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TRIBOLOGICAL AND CHEMICAL STUDY OF CHEMICAL VAPOUR DEPOSITION COATING

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Abstract

The corrosion and erosion in the ferrous material has been a very big concern for the modern day machine parts. It affects the performance as well as the life of the m/c part. One of the very critical part for the mechanical system is the valve used for fluid flow, the collar of the valve made up of casted ferrous material oxidises very rapidly, the nature of the iron oxide prove negative for the performance of the system. The leakage of fluid due to erosion of collar results in reduced performance. The collar has to work against the housing and there is a mutual rubbing between the collar and housing causes wear of the collar as it is designed as softer material. In this article the tribological and corrosion study of chemical vapour deposition coating of Chromium and Nickel has been done. The study for the contributing factors affecting the tribological performance of the collar has been carried out using Taguchi L9 orthogonal array. The results showed the coated sample had superior tribological and chemical performance compared to the plain substrate material.

Keywords: Tribology; Taguchi Design; Chemical Vapour Deposition; Corrosion Test; Coating.

1. INTRODUCTION

Coating of metal surfaces plays a vital role in today's world, where new inventions are being carried out by mankind which requires materials to retain their properties at extreme conditions. The coating not only protects the surface from the external atmosphere but also provide better tribological and mechanical behaviour. There are various conventional and non-conventional process of coating which are being practised in industries across the world for different purposes. Purpose of the coating decides the coating process to be used. Some of most practised coating processes which are mainly use for improving the tribological properties of the materials are Thermal spraying, Electrodepositing, Electro-less coating, Vapour deposition process etc. The vapour deposition coating is further divided into two categories as described below:

Physical Vapour Deposition (PVD) – It includes conversion of coating material from condensed phase to vapour phase and then again to condensed phase in vacuum. Sputtering and evaporation are two most commonly types of processes used. There are various types of PVD processes such as Diamond like Coating (DLC), magnetron sputtering, ion plating, vacuum evaporation, cathodic arc deposition, etc.

Chemical Vapour Deposition (CVD) – It incorporates the utilization of volatile chemicals to deposit the coating on substrate and some particular gases to remove volatile by-products. The laser texturing on cast iron which was made to reciprocate against hardened steel under starved lubrication. He used design of experiments approach to texture the cast iron surfaces. The cast iron under mixed and boundary lubrication, subject to cyclic loading. This could be related to the aspect ratio of dimples and an optimal aspect ratio of 0.1 gave best results. The PVD coated silicon wafers, rendered by lithography and anisotropic etching, with TiN or DLC coatings for substrate texture retention. TiN and DLC coatings were applied to introduce wear resistant properties. Thus, many studies focus on determining parameters which influence the coefficient of friction between two surfaces and have tried to replicate the reciprocating pairs of automobiles by subjecting them to almost similar conditions [1]. Various textured surfaces have been studied and the mechanisms by which they improve the tribological performances have been stated. Similarly, comparisons on the basis of coefficient of friction have been made between hard chrome coated substrate [2]. Thermally sprayed NiCrBSi coatings are being applied to the components where both wear and the high-temperature oxidation resistance is required. NiCrBSi is a self-fluxing alloy [3]. B and Si present in the powder enhance the self-fluxing property of the metal which is favourable for coating deposition. The formation of hard phase with Ni, such as Ni_3B also occurs. Chromium present in the powder also increases corrosion and wear resistance by forming hard phases studied the wear performance of Atmospheric plasma and flame sprayed NiCrBSi coatings deposited on carbon steel (SAE 1045) at room temperature and 500°C. The authors conducted the reciprocating wear tests in the laboratory and concluded that NiCrBSi coated specimens maintained wear resistance up to 500°C. Researcher manufactured NiCrBSi via APS and subsequent laser re-melting [4-7]. The wear experiments were performed at room temperature. The authors compared the coating with hard chromium plating and found superior properties possessed by the NiCrBSi coated material. The wear and friction behaviour of laser clad NiCrBSi and NiCrBSi/WC-Ni composite coatings deposited on stainless steel substrates at 500°C using ball-on-disc tribometer [11-13]. The coated specimen demonstrated much lower wear rates than uncoated stainless steel specimen. Prominent wear mechanisms in coated samples were reported as mild abrasive wear and fatigue wear whereas uncoated stainless steel specimen showed adhesive wear, abrasive wear, severe plastic deformation and cutting [8-10].

2. EXPERIMENTAL SETUP

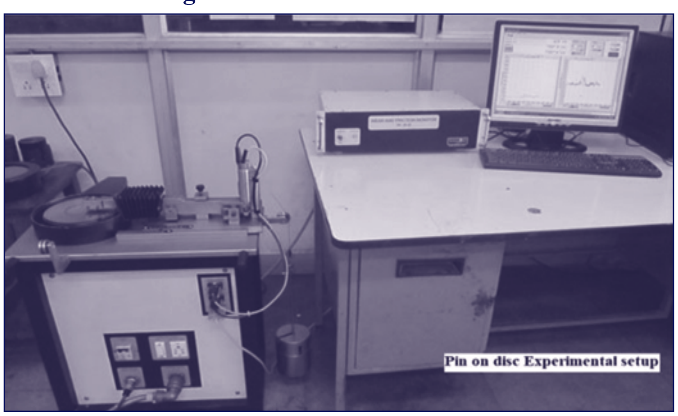
2.1 Chemical Vapour Deposition Setup: The coating was done using the electro-deposition method. The substrate material was connected to the negative terminal i.e cathode of the D.C. power supply and the coating material was connected to positive terminal i.e. anode. The ions transfer from the anode to the cathode through the media called as electrolyte. In chemical vapour deposition there is no direct bombardment of ions on the cathode like in physical vapour deposition. In chemical vapour deposition there is a media present which assist in generation of plasma. This plasma contains the coating material hits the substrate surface and more stable coating can be achieved. It has low coating rate with high starting expense for the setup and generally used for producing micro or nano level coating. Rather than most PVD methods, CVD is attractive for the covering of complex geometric work piece work surface. At a simple level, CVD uses synthetic responses of a precursor gas in a chamber containing the work piece at elevated temperature.

2.2 Micro-Hardness Test: The hardness test was performed by Vicker Hardness Machine. The specimen was prepared by taking the traverse cross-section of the stir zone. During the test, load and dwell time was 300gf, 5seconds. The avg. of five hardness values was regarded within each test region.

2.3 Tribological Testing

2.3.1 Pin on Disc Tribometer: The TR-20-LE Pin on Disc tribometer had been used for friction and wear measurement of the tribopair in sliding contact in presence of the nano-lubricant in fully flooded and starved lubrication conditions according to ASTM G99 as shown in Figure 1.

Figure 1: Pin on Disc Tribometer



In the Tribometer there is sliding motion between the loaded pin and rotating disc. The parameters like load in normal direction, rotational speed of the disc and wear track diameter can be controlled or changed to achieve the desired tribological parameters. The machine made up from several assemblies like, loading lever assembly, spindle assembly, sliding plate assembly & environmental chamber which have been mounted on base structure. The structure made up of steel tubes absorbs shocks and load during the test. The disc had been clamped on the spindle with the help of screw which had been driven by an A.C. motor through timer belt. The holding lever assembly made of single bar with specimen holder and dead weights. The dead weights had been suspended by wire rope to apply normal load on pin specimen. The fixed pivot point of lever at centre ensured that load applied at one end of pin gets equally distributed. The frictional force produced between pin and disc was measured by load cell. The lubrication chamber made up of two parts fixed around the disc to prevent oil spillage. The top part had leak proof toughened glass and bottom part consisted a cylindrical leak proof chamber with large outlet for draining oil during test. At entry port to tank a wire gauge mounted to collect debris and allows oil to flow through.

3. RESULTS AND DISCUSSION

3.1 Micro-Hardness Test: The hardness of the substrate pin, chromium plated pins and nickel plated pins were determined using Vickers's hardness and the following graphs were observed. The micro hardness of the counter body that is a mild steel disc has also been observed. The values of the Vickers hardness number are mentioned in the Table 1.

Table 1: Vicker Hardness Value of Different Materials

Sr. No	Material	HV Value	Remark
1	Chromium Coated Pipn	589.23	
2	Mild Steel Plate	182.12	
3	Nickel Coated Pins	488.45	
4	Pure Substrate Pins	201.34	

3.2 Tribology Test: The tribological investigation was conducted on the pin on disc Tribometer according to ASTM G99 both dry condition for reference and in presence of some medium. The medium for the tribological investigation as the water based slurry which was obtained from the industry and deionized water to study the effect of slurry present in water. The medium was introduced in the form of dip as the case of starved supply and in the fully flooded way. The coefficient of friction and the specific wear rate were measured at different speeds and constant load conditions. To study the effect of each parameter the design of experiment was implemented. The two parameters were selected one is the medium and other is the sliding speed each having four levels. The sliding speed had four levels that were computed according to the valve opening at different angles. The parameters have been shown in the Table 2.

Table 2: Parameters for the tribological investigations

Test Conditions	Levels
Sliding speed	4, 6, 8 m/s
Medium	Slurry starved, Slurry Fully Flooded, DI Water Fully Flooded,
Pin material	Substrate, Cr Coating, Ni Coating

Design of Experiment (D.O.E.): The parameters for the tribological investigations have already being defined in Table 2. There are 2 parameters at 4 different levels. The L9 orthogonal array shown in Table 3 was used for Taguchi and

ANOVA analysis, which results in finding the percentage contribution of each factor. The C.O.F and S.W.R. were used as output parameters for this analysis.

Table 3: L9 Orthogonal Array

Sr. No	Pin Material	Medium	Speed
1	Uncoated	SS	4
2	Uncoated	SFF	6
3	Uncoated	WFF	8
4	Cr Coated	SS	6
5	Cr Coated	SFF	8
6	Cr Coated	WFF	4
7	Ni Coated	SS	8
8	Ni Coated	SFF	4
9	Ni Coated	WFF	6

3.2.1 COF Analysis

The Tribological analysis of Pin-on-Disc was completed by Tribometer and COF was computed. Taughi analysis L9 was applied. The COF was also calculated for the substrate and the coated material in presence of different medium and at variable sliding speed. The values for the measured COF have been given in the Figure 2 & Mean Effect Plot of SN ratio for COF shown in Figure 3 as below.

Figure 2: Variation of COF

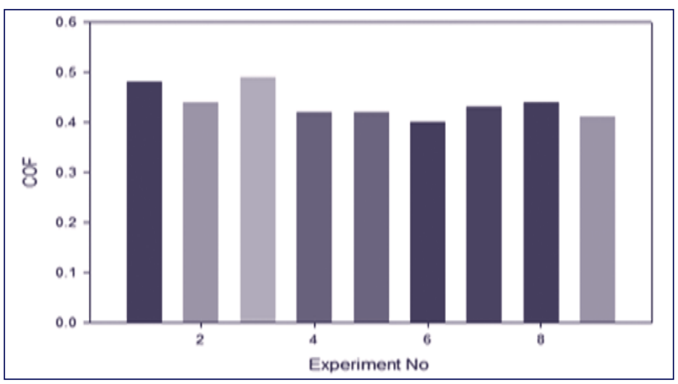


Figure 3: Mean Effect Plot of SN ratio for COF

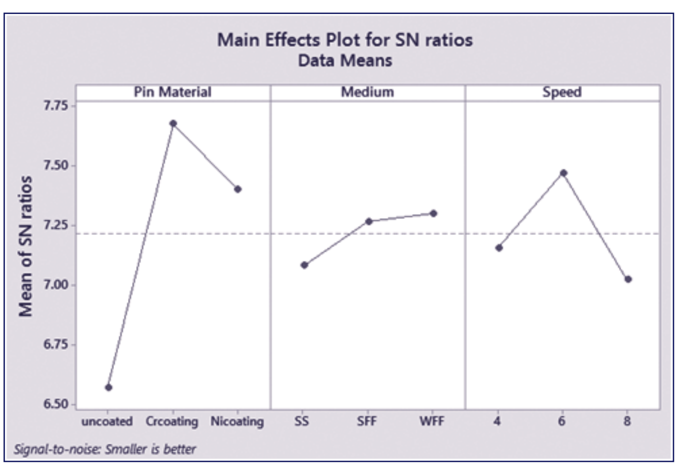


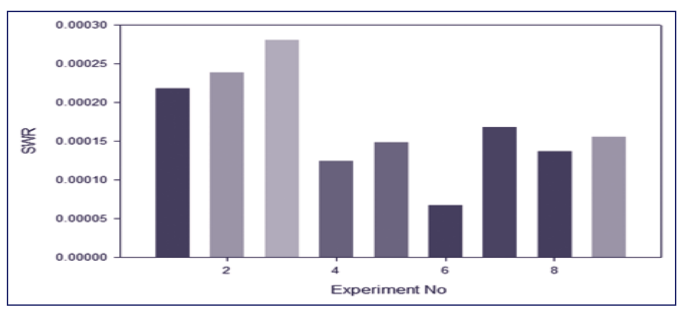
Table 4: Taguchi Analysis: COF versus Pin Material, Medium, Speed

Response Table for Signal to Noise Ratios			
Smaller is better			
Level	**Pin Material**	**Medium**	**Speed**
1	6.567	7.08	7.155
2	7.676	7.266	7.47
3	7.402	7.3	7.021
Delta	1.109	0.219	0.45
Rank	1	3	2
Response Table for Means			
Level	**Pin Material**	**Medium**	**Speed**
1	0.47	0.4433	0.44
2	0.4133	0.4333	0.4233
3	0.4267	0.4333	0.4467
Delta	0.0567	0.01	0.0233
Rank	1	3	2

The Taguchi analysis for C.O.F. was done as smaller is better as the desired effect is that the C.O.F. show be minimum for achieving better tribological performance. The S/N ratio and mean values shows that the effect of pin material was maximum on the C.O.F. followed by speed while the medium had minimum effect of C.O.F as shown in Table-4.

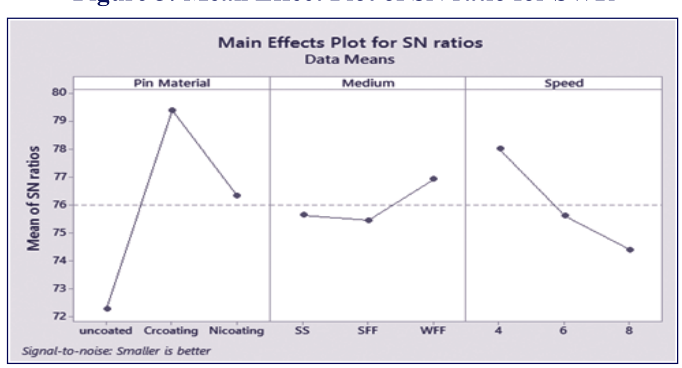
3.2.2 Specific Wear Rate (SWR) Analysis: The Tribological analysis of Pin-on-Disc was completed by Tribometer and SWR was computed. Taughi analysis L9 was applied. The variation of SWR has been shown in Figure 4.

Figure 4: Variation in SWR



There is effect of each parameter i.e. pin material, medium and sliding speed on the SWR as shown in Figure 5.

Figure 5: Mean Effect Plot of SN ratio for SWR



The Taguchi analysis for S.W.R. was done as smaller is better as the desired effect is that the S.W.R. show be minimum for achieving better tribological performance. The S/N ratio and mean values shows that the effect of pin material was maximum on the S.W.R. followed by speed while the medium had minimum effect on S.W.R as shown in Figure 5 and SWR versus Pin Material, Medium, and Speed is computed in Table 5.

Table 5: Taguchi Analysis: SWR versus Pin Material, Medium, Speed

Response Table for Signal to Noise Ratios			
Smaller is better			
Level	**Pin Material**	**Medium**	**Speed**
1	72.25	75.62	78
2	79.39	75.43	75.59
3	76.32	76.91	74.37
Delta	7.13	1.48	3.62
Rank	1	3	2
Response Table for Means			
Level	**Pin Material**	**Medium**	**Speed**
1	0.000245	0.00017	0.000141
2	0.000113	0.000175	0.000172
3	0.000153	0.000167	0.000199
Delta	0.000132	0.000007	0.000058
Rank	1	3	2

4. CONCLUSION

The coating of Cr and Ni using chemical vapour deposition on the substrate was successfully done. The mechanical, chemical and tribological properties of the prepared samples were computed and compared with the substrate.

- The micro-hardness values in case of substrate pin were recorded as 201.34 HV and the micro-hardness for the Cr coating was 589.23 HV and Ni Coating was 488.45 HV. The counter body on mild steel was 182.12 HV.
- The tribological performance of the coated samples was better for specific wear rate and coefficient of friction as compared to the uncoated specimen.
- The tribological investigation of POD was done according to Taguchi L9 orthogonal arrey. Taguchi analysis showed that pin material had maximum impact on the COF followed by speed and lastely by medium.
- The Taguchi analysis showed that pin material had maximum impact on the SWR followed by speed and media.

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