WEAR PERFORMANCE OF TIALN NANO-COATINGS APPLICABLE TO ROTAVATOR BLADES AT VARYING LOADS

[1]Jasmaninder Singh Grewal, [2] Manpreet Singh
[1]Guru Nanak Dev Engineering College, Ludhiana – 141006, Punjab, India.

Abstract : Two coatings of TiAlN multilayer and monolayer were selected and deposited on EN-19 high-quality alloy steel by Physical Vapor Deposition magnetron sputtering method. These were investigated with the help of Pin-on-Disk method which gives us information about the abrasive wear, frictional force and coefficient of friction of tested samples. The examination of uncoated and coated specimens was done by keeping constant velocity of 1 m/s and varying loads of 20N, 30N and 40N. The morphology of multilayer and monolayer samples were also examined by using SEM/EDAX. The results shown that multilayer specimen has less wear rate as compared to monolayer and substrate respectively.

Index Terms- **TiAlN, Abrasive Wear, Physical Vapour Deposition (PVD), Rotavator Tiller.**

I. INTRODUCTION

Agriculture is a major industry, because farmers cultivate food and more job opportunities are generated in other agri-based industries. Agricultural tool making is one of the serving industries. The majority of people tried for procurements of farming tools. A mechanical cultivator is known as Rotavator tiller, is repeatedly used in the direction of reducing absolute time and individual diligent work in top layer soil. Due to under severe stacking, rotavator blade edges are exposed to harsh wear. The main objective of the examination is to improve the operational existence of rotavator blade so to slice the inactive time required to restore the sharp edge after a period of time. Due to cost-effective demand to further boost the efficiency of the processes, it is essential to utilize the wear resistant coatings.

The PVD coating process is rapidly growing due to high hardness, low coefficient of friction and having a property of wear resistance. Liew et al researched that nano coatings like TiAlN have the maximum wear resistance than the substrate.[6]. Khlifia et al deliberate TiAlN/TiN based mono layered coatings have better surface roughness but multilayer layer coatings have superior mechanical properties and rougher surface, [5]. With many variations done in chemical compositions, deposition and formation in coatings and rigorous change in the coating structure, these coatings can be applicable in diverse applications for different purposes.

The present research work is focused on the analysis of TiAlN multilayer layer structured and TiAlN mono structured coatings deposited on EN-19 with reference to wear and frictional performance, which is relatively a new coating with a new composition of Titanium and Aluminium. Pin-on-Disk (Tribological) apparatus is used for conducting tests as per G 99-95 standard, [10].

II. MATERIALS AND METHODS

2.1 Material Selection

Being from farmer's family, the problem being faced is of repair and replacing of rotavator blades which are worn out due to severe stacking. EN-19 which is material of rotavator blades is selected to improve its wear resistance.

Specimens are prepared of size 8 mm diameter and 30 mm long and used as the substrate for coatings. Chemical composition of the substrate is given below in table 1.

Table 1: - Chemical Composition (Wt %) of EN-19 Substrate

EN-19	**C**	**S**	**P**	**Si**	**Mn**	**Cr**	**Mo**
Nominal	0.35-0.45	0.050	0.035	0.10-0.35	0.50-0.80	0.90-1.50	0.20-0.40
Actual	0.370	0.014	0.024	0.320	0.72	1.300	0.250

2.2 Coating Deposition on EN-19 Substrate

TiAlN based multilayer layer (BALINIT-PERTURA) and monolayer (BALINIT-LATUMA) were successfully deposited on EN-19 substrate by Physical Vapour Deposition DC-Magnetron Sputtering. The various parameters are given in below table 2.

Table 2:- Coating Information and Technical Detail

Parameters	BALINIT-PERTURA	BALINIT-LATUMA
Layer Type	Multi	Mono
Machine Used	Standard Balzers rapid coating system(RCS) machine	Standard Balzers rapid coating system(RCS) machine
Deposition Temp. (ºC)	500	500
Target	Ti and Al	Al and Ti
Reactive Gas	Nitrogen	Nitrogen
Pressure in Vacuum chamber (bar)	10^{-3}	10^{-3}
No. of Target per Machine	8	8

Cycle time (h)	10	8
Max Service Temp. (ºC)	1000	1000
Substrate bias voltage	-40V to -170 V	-40V to -170 V
Note: - Target material: +ive biasing; substrate material: -ive biasing.		

2.3 Characterization of Coatings

Characterization of coatings was done by Surface roughness and SEM/EDAX. Surface roughness was tested with the help of Mitutoyo Surftest SJ-410 apparatus. For elemental characterization and composition, Scanning Electron Microscope/ Energy Dispersive X-Ray Analysis (SEM/EDAX) were used.

SEM/EDAX is non-destructive technique (NDT), ultra-modern used for testing a large variety of fluids, metals, minerals, materials and coatings, etc. SEM/EDAX was done to get the elemental composition present upon the face of the substrate as confirmatory test. Carl Zeiss FE-SEM quanta 200 FEG machine used to do this analysis. It can provide high-resolution magnification around 12X-1000kX. FEG gun is used with Schottky emitter whereas SE, EBSD, EDS and BSE were used as a detector.

2.4 Selection of parameters and machine used

To inspect the coefficient of friction and wear, the Pin-on-disk method was used. This tribological apparatus (TR-201, DUCOM India) normally include a sample holder with adjustable arm, a high tensile steel revolving disk with diameter from 2 mm up to 160 mm, Specimen holder holds cylindrical pin perpendicularly range against rotating disk made of EN-31 grade steel. The whole setup is linked to the computer and control panel as shown in figure 1(a) to (e). Control panel is used to control the speed of disk with respect to time and rpm of the disk. In computer, graphs of the coefficient of friction, friction and wear with relative to time is drawn with the help of winducom software.

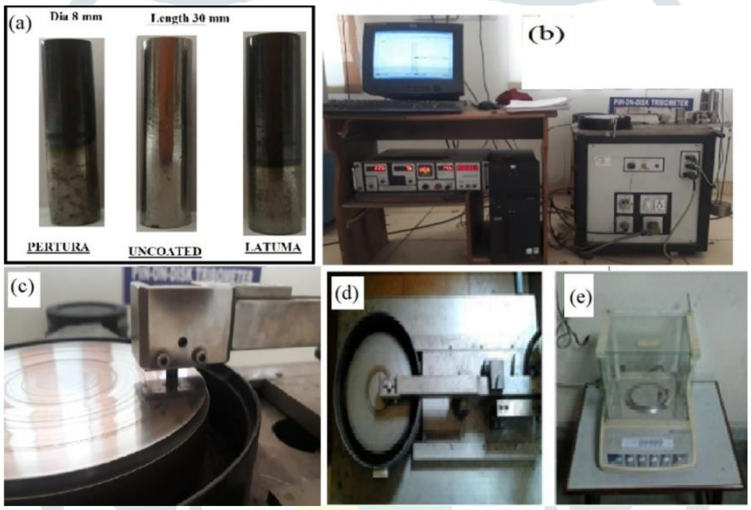

Fig 1; - (a) Specimens (b) Tribological Pin-on-Disk Apparatus as per ASTM G99-95 Standard
(c) Specimen holding position (d) Top View of Apparatus (e) Electronic Weighing Scale

The loads of 20N, 30N and 40 N were selected by keeping velocity constant at 1 m/s. Disk diameter was fixed at 130 mm. According to disk diameter, the disk speed was calculated as 147 rpm.

III. EXPERIMENTATION

Emery paper was used to polish and clean both pins and disk. To obtain precise results, it is essential that disk and pin have no foreign materials i.e. oil, grease or debris present on surface. 9 numbers of pins were prepared to do examination. 3 pieces each for uncoated, TiAlN based multilayer coating and TiAlN based mono layered coating were prepared. Wear test was carried out for 90 minutes by following cycles i.e. 5 min, 5 min, 10 min, 10 min, 15 min, 15 min and 30 min respectively. After each cycle, pin was removed and preset at same orientation. During tests, data was collected from software after completion of each cycle.

IV. RESULTS AND DISCUSSIONS

4.1 Visual Examination

Visual examination is used to recognize two distinctive material's physical appearances. The samples were analyzed after the PVD coatings. Samples are recognized by their colors. Multilayer coatings sample were in dull dim grey color though monolayer coating samples are grey in color. Also, there were no rupture and cracks seen on coating surfaces.

4.2 Surface Roughness

Wear rate and friction are directly connected to surface roughness, by escalating the surface roughness mean more wear rate and friction and vice-versa. Mitutoyo Surftest SJ-410 equipment gives the value of surface roughness of three types of samples. The values are given below in table 3.

Table. 3: Surface Roughness of Uncoated, PERTURA and LATUMA

Material Substrate	Surface Roughness (μm)
Uncoated	R_a = 0.147 R_q = 0.395 R_z = 2.905
TiAlN (Mono Layer)	R_a = 0.124 R_q = 0.202 R_z = 2.263
TiAlN (Multilayer layer)	R_a = 0.125 R_q = 0.257 R_z = 2.666

4.3 SEM/EDAX of As Coated Specimens

SEM was done to obtain micrographs and EDAX to search out elemental configuration with respect to weight percentage as well atomic percentage present on the specimen's surface. The SEM micrographs and EDAX charts are shown in figure 2 and 3 respectively of monolayer and multilayer coatings. Elemental composition of multilayer and monolayer is considered and computed. In monolayer coating, Titanium and Aluminium were deposited almost equal by weight percentage on substrate with traces of Nitrogen.

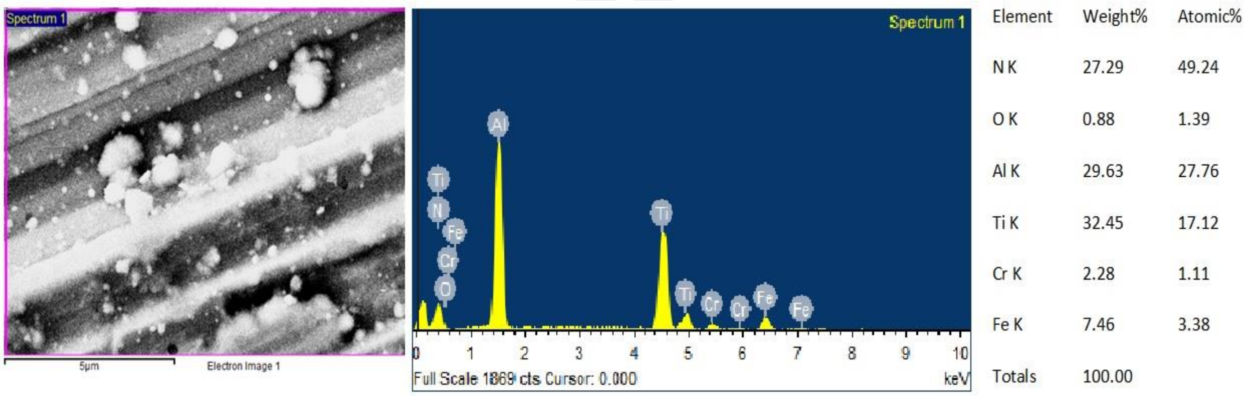

Fig. 2: SEM/EDAX micrographs of TiAlN based monolayer coating

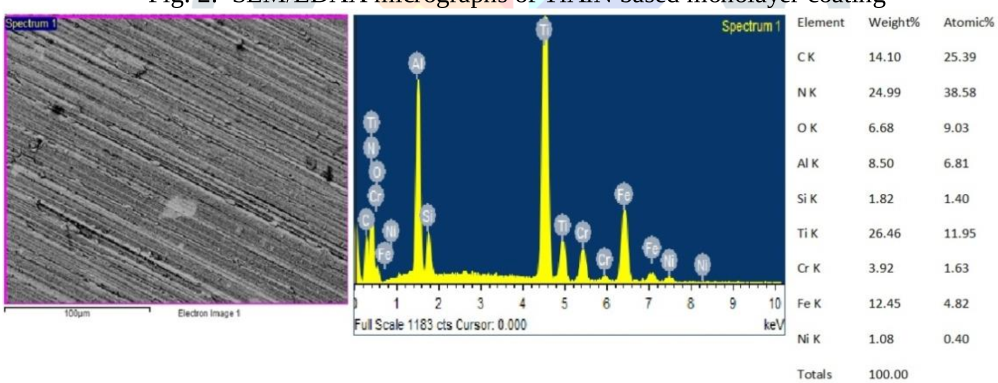

Fig. 3: SEM/EDAX micrographs of TiAlN based multilayer coating

Multilayer coating has fine splats whereas monolayer coating has coarse splats. In monolayer coating, it is visibly seen that atom of Al, Ti and N are differentiated by volume of size. The elemental composition of both coatings (Multilayer and monolayer) related to spectrum 1 is confirming the existence of Ti, Al and N. Small amount of Oxygen indicates the formation of oxides during detonation process. In multilayer coating, the presence of C and Si indicate the possibility of presence of Silicon Carbide. The presence of Nickel made it corrosion resistant.

4.4 Cumulative weight loss and Coefficient of Friction

The line graphs from figure 4 (a) to 4 (c), represents when the load was varied and disk speed was constant then the cumulative weight loss of uncoated samples was increased in range of 0.006 grams in each variation but in case of multilayer coating less weight loss witnessed as compared to monolayer coating. It is noted that marginal weight loss observed in TiAlN based multilayer and TiAlN based monolayer with respect to time interval in almost all the cases. In fig 4(c), uncoated substrate has also marginal wear loss at certain period after that it suddenly increased after 60 minutes.

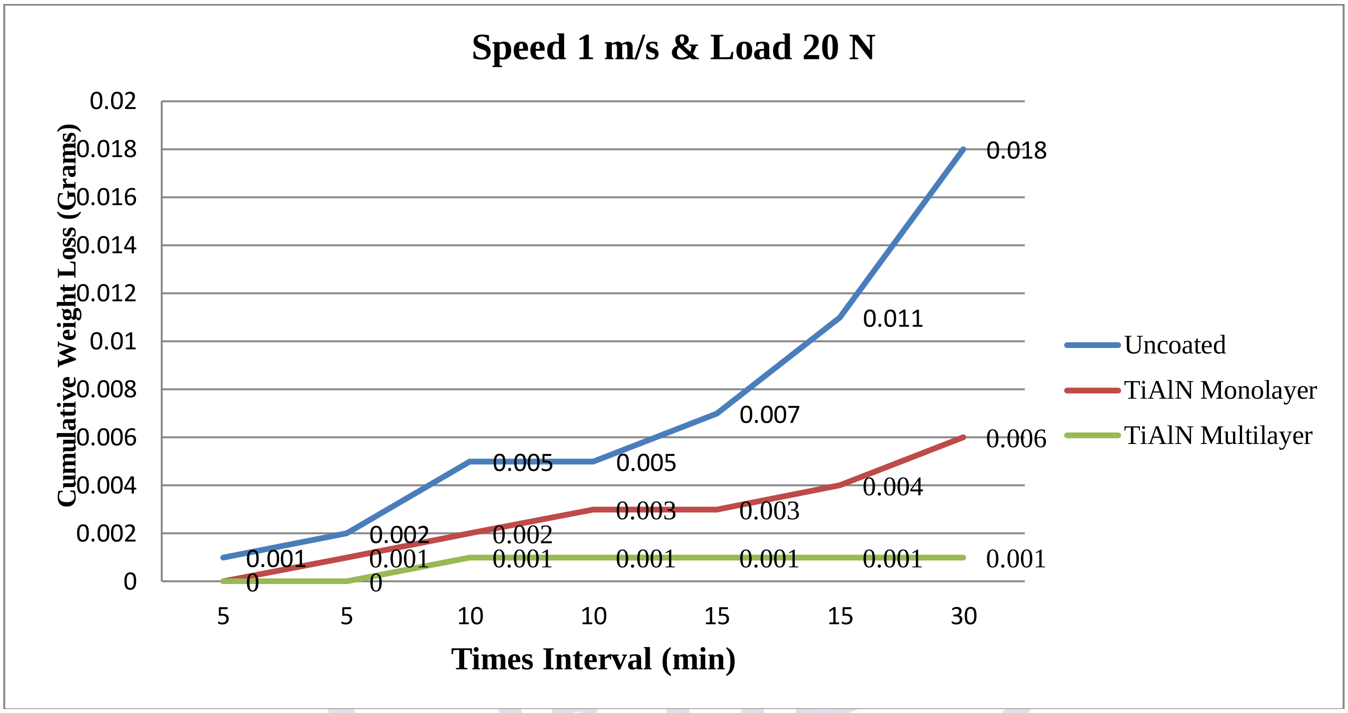
Speed 1 m/s & Load 20 N
Cumulative Weight Loss (Grams)
Times Interval (min)
Uncoated
TiAlN Monolayer
TiAlN Multilayer
0.018
0.011
0.007
0.006
0.005
0.005
0.004
0.003
0.003
0.002
0.002
0.001
0.001
0.001
0.001
0.001
0.001
0.001
0
0
5
5
10
10
15
15
30

Fig. 4(a)

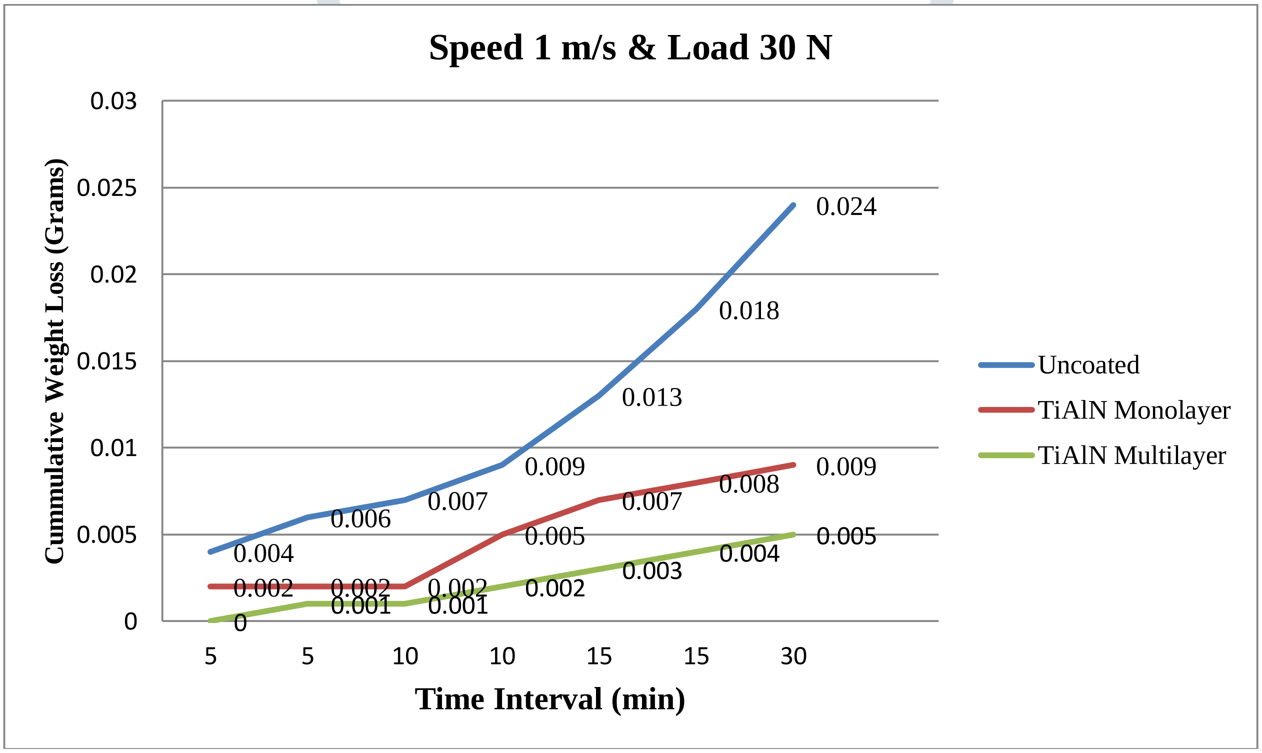
Speed 1 m/s & Load 30 N
Cummulative Weight Loss (Grams)
Time Interval (min)
Uncoated
TiAlN Monolayer
TiAlN Multilayer
0.024
0.018
0.013
0.009
0.009
0.008
0.007
0.007
0.006
0.005
0.005
0.004
0.004
0.003
0.002
0.002
0.002
0.002
0.001
0.001
0
5
5
10
10
15
15
30

Fig. 4(b)

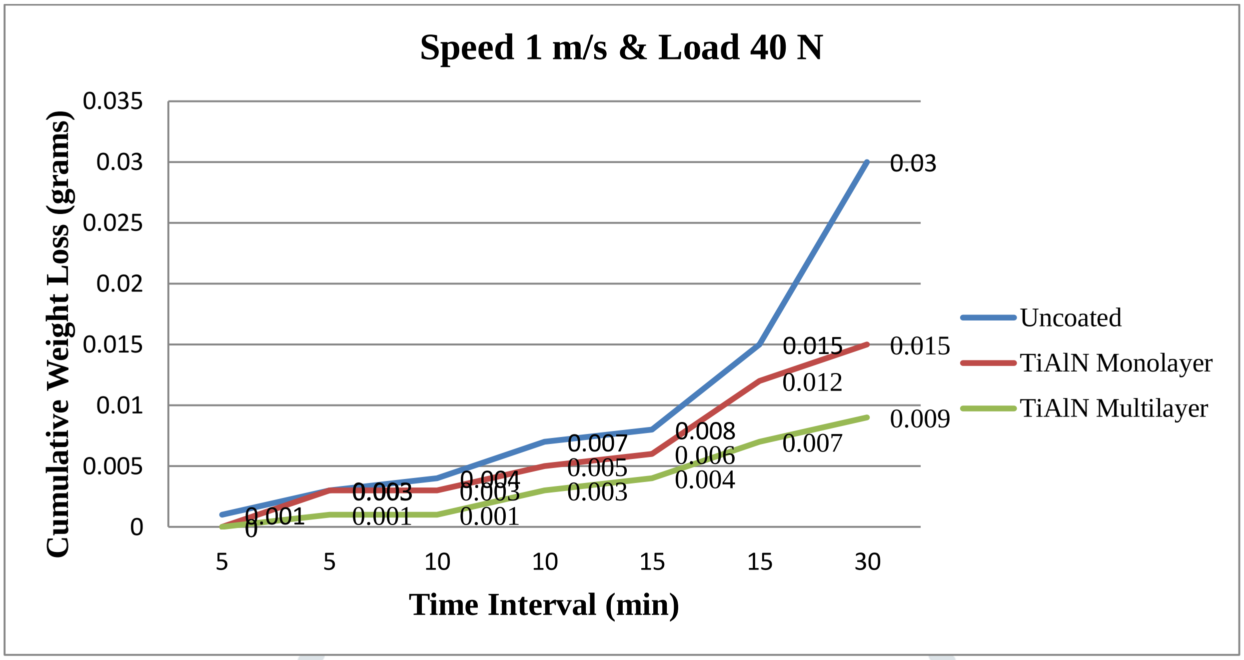

Fig 4(c)

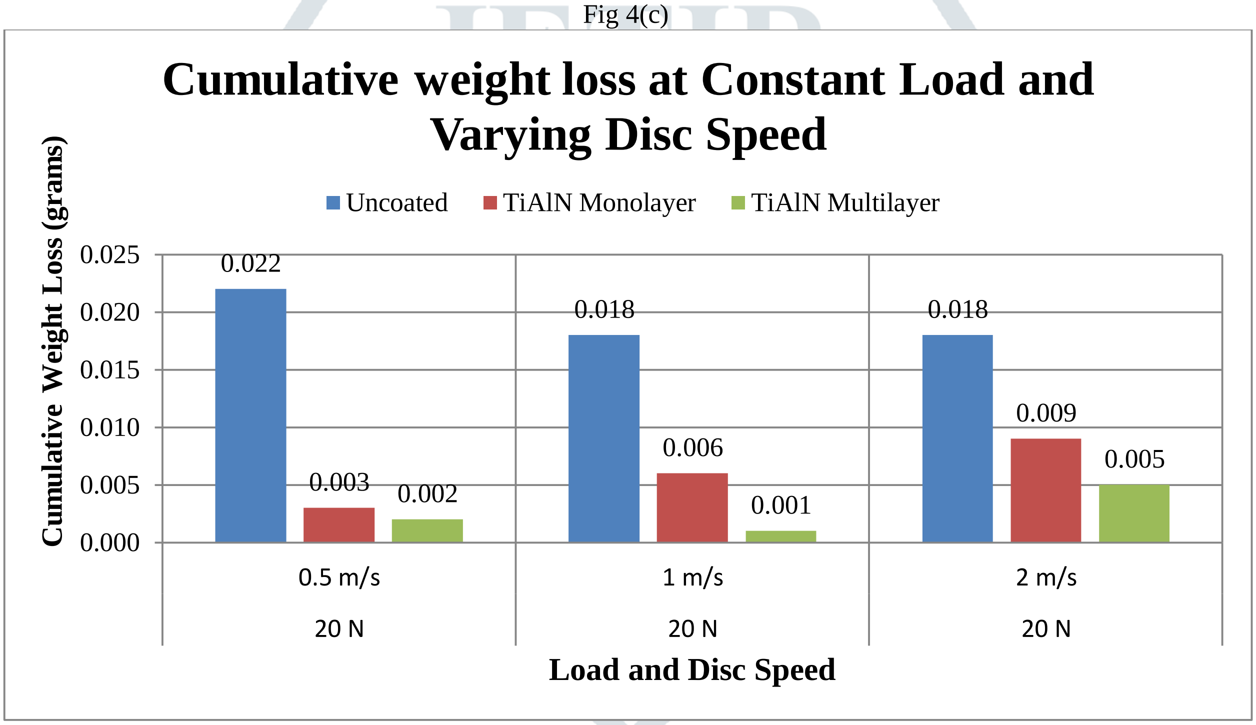

Fig. 5: Comparative Cumulative weight loss

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In fig. 5, Cumulative Weight loss (CWL) bar charts are drawn, for varying load at constant sliding velocity, in one time cycle (90 min) for each coating and EN-19 substrate. It is also noted that uncoated substrate has more CWL than coated samples.

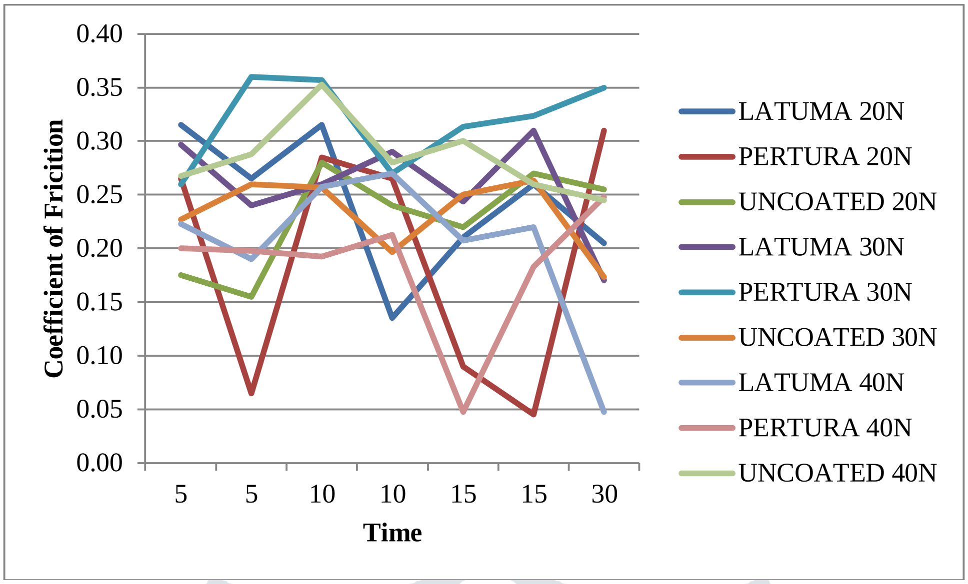
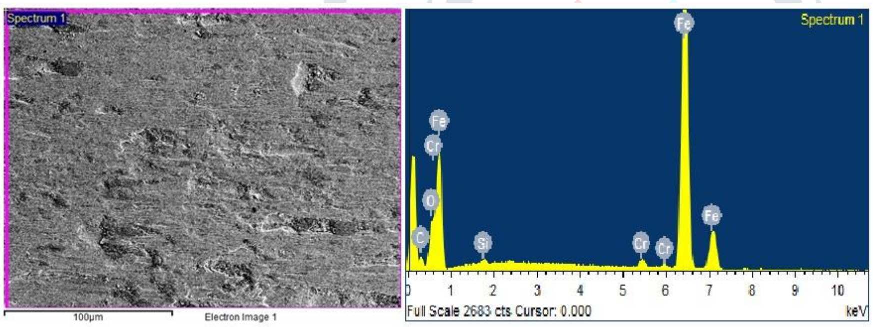


Fig. 6(a): Friction coefficient as a function of time

In fig. 6, it is observed that the TiAlN multilayer coating have less coefficient of friction (COF) as compared to TiAlN monolayer coating and uncoated samples. Very erratic behavior of COF has been seen as it depends upon surface conditions of samples.

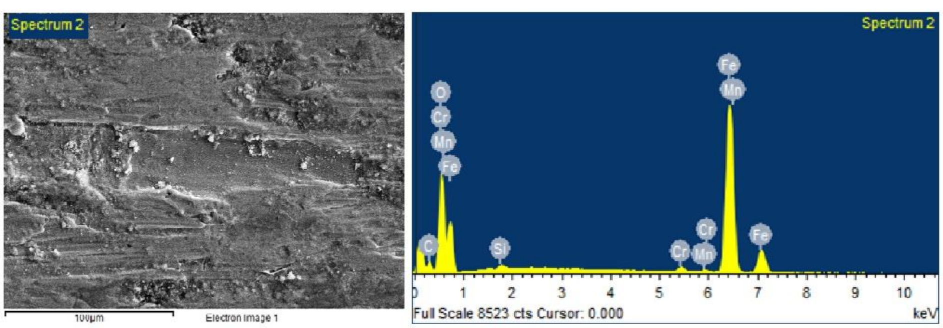
4.5 SEM/EDAX of Worn out Specimens

Worn out sample are inspected with assistance of SEM/EDAX. Figure 7 (a) to (o) indicates SEM micrographs of Uncoated, monolayer and multilayer worn specimens at 100X concerning varying load i.e. 20 N, 30 N and 40 N and steady sliding speed of 1 m/s.



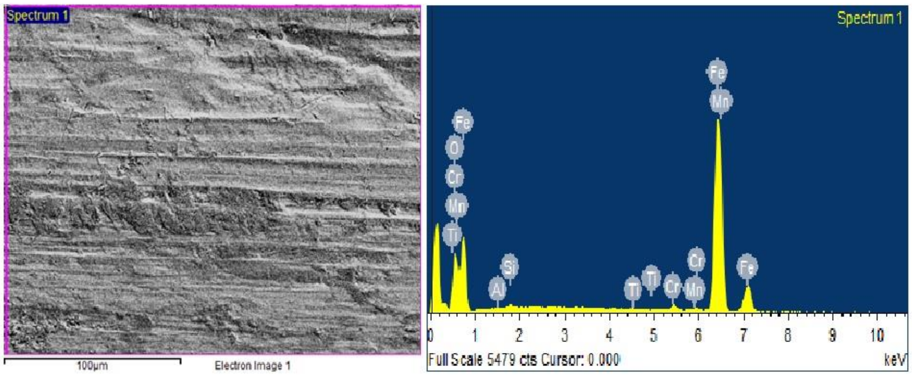
Element	Weight%	Atomic%
C K	2.89	10.32
O K	7.72	20.66
Si K	0.58	0.88
Cr K	1.40	1.15
Fe K	87.40	66.99
Totals	100.00	

Fig 7 (a): - Uncoated specimen at 20N load and 1 m/s



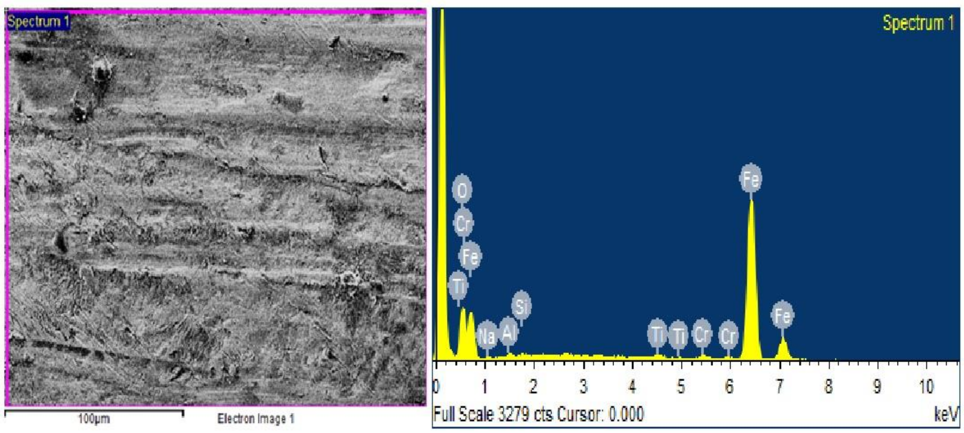
Element	Weight%	Atomic%
C K	7.05	17.37
O K	25.01	46.27
Si K	0.58	0.61
Cr K	1.02	0.58
Mn K	0.49	0.26
Fe K	65.86	34.91
Totals	100.00	

Fig 7(b): - Uncoated specimen at 30N load and 1 m/s



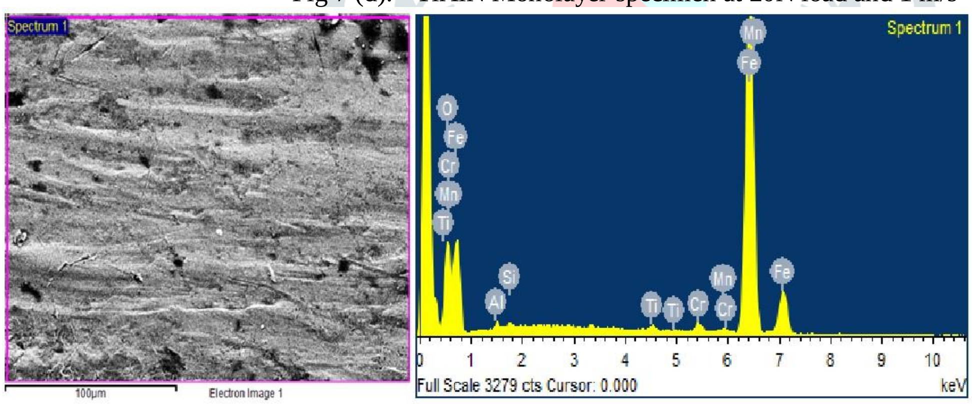
Element	Weight%	Atomic%
O K	15.16	38.22
Al K	0.16	0.24
Si K	0.42	0.60
Ti K	0.03	0.03
Cr K	1.27	0.99
Mn K	0.62	0.45
Fe K	82.35	59.48
Totals	100.00	

Fig 7 (c): - Uncoated specimen at 40N load and 1 m/s



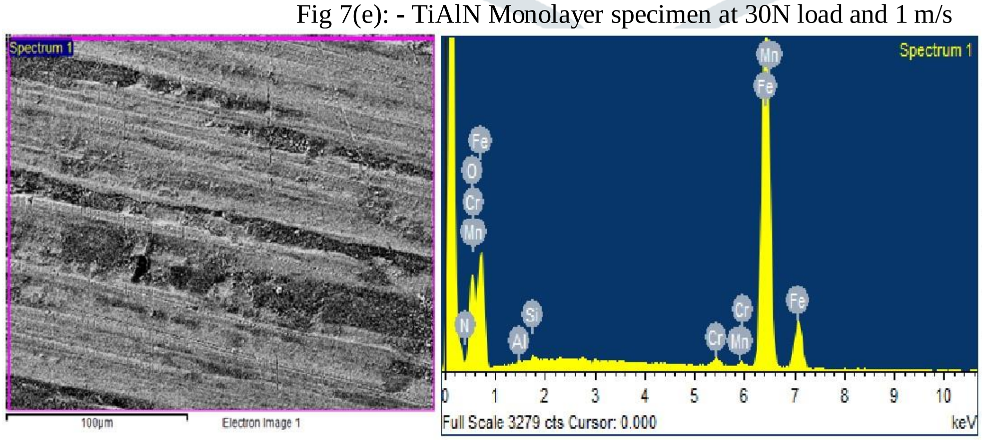
Element	Weight%	Atomic%
O K	18.59	43.40
Na K	1.16	1.89
Al K	1.01	1.39
Si K	0.31	0.41
Ti K	0.59	0.46
Cr K	0.81	0.58
Fe K	77.53	51.86
Totals	100.00	

Fig 7 (d): - TiAlN Monolayer specimen at 20N load and 1 m/s



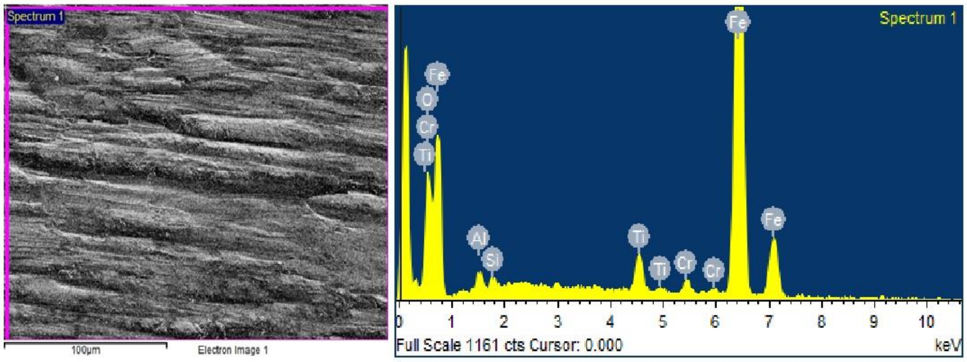
Element	Weight%	Atomic%
O K	16.83	41.04
Al K	0.63	0.91
Si K	0.39	0.54
Ti K	0.53	0.43
Cr K	1.20	0.90
Mn K	0.60	0.42
Fe K	79.82	55.75
Totals	100.00	

Fig 7(e): - TiAlN Monolayer specimen at 30N load and 1 m/s



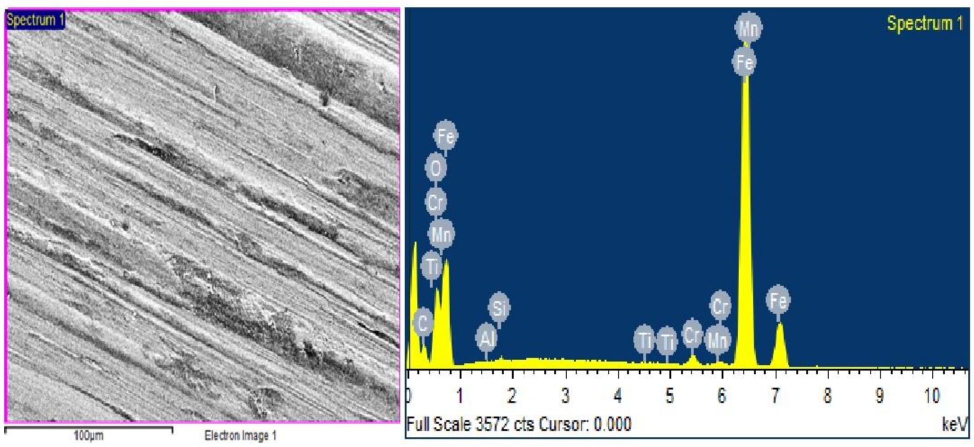
Element	Weight%	Atomic%
N K	3.96	10.12
O K	17.47	39.11
Al K	0.15	0.20
Si K	0.35	0.45
Cr K	0.95	0.65
Mn K	0.60	0.39
Fe K	76.52	49.08
Totals	100.00	

Fig 7(f): - TiAlN Monolayer specimen at 40N load and 1 m/s



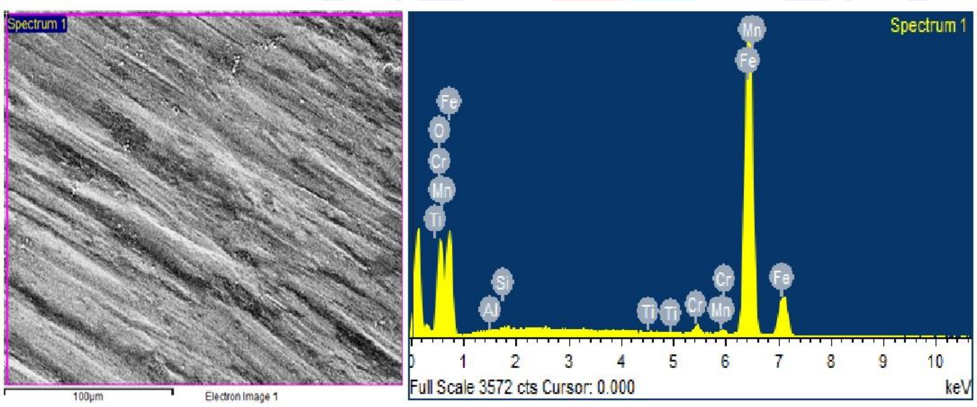
Element	Weight%	Atomic%
O K	14.92	37.22
Al K	1.37	2.03
Si K	0.69	0.98
Ti K	3.20	2.67
Cr K	1.42	1.09
Fe K	78.39	56.01
Totals	100.00	

Fig 7 (g): - TiAlN Multilayer specimen at 20N load and 1 m/s



Element	Weight%	Atomic%
C K	4.70	14.63
O K	12.79	29.84
Al K	0.07	0.09
Si K	0.34	0.46
Ti K	0.13	0.10
Cr K	1.26	0.90
Mn K	0.59	0.40
Fe K	80.12	53.57
Totals	100.00	

Fig 7 (h): - TiAlN Multilayer specimen at 30N load and 1 m/s



Element	Weight%	Atomic%
O K	15.74	39.28
Al K	0.16	0.23
Si K	0.42	0.59
Ti K	0.03	0.02
Cr K	1.26	0.97
Mn K	0.78	0.57
Fe K	81.62	58.34
Totals	100.00	

Fig 7(i): - TiAlN Multilayer specimen at 40N load and 1 m/s

After examining SEM micrographs and EDAX reports, it was found that uncoated specimens have larger worn out area and wider spots were located. There were small traces of debris from counter sliding member. From fig 7(a) to (c), the uncoated specimens SEM micrographs and EDAX are shown in order to varying load and constant sliding velocity. Similarly from 7(d) to (f) are micrographs for monolayer coatings and from 7(g) to (i) for Multilayer coatings. When the micrograph of multilayer and monolayer coatings was examined then there was seen that small crest and troughs on the worn out surface. On studying EDAX image, it was found that coating elements was covered by Fe element near about 68 % to 82% and very small amount of Ti and Al was seen on surface. Presence of Fe, Mn and O means the coating are protected but wore out sliding member, which is clearly mean that debris are deposited on coated surfaces. The presence of O on top surface means that there is possibility of presence of Titanium oxide or aluminum oxide.

V. CONCLUSION

TiAlN (monolayer and multilayer) coatings were studied in this paper, which were deposited on EN-19 substrate by PVD magnetron sputtering process. Wear and friction properties were studied using tribological (Pin-on-Disk) method at alternate parameters. The following results and conclusions were recorded.

- The coatings were successfully deposited uniformly all over EN-19 substrate. The thickness of coating was in the range of 3-10 µm.
- The surface roughness found to be in the following order: Uncoated > TiAlN multilayer > TiAlN monolayer.
- The present work shows that the cumulative weight loss is in the following order: TiAlN multilayer < TiAlN monolayer < uncoated EN-19.

- SEM/EDX analysis shows that multilayer and monolayer coating had better surface properties than uncoated substrate.

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