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An Integrated Tribological and Vibration Signal Behaviour of TiN and AlCrN based PVD Coatings for Roller Bearings

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Abstract

Objective: The goal of current work is to check the suitability of Titanium Nitride (TiN) and Aluminium Chromium Nitride (AlCrN) coatings for the outer race of roller bearings. **Methods:** Physical Vapour Deposition (PVD) method of coating is employed since it provides less coating thickness. Tribological behaviour is studied for wear rate and co-efficient of friction using PIN-ON-DISC machine. Statistical method of Vibration analysis is performed by extracting values such as kurtosis, skewness, crest factor and RMS from time domain signals captured. **Findings:** It is revealed in the results that wear rate for TiN coated bearing is 0.03mm^3/min which is less than that of AlCrN coated bearing and uncoated bearing. Findings of the vibration study showed that kurtosis value is 7.6 for worn out AlCrN coated bearing compared to 4.4 for worn out TiN coated bearing. This clearly shows that TiN offers better wear resistance which supports the results of wear analysis. It is observed in SEM images of morphological studies that more wear tracks and ploughing marks occurred in uncoated and AlCrN coated bearing surfaces compared to TiN coated bearing. **Application/Improvements:** Current work provides a good integrated approach for tribological and vibration signal behavior of TiN and AlCrN based PVD coatings thus improving correlation between the two methods and it can be prolonged for prognosis.

Keywords: Kurtosis, Physical Vapor Deposition, Tribology, Time Domain Signal, Wear Rate

1. Introduction

Surface engineering is the discipline of altering the topographical and/or chemical properties of the surface of a component. Plasma spraying method of coating offers good economic advantage and better quality and it is an example under surface engineering. The materials like ceramics, unalloyed metals or alloys and polymeric constituents can be coated by this technique[1,2].

In[3], the wear resistance of W-C:H, CrAlN, ZrN, WC/C, TiAlN, ZrC coated using PVD for cylindrical roller thrust bearings is studied and concluded that more roughness was the key reason for initial cracks on the PVD coatings on the micro blasted surfaces.

Ni–Cu–Ag based PVD coatings are analyzed for tribology behavior with application to hybrid bearings in altered lubrication environments[4]. The results revealed that the coatings can be appropriate for low temperature tribosystems of turbopumps. It is concluded that wear rate of coatings based on volume rises quickly with rise in contacting load under cryogenic environments. In[5], work is carried out on wear mechanisms of low thickness, tough and less friction coatings used for steel roller bearings. Cr + W–C:H ,Cr2N and CrN + *n*C coatings were

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paralleled to uncoated 100Cr6 steel by adopting a special thrust bearing test. It is concluded that Cr + W–C:H gives the greatest overall coating stability. In[6], with application to cement mortars, BTEX abatement is researched by employing photocatalytic TiO_2 coatings on bearings. It is found that rise in humidity has a negative effect on the degradation of BTEX at low early concentrations of pollutants. In[7], coatings based on ternary nitride such as Titanium Molybdenum Nitride, Titanium Aluminium Nitride and Titanium Vanadium Nitride are analyzed for wear and mechanical properties.

Kurtosis is obtained as fourth and normalized statistical moment of data. It is considered as chief diagnostic key and it has been broadly used for damage finding in roller bearings[8-10].

In[11], vibration signal was decomposed into nine levels using Discrete Wavelet Transform. The levels showing clear classification among the bearings indicate the bands with characteristic defect frequencies of faults. In[12], Adopting classification technique, remaining life of the bearing is assessed by proposing the model based on random forest classifier. 95.64% was the accuracy of the proposed model. In[13], Suiting to the real time application, a predictive model was suggested to anticipate the remaining life of the bearing. Results showed that support vector regression technique ascertains to be impressive in forecasting the bearing's remaining life.

However, there are few works about tribological study of Titanium Nitride (TiN) and Aluminium Chromium Nitride (AlCrN) based PVD coatings for roller radial bearings. The objective of current work is to check the suitability of coating materials such as TiN and AlCrN for the bearings. Tribological behaviour is studied for wear rate and co-efficient of friction using PIN-ON-DISC tribometer and morphological studies are carried out by capturing SEM images and EDS analysis. Vibration analysis is carried out by extracting statistical parameters from time domain signals.

2. Experimental Procedures

2.1 Coating Preparations

Physical vapor deposition method is employed to prepare the coatings of TiN and AlCrN on the outer rings of the bearing. The process of depositing materials directly from the vapor phase comprises the methods such as evaporation, sputtering and ion plating.

Figure 1. Bearing outer race coated with TiN.

The process is carried out between temperatures 150^0 C to 500^0 C and in high vacuum. The evaporation of great purity solid coating materials (chromium, titanium and aluminum) is done by applying heat. A reactive agent like nitrogen with carbon gas is passed at the same instant. This produces a product with the metal vapor and gets placed on the bearing outer race. A thin and greatly adherent coating is produced. The parts are revolved at uniform speed to get uniform thickness of coatings. Figure 1 shows the coated outer race of the bearing.

2.2 Experimental Test Rig

Figure 2 shows the test rig employed in this study. It consists of a shaft supported on two bearings. At one end there is ball bearing of self-aligning type and at the other end there is roller bearing which is to be tested. The roller bearing is tested at constant load of 100 N and at a constant speed 1000rpm.

Figure 2. Experimental Bearing test rig.

The shaft is turned to the designed diameter on a precision lathe. Two bearing seating on the shaft are ground and hardened. Figure 3 shows the AlCrN coated bearing in its housing. Table 1 shows the Specifications of the test bearing employed in the experiment.

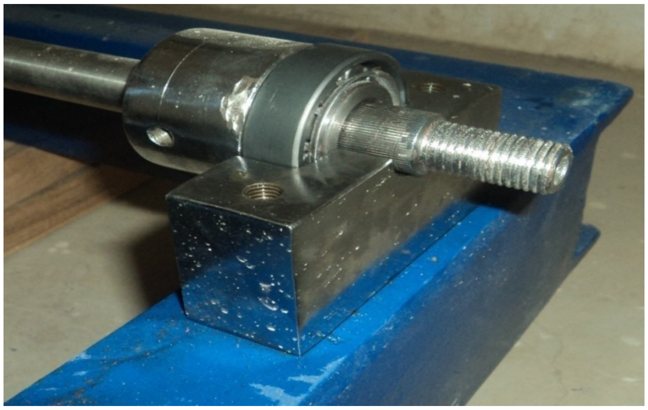


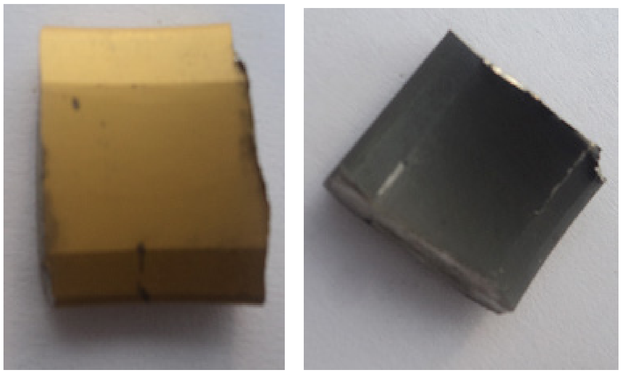
Figure 3. Mounting of coated test bearing.

Table 1. Specifications of the test bearing

Feature	Details
Bearing type	Roller (SKF N-304)
Number of rollers	10
Outside diameter	52 mm
Inside diameter	20 mm
Pitch diameter	36 mm
Roller diameter	07 mm

2.3 Preparation of Samples

The outer race of the coated bearings is cut in low speed wire Electro Discharge Machining (EDM) machine before and after running the bearings in the test rig to obtain the samples as shown in Figure 4 for morphological studies.



(a) (b)

Figure 4. Samples for morphology study (a) TiN coated bearing sample (b) AlCrN coated bearing sample.

2.4 Pin on Disc Tribometer

The pin-on-disc tribometer is used to measure wear rate. According to ASTM G99 standards, trials were conducted on the 3 samples namely uncoated bearing steel, TiN coated bearing steel and AlCrN coated bearing steel. The discs up to 165 mm in diameter and 8 mm thick and an electronic sensor for assessing the friction force are used. The wear test is carried out at a load of 1 kg, speed of 250 rpm and track radius of 80mm on the disc which is made of hardened EN-32.

2.5 Statistical Parameters in Time Domain Signal Analysis

Vibration data is analyzed in the time domain for influences that relate to the spin of the rolling elements on the defects for every shaft rotation. Statistical parameters such as peak, RMS (Root Mean Square), crest factor and kurtosis presented in equations (1)-(4) are extracted for a sample in time domain. As the defect arises, a rise in these values will also occur. x(t) is time signal which has N data points[14].

$$\text{peak} = \frac{1}{2}\left(\max(x(t)) - \min(x(t))\right) \quad (1)$$

$$\text{RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x(i)-\bar{x})^2} \quad (2)$$

$$\text{Crest Factor} = \frac{\text{peak}}{\text{RMS}} \quad (3)$$

$$\text{Kurtosis} = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(x(i)-\bar{x})^4}}{\text{RMS}^4} \quad (4)$$

2.6 Instrumentation

A 4 channeled data acquisition system of commercial type OROS (model Sl.No-900159) was used to capture the vibration signals from the bearing. The test bearing housing is mounted with accelerometer of B&K 4525. After amplification, signals are stored in a computer for next processing.

3. Results and Discussions

3.1 Friction and Wear Behavior of Coatings

Friction response of a material can be understood by studying the dependency of coefficient of friction on sliding distance at constant load and speed. Friction coefficient is determined as a function of normal and friction force. Friction force has been found out continuously all through the sliding distance concealed during the test. The coefficient of friction versus sliding distance is plotted for coated and uncoated specimens as shown in the Figure 5. It shows that there is increase in Co Efficient of Friction (COF) which is due to initial roughness of the two surfaces in contact. Increase in COF may also be due to removal of hard particles from the coated surface. TiN coating shows less and constant variation in COF compared to uncoated and AlCrN coating[15].

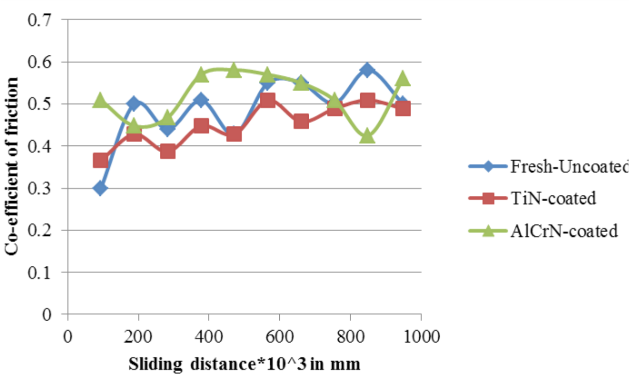


Figure 5. Variation in friction coefficient as a function of sliding distance.

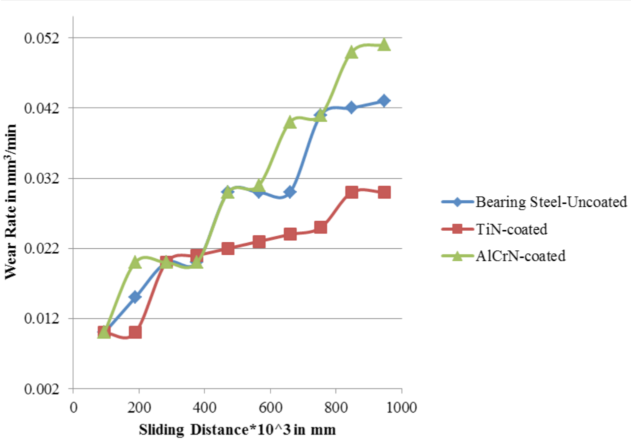


Figure 6. Variation in wear rate as a function of sliding

Wear behavior of uncoated and coated bearings were studied at 10N load and at 250rpm. Figure 6 illustrates the TiN coated bearing shows lower wear rate when compared to uncoated and AlCrN coated bearing materials. This indicates that the TiN coated bearing resulted in a protective titanium oxide layer due to their existence in a considerable amount in the alloy[16]. This is further validated by the SEM/EDS analysis of Figure 8 which indicates the surface without wear tracks indicating lower wear rate. The Figure 6 also shows there is a continuous increase in wear rate during running-in period of uncoated and AlCrN coated material which is mainly due to abrasion released debris materials which are entrapped between sample and hardened disc. This is confirmed by the surface morphology of AlCrN coated bearing samples as shown in Figure 9 (b)

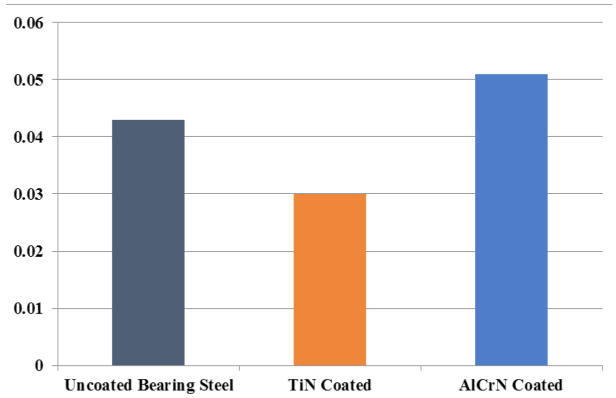


Figure 7. Bar graph showing the comparison of wear rates at 10N load.

The bar chart in Figure 7 provides the evaluation of wear loss obtained for uncoated and coated samples. At 10 N load, highest wear volumes were obtained for the PVD coated AlCrN and uncoated samples. The least wear was obtained for the TiN coated material.

3.2 SEM and EDS Analysis

The surface morphologies were observed by using Scanning Electron Microscope (SEM) and Energy Dispersive Microscopy (EDS) analyses the coatings' compositions.

TiN coated bearing samples did not show much difference in the SEM morphology before and after the test since titanium offered more wear resistance as evident from Figure 8 (a) and (b). Also, EDS patterns(c) and (d)

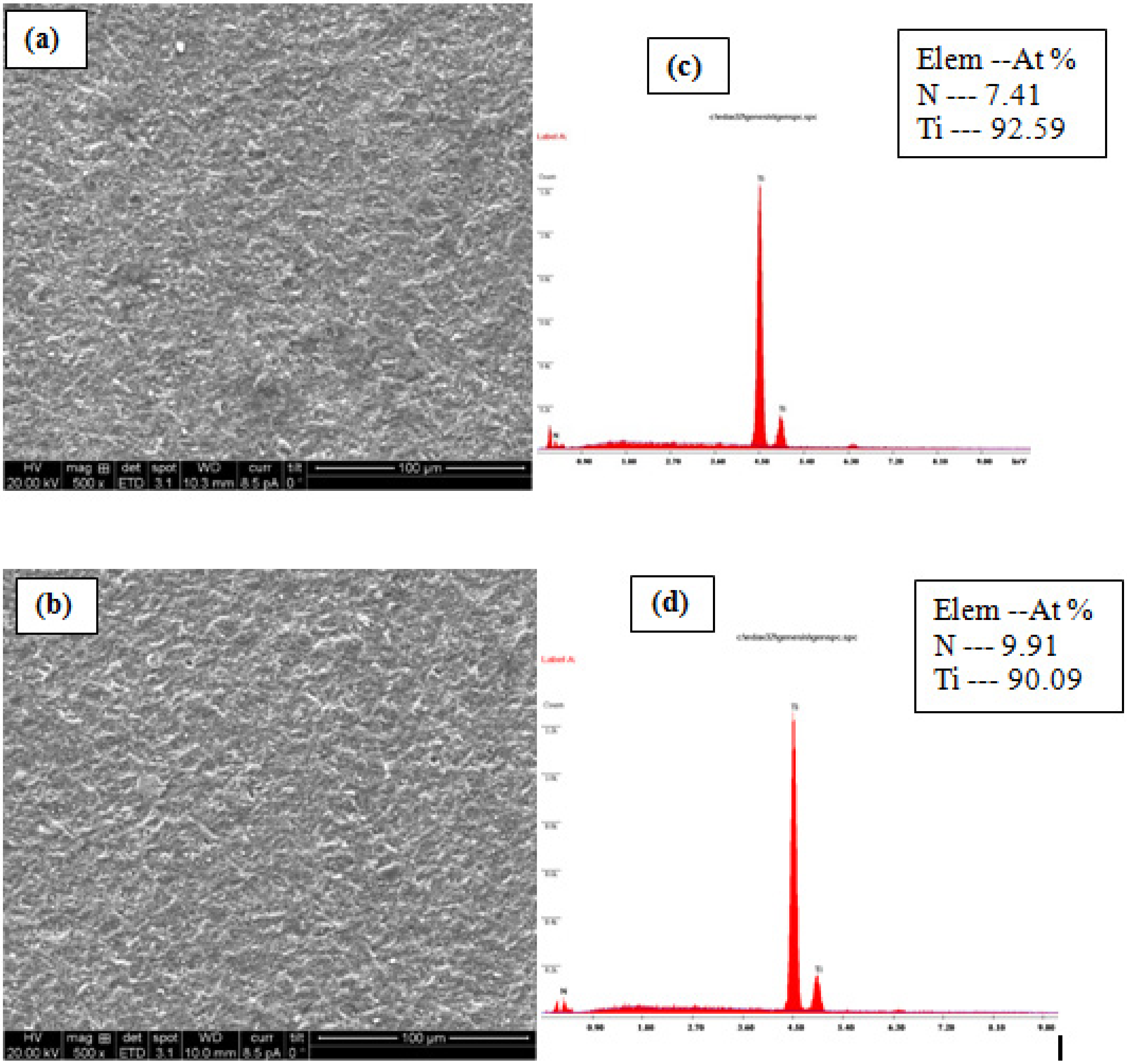


Figure 8. Surface morphologies and EDS patterns of TiN coated bearing sample (a) surface morphology of fresh sample (b) morphology of worn out surface (c) EDS pattern of fresh sample (d) EDS pattern of worn out sample.

depicted that the content of Ti is much more than that of element N.

SEM Morphologies for AlCrN clearly show that wear tracks are formed on the coating surface and also coating material got removed due to ploughing mechanism at certain places as shown in Figure 9 (b). It is basically because of the reason that Al content is more in the coating as it is evident from EDS patterns shown in (c) and (d). It offered very less wear resistance.

3.3 Vibration Analysis of Coated Bearings

After running the bearings for 200 hours at 100 N load, vibration signals are captured for uncoated and coated bearings by mounting the accelerometer on the bearing

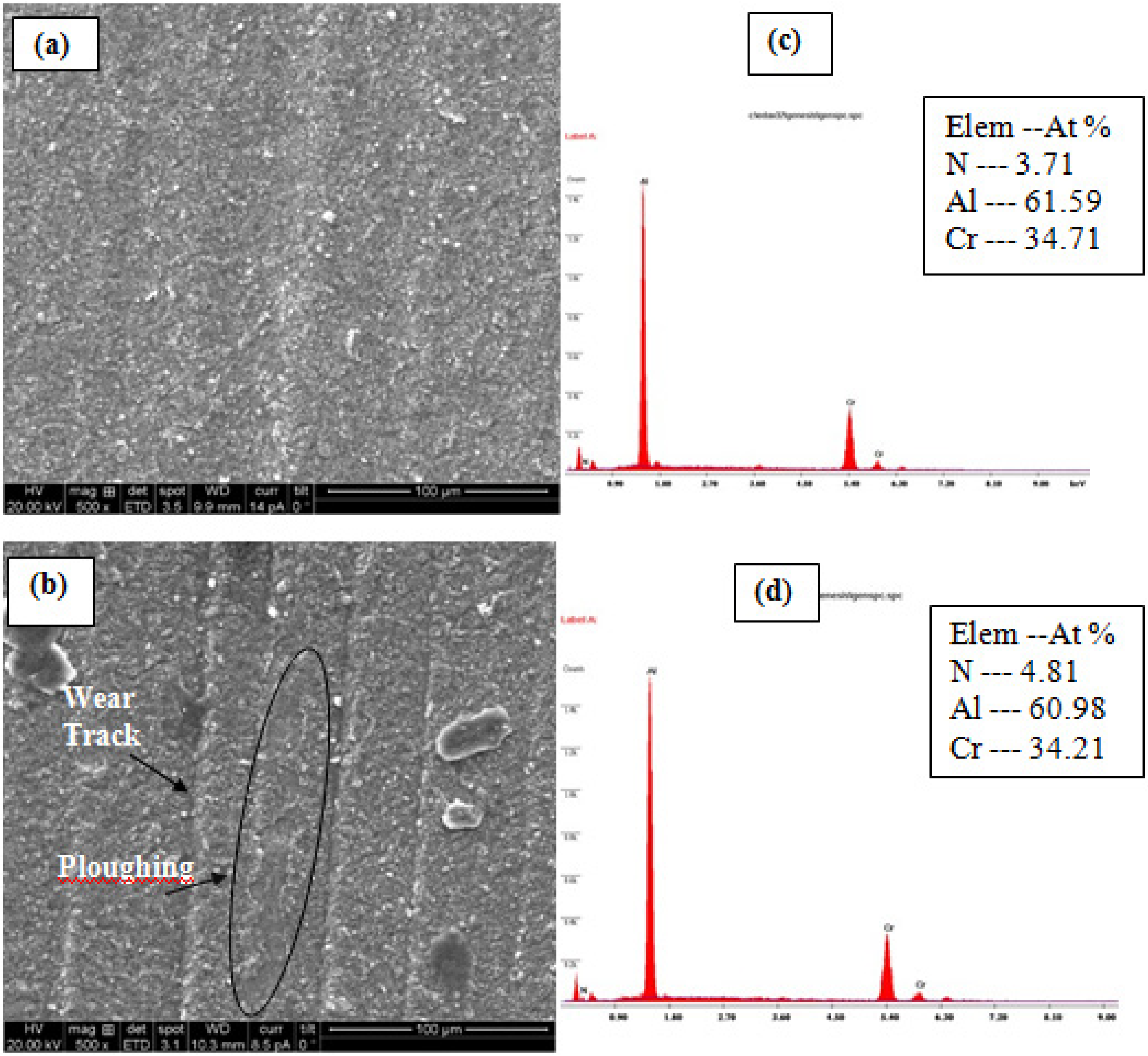


Figure 9. Surface morphologies and EDS patterns of AlCrN coated bearing sample (a) surface morphology of fresh sample (b) morphology of worn out surface (c) EDS pattern of fresh sample (d) EDS pattern of worn out sample.

housing. Further, MATLAB R2013b software is used to find various statistical parameters viz, Kurtosis, Crest factor, Skewness and RMS values for each sample. Figures 10 and 11 represent vibration signals from worn out AlCrN and worn outTiN coated bearings. The X-axis in the graph indicates time in seconds and Y-axis is acceleration in m/s^2. The kurtosis is a very good indicator for the analysis of surface wear[14]. The value of kurtosis is 3 for an undamaged bearing and increases with increase in wear/damage. Findings in the present study revealed that it is 7.6 for worn out AlCrN coated bearing compared to 4.4 for worn out TiN coated bearing. This clearly shows that TiN offers better wear resistance which supports the results of wear analysis.

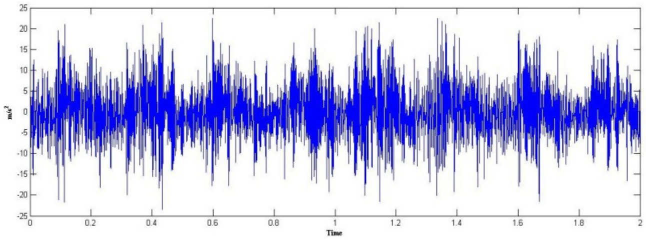


Figure 10. Vibration signals of worn out AlCrN coated

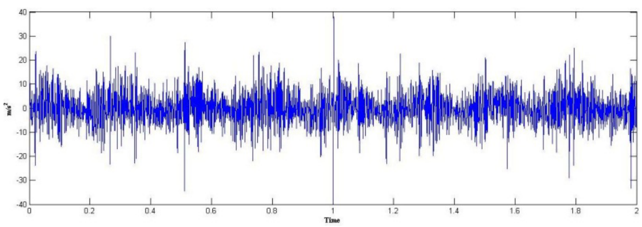


Figure 11. Vibration signals of worn out TiN coated bearing in the time domain.

The vibration severity criteria as given by standards such as ISO 2372 indicate that RMS value of the vibration velocity of the machine can be used to determine its condition.

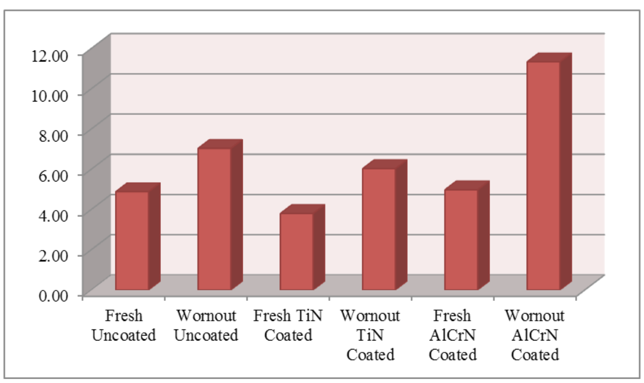


Figure 12. Comparison of RMS values for uncoated and worn out coated bearings.

Figure 12 shows that the RMS value of vibratory velocity for wornout TiN coated bearing is 6.03 m/s^2 which is less compared to 7.03 m/s^2 for uncoated bearing and 11.34 m/s^2 for worn-out AlCrN coated bearing. Hence, TiN coated bearings result into less vibration as it undergoes very less wear and shaft runs smoothly with TiN coated bearing.

Table 2. Skewness and Crest factor values for various cases of bearings

Case	Skewness	Crest Factor
Fresh Uncoated	-0.1336	4.2780
Wornout Uncoated	0.4661	6.9569
Fresh TiN Coated	-0.2171	5.2295
Wornout TiN Coated	0.1990	5.7366
Fresh AlCrN Coated	0.0328	5.9346
Wornout AlCrN Coated	0.1403	3.6685

Table 2 shows the skewness and crest factor values for various coating cases which will not reveal much significant fault information about bearings.

4. Discussions and Conclusions

In this work, the suitability of the TiN and AlCrN coatings is tested for the outer race of the roller bearings. The PVD method of coating is selected since it offers low process temperature and minimum coating thickness. Wear test is performed using pin -on- disc tribometer at 250rpm speed. Coated and uncoated bearings are run in the fabricated bearing test rig for 200 hours at 100 N load to seed the wear condition. After cutting the outer race of the bearing using Wire EDM, surface morphologies and EDS patterns of the coated samples are studied using SEM and EDS analysis. Vibration analysis is also carried out to support the wear study results.

From above discussion, following conclusions can be drawn:

1. The wear rate of TiN coating is found to be less compared to AlCrN coated and uncoated specimens because of high wear resistance feature of TiN.
2. SEM analysis revealed that more wear tracks and surface damage are occurred in AlCrN coated surfaces compared to TiN coated surface.
3. EDS patterns depicted that there was no much change in the composition of coating elements before and after the test.
4. The results of vibration signal analysis support the wear test results since RMS and kurtosis value of TiN coated bearing signals is less compared to that of AlCrN coated and uncoated bearing. Shaft runs smoothly with TiN coated bearing by emitting very less vibrations.

5. Overall investigation in the present work reveals that TiN coating enhances the performance of bearings from both tribological and vibration point of view.

6. Acknowledgements

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