OPTIMIZATION OF TRIBOLOGICAL PROPERTIES BY COATED ELEMENT

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Abstract - *Low carbon steel materials are used for different machine parts. In this thesis we study Tribological properties of material like wear, co efficient of friction etc. Tribological Properties are minimized while progressive loss of substances from the operating surface of a body occurring as a result of relative motion and also material may get fails after some days. It is not possible to reduce wear rates completely zero, but we can minimize. We can improve tribological properties of material by coating. Substrate is coated with the material which has low coefficient of friction and high wear resistance property. A pressure vapor deposited coatings TiN, TiC, and TiAlN are done on mild steel 1018 material which shows that, their tribological behavior on the surface provides low friction while sliding against mild steel and also found that carbon-rich coatings shows lower friction than others. Tribological properties are determined experimentally by pin and disc experiment and those results are validated in ANSYS Workbench software. Simulation of contact is performed on pin on disk model, while model is used for contact analysis. Using displacement boundary condition on pin, disk and applying 5 m/s rotational velocity on disc the analysis is done. Then by applying normal load on the pin wear volume and wear rates are determined. This process is performed on Coated and uncoated pin materials taken for wear analysis. Using wear volume the wear rate is calculated those values helps to determine which pin material gives optimum wear rates.*

Keywords: *wear analysis, contact stress analysis, Tribological properties of coated metals.*

1. INTRODUCTION

Wear, Friction are the two surface properties they are responsible for many problems and large costs for engineers and designers. Designers always consider these factors into account while making the new equipments/components. When two bodies come in contact by mechanically sliding each other, there is a friction and frictional force acts perpendicular to sliding direction. For some of the application friction is necessary but for certain application frictional coefficient should be low for example, wheel bearing, mounting plates, brackets etc. Other phenomena take place when two metals are in mechanical contact that is wear, when two bodies are in contact, material removes that creates problems. Controlled wear is necessary for certain application example drilling hole in concrete wall. So the designers are making the equipments that worn as little as possible. With respect to wear and friction tribology is the main phenomena that is important while transportation of goods in a car truck and by train. Many benefits can be gained by minimizing wear and friction. In this thesis we discuss the properties for deeper understanding tribology which can improve the performance of components.

In order to reduce the wear we can use the lubricant, depending on lubrication condition friction may occur. Dry friction, Semi dry friction and Liquid friction, in dry lubrication metal to metal contact happens so the friction is more. In semi dry friction there is a thin layer of lubrication between the two surfaces so lubrication is lesser in quantity then surfaces comes in contact easily so the friction happens. In liquid friction there is thick layer of lubrication between the surfaces so that load acting is transferred to the layer of lubrication to another layer so friction is less.

Tribology And Surface Engineering

Tribology is the scientific discipline between wear, friction with lubrication. The major part of tribology is design a rolling and sliding surfaces in such way that it shows the minimum friction and high wear resistance. Low friction between the contacting surfaces means less energy loss and lower fuel consumption. While developing any technical equipment the choice of material for certain details is compromised because all materials will not shows the same properties, if one has more harder it will have a low toughness, for example harder material is usually brittle. For of the applications harder and tough materials are desired but for overall performance there will be compromise between hardness and toughness. In order to get the desired tribological properties we choose the low tribological properties for example more tough, low price and low weight and that material is coated with high wear resistance, low friction coefficient material. Another name for this process is surface engineering. Name suggests that we are manipulating the surfaces in order to get the desired properties. Similarly by case Hardening and nitriding hard surfaces may get. Technique of applying coating on poor substrate is successfully applied on various fields of technology like electrical equipment, optical devices and tools of cutting and forming. By coating both bulk and surface properties are optimized. Some Materials are not possible to synthesis they are used as coating material. Another advantages of coating is expensive materials are used in a very small quantity.

1.3 Vacuum Deposition Process

This process is one of the special group coating, Coatings are formed on the surface of the substrate that should be coated, vapor containing the coating material elements. This process is carried out in controlled atmosphere at relatively low pressure and high temperature. In this thesis coating ir prepared by PVD process. PVD is characterized by the process in which material changes its phase from condensed phase to vapor phase and then return back to its condensed phase by forming a thin film on base material. The most used type of PVD Techniques Evaporative deposition, sputter deposition, ion induced deposition, cathode arc deposition. Sputtering process works on the bases of the momentum of principle formed by collision of atoms and molecules. Plasma glow, ion accelerator radioactive element is used to evaporate material; argon gas is used for inert atmosphere.

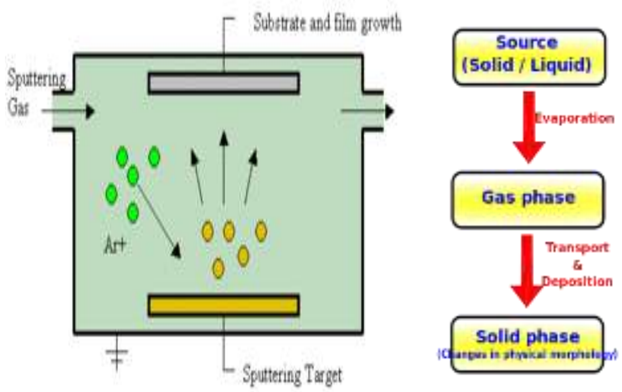


Fig.1.PVD Process

2. EXPERIMENT DETAILS

2.1 Machine used

In this thesis we used a pin on disk experiment set up for calculation of wear properties. The system consists of a spindle and chuck for holding the revolving disk, a lever arm device to hold the pin and attachments to allow the pin against the rotating disk with controlled load. Wear track on the disk is circle on that same path multiple wear tracks are generated. It consists of a variable speed motor capable of maintaining constant speed. Motor is attached in such a way that it should not affect the test. Pin specimen holder is stationary which is perpendicular to the disk which is attached to the pivot. Lever has a provision for placing the load. Sensors are used on the lever to detect the actual load acting on disk while rotation. Pin and the arm are constructed in such a way that it should have a less vibrations. For speed regulations there a speed regulator provided on the instrument. Specimens are weighed before the conduction of test by Digital weighing machine and test is carried out for different load and speed with respect to time, after the test again the pin is weighed. From all the collected data wear resistance, wear coefficient are calculated. Test apparatus as shown in Figure.2

Fig.2 Pin on Disc Apparatus

2.2 Material used

2.2.1 Disc

Disc used in the experiment is Mild Steel black material dimensions are 200mm diameter and 15mm thickness. Surface of disk is blackodised to prevent from corrosion environment. Disk used in test is shown in figure.3

Fig.3 Disc

2.2.2 Pin

The main part of this thesis is selection of material on which the experiments are carried out. I have chosen the material low carbon steel, Mild Steel (1018 grade). Low carbon steel is most widely used material in industries machine components, gears, pinions, mounting block, brackets, pinions etc. Dimension 120mm length and 16mm diameter raw materials are purchased and turned the specimens according to dimension required for pin on disk experiment that is 100mm length and 10mm diameter. For more surface area we have made a step on one side of the specimen about 10 mm length and 15mm diameter. Uncoated specimen prepared for test is shown in figure.4

Fig.4 Pin (Mild steel)

2.2.3 TiC (Titanium carbide) coated pin

Fig.5 TiC coated pin

Figure.5 shows the TiC coated substrate Material. TiC material is very hard and stiff often used for many of the applications where low friction is desired. TiC is available in black powder form which is used in sputtering target, due to higher temperature, directly by changing the phase of the material TiC is deposited on the substrate. By rotating the substrate smooth constant layers are deposited 2 micron thickness is maintained for TiC Coating.

2.2.4 TiN (Titanium Nitride) coated pin

Fig.6 TiN coated pin

Titanium nitride is ceramic material it is very hard which is widely used for coating to improve the surface properties. TiN are used for decorative purpose also it gives a shining to the materials. Smooth and hard edges/corners can be prepared like milling cutters and drill bits.as shown in fig.6

2.2.5 TiAlN (Titanium Aluminium Nitride) coated pin

Fig.7 TiAlN coated pin

TiAlN is the hard coating contains aluminum, titanium and nitrogen as main constituents. In chemical composition more than 50% aluminium is present. This material increase the oxidation resistance at elevated temperature and also due microstructure changes at higher temperature hardness of the coating is high. 2micron thickness coating is made on substrate material by PVD process.

2.3 Wear Test

In order to calculate wear properties by pin on disk experiment optimum input parameters are determined first. To find optimized parameters 10 same dimension uncoated samples are tested under different speeds and different loads with respect to time. From the preliminary experiment it is confirmed under speed of 800m/s and for 3kg load with sliding time of 180 seconds test shows optimum wear properties. By keeping this input parameters constant, rotating disc speed 800m/s, load 3kg and time as 180 seconds for all the coated and uncoated materials test is conducted and results are noted. Once the preliminary test was over then specimens A. Uncoated B. TiC coated C. TiN Coated D. TiAlN coated are prepared and mark the specimens as A, B, C and D respectively. From the test we obtain the results that are tabulated in Table no 1.

Table.1 wear test results

Specimen	Applied load in Kg	Actual load in Kg	Speed in m/s	Time in seconds	Initial weight of specimen in gm	Final weight of specimen in gm
A	3	2.49	800	180	66.88	66.72
B	3	2.49	800	180	68.07	67.97
C	3	2.49	800	180	69.25	69.13
D	3	2.49	800	180	68.66	68.58

2.3.1 Wear measurement

Wear is measured on the bases, loss of volume per test. From the mass loss and density of the material wear volume is Determined. From the speed and radius at which the pin is fixed from the centre of the disk wear velocity and sliding distance are calculated. And from formulae mentioned below wear coefficient id calculated.

1. Wear velocity = $\frac{2\pi NR}{60}$ m/s

2. Sliding Distance = Velocity × time

3. Wear Volume= $W_v = \frac{wi-wf}{\rho}$ m^3

Where, ρ = Density of pin =7900 kg/m^3

W_i = Initial weight of specimen.

W_f = Final weight of specimen.

4. Wear Co-efficient =

$$K = \frac{Wear\ volume}{Actual\ Load * 9.81 * velocity * time}$$

3. Contact model and wear analysis:

When two bodies comes in contact with relative motion due to loading on contact bodies the stresses generated and deformation is high so material get failed due to wear. Wear analysis is performed mostly by experimental method in order to analyses the loss of volume due to wear. Many of the researcher's are working on software simulation of wear analysis. FEM is the common method to solve the wear analysis by simulation using ANSYS workbench.

3.1 Pin on disk Model and Wear Analysis

3.1.1 Assumptions

Assumptions are made to simplify the solution they are as follows.

1) The contact between the Pin and disk is frictional contact type.
2) Pin is taken as flexible and disk is taken as rigid.
3) Co-efficient of friction between pin and disk is taken as 0.3
4) Contact behaviour of pin and disk is taken as asymmetric.
5) Analysis carried out is non linear.

3.1.2 Simulation method

Wear simulation is performed on ANSYS workbench software. Contact analysis followed by certain sequence of steps for the solution, they are as follows.

1) Before starting of analysis select the analysis is performed whether ANSYS APDL or ANSYS workbench. In my thesis, performed this analysis on ANSYS workbench.
2) Pin and disk Model is created in CatiaV5 as .igs file.
3) Import the geometry in ANSYS.
4) Select the contact surfaces and the contact type whether it is frictional or bonded contact.
5) Mesh the model by giving appropriate element size.
6) Apply boundary conditions and normal loads on pin and disk model and simulate.
7) Define the analysis settings and the necessary commands to solve wear simulation.

3.2 Model geometry and mesh details

When two materials come in contact with respect to relative motion the material may get failed due to wear and friction between them. It is not possible to take the machine part as it is and to test it on pin on disk setup. So specimens are prepared as per the standard dimension of Experiment and test is conducted. Similarly to make a prototype in 3D, pin and disc model is created in CATIA tool as per the dimensions. Two parts created in CATIA, Pin and disk is assembled to create surface contact pin on disk. Disk rotates with a certain given velocity and pin is stationary on disk. Load is applied on the stationary pin. Import the model in ANSYS workbench and generate the model. Rename the parts that are generated in ANSYS geometry by PIN and DISK.

3.2.1 CATIA MODEL:

Figure.8 shows the Model is created in CATIA v5 as per the dimensions as shown in Table no.2 In order to assign real constants pin and disc are made separately and assembled in product section. To import the model in ANSYS workbench, the created model in CATIA is saved in .igs format.

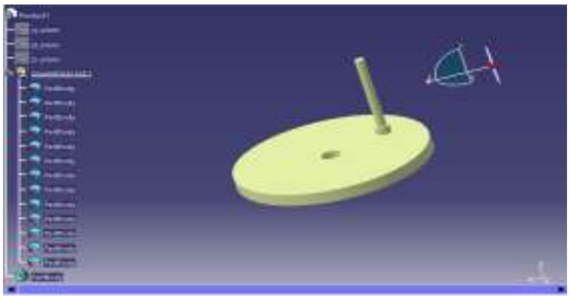
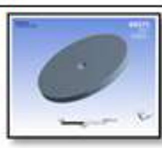


Fig.8 CATIA model

Dimensions of the pin and Disk:

Table No.2 Dimensions of specimens

Item	Description		Dimensions
1	Disc		Outer diameter = 200mm Inner diameter = 15mm Thickness = 15mm
2	Pin Top		Diameter = 15 mm Length = 10mm
3	Pin Bottom		Diameter = 10mm Length = 90mm

3.2.2 MODEL generated in ANSYS:

Import the created model in ANSYS geometry, and rename the parts as PIN and DISC. Generated geometry in ANSYS workbench is as shown in Figure.9

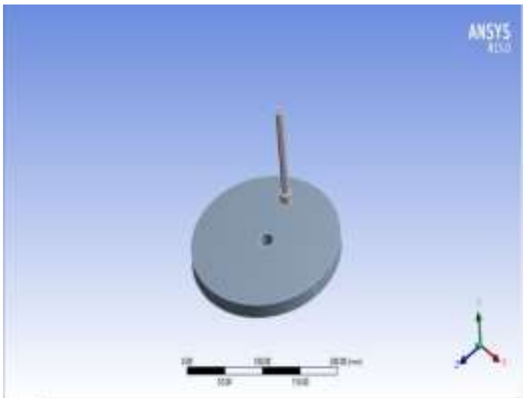


Fig.9 Generated model in ANSYS

3.2.3 Details of mesh:

Meshing is nothing but elements are divided by number of nodes in order to get the accurate results. Fem solves the model by dividing the elements into smaller size nodes or grids. Grids are of different shapes size and shape, for two dimensional cell shapes it may be triangle and quadrilateral. For three dimensional shapes, it may be tetrahedron and hexahedron. In this thesis we are done meshing by tetrahedron for pin and hexahedron shapes for disc. Mesh sizing for pin and disc are given as 5mm. meshed pin on disc model is shown in Figure.10

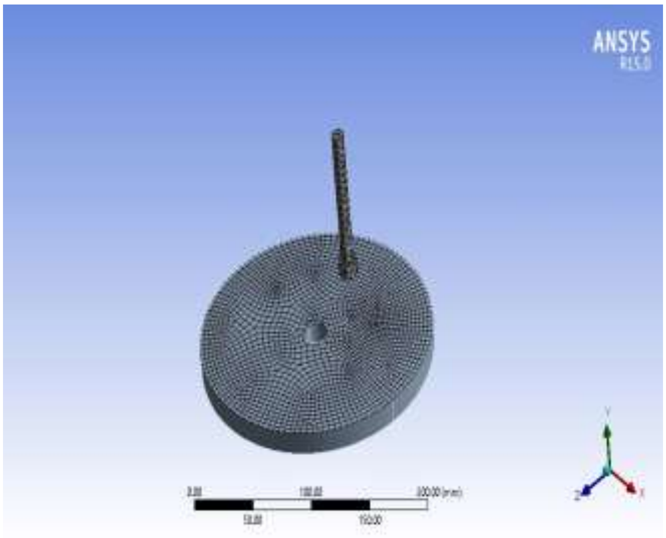


Fig.10 Meshed model

3.3 Contact surface:

It is very important part of the wear solution, contact pairs are set by real constant numbers different contact pairs May b set by different real constant sets. In order to get the solution accurately one pair must be flexible and one is rigid. For rigid to flexible target, target must be rigid and contact must be flexible in order to penetrate the elements contact elements are constrained. There are different guidelines for contact surface.

1) Among two surfaces one is stiffer and one is softer, softer surface is taken as contact and stiff surface is taken as target.

2) If two surfaces cross sections are different smaller cross section surface is target and bigger cross sectional surface is target.

Figure shows the contact details of pin and disk. Once the model is generated in ANSYS, next step is to connect the bodies by connections. This simulation is solved by considering pin as flexible and disc as rigid. Contact type between the surfaces is frictional contact details are as shown in Figure.11 Contact body view and target body view is shown in Figure .12

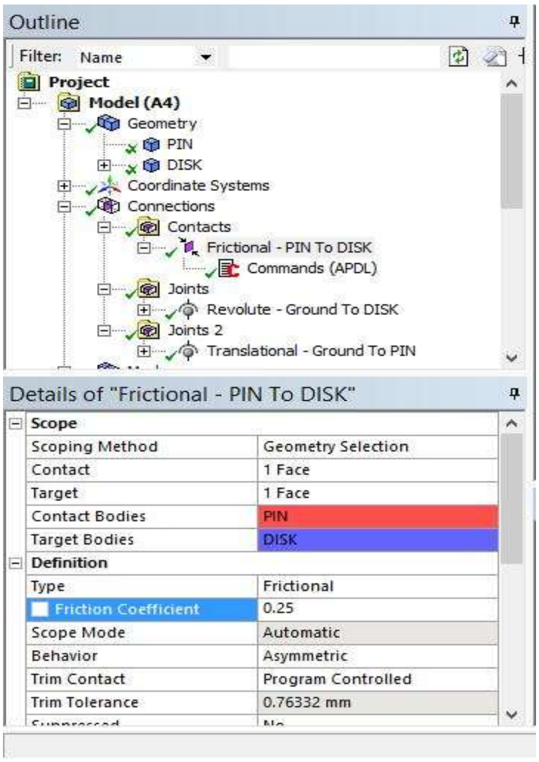


Fig 11 Details of Frictional pin and disk

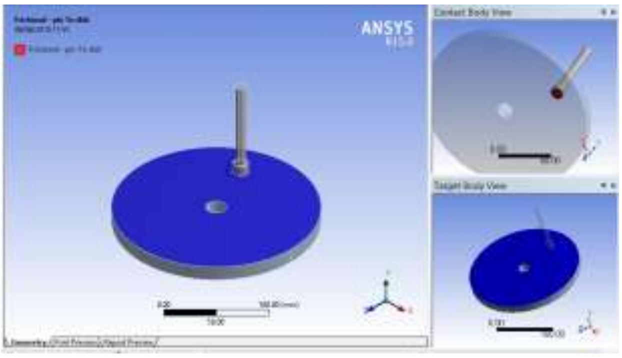


Fig.12 Contact body and target body views

3.3.1 Boundary Conditions

The boundary conditions are given for getting accurate results, compatible to real time conditions of pin and disc contact pair. Boundary conditions are given for both Pin and disc. According to experiment pin is fixed on disc, only the movement in y direction is free. Displacement of Pin is zero for x and z direction and free movement only in y direction. Disc is rotates on certain velocity in experiment so for disc boundary conditions are fixed in Y direction. Disc movement is only for x and z direction. Boundary condition for pin is as shown in figure. Boundary condition for disc is as shown in Figure.13 and Figure.14.

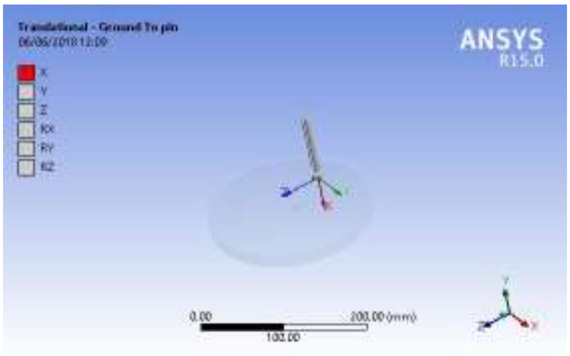


Fig.13 Boundary condition for Pin

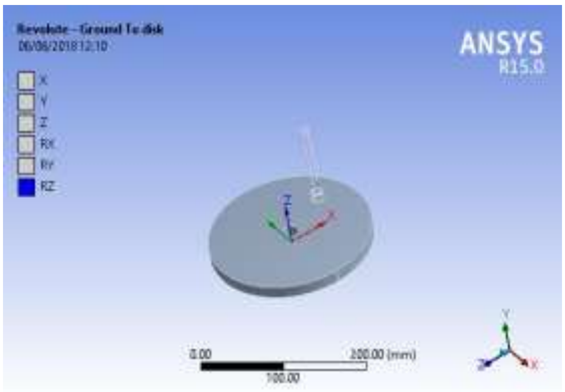


Fig.14 Boundary condition for Disc

3.3.2 Loading conditions :

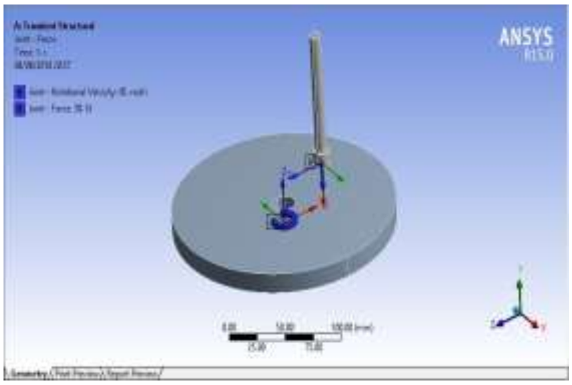
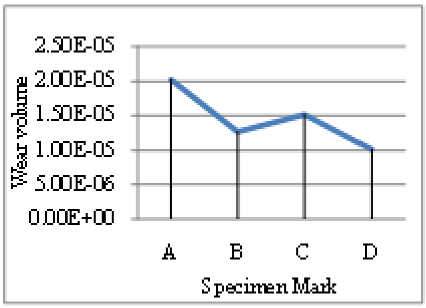


Fig 15 loading conditions

Calculation of rotational speed:



Angular velocity (ω) = v / r

Where, v = speed of rotating disc = 800rpm

r = radius of rotating disc = 100mm = 0.1m

Velocity (v) = $\frac{2\pi NR}{60}$ = $\frac{2\times\pi\times800\times60}{60}$ = 5026.54 mm/s = 5.02 m/s

ω = 5.02 /0.1 = 50.2 rad/ sec

Rotational velocity need to apply on disc is 50.2 rad/sec but disc is rotating at 800 rpm which is greater than the assumed value. For severe conditions, higher angular velocity has to be applied.

Angular velocity for 800rpm is given by,

ω = 800 × (2π)/60 = 83.7rad /sec = 84rad /sec

From the calculations angular velocity applied for disc is 84 rad/sec and the force applied on the pin is 30N. Rotational velocity and load applied models are shown in Figure.15.

4. Results and Discussion

4.1 Experimental Results:

From the preliminary experiment we got optimised parameters to conduct the wear test on pin on disk. Experiment is conducted for both coated and uncoated materials and we have got the results that are tabulated in Table No 3.

Table No.3 pin on disc results

Specimen	Load in Kg	Speed rpm	Time Seconds	Wear Volume m^3	Wear Co-Efficient $(m^2)/N$
A-Uncoated	3	800	180	2.025×10^{-5}	9.174×10^{-10}
B-TiC	3	800	180	1.265×10^{-5}	5.73×10^{-10}
C-TiN	3	800	180	1.518×10^{-5}	7.05×10^{-10}
D-TiAlN	3	800	180	1.012×10^{-5}	4.70×10^{-10}

From the above results it is clear that uncoated specimens are showing higher wear rates and wear coefficient than the coated specimens. When the substrate material is coated by ceramic materials then substrate material becomes harder than the uncoated specimen. It is clear that when the material becomes harder the wear rates are starts decreases.

4.1.1 Wear volume:

From the pin on disc experiment we got the wear co-efficient and wear volume for coated and uncoated materials. To understand the variations in property values graph is drawn between wear volume and different coating specimens. It is true that as load increases the wear rate also increases. But from graph it is clear that uncoated specimen shows the maximum wear rates than the coated specimens. Graph is shown below Figure 16.

A-Uncoated

B-TiC coated

C-TiN coated

D-TiAlN

Fig 16 Wear volume Vs different specimens

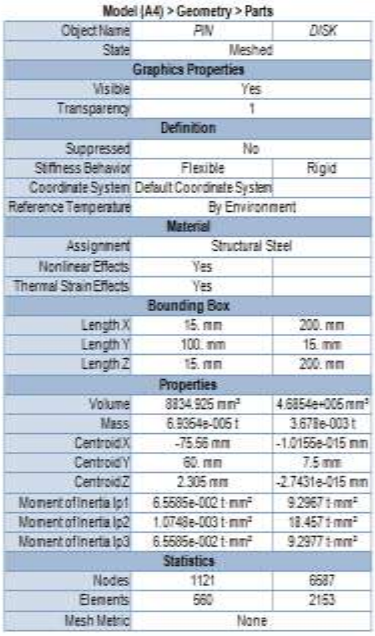
4.2 FEA RESULTS

4.2.1 Wear volume

From the Pin on Disc instrument wear volume is determined by measuring the loss of mass. And by using the wear volume we determine the wear coefficient by equations set by ASTM standard. From wear simulation in ANSYS workbench wear volume is determined for both coated and uncoated materials. What are the Boundary conditions and loads applied are discussed in earlier stage. How the wear volume is calculated and what commands given are as shown below.

```
/post1
set,last,last
esel,s,mat,,1
etable,a,volu
ssum
*get,my_volume,ssum,,item,a
alls
```

In order to get the wear volume first we find original volume before the simulation from the pin properties in details of PIN contact.



Model (A4) > Geometry > Parts

Object Name	PIN	DISK
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	Rigid
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Material		
Assignment	Structural Steel	
Nonlinear Effects	Yes	
Thermal Strain Effects	Yes	
Bounding Box		
Length X	15. mm	200. mm
Length Y	100. mm	15. mm
Length Z	15. mm	200. mm
Properties		
Volume	8834.925 mm³	4.6854e+006 mm³
Mass	6.9364e-005 t	3.678e-003 t
Centroid X	-75.56 mm	-1.0156e-015 mm
Centroid Y	60. mm	7.5 mm
Centroid Z	2.305 mm	-2.7431e-015 mm
Moment of Inertia Ip1	6.5585e-002 t·mm²	9.2967 t·mm²
Moment of Inertia Ip2	1.0748e-003 t·mm²	18.457 t·mm²
Moment of Inertia Ip3	6.5585e-002 t·mm²	9.2977 t·mm²
Statistics		
Nodes	1121	6587
Elements	560	2153
Mesh Metric	None	

Fig 17 Volume before simulation

Contact type is frictional contact type so friction and boundary conditions are applied for model. In order to find the wear volume commands are given to the solution

Figure.17 and Fig.18 shows the ANSYS results for uncoated MILD steel. Similarly by applying same procedure volumes are calculated for coated specimens. For coated materials only the difference is assignment of materials for respective solutions. We have done the simulations for all the materials and the resulting volumes tabulated below Table No.4

Fig.18 Eroded Volume results from ANSYS

Table No.4 ANSYS results for wear volume

Material	Volume Before simulation in mm^3	Volume after simulation in mm^3	Wear volume in m^3
A-Uncoated	8834.925	8834.908	1.7×10^{-5}
B-TiC	8834.927	8834.916	1.1×10^{-5}
C-TiN	8834.927	8834.914	1.3×10^{-5}
D-TiAlN	8834.927	8834.917	1.0×10^{-5}

4.3 Comparison between Experimental and FEA results:

From the Experiment and FEA analysis we determine the wear volume for all coated and uncoated specimens for the better understanding we have plotted the graph for wear volume and all specimens shown in below Fig.19

Table No.5 Result comparison

Specimen mark	Experimental results	FEA results
A-Uncoated	2.025×10^{-5}	1.7×10^{-5}
B-TiC	1.265×10^{-5}	1.1×10^{-5}
C-TiN	1.518×10^{-5}	1.3×10^{-5}
D-TiAlN	1.012×10^{-5}	1.0×10^{-5}

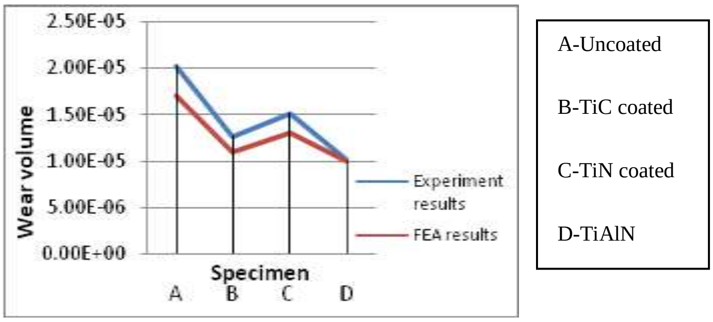


Fig.19 Wear volume Vs different coating specimens

From the Wear simulation in ANSYS wear rate amount of eroded volume is lower than the amount of wear volume shows from experimental. We are getting error between the results because while simulation we are consider many of the assumption while solving the pin on disk model.

5. CONCLUSION

When the two metals comes in contact to each other when there is a relative motion between them and normal force is acting on contact then material wear out or after some days it may get failed. In order to reduce the wear rate ceramic coating is applied on the substrate material that is mild steel (1018 grade). While conducting the experiment we have used the same input parameters for both coated and uncoated materials. A result shows that uncoated materials gives higher wear rates than the coated material. Similarly in wear coefficient case uncoated materials gives higher coefficients than the coatings.

Mild steel is used in many applications like worms, gears, pinion, machine parts, tie rods, brackets. While manufacturing these parts if mild steel surface is coated by ceramic material that is by TiC, TiN and TAlN, then material gives the greater life to the parts.

From the wear simulation by ANSYS workbench following conclusions are made:

1) From ANSYS workbench, It becomes easy to analyze the pin on disk model.

2) By increasing the tensile yield strength of the material wear rates and wear coefficients are minimized.

3) Maximum stresses are generated at the point of contact.

4) From Wear simulation in ANSYS Workbench we can easily determine the eroded volume.

5) Coated specimen's shows high wear resistance property than the uncoated specimens.

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