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# Study on Tribological Behaviour of DLC Coating On Bearing Steel

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**ABSTRACT:** The aim of the paper is to improve the wear resistance of the bearing material, through coating the Diamond Like Carbon (DLC) material on bearing steel (En31) by Physical Vapor Deposition(PVD) process. DLC possesses higher hardness with high wear resistance, low friction and chemically inert. Abrasive wear of both coated and uncoated specimen will be compared. In conventional bearings, material is subjected to a high cyclic loading and high levels of abrasion, the fatigue, friction and wear. When a bearing fails, it will affect the machine and reliability of the whole system. Therefore, prolonging the service life and reliability of the bearing by improving the wear resistance would be achieved by DLC coating.

**Keywords:** Diamond Like Carbon (DLC), Bearing steel (En31), Physical Vapor Deposition (PVD), Abrasive Wear**.**

## I. INTRODUCTION

Bearing steels are widely used for making bearings and other mechanical components, which subjected high to wear due to their distinguished mechanical properties, and many efforts have been employed to improve the wear resistance of bearings. One application among them, is surface modification with hardest material than the base material [1-2]. Diamond- like-carbon (DLC) coating is used in the automotive industries due to its superior tribological performance [3]. In recent years, diamond-like carbon (DLC) films have been gains more attention due to their characteristics like high hardness, chemical inertness, low friction coefficient, good wear resistance.[4-6]. Hydrogen-free DLC (a:C) thin films were deposited on the substrate surface by using filtered vacuum arc plasma deposition in conjunction with substrate biasing for control of ion deposition energy. The carbon plasma source was a repetitively pulsed vacuum arc plasma gun utilizing a carbon cathode. The substrate was continuously pulse-biased to a selected negative voltage for controlling the carbon ion energy at the time of the deposition. This technique has been called Metal Plasma Immersion Ion Implantation and Deposition (MePIIID) [7]. DLC coatings consists of a mixture of both diamond ($sp^3$) and graphite ($sp^2$). The relative amounts of these two phases will determine much of the coating properties. The amount of $sp^3$ and $sp^2$ bonds present in the prepared DLC material would be analysed by using raman spectroscopy [8]. Tribological tests were performed on pin-on-disc apparatus and abrasion wear testing apparatus to find out the wear resistance and coefficient of friction of the DLC coated specimen. Hardness of the coated specimen was found out by using micro-vickers test. For comparison, a uncoated bearing material was also tested under the same conditions as that of the coated material.

According to the Literature survey, the wear behaviour of the bearing steel would be improved by the DLC coatings synthesized by PIID (Plasma Ion Immersion and Deposition) technique. DLC films possess good adhesiveness towards the substrate and the coefficient of friction was reduced upto 60% [9]. Wear performance of the coating improves with the coating thickness, and for the lubricated conditions, the DLC coatings possess better performance when compared with the uncoated material [10]. DLC coatings possess more damage to the surface, when they are tear off from the surface due to the presence of hard contaminants [11]. Hydrogenated DLC (a:C-H) and non-hydrogenated DLC(a:C) were tested under lubricating conditions by using oleic and linoleic acids. The results implies that, during scratch test, the hydrogenated coatings possess ductile failure and non-hydrogenated coatings possess brittle failure [12]. The failure resistance of the bearing highly depends on the hardness of the coated material. And also, the wear of the material increases with the increase in thickness [13]. For the bearing steel, the friction coefficient was high for the DLC coatings, when operated under higher loads [14]. DLC possess good adhesion on the substrate, without the formation of any cracks and deformation. The wear tracks obtained during friction was narrower and shallower and delamination of the coating, doesn't occurs during friction testing, performed under ambient atmospheric conditions [15]. Coating by PIID technique enhance the mechanical properties of the bearing steel and the nano-hardness would be improved upto 300% [16].

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## II. EXPERIMENTAL DETAILS:

2.1 MATERIAL PREPARATION

The cylindrical samples of En31 were machined to a diameter of 55mm and 25mm with a thickness of 10mm. Samples were tempered to a temperature of 550$^{o}$C (HRC 19) and then the DLC coating was done on the polished surface. Tempering was carried out because to improve the toughness, which leads to good adhesive strength of coating. The principal composition of En31 steel was given in TABLE 2.1. The remaining % was Fe.

**Table - I chemical composition of En31 steel**

| Element | C | Si | Mn | P | S | Cr | Cu | Ti | Va | W |
|---|---|---|---|---|---|---|---|---|---|---|
| Composition | 0.965 | 0.281 | 0.539 | 0.039 | 0.043 | 1.215 | 0.143 | 0.009 | 0.045 | 0.021 |

2.2. FABRICATION OF DLC FILM:

Coating of the film on the substrate was done by MePIID. The base vacuum pressure was set about 2 x10$^{-6}$ torr. The vacuum arc plasma gun generates plasma carbon as pulses of 10ms with a duration of 5ms. Drift energy involved is 8eV. The produced plasma was filtered and deposited on the substrate.

2.3. CHARACTERISATION METHODS:

After the coating has been done, the microstructure and the mechanical properties were evaluated. The DLC film was characterized by using Scanning Electron Microscope analysis, EDX analysis and Raman spectroscopy. The Raman spectra of the DLC film was performed on argon laser with an excitation wavelength of 479nm and the duration of the spectra was about 60s and the wavelength range was chosen from 800 to 2000cm$^{-1}$. Hardness at the surface of the coated and the uncoated bearing material was found out by using Micro-Vickers hardness tester. Because of the very low thickness of the coated film, it was not accurate to find out the hardness by Rockwell or any other methods. And the hardness was found to be as 240$HV_{0.3}$ for the bare bearing steel and 656$HV_{0.3}$ for the coated one. Hardness was increased upto 3 times because of the DLC.

## III. RESULTS AND DISCUSSION

3.1. SEM ANALYSIS:

From the SEM image (Fig.1), the thickness of the DLC film was found to be 1.74µm. The coating thickness was comparatively uniform. And Fig.2 infers the good adhesive bonding of the DLC film with the substrate.

3.2. EDX ANALYSIS:

Energy Dispersive X-ray analysis was carried out on the coated surface to found out the composition of the elements present in the DLC films. From the Fig 3.3, it was observed that, the coated DLC film contains 65% of carbon and 32% of chromium and 2.6% of iron. Nitrogen is of negligible amount. The high carbon content present in the DLC films leads to excellent wear and corrosion resistance.

3.3. RAMAN SPECTROSCOPY

Raman spectroscopy is an effective technique to characterize the C=C bond structure of the DLC film. Generally, the Raman peak of DLC is composed of two broad peaks, namely the D peak (disorder peak) and G peak (graphite peak). The high frequency band (G band (1580 cm$^{-1}$)) in DLC Raman spectra has been assigned to the sp$^{2}$-bonded phase and the low frequency bond (D band (1380 cm$^{-1}$)) has been assigned to the sp$^{3}$-bonded phase. The main performance of DLC film depends on the value of sp$^{3}$/sp$^{2}$. i.e.

$I_D/I_G$. The smaller the integral intensity ratio of $I_D/I_G$, the higher the content of $sp^3$ bonds in diamond-like carbon, and the DLC possess properties more similar to the diamond.

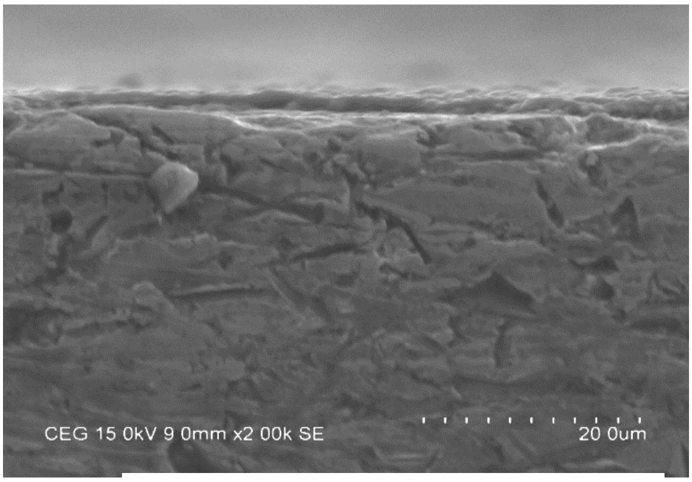


**Figure 3.1 Thickness of the coated film**

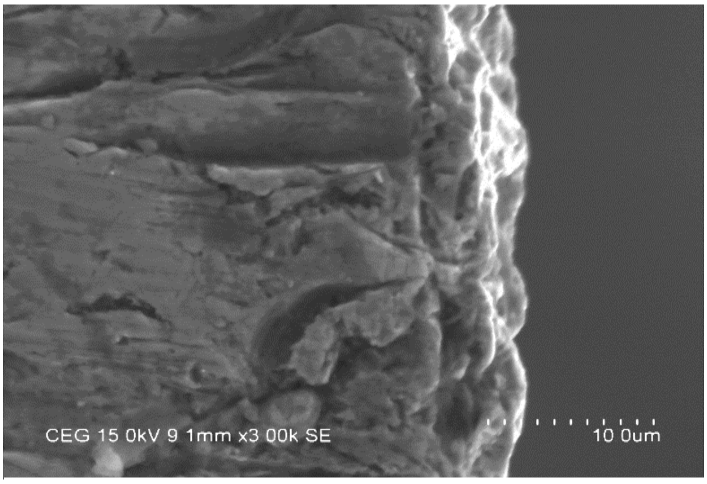


**Figure 3.2 Adhesiveness of the DLC film with the substrate**

**Table - II chemical composition of DLC film**

| Element | C | Cr | Fe |
|---|---|---|---|
| Composition (%) | 64.99 | 32.41 | 2.60 |

In Raman spectra, the D peak and G peak corresponds to 1360 $cm^{-1}$ and 1560 $cm^{-1}$. And the $I_D/I_G$ value is 0.87. The graph implies that the amount of $sp^3$ bond content in the DLC film is less than $sp^2$ bond content by 13%.

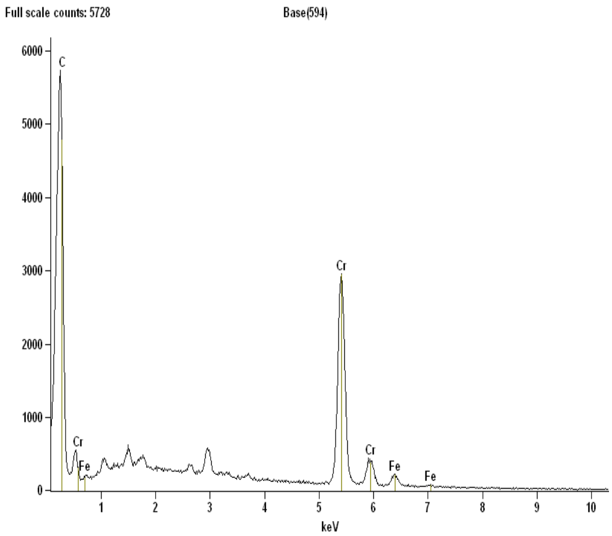


**Figure 3.3 EDX analysis of the DLC film**

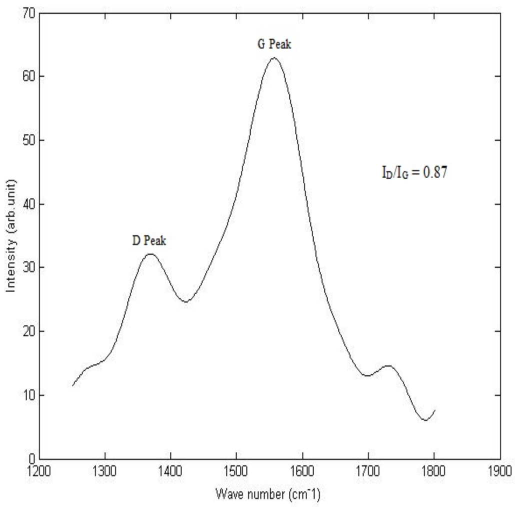


Figure 3.4 Raman Spectroscopy of the DLC coated film

3.5 ABRASIVE WEAR (ASTM G77)

Abrasive wear of the coated and the uncoated specimen was found out by using a Micro-abrasion tester. The apparatus consists of a ball made up of En31 and a specimen of diameter 24.63mm was made to be fit in the holder. Counter weight was given to the holder, when the specimen is in contact with the ball. Abrasion wear was measured at the conditions of 2N load, 200rpm and 3N load and 300rpm, each for 5mins. Abrasive particles used was sub-micron diamond paste.

From the Fig 3.5, it was inferred that, the coefficient of friction, decreases with increase in load and speed for the uncoated material. The same condition prevails for the coated material too. When comparing the uncoated material with the coated material, for the 2N load and 200 rpm, coefficient of friction reduces by 8% and for 3N load and 300 rpm, the coefficient of friction reduces by 32%.

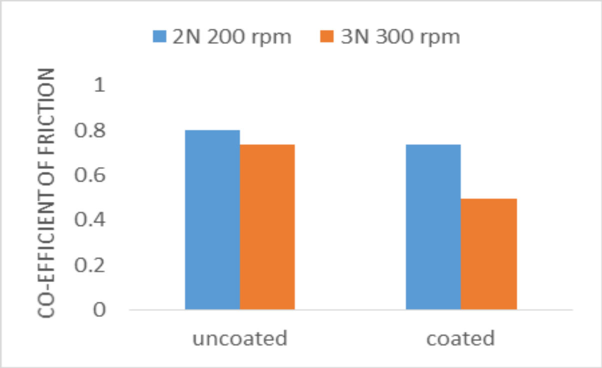


Figure 3.5 coefficient of friction Vs Coated/Uncoated material

3.6 WEAR RATE:

Wear rate (Abrasion Wear) is given by the difference in weights of the specimen before and after abrasion testing. Fig 3.6 gives the weight loss of the uncoated material, before and after abrasion testing. For 2N and 200 rpm, the Wear rate was found to be 0.0321%. For 3N and 300 rpm, the Wear rate was found to be 0.016%.

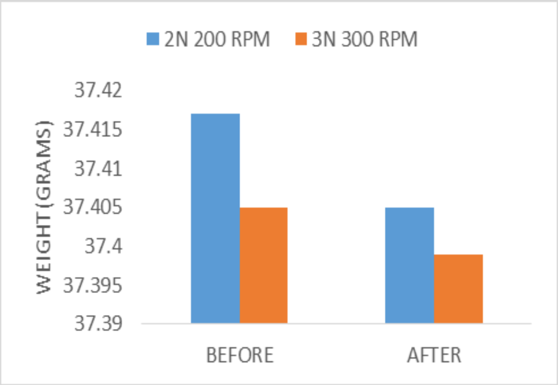


Figure 3.6 weight loss for the uncoated material

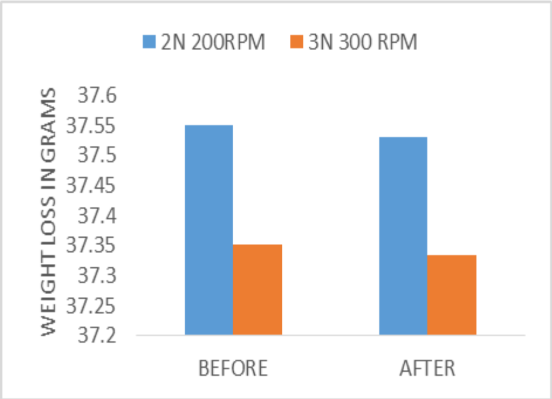


Figure 3.7 weight loss rate for the coated material

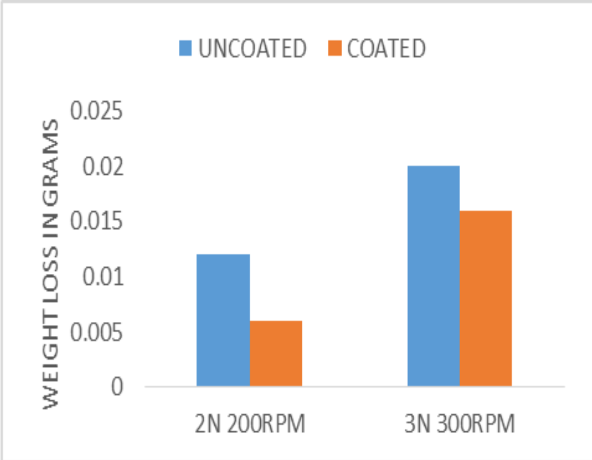


Figure 3.8 comparison of weight loss due to wear for the coated and the uncoated specimen

Figure 3.7 shows the wear rate of the coated material under the different load and speed values. For 2N and 200rpm, wear rate was found to be 0.053% and for 3N and 300 rpm, wear rate was found to be 0.043%. Figure 3.8 shows the comparison of weight loss due to wear for the coated and the uncoated specimen. It implies that the wear rate decrease with increase in load and speed for both the coated ant the uncoated specimen. For 2N load and 200rpm, the coated specimen possess wear rate reduction by 50% and for 3N and 300rpm, wear rate reduced to 80% when compared with the uncoated specimen.

## IV. CONCLUSIONS

Study on tribological behaviour of DLC coating on bearing steel has been carried out and comparison has been made out with the uncoated material. Wear characteristics and coefficient of friction were discussed by using micro-abrasion tester.

1. The hardness of the coated specimen is $656HV_{0.3}$. When compared to the bare bearing steel material, there will be an increase in hardness upto 3 times.
2. Raman spectroscopy of the coated film indicates that $I_D/I_G$ value is 0.87. The amount of sp3 bond atoms present in the film will be lesser than the sp2 bonded atoms by 13%.
3. Abrasive wear measured by Micro-abrasion tester indicates that the coefficient of friction decreases with increase in applied loads and speed. Wear rate leads to increase with increase in applied load and speed.

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## REFERENCES

[1] M.S. Jellesen, T.L. Christiansen, L.R. Hilbert and P. Møller, "Tribological behavior under aggressive environment of diamond-like carbon film with incorporated nanocrystalline diamond particles", Surface and Coatings Technology, vol. 206, pp. 434–439, 2011.

[2] S.E. Franklin and J. Baranowska, "Conditions affecting the sliding tribological performance of selected coatings for high vacuum bearing application", Wear, vol. 263, pp. 1300-1305, 2007. [3] S. V. Hainsworth and N. J. Uhure, "Diamond like carbon coatings for tribology: production techniques, characterization methods and applications", International Materials Reviews, Vol. 52(3) ,pp. 153–74, 2007.

[4] M. Yatsuzuka, Y. Oka, M. Nishijima and K. Hiraga, "Performant DLC Films with Enhanced Wear Resistance", Vacuum, pp. 190-194, 2008.

[5] G. X. Xie, B. R. Zheng, W. Li and W. Xue, "Investigation of Interfacial Composition, Structure, and Topography on Tribometric Friction", Applied Surface Science ,Vol. 254 , pp. 7022 – 7028, 2008.

[6] M. Minn and S. K. Sinha, "Wear Failures of Plastics", Wear, Vol. 11, pp. 3830-3833, 2010.
[7] A. Anders, "Microstructural characterization of N, Ti mixed coatings deposited by plasma based ion implantation and magnetron sputtering deposition", Journal of Materials Science Letters, Vol. 19, pp. 635-638, 1997.
[8] J. P. Hirvonen, J. Koskinen, J. R. Jervis and M. Nastasi, "Present progress in the development of low friction coatings", Surface Coatings &. Technology, Vol. 80(1–2), pp. 139–50, 1996.
[9] H. X. Liu, X. F. Wang, L. P. Wang **and** B. Y. Tang, "Wear behaviour and rolling contact fatigue life of Ti/TiN/DLC multilayer films fabricated on bearing steel by PIIID", Surface & Coatings Technology, Vol. 228, pp. 848-853, 2012.
[10] F. Masahiro, M. Ananth Kumar and Y. Akira, "Influence of DLC coating thickness on tribological characteristics under sliding rolling contact condition", Tribology International, Vol. 44, issue 11, pp. 1289-1295, 2011.
[11] Neha Sharma, N. Kumar, S. Dash, C. R. Das, R. V. SubbaRao, **A. K. Tyagi and** BaldevRaj, "Scratch resistance and tribological properties of DLC coatings under dry and lubrication conditions", Tribology International, Vol. 56, pp. 129–140, 2012.
[12] W. Xingyang, O. Tsuguyori, N. Takako and T. Akihiro, "Hardness effect of stainless steel substrates on tribological properties of water-lubricated DLC films against AISI 440C ball", Wear, Vol. 268, pp. 329–334, 2010.
[13] C. Martini, L. Ceschini, B. Casadei, I. Boromei and J. B. Guion, "Dry sliding behaviour of hydrogenated amorphous carbon (a-C:H) coatings on Ti-6Al-4V", Wear, Vol. 271, pp. 2025– 2036, 2011.
[14] Y. S. Zou, Y. F. Wu, H. Yang, K. Cang, G. H. Song, Z. X. Li and K. Zhou, "The microstructure, mechanical and friction properties of protective diamond like carbon films on magnesium alloy", Applied Surface Science, Volume 258, pp. 1624– 1629, 2011.
[15] Haruyuki Yasui, Makoto Taki, Yushi Hasegawa and Shigeki Takago, " Mechanical properties of high-density diamond like carbon (HD-DLC) films prepared using filtered arc deposition", Surface & Coatings Technology, Vol. 206, pp. 1003–1006, 2011.
[16] Hongxi Liu, Qian Xu, Chuanqi Wang, Xiaowei Zhang and Baoyin Tang, "Investigating the microstructure and mechanical behaviors of DLC films on AISI52100 bearing steel surface fabricated by plasma immersion ion implantation and deposition", Journal of Materials Science Materials in Medicine, Vol. 228, pp. S159–S163, 2013.