Experimental and Investigation of Nano Composite Coated TI-C-N Surfaces with Ball-Cratering Test Method

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Abstract: This paper describe 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 machine was used with a various loads of 2N, 3N and 4N, 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 750HVat 100g 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. This result shows off hard Ti-C-N coated particles viewing on the worn surface.

Key words: Friction and Wear resistant · TiCN · SEM-EDAX · PVD coating

INTRODUCTION

In modern internal combustion engines mechanical losses increases due to friction 4 and 15% of the total energy consumed [1]. 40-55% of those total mechanical losses 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 PVD (physical vapour deposition) 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 20GPa [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]. 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 [15-19]. 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.

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Experiment

Coating Deposition: The AISI SS410 steel (Ø10mm x 15mm) were 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 (Physical vapor deposition) with argon (Ar) and pure nitrogen atmospheres. The composition coating TiCN with a thickness around $3.8 \pm 1\mu m$ is as shown in the Fig. 1. Were deposited on the surface of AISI SS410 steel and the process parameters are shown in the Table 1.

Characterization: The coating surface were 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. The Fig. 2 shows the chemical composition of Ti-C-N coating, were observed

by energy dispersive X-ray analysis (EDAX). The Table 2. Shows the presence of Ti (50%) as the main phase along with C (25%) and N (25%). A small amount of Cr, Mo, Fe and C is observed due to the pores present in the coating.

Tribological Testing: The Fig. 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 25mm) 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 experiment, the surfaces of coated and uncoated were thoroughly cleaned with ethanol. All the wear test were 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

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

Table 2: Chemical composition of the substrate and coating

Composition (%)	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%

Table 3: Micro-scale abrasion test parameters.

| Substrate	1.Uncoated specimen, roughness Ra=0.67µm, 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=0.068µm, Hardness - 750 VHN at 100g load
Sliding Speed	150rev/minute
Load	2N (0.203Kgf), 3N(0.305Kgf) and 4N(0.407Kgf)
Total sliding distance	353.43 m
Condition	Metal to Metal Point contact, No slurry
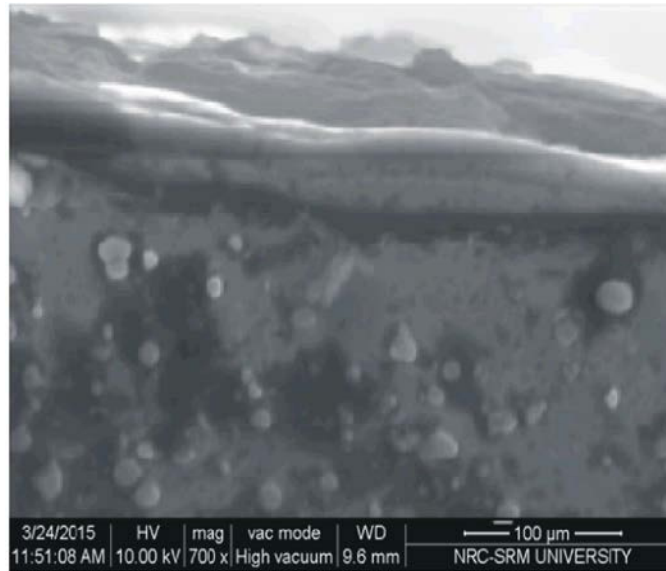
Fig. 1: SEM micrograph of cross-section of worn TiCN coated die segment
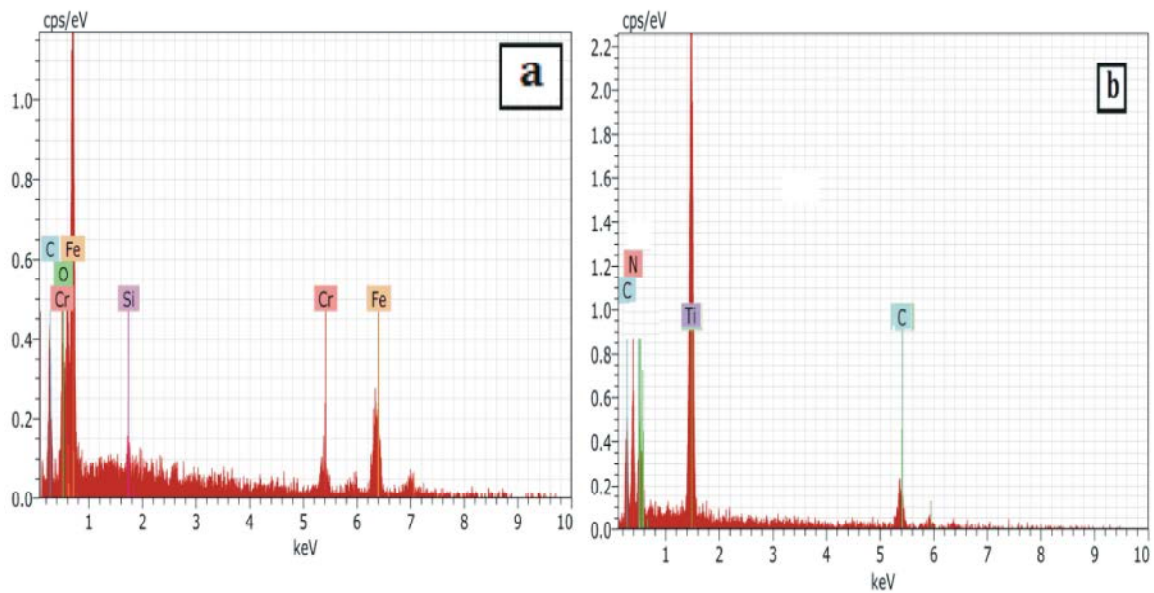

Fig. 2: EDS analyses for worn surfaces of a) Uncoated substrate and b) Ti-C-N coated substrate
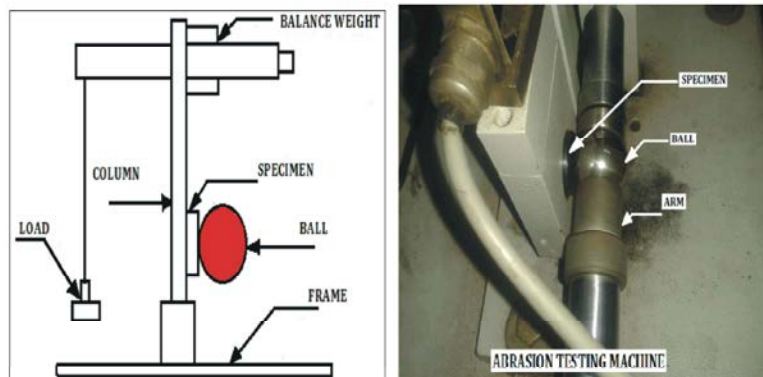

Fig. 3: Schematic diagram of micro –scale abrasion tester

load at 2N(0.203Kgf), 3N(0.305Kgf)and 4N (0.407Kgf) 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 (2).

W = (M1 – M2)/M1 - (2)
where M1 – Total Mass wt. of before the test.
M2 – Total Mass wt. of after the test.

RESULT AND DISCUSSION

Micro Hardness Test: The Vickers hardness indenture (HV10Kg) was used to determine the hardness of the different location of the coated substrate and uncoated substrate. After examination, the average hardness value (337HV) was observed in Ti-C-N coating and minimum hardness value (183 HV) was found in uncoated specimen is as shown in the Fig. 4. The higher hardness
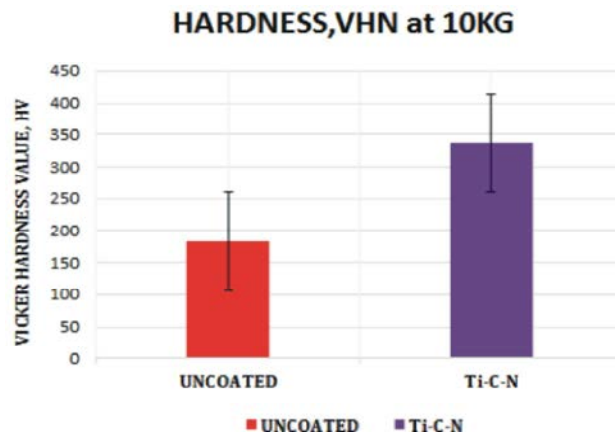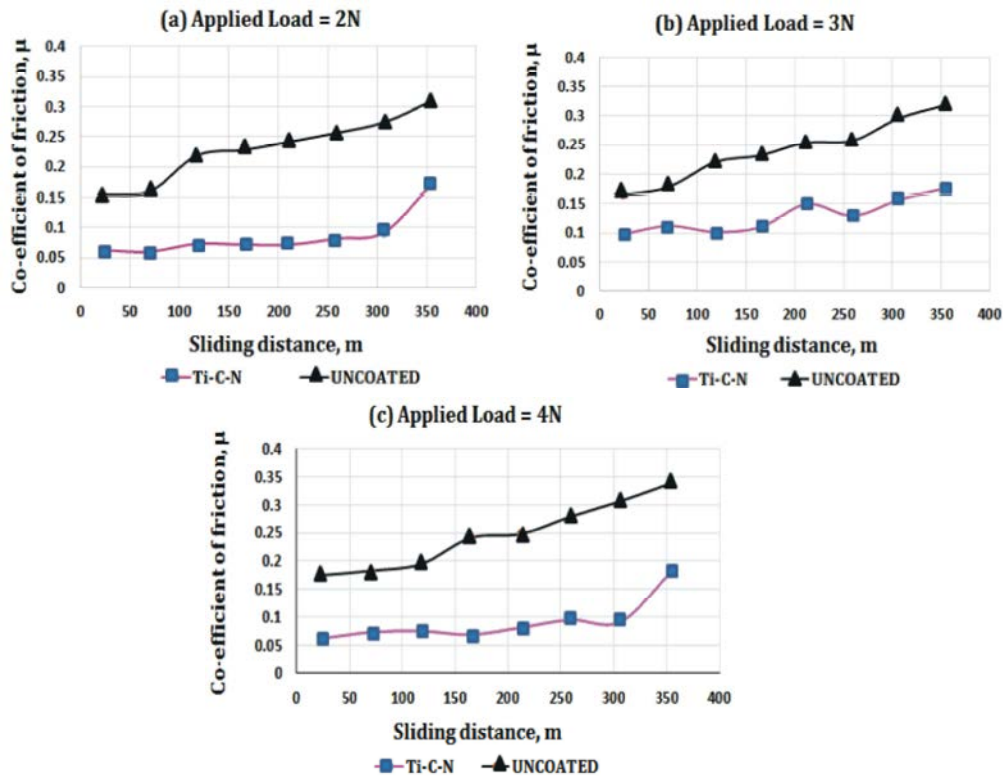

Fig. 4: Micro Hardness of the coated specimen

Fig. 5: The friction Coefficient of uncoated and coated films at different applied loads :(a) applied load = 2N, (b) applied load = 3N and (c) applied load =4N
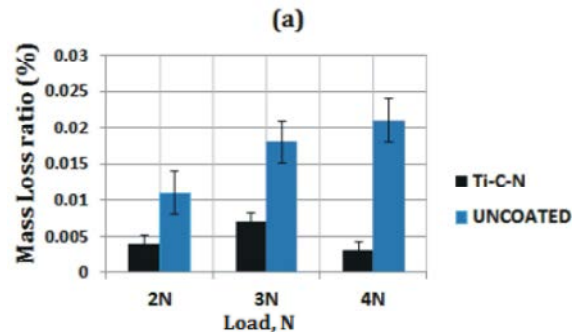
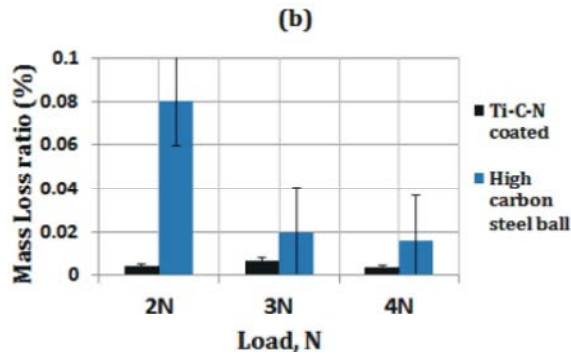Fig. 6: (a) Total wear of the investigated films at different loads

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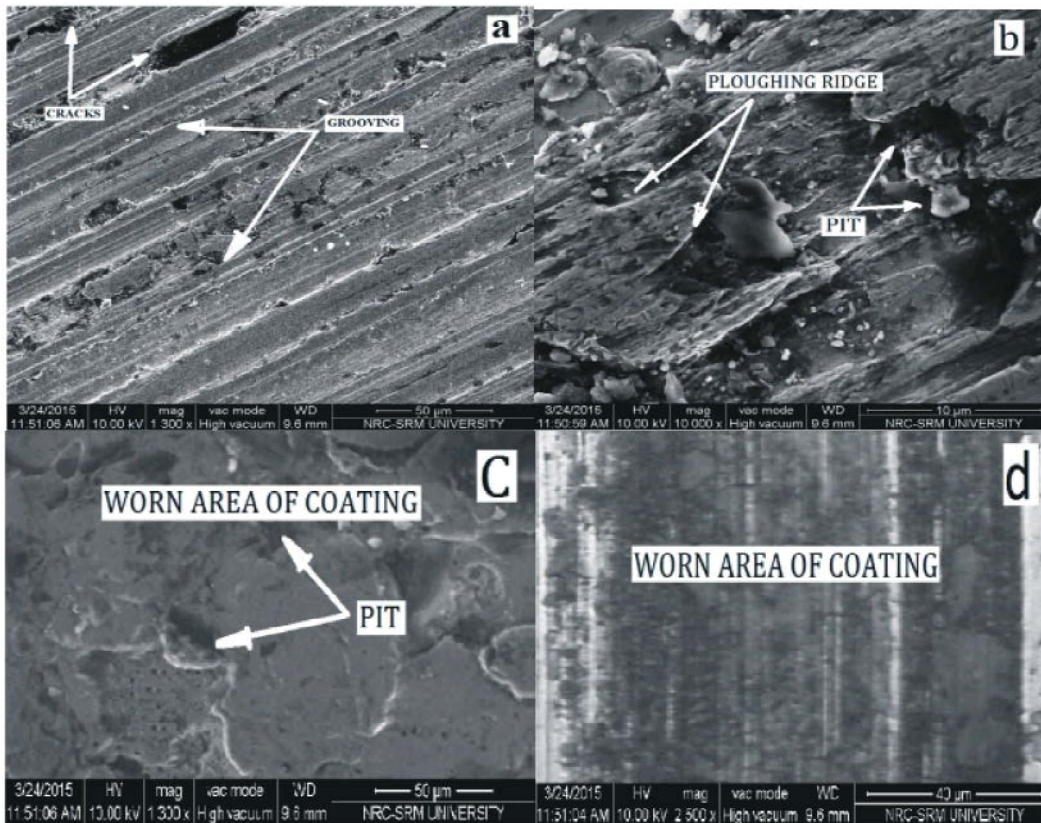

Fig. 7: SEM images of the worn surface produced by ball cratering abrasive wear testing machine of (a) (b) are uncoated and (c) (d) are Ti-C-N coated

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].

Friction Behavior: The friction co-efficient for the uncoated and coated substrate at the different loads is illustrated in Fig. 5. It can be noted that the coefficient of friction initially decreases and then the increases with increase in number of cycles. At applied load 2N, the friction coefficient does not show asymptotic behavior with increasing the number of cycles with in the test duration is as shown in the Fig. 5. (a). For the applied 3N load the friction co-efficient increases with the applied load exhibits from Fig. 5.(b), where for the 4N load the friction co-efficient decreases with increase in load as shown in Fig. 5.(c). 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.

Wear Characteristics: The Fig. 6.(a) shows the mass loss for the uncoated and coated substrate. At 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 good performance and wear resistance than the uncoated substrate.

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 ms^{-1} is as shown in the Fig. 6.(b). In this stage the high carbon steel ball was severely worn by coatings with high hardness.

SEM Micrograph: Fig. 7. shows the microscope image of the uncoated and coated substrate after ball cratering wear test. In Fig. 7.(a) 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 353.43m is as shown in the Fig. 7. (c) 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. Finally result shows hard Ti-C-N coated particles viewing on the worn surface. The occurrence of wear is attributed to the four wear mechanisms adhesion, abrasion, surface fatigue and tribochemical reaction [18].

CONCLUSIONS

- The friction coefficient at maximum load is governed by the roughness of the coated surface. At minimum load, the presence of graphitic carbon determines the co-efficient of friction.
- The total wear decreased with the hardness of investigated film in the present work. Total wear increases with applied load of the abrasive wear test in Newton load range.
- Coating thickness is an important character in the tribological behaviour because of the coating has very lower porosity and very dense structure.
- 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 on the worn surface.
- 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.
- The more grooving region, pits, ploughing ridge and cavities with Ti-C-N particles were observed on the worn surface of the High Carbon steel. This result displays off hard Ti-C-N coated particles viewing on the worn surface.

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