Study of Wear Characteristics for Various Coating Materials

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Abstract— Wear is defined as the progressive loss of substance from the surfaces of the solid body caused by the mechanical action like contact or relative motion between the bodies. The debris method currently used to quantify wear produces results strongly dependent on conditions. This test explains the wear characteristics under various coated methods, Adhesion and other mechanical behaviour of coatings at present routinely tested in industry and research organizations using the wear test. Where a simple procedure was conducted on pin-on-disc experiment to stimulate the industrial wear problems. Various coating methods where done on the 0.18% low carbon steel and the wear test was done under normal load, and sliding speed. After the wear test studying the friction force of the wear and volume loss in the wear is studied .Wear analysis is characterized by the SEM (scanning electron microscope), Surface roughness test was also carried out for coated and uncoated material and stimulate in ANSYS for contact stress analysis and validate the results.

Key words: Wear behaviour, Low Carbon Steel, SEM, Surface Roughness

I. Introduction

Tribology is a science that deals with friction, lubrication and wear in all contacting surface, were the two plane which are an intimate contact and subjected to load have some relative speed comes under the tribological. Tribological information helps to progress the service life, safety and dependability of contacting machine components and yields significant economic benefits, so we can say tribology is most important for all machine components.

Wear can be described as the undesirable removal of material from working solid surface. It says that wear is volume loss of debris (also called wear particles) that divides from the sample during testing. Wear occurs by solid or by fluids so both the kind of wear are possible, when there is a wear by hard surface then dependent parameter are going to effect the performance will be load, velocity, environment, and materials, were the fluid wear depends on the parameter of velocity, environment and material. Either quantity is made intensive by separating the debris weight or debris volume by the contact plane of the specimen. The flotsam and jetsam technique utilized presently to quantify the wear produces comes about firmly wards on testing conditions. This is why it has been undertaken the challenge to build up a new method to supply as measure of wear.

Wear testing is an extremely helpful for understanding material distortion and material finding systems in abrasives wear. Wear test can be employed as a tool for understanding material wear process in the presence of hard asperities**.** Wear is a cut of strophic failure that means we will never get immediate failure due to wear. For a given set of condition ,wear behaviour is normally dived into two times based on their working condition one is “running in” and “steady state” during steady state ,wear condition are relatively stable. Research in this area of the wear is a vital important for the economic point of view because it is a major problem for a nation and its directly cost is estimated to vary between 1% and 4% of a national gross and national product.

Coming to the material science, by changing the surface properties we can alter wear behaviour many times, by just coating few micron level coating on the surface, surface life of a material can be changed can be enhanced significantly so its coating changed slightly repair life of the component .coating can be in a micrometer or it can be just a surface treatment surface like pointed paining ,short paining increase the stability of surface, causes the lesser plastic deformation under the loads. So, that enchases its properties to sustain wear or to torrid wear. Their range of application includes such components as knives, blades and other cutting tools, medical devices and implants, power transmission rings and rods, seals and pump components in the oil and gas industry, piston rings and valves in engines, piston in hydraulic systems, gears, bearing and many others. Numerous methods of deposition are available but the two main processes are chemical vapour deposition (CVD) and physical vapour deposition (PVD). The different deposition techniques produce coatings of varying hardness, thickness, roughness, morphology and adhesion to the substrate. Considering on the intended on the end use, it is important to characterize these properties given that the technology involved is continuing to increase and is still partially misunderstood by both manufacturers and users.

II. Experimental details

A. Machine Used

Fig. 1: Pin on Disk apparatus

A pin-on-disc wear apparatus was used for the experiment. This machine gives the study of friction and wear characteristic in sliding contact under desired condition of any material. Sliding occurs between the stationary pin on a rotating disc. In the fig 1 pin surface was made flat such that it will support the load over its entire cross section .the test is carried out of one normal load of 3kg and sliding speed of 800rpm is given. Where the wear removal of the material may occur in both substance of the material pin or disc. Before the start of each experiment, precautions steps were taken to make sure that the load was applied in normal direction on the pin with respect to the disc. Before and after the test the weight of the specimen (pin) is estimated on the digital weighing machine and further calculation were done from the collected data.

B. Material and specimens

1) Disc

The disc used in the experiment is MS material and machining operation like facing, turning, chamfering and finally grinding for the surface finishing were carried out on the disc to bring it to the proper measurement. Where the diameter of the disc is 200mm and thickness of disc is 15mm and the disc is blackodising to prevent the corrosion from the environment.

2) Pin

I have selected five round bar of size 150mm length and 20mm diameter of low carbon steel(AISI 1018 grade) has been selected as a pin material. further machining operations were carried on the all the five round bar, the machining operations are turning, facing ,chamfering and at last fine grinding operation is done for the surface finish on the pin material for the required measurement as shown in the below fig 2 And then the material is coated by various coating methods as explained bellow.

Fig. 2: Pin on Disk apparatus

3) Chemical Composition

The chemical element present and there composition in low carbon steel 1018 material is shown in below table2.1

Element	Content
Carbon,C	0.14 – 0.20%
Iron,Fe	9.81 – 99.26%
Manganese,Mn	0.60 – 0.90%
Phosphorous,P	0.04 max
Sulfur,S	0.05 max

Table 1: Chemical composition

4) Specification of pin-on-disc apparatus

Parameter	Units	Min	Max
Pin size	mm^2	10×10	10×10
Disc size	mm^2	200X15	200X15
Disc rotation	Rpm	200	1200
Normal load	Kg	1	5

Table 2: Specification of pin-on-disc apparatus

C. Coating Methods

The coating method used here is chemical and electrochemical techniques. Several electrochemical techniques are available for deposition of hard coating. In that electroplating reminds for hard chrome coating and nickel based coating are considered. Electroplating is the process that utilize the electric current to reduce the metal cat ions so that they form a thin layer of the coating material on the electrode .It consist of large container in which the solution is present in it .the part to be plated (pin material) act as an cathode of the circuit and anode is made up of the metal to be plated on the part both the component are immersed in the solution an electric current is passed to that solution cat ions from the plating solution become positively charged and travel to the negatively charged cathode and bond. It provides electrons to reduce the positively charge ions to metallic form. By this coating material get deposited on the material. Following coatings were done as said below

1) Hard Chrome Coating

In hard chrome the pin to be coated act as an cathode and the solution consist chromium and sulphate as the catalyst in it. By varying the time the coating thickness is maintained in it. 1μm coating thickness is provided on the pin part the time taken is 15min for coating process.

2) Nickel based Coating

In nickel based coating the pin to be coated act as an cathode and the solution consist of nickel salt is dissolved in the solution. By varying the time the coating thickness is maintained in it. 1μm coating thickness is provided on the pin part the time taken is 20min for coating process.

3) Zinc Coating

Zinc plating requires the electrolyte arrangement as the plating bath consists of the zinc metal ionic arrangement. 2μm coating thickness is provided on the pin part the time taken is 10 min for coating process.

4) Wear Test

All the four material were chosen based upon their application depending upon their different coating the material was name as A, B, C and D. The pin specimen were tested in pin-on-disc Apparatus .To perform the test specimen was clamped in jaw, the rotation speed of disc was fixed at 800rpm, timer was set for 2 min. First the load for A, B, C and D were tested at the fixed load of 3KG then the reading were taken and compared.

5) Wear Measurement

Wear rate was estimated by measuring the mass loss in the specimen after each test and mass loss, Δm in the specimen was obtained. We can calculate the mass loss by measuring the height loss (Δh) in each experiment, the area of cross section (A) of sample and the density (ρ) of the alloy by using the relation.

6) Formulae

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

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

$$\text{Wear Co-efficient} = \frac{\text{Wear volume}}{\text{Actual Load} * 9.81 * \text{velocity} * \text{time}}$$

$$\text{Volume after wear} = \frac{\text{Final weight of specimen.}}{\text{Density of coated pin}}$$

III. MODELLING OF PIN-ON-DISC

A. Pin-on-Disc Model

First each part is made separately in the modelling software CATIAV5 .For completing this work three pin and disc were modelled each pin are given an offset coating of 1micron m and dimension of each pin are 100mm length and diameter is 15mm and disc dimension are 200mm diameter and 15mm thickness. Then the part modelled are further assembled correctly. Arrange the pin correctly at 60mm radius from the middle segment of the disc as shown in fig 3.

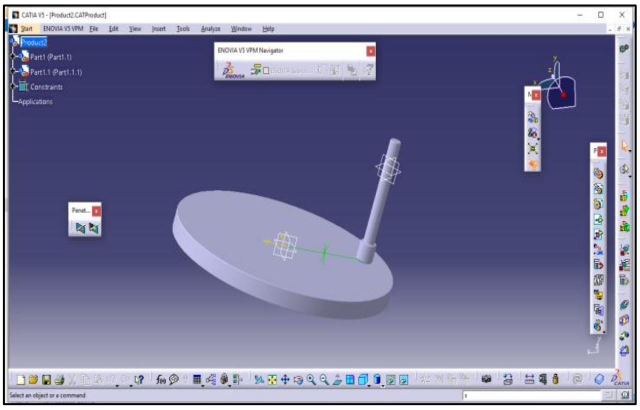

Fig. 3: Pin on Disk apparatus

B. Analysis in finite elemental analysis

The model made in CATIA V5 software is converted into "igs" then it is opened in ANSYS workbench. Then the material properties are given to pin, disc and coating material as given in below table 3 and table 4.

Material	Geometry	Young's Modulus (Pa)	Tensile yield strength (Pa)	Poisson's ratio	Density (kg/m^3)
AISI 1018	Pin	2.05×10^{11}	3.7×10^{08}	0.29	7870
AISI 1065	Disc	2.10×10^{11}	4.9×10^{08}	0.29	7850

Table 3: Material properties for pin and disc

Material	Geometry	Young's Modulus (Pa)	Poisson's ratio	Density (kg/m^3)
Hard chrome coating	Pin layer	2.79×10^{11}	0.21	7180
Nickel coating	Pin layer	2.20×10^{11}	0.31	8900
Zinc coating	Pin layer	9.65×10^{10}	0.33	7100

Table 4: Material properties for coating material

Then the connection between the pin and disc is given as frictional contact, value of co-efficient of friction as 0.2. Meshing is the next step, fine mesh is provided the meshed view of the model is given in the Fig: 4.

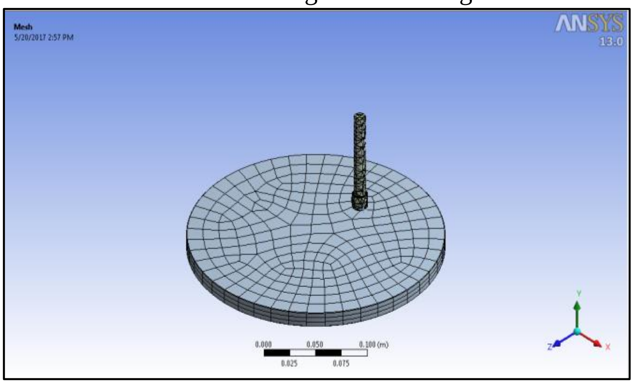

Fig. 4: Pin on Disk apparatus

C. Boundary Conditions

Here the displacement in the x, y and z direction of the outer round faces of the pin and all the boundary of the disc were constrained and fixed.

The force is applied on the top surface of the pin, its value is -29.33N acting downward direction as shown in fig 4 Along with that a rotational velocity of 83.77 rad/sec (800rpm) is provided for the disc in the z direction, for the rotation of disc is antic lock wise direction as shown in Fig 4

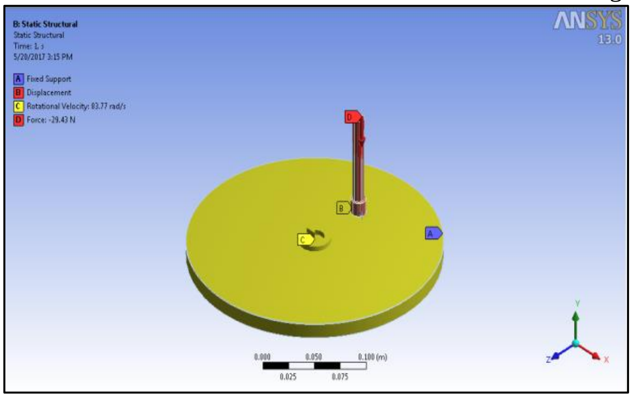

Fig. 5: Pin on Disk apparatus

D. Analysis

When the force is applied in the top face of the pin, then the equivalent (von-Misses) stress is finding out, then the highest and the lowest value is noted as shown in fig 6. The portion where highest and lowest value obtained is also noted. After this, contact stress is finding out, then the highest and the lowest value is noted. The portion where highest and lowest value obtained is also noted. Contact pressure is also noted for highest and lowest values then contact penetration is noted down.

In the fig 6 shows the equivalent (von-mises) stress for the hard chrome coating were the maximum value is 72178Pa and minimum value is 0Pa.

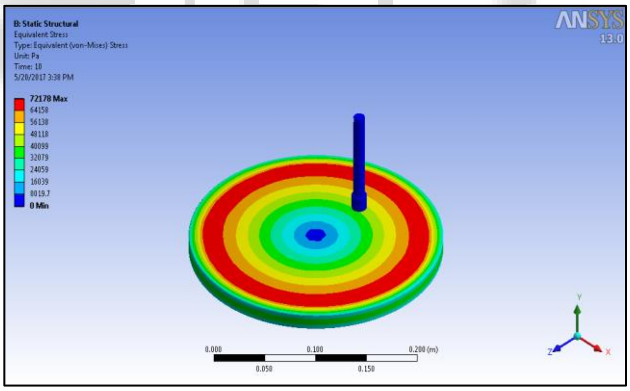

Fig. 6: Pin on Disk apparatus

After this, contact stress is finding out, the contact stress for hard chrome coating is shown in below fig 7 were maximum values is 9.928×10^{-8}Paand minimum value is 0Pa.

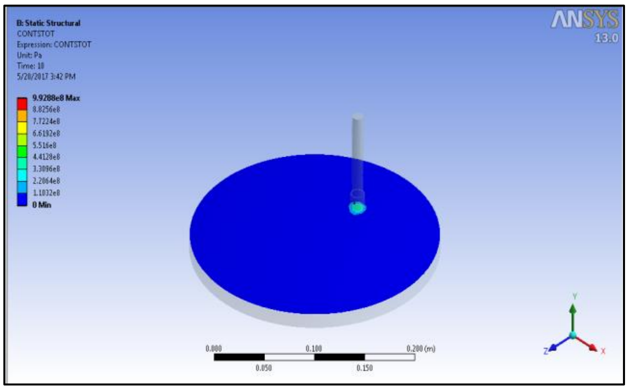

Fig. 7: Pin on Disk apparatus

Contact penetration is also noted, the contact penetration for hard chrome coating is shown in below fig 8 were maximum value 1μ is and minimum value is 0 We assume that portion is worn out.

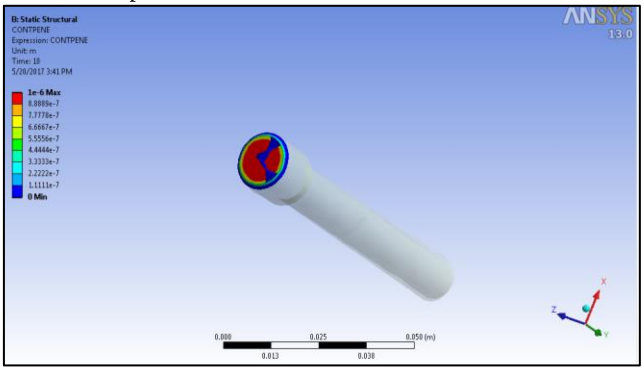

Fig. 8: Pin on Disk apparatus

It is repeated for the other two models for 29.33N loads Along with that a rotational velocity of 83.77 rad/sec (800rpm) and time for 120 cycles(2min) is given and listed in the below table 5.

Sl. no	Component	load N	Max Von-mises stress Pa	Max contact stress Pa	Max penetration m
1	Hard chrome coated	29.43	72178	9.928×10^{-8}	1μ
2	Nickel coated	29.43	71872	9.727×10^{-8}	1μ
3	Zinc Coated	29.43	71535	2.035×10^{-9}	2μ

Table 5: ANSYS results

Error obtained for all the tree coating from theoretical and ANSYS is shown in below table 6.

Sl. no	Components	Volume loss after wear		Error %
		Theoretical	ANSYSY	
1	Hard chrome coated	8.980323×10^{-6}	8.984796×10^{-6}	0.048
2	Nickel coated	8.982289×10^{-6}	8.984796×10^{-6}	0.027
3	Zinc Coated	8.981650×10^{-6}	8.98464×10^{-6}	0.033

Table 6: Validation results

IV. Results and Discussion

By the obtained data from the calculation for the wear loss and wear co-efficient for one normal load and one sliding speed for different material were A)uncoated material, B)hard chrome coated , C)zinc coating and D)nickel coating as shown in below table

A. *Tabular Column*

Sl. No	Material Mark	Load Kg	Speed Rpm	Time S	Wear Volume	Wear Co-Efficient
1	A	3.13	815	120	5.063×10^{-6}	2.733×10^{-13}
2	B	3.13	815	120	4.627×10^{-6}	2.498×10^{-13}
3	C	3.13	815	120	3.299×10^{-6}	1.781×10^{-13}
4	D	3.13	815	120	2.661×10^{-6}	1.436×10^{-13}

Table 7: Tabular column for wear volume and wear co-efficient

By seeing the above data from the tabular column the wear loss is less for nickel based coating and has more wear co-efficient comparing to the uncoated material, hard chrome coated, and zinc coating

B. *Graphs*

The data collected from the above tabular column the effect of this parameter have studied by obtaining the graph for different parameter like effect of the wear volume v/s wear coefficient, wear volume v/s specimen, wear co-efficient v/s specimen. The material mark as A) uncoated material, B) hard chrome coated material, C) zinc coated material and D) nickel coated material.

1) *Effect of Mass Loss*

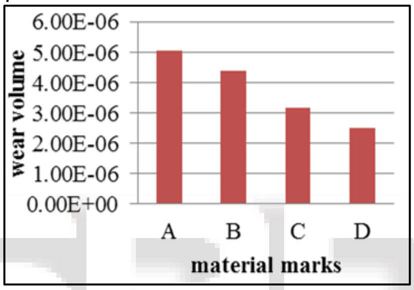

Fig. 9: Pin on Disk apparatus

2) *Effect of Wear Coefficient*

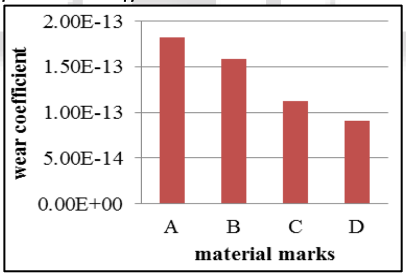

Fig. 10: Pin on Disk apparatus

3) *Wear Volume V/S Wear Coefficient*

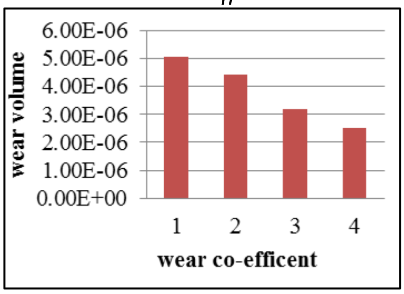

Fig. 11: Pin on Disk apparatus

C. *Scanning Electron Microscope*

A SEM is a type of electron magnifying lens produces an image of a sample by scanning the surface with a focus beam of electrons. The SEM is done for both the surface as wear out surface and polished surface are obtained at magnification of 33x, 150x, 330x and 700x the micrograph for all the sample are shown below.

1) Hard Chrome Coating

Show the particular surface zoom from x150 the pores were also found on an worn part of the surface. Were deep crack was found on the chrome surface as seen these cracks are distributed throughout the entire coating shown in below fig 12 and 13.

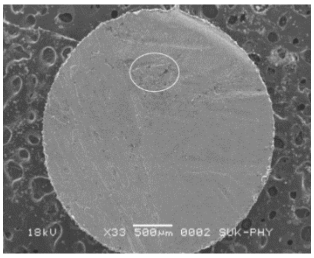

Fig. 12: Total surface

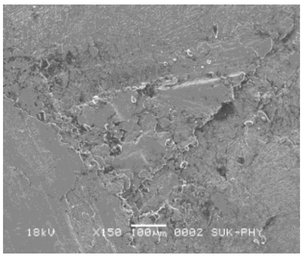

Fig. 13: Worn part

2) Nickel Based Coating

The SEM for the nickel based coating are shown in figures the fig 14 shows the total surface of lubricated and unlubricated crack was found on the nickel surface as seen these cracks are distributed throughout the entire coating surface, the fig 15 show the layer on top layer radial cracks was found, the crack direction was not perpendicular to the substrate.

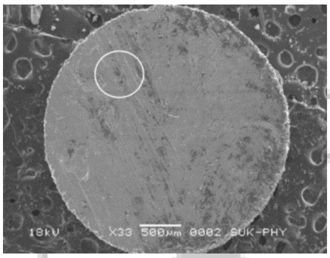

Fig. 14: Total surface

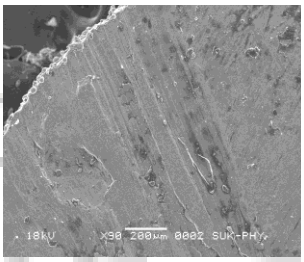

Fig. 15: Worn part

The SEM for the Zinc based coating are shown in figures the fig 16 shows the total surface of lubricated and unlubricated surface were half surface is lubricated and left out is unlubricated. Fig 17 illustrates the layer on the top of the coating indicates significant larger amount of zinc is seen.

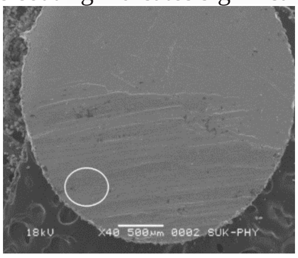

Fig. 16: Total surface

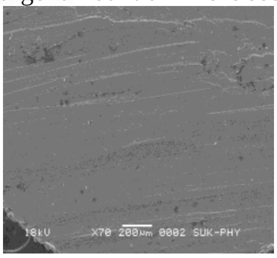

Fig. 17: Worn part

V. CONCLUSION

An experiment was conducted on pin-on-disc for uncoated and various coating material on low carbon steel, the experiment resulted in

1) Wear behaviour is dependent on applied load, sliding speed mainly.
2) At room temperature the nickel based coating of thickness 1μmbetter wear co-efficient than hard chrome and zinc coating.
3) The SEM analysis of the worn track concludes that more plastic deformation and material has been incurred by the uncoated material then the other coated material.
4) It can be accomplished from experiment and analysis in ANSYS that the nickel coating has good wear coefficient and wear loss then hard chrome and zinc coating.

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