TRIBOLOGICAL BEHAVIOUR STUDY OF CERAMIC COMPOSITES

A THESIS SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY
IN
MECHANICAL ENGINEERING

BY

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DEPARTMENT OF MECHANICAL ENGINEERING

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CERTIFICATE

This is to certify that the thesis entitled ***"Tribological Behaviour Study of Ceramic Composites"*** submitted by ***Rajan Tiwari (Roll Number.: 110ME0556)***, ***Shubham Sameer (Roll No.: 110ME0328)*** and ***Sandeep P.B.S (Roll No.:110ME0487)*** in partial fulfillment of the requirements for the award of ***Bachelor of Technology*** in Mechanical Engineering at National Institute of Technology, Rourkela is an authentic work carried out under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to elsewhere for the award of any degree.

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ABSTRACT

Composites are materials consisting of two or more chemically distinct constituents, on a macro-scale, having a distinct interface separating them. In a composite one of the materials is embedded in a fiber of other. The fiber acts as the supporting structure or matrix and bears most of the load while the other component is embedded in the matrix. Polymer matrix ceramic composites are the one in which the polymer acts as the supporting matrix and the ceramic particles are embedded in it. It is known for its high strength to weight ratio and finds application in the areas where weight reduction is required and a small change in weight can bring about a considerable difference. More ever they also have good shock absorbing and damping properties. The failure mechanisms of composites are very different as compared to conventional materials and their performance is mostly governed by their tribological properties. This is because the composites properties are controlled by the fact that how various layers of composites interact with respect to one another. In this paper we are going to study the wear properties of two of the most widely used composites Alumina and Zirconia by varying the weight percentage of the ceramics in the polymer matrix and then comparing the results so obtained.

Keywords: Composites, tribology, wear, alumina, zirconia

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CHAPTER 1
INTRODUCTION

1.1 COMPOSITES

Composites are necessary in modern days because in many of the applications the properties of materials we require cannot be achieved by use of conventional materials like metals , ceramics etc. what we actually require is a material with hybrid properties and there comes the role of composites. One such application is in aircraft technology where strong, light, corrosion resistant, abrasion resistant materials are required and to meet such specific demands the composites have to be fabricated.

A composite can be said to be a multiphase material which exhibits a significant portion of properties of both the phases such that by combining their properties a desired set of properties can be achieved. This is known as principle of combined action and it is used to fabricate composites as required by the various applications. Composites can contain any or all of the following in multiple phases like ceramics, metals or polymer [1].

In present context composites are said to be materials that are artificially made. They consist of phases that are chemically dissimilar and have a distinct surface separating them.

With the evolution in techniques of composite making scientists and engineers have been able to fabricate extraordinary materials whose properties find application in wide variety of uses and this has really revolutionized the field of material science.

Most matrix consists of two phases one acts as the supporting structure called as matrix which supports the structure of the composite and the other acts as the dispersed phase .However the matrix can be classified on the nature of the matrix and the dispersed phase.

Based on the nature of the matrix and the filler material the composites can be classified as follows: [1]

- Particle reinforced Composites
    - Large particle
    - Dispersion strengthened
- Fiber reinforced Composites
    - Continuous
    - Discontinuous
- Structural Composites
    - Laminates
    - Sandwich panels

Particle reinforced composites

In this type of composites the particle is reinforced in the matrix and the matrix bears the majority of the load whereas the function of the filler material is to prevent the dislocations in the matrix and since the dislocations are prevented naturally the plastic deformation is difficult to occur thereby the hardness as well as tensile strength increases thus addition of fillers improve the properties. Apart from this the size of filler material, particle also influences the property of the composite Therefore they are classified on the basis of their particle size.

Fibre reinforced composites

Here the dispersed phase is in fiber state they are generally used where high strength and stiffness is required as compared to their weight. The most important parameters affecting the property of such composites is the length of the fiber.

It can be long and aligned or short and discontinuous. However if its short then it doesn't bear much of the applied load and therefore the change in properties are not that evident as in the case of long fiber composites. The fiber orientation and concentration also influence the properties.

The composites can be classified into three different types on the basis of matrix type:

1) Metal matrix composites
2) Ceramic matrix composites
3) Polymer matrix composites

Metal matrix composites: When the metal is used as the matrix or supporting structure it is called as the metal matrix composites. Here the filler material brings about a significant change in the functional property of metal and most of the properties like wear resistance, creep resistance improve because of this it finds application in areas such as Due to above mentioned reason it is used in the combustion chamber nozzle (in the rocket, space shuttle), housings, tubing, cables, heat exchangers, structural members etc.

Ceramic matrix composites: When the ceramic acts as the matrix phase it is known as the ceramic matrix composites. They possess higher hardness and wear resistance as compared to conventional ceramics while retaining their properties like low density, inertness to chemical reactions and higher thermal resistance.

Polymer matrix composites: This is the composite which we have used in our project so let us investigate in detail about it. In the polymer matrix composite, the supporting structure or the matrix is made up of polymer. Polymers are compound formed as a result of polymerization reaction in which small monomers forms long chains of compound. They are very light weight and their strength to weight ratio is considerably higher than others. They also have good wear resistance and have good shock absorbing properties and thus find various applications in aircraft and automobile industries

The polymer matrix can further be classified in following category based on the nature of the polymer.

1) **Thermosetting Polymer matrix composites**: They consist of polymer which have high molecular weight and good 3-D bond strength and as a result of which that retain their bond structure even after polymerization. Example: epoxy
2) **Thermoplastic polymer matrix composites:** They consist of polymers which have lower molecular weight and weaker bond strength and beyond a certain temperature they become malleable and pliable but retain its shape after cooling. Due to these difficulties thermosetting polymers are more preferred in industry because of their ease in processing plus they are cheaper as compared to thermoplastic polymers.

1.2 WEAR

Wear can be defined as process of material removing from the surface of the body due to friction force produced during coming and sliding. The wear can be of various natures depending upon how the friction is produced. They can be abrasive wear, erosion wear, fatigue wear, chemical wear etc.

Abrasive Wear:

It involves that a hard particle rubs against a softer one and in due course erodes it. During the wear if not more than two particles are involved then it is called as two body abrasive wear. The wear pattern is dependent on angle of attack and the interfacial shear strength.

Wear by Brittle Fracture:

This type of wear is seen in the case of brittle solids because when they are subjected to wear they suffer subsurface cracks and these cracks propagate resulting in degradation of subsurface resulting in material loss. This is known as wear by brittle fracture.

Fatigue wear:

This type of wear is where due to cyclic loading fatigue occurs which results in subsurface cracks even in the case of ductile material and because of it cracks propagate and material is worn out .The subsurface cracks occur in these ductile materials only when the fatigue starts.

Impact wear:

In this kind of wear the material is worn out due to repeated impacts either by particles or by hard particles. If the impact is by particles it is called erosive wear and if it is by a hard object it is called as percussive wear. What actually happens is that the impact energy of particles is transferred to do plastic deformation resulting in wear.

Chemical wear: This type of wear occurs because of chemical reaction which may occur because the material may be in a corrosive environment or because of chemical reactions kicking in when subjected to heat which may be the result of flash occurring due to certain processes.

Wear studies are done by studying the surface profile after it has been subjected to wear and/or examining the wear debris.

1.3 CERAMIC COMPOSITES TO BE STUDIED

Aluminium Oxide Composites (Al_2O_3)

Alumina or aluminium oxide (Al_2O_3) is one of the most commonly used ceramic particles. They can be used to fabricate a wide range of material just by adjusting the matrix design and particle size. There are both coarse and fine-grained varieties. They find application in making heavy duty forming tools, as resistor cores and substrate in electronic industry, tiles to protect from wear as well as ballistics, as thread guides in field of textile engineering as seals and regulators in valves and taps, as catalyst carriers for chemical based industries and as heat. Some of the common properties of the aluminium oxides are as follows: [2]

- Very good electrical insulation (1x1014 to 1x1015Ωcm)
- Moderate to extremely high mechanical strength (300 to 630 MPa)
- Very high compressive strength (2,000 to 4,000 MPa)
- High hardness (15 to 19 GPa)
- Moderate thermal conductivity (20 to 30 W/mK)
- High corrosion and wear resistance
- Good gliding properties
- Low density (3.75 to 3.95 g/cm3)
- Operating temperature without mechanical load 1,000 to 1,500°C.
- Bioinert

Zirconium Dioxide (ZrO_2)

Zirconium oxide known as ‘zirconia’ is a ceramic known for its resistance to crack propagation and high thermal expansion and because of these properties they find application in areas where steel and ceramics have to be joined. Some of the common properties of Zirconia are as follows: [3]

- High thermal expansion ($\alpha = 11 \times 10^{-6}/K$, similar to some types of steel)
- Excellent thermal insulation/low thermal conductivity (2.5 to 3 W/mK)
- Very high resistance to crack propagation, high fracture toughness (6.5 to 8 $MPa.m^{1/2}$)
- Ability to conduct oxygen ions (used for the measurement of oxygen partial pressures in lambda probes)

Zirconium Oxide ceramics have considerably low thermal conductivity and high strength. However they are expensive as compared to other ceramics like alumina ceramics. They are used as tool for making tools that are used for wire forming or as auxillary tools in welding processes .they also find wide application in dental industry and as insulating rings in thermal processes and as cells used for oxygen measurement in lambda probes. [3]

CHAPTER 2
LITERATURE REVIEW

Composite materials are materials consisting of two more distinct chemical constituents in different phases which combine together to form new material with property unique to both of the material. They are used because in modern day materials with extraordinary properties are required and these properties can't be achieved using conventional materials like metals, ceramics or polymers [1]. The load bearing phase of a composite is done by the matrix which acts as the supporting structure of the composite, it is a continuous phase with the filler material acting as the dispersed phase. On the basis of the matrix structure the composites can be divided in three categories namely polymer matrix, ceramic matrix and metal matrix and in the context of our project we are using polymer matrix ceramic composites. In polymer matrix ceramic composite the supporting structure consists of polymer and the ceramic acts as the filler material These composites are one of the more commonly used composites because of their ease in fabrication and also because the polymer matrix composites are known for their light weight, high strength to weight ratio, corrosion and abrasion resistance [1] and because of these reasons they are finding application in areas such as automobile or aeronautics where weight is a very important factor effecting the functioning of equipment.

One of the important parameters effecting the performance of composites are their wear characteristics that is how the wear occurs like fatigue wear, impact wear, abrasive wear etc. and the different between each of these mechanisms apart from this the mechanisms to study wear characteristics by investigating into surface profile and wear debris is equally important [4].

The composites used were alumina and zirconia which are one of the common ceramics used. Alumina is known for its high strength , high hardness wear resistance ,corrosion resistance, low density and for biological inertness moreover alumina is also one of the easily available ceramics and is also relatively cheaper compared to other ceramic particles and as a result of which it finds greater application in industry as compared to other ceramics [2] and zirconia for its resistance to crack propagation, high thermal expansion and thermal insulation [3].These ceramics are dispersed in polymer matrix .

The composite used in our project was particle reinforced types and the particle reinforced composites the particle bear only a small fraction of the applied load but the majority of the load is bore by the matrix but however the increase the wear resistance and hardness by preventing dislocations from occurring in the polymer matrix and therefore plastic deformation decreases and the resultant change in property occurs. The shape of particles also influence the properties of the composites[5].This change in properties was so significant that in certain case the wear resistance increased by many manifold [1, 6,7]. The extent which the ceramic particles influence the nature of composite is dependent on both the size and the concentration of composite [6, 8]. The concentration of composites beyond up to a certain level also known as the optimum level increases the properties such as wear resistance and hardness however the change in the property is not that significant after a certain level of concentration.

The wear properties are also influenced by the other mechanical parameters such as the coefficient of sliding friction, the load applied for wear to occur and the sliding speed. These are some of the physical parameters which effect the wear behaviour of polymer matrix ceramic composites and in order to check for all these parameters the experiment chosen was a pin on disc experiment which consists of a pin on which the composite is fixed and load is applied as required and the disc is rotated at the varying rotational speed (which varies the sliding distance) [9] and thus in this experiment all the parameters can be controlled and therefore in our present work we have used it so that the experiment can be better suited to check for all the results and comparisons we require.

2.1 AIM OF PRESENT WORK

The aim of present work is to investigate the wear properties of two different polymer matrix ceramic composites namely Alumina and Zirconia and these both ceramic composites are subjected to wear at different concentrations in polymer matrix and the wear rate for both the ceramics at different concentrations are calculated and compared in order to find the most optimum concentrations for each of the composites. Thereby the results of the two ceramic composites are to be compared with each in order to find out the ceramic which brings about a better change in properties that is the ceramic which gives a more wear resistant composite.

CHAPTER 3
METHODOLOGY

3.1 FABRICATION OF CERAMIC COMPOSITES

This ceramic materials selected for the study are Al_2O_3 and ZrO_2 and the polymer selected is epoxy (formaldehyde and phenol). The procedure for making the required ceramic composites by casting is described below.

Step 1. The first step is to determine a suitable casting mould. Hard glass test tube of *Borosil15×125* was used to make the composites. The glass test tube was chosen so that it will be easily available. Also it will be easier to break the test tube and take out the ceramic composites formed.

Step 2. The combined weight of hardener and epoxy is determined. In this experiment the hardener composition is 25% by weight. Thus, 1.75gm of hardener and 5.25 gm of epoxy is used to make a combined weight of 7gms. Then the weight of each ceramic material is computed such that the composition in 10%, 20% and 30% and kept in labelled paper packets.

Table 3.1: Weight of the ceramic material required for making ceramic composites

Percentage composition of ceramic material (%)	**Weight of the ceramic material required (gms)**
10	0.77
20	1.75
30	3.00

Step 3. The inner wall of the test tube is lightly oiled and then 5.25gm of epoxy is poured down. Now, the required ceramic powder is poured down in the test tubes from the

labeled paper packets. The test tube is then labelled. The epoxy and the ceramic composite are stirred properly.

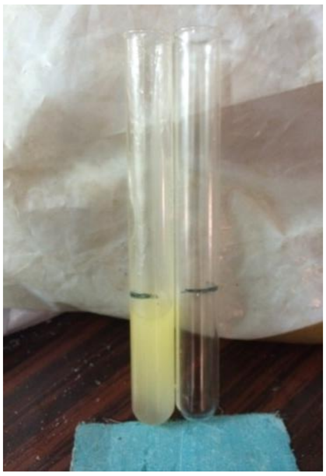


Fig 3.1: 5.25gm of epoxy poured in the test tube

Fig 3.2: Ceramic powder from labelled packets is then poured into the test tube containing epoxy.

Fig 3.3: Ceramic powder and epoxy solution after stirring properly

Step 4. 1.75gm of hardener is then poured into the test tube and then stirred properly

Fig 3.4: Hardener poured into the ceramic powder and epoxy solution

Fig 3.5: The solution of ceramic powder, epoxy and hardener ready for solidification after stirring

Step 5. In order to form the ceramic composite, the solution should be left to solidify. The ceramic powder must be distributed such that more material is near the periphery as the ends are subjected to more wear as compared to inner sides. Thus, the test tube with the ceramic powder, epoxy and hardener solution is kept in a centrifuge and then rotated in a constant speed of 350 rpm over 24 hours. The solidified ceramic composite is taken out by breaking the glass.

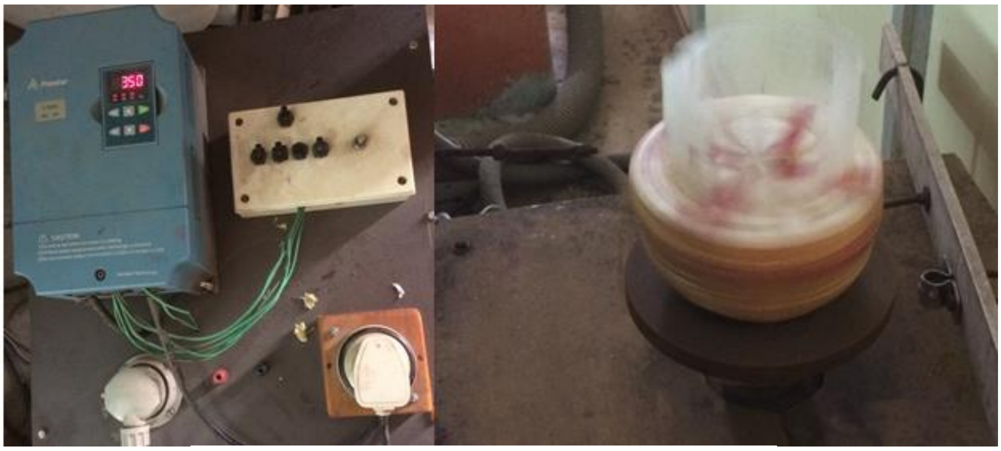


Fig 3.6: Centrifuge rotating at a constant speed of 350rpm for solidification

3.2 WEAR RATE CHARACTERISTICS

The ceramic composites are subjected to wear during its operation. If the wear rate is high under working conditions, the material may fail and cause loss to life and property. As such, the study of wear of the material is very important. In this regard, the wear characteristics of the ceramic composites are studied with the help of a pin on disc machine. The ceramic composites formed are subjected to abrasive wear by bringing it in contact with a rotating disc plate and applying normal force on the sample with the application of weights. The schematic diagram of the pin on disc machine is shown alongside.

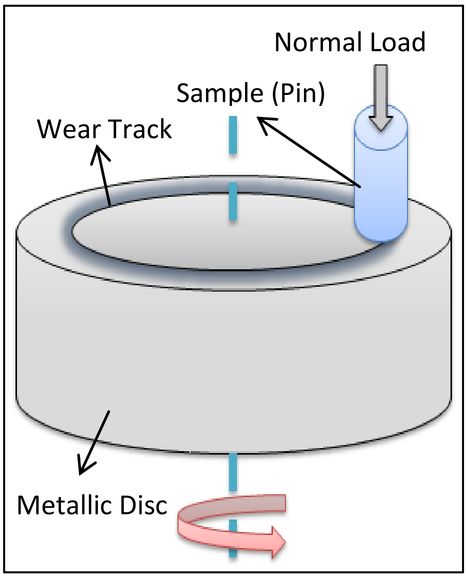


Fig 3.7: Schematic Diagram of the Pin-on-disc Machine

The experimental procedure for pin and disc machine took place in a series of steps which are explained below.

Fig 3.8: Experimental Setup of the Pin-on-disc Machine

Step 1. The apparatus that is the disc the weighing machines should all be properly cleaned so that the experiment reading is not affected.

Step 2. The sample is cut to required length with the help of the hex blade. The weight of the jaw of the pin machine (that would hold the sample) is weighed along with the tightening nut attached to it and its weight recorded. Then the sample is placed in the jaw and the combined weight of the jaw with the tightening nut and the sample is measured and recorded.

Fig 3.9: Cutting the sample to required length for fixing it to the

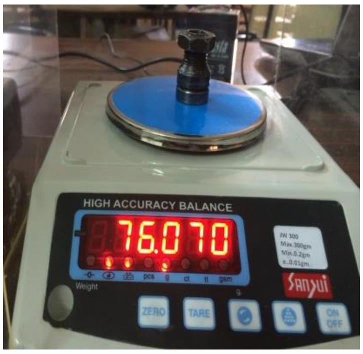


Fig 3.10: Weighing of the sample holding jaw

Fig 3.11: Finding the combined weight of the jaw, tightening nut and the sample

Step 3. The machine is set at desired R.P.M and time (5 mins) before the rotation of disc would be started.

Step 4. After setting up of machine the sample is loaded, weights applied, all the nuts tightened and machine is started.

Step 5. After a runtime of five minutes the machine is switched off.

Step 6. The sample reweighed and from this the weight loss in sample is calculated.

Step 7. The sample is loaded again and new R.P.M for the machine is setup and machine is rotated and the same procedure is repeated.

Step 8. Once testing for all the R.P.Ms i.e. (250, 500, 750, 1000) is completed the sample is removed from the jaw.

Step 9. The procedure is repeated for all the other samples of zirconia and aluminium oxide.

Step 10. Calculations of wear rate done and comparisons were made. The wear rate is given by the following formula

$$\text{Wear Rate (WR)} = \frac{\text{Loss in mass } (\Delta W)}{\text{Sliding Distance (SD)}}$$

CHAPTER 4
RESULTS AND DISCUSSION

4.1 TABULATION OF EXPERIMENTAL DATA

Table 4.1: Experimental Data for Alumina Composites for 3.5 kg load and time=5 mins

Composite	RPM of the machine	Initial weight of the sample (gms)	Final weight of the sample (gms)	Weight loss of the sample (gms)	Sliding distance (m)	Wear Rate ($X10^{-7}$ N/m)
10% Al_2O_3	250	1.583	1.565	0.018	589.05	3.00
	500	1.565	1.541	0.024	1178.10	2.00
	750	1.541	1.510	0.031	1767.15	1.72
	1000	1.510	1.474	0.036	2356.19	1.50
20% Al_2O_3	250	1.456	1.443	0.013	589.05	2.17
	500	1.443	1.423	0.020	1178.10	1.67
	750	1.423	1.397	0.026	1767.15	1.44
	1000	1.397	1.365	0.032	2356.19	1.33
30% Al_2O_3	250	1.361	1.351	0.010	589.05	1.67
	500	1.351	1.337	0.014	1178.10	1.17
	750	1.337	1.318	0.019	1767.15	1.05
	1000	1.318	1.293	0.025	2356.19	1.04

Sample Calulation for 10 % Al_2O_3, 250 rpm

Wear track radius (r) = 7.5cm

Initial weight of the sample = 1.583 gms

Final weight of the sample = 1.565 gms

Weight loss of the sample (ΔW) = (1.583 -1.565) gms = 0.018 gms

Sliding distance (SD) is given by

$$SD = 2\pi Nrt = 2 \times 3.14 \times 250 \times 0.075 \times 5 = 589.05\ m$$

Wear rate is now computed as follows

$$WR = \frac{\Delta W}{SD} = \frac{0.018 \times 10^{-3} \times 9.81}{589.05} = 2.998 \times 10^{-7} \approx 3.00 \times 10^{-7}\ N/m$$

Similarly, the tabulation of experimental data for zirconia composites is done and wear rate is computed.

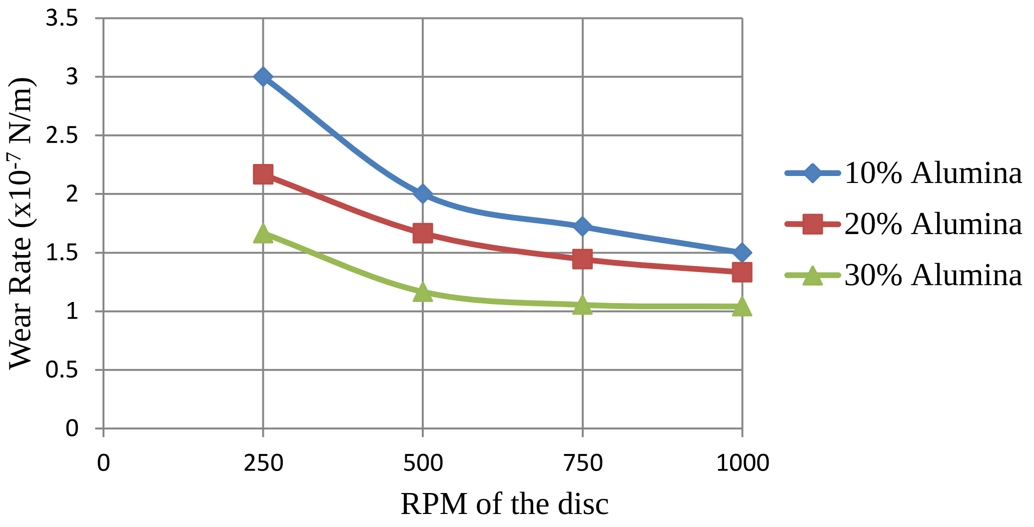
Table 4.2: Experimental Data for Zirconia Composites for 3.5 kg load and time=5 mins

Composite	RPM of the machine	Initial weight of the sample (gms)	Final weight of the sample (gms)	Weight loss of the sample (gms)	Sliding distance (m)	Wear Rate ($X10^{-7}$ N/m)
10% ZrO_2	250	2.222	2.200	0.022	589.05	3.66
	500	2.200	2.170	0.030	1178.10	2.50
	750	2.170	2.134	0.036	1767.15	2.00
	1000	2.134	2.093	0.041	2356.19	1.71
20% ZrO_2	250	1.581	1.563	0.018	589.05	3.00
	500	1.563	1.537	0.026	1178.10	2.17
	750	1.537	1.506	0.031	1767.15	1.72
	1000	1.506	1.471	0.035	2356.19	1.46
30% ZrO_2	250	1.920	1.904	0.016	589.05	2.66
	500	1.904	1.880	0.024	1178.10	2.00
	750	1.880	1.852	0.028	1767.15	1.55
	1000	1.852	1.820	0.032	2356.19	1.33

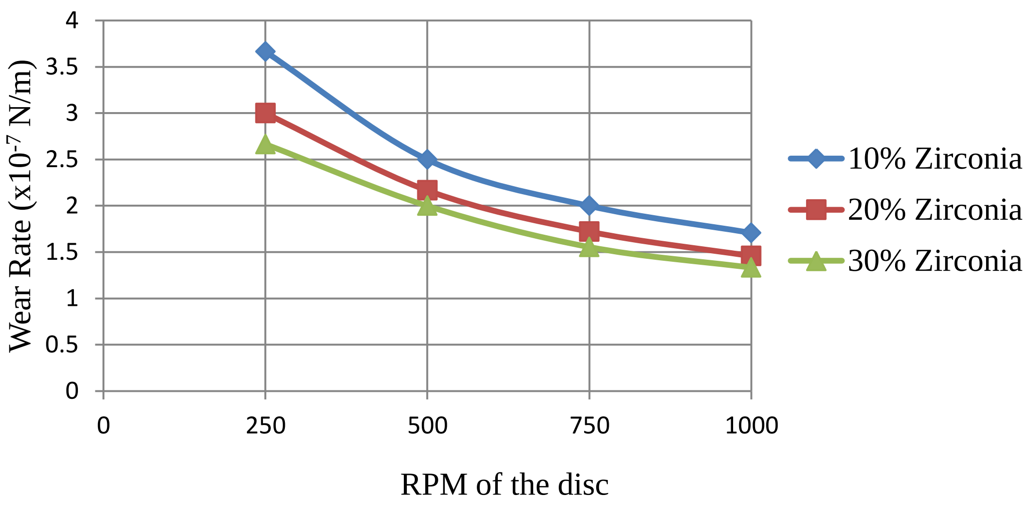
4.2 GRAPHS AND CHARTS

Effect of Increasing RPM on Wear Rate

Graph 4.1: RPM Vs Wear Rate of Aluminium Oxide Composites



Graph 4.2: RPM Vs Wear Rate of Zirconium Dioxide Composites



From the graphs above, it can be seen that the wear rate of both alumina and zirconia decreases with increase in rpm of the metallic wheel (disc) in the pin on disc machine. By increasing the rpm, we are in fact increasing the sliding distance of the sample (pin).

Comparison of Wear Rate of Zirconia and Alumina Composites

Chart 4.1: Comparison of wear Rate of 10% Composition of Zirconia and Aluminium Oxide Composites

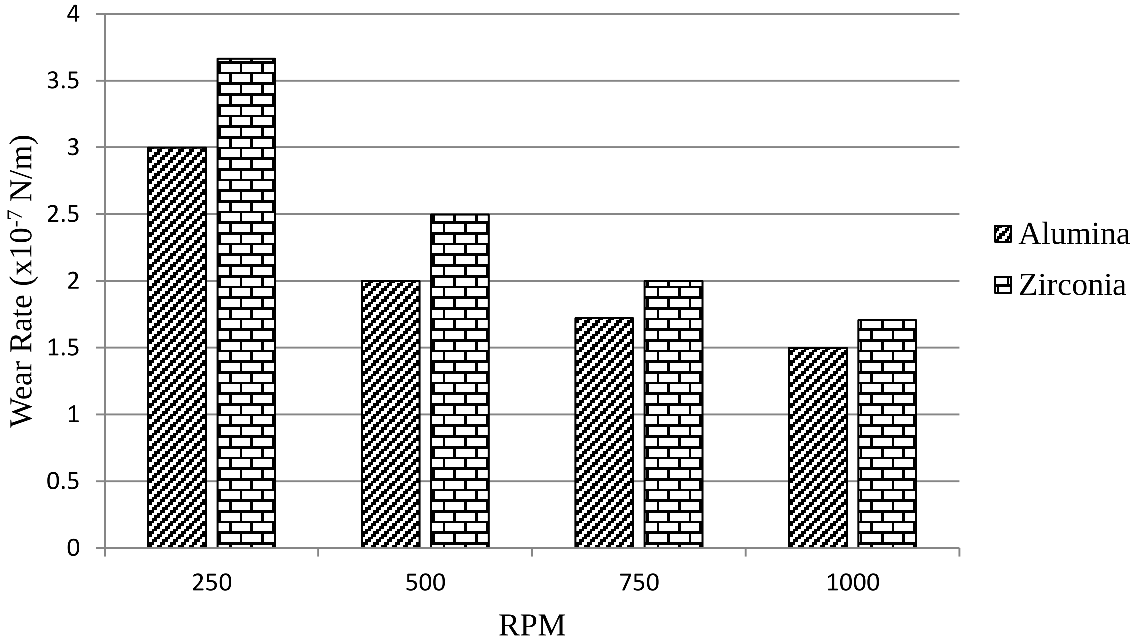
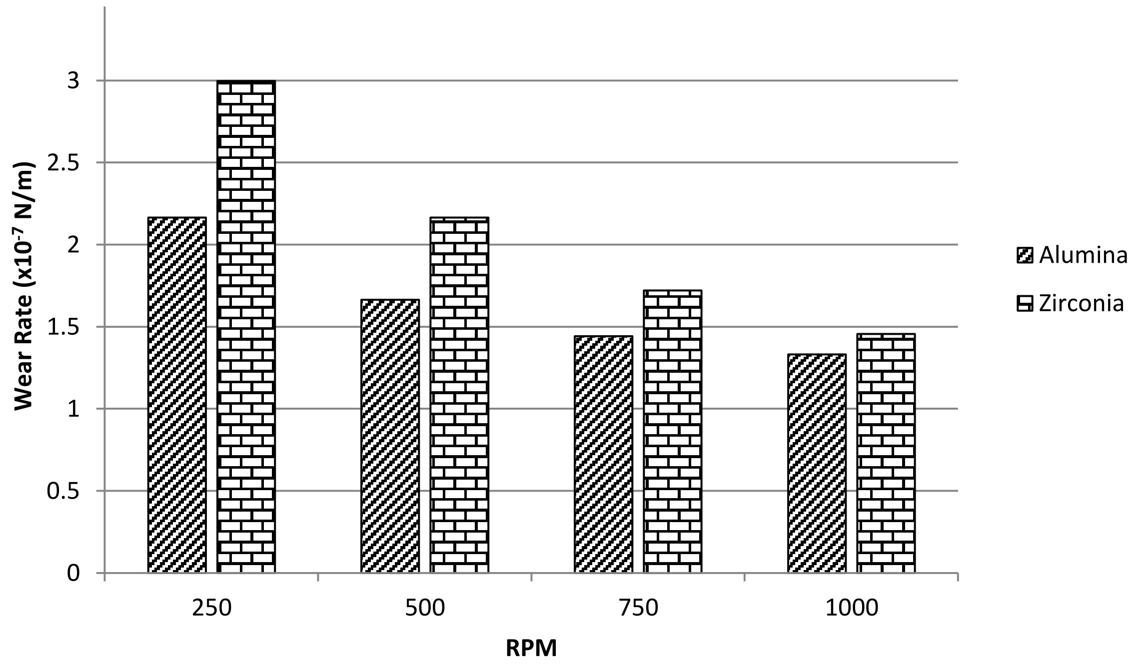
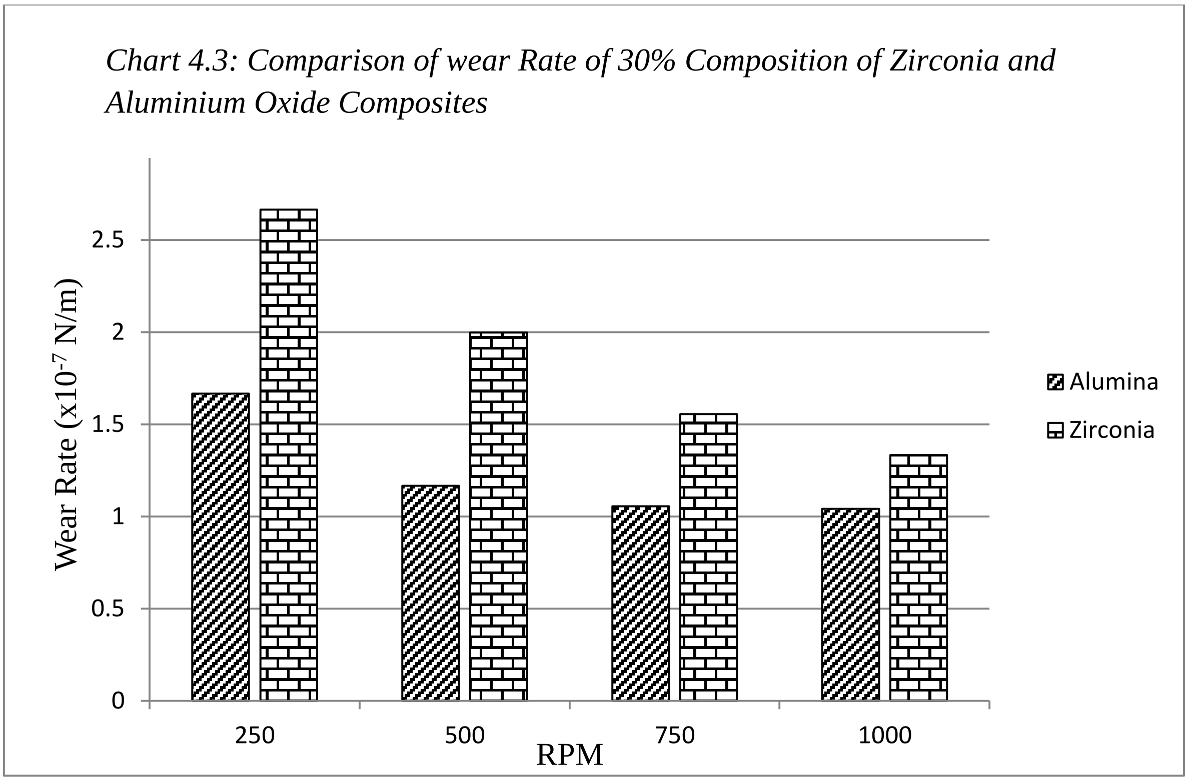


Chart 4.2: Comparison of wear Rate of 20% Composition of Zirconia and Aluminium Oxide Composites





From the charts 4.1, 4.2 and 4.3 above, it can be inferred that the wear rate of the zirconia composites is higher than that of the alumina composites for the same percentage composition by weight up to 30%.

CHAPTER 5
CONCLUSIONS

Separate ceramic composites of Aluminium Dioxide (Alumina) and Zirconium Dioxide (Zirconia) were fabricated by casting method in the test tubes by varying the percentage composition (10%, 20% and 30%) by weight of the ceramic material. The wear characteristics of the Alumina and Zirconia were studied, compared with each other and presented. The following conclusions were drawn from the experimental investigation.

1) The wear rate decreases with increase in sliding distance. From this it can be concluded that the wear rate is not constant throughout but varies with sliding distance for both Alumina and Zirconia.
2) The wear rate decreases for Alumina decreased with increase in percentage composition by weight of Alumina up to 30 %.
3) The wear rate for Zirconia decreases with increase in percentage composition by weight of Zirconia up to 30 %.
4) The wear rate for Alumina is less than Zirconia thus Alumina is more wear resistant ceramic composite as compared to Zirconia.

5.1 SCOPE OF FUTURE WORK

The current research provides a very broad scope for future research. This research can be further extended to study the wear rate characteristics of Alumina and Zirconia by increasing the percentage composition by weight beyond 30%. In addition, further work can be done by casting a composite of Zirconia and Alumina combined together with different ratios and comparing them with their individual composites.

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