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Investigation of composite coated Ti-C-N surfaces with ball-cratering test method

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Abstract: We present the performance of dry sliding metal-metal wear performance of AISI SS410 and Ti-C-N coated specimens at room temperature. In this investigation, the ball cratering abrasive wear testing method was used with a various loads of 2N, 3N and 4N, with total sliding distance of 353.43 m and at a constant sliding speed of 0.3927 ms^{-1}. In this testing machine the abrasive ball of high carbon steel with 750 HV at 100 g load is rotated against the Ti-C-N composite coated and uncoated AISI SS410. The worn surfaces were examined with scanning electron microscopy (SEM) (with EDAX attachment). The more grooving region, pits, ploughing ridge were found on the worn surface of the high carbon steel.

Keywords: Friction and wear resistant; TiCN**;** SEM-EDAX; PVD coating

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1. Introduction:

In modern internal combustion engines mechanical losses increases due to friction 4 and 15% of the total energy consumed [1]. Mechanical losses of about 40% - 55% occur in the power cylinder [2], and the piston ring generated half of the power cylinder friction losses [1, 3, 4]. Recent studies show that 80% of the total cost for the protection of metals is related to coating application [5]. Deposition of coatings provide a way of extending the limits of the use of the materials and their performance capabilities, by allowing the mechanical properties of the substrate materials to be maintained while protecting against wear, oxidation and corrosion [6]. Tribological failure like scuffing failure occurs which is characterized by a sudden rise in friction, contact temperature, vibration and noise, resulting in a surface roughening through severe plastic flow and loss of surface integrity [7, 8]. The physical vapour deposition (PVD) techniques are widely used nowadays for improvement of the mechanical, corrosion protection capability and other properties, of a broad range of engineering materials [9, 10]. The TiN coating was developed in the early 1970s [11] and this hard coating is an important role in surface engineering parts for two decades because of high hardness over 20 GPa [12]. As one of the major milestones in the advances of hard coating development, TiAlN has been commercially very successful due to significantly improved oxidation resistance and hardness over TiN [13-18]. Use of real engine tests for the evaluation of tribological performance is very costly and time consuming. One way to speed up the process, while maintaining accuracy of the prediction, is to develop mathematical models for each wear mechanism. In this work investigates to determine the tribological characteristics of the piston ring and cylinder block surfaces was evaluated. The worn surfaces were investigated with scanning electron microscopy (SEM) with EDAX **[19-25]**. The present work is undertaken to understand the effect of the sputtering conditions on the micro tribological behavior of Ti-C-N composite coated and to compare the results with the uncoated substrate.

2. Experiment:

2.1 Coating deposition: The AISI SS410 steel (Ø25mm x 15mm) was used as the substrate material. Their working faces were polished using a series of coarser to fine grade of silicon carbide emery papers and ultrasonically cleaned in acetone and ethanol, respectively. The coatings were prepared using a PVD techniques with argon (Ar) and pure nitrogen atmospheres. The composition coating TiCN with a thickness around 3.8 ±1µm is as shown in the Figure (1). Coatings were deposited on the surface of AISI SS410 steel and the process parameters are shown in the Table (1).

Table (1): PVD coating deposition parameters.

A machine used	Standard Balzers (RCS) machine
Make	Oerlikon Balzers, Swiss
Targets power	3.5KW
Reactive gas	Nitrogen
Nitrogen deposition Pressure	3.5 Pa
Substrate bias voltage	-40 V to -170 V
Substrate temperature	450 °C ±10°C
Coating thickness	3.8 ± 1 µm

2.2. Characterization: The coating surface was polished using a series of coarse to fine grade of silicon carbide emery papers. The image analyzer software of Dewinter Materials plus 1.01 based on ASTM B276 was used for calculating the porosity and PMP3 inverted metallurgical microscope used to obtain the images. As per the standard procedure, the porosity was observed to be less than 2% of the different area of the coated surface. After this wear test was followed. Figure (2) shows the chemical composition of Ti-C-N coating, were observed by energy dispersive X-ray analysis (EDAX). Table (2) shows the presence of Ti (50 at.%) as the main phase along with C (25 at.%) and N (25 at.%). A small amount of Cr, Mo, Fe and C is observed due to the pores present in the coating.

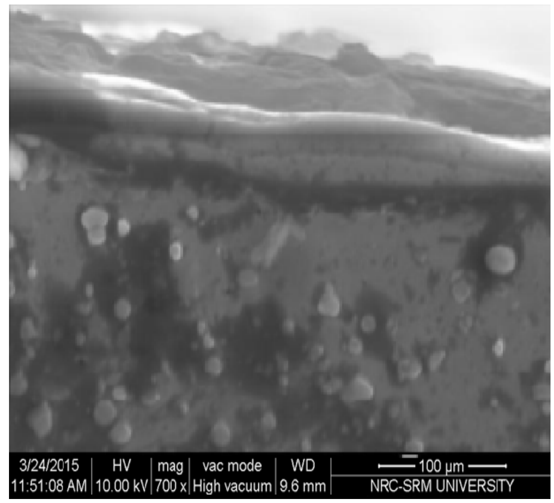


Figure (1) : SEM micrograph of cross-section of worn TiCN coated die segment.

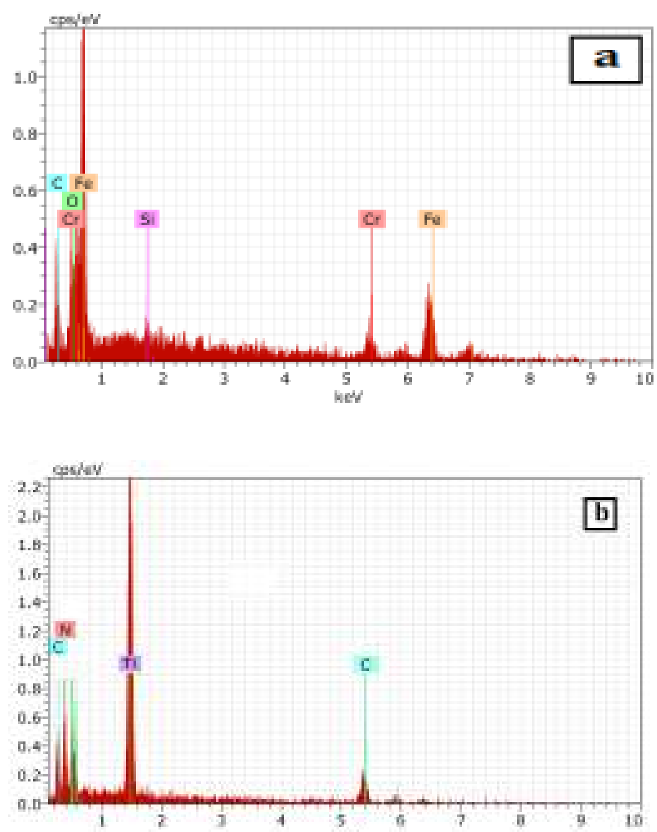


Figure (2): EDS analyses for worn surfaces of a) Uncoated substrate and b) Ti-C-N coated substrate.

Table (2): Chemical composition of the substrate and coating.

Composition (at. %)	P	Mn	C	Cr	S	Si	Ti	N
Material (SS410)	1.0 %	1.0 %	0.15 %	11.5-13.5 %	0.03 %	1.0 %	-	-
Ti-C-N Coated	-	-	25%	-	-	-	50%	25 %

2.3. Tribological testing: Figure (3) shows the schematic line drawing of the ball cratering wear. The coated substrate was clamped on to a platform and fixed to the arm. This arm was rotated, around its hinge until the coated substrate were pressed against a high carbon steel ball (diameter 25 mm) rotating at 150 revs/minute. The tester has an accurate control of both the normal load and ball-sliding speed. In this testing standard ASTM G77 is used as shown in Table (3). The dry sliding abrasive wear test was conducted on the AISI SS410 and Ti-C-N coated against high carbon steel ball. After testing to observe the worn surface by SEM. Before the experiment, the surfaces of coated and uncoated were thoroughly cleaned with ethanol. All the wear test was performed at the room temperature having relative humidity 60%. These tests were carried out at different load, constant sliding distance and sliding speed conditions. Here we varied the load at 2N (0.203 Kgf), 3N (0.305 Kgf) and 4N (0.407 Kgf) through a total sliding distance 353.43 m with a constant sliding speed of 0.3927 ms^{-1}. The weight loss measuring instrument precision value is 0.0001. Wear rate can be determined by using this equation (1).

$$W = (M1 - M2)/M1 \quad (1)$$

where M1 – Total Mass wt. Of before the test.
M2 – Total Mass wt. Of after the test.

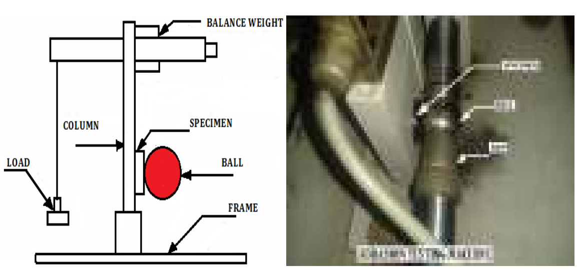


Figure (3): Schematic diagram of micro –scale abrasion tester.

Table (3): Micro-scale abrasion test parameters.

Substrate	1.Uncoated specimen, roughness Ra=0.67 µm, 2. Ti-C-N coated specimen, Surface roughness Ra= 0.785 µm,
Sphere Ball Material	High Carbon steel, Ball diameter - 25 mm, Surface roughness Ra=0.068 µm, Hardness - 750 VHN at 100 g load
Sliding Speed	150 rev/minute
Load	2N (0.203 Kgf), 3N(0.305 Kgf) and 4N(0.407 Kgf)
Total sliding distance	353.43 m
Condition	Metal to Metal Point contact, No slurry

3. Result and Discussion:

3.1. Micro-hardness test: The Vickers hardness indenture (HV 10 Kg) was used to determine the hardness of the different location of the coated substrate and uncoated substrate. After examination, the average hardness value (337 HV) was observed in Ti-C-N coating and minimum hardness value (183 HV) was found in uncoated specimen is as shown in the Figure (4). The higher hardness and possibly harder wear debris. The coating has lower porosity and very dense structure. In this coated substrate has good wear resistance because of the absence of grain boundaries. Elastic modulus and hardness were determined using the procedure described in [16-17].

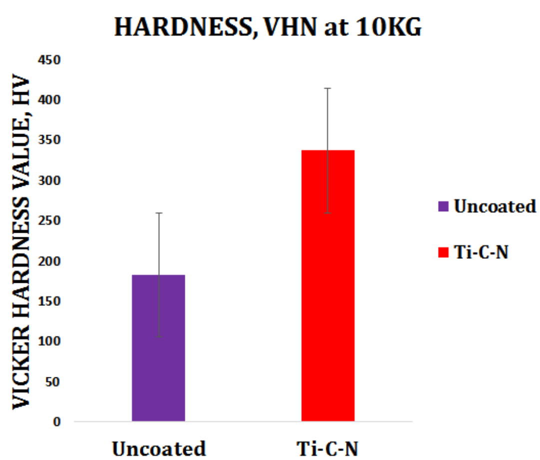
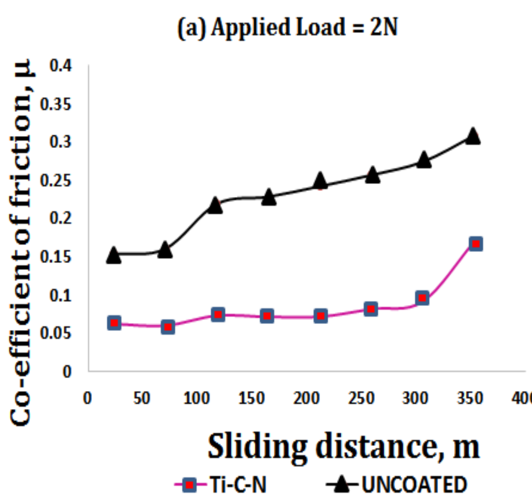
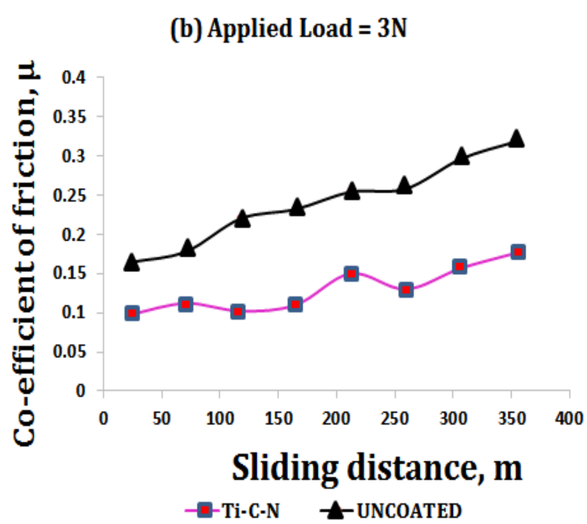


Figure (4): Micro-hardness of the coated specimen.

3.2. Frictional behavior: The co-efficient of friction for the uncoated and coated substrate at the different loads is illustrated in Figure (5). It can be noted that the coefficient of friction initially decreases and then increases with the increase in the number of cycles. At applied load 2N, the co-efficient of friction does not show the asymptotic behavior by increasing the number of cycles within the test duration is as shown in the Figure (5a). For the applied 3N load the friction co-efficient increases with the applied load exhibits from Figure (5b), where for the 4N load the co-efficient of friction decreases with increase in load as shown in Figure (5c). Finally the lowest coefficient of friction is observed from the 2N and 4N load. In contrast, the Ti-C-N film has the lowest friction co-efficient at the lowest applied 2N.





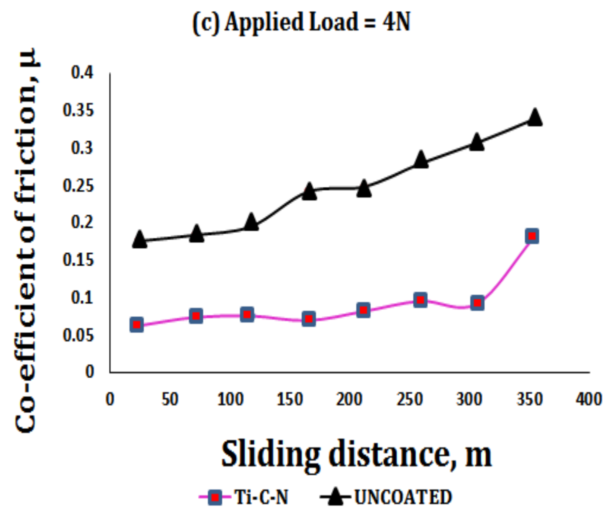


Figure (5): The co-efficient of friction of uncoated and coated films at different applied loads : (a) applied load = 2N, (b) applied load = 3N and (c) applied load = 4N.

3.3.Wear characteristics: Figure (6a) shows the mass loss for the uncoated and coated substrate. In the different load condition, the coating shows comparatively less wear than the uncoated specimen. The mass loss volume gradually increases with increase the load. The wear performance is nearly 80% - 90% greater than that of the uncoated substrate of a 2N and 4N applied load. But in 3N applied load shows 25% - 30%, respectively than the wear performance of the uncoated substrate. Thus, above this 2N and 4N applied load gives the best performance and wear resistance than the uncoated substrate.

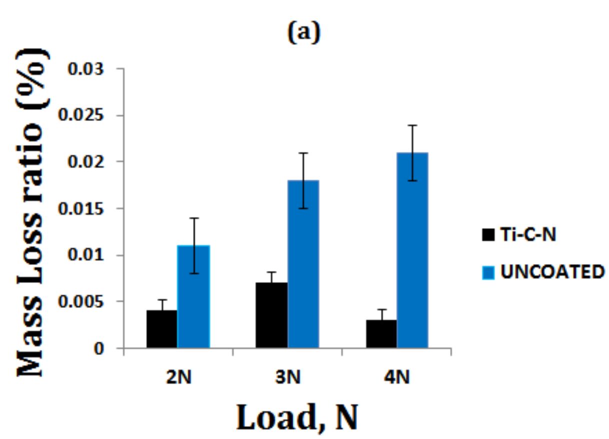


Figure (6a): Total wear of the investigated films at different loads.

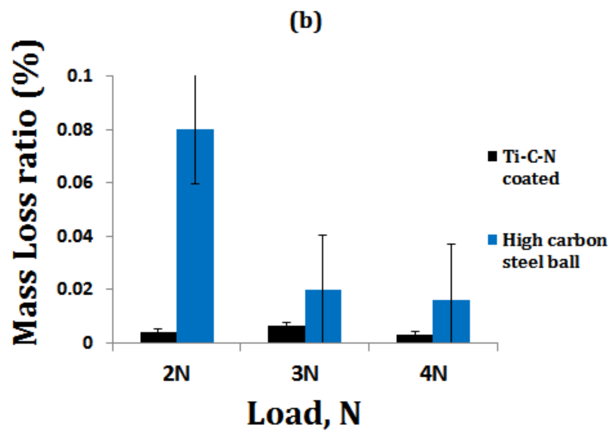


Figure (6b): Total wear of High carbon steel ball and Ti-C-N coated at different loads.

When Ti-C-N coated substrate sliding against high carbon steel balls, the behavior of the material was highly prejudiced by the differences in hardness between the ball and the coating. Against Ti-C-N the wear rate was computed at the various loads of 2N, 3N and 4N for the total sliding distance 353.43 m at a constant sliding speed of 0.3927 m/s is as shown in the Figure (6b). In this stage the high carbon steel ball was severely worn by coatings with high hardness.

3.4 SEM micrograph: Figure (7) shows the microscope image of the uncoated and coated substrate after ball cratering wear test. In Figure (7a and b) shows the abrasive marks, pits, cracks and wear-tracks on the uncoated substrate. A few deep grooving and ploughing was observed during the test. The material loss is based on the hardness of the substrate. The SEM image of the Ti-C-N coating with different load with a sliding distance of 353.43 m is as shown in the Figure (7c and d). The more grooving region, pits and cavities with Ti-C-N particles were observed on the worn surface of the high carbon steel ball. Final result shows hard Ti-C-N coated particles viewing of the worn surface. The occurrence of wear is attributed to the four wear mechanisms adhesion, abrasion, surface fatigue and tribochemical reaction [18].

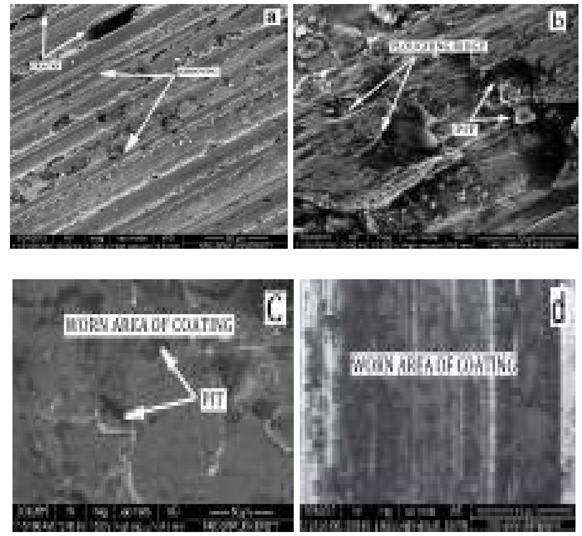


Figure (7): SEM images of the worn surface produced by ball cratering abrasive wear testing machine of (a) (b) are uncoated and (c) (d) are Ti-C-N coated

4. Conclusions:

1. The co-efficient of friction at maximum load is governed by the roughness of the coated surface.
2. The total wear decreased with the hardness of investigating film in the present work. Total wear increases with applied load of the abrasive wear test in the Newton load range.
3. Coating thickness is an important character in the tribological behavior because of the coating has very lower porosity and very dense structure.
4. The more grooving region, pits, ploughing ridge and cavities with Ti-C-N composite particles were found on the worn surface of the stainless steel AISI 410. This result shows off hard Ti-C-N coated particles viewing of the worn surface.
5. From the abrasive wear test results we find the Ti-C-N composite coated surface having a good co-efficient of friction, low wear loss, high thermal resistance and long-time wear resistance. So this Ti-C-N composite coating can also be used in automobile applications because of good mechanical and material properties.

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