WEAR ANALYSIS OF GRAPHENE NANOPLATELETS & SILICON CARBIDE DISC BRAKE PAD ASSEMBLY

Dissertation-II

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By

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CERTIFICATE

I hereby certify that the work being presented in the dissertation entitled "Wear Analysis of Graphene & Silicon Carbide Disc Brake Pad Assembly" in partial fulfillment of the requirement of the award of the Degree of master of technology and submitted to the Department of Mechanical Engineering of Lovely Professional University, Phagwara, is an authentic record of my own work carried out under the supervision of Bilji C Matthew, Asst. Professor, Department of Mechanical Engineering, Lovely Professional University. The matter embodied in this dissertation has not been submitted in part or full to any other University or Institute for the award of any degree.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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CHAPTER 1
INTRODUCTION

The automobile industry is booming day by day with newer technology and newer amendments in the field the work and researches are still going on for further improvement in the field of automobile industry. The one of the important area in the automobile is the deceleration of the motive vehicle which brings it to rest is its braking system which comprises of a mechanism to control it, the calipers, the disc and the and the brake pads. The main physics behind this system is the conversion of energy from one form to the another. In particular we can say that the moving vehicle producing a kinetic energy is brought to rest by converting that energy to thermal energy by the means of physical contact way.

And the most common factor associated with the braking system is brake disc and brake pads assembly and the kind of materials, to exhibit better friction & wear condition the material like Aluminium composed matrix which act as an abrasive in the material foundation of brake pad and it is being re-enforced with SiC particles to provide higher specific het coefficient capacity, and mostly providing the lower density of wear particles. Although many experiments have been carried out to study the behavior of Al-SiC composites against the brake rotor application and very few information being provided over these open journals. Hence, the tribological behavior with the smart material needed to be tested. This will be based on the percentage of different materials being reinforced in the brake pad and disc assembly. With the addition of the nominal percentage of the preferred alternative material for this study. Mainly this will examine the effect of load and speed on the wear rate of the material being tested here. [11] the main component of the vehicle's deceleration is the braking system present in the vehicle which happens by the means of the braking system and it is obtained by the means of same frictional co-efficient and hence the use for some of the material being discovered recently. If they show certain common internet in the present field of tribometry. Nowadays brake materials are tested by many manufacturers ever materials featuring steady frictional co-efficient, low wear rate, reduced emission of particulate matter(PM) and noise. [2]

Wear rate depends on the several parameters applied load on the contractual surface, speed of the sliding mechanism, the type of material and its hardness, the temperature raised, frictional co-efficient, the time duration during the slide, variation in load categories and even the humidity of the outer environment etc. [9]

The following diagram shows the representation of a separate Brake disc and brake pads.

Figure 1: Brake pads

Source: Akebono brake industry company ltd.

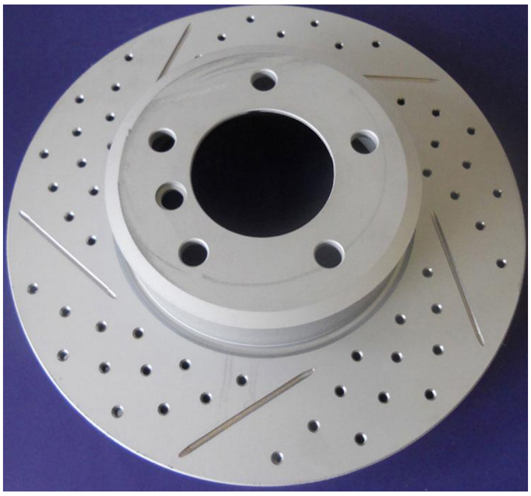

Figure 2: Brake Disc

Source: Cquence Performance Break parts

All materials of a break pad cannot be displayed as each manufacturers pad's materials are a closely guarded secret but basically, they consist of the following materials mostly in semi metallic brake pads.

Steel, copper, brass, iron, potassium, titanate, glass and Kevlar. [11]

Harder materials are used in semi metallic brake pads to provide higher co-efficient of friction(μ) 0.28-0.38 they give poor wear at low temperature but excellent wear properties at higher temperatures of more than 200^0c. to increase frictional properties abrasives are used such as Aluminium oxide, iron oxide, quartz and Zircon etc. [4]

Lubricants like graphite are used for influencing the wear properties. To improve thermal properties and noise reduction elements like barium sulphate, antimony sulphate, Bismuth powdered form and Magnesium & chromium oxides. [5]

The following Table shows an elemental composition of the brake pad Material by the means of XRF [2]

Table No. 1

Element	Weight %
Mg	2.8
Al	3.2
Si	1.7
S	1.3
K	2.3
Ca	1.0
Ti	5.2
Fe	8.3
Cu	7.5
Zn	2.1
Zr	22.7
Sn	1.9
Ba	2.9
Bi	0.6
Sb	0.9

The above table illustrates the X-Ray fluorescence technique to determine the material of the pad on elemental basis by the means of Non-destructive technique.

Here in the below there are some of the illustrations of comparative results shown by through the graphical presentation the effect of wear with respect to the angular velocity of the brake rotor. [1]

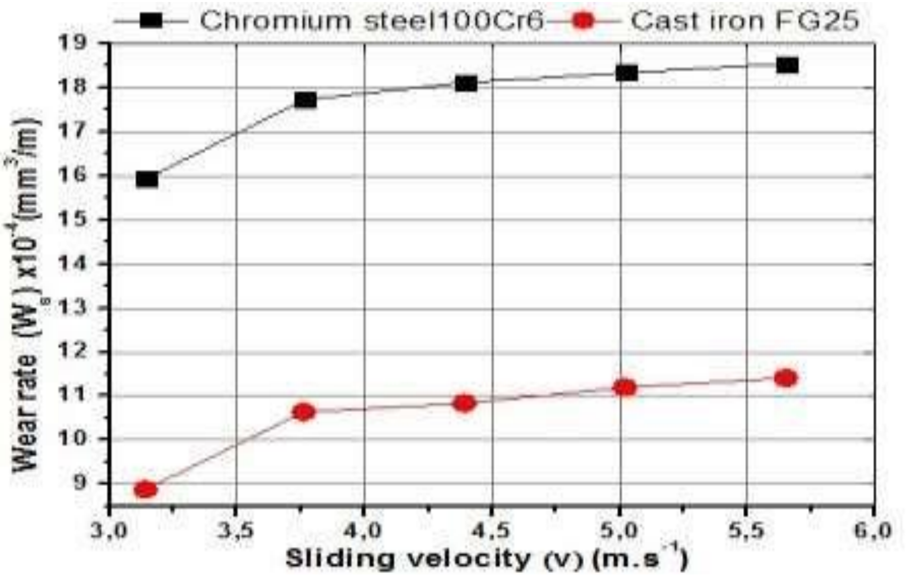

Figure: 3 behavior of wear rate on sliding velocity

Source: ISSN 1392-1207 MECHANIKA

The above graph shows the behavior of wear rate with respect to sliding velocity of the rotor by keeping the braking force as a constant parameter. The above graph was obtained on a SRV4 machine which is basically an oscillating or rotational feed frictional behavior tribology calculating machine for wear and friction parameters. But it is vastly used for lubricating materials to check their wear at high temperature characteristics.

CHAPTER 2

SCOPE OF STUDY

In the present scenario the world of technology is moving towards smart materials and mainly the research is being done in the field of engineering. Hence the field including Automobile, Manufacturing, Production, electronics and electrical etc. several industries are indulged in the work of smart materials. Hence, this project pre-report includes the work of the one of the esteemed area of automotive industry and is the required area where the need for smart material is to be considered. The automotive industry faces a greater challenge when it comes to the "wear" of the materials under load and friction. The report is being prepared on the wear analysis of brake pads of semi metallic alloy including silicon carbide and Graphene Nanoplatelets.

The one of the reason to go for the alternate material is to test the behavior of the Nano material in the progressive field of friction and frictional autopsy. The carbon-carbon bond and its strong nature in terms of strength. The graphene possesses an intrinsic tensile strength of 1.305 GPA and even possess a greater fracture toughness of 4 MPA. It can even distribute force of impact ten times greater than of steel. [3] On the other hand, silicon carbide is the one of the base materials for the production of brake pads. It comprises of many similar features suiting best for frictional material as silicon reacts with graphite to form carbon-carbon composite to become carbon-fiber-reinforced [4] material too possess a higher frictional strength.

CHAPTER 3

OBJECTIVE OF THE STUDY

The wear analysis of brake pads comprising of alternative materials as additives as Graphene Nanoplatelets and silicon carbide with the abrasive effect of Aluminium oxide on to them.

1. To find out the surface topography of brake disc and brake pad. [10]
2. To perform a pin on disc operation to view the wear rate illustration.
3. Study the wear rate as per applied load with speed characteristic.
4. Contact temperature as per different load characteristics. [1]
5. Contact temperature with speed characteristics.
6. Graphs to be conducted to show the difference. [1]
7. To find out the materials involved and their characterization with respect to the different amendments made in the experimental process.
8. To design a 3-d finite element model for the study.
9. Experimental study of tribological behavior of materials of brake disc and brake pads.
10. To compute and compare the results with the illustrated parameters in the Finite Element Model and experimental result. [1]

CHAPTER 4
REVIEW OF LITERATURE

Archard J, F 1953 et al. One widely used model for wear based equation is Archard's Law. The Archard equation is basically used to describe the sliding "wear" process based on the theory of asperity which says that any surface on an atomic scale is never smooth. [5] Hence the Archard's equation defines the total volume of the debris formed on behalf of sliding surface area, contact area, pressure applied and time intended for the process.

Where $Q= Kwl/H$ [6]

Q is the volume of debris formed, k is the dimensionless constant, W is the normal load applied, L is the sliding distance, H is the hardness of the Softest contacting surfaces. Where by the application local wear depth formulation at each point of surface is calculated using.

$\Delta h\ (x, y) = k/H\ P\ (x, y) * \Delta t*V$ [7]

P (x, y) is local contact pressure. T is the time step in which contact occurs and V is the sliding speed.

Aghagabad, R.Warnes et al. "k" is the dimensionless Archard's Constant, which is probably of wear debris formulation in asperity encounters for the mild wear it is k=10^-8 and for sever wear it is k=10^-2, in order to demonstrate the method of wear simulation study of a reciprocating sliding seal is done on a rubber seal coupled with an Aluminium rod. The study was carried on a used rubber seal taken out of the vehicle after a duration of service but ample amount of service was left for the rubber even. The load parameters speed of rotation such parameters were deeded during the 3-d design in the finite element method and the simulation was carried out for the reciprocating seal the parameters were such that the real situation during the vehicular characterization and at the end results were illustrated for the remaining span of life of the rubber seal and even the load criteria its behavior and wear rate for particular speed and load on the rubber were determined in the finite element model.[8]

N.H Elabbasi, Hencock et al. Wear simulation is a complex phenomenon with many industrial work involving mechanical brakes, seals, contraction and expansion, metal forming and orthopedic implants. The rate of wear depends on the type of material, contact pressure and elapsed time. We develop a 3-D thermal structural disc involving the brake disc assembly on FEM 3-D. surface topography of the pads to be measured. The contact tests using pressure indicating films are carried out in order to capture the static pressure distribution. A general law for the wear comprising of the Archard's equation to find out the generalized equation including the temperature with boundary condition. Hence, ordinary differential equation (ODE) in COMSOL Multiphysics with independent variables of thickness depth. The ordinary differential equation is solved for the upper face of the pads in contact. By developing a 3-D thermal structure. The structural and thermal illustrative were based on frictional heat generation, thermal expansion and thermal contact rotation in the thermal field by applying a rotational convective term in the heat transfer equation. The wear thickness profile was measured for every heat rotational value time period of 100 seconds. [9]

Hong u.s, Jong.S. et al. The frictional properties is not an intrinsic property of a particular material on the other hand this property depends on the tribological system which include material, and the other conditions. Those conditions include the load, outer humidity based on temperature, the kind of material, surface topography of material. [10] The wear procedure during braking includes abrasive wear, chemical reactions and fatigue wear. [11] Another wear rate formulae were given by the above based illustration as

$W_s = \Delta M / \rho L$ [11]

Where ΔM is the mass loss from the total mass or can be also called as the mass of the debris generated, L is the sliding distance, ρ is the density and Ws is the rate of wear in (mm^3/m).

Abdelkrim Lamjahdy et al. This case study involved the experiment being performed by using a pin on disc kind of test bench. Thermocouples were provided to measure the temperature rise; erosion rate was measured by the amount of volume loss out of total volume. The similar tests were conducted to measure relationships between temperature-speed, erosion volume-speed, erosion volume-force applied. The approach used here were XMS tests for finding out these relations, taking the brake pad as one of the important parameter for safety concern the performance characteristics to be find which basically depends on contact conditions which includes frictional heat and wear. [12]

Nitin V.K, K. Jagadeesan et al. The rotor and the pad both does have contractual interface, classified as dry sliding contact. While braking they both undergo wear mechanism. Contact tests were conducted using pressure indicating films to capture static pressure distribution. Surface topography was measured for the brake pads. This test was done for various braking conditions so that the static contact pressure distribution is measured. Predicting the results of FEM model were compared with simulated results.[13]

$\Delta h = \Delta h / t = k * P * v / H$ [6]

Where Δh is wear displacement, k is wear coefficient, t is sliding time, P is the applied pressure and V is the sliding velocity.

A.Belhocine, A.r Abu Bakar et al. During the braking process the kinetic energy conversion to the thermal energy is done at first stage by the means of conduction and further by means of convection and later by means of convection to the environment. The initial stage is our interest as the conduction takes place due to the contacting of the two surfaces of brake disc and brake pads. In this process the materials involved in the brake disc is Gray Cast Iron with high carbon content, which is relatively hard and wear resistance, even cheaper compared to Chromium steel and Aluminium and its heat dissipation energy is amendable. The Heat generation takes due to friction and the condition of braking. It is also distinguished in this paper is that if the condition of braking is much severe than the illustration for the thermal analysis has to be definitely carried out coz in the case of severe braking the temperature rise is very high and the time for the rise in temperature is very less and so is the dissipation of heat affect. Hence the results were carried out for better implant of thermal analysis. [14]

Piyush Chandra Verma et al. The one of the interest in this review was shown to the emission due to wear where it induced that 35% of the wear debris of brake pads are airborne (PM) particulate matter and out of that 86% of them do had the size of 2.5µM. Hence, several investigations carried out and the wear process was estimated to be the characterization of frictional layer on third body which is a mechanically mixed layer bearing the contact layer and the layer formed plateaus which is mainly formed due to the detachment of wear material and due to the heat, they form a primary plateau consisting of hard constituents. [2]

Dingenstien, Thomas et al. This paper indicates and is concerned about the clamping force which clams the brake pads with the calipers of the brake pads and the other fixtures attached to the braking system and is responsible for holding the stack of pads at a fixed position during the normal or sever braking conditions the braking process deals with the friction processing area and even determining the piston force and piston being sided at the same time. These forces tend to cause a tangential force which shifts in tangential direction. Hence this paper visualized the movement of caliper during a braking process and required method of visual measurement was taken to be recorded resulting in the movement of brake pads.

This test setup included by three kind of test benches like centrifugal test bench for better accessibility of components. The roll test for nearer illustration comprising with suspension system movement of vehicle where piezo transducers were use to measure suspension rise amplification. [15]

AR. Abu Bakar et al. in order to find out the predicted result coming out of 3-D model of Finite elemental analysis pressure indicating films of very low pressure ranging from 0.8MPa to 2.5MPa which was able to present the stress marks indicating only the pressure induced but not the quantity of pressure i.e. magnitude was unable to be predicted. Hence to capitalize this issue TOPAQ pressure analysis which can collaborate both qualitative and quantitate measurement are taken whose accuracy was ±4% for tactile pressure measurement. And the three-stage wear test was conducted for 1MPa for 10 minutes for 6 rad/sec. similarly for different speed and time of 20 minutes and then for 60 minutes. Then contact tests were conducted for 2.5MPa for similar 10,20 and 60 minutes respectively which was done for static conditions with stationary disc.

In FE model a Mitutoyo Linear Gauge LG-1030E and a digital scale indicator provided the reading and scaling of surface of both pads. Which adjusted the coordinates and nodes of brake pad interface in a simulation able manner. [16]

K.Naresh Kumar et al. The thermal and static analysis based on the brake pads and brake rotor was illustrated on the Ansys 15. The static test was done by taking two different alternative material as S2 glass fiber and carbon fibre for brake pads and Gray Cast iron for the brake rotor material respectively. Aluminium alloy is also used for intrinsic properties such as conductivity, strength workability, corrosion resistance and versatility. The 3-D model was prepared in solid works taking the dimensional geometry from a regular used car in India for the brake disc assembly. After the preparation of the 3-d model on solid works the same model was implanted in the Ansys 15 with proper boundary condition and variable degree of freedom for the simulation process and for further analysis work and results were computed by the means of computing for different time period and on different alternative materials and the compared results gave an experimental based analysis on the Ansys 2015. The results of each alternative material were compared for several parameters of braking applications. Based on the results the best material for thermal undeform ability for the braking condition and applicability was chosen to be Carbon fiber. The wear and thermal deformability was tested in several wise. [17]

JR Laguna Camacho et al. This study was based for the wear mechanism of brake shoe and disk but on a used pad of serviced for 8 months in a vehicle but the vehicle chosen was belonged to a city of nominal range temperature of 40-50^{0}C which usually lead to more wear process as the ambient temperature is already high in this region. The images for the worn and unworn surfaces were taken using Scanning Electron Microscopy (SEM). And even Chemical Analysis by Energy Dispersion Electron X-Ray Spectroscopy and perspective degradation was viewed on Atomic Force Macroscopy.

The tribological characterization of disk and Brake shoes conducted by taking small sample or region areas over the break shoe and as well as brake rotor for chemical analysis to compare the results. Micrography of the damaged surfaces and identification of different materials of disc and pads were utilized. These three kinds of tests being conducted for worn and unworn surface for different zones and different weight percentage. And the illustrated images of each tests and results were computed and compared to the unworn pads. And similarly, the result of other city serviced brake pads was computed by the same methodology where the nominal temperature was low comparatively. And conclusions were taken as the disk pads were sliding ad body abrasive wear, and direction of slide gave grooved appearance. [18]

G.P. Ostermeyer et al. In the brake system Characterization structures are to be found in the contact area. The patches formed due to frictional contact and its wear mechanism of the pad lead to a new type of differential equation of second order for the dynamic friction co-efficient describing stationary and transient conditions. After generation of the 2^{nd} order differential equation numerical integrations were computed on the related software. And the results were compared with the result of the optical analysis of the layers showing typical structure on the brake pad. [19]

Hyeong Gyu Namgug et al. In order to understand the wear debris of brake pads and its harmful affects on human hence the size of the (PM) particulate matter in the form of emission were needed to be known as the first priority. The increase or decrease due to temperature behavior, force behavior, and atmospheric humidity. The 9 different kinds of braking conditions using different instruments was conducted. And the results were characterized as of mainly of 2 types in terms of braking energy. The wear tests was carried out for criterion like OPC optical particle counter and APS aerodynamic particle size. The test was carried out for particularly high-speed subway trains which consisted of Non-Asbestos Organic (NAO) pad. The speed regulation of the subway train were tested for nominal range 100 kmph to 400 kmph and the brake force required for the braking which was tested was 60KN. Higher the speed higher the brake force for particular time period were conducted. [20]

Jehns Wahlstrom, et al. A major challenge when numerically simulating the disc brake contact is that various phenomenon occurs at different size scales, which makes it difficult to determine the model that adequately describes the contact situation. Numerical simulation can be performed in various approaches one of the best in that is (FEA) Finite element Analysis which does the simulation on a macroscopic scale. The numerical simulation approach in FEA was hard to achieve hence Whalstrom developed a cellular automation approach that can be used to simulate braking times in terms of seconds and length in terms of centimeters. Thus this literature approaches in the findings of microscopic and macroscopic scales for input parameters.

Chapter 5
Materials and Experimental Setup

The required materials and equipment of experimental setup for further proceedings are:

- Serviced Brake pads (purchased from Arun motors, Bahadurpura, Hyderabad)
- Serviced Brake disc (purchased from Arun motors, Hyderabad)
- Graphene Nanoplatelet GP-500(Purchased from, Ultra nanotech Pvt. Ltd. Gurgaon Delhi)
- Green Silicon carbide (purchased from Scienketic technology, Chandigarh)
- Aluminium oxide (Purchased from Vinayaka enterprises, Delhi)
- Pin on disc bench (available in R&D lab Thapar University, Patiala)

Ansys 15 Finite Element Analysis (DSR design and Engineering, Nacharam, Hyderabad)

Figure 4 Serviced Brake pads

Figure 5   Serviced Brake disc

Figure 6 Graphene Nanoplatelet (GP-500) 10gms

CHAPTER 6

RESEARCH METHODOLOGY

As many of the research work done by various Scholars showed a great interest in the tribology where the frictional and wear parameter are measured for different materials which are in contact with each other. As being a candidate from automobile field of study this tribology is very familiar for many applications of automobile industry. And many research have been done in the field of braking where the tribology is the main principle for its workability. Hence the study for different materials in the tribology is still commencing in the present scenario. I have taken Graphene Nanoplatelet as the alternative material due to its nature of making carbon-carbon bond for higher tensile strength and greater durability with the Silicon Carbide.

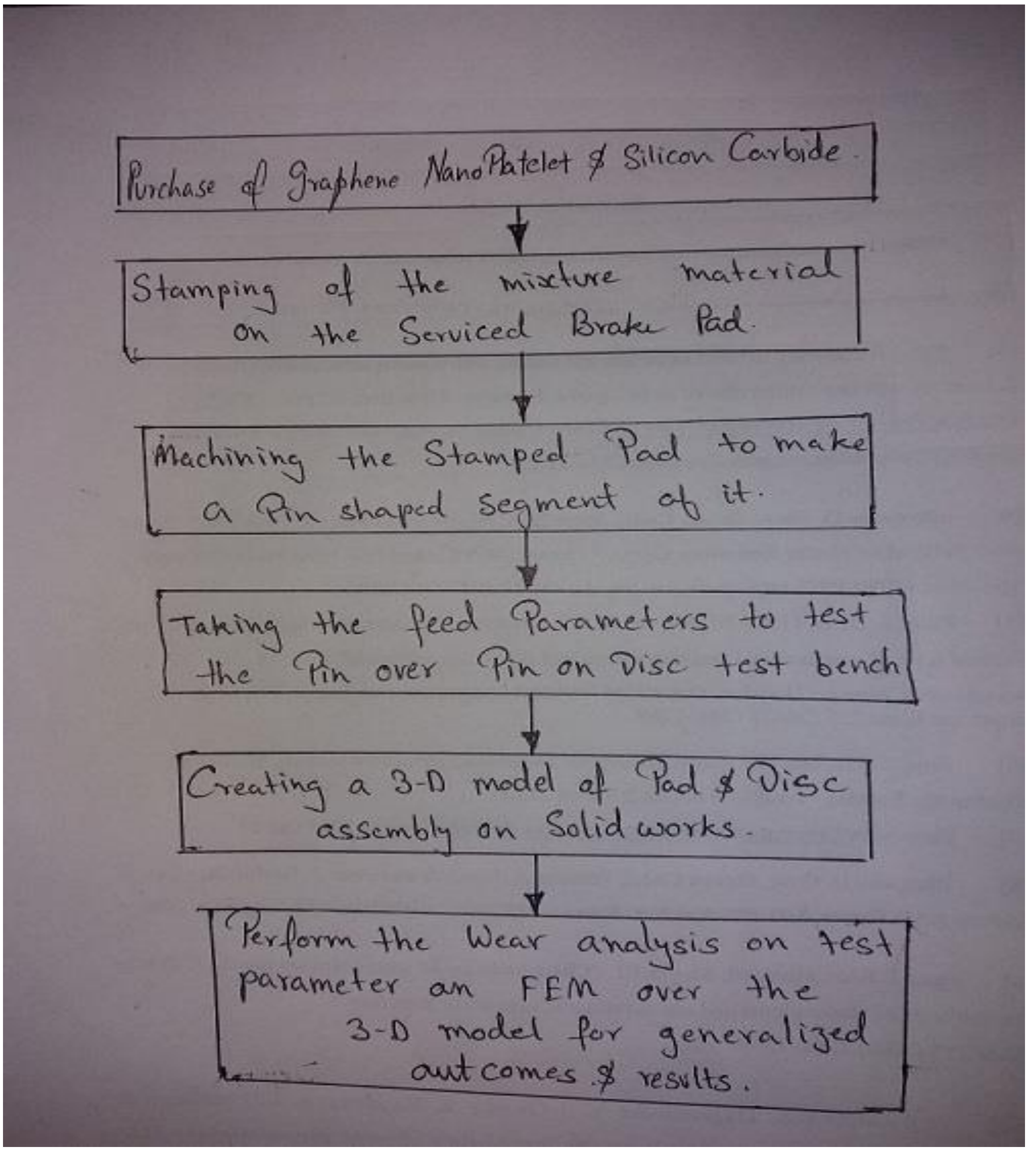

Figure 7 Flow Chart for Research Process

The above figure gives an overall procedure for the study to be carried out on the further based work to be done. The first step involves the material to be used and secondly being stamped it on the serviced brake pad as the wear and contacting friction occurs on the upper layer of brake pad and disc. The next step of the research methodology is to Machine that stamped brake pad to make a pin shaped segment of it as the test bench selected for the tribology testing is Pin on Disc test bench. And based on the parameters of the test carried outcomes they will act as the feed parameter for the wear analysis purpose.

The outcome parameters of the test rig such as

- wear rate W_s,
- applied force N,
- Sliding Velocity Rad/sec V,
- Volume of the wear Debris based on Archard's equation

will be given as the input parameter for the software analysis and the solid 3-D model made on these parameters will be carried out for further generalized outcomes and results.

CHAPTER 7

PROPOSED WORK PLAN WITH TIMELINE

Table No. 2: - Proposed work plan

Month/Date	Work Done/To be Done	Description
August	Topic Selection	Selected the topic for Wear analysis after the discussion with Mentor
September	Literature	Started to study about the various papers on the Wear analysis and its affects
October	Continuation of literature survey	Continued Studying about the wear Analysis decided for alternative material
November	Collection of Materials and report writing	Purchased all required materials (GP-500, SiC, Al_2O_3) for the experiments and writing the projected report.
December	Materials and Equipment	Stamping, Machining, and getting it segmented work for processing the experiment.
January	Permissions	Getting permissions for further proceedings in experimentation work.
February	Preparations & Experiments	The pin will be prepared and experiments will be done on test rig.
March	Analyzing and Report	Results obtained will be analyzed and report will be written
April	Paper writing	Paper writing for publishing in journal will be started

CHAPTER 8

EXPECTED OUTCOMES AND CONCLUSION

To learn about

- The wear analysis of the Break pad and Disc assembly and the effect of alternative material on the frictional behavior.
- The formations of wear plateaus and its nature (ductile or brittle fragments)
- Thermal behavior of the assembly.
- Study the outcomes and compare the result with another pin and the pin prepared.
- Understanding the physical mechanism involved in sliding contact disc
- Discussing the result and errors occurred and concluding the drawbacks to overcome on it.

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