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Effect of PVD Coating and Carburizing on Wear Characteristics of Low Carbon Steel

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Abstract:- Wear is a relative cyclic motion with small amplitude which occurs between two oscillating surfaces, depending upon the loading conditions, material properties and environment. Surface Engineering such as surface treatment, coating and surface modifications are employed to minimise the friction and improve wear resistance of steel. In this work the low carbon steel substrate is coated with Al_2O_3 by using physical vapour deposition process and the other sampling material is heat treated by carburizing process. In the present study, the wear resistance of heat treated and coated steels were evaluated through the pin-on-disk using variable loads and wear is measured by the wear track width and wear graphs are shown for coated material and heat treated material. Finally, the comparison is concluded by observing the variations in wear characteristics between the two samples. Furthermore morphological study of wear is made for in-depth analysis.

Keywords:- Carburizing, Microhardness, PVD Coating, Sliding Speed**,** Wear Graph, Wear Morphology

I. INTRODUCTION

Low carbon steel is the most common form of steel that are commonly used as a sheet metal forming in automobile bodies, rivets, screws, nails, gears, and other sliding contact purposes. By doing these operations the surfaces and subsurface, contacts and there is an interaction with hard particles such that the materials gets deformed or worn out on the upper surface. In order to minimise this consequences, the advanced surface engineering techniques are used. Coating and case hardening processes involve the application of a thin film of functional material to a substrate. As this work is concerned "heat treatment of low carbon steel" an experimental work which mostly deals with carburizing process. The traditional method of applying the carbon to the surfaces of the iron involved packing the iron in a mixture of ground bone or charcoal or a combination of leathers, hooves, salt and urine, all inside a well-sealed box. The resulting package is then heated to a high temperature, but still under the melting point of the iron and left at that temperature for a length of time. Furthermore, Physical vapor deposition (PVD) is used to deposit thin films by the condensation of a vaporized form of the desired film material onto various work piece surfaces for comparison.

J.L. Mo, [1] was investigated the AlCrN coating exhibited higher hardness, but lower wear resistance as compared to the CrN coating. Battiston et al [2] was carried out the wear tests by sliding and abrasion whose pin and ball substrates were steels. The MOCVD coating processes were carried out 200°C under N_2 +O_2 atmosphere. For both sphere coated with Alumina and uncoated the wear rate were similar. Nitrided tool steels coated with Alumina showed superior wear resistance characteristics for cold working tooling. H.W.Strauss et al [3] was done the wear mechanisms and tribo/transfer film morphology were also studied. Studies revealed that ZnNi coatings had superior resistance to adhesive wear, higher Micro hardness when compared to cadmium coatings. Under unlubricated conditions friction coefficient of Zn–Ni coatings were found to decrease. Y. Sun, [4] have shown the low temperature plasma carburizing technique. The results show that the hard and corrosion resistant carburized layers are effective in preventing surface plastic deformation, eliminating adhesive and severe abrasive wear. Under dry sliding conditions, the entire carburized layers exhibit increased wear resistance. Shiv Kumar et al [5] the dry sliding wear behavior of a medium carbon steel against an alumina disk was studied in different heat treated conditions. The wear mechanism in the hardened and tempered steel at 30N and 40N loads involved an initial adhesive wear followed by an intermediate oxidative wear regime and reappearance of the adhesive wear regime on removal of oxide layer. The wear resistance at higher load (45N) became inferior to the forced air cooled steel due to lesser extent of work hardening.

On the whole the papers highlighted show the wear resistance improvement at various processes on the steel or other materials, and also it indicates that the surface engineering techniques are well applicable for low carbon steel. From the past literatures, it is found that no work was done in PVD process and heat treatment process using low carbon steels. Hence an attempt is made to compare the ordinary, coated and heat treated materials and identify the best suitable materials for industrial applications.

II. EXPERIMENTAL PROCEDURE

2.1 Materials & Methods

In the reactive sputtering process, the parts in the vacuum chamber for coating are first heated. They are then ion etched by bombardment with argon ions. This renders the metal surface pure and clean, free from any atomic contamination. A high negative voltage is then applied to the sputtering sources. The result is the deposition on the substrates of a thin film. PVD processing is carried out at a temperatures between 250 to 1400°C as shown in Fig 1a. Similarly, the low carbon steel acts as a substrate which was well suited for Liquid Carburizing to improve the carbon layer on the material. The process was carried around 650°C as shown in Fig 1b. After the carburizing and coating the sample were tested for its characterization. The coated, carburized and raw material was tested through Vickers hardness testing machine for micro hardness level. Correspondingly, the present study investigates, all the three samples for their wear behavior with two different loading conditions at 200 rpm disc rotation as shown in Table 1.

Figure: 1a & 1b Photographic Image of PVD Coated and Carburized Low Carbon Steel

TABLE 1: WEAR TESTING PARAMETERS			
PARAMETER	**UNIT**	**MIN**	**MAX**
Pin Size	**mm**	**10**	**10**
Disc Size	**mm**	**100 x 8**	
Sliding Speed	**m/s**	**0.05**	**10**
Disc Rotation	**rpm**	**100**	**200**
Normal Load	**Kg**	**0.5**	**1**

III. EXPERIMENTAL RESULTS

The low carbon steel samples were prepared and tested through Vickers hardness testing machine with diamond pyramid indenter. Table 2 shows the Vickers hardness number with respective samples.

TABLE 2: SHOWS THE VICKERS HARDNESS NUMBER				
S. NO	**LOADS (GM)**	**RAWMATERIAL (VHN)**	**CARBURIZED (VHN)**	**PVD COATED (VHN)**
1	**25**	**122.4**	**302.1**	**410.3**
2	**25**	**123.4**	**309.6**	**416.7**
3	**25**	**125.5**	**314.8**	**523.4**

Experimental results of pin on disc for pin cumulative lost volume versus sliding distance data are presented in graph. The lost volume was calculated by the division of the measured lost mass of the substrate density. Results are for cumulative lost volume for each specimen sliding against hardened steel disc for total distance 1000m and normal loads of 0.5kg and 1 kg, respectively. The wear rate Q (=lost volume/sliding distance) is different for coated, uncoated and core material. After testing the component in pin-on disc apparatus, it is observed that for the carburized material the value of wear loss is 165µm. For the core material, the result obtained shows that the value of wear loss is 115µm. Moreover, for the coated material value of wear loss observed is 95µm up to 4 minutes based on the graph with the constant load of 0.5kg and disk rotates by speed of 200 rpm. Whereas the loading condition of 1kg and disk rotates by speed of 200 rpm, the result is obtained 210 µm for core material and 145µm for carburized material. As far as coated material concerned the material loss is 120 µm up to 3 minutes disk rotation. These results are shown in the computer generated graph (Fig (2a, 2b, 2c) - (3a, 3b, 3c)) by winducom software. From the graph in Fig 3a, 3b, 3c it is found that the wear rate almost double when the load increased from 0.5kg to1kg.The coated pins have shown superior wear resistance than the other pins. In graphs, lost volume with the sliding distance are presented for normal load of 0.5to1kg.The coated curves are constant loss initially and then reaches peak value whereas other curves are irregular, indicating a non-linear wear rate.

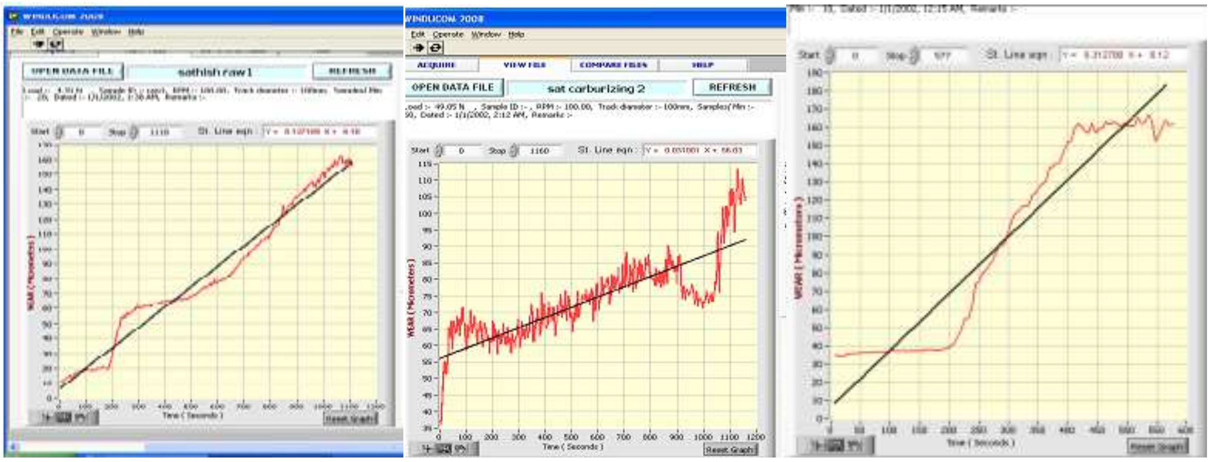

Figure: 2 a, b, c Wear graph for core material, carburized material, coated material at 0.5kg loading condition against 200 rpm disc rotation

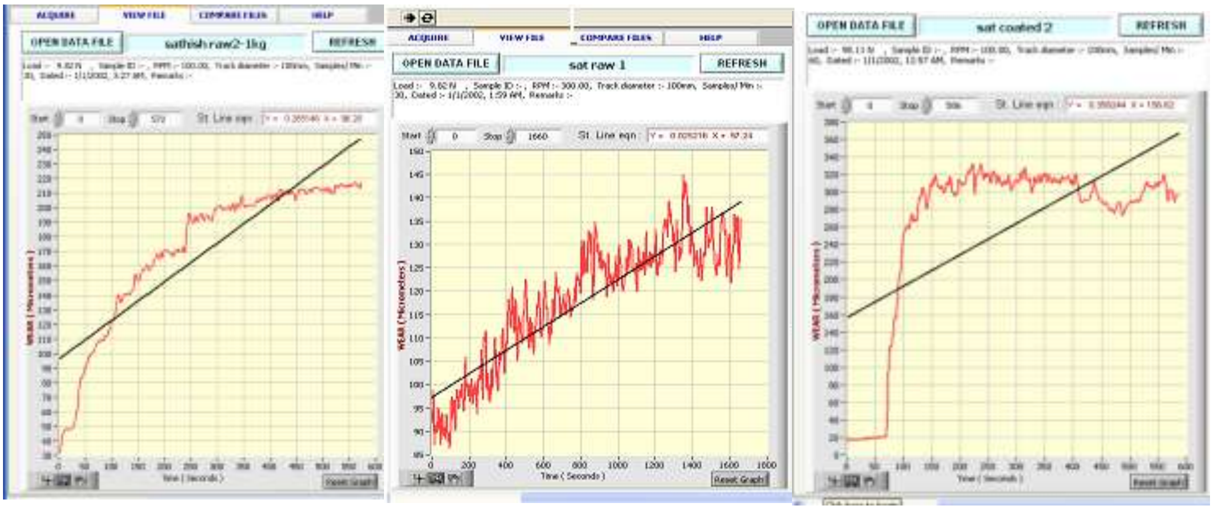

Figure: 3 a, b, c Wear graph for core, carburized, coated material at 1kg loading condition against 200 rpm disc rotation

IV. WEAR MORPHOLOGY

The scanning electron microscope (SEM) images of worn surfaces of the low carbon steel after wear test at normal loads exhibits adhesion strength of alumina coating (Fig 4)and the presence of oxides(appearing bright).The adhesion strength, broken adhesion joint ,plastic flow and cracking are visible at higher magnification (Fig 4-6). Cracks may initiate in the highly work-hardened layer, particularly in the subsurface region. When cracks grow and get interconnected, a layer of metal is removed through delamination in the form of metallic sheets. The presences of sheet like wear debris (Fig 5a & b). The mild wear surface or in between surface layer (Fig 5a & b) is slightly damaged and smooth even after test for sliding distance of 1000m under loading condition. However, the wear debris adhered layer on the oxidized surface has flaked off in the places due to local high pressure. Moreover, the adherence of the oxidized wear particles to the sliding surfaces yields compacted, protective oxide films, which also reduce the wear rate. So that the image is explained as an initial oxidative wear regime up to 200m and the elimination of oxide layer afterwards that brings an adhesive wear regime. This indicates alternate regimes of oxidation (corresponding to the decrease in the cumulative wear loss) and adhesion (corresponding to the increase in the cumulative wear loss) occurring in quick succession. Fig 6 has shown the plastic deformation direction when higher load condition is applied on the arm of an apparatus.

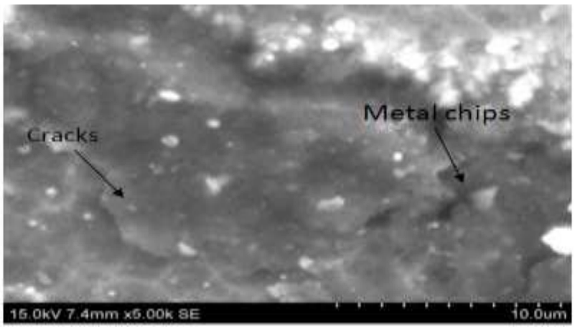

Figure: 4 SEM image of wear morphology on coated surface in low carbon steel

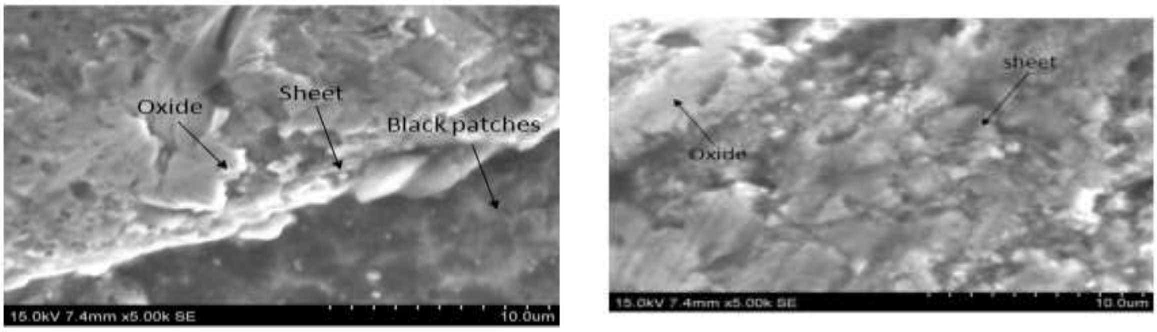

Figure: 5a & 5b SEM micrograph of in between and worn surface

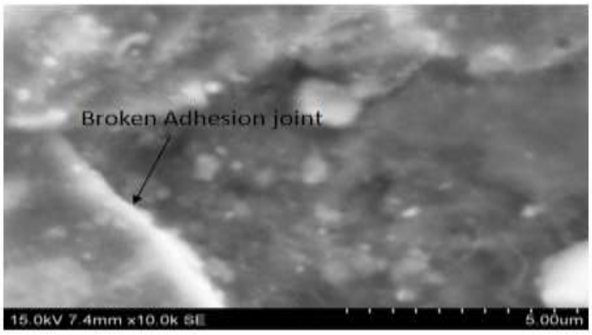

Figure: 6 SEM micrograph of the coated surface low carbon steel at higher magnification

Energy-dispersive X-ray spectroscopy (EDS, EDX, or XEDS) is an analytical technique used for the elemental analysis or chemical characterization of a sample. It relies on the investigation of an interaction of some source of X-ray excitation and a sample. Its characterization capabilities are due in large part to the fundamental principle that each element has a unique atomic structure allowing unique set of peaks on its X-ray spectrum. In this study, EDS was considered as an elemental identification of the material. This provides chemical composition, oxidized layer and elemental difference between the worn and coated surfaces. Fig (5a & 5b -6) shows the oxide content, less amount of alumina deposition whereas Fig (7-8) provides high alumina deposition and no oxide layer in the sample which is shown in Table 3 & 4.

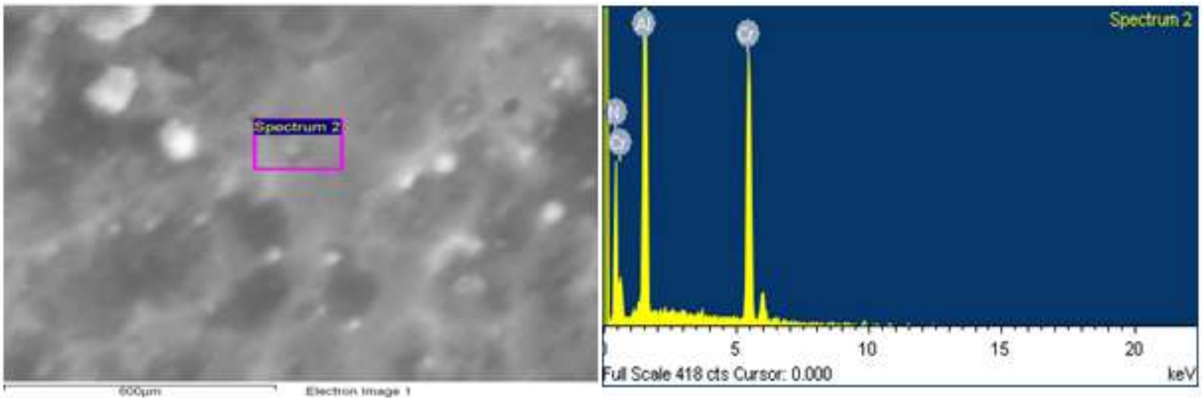

Figure: 7 SEM & EDAX Spectrum of coated surface

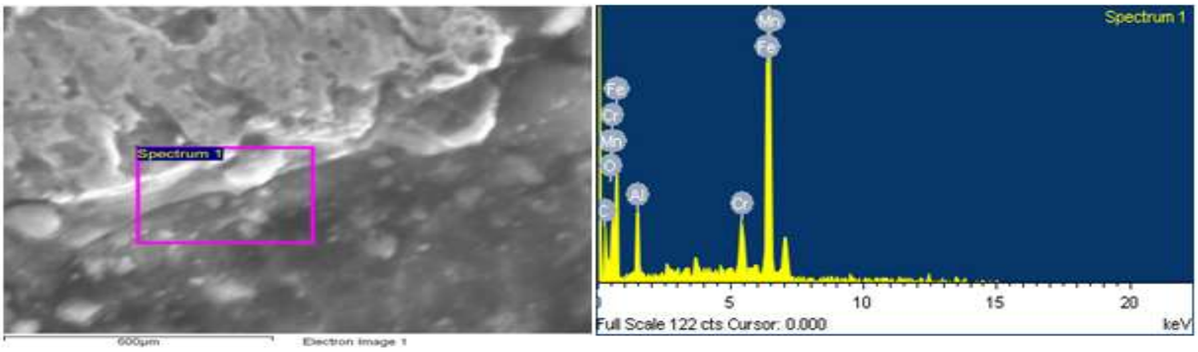

Figure: 8 SEM & EDAX Spectrum of Worn surface

TABLE 3 COATED SURFACE CHEMICAL COMPOSITION		
ELEMENT	WEIGHT %	ATOMIC %
N K	41.52	64.01
Al K	30.39	24.32
Cr K	28.10	11.67
Total	100.00	

TABLE 4 WORN SURFACE CHEMICAL COMPOSITION		
ELEMENT	WEIGHT%	ATOMIC%
C K	18.41	45.10
O K	7.22	13.28
Al K	4.01	4.37
CrK	4.53	2.56
MK	0.04	0.02
Fe K	65.80	34.67
Total	100.00	

V. CONCLUSION

From the above, all the three results are compared for their wear resistance. The primary results are summarized concerning the total specific wear rate. As a result of Vickers hardness test, the heat treated and coated materials shows better hardness than core material. Moreover, coated material hardness was increased more than 300 VHN in alumina layer deposition. As far as wear resistance is concerned, the coated material properties was increased. Wear graph exhibits that the carburized and coated materials show better wear resistance than normal low carbon steel. Furthermore, the morphological characterization are made in order to understand the mechanism involved during the wear. In all the related studies the PVD surface coating material proved to be preferable than the carburized material.

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