Effect of Wear Resistant Coatings on Oil Hydraulic Components-A Review

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Abstract: **The hydraulic vane pump, direction control valve, cylinder actuator etc., are subjected to wear due to mixed friction, corrosion, low hardness etc. This wear can be minimised by applying coating of wear resistant materials like zirconium, diamond like carbon (DLC), tungsten carbide cobalt, tungsten nickel using different coating methodologies like plasma spraying, flame spraying, physical vapour deposition method. Some results of the simulation of wear between vanes and rotor in oil vane pump using ANSYS software are shown. Wear test reveals that to minimise the wear and increase the component efficiency, the tribology can be changed by applying coating of wear resistant materials suitable for the base material, with suitable coating techniques.**

Keywords: Wear, coating material, simulation, coating techniques.

I. INTRODUCTION:

The hydraulic vane pump of fixed or variable displacement, direction control valve (DCV), cylinder actuator spool etc., are 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]. Now a days some pump producing industries use ceramic coatings like chromium oxide, aluminium oxide, titanium carbon nitride or zirconium as wear coatings to increase the life of the pump. Thanks to their outstanding corrosion resistance, hardness, thermal stability and other quantities. Other than ceramic coatings Diamond like coating (DLC) also gained acceptance. One of the solution to minimise the wear would be to find desirable coating material with required properties appropriate for the base materials and suitable techniques of coating the materials[2]. 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.[3,4]

II. COATING METHODOLOGY:

The choice of processing technique depends on the different factors like adhesion, temperature, density of the chosen coating material and the base material. Widely used processing techniques are:

1. Plasma Spraying: The important plasma spraying technique are vacuum plasma spraying (VPS) or air plasma spraying (APS). The vacuum plasma spraying is producing dense coating made of reactive materials without the danger of oxidation.[5-7]
2. Physical Vapour Deposition (PVD): The basic physical vapour deposition fall into two general categories: sputtering and evaporation. The thickness of the coating using PVD varies from angstroms to millimetres. Several PVD techniques are available for deposition of hard coatings. Among them, cathodic arc vapour (plasma or arc ion plating) deposition, magnetron sputtering (or sputter ion plating), and combined magnetron and arc processes are the most widely used techniques to deposit various hard coatings. These PVD processes differ with respect to the type of evaporation of the metallic components and the plasma conditions employed during the deposition process. The transition of the metallic component (to be deposited) from a solid to a vapour phase (in which metal atoms are ionized in different ways) may be performed by heating of an evaporation source (as in cathodic arc) or by sputtering of a target (as in magnetron sputtering). Cathodic arc and magnetron sputtering techniques allow evaporation of metals with different melting points such as Ti and Al from a Ti-Al alloy cathode/target. The PVD arc evaporation process employs higher energy input than the PVD sputtering process. A trend has been to combine the advantages of sputtering and cathodic arc techniques. The Arc Bond Sputter (referred to as ABS) technique was developed by combining the features of steered cathodic arc and unbalanced magnetron processes. From the study, It was noted that ABS Technique for PVD hard coating is the best technique but at the same time the most expensive one. A systematic study of the influence of deposition parameters on the morphology of the arc deposited coatings needs to be carried out. Such an investigation can be used to develop a correlation between the arc deposited coating morphology and its properties.[8-10]

III. COATING CHARACTERISTICS:

Coatings may have one or more of the following wear resistant properties: (i) corrosion protection;(ii) wear resistance; (iii) hardness; (iv) high melting temperature; (v) low permeability and diffusion for oxygen to prevent internal substrate corrosion; (vi) high density, to avoid gas flux through open pores to the substrate; (vii) stress free or in a state of compressive stress at the working temperature; and (viii) good adhesion.[11]

IV. COATING MATERIALS:

A. *Ceramic coatings:* Ceramic coatings find a wide range of applications in mechanical engineering. In the pump industry, tribological problems or material attacks by wear, corrosion and abrasion are counteracted by using appropriate coatings. The results from the paper [1] obtained for different types of coatings tested under pump-specific loads in comparison with conventional materials. The coatings ((WC/Co, WC/Ni, Cr 3C2/NiCr, Ni-SiC/ INCONEL) were applied using the vacuum plasma spraying process[12]. The following were the obtained results:

a. *Abrasion tests:* The tungsten (WC) coatings achieved the best results. Their wear resistanve exceeded that of cast iron by a factor of 10. Solid INCONEL is somewhat better than duplex steel. Comparing the wear rates of the various Cr_3C_2 coatings, one notices the infunce of the carbide content. A carbide content of between 75% and 93% allows less than half as much wear as a coating that contains 65% carbide[13].
b. *Corrosion tests:* Solid INCONEL showed the best resistance to corrosion. Pure nickel behaved much like an 80/20 NiCr coatings. The WC coatings proved to have the best anti corrosion properties. Bonded with Ni and Co, their stability was equal to that of pure nickel.
c. *Tribological tests:* The best behaviours was obtained at a SiC/SiC couple of course. But the developed SiCNi/INCONEL coating shows also a very good friction coefficient at high speed and load. Compared with other coatings due to this test station the SiC coating behaves like WC/Co and Cr 3C2 /NiCr. It was found that the results respond very sensitive to roughness and to microstructure of the materials.

B. *Diamond like carbon(DLC):* DLC coatings have elicited considerable attention in tribological applicable due to their chemical inertness, low static and dynamic friction coefficients. Deposition of DLC can be achieved at low substrate temperaturs and at high deposition rate utilizing ion-beam deposition (IBD), d.c. or r.f. sputtering, ion plating and cathode arc methods in [5,6]. DLC coatings excel at providing low friction even in applications where lubrication is inconsistent or non-existent. DLC coatings can consistently operate in applications with continuous operating temperatures up to 480 degrees Fahrenheit (250 degrees Celsius). Above this temperature, the coating properties change and the friction coefficient increases causing the coating exhibit a higher wear rate.
Although DLC coatings are not applied primarily for corrosion protection, they will provide improved corrosion protection and protect product from corrosive environments. Unlike other low friction coatings available, DLC can be deposited with a surface hardness of 1500 Hv or 3200 Hv depending on the operating environment, loads, impact, lubrication and conditions of use. With our amorphous carbon hydrogenated DLC films, the high surface hardness of up to 3200 Hv will provide exceptional protection against wear while still providing ductility and maintaining the low sliding friction on the surface of your component.[14-16]

V. WEAR LOCATION:

In most wear studies they make a distinction between OCA and CFOA wear. OCA wear stands for attritional wear in occlusal contact areas. CFOA wear stands for wear in contactfree occlusal areas.
An often forgotten wear location is the approximal wear at proximal contacts. Schmidlin et al. [17] studied with a computer-controlled masticator the approximal wear of two composites (P-50, 3M and Tetric Ceram, Ivoclar-Vivadent) which was assessed in a two-body wear test after thermomechanical loading.Wear showed a non-linear pattern, which was comparable to occlusal abrasion. After the first loading cycle, wear increased significantly, and subsequently decreased. After a 5-year-equivalent, the mean substance loss for composite specimens was 20.3±15.6 µm for P-50 and 17.5±3.1 µm for Tetric Ceram. Approximal wear between enamel surfaces was 3.9±4.3 µm. Also Wendt et al. [18] focussed on this approximal wear.

VI. WEAR TEST CRITERIA:

In selecting a suitable wear test, the following points should be considered: (i) ensure that the test selected is measuring the desired properties of a material; (ii) whether the material is in bulk form or is a thick or thin coating; (iii) whether the forces and stress limited are suitable for the test; (iv) whether abrasives be present, considering the abrasive size, form and velocity; (v) whether the contact between the components is rolling, sliding, impact or erosion only, or a combination of these, bearing in mind that the surface finish of the test samples should be similar to that of the actual components; (vi) whether temperature and humidity factors are important; (vii) whether the test environment is similar to the actual working environment; (viii) the duration of the test; and (ix) whether the materials used in testing is typical of the actual materials used in the machine parts.[19]

VII. METHODS OF WEAR TESTING:

Tests are used for quality control functions such as thickness, porosity, adhesion, strength, hardness, ductility, chemical composition, stress and wear resistance. Non-destructive tests include visual, penetrant dies, magnetic particle and acoustic techniques. Fig.1 shows the factors influencing the wear mechanisms during sliding contact. Fig2. shows the metallurgical properties influencing sliding wear. The wear test carried on a specimen are (i) Abrasive and adhesive test (ii) Pin-on-disc (iii) Pin-on-drum abrasive wear test (iv) Repeated impact ear test (v) Adhesion test using acoustic amission monitoring (vi) Rubbing test (vii) Block on ring test (viii) taber test (ix) Dry sand rubber wheel test (x) Alumina slurry test. The two major tests done are:

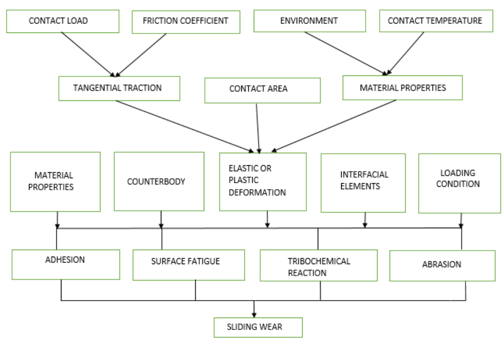


Fig.1. Factors influencing wear during sliding contact

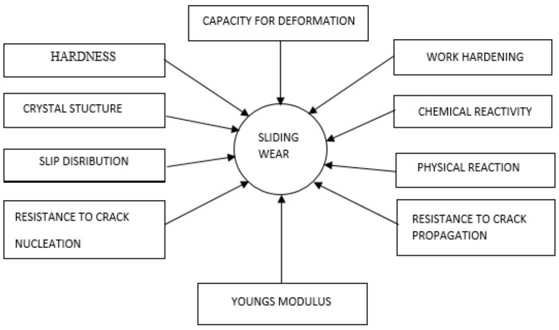


Fig.2. Metallurgical properties, influencing sliding wear

7.1. *Abrasive and adhesive test:*

Hardness is often used as an initial guide to the suitability of coating materials. The effect of a wearing however is complicaed, as different wear mechanisms can prevail in service. Scratch hardness is the oldest technique. Abrasive tests are given by Kato et al. [10] and others [11,12]. Adhesion tests, a mecchanically stable crack is introduced into the interface of the coating and substrate. The resistance to propagation of the crack along the interface is used as a measure of adhesion. In scratch-adhesion tests, a stylus is drawn over the surface under a continually increasing normal load until the coating fails.

7.2. *Pin-on-disc:*

According to research done by Glaeser and Ruff reported that pin-on-disc were the most widely used wear testing method, followed by pin-on-flat [9]. In a two-body abrasion test, a coated pin is pressed against a rotating abrasive paper making a spiral path to avoid overlapping.

VIII. SIMULATION RESULTS:

Simulation of wear between vane and rotor in vane oil pump using ANSYS software package is carried out and the following results are obtained. The contact gap of Titanium aluminum nitride and stresses acting was the least as shown in table 8.1.1 and 8.1.2.

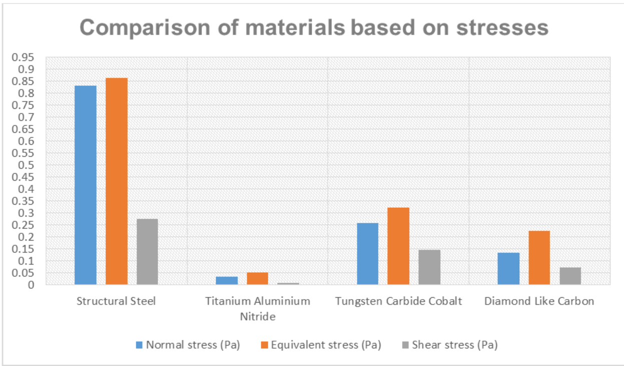
8.1.1. Details of contact gap for base and coating material:

Material	Total volume of debris (in mm^3)	Contact gap (in microns)
Structural Steel	0.363	0.268
Titanium Aluminium Nitride	0.1148	0.085
Tungsten Carbide Cobalt	0.1324	0.098
Diamond Like Carbon	0.1722	0.127

8.1.2. Stresses acting on the vane and rotor due to friction:

Material	Normal stress (Pa)	Equivalent stress (Pa)	Shear stress (Pa)
Structural Steel	0.83149	0.86393	0.27659
Titanium Aluminium Nitride	0.03418	0.051526	0.0086562
Tungsten Carbide Cobalt	0.25718	0.32403	0.14593
Diamond Like Carbon	0.13619	0.22607	0.071767

8.2.1. Graphical comparison of materials based on stresses



IX. CONCLUSION

- Wear rate of a part depends on target and contact material.
- Coated Vanes provide a lesser wear volume compared to normal vane made of HSS.
- In further studies, effect of ceramic, zirconium coatings can be chosen.
- Effect of rotor angular velocities and normal force on the wear rate can be examined.
- It is necessary to evaluate hydraulic fluids over a wide range of test conditions, loads, speeds, material pairs and where necessary contact geometry.

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