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Experimental investigations and study of tribological behaviour of alternate WC coated bearing surfaces

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Abstract

Coated bearing surfaces exhibit relatively better tribological properties compared with non-coated surfaces irrespective of the coating technology used. An attempt is made to study the effectiveness of alternately coated bearing surfaces with hard material. Striped alternate coated bearing surface with hard material ends up with a bearing surface having alternate bands of soft and hard materials. I the current work Tungsten carbide is taken as hard coating material. A Circular MS (2%-C, 1.65%-Mn, 0.6%-Cu, and 0.6%-Si) disc with alternate WC coating has been developed with plasma spray technique and experiments are designed using full factorial design approach. Tribological properties like wear, coefficient of friction and frictional force were found by conducting number of experiments on both uncoated and coated disks. Pin-on-disk apparatus is used for experimentation. Significant factors were identified and models are developed by using regression analysis. ANOVA is used for analysing results. Experimental results for both the alternate coated and uncoated discs were analysed and correlated.

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Keywords: Alternate coating; full factorial design; POD test; Tribological behaviour.

1. Introduction

Lubricating and maintaining lubrication is critical to the life of the bearing surface. Coatings which act as lubricants are the alternatives for such type of lubrication and control due to the effective tribological properties of coating materials.

Tribological coating systems can be developed and implemented using different coating techniques. The coating material is either in the form of a solid or in the form of a gas and is vaporized in a vacuum. In contrast to conventional coating methods, it is possible to produce unique compositions of different materials and coatings with this environment friendly coating processes.

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The Tribological properties of selected thermally sprayed coatings were evaluated by pin-on-disc method and the coefficient of friction, wear rate and wear mechanism were recorded in dependence on used load. It was shown, that the best tribological properties (the lowest coefficient of friction and wear rate) were attained [Houdkov et al., 2004].

The comparison of the tribological behavior of sputtered MoS2 coatings in fretting and pin-on-disk tests under different conditions is studied [You-RongLiu et al., 1999]. The relationship between the mechanical properties of the coatings and their wear performance in both type of sliding tests is discussed [T.Rameshkumar et al. (2010)]

Tungsten carbide (WC) has superior wear resistance and ideal for long-wearing surfaces and edges. As WC coatings deliver superior qualities like wear prevention, corrosion protection it has been chosen as a coating material for the selected durable abrasive or wear-resistant protective surface as compared to hard chrome plate. The tribological properties of selected thermally sprayed coatings (WC) were evaluated by pin-on-disc (POD) method and are reported in literature. [Nicholas J Breaux et al.2002, Christofides et al., 2002, Arslan et al. 2005, Reneviera et al. 2003].

2. Experimental procedure

2.1. Pre-treatment and disc preparation

Two circular discs with 100mm diameter are prepared from MS plate to suit the specifications of POD apparatus available as shown in the fig 1(a). In view that plasma spray process is used for coating the discs; the substrate preparation is required for better bonding strength and surface quality. The surface is cleaned using sand blasting. In this process sharp particles of aluminium oxide with specific mesh size are propelled via pressurized air at a surface to remove scale and surface contaminants.

Fig. 1. a) Uncoated disk of dia.100mm. b) Disk after grid blasting process

This also roughens the surface of the base material on which the coating is intended to apply. It helps to attain the maximum bond strength to the base material. This blasting is done (at Oxygen Pressure - 8 bar, LPG - 5 bar, Compressed air -7-8 bar, Flow rate - 2000 μ/sec) until "white metal" standard is attained and coating is applied immediately after grit blasting process. As shown in the fig.1 (b) the disc is divided into four quadrants and alternate quadrants are prepared for coating with grid blasting.

The Plasma Spray Process shown in fig.2 involves spraying of molten or heat softened material onto a surface to provide a coating. Material in the form of powder is injected into a very high temperature plasma flame, where it is rapidly heated and accelerated to a high velocity.

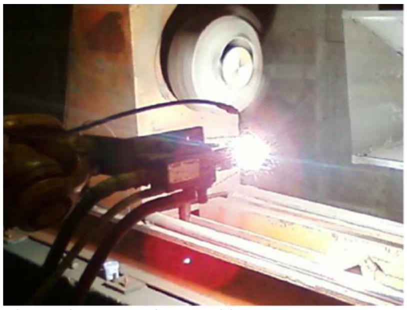
Fig.2. Plasma coating machine.


Fig.3. Disk after coating.

The hot material impacts on the substrate surface and rapidly cools forming a coating. After coating the plat in the alternate quadrants with WC, the plate surface is further lapped to maintain smooth movement of the pin.

2.2. Tribological tests

Lapped coated MS disc is shown in the fig. 3 and the hardness test has been conducted for both coated and non-coated samples by using Vickers hardness test and the results are shown in Table.1. Here, scale 'C', diamond indenter was used to apply a load of 150kgf. The test was conducted for two sets of samples of both coated and non-coated.

Friction tests were conducted using a pin-on-disk friction machine in a unidirectional sliding mode. The upper specimens were selected square pin samples and the lower specimens were three disks of two coated and one uncoated samples. The pin is positioned at track diameter of 60mm and is loaded with a static load of 20N and 30N applied through a loading arm while the disk is rotating at a speed of 250rpm and 500rpm for duration of 30 seconds.

Table 1.Hardness of coated and uncoated disks

Specimen	Uncoated	WC coated
Hardness No.	90	125

To minimise the effect of surface roughness in POD test, surface roughness of all the specimens were measured and specimens with lowest values of Ra(μm), Rz(μm) has been selected for pin on disc test. POD test has been performed using the parameters shown in table -2. Full factorial design is used to plan the experiments. Wear, coefficient of friction and frictional force are the responses. ANOVA is used to analyse the results.

Table 2.The process parameters and their chosen levels

Parameters	Notation		Levels	
	Coded	Un-coded	Low(-1)	High(+1)
Speed of rotation of Disk (in RPM)	A	X_1	250	500
Load on the Pin (in N)	B	X_2	20	30

The other testing parameters time and track diameters are kept constant at 30 Sec. and 60mm respectively.

Table 3.Full factorial design and response results of uncoated plate

Coded Value				Real Value		Responses		
Std. Order	Run Order	A	B	Speed (RPM)	Load (N)	Wear Rate (in µm)	Coefficient of Friction	Frictional Force (N)
2	1	+1	-1	500	20	525	0.25	4
3	2	-1	+1	250	30	165	0.2	4
4	3	+1	+1	500	30	1200	0.45	12
1	4	-1	-1	250	20	180	0.2	4

Table 4.Full factorial design and response results of alternate WC coated plate

Coded Value				Real Value		Responses		
Std Order	Run Order	A	B	Speed (RPM)	Load (N)	Wear Rate (in µm)	Coefficient of Friction	Frictional Force (N)
2	1	1	1	250	20	35	0.12	4
4	2	1	1	500	20	90	0.35	1
3	3	1	1	250	30	130	0.7	10
1	4	1	1	500	30	500	0.45	12

3. Results and discussion

3.1 wear behaviour of uncoated plate

3.1.1. Wear rate

The wear rate (WR) of the uncoated disk is expressed as a linear function of input variables in uncoded form is given by equation (1).

$$WR = -1342 + 2.76 \times Speed + 33.0 \times Load \qquad (1)$$

Significance test has been conducted to determine the influence of various factors and their interaction on the wear rate. The results of the test are shown in table-5.

Table 5.Results of the significance test for the linear model of WR

Predictor	Coef	SE Coef	T	P
Constant	-1342	1021	-1.32	0.414
Speed	2.760	1.380	2.00	0.295
Load	33.0	34.50	0.96	0.514

Considering 50 percent of confidence and from table-5, as the ‘P’ values for the speed is low, these are considered to be more significant factors to the response - wear rate. The main effects plot which shows the contribution of the factors to the response wear rate is shown in fig.4.(a)

Table-6 shows the results of ANOVA which has been conducted to test the significance of various factors on the wear rate.

Table 6. Results of ANOVA for the response – Wear rate

Source	DF	SS	MS	F	P
Speed	1	476100	476100	4.00	0.295
Load	1	108900	108900	0.91	0.514
Error	1	119025	119025		
Total	3	704025			

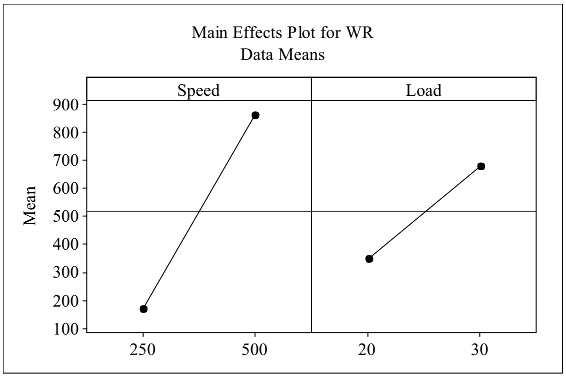

Fig.4.(a) Main effects plot for response - Wear rate

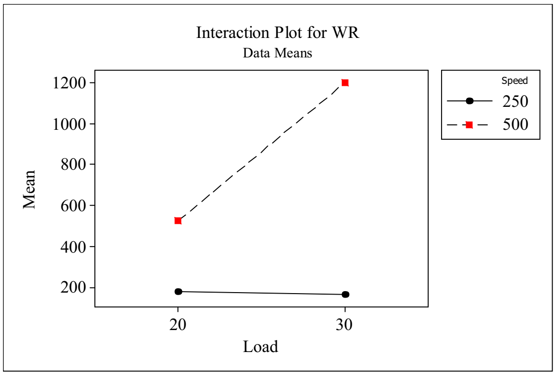

Fig.4.(b) Interaction plot for Wear rate

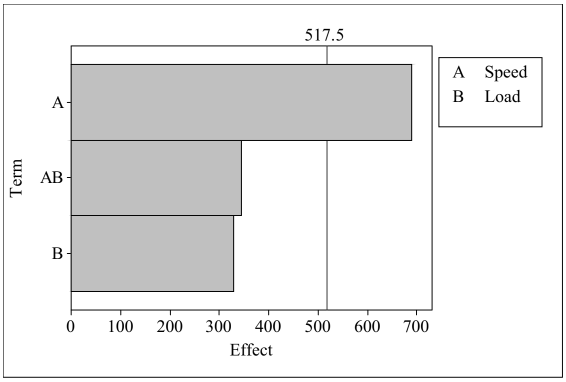

Fig.4(c) Pareto chart for Wear rate

Fig.4: Results of Full factorial analysis of response – wear rate.

Fig.4. (b) shows the interaction plot which shows that there is no significant effect of interaction of factors on the response wear rate. Pareto chart for wear rate is shown in fig4.(c). It shows that speed is the significant factor affecting the wear rate.

3.1.2 Coefficient of friction

At 50 percent of confidence interval, second response i.e., coefficient of friction (COF) is analysed. Fig.5. shows the pareto chart for COF. It may be observed that none of the factors are significant factors.

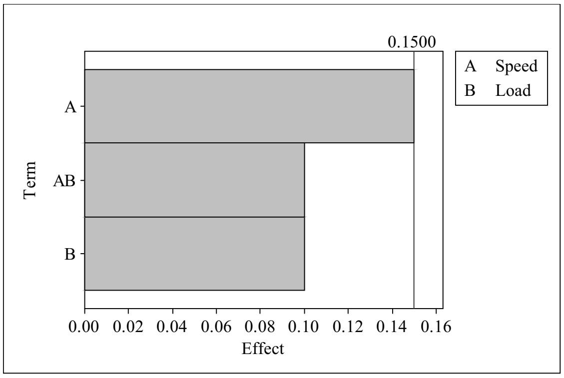

Fig. 5. Pareto chart for response-COF

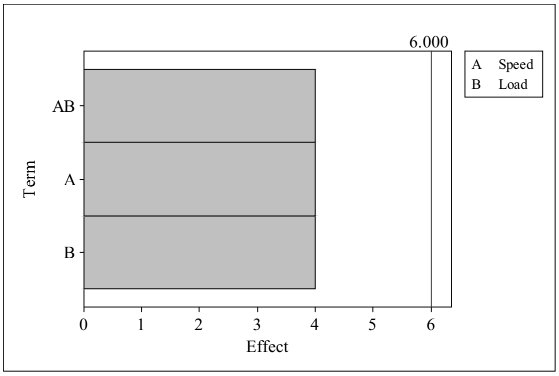

Fig. 6. Pareto chart for Response - FF

3.1.3. Frictional force

At the same 50 percent confidence interval, third response i.e., Frictional force (FF) is analysed. Fig. 6 shows the pareto chart for FF. It may be observed that none of three i.e., A, B and AB are significant factors for response FF.

3.2 Wear behaviour of coated disc

3.2.1 Wear rate

The wear rate of the WC alternate coated disk is expressed as a linear function of input variables in uncoded form is given by equation (2).

$$WR = -\ 761 + 0.850 \times Speed + 25.2 \times Load \qquad (2)$$

Significance test has been conducted to determine the influence of various factors and their interaction on the wear rate. The results of the test are shown in table-6.

Table 6. Results of the significance test for the linear model of wear rate

Predictor	Coef	SE Coef	T	P
Constant	-761.2	465.9	-1.63	0.350
Speed	0.850	0.6300	1.35	0.406
Load	25.25	15.75	1.60	0.355

From Fig.7. (a) it may be observed that the significance of the factor A i.e., Speed has been reduced by alternate coating of WC. Further it is evident from fig 7. (b) and 7.(c) that other factors B and AB stay insignificant for response wear rate.

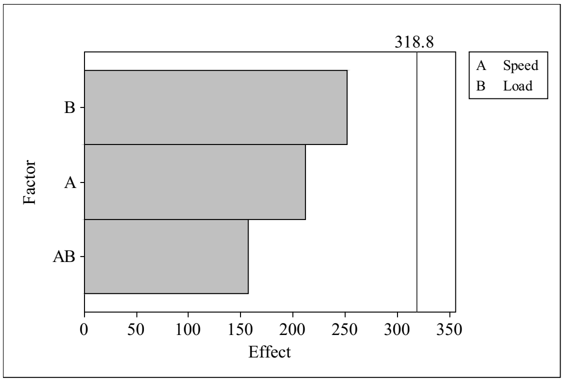

Fig.7.(a) Pareto chart for Wear rate

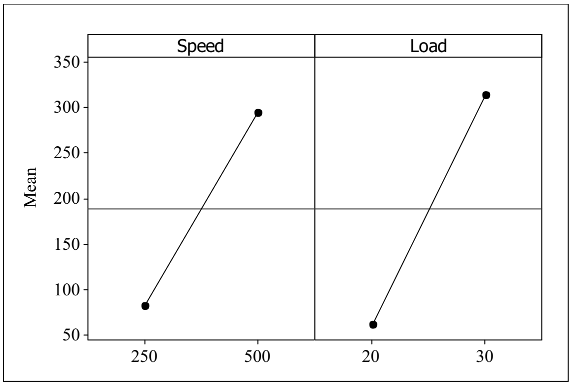

Fig.7(b) Main effects plot for response - Wear rate

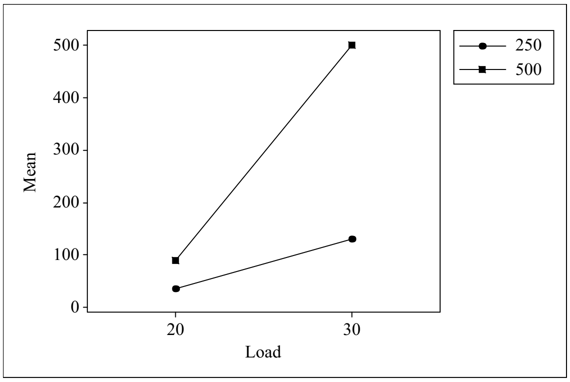

Fig.7(c) Interaction plot for Wear rate

Fig.7. Results of Full factorial analysis of WC alternate coated disk response – wear rate.

Table-7 shows the results of ANOVA which has been conducted to test the significance of various factors on the wear rate of the coated disk.

Table 7.Results of ANOVA for the response – Wear rate

Source	DF	SS	MS	F	P
Speed	1	45156	45156.3	1.82	0.406
Load	1	63756	63756.3	2.57	0.355
Error	1	24806	24806.3		
Total	3	133719			

3.2.2 Coefficient of friction

At 50 percent of confidence interval, second response i.e., coefficient of friction of coated disk (COFC) is analysed. Fig.8. shows the pareto chart for COE. It may be observed that none of the factors are significant factors and factor A i.e speed influence is negligible when compared with others.

3.2.3. Frictional force

At 50 percent confidence interval, third response i.e., Frictional force of coated disk (FFC) is analysed. Fig. 9 shows the pareto chart for FFC. It may be observed that the factor B i.e., load becomes significant factor. It is due to the reduction of friction between the contact surfaces.

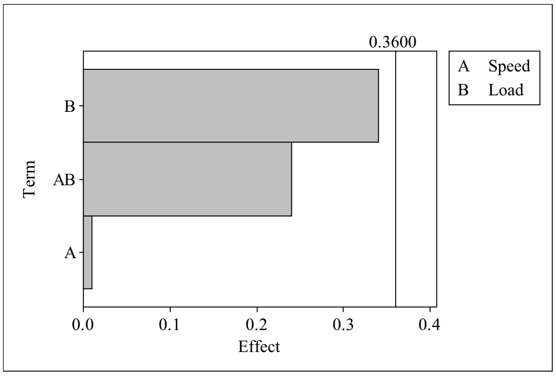

Fig.8. Pareto chart for response COFC

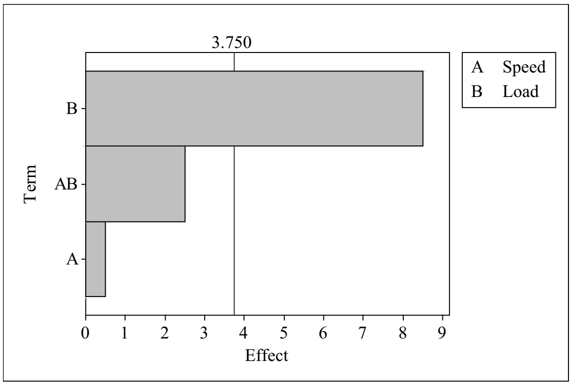

Fig.9.(a) Pareto chart

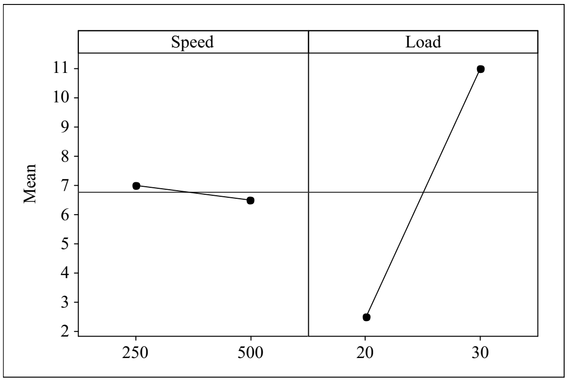

Fig.9.(b) Main effects

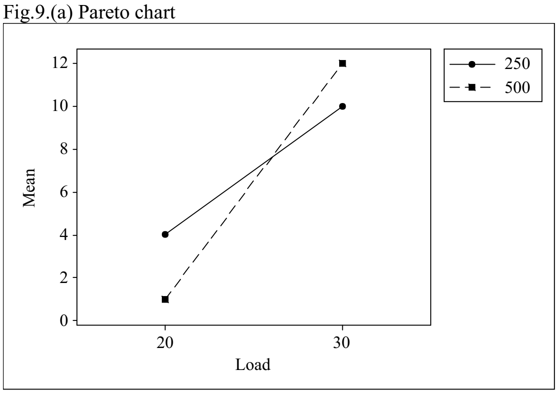

Fig9.(c) Interaction factors

Fig.9. Full factorial analysis of WC alternate coated disk for response – FFC

The response frictional force of coated disk is expressed as a linear function of input variables in uncoded form is given by equation (3).

$$FFC = -13.8 - 0.0020 \times Speed + 0.850 \times Load \quad (3)$$

Significance test has been conducted to determine the influence of various factors and their interaction on the FFC. The results of the test are shown in table-8.

Table 8.Results of the significance test for the linear model of FFC

Predictor	Coef	SE Coef	T	P
Constant	-13.750	7.395	-1.86	0.314
Speed	-0.00200	0.01000	-0.20	0.874
Load	0.8500	0.2500	3.40	0.182

Table – 9 shows the ANOVA table for response - FFC. Factor with minimum value of ‘P’ and maximum value of ‘F’ is the significant factor.

Table 9.Results of ANOVA for the response – FFC

Source	DF	SS	MS	F	P
Speed	1	0.25	0.25	0.04	0.874
Load	1	72.25	72.25	11.56	0.152
Error	1	6.25	6.25		
Total	3	78.75			

From the above full factorial analysis, it is evident that there is a decrease in wear for alternate coated samples in comparison with uncoated disks. It is due to high hardness of the coated surface. Comparison of table 4 and 5shows that in all the cases wear (in microns) are about two to three times higher for uncoated disks.

4. Conclusions

The present full factorial analysis of WC alternate coated disk wear behaviour in comparison with uncoated disk conclude the following

- Speed of rotation is a significant factor for wear of an uncoated disk. But not significant for other responses i.e. coefficient of friction and frictional force.
- Load becomes the significant factor for response frictional force of an alternate coated disk. But not for the other two responses i.e., wear rate and coefficient of friction.
- The results shown that the tribological properties have been enhanced by the alternate coating.
- Coefficient of friction has been reduced by the coating.
- The amount of wear is reduced by almost 2 to 3 times of the wear of an uncoated disk.

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