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Wear Analysis on Silicon carbide coated HSS Pin on SS Disc Substrate

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Abtract
Wear takes predominant role in reducing the cutting life time of tool materials. This investigation focuses on the influence of Silicon Carbide nanocoating on the HSS tool material. Silicon carbide powder was coated on the high speed steel pin by using physical vapour deposition (PVD) technique. The stainless steel was selected as a work piece material. The performance parameters like volume loss, wear rate, stresses developed and temperature rise were compared between coated high speed steel pin and uncoated high speed steel pin upon machining the stainless steel disc. The performance parameters were calculated by using coefficient of friction values which were obtained from the pin on disc test. Substantial resistance to wear has been achieved by the coating. Scanning electron microscope (SEM) Analysis and Energy dispersive analysis by X-ray (EDAX) were used as characterization techniques.

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Keywords: PVD, Pin-On-Disc, SEM and EDAX

1. Introduction

Nanocoating of carbides and oxides over the tool materials certainly enhances their life and productivity. Silicon carbide known for its hardness, high modulus and extremely high sublimation temperature would be challenging to coat it on a cutting tool material like HSS. Physical Vapor Deposition (PVD) techniques are widely practiced to coat the oxides and carbides on tool materials. Creation of material systems is an avenue thrown open for addressing many engineering problems; enhanced wear performance is one among them. Pin on disc tests are widely conducted in the laboratories to evaluate the wear of sliding contacts between metals. In this work SiC is coated on HSS pin and analyzed the wear characteristics by dry sliding it upon the SS substrate. The Co-efficient of friction values were acquired from the experimental setup. These values were the basis to calculate the various stresses, wear rate and temperature distribution.

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2. Experimental

2.1 Material Selection and Dimensions

High speed steel (HSS) known for its extensive use as tool material, M2 grade (tungsten-molybdenum), is selected as the material to make the Pin, later to be utilized as a tool for the analysis. Stainless steel (Grade SS304) is used as the Disc material. Silicon Carbide, an excellent ceramic with high endurance used in applications such as car brakes, clutches and plates in bullet proof jackets, is used as the coating material. The diameter and length of the Pin used for the study are 6mm and 50mm respectively. The diameter and thickness of the disk are 55mm and 10mm respectively.

2.2 PVD coating

Electron Beam Physical Vapour Deposition or EBPVD is a form of physical vapour deposition in which a target anode is bombarded with an electron beam given off by a charged tungsten filament under high vacuum. The electron beam causes atoms from the target to transform into the gaseous phase. These atoms then precipitate into solid form, coating everything in the vacuum chamber (within line of sight) as a thin layer of coating material. The specification of the PVD coating machine used for the experimental analysis is given below.

Coating chamber material	:	stainless steel (grade 304)
Coating chamber inner dimension	:	600mm(w),500mm(D),760mm(H)
Substrate holder material	:	stainless steel (grade 304)
Substrate drive speed	:	2-15 rpm
Substrate heater	:	350 degree celsius
Temperature measurement control	:	PID Controller
Operating pressure	:	Below $5*10^{-4}$
Power rating	:	10KW
Beam voltage	:	4-10KV DC
Beam current	:	0-1 Amp

SiliconCarbide is coated on the Pin using the EBPVD equipment, the subsequent microscopic analysis confirm the effective coating that has taken place.

2.3 Pin on Disc

The weight of the pins, both coated and uncoated are measured. Then the pin is clamped in the support. Before that the disc was fixed in the rotor which is coupled with motor via belt drive pulley. Then the load is applied against the pin supported beam.

Fig 1. Pin on Disc Equipment

The pin on disc equipment has a computer based controller, used to control the parameters of the pin on disc apparatus. The parameters required are speed in rpm and load in Kg. Based on the parameters the system will generate the values of coefficient of friction and values of frictional force for the given time period in the interval of 1 minute.

2.4 Specifications:

Pin diameter	:	6mm	Applied load	:	1 Kg
Pin length	:	50mm	Speed of the rotor	:	900 rpm
Disc diameter	:	55mm	Total time	:	15 min
Disc thickness	:	10mm			

3.0 Results and Discussion

3.1 Microscopic Analysis

The figure 2 shows that layer of silicon carbide on the High Speed Steel pin with 1000 times of magnification. The image confirms the thickness of 741 nm.

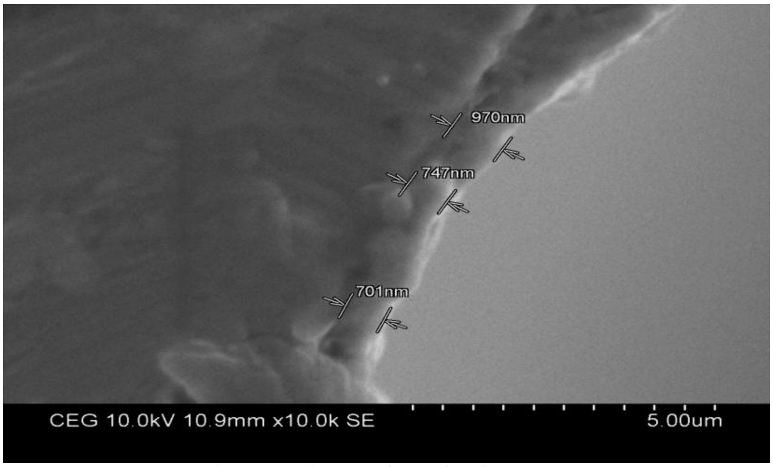

Fig 2.SEM images of coated tool

***3.**2 Experimental values of the coated and uncoated HIGH SPEED STEEL PIN:*

Table 1 Readings of the coated and Uncoated High Speed Steel pin

TIME IN Min	LOAD IN Kg	COEFF. OF FRICTION		FRICTION FORCE (N)	
		COATED	UNCOATED	COATED	UNCOATED
1	1	0.24	0.82	0.24	0.82
2	1	0.53	0.53	0.53	0.53
3	1	0.16	0.52	0.16	0.52
4	1	0.28	0.65	0.28	0.65
5	1	0.48	0.47	0.48	0.47
6	1	0.32	0.34	0.32	0.34
7	1	0.2	0.58	0.2	0.58
8	1	0.26	0.45	0.26	0.45
9	1	0.53	0.09	0.53	0.09
10	1	0.23	0.50	0.23	0.50
11	1	0.57	0.09	0.57	0.09
12	1	0.22	0.50	0.22	0.50
13	1	0.54	0.43	0.54	0.43
14	1	0.37	0.53	0.37	0.53
15	1	0.23	0.41	0.23	0.41

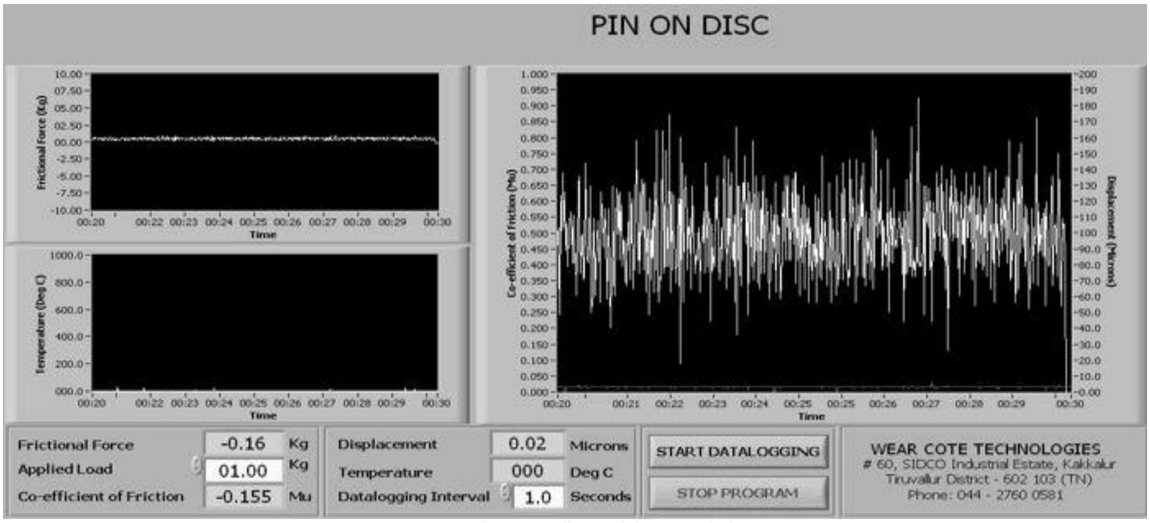

Fig 3. Readings of the coated pin

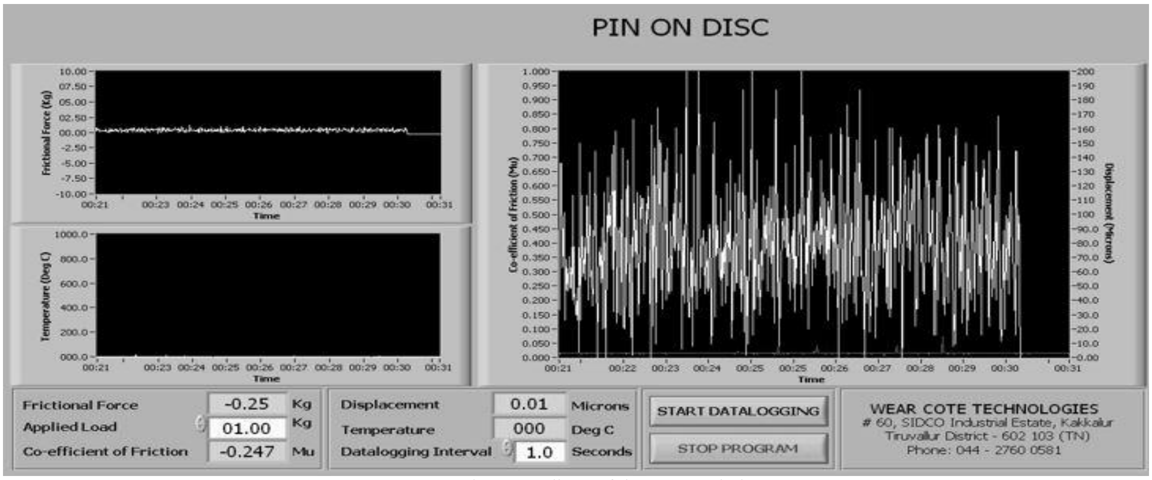

Fig 4. Readings of the uncoated pin

3.4 VOLUME LOSS CALCULATION:

3.4.1Pin volume loss calculation:

The Pin volume loss can be calculated using the formula,

$$\text{Pin Volume loss} = \frac{\pi(\text{wear diameter})^4}{64(\text{pin radius,mm})} \tag{1}$$

the volume loss for Uncoated pin and coated pin are 27468.72 mm^3 and 19394.75 mm^3. The Volume loss in coated pin is very much lesser than uncoated pin.

3.4.2 Disc volume loss calculation:

The Disc volume loss is represented as,

$$\text{Disc Volume loss} = \frac{\pi(\textit{wear}\ \text{track radius})(\text{track width})^3}{6(\textit{sphere}\ \text{radius, mm})}, \tag{2}$$

the volume loss for the uncoated pin is 392.6 mm^3 where as the coated pin loss is 44.97 mm^3. The volume loss of the disc while using coated pin is comparatively less for uncoated pin.

3.5 Wear rate analysis:

To find the wear rate, the following equation is used, Wear rate,

$$= \frac{(\text{mass of pin before machining * mass of pin after machining})/\text{ density}}{(\text{load*sliding distance})} \quad (3)$$

the wear rate of the Uncoated Pin is $3.289*10^{-14}$ mm/Nm , which is more than the wear rate of coated pin which amounts to $2.192*10^{-14}$mm/Nm

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3.6 Compressive stress induced in the pins:

The compressive stresses induced in the uncoated and coated pins are calculated using the formula,

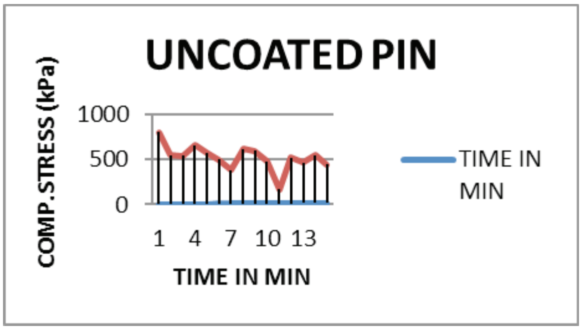
$$\sigma_{max} = p_0\left[\frac{1-2}{3}\mu + \frac{4+\mu}{3}\pi f\right] \quad (4)$$

Where μ = Poisson's ratio

P_0 = Pressure applied

f = coefficient of friction

The compressive stress of the uncoated pin for μ=0.25 is calculated as 799kPa and for the coated pin it is estimated as 295.48kPa. The Values are determined for the coefficient of friction 0.24. Similarly compressive stresses are determined for the various values of Co-efficient of friction at the interval of 1 minute. The compressive stresses of coated pin are much less when compared to the compressive stresses of uncoated pin.



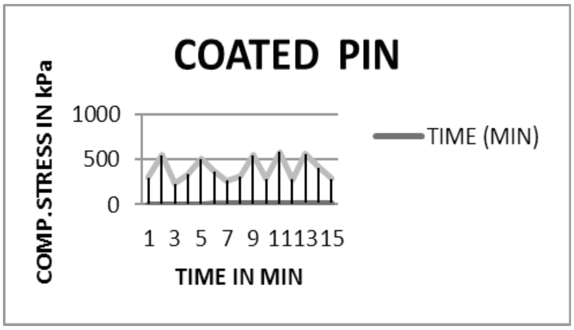


Fig 5. The variation in compressive stresses in the Coated and Uncoated Pins

3.7 Temperature rise and Thermal stresses in the pin:

$$\text{Temperature change} = \frac{f*p*v}{\sqrt{ab}} * \frac{1}{\left(\frac{k}{\theta}\right)} \text{ in Kelvin} \quad (5)$$

Where f = coefficient of friction

p = load applied

v = sliding velocity

a = major axis diameter

b = minor axis diameter

For circular pin a = b. radius = 3mm
k = thermal conductivity of the pin =26 W/mK.
θ = flash temperature no= 1783K
Sliding velocity = 2.5918 m/s

For the coefficient of friction the rise in temperature is calculated. Similarly for different coefficient of friction values at an interval of 1 min the temperature raise can be calculated for coated and uncoated pins. The thermal stresses can be calculated with the help of temperature raise using the relation $\sigma_{thermal} = \alpha \Delta T E$, α-co-efficient of thermal expansion, ΔT- Rise in temperature and E- Young's Modulus. The thermal stress developed in the uncoated pin is 861.72 MPa and in the coated pin it is appreciably a lesser value of 258.37 MPa.

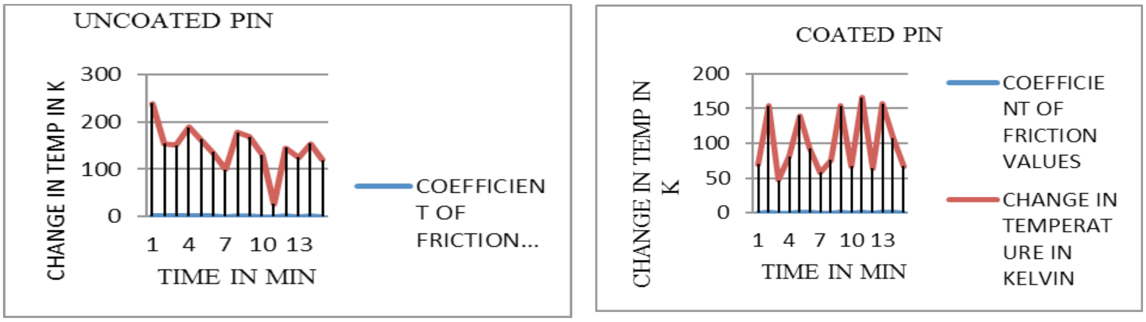


Fig 6. Comparisons of Change in temperature for uncoated pin and coated pin.

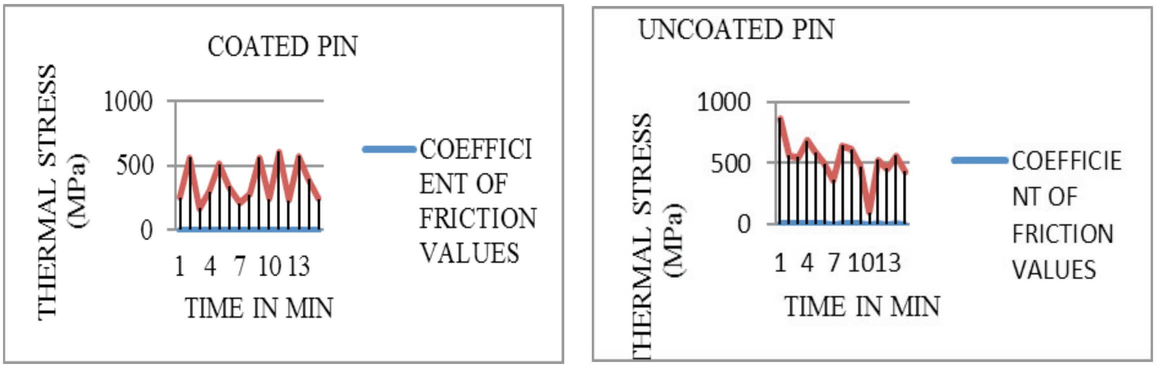


Fig 7. Comparisons of Thermal Stress for coated pin and uncoated pin.

4. Conclusion

The PVD coating on the high speed steel tool was carried out successfully and the machining of the stainless steel was also carried out. The performance parameters are described below.

- Pin volume loss of the uncoated pin and coated pin are 27468.72 mm^3 and 19394.75 mm^3. Similarly Disc volume loss of the uncoated pin and coated pin are 392.6 mm^3 and 44.97 mm^3 respectively. It shows that coated pin is having less volume loss in the pin and disc.
- Wear rate of the coated and uncoated pin are $3.289*10^{-14}$ mm/Nm and $2.192*10^{-14}$ mm/Nm respectively. We could conclude that the wear rate is less for coated pin.
- In the case of compressive stress point of view the uncoated pin is having around 800kPa and the coated pin is having only 600kPa. So that less compressive stress is induced in the coated pin.
- And also the Temperature rise in the coated pin (160 K) which is lesser than that of the uncoated pin

(250K).

- Due to temperature rise, thermal stresses will be induced. The coated pin is having a maximum of 550MPa. But the uncoated pin is having a maximum of 800MPa.

From the coating process we can conclude that the metallic powder coating on the tool enhances the properties of the tool with increased productivity and increased tool life. It is possible to machine the work piece which is harder than the tool after the coating process.

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