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S.D.M. COLLEGE OF ENGINEERING & TECHNOLOGY
DHAVALAGIRI, DHARWAD-580002

(AFFILIATED TO VISVESWARAYA TECHNOLOGICAL UNIVERSITY)

Minor-Project-2 Report on

"Experimental and Finite Element Analysis of wear characteristics of Aluminum 6061 sheet"

Bachelor of Mechanical Engineering

VI Semester

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2021-22

ABSTRACT

The main objective of this work was to evaluate the wear characteristics in Pin-on-Disc (POD) tribology test setup with of Aluminium 6061 sheet as the tribo elements under self-mated conditions using finite element method (FEM). Type Aluminium 6061 sheet is a major core and structural material in the Welded assemblies Marine frames Aircraft and truck frames. Any mechanical systems with moving parts encounter the problem of wear and industries across the world are trying to reduce its detrimental effects in this paper, Finite Element Method (FEM) is used for analysis of wear characteristics of Al6061 Aluminum alloy. Finite Element Method (FEM), introduced at the end of sixties, is used for solving engineering problems by mathematical formulations. The present study estimates the thermal stresses and temperature distribution induced at the contact surface during frictional sliding. With the help of the apparatus we find different variations such that load and wear rate and time and wear rate variations when load is constant and also pin radius and wear rate variations. These wear testers are generally used in light truck brake pads, on railway tracks, disc brakes.

CONTENTS

Chapter 1.Introduction

Study of friction and wear Study of friction, wear and associated lubrication in case of interacting surfaces under relative motion is the purview of tribology. Wear determines the useful life of a part/product. Product quality as well as reliability also depends on wear. Hence the study of friction, wear and their control play an important role in different engineering applications.

For the functional reliability of any component, it is very important to control the friction and wear in case of sliding contact. A fundamental knowledge base is helpful to achieve the control. Friction and wear are system dependent properties. There are several research-based models and formulations in the field of friction and wear. However, majority of them are not suitable to predict the tribological behavior in a particular work situation. This practical limitation necessitates the iteration of friction and wear data through practical experimentation in a particular situation and for a particular tool-work materials combination.

Present work has been carried out to study the wear characteristics of Aluminum 6061 alloy. Aluminum is a heat-strengthened alloy with good formability, weldability, machinability, and medium strength. It can still maintain good operability after annealing. The main alloying elements of 6061 aluminum are Magnesium and silicon form the Mg2Si phase. If it contains a certain amount of manganese and chromium, it can neutralize the bad effects of iron; sometimes a small amount of copper or zinc is added to increase the strength of the alloy without significantly reducing its corrosion resistance; there is a small amount of conductive materials In order to offset the adverse effects of titanium and iron on conductivity; zirconium or titanium can refine the grain and control the recrystallization structure; in order to improve the machinability, lead and bismuth can be added. Mg2Si is solid-dissolved in aluminum, which makes the alloy have artificial age hardening function.

The nominal composition of type 6061 aluminum is 97.9% Al, 0.6% Si, 1.0%Mg, 0.2%Cr, and 0.28% Cu. The density of 6061 aluminum alloy is 2.7 g/cm^3 (0.0975 lb/in^3). 6061 aluminum alloy is heat treatable, easily formed, weld-able, and is good at resisting corrosion.

Applications of Type 6061 Aluminum:

*Its list of uses is exhaustive, but some major applications of 6061 aluminum alloy include:

- Welded assemblies, Marine frames, Aircraft and truck frames Chemical equipment, Electronic parts, Furniture, Fasteners, Heat Exchangers and Heat Sinks.

Figure 1: Aluminium sheets

OBJECTIVES OF THE PROJECT

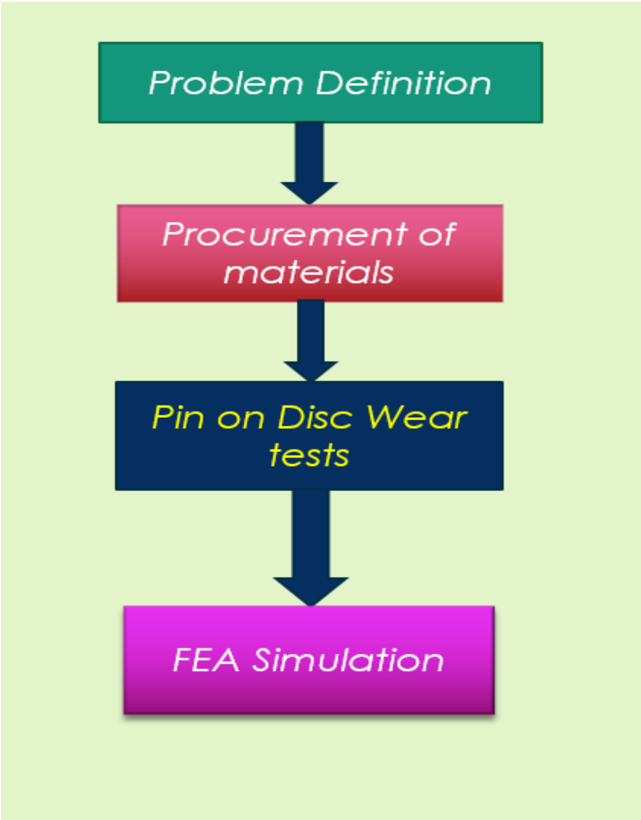
1)To Study the wear Behavior (pin-on-disc)of aluminum 6061sheet.

2)To perform wear tests of heat treated samples.

3) To perform finite element analysis using Abaqus software.

Chapter 2. Literature Review

Methodology



Literature review

C. Gonz´alez et.al, the paper is titled as Numerical analysis of pin on disc tests on Al–Li/SiC composites in the paper they have analysed the wear characteristics of al-li composites. The investigation was performed on a commercial Al–Li alloy 8090 and the composite reinforced with 15% of silicon carbide particles. Due to the presence of lithium, this alloy exhibits elastic modulus significantly higher than more convention.al aluminium alloys. The elastic modulus of the composite Al–Li 8090 + 15% of SiC is over 100 GPa. The material was supplied by Cospray (Banbury, UK) in the form of an extruded bar produced by spray co-deposition of the matrix and particles onto a substrate. The size of the reinforcements was 7.5±2.4_m with an aspect ratio of 2.4±1.2. Matrix grain size is on average 12 _m in the longitudinal direction and 6 _m in the long and short transversal ones. Details about microstructure can be consulted in the reference.[1-3]

Pin on disk tests were performed to evaluate the wear behaviour of the materials. Wear tests were carried out in aWazau machine TRM 1000, able to perform a standardized pin on disc test. Nevertheless, several modifications were introduced, mainly regarding the pin shape. Prismatic pins were made of the material under study with rectangular section of 2.5mm×6.3 mm. With this geometry, the nominal contact area was maintained constant during the tests in spite of the wear process. The disk, made of carbon steel (SAE 1045), rotates horizontally at sliding speed of 0.1 m/s. A dead weight loading system was used to perform three sets of tests carried out at normal loads of 100, 150 and 250 N, corresponding to nominal pressures of 6.3, 12.5 and 16.5MPa, respectively. The bulk test temperature was modified from room temperature to 250 ◦C by a furnace installed in the machine. Preliminary tests show that 500m was sufficient distance to reach a steady-state wear regime. Specimens were not lubricated and the debris formed was not eliminated. Friction torque and the linear wear amount were continuously measured during the test, providing data of friction coefficient and wear rate.

Sumit Khot, Utpal Borah entitled Finite Element Analysis of Pin-on-Disc Tribology

Test have done simple finite element analysis about pin on disc wear test Introduction Wear can be defined as the phenomenon of removing the material from the surface due to interaction with a mating surface. There is a fact that almost all the machines due to wear lose their durability and reliability. Hence there is a possibility of inventing new machines which are more advanced are reduced because of wear problems. Wear rates can be changed drastically between the range of (10-15-10-1) mm 3 /Nm which depends upon the selection of the materials, components and methods used. Wear can be either good or bad. Examples of productive wear are shaving, writing with a pencil, polishing. Wear is undesirable in almost all machine application such as bearings, seals, gears and cams. The primary aim of the work that they have carried is to evaluate the state of stress and strains and its evolution with the sliding cycles for the case of 316LN Stainless Steel in the form of a rounded pin in contact with a metallic spinning disc using FEA program. The simulation is expected to permit isolation of the individual effects of operating parameters such as load, sliding speed and sliding distance. Also, in terms of suggesting further improvements to the simulation process and widening its application, this type of conformal contact in which, the deflection of the pin arising from the frictional reaction created during sliding is non-negligible. The process leading to loss of material is known as "wear". Major types of wear include abrasion, friction (adhesion and cohesion), erosion, and corrosion. Wear can be minimized by modifying the surface properties of solids by one or more of "surface engineering" processes (also called surface finishing) or by use of lubricants (for frictional and adhesive wear). Contacting elements of structures are very common in technology. Many mechanical devices and mechanisms are constructed with the aid of component parts contacting one with another. Contact regions occur between tools and work pieces in machining processes. Loads, motions and heat are transmitted through the contacts of structures. Friction and wear accompany any sliding contact. It has been agreed that wear cannot be totally prevented. In machine technology, wear is an equally important reason of damage of materials as fracture, fatigue and corrosion.[3-8]

FEM consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEM may be used to help determine the design modifications to meet the new condition. There are generally two types of analysis that are used: 2-D modeling, and 3-D modeling. While 2-D modeling conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less accurate results. 3-D modeling, however, produces more accurate results while sacrificing the ability to run on all but the fastest computers effectively. Within each of these modeling schemes, the programmer can insert numerous algorithms (functions) which may make the system behave linearly or non-linearly.[4-11]

Contact analysis that the authors have used.

Hertz Contact Analysis

Contact mechanics deals with bulk properties that consider surface and geometrical constraints. It is in the nature of many rheological tools to probe the materials from "outside". For instance, a probe in the form of a pin in a pin-on-disk tester is brought into contact with the material of interest, measuring properties such as hardness, wear rates, etc. Geometrical effects on local elastic deformation properties have been considered as Hertz Theory of Elastic Deformation. This theory relates the circular contact area of a sphere with a plane (or more general between two spheres) to the elastic deformation properties of the materials. Finite element simulations of ball indentation tests will be perform and analyzed using the Hertz ball indentation method. The accuracy and reliability of this method will be assessed. It shows that ball indentation testing techniques can be used to evaluate stresses and strains between the ball and disc. This work is aim at assessing the accuracy and reliability of this method based on finite element analysis (FEA) simulations of the ball indentation process.[8-12]

A pin-on-disc study of the tribology characteristics of sintered versus standard steel gear materials entitled by Podra and Anderson have studied about tribological characteristics of steel gear. The FE simulation was designed to model the macroscopic 2D profile of the contacting surface of the pin generated due to wear as a function of the contact pressure and sliding distance for certain sliding speed.

The “direct generation” method was used to create the meshing. This means, that the coordinate location of every node and the size, shape and connectivity of every element was determined manually. This technique, in contrast to creating solid models using computer-aided design (CAD) components of ANSYS, automatically picks and connects the nodes, creating elements based on a few user-defined restrictions. Direct generation is a time consuming process, but allows complete control over nodal and element numbering, which is important for incorporating the wear algorithms. Four types of elements were used in the pin and disc mesh as shown. The region labeled “Wear Elements” is made of uniform-sized, four-noded quadrilateral elements taking into account that the best numerical results are obtained when the size of the elements remain uniform and the shape is of the original parent element. Furthermore, it was expected that the robust square shape of the elements would delay any ill conditioning. A denser mesh was used in this region because of expected high contact stress gradients.[12-13]

Boundary conditions for FE model

The boundary conditions for the idealized case and referred to as direct loading are shown as proposed by Podra and Anderson. Nodes hold the pin, but the whole system can move freely along the vertical axis. The contact pressure applied directly to the top of the pin is derived from the normal load. These boundary conditions are a recognized representation of the pin holder and are simple to implement, which made them an appropriate starting point. In the case of lever-arm configuration and as shown in the pin holder was devised using the solid model approach, defined earlier. The rectangular section representing the arm was allowed to rotate with respect to the pivot and contained a region of higher mesh density contacting the pin that acted as its holder. Also included was a joint element, shown in the top right corner of the FE model, allowing the arm to pivot freely in the X–Z plane. The load was applied as a uniformly distributed pressure on the uppermost nodes of the arm, perfectly aligned with the pin. The option in ANSYS allowing a gradual increase of the load was chosen, knowing that this procedure would typically yield better results due to the iterative solution technique. To simulate the relative motion of the spinning disc in contact with the stationary pin, a single horizontal translation was used. The arm was allowed to pivot to bring the pin in permanent contact with the disc.[13-15]

Chapter 3. Experimentation (wear test)

Materials: The investigation was performed on a commercial Al 6061 alloy the material was procured and then cut using CNC machine. Samples of size 8mm diameter and 25mm height were taken for the project work.

The chemical composition of the alloy (AL-6061) is as followed:

Constituent element	Minimum (% by weight)	Maximum (% by weight)
Al	95.85%	98.56%
Mg	0.80%	1.20%
Si	0.40%	0.80%
Fe	0	0.70%

*Wear-According to ASTM G-40-04, Wear is defined as ―Damage to a solid surface, usually involving progressive loss of material, due to relative motion between that surface and contacting substances. Wear is related to interactions between surfaces and more specifically the removal and deformation of material on a surface as a result of mechanical action of the opposite surface. The need for relative motion between two surfaces and initial mechanical contact between asperities is an important distinction between mechanical wear compared to other processes with similar outcomes.

*Sample preparation: As our main objective is to find wear rate for sheet metal made of aluminum 6061 of 1mm thickness is taken and cut into circular pieces of diameter 8mm using CNC machine and the pin is prepared on lathe machine of 8mm diameter and 24mm height. The specimens are attached to the prepared pin using a metal fixer.

Wear tests of samples have been carried out on pin on disc apparatus supported with magnum software. The samples have been slid against disc. The track radius is 50mm and hardness of 60HRC. Wear rate is measured in terms of meter cube/min. With the help of linear variable differential transformer. All the test has been carried out at an average room temperature. As most important parameters are identified as rotational speed of wheel (rpm), load on the job and duration of test run but here rotational speed of wheel, load on the job is kept constant, time is varied. RPM set for 150 and a load of 20N is applied for the first 3 trails and 200 RPM and a load of 20N for the next 3 trials , for a time interval of 4,6,8 minutes of the said parameters have been selected for the wear test. A total of 6 experiments were conducted for as received, heat treated(1 HR aging) and heat treated(2 HR aging). Initial and final weights of all the specimen (before and after the wear test) are noted down. Difference of two values indicates the weight loss of the specimen due to wear.

*Pin on disc tester:

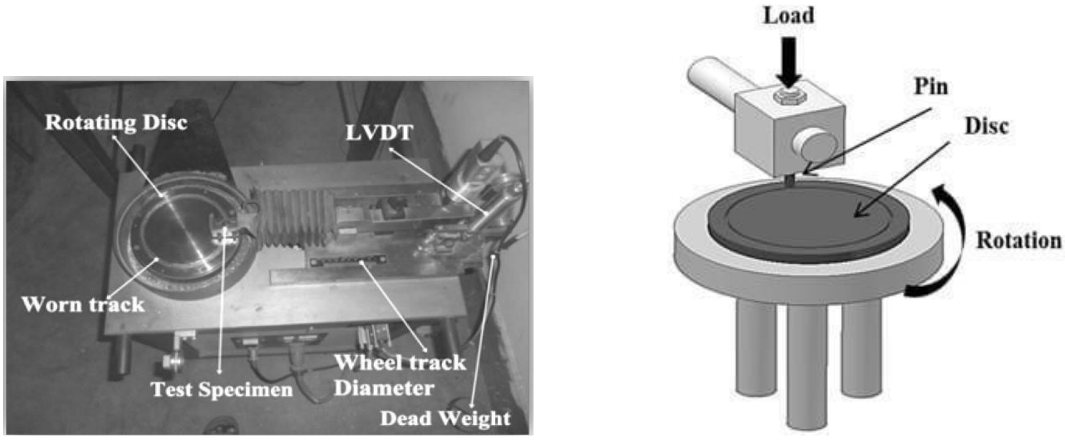


Figure 2: Pin on disc apparatus

To study the wear of a material we must simulate the process in controlled manner to study the effect to the effect on different samples and the same test conditions. To achieve this, a magnum Pin-on-Disc Tribometer will be used. In this test, the wearing block of aluminum 6061 and the static sample is used which will be in contact with the surface will be an 8mm diameter aluminum metal. The sample is mounted on a rotating stage and a pin which will be in contact with the sample surface within a known force and to create wear. It is used as a comparative test in which controlled wear is performed on the samples to study. The volume/weight lost allows calculating the wear rate of the material. And the data is obtained directly from software. Similarly, the test is carried out for different heat-treated samples. Figure below shows before and after wear samples.

Heat Treatment

Purpose of Heat Treatment:

Many materials may have to go through procedures that change their grain structure during the manufacturing process. Heat treatment is a technique of changing the physical properties of metals, such as their ductility, and then improving them to meet different industry demands by utilizing controlled heating and cooling procedures. These heat treatments differ based on the metal form and the mechanical properties needed for the required strength specifications, the proper heat treatment procedures must be followed.

The hardness and strength of some aluminum alloys (e.g., the 2xxx, 6xxx, 7xxx, and 8xxx series) can be increased through heat treatment. Natural aging, artificial aging, annealing, solution heat treatment, homogenizing are some of the aluminum heat treatments.

Heat treatment of the samples is done in electric muffle furnace and then cooled in an open environment. Aging and water quenching is done. Aluminum 6061 has been selected for present experimental work. The material has been collected directly from the market and samples of size 8mm dia and 1mm thickness are used.

Conducted heat treatment of samples in a microprocessor controlled electric muffle furnace. The setup is shown in figure 3. Several ways of hardening and softening is discussed by different researches in the research studies.[12-15]

Figure 3: Muffle Furnace

Initially samples are heated around 540°C and allowed to dwell for 2 hours inside the furnace itself, then the samples are transferred to room temperature medium and air cooling is done.

*Aging: For this particular process, test specimens are heated up to 240°C from room temperature and 1 hour and 2hour dwelling is given respectively and water quenched then.

During quenching heat treatment, the material is heated up to suitable temperature to and then quenched in water to fully harden, varying on the kind of metal being worked on. Items that go through this are then aged, tempered or stress received to achieve the desired stability.

Sudden cooling from high temperature is technically known as quenching.

Chapter 4. Finite element analysis

FEM consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEM may be used to help determine the design modifications to meet the new condition. There are generally two types of analysis that are used: 2-D modeling, and 3-D modeling. While 2-D modeling conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less accurate results. 3-D modeling, however, produces more accurate results while sacrificing the ability to run on all but the fastest computers effectively. Within each of these modeling schemes, the programmer can insert numerous algorithms which may make the system behave linearly or non-linearly.[14-15]

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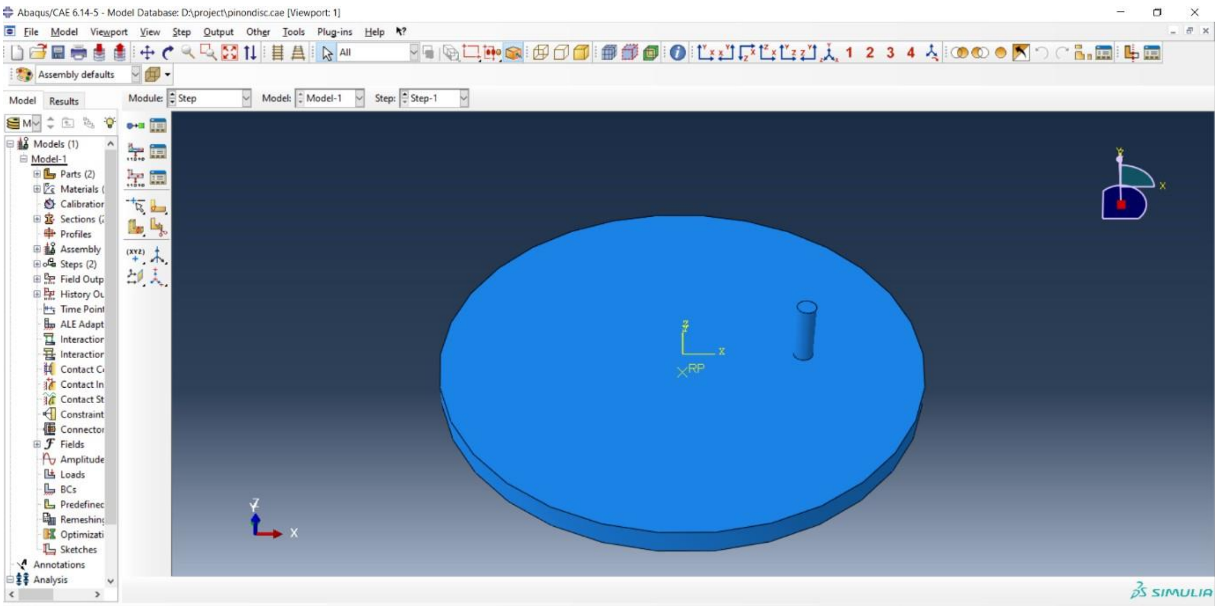


Figure 4: FEM MODEL

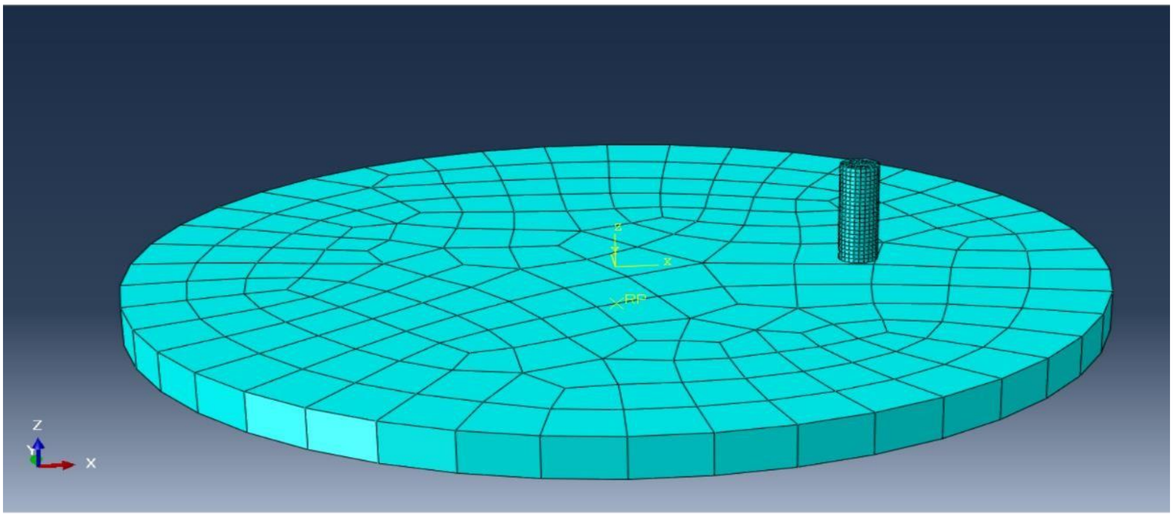


Figure 5 Meshed model

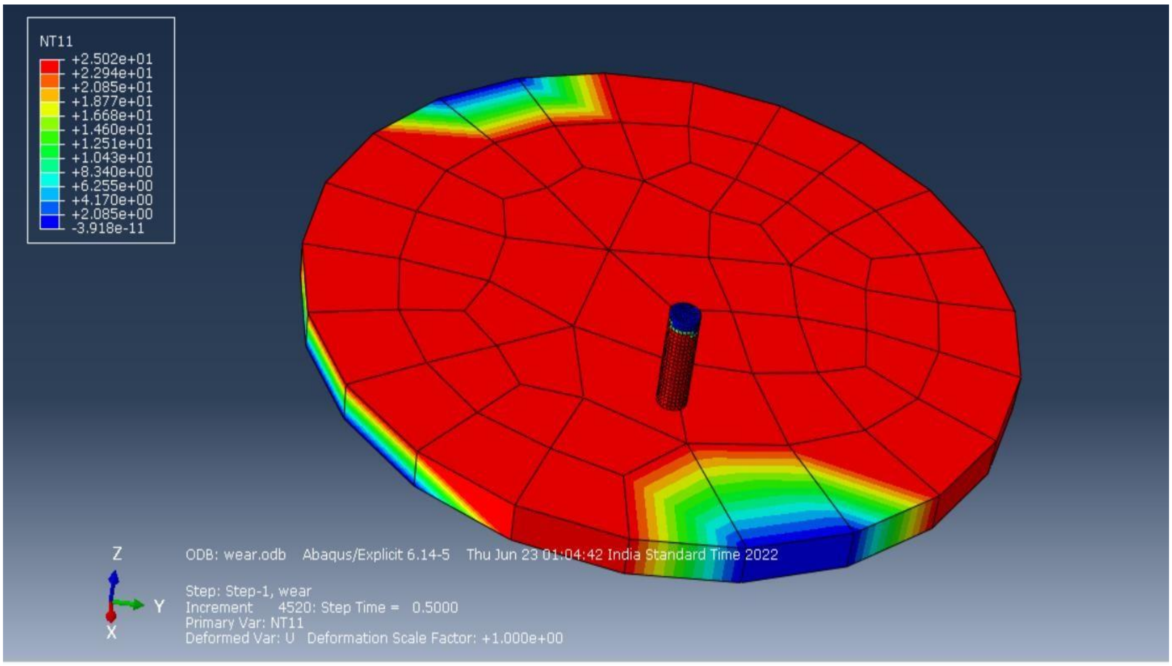


Figure 6 Temperature distribution at disc nodes

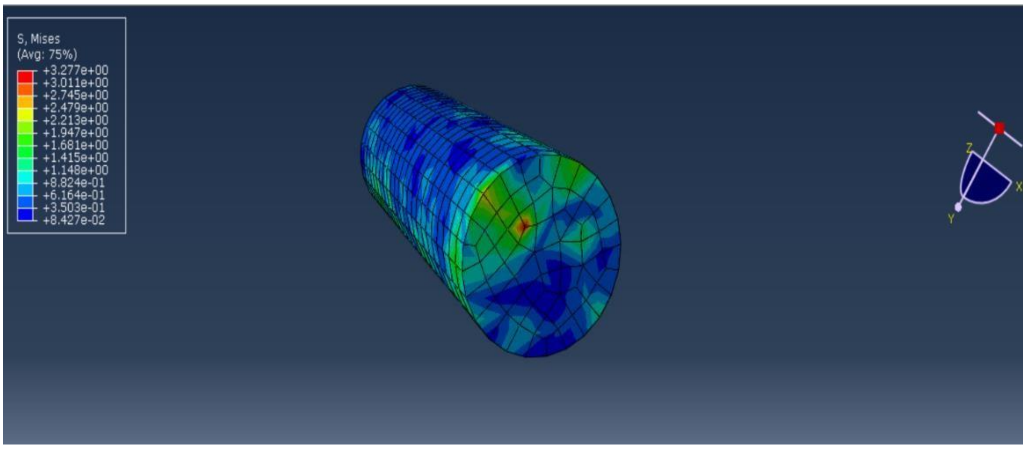


Figure 7 Stress distribution on pin

Chapter 5. Results

Some predefined parameters are given for conducting the experiment.

FORCE= 20N

SPEED OF ROTATION = 150,200 RPM

TEST DURATION= 4,6,8 Mins

RADIUS OF WEAR TRACK= 50mm

5.1: The results of as received samples were done first so the resuts obtained are tabulateddown:

Load in(N)	Frictional Force(N)	Speed in rpm	Time of running(t) min	Sliding distance 2πrNt	Weight (g)			Wear Rate (m3/min)
					w1	w2	w1-w2	
20	7.3	150	4	188.496	3.460	3.450	0.01	19.66*10^-9
20	8.0	150	6	282.743	3.450	3.430	0.02	26.17*10^-9
20	7.8	150	8	376.991	3.450	3.390	0.06	58.8*10^-9
20	7.4	200	4	251.327	3.450	3.440	0.01	14.72*10^-9
20	7.9	200	6	376.991	3.450	3.430	0.02	19.6*10^-9
20	8.2	200	8	502.655	3.450	3.410	0.04	29.47*10^-9

5.2: The results of 1 hour aging at 240°Cobtained are tabulated down:

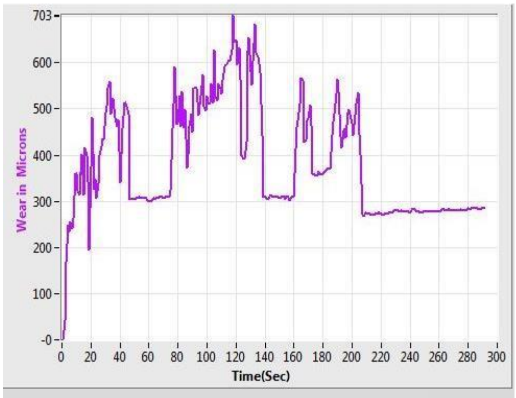
Load in(N)	Frictional Force(N)	Speed in rpm	Time of running(t) min	Sliding distance 2πrNt	Weight (g)			Wear Rate (m3/min) $\times 10^{-8}$
					w1	w2	w1-w2	
20	7.3	150	4	226.195	3.460	3.450	0.01	1.64
20	7.5	150	6	339.292	3.470	3.450	0.02	2.1
20	7.8	150	8	452.389	3.440	3.410	0.03	2.5
20	8.2	200	4	301.593	3.450	3.440	0.01	1.22
20	8.5	200	6	452.389	3.460	3.430	0.03	2.5
20	8.8	200	8	603.186	3.460	3.410	0.05	3.01

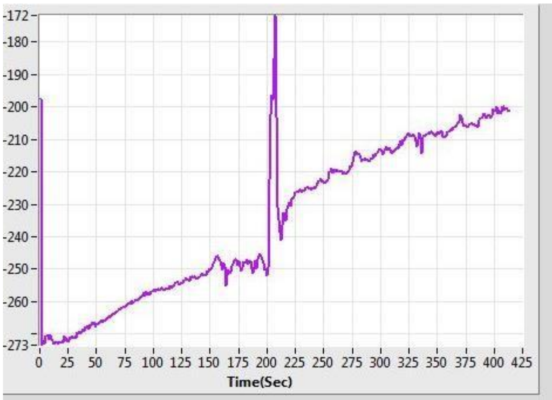
5:3 The results of 2 hour aging at 240°Cobtained are tabulated down:

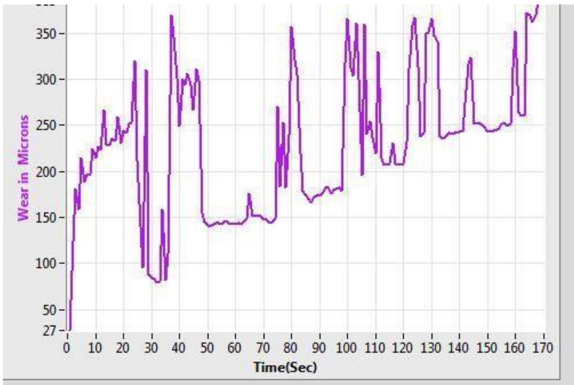
Load in(N)	Frictional Force(N)	Speed in rpm	Time of running(t) min	Sliding distance 2πrNt	Weight (g)			Wear Rate (m3/min) ×10^{-8}
					w1	w2	w1-w2	
20	9.2	150	4	226.195	3.400	3.390	0.01	1.64
20	9.4	150	6	339.292	3.420	3.400	0.02	2.2
20	9.8	150	8	452.389	3.410	3.380	0.03	2.5
20	11.2	200	4	301.593	3.410	3.400	0.01	1.23
20	11.4	200	6	452.389	3.410	3.390	0.02	1.6
20	11.8	200	8	603.186	3.400	3.360	0.04	2.4

5:4 Graphs that are obtained:

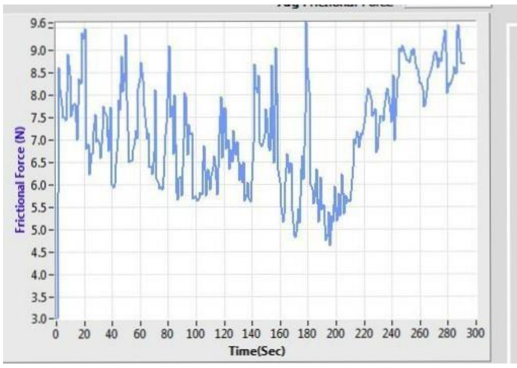
1) Time(in seconds) vs Wear(In microns):

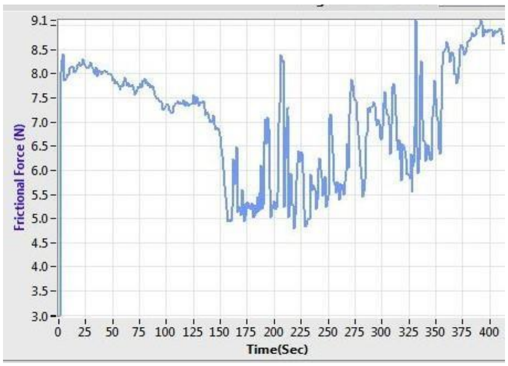


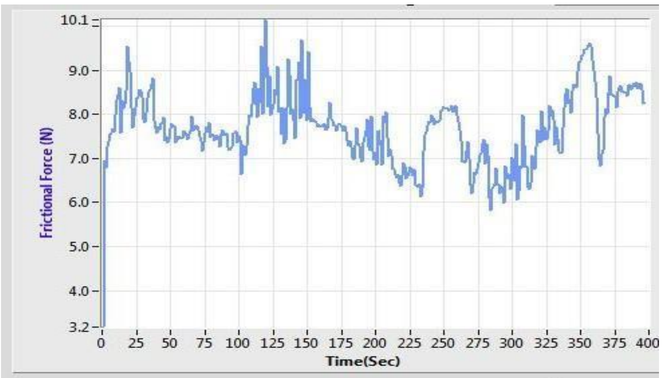




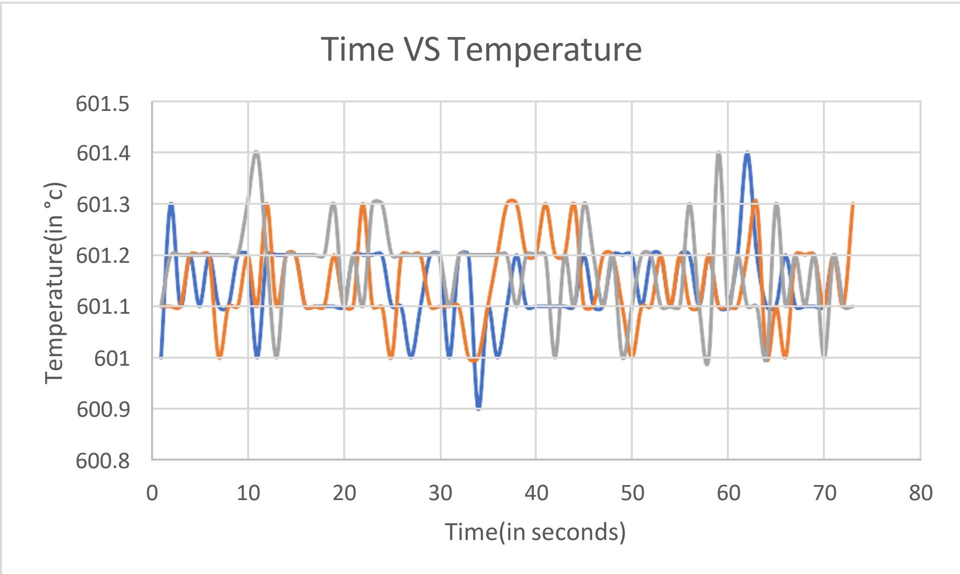
2) Time vs Friction Force:







3) Time Vs Temperature.



Chapter 6: Conclusions

Some important findings / conclusions made from the present study are:

* Wear characteristics of aluminium 6061 alloy sheet is studied .

*Finite simulation of aluminium 6061 was done.

* Different parameter of graphs were studied.

* We found that the normal samples as received shows very high wear rate whereas Aging samples or the samples which are water quenched are good wear resistant.

Chapter 7: References

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Workweek Schedule

	Month	March				April				May				June			
Sl.no	Week	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Literature survey			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
2	Experimentation(Untreated)							✓	✓	✓							
3	Experimentation(Heated)										✓	✓					
4	FEA												✓	✓	✓	✓	
5	Report Writing													✓	✓	✓	✓