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**1** International Journal of Innovative Research in Engineering (11 Arial Narrow) Volume X, Issue X (XXXX-XXXX 2022), PP XX-XX www.theijire.com **Wear Behavior of** DLC Coated HSS with Hydraulic Fluids (16 Bold) Ashutosh Kumar Singh<sup>1</sup>, Ayush Guha<sup>2</sup> <sup>1</sup>(RV College of Engineering, India) <sup>2</sup>(RV College of Engineering, India) Corresponding Author: ashu.aks2510@gmail.com How to cite this paper: Y. First Author<sup>1</sup>, Second Author<sup>2</sup> Paper Title IJIRE-VXIX,YYYY Copyright © 2022 by author(s) and 5th Dimension Research Publication This work is licensed under the Creative Commons Attribution International License (CC BY 4.0). <http://creativecommons.org/licenses/by/4.0/>

**Abstract:** The worldwide rotary pump market was estimated at around \$5000 million in 2020 and the market is supposed to increase by 20% toward the end of 2026, seeing a compounded annual growth rate of 3% over a period from 2022-2026. The scrapping of an engineered component made from non-renewable resources at an early stage in life due to wear goes against the ethics of the conservation of natural resources as the frictional processes lead to dissipation of **12** a part of input energy. In this context many research works focused on analyzing wear behavior using various formulated and vegetable oils but no works investigated on using hydraulic oils as lubricant for wear preventative nature. The objective of the work was to obtain diamond-like carbon coating on high-speed steel samples and test them for better wear preventative behavior with different hydraulic fluids. The HSS ball sample of 12.7 mm diameter were used as a substrate on which the dlc coating was to be developed using then RF-PECVD technique. The developed DLC coating was characterized by conducting X-Ray diffraction which suggested the coating to be of amorphous structure, Raman spectroscopy which determined the content of graphite (sp<sup>2</sup>) to be 47% and that of diamond (sp<sup>3</sup>) to be 53%. Further nanoindentation was conducted to compare the hardness of the high-speed steel sample before and after coating which was 12.22GPa and 35.56GPa respectively. **1** The four ball test was performed to investigate the anti-wear properties of lubricating oil at specific conditions such as higher load, controlled temperature and constant rotating speed of the ball as per the ASTM D4172. The four ball results show that the coefficient of friction for samples reduces by around 36% when test oil 3 is used in uncoated samples and 48% in coated samples. Also, **2** the wear rate for the test oil 3 for coated samples was found to be 0.7381x10<sup>-6</sup> mm/Nm, which is the lowest wear rate among the other test oils. The outcome of the project is the reduction of **12** coefficient of friction by 84% with

respect to dry condition when test oil 3 is used. Therefore, it can be deduced that test oil 3 stands out as the most effective lubricant among the trio of test oils. In this direction, further work can be carried out by carrying out four ball tests with lubricant oils in combination with additives to it so as to enhance the base oil property and suppress undesirable base oil properties. Fabrication and manufacturing of the vane model can be done to validate the result with the help of experimental work. (10) Key Word: (11Bold) DLC; HSS; Raman Spectrograph;AFM; 4-Ball Test,Hydraulic Oil

(10) I. **3 Introduction** The hydraulic vane pump of fixed or variable displacement is subjected to different wear due to mixed friction, sliding wear, corrosion, cavitation, chemical effects while operating continuously for a longer period of time and thus the life as well as the efficiency is reduced [1]. Wear caused by the abrasion of small particles has been studied extensively, particularly in unlubricated systems [2]. The important parameters **2 have been found to** be the hardness of the surface being abraded and the hardness, size, shape and toughness of the abrasive particles. Abrasion with lubricated systems has also received considerable attention [3- 6]. Nowadays **3 some pump producing industries use ceramic coatings like chromium oxide, aluminum oxide, titanium carbon nitride or zirconium as wear coatings to increase the life of the pump.** Thanks to their outstanding corrosion resistance, hardness, thermal 1 | Page

**Wear Behavior of** DLC Coated HSS with Hydraulic Fluids stability and other properties. Other than ceramic coatings Diamond like coating (DLC) also gained acceptance. **4 Diamond-like carbon (DLC) coatings are perfectly suited to the most extreme wear conditions and high sliding speeds, even without lubrication.** They minimize frictional losses, making them ideal for engine components such as fuel injection systems, valve trains and pistons. Numerous additional applications, spanning from pumps and compressors to bearing shells and rollers, as well as from textile machinery to medical technology, also make use of the remarkable sliding characteristics offered by DLC coatings. One of the solutions to minimize **3 the wear would be to find desirable coating material with required properties appropriate for the base materials and suitable techniques of coating the materials[7].** Also anti-wear agents can be added in the hydraulic fluids. The bonding strength is also of importance as the vane pumps operate at higher speeds for longer duration.[8,9] II. Material And Methods

Specifications of HSS Balls: Weight Of Ball : 8.8 gm Diameter Of Ball : 12.7 mm Hardness : 415 HV

Average Roughness: 0.93  $\mu\text{m}$  Selection of Coating Material **DIAMOND LIKE CARBON** (a-C:H)

Properties: • Extremely hard • Low friction losses • **4** **Ideal for high speeds** • **Excellent abrasion**

**protection** • **Higher sliding velocity** Table No. 1 Carbon Based Coating Me-DLC( WC-C:H) DLC a-

c:H Doped DLC a-C:H a-C:H sputtered C ta-C Method PVD PACVD PACVD PVD PVD Film nr.

according VDI 2840 2.6 2.4 2.7 2.4 2.2 Hardness(HV 0.05) 800-2200 1500-3500 1500-2500 2000-

4000 3000-8000 **Coefficient of friction** 0.1-0.2 0.05-0.15 0.05-0.1 0.05-0.1 0.02-0.1 Internal

Stress(GPa) .1-1.5 1-3 1-3 2-6 1-3 Thickness( $\mu\text{m}$ ) 1-10 1-3 1-3 1-3 1-3 Industrial use +++ +++ +++

+++ +++ Mass Production + +++ ++ +++ +++ In Table No.1, various carbon based coatings are

shown out of which the selected coating has been highlighted Specifications of DLC Coated HSS

Balls 2 | Page

Wear Behavior of DLC Coated HSS with Hydraulic Fluids • Coating Material: **3** **Diamond Like**

**Carbon** (a-C:H) • Coating Technology: PECVD • Weight Of Ball: 8.97 gm • Coating Thickness: 3

$\mu\text{m}$  • Hardness:~1500-2500 HV Coating Architecture Used-a-C:H Coating Architecture: In a typical

sputter procedure, graphite targets can produce the hydrogenated a-C:H top coating. However, in order

to provide the top layer appropriate hardness, this procedure must be reactive. Sputtered a-C:H

typically has a hardness value that is significantly higher than a-C:H made using PECVD. However, as

the coating would be too soft otherwise, reactive sputtering is required. The performance in terms of

friction might arc toward ta-C for high-volume production. Although the delayed application method

makes the coating more expensive, it is nonetheless used in high-volume manufacturing due to the

coating's superior friction performance. Figure 1 shows HSS Balls before and after DLC coating. Fig 1

(a) HSS Balls Fig 1 (b) DLC Coated HSS Ball 3 | Page

Wear Behavior of DLC Coated HSS with Hydraulic Fluids Selection of Oil:One of the most crucial

parts **3** **of a hydraulic** system is hydraulic fluid. It carries out a variety of tasks, including **6** **power**

**transmission, lubrication, heat transfer, and** the transportation of contaminants, **wear debris, and**

sludge. Given the significant roles that fluids play, choosing the right fluid is essential for maximizing

the performance and lifespan <sup>32</sup> of hydraulic pumps, motors, and other components. Fluid Properties to Consider while selecting Oil: The most significant property is viscosity, which characterizes a fluid's <sup>34</sup> resistance to flow. <sup>27</sup> Low viscosity fluids create boundary lubrication conditions with low film thickness, which can cause metal-to-metal contact and harm system components. On <sup>6</sup> the other hand, high viscosity, or strong resistance to flow, can cause slow operation and reduced mechanical efficiency. Elevated fluid temperature can be caused by energy losses from high viscosity. Temperature directly affects viscosity, with system design, operating temperature, and ambient temperature all playing a role. Based <sup>3</sup> on the operating temperatures, a suitable viscosity grade fluid needs to be chosen for each application. The viscosity of the fluid at working temperature must be within the range recommended by the system's components, particularly the pump. For choosing <sup>25</sup> the fluid viscosity grade, minimum, normal, and maximum operating temperatures must be taken into account. [34-35] To maximize hydraulic system performance and component longevity, good AW characteristics are necessary. Inadequate AW characteristics can cause boundary lubrication regime <sup>4</sup> scuffing and cold welding, which will remove surface material. [36]. Various standard tests to consider: ASTM D 943: Oxidation Characteristics of Inhibited Mineral Oils: considered useful in estimating the oxidation stability of lubricants. Uninhibited <sup>7</sup> oils will usually fail within 200 h, while high quality oils can exceed 5000 h – 10,000 h. Longer the oxidation life is in the D 943 test, the longer the lubricant will perform in the field. The Vickers 35VQ25 test assesses the <sup>8</sup> anti-wear properties of hydraulic oil by analyzing weight loss in a 35VQ25 vane pump's cam ring and vane, with a requirement for a minimum of three cartridges undergoing 50-hour testing each. For a fluid to pass this assessment, the first three cartridges, or the initial four out of five, must demonstrate satisfactory performance. ASTM D665 A and B: To determine the rust preventive properties of turbine oils and other industrial lubricants, particularly circulating systems. An outcome marked as "Pass" in this test signifies that, under conditions of moisture, the lubricant is unlikely to result in substantial rust formation within the equipment.

Typical Properties of oil: Table No. 2: Typical Properties Of Lubricant Oil

NAMING CONVENTION	TEST OIL 1	TEST OIL 2	TEST OIL 3	AW	HYDRAULIC
GRADE 32	46	68	<sup>25</sup> ISO VISCOSITY GRADE 32	46	68
DENSITY@ 15°C,	kg/m <sup>3</sup>	854	857	865	
Pour Point °C	-39	-36	-33		
Flash Point °C	230	248	254		
Viscosity Index	115	114	111		
Rust Test	Pass				

Pass Pass Denison HF- Pump Test Approved Approved Approved Oxidation Stability,hrs D-943

5000+ 5000+ 5000+ 33VQ25 8 Vane Pump Test Pass Pass Pass 4 | Page

Wear Behavior of DLC Coated HSS with Hydraulic Fluids Table No:2 shows the different important properties 22 of the oil like ISO Grade, Density, Viscosity and test results that were taken into consideration for selection of oils. From above data we can see that operating viscosity of the oil should be between 10 cSt and 108 cSt. The viscosity index of hydraulic system oil should not be less than 90. It has the ASTM D-943 of 5000+hrs for all the oils. It passes the 33VQ25 8 Vane Pump Test and Denison HF-Test has been approved for all the oils. Therefore we conclude 3 that the test oil 032, 046 and 068 as shown in Figure 4.2 passes all the criteria for right oil selection. Fig. 2: Test oil 1, 2 and 3 Characterisation and Experimentation X Ray Diffraction: A crystal consists of periodically arranged atoms during a three-dimensional space. On the opposite 5 hand, amorphous materials don't possess that periodicity and atoms are randomly distributed in 3D space. So, this forms the basis to differentiate between amorphous and crystalline structure of the coating. When there's periodic arrangement of atoms the X-rays are scattered only in certain directions once they hit the formed lattice planes which are formed by atoms. This may cause high intensity peaks that will have the width of the peaks lesser when compared to its height. Whereas in case of an amorphous structure the X-rays are scattered in many directions resulting in an oversized bump distributed during a wide selection (two Theta) rather than high intensity narrower peaks. 3 As shown in Figure 3 no sharp peaks are observed in the intensity v/s two theta graph concluding amorphous structure of the coating. Fig 3: X Ray Diffraction Graph Intensity v/s two theta Specifications Of The Machine X-Ray Tube 5 | Page

20 Wear Behavior of DLC Coated HSS with Hydraulic Fluids Table 3: Specifications of X ray Tube  
Description Specification TYPE Sealed Type ANODE Cu FOCUS SIZE 1 x 10mm (2.0kW) or 2 x 12mm (2.7kW) RATING 2.0kW or 2.7kW Table No 3: shows the important specifications of X Ray Tube used for X Ray diffraction. These specifications are important in determining the nature of the coating. Raman spectroscopy DLC is a metastable amorphous carbon composed of a disordered network with sp<sup>2</sup> and sp<sup>3</sup> bonds. By modulating the ratio of sp<sup>2</sup>/sp<sup>3</sup> bonds, the properties can be

altered. To ensure the correct content of sp<sup>2</sup> and sp<sup>3</sup> in the obtained coating, Raman Spectroscopy is performed on the samples. <sup>12</sup> The extent of defects (diamond- sp<sup>3</sup>) in the graphite material (sp<sup>2</sup>) can be obtained from the integrated intensity ratio of the D band and G band (ID/IG) obtained from the Intensity v/s Raman Shift plot of the material. Higher the value of ID/IG higher the defect in the system, and hence, higher the content of diamond in the coating 6 | Page

<sup>11</sup> Wear Behavior of DLC Coated HSS with Hydraulic Fluids Fig 4 Raman Spectroscopy plot of the DLC Coating (Intensity vs. Raman Shift) The graph in Figure 4 of Intensity vs. Raman Shift was plotted on the Origin shift to obtain the D-Peak and G-Peak heights. The D-Peak was observed at a Raman Shift of 1364.03 cm<sup>-1</sup> and G-Peak was observed at a Raman Shift of 1534.26 cm<sup>-1</sup>. The ratio ID/IG shows a ratio of 0.88. This <sup>2</sup> shows that the coating has 47% content of Graphite (sp<sup>2</sup>) and 53% Diamond (sp<sup>3</sup>). This amount is acceptable for the required application. Table 4 Specifications of Raman Spectrometer Description Specification Make Witech Make Model Name Alpha 300 RAS Laser 532 nm Laser Source ND YAG (Neodymium doped yttrium aluminum garnet ) Table 4 shows the important <sup>20</sup> specifications of the Raman Spectrometer. 532 nm wavelength laser was <sup>3</sup> used in the experiment. Nano Indentation: Nanoindentation <sup>15</sup> has become an essential non-destructive technique for determining mechanical properties under extreme conditions. The method has been effectively utilized to determine the elastic modulus and hardness. Researchers have extensively employed this robust approach to explore the <sup>35</sup> mechanical properties of polymers and their composites. Nanoindentation has proven to be a proficient technique in capturing localized mechanical alterations within nanocomposites. Fig 5(a) Hardness for uncoated balls 7 | Page

<sup>36</sup> Wear Behavior of DLC Coated HSS with Hydraulic Fluids Fig 5(b) Hardness for coated balls From Figure 5 (a) & (b) we can verify that hardness for uncoated sample is 12.22GPa and DLC coated sample is 35.56GPa and therefore the hardness has increased around three times after coating. <sup>20</sup> Atomic Force Microscopy The images were processed with line by line leveling to normalize the Z range. The data from these images will be analyzed and information about roughness, feature height, and grain <sup>11</sup> analysis will be explored. The 3D images show exaggeration in the Z

range in order to display the features on the sample. The color change indicates the height of the sample in the Z range from the dark brown being at zero and the bright yellow being the highest point in the sample. AFM images give 3-Dimensional array of numbers. The quality of analysis depends on the quality of AFM images. The AFM images gives surface roughness, height analysis and grain analysis. Surface roughness includes a set of four standard equations that are used to calculate roughness of the sample surface: Eq. 1. Surface Roughness:  $\sigma^2 = \sum (x_i - \bar{x})^2 / n$ ,  $\bar{x} = \sum x_i / n$   $\sigma = 471.72 \text{ nm}$  Eq. 2. Root Mean Square:  $\sigma^2 = \sqrt{(\sum (x_i - \bar{x})^2 / n)} = 597.07 \text{ nm}$  Eq. 3. Mean Value:  $\bar{x} = \sum x_i / n$   $\bar{x} = 198.59 \text{ nm}$  Fig 6 AFM of DLC coating As in Figure 6 and Table 5 Sq root mean square roughness was found to be 597.07nm, Sp maximum peak found was 2193.2nm, Sv valley depth -1943.1nm, Sa arithmetical mean height was 471.72nm. Table 5 Surface parameters using Atomic Force Microscopy 8 | Page

Wear Behavior of DLC Coated HSS with Hydraulic Fluids Area Roughness Area 2.496 nm<sup>2</sup> Sa 471.72 nm Sq 597.07 nm Sy 4.1363 μm Sp 2193.2 nm Sv -1943.1 nm Sm 198.59 pm Specifications Of The Machine Table 6 Specifications of Atomic Force Microscope Description Specification XY scan range 100 μm (tolerance +/- 10%) Z range 15 μm (tolerance +/- 10%) Power AC 100 – 240V - 47-63Hz Table 6 shows the important specifications of the AFM machine. Experimentation - Four Ball Test 1 Lubrication is widely used in machines, automobiles and industries to eliminate surface to surface contact of components of machines and engines. Lubrication increases the efficiency as well as the working life and protects against the corrosion and wear. [38] Wear affects the life of components; if wear of components increases, life of that component decreases. [39] This inter-relationship between component performance and component lubricant is an important diagnostic tool to evaluate the component's health and performance. The components are affected by adhesive and abrasive wear of various other components and due to this contamination abrasion of surface of vanes, cam-rings and rotor. [40] The contaminations were identified as abrasive due to the observed marks and debris produced between the surfaces being tested. The primary role of a lubricant is to diminish friction, wear, corrosion, temperature, pollutants, and impacts. Anti-wear additives eliminate the metal-to-metal contact by addition of lubricant film forming agents that protect by direct contact of



surfaces and abrasive wear phenomena. [41] The addition of anti-wear additives is used for enhancing the anti-friction and anti-wear properties of lubricants. The four-ball tester is used to investigate the anti-wear properties of lubricating oil at various conditions such as higher load, controlled temperature and constant rotating speed of ball, Investigate the comparison of depletion of the anti-wear additive and properties of fresh and different working life cycle lubricant oils using four ball tester and make interrelationship between the working life of lubricating oil and performance of sliding components.

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Wear Behavior of DLC Coated HSS with Hydraulic Fluids Standard Used [22 American Society for Testing and Materials \(ASTM D4172\)](#) Temperature : 75 degree celsius Speed : 1200 rotations per minute Duration : 60 minutes Load : 392 Newtons Experimental Procedure The tests are carried out in accordance with [1 the standard test methods for measurement of wear preventive properties of Lubricating Fluids, using an ASTM D4172 standard.](#) Newly coated balls with a Diamond-Like coat [3 are used for](#) each set of tests. The coated steel balls are [1 placed into the oil cup assembly and the oil cup is tightened using a torque wrench to prevent the bottom coated steel balls from moving during the experiments as shown in Figure 5.5 \(a\), 5.5 \(b\) and 5.5 \(c\). The upper spinning ball is locked inside the collet and tightened into the spindle. The test lubricant is introduced into the oil cup assembly. It must be ensured that the oil fills all of the voids in the test cup assembly. The oil cup assembly components are installed into the frictionless disc in the four-ball machine and, to avoid shock, the test load of 392 newtons is applied slowly. The lubricant is then heated to the desired temperature of 75° C. When the set temperature is reached, the drive motor, which is set to drive the top ball at the 1200 revolutions per minute. After the 1-hour test period, the heater is turned off and the oil cup assembly is removed from the machine. The test oil is then drained from the oil cup and the scar area is wiped using a tissue. The bottom balls are then placed on a microscope base that is designed to hold the balls during microscopic evaluation. On each of the three lower balls, measurements of the wear spot are made with a microscope and compared. III. Result The final results of each characterization performed of the Diamond-Like Coating of high speed steel ball samples and the four ball test performed on both coated and uncoated samples \[8\]\(#\) will be discussed in this chapter.](#)

Table 7: Four ball test results Sample ID Type 1 Frictional torque in Nm Scar diameter in mm Ball 1

Ball 2	Ball 3	Average	Test oil 1 Uncoated	0.14	0.628	0.615	0.620	0.621	Coated	0.13	0.558	0.571
0.568	0.565	Test oil 2 Uncoated	0.17	0.593	0.591	0.584	0.589	Coated	0.12	0.538	0.533	0.529
0.533		Test oil 3 Uncoated	0.09	0.602	0.561	0.569	0.577	Coated	0.07	0.480	0.471	0.476

IV. Discussion  
There are 34 a total of six experimental setups that are performed using four ball tribometers which include three tests using the uncoated ball samples and three coated ball samples and each test done with one oil sample at a time. As per the result 2 as shown in Table 7 it is observed that for all the oil samples the wear scar diameter obtained has reduced effectively when the ball sample is coated as compared to uncoated. Observing the differences of the average wear scar diameter for each oil sample it is clearly observed that oil sample test oil 3 reduces the wear scar diameter most effectively in comparison with test oil 2 and test oil 1. Figure 6.1, 6.2, 6.3, 6.4, 6.5, 6.6 shows wear scar images of the tested balls 10 | Page

**Wear Behavior of** DLC Coated HSS with Hydraulic Fluids generated by optical microscopy This explains that oil sample 3 displays the nature of slowest wear rate 21 in the four-ball test and hence is successfully able to display good wear preventive behavior. This nature of slow wear rate of test oil 3 as compared to other samples occurs as it provides higher shearing stability which means that during the life cycle the viscosity loss is the least than in the cases of test oil 2 and test oil 1. Fig 8

Comparison of friction torque for different lubricants The graph in Figure 8 shows that frictional torque is minimum when test oil 3 oil is used as compared to other lubricants. Moreover, DLC coating shows further reduction in frictional torque as compared to uncoated condition. Fig 8

Comparison 2 of wear scar diameter for different lubricants More the scar diameter, the more the wear. The graph in Figure 6.8 shows that wear is minimum when test oil 3 oil is used as compared to other lubricants. Moreover, DLC coating shows further reduction in wear as compared to uncoated condition. Wear can 11 | Page

**Wear Behavior of** DLC Coated HSS with Hydraulic Fluids be also evaluated by another parameter, called the wear rate. Tests are done with 1 h duration, with a constant rotational speed of 1200 rpm.

Deleanu, L [43] calculated sliding distances for 1 h:  $L_{1200} = 1641.6 \text{ m}$  ( $v = 0.1456 \text{ m/s}$  or rpm). <sup>2</sup> It is possible that the graph of the WSD dependence on test parameter is not relevant due to the difference in the sliding distances, and so, on the basis of the literature [43], the wear can be also evaluated by another parameter, called the wear rate, where:  $\square = \square \square \square [\square \square / \square \cdot \square]$  where WSD is the wear scar diameter average for a test,  $F$  – the load applied on the four balls,  $L$  – the sliding distance. The product  $F \cdot L$  is the mechanical work done by the tribosystem, in other words, the wear rate shows the loss of material volume or mass for the mechanical work unit performed by the system. Fig 9 Comparison of wear rate for different lubricants The graph in Figure 9 shows that wear is minimum when test oil 3 oil is used as compared to other lubricants. Moreover, DLC coating shows further reduction in wear as compared to uncoated condition. 12 | Page

Wear Behavior of DLC Coated HSS with Hydraulic Fluids Fig 10: <sup>13</sup> Coefficient of friction for uncoated samples Fig 11: Coefficient of friction for coated sample Figure 10 shows the coefficient of friction for uncoated samples during the one hour of four ball wear testing. Figure 11 shows the same for coated samples. The coefficient of friction increases as the test starts and gets fairly constant after sometime. For both the conditions, coated and uncoated <sup>2</sup> the coefficient of friction is least of test oil 3 oil. The high viscosity of test oil 3 helps in reducing this value as compared to other two lubricants. The coefficient of friction values for test oil 1 and test oil 2 are almost similar and thus, do not show much difference. When comparing the two graphs, an overall decrease in coefficient of friction is evident in the case of coated samples. This shows that the DLC coating has helped in reducing <sup>13</sup> the coefficient of friction. Table 6.2: <sup>24</sup> Average Coefficient of Friction of different samples Oil Average Coefficient of Friction Uncoated Samples Coated Samples Test oil 1 0.0667 0.0619 Test oil 2 0.0718 0.0601 Test oil 3 0.0438 0.0316 Table 6.2 shows average coefficient of friction of different samples. A significant reduction in <sup>1</sup> coefficient of friction by around 48% is observed for the test oil 3 in coated samples and 36% for uncoated samples. The high viscosity of test oil 3 helps in reducing this value <sup>2</sup> as compared to other two lubricants. This makes this lubricant better than the other two in terms of reducing friction. Also, coating the samples with DLC has helped in further reducing <sup>13</sup> the coefficient of friction by 28% for test oil 3, making it suitable for the required applications. 13 | Page

39 Wear Behavior of DLC Coated HSS with Hydraulic Fluids Fig 12: Frictional Force for uncoated samples Fig 13: Frictional Force for coated samples 14 | Page

Wear Behavior of DLC Coated HSS with Hydraulic Fluids Figure 6.12 shows the frictional force for uncoated samples during the one hour of four ball wear testing. Figure 13 shows the same for coated samples. The frictional force increases as the test starts and gets fairly constant after some time. For both the conditions, coated and uncoated the frictional force is least of test oil 3 oil. The high viscosity and low 11 coefficient of friction of test oil 3 helps in reducing this value as compared to other two lubricants. The frictional force values for test oil 1 and test oil 2 are almost similar and thus, do not show much difference. 2 When comparing the two graphs, an overall decrease in frictional force is evident in the case of coated samples. The reduction of frictional force helps in reducing the wear that occurs due to abrasion. This 11 shows that the DLC coating has helped in reducing the frictional force and wear. Table 6.3: 28 Average Frictional force of different samples Oil Average Frictional Force (N) Uncoated Samples Coated Samples Test oil 1 0.1171 0.1089 Test oil 2 0.1389 0.1058 Test oil 3 0.0719 0.0558 Table 6.3 shows the average frictional force of different samples. A significant reduction in frictional force by around 48% is observed for 11 the test oil 3 in coated samples and 40% for uncoated samples. The high viscosity of test oil 3 helps in reducing this value as compared to other two lubricants. This makes this lubricant better than the other two in terms of reducing friction. Also, coating the samples with DLC has helped in further reducing the frictional force by 23% for test oil 3, making it suitable for the required applications. V. Conclusion The following are the conclusions that are made from 2 the results obtained of the characterization tests and then the best hydraulic fluid for high wear preventative properties is found out. • DLC Coating of thickness 3  $\mu\text{m}$  was successfully deposited at Oerlikon Balzers facility on HSS Ball substrate, procured from Ducom Instruments using RF-PECVD technique. • Surface topography, carbon and graphite content, amorphous structure and hardness were verified using AFM, Raman Spectroscopy, XRD and Nano-indentation respectively. • Viscosity, density and flash point of the lubricants were verified as per the Hindustan Petroleum Ltd. datasheet. • From 2 the four ball test it was deduced that oil sample test oil 3 shows the best wear

preventative properties **as compared to other** oil samples as it was able to bring **the wear scar diameter** to the lower range when DLC coating was applied **3 to that of** uncoated. The research work can be extended by carrying out four ball tests with lubricant oils in combination with additives to it so as to enhance the base oil property and suppress undesirable base oil properties. The research work can further be extended by performing debris **1 analysis of the** hydraulic oil post four ball test to have better understanding of the abraded **particles in the test oil**. Fabrication and manufacturing of the vane model can be done to validate the result **2 with the help of** experimental work. References **3 [1]**, Brian Nesbitt, 'Handbook **of Pumps and Pumping : Pumping Manual** International', Elsevier, Vol 1, 2006, 132-152, ISBN: 9781856174763 [2]. **14 F. F. Tao & J. K. Appeldoorn** 'An **Experimental Study of the Wear Caused by Loose Abrasive Particles in** Oil', ASLE Transactions, Vol 13, 2014, 169-178 [3]. Kenji Ohara<sup>1</sup>, Kiyoshi Hanyuda, Yasushi, Kawamura, Kentaro Omura, Imari Kameda, v Noritsugu Umehara, Hiroyuki Kousaka, 'Analysis of Wear Track on DLC Coatings after Sliding with MoDTC-Containing Lubricants', Japanese Society of Tribologists, Vol 12, 2017, 110-116 [4]. Josyula, S.K., Dube, A., Patro, D., Veeregowda, D.H. "On the Fictitious Grease Lubrication Performance in a Four-Ball Tester", Multidisciplinary Digital Publishing Institute, Vol 9, 2021, 33-34 15 | Page

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