950	0.703
5.	46.600	45.775	0.825	45.120	0.655
mean			0.830		0.642

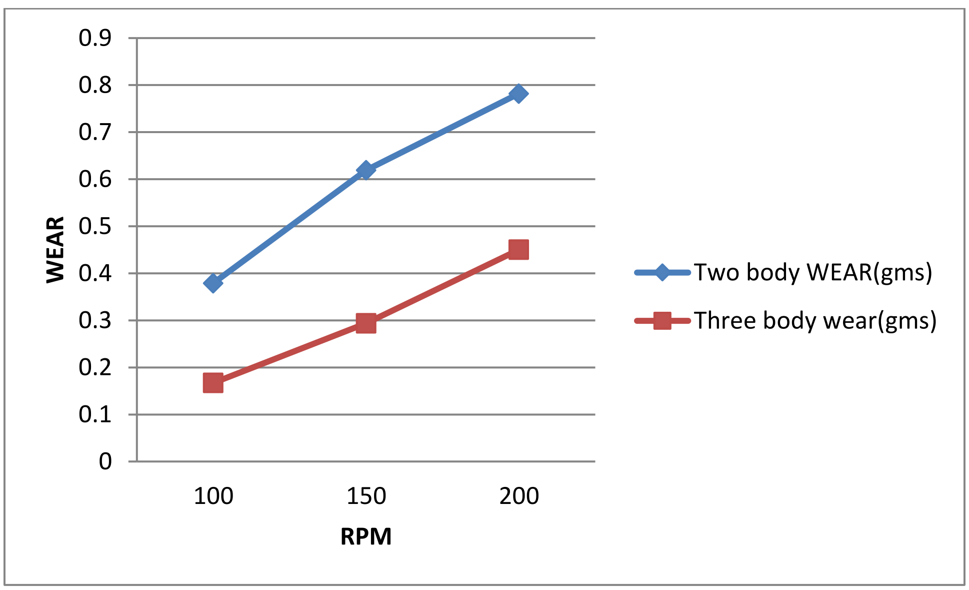
SET NO.9(200RPM,15N)

TEST NO. MASS BEFORE TEST mass after WEAR BY MASSmass after	Wear by mass

(gm) (two body wear)(gm) (two body wear)gm three body test					
1.	46.210	45.305	0.905	44.665	0.640
2.	46.450	45.571	0.879	44.910	0.661
3.	44.910	44.102	0.808	43.720	0.382
4.	44.950	44.110	0.840	43.620	0.490
5.	45.120	44.250	0.870	43.770	0.480
mean			0.860		0.530

At 5N- RPM vs. WEAR

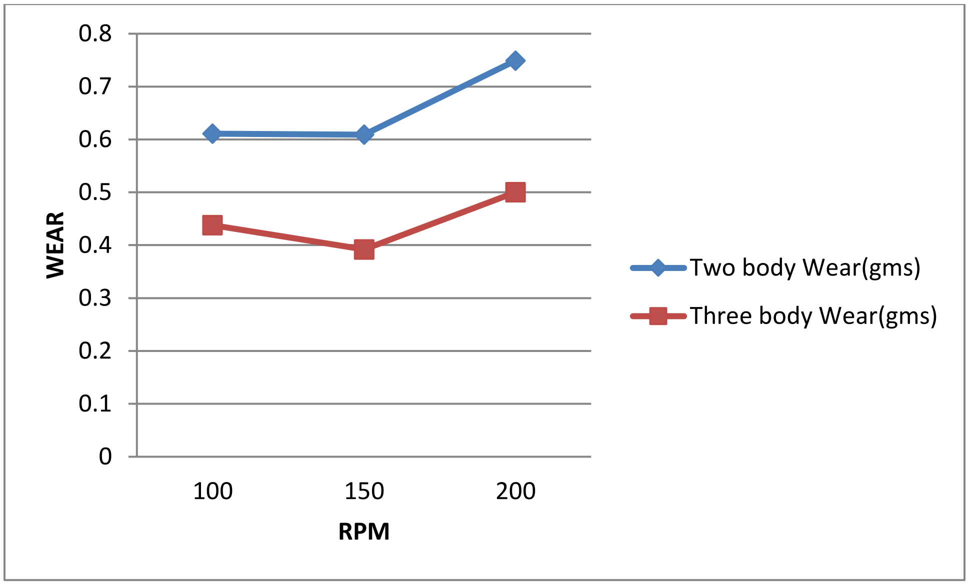
RPM	Two body WEAR(gms)	Three body wear(gms)
100	0.379	0.167
150	0.619	0.294
200	0.782	0.450



At 10 N- RPM vs. WEAR

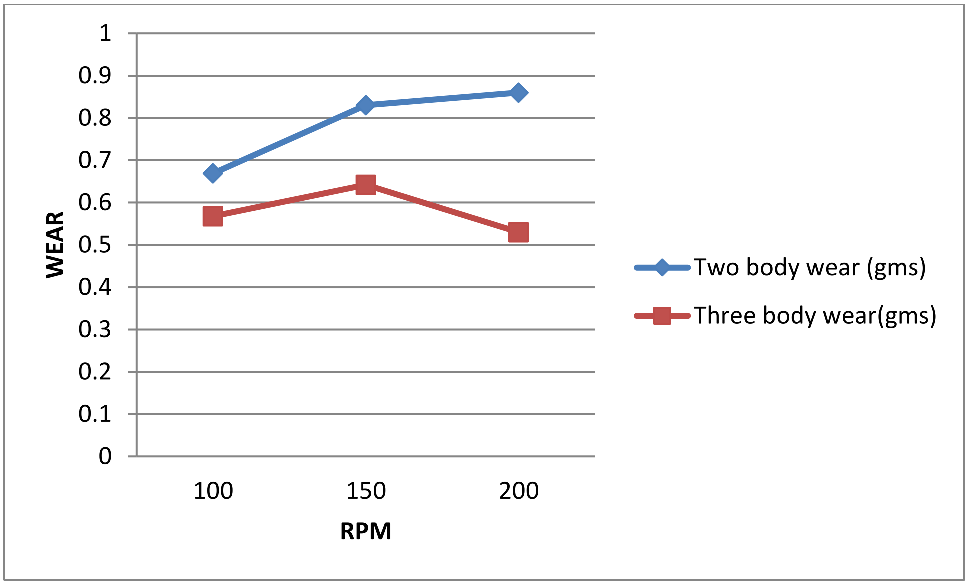
rpm	Two body Wear(gms)	Three body Wear(gms)
100	0.611	0.438

150	0.609	0.392
200	0.749	0.500



At 15 N- RPM vs. WEAR

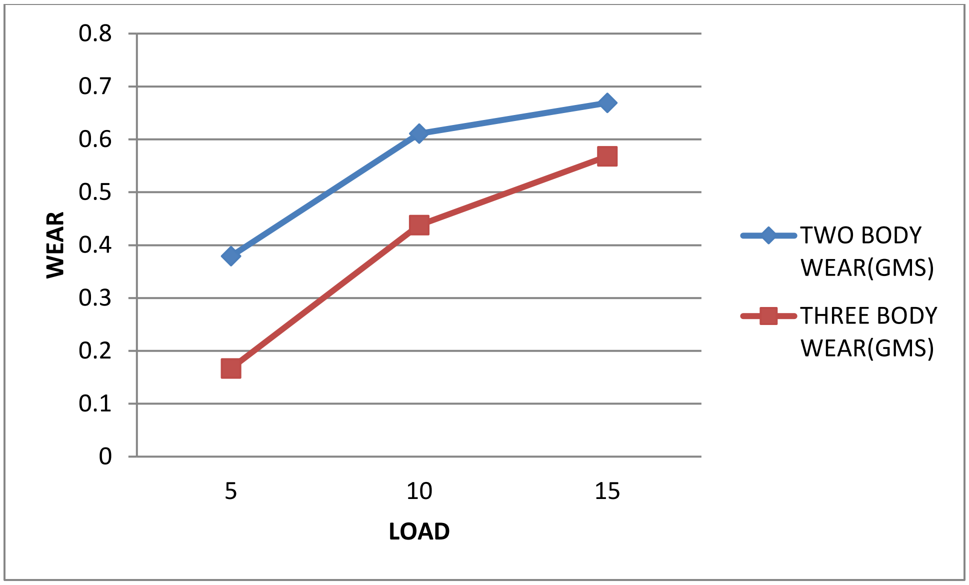
RPM	Two body wear (gms)	Three body wear(gms)
100	0.669	0.568
150	0.830	0.642
200	0.860	0.530



Effect of Speed (rpm) On Abrasive Wear of ALUMINIUM AL6063 AT CONSTANT ANGULAR SPEED

LOAD VS WEAR (100RPM)

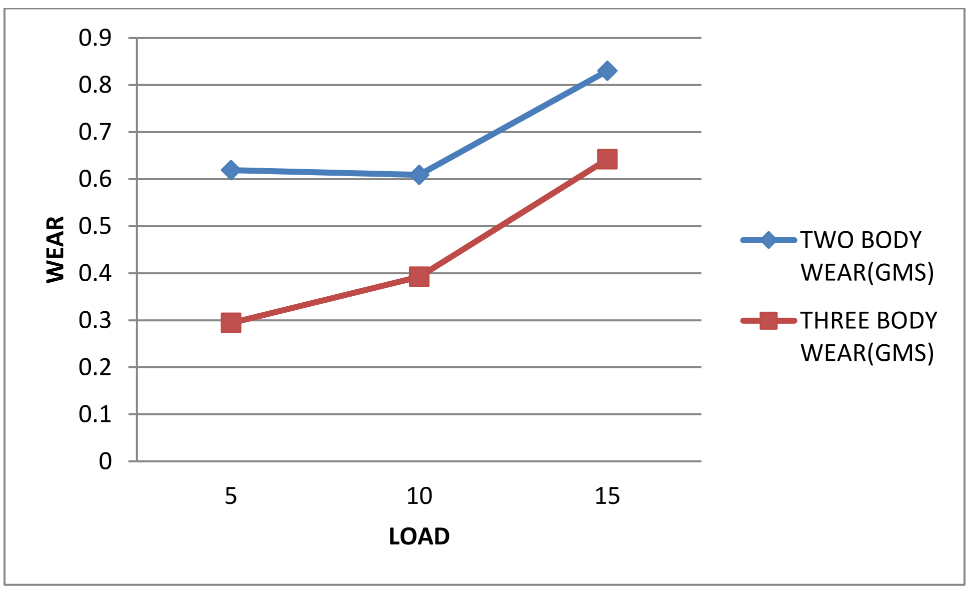
LOAD(N)	TWO BODY WEAR(GMS)	THREE BODY WEAR(GMS)
5	0.379	0.167
10	0.611	0.438
15	0.669	0.568



GRAPH

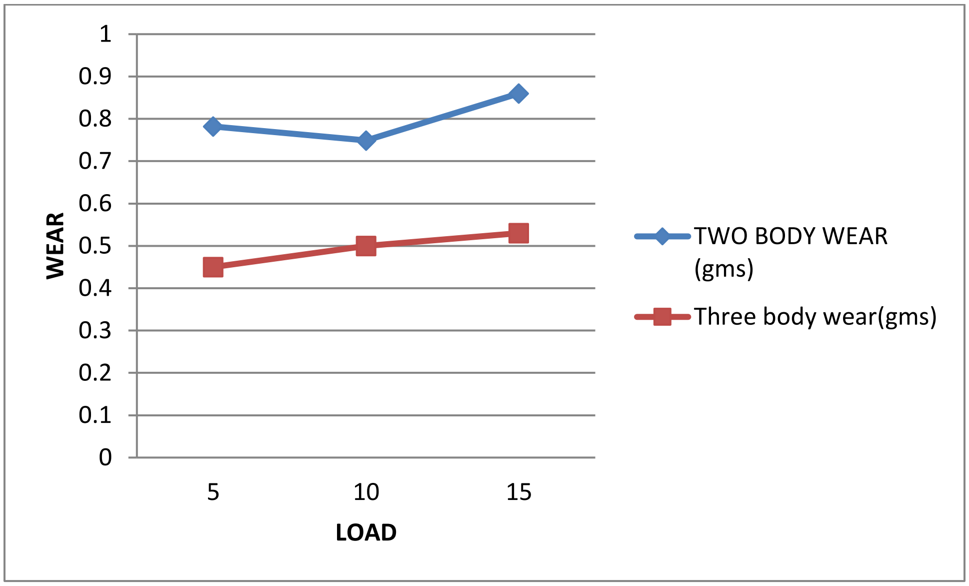
LOAD VS WEAR (150RPM)

LOAD(N)	TWO BODY WEAR(GMS)	THREE BODY WEAR(GMS)
5	0.619	0.294
10	0.609	0.392
15	0.830	0.642



LOAD VS WEAR (200RPM)

LOAD(N)	TWO BODY WEAR (gms)	Three body wear(gms)
5	0.782	0.450
10	0.749	0.500
15	0.860	0.530



DISCUSSION

The main findings of the investigation have been listed out. The suggestion for the future work have also been indicated. The specimen do not get fresh abrasive surface,due to this wear resistance increases. Following results are discussed below:

GRAPH-5.1

This graph shows RPM vs WEAR at 5 N. The wear loss increases while RPM increases. The graph is not linear in nature.

GRAPH-5.2

This graph shows RPM vs WEAR at 10 N. The wear loss increases while RPM increases. The graph is not linear in nature.

GRAPH-5.3

This graph shows RPM vs WEAR at 15 N. The wear loss increases while RPM increases. The graph is not linear in nature. In this graph wear loss is more as compare to graph 1 and graph 2.

GRAPH-5.4

This graph shows LOAD vs WEAR at 5 N. The wear loss increases while load increases. The graph is linear in nature , this shows linear relationship between load and wear.

GRAPH-5.5

This graph shows LOAD vs WEAR at 10 N. The wear loss increases while load increases. The graph is linear in nature , this shows linear relationship between load and wear.

GRAPH-5.6

This graph shows LOAD vs WEAR at 15 N. The wear loss increases while load increases. The graph is linear in nature , this shows linear relationship between load and wear. In this graph wear loss is more as compare to graph 1 and graph 2.

CONCLUSION

It is concluded from the above discussion that wear is function of applied load. Initially, it was understood that wear depends upon applied load, surface parameters and mechanical properties such as hardness, toughness etc.

Thus it can be concluded that:

- There is a linear relationship between wear and load
- The wear loss increases while load increases. Wear loss is more at 15 N load as compare to 5N and 10 N load.
- The wear loss increases while RPM increases.
- The wear loss in first minute is more as compare to last minute while increasing the RPM

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