Effect of Surface Treatment and Physical Vapour Deposition on Mechanical Properties of AISI4140 Steel

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Abstract- *In the present study, samples made of AISI4140 steel, pretreated with Plasma Nitriding (PN) and coated with coatings like Aluminium Chromium Nitride (AlCrN), Aluminium Titanium Nitride (AlTiN) and Chromium Nitride (CrN) using Physical Vapour Deposition (PVD) technique, were investigated in terms of their dry and wet sliding wear behaviour. Wear tests were performed with pin-on-disc machine .The properties of AlCrN, TiAlN and CrN coating were evaluated by impact, wear and compression testing.*

The result showed that among coated material, CrN coated AISI 4140 steel which is pretreated with nitriding followed by micro blasting and post treated by micro blasting has shown maximum compressive strength and %rise in maximum compressive strength with respect untreated AISI4140 steel sample. CrN material has shown maximum rise in toughness. COF increased with increasing load as well as sliding distance. Hence pretreatment with nitriding shows improvement in machining performance with improved coating adhesion and wear resistance.

Keywords- AISI4140 Steel, AlCrN, AlTiN, CrN, Electron Diffraction Spectrum (EDS), Plasma Nitriding Scanning Electron Microscope (SEM).

I. INTRODUCTION

THIS work has been conducted to investigate of the performance of forming tool with micro blasting as pretreatment and to investigate the influence of Plasma Nitriding with different low friction coating on AISI4140 steel. AISI4140 steel is high strength medium carbon, low alloy steel. It shows positive response to all variety of heat treatments [1]. Purpose of heat treatments is improved alter mechanical properties of tool steel and to obtain improved properties such as hardness, toughness, elasticity, and ductility.AISI4140 steel is currently material has great interest in automotive machining application. AISI4140 steel is extensively used manufacturing of various parts connected with increasing demand on higher productivity which required for tool property improvements. However there is requirement in forming industries for improvement of tribomechanical properties of forming tool steel. Manufacturing of different parts and components like conveyor rolls, hydraulic machinery shaft, connecting rods hollow shafts axels, forming dies, ejectors, crankshaft , trim dies and guides for such applications AISI4140 material used in metal forming industries [2].

In metal forming process different applications were used for fixing on tool and machine for achieving finished components from that we choose punching and blanking operation. The load experienced by punching and dies is sudden impact on the edges of punch and die. Hence there is requirement of structurally very strong tool which can sustain normal and shearing load which is applied to their surfaces [1-2].

Tribological applications using nitriding and coating are effective and economical techniques to reduce friction and protect the surface from wear. Tribological properties of coating significantly affected due to oxidation behavior of wear mechanism and debris removal behavior of coating. Service life of critical components can be affected due to micro pitting; scuffing mode which leads to mechanical failures when component can be affected due to harsh environment [3].

Adnan Calik [4] studied the effect of coating rates on microstructure and mechanical properties of AISI1020, AISI 4140 and AISI 1060 steel. These material samples were heated and treated at 1250˚k for 4h and cooled with different methods and observed that microstructure of steel can be changed and significantly improved by varying the cooling rates for achieving wear resistance.

Abhishek Sharma et.al [5] studied Plasma nitriding process on AISI4140 steel and observed surface hardness increases after plasma nitriding which gives greater diffusivity at higher temperature. Coating and nitriding has great influence in case of surface engineering i.e in surface treatments. PVD hard coating provided high hardness and high tribological properties. However there is no guarantee that only PVD coating gives optimal tribological performance without pretreatment with nitriding because plastic deformation is main reason of failure of coating substrate.

Zegni et.al [6] studied the effect of coating and nitriding on wear behavior of AISI D3 steel coated with TiC, TiN and Al_2O_3 experimentally. They observed wear resistance using Vikers hardness test. The Al_2O_3 and TiN coatings out-performs TiC coating because both coatings were pre - nitrided. Salt bath nitriding is one of the best methods of nitriding which gives significant improvement in wear resistance [7].

J. L. Mo et.al [8] studied the properties of CrN, AlCrN and AlTiN coating deposited on cemented carbide substrate by multi arc Physical Vapour Deposition technique and result observed by cyclic impact wear and microscale abrasion and they concluded that the AlTiN coating showed more abrasive wear as compared to AlCrN. They also studied sliding tribological behavior of PVD CrN and AlCrN coating against Si_3N_4 ceramic and pure titanium and the wear scar of coating observed under surface profilometer Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy [EDX]. Results showed that AlCrN coating has significant improvement in removal of wear as compared to CrN coating.

Mustafa Ulutan et.al [10] studied surface treatments and their effects on friction and wear behavior on AISI4140 steel quenching, carburizing and boronizing treatments, were performed on samples and after surface treatment microstructure study was done with the help SEM and optical microscopy and they observed that the carburized sample shows lowest weight lost and lowest coefficient of friction .

Eventually it has been observed that various works has been carried out on tribologial performance of different coated tool steel. The effect of niriding, microblasting, coating (AlCrN, AlTiN, CrN) comparison with untreated AISI4140 steel has not been studied yet, so in this paper are efforts can made for improving tribological as well as mechanical properties means for improving life of forming tool material AISI4140 steel.

II. OBJECTIVES

1. To investigate mechanical characteristics such as impact strength and compressive strength of pretreated coated AISI 4140 steel.
2. To investigate Tribological characteristics such as wear behavior of AISI 4140 steel.
3. To compare results of mechanical and tribological tests of pre treated and coated material.
4. To decide best suitable tool for forming tool application.

III. MTHODOLOGY

i. Literature Review
ii. Problem Defination
iii. Selection of material
iv. Preparation of specimen
v. Mechanical characterization – Impact and Compression
vi. Tribological characterization – Wear volume and Coefficient of friction.

IV. MATERIALS AND METHODES

AISI4140 steel grade is a versatile steel grade. This steel is used for increase speed; enlarge tool life without affecting mechanical properties hence it can improve machinability. Further hardness of 4140 steel can be improved by applying flame or by nitriding process chemical composition of AISI 4140 steel is shown Table I.

TABLE I

Chemical Composition Of AISI4140 Steel

Element	AS PER GRADE SPECIMEN	Observed values
C	0.35-0.45	0.417
Si	0.10-0.35	0.23
Mn	0.45-0.90	0.83
P	0.05 max	0.02

AISI4140 Material was selected because this steel is having ability of not losing its toughness even after nitriding. The material sample is bar of 8 mm diameter and 30 mm in height. The ends of specimens were polished till getting roughness 4μm as indicated standard, ASTM G99-04. The materials used in present study and notations are presented in table II.

TABLE II

Material Notation

Material	NOTATION
Untreated	UN
Nitriding	N
Nitriding+Microblasting	N-B

A. *Nitriding*

Nitriding is nothing but case hardening techniques in which steel can be heated at temperature range between 450-600˚c. In this process nitrogen diffused on the surface of substrate which forms nitrides compound layer that provides high wear resistance properties. Chemical composition of the surface substrate gets changed during nitriding process which is carried out at medium temperature. Hence this process is known as thermo-chemical process. Based on medium used to provide nitrogen, nitriding process can be classified gas nitriding, plasma nitriding, pack nitriding and salt bath nitriding in present work; we have used plasma nitriding techniques for pre treatment on AISI4140 steel. Plasma discharge technology was used for plasma nitriding at lower temperature to introduce nascent nitrogen on surface of steel. During process high voltage electrical energy formed in vacuum. Then Nitrogen ions can be impinged on work piece which connected as cathode bombardment of ion results in heating the work piece, cleans surface and provides nitrogen for diffusion in to the steel material.

B. *Microblasting*

Abrasive blasting is a process in which process small nozzles (i.e.0.25mm to 1.5 mm dia) used for providing fine stream of abrasive accurately to a small part or a small area on large part. Mostly blasted area 1 mm^2 to few cm^2 at most. This blasting is called pencil blasting. The fine jet of abrasive blasting was accurate enough to write directly on glass and delicate enough to cut a pattern in an egg shell. Particle size contain abrasive media is from 10 micrometers up to 150 micrometers often it requires higher pressure. Commercial bench mounted unit are most commonly used micro abrasive system consisting of a power supply and mixture, exhaust hood, Nozzle and gas supply. The Nozzle can be automatically operated which is fixture mounted or handheld. It beings is essential to remove the white or melting zone from mould surface. Micro blasting technique used for the purpose improving the surface roughness according to VDI Norms 3400 prescriptions, for example from class 21 to class 18.It is possible to achieve surface roughness values of less than 0.5µm hrms can be achieve. The greater benefit is smoothening time required by the spark erosion machine as well as an impeccable further surface treatment without use of conventional tools using micro blasting equipments. Removing surface impurities is possible in an optimal manner caused by spark erosion size mainly affected to surface treatment; it is possible to blast away the white zone of various thicknesses within minutes without removing the corners and edges, while entirely preserving the tolerances in respect of dimensions and form. By applying mould making techniques, excellent rationalization effect can surely be achieved. Every tool manufacture should always measure the effectively eroded dimension exclusive of white zone. Various factors can be affected to micro blasting process like Air pressure, powder flow rate, nozzle size, Angle of contact etc.

C. *Coating*

In surface engineering, including surface treatments and coating is effective as well as flexible solution for tribological problems coating results including residual compressive stresses, decreasing the friction coefficient, increasing the surface hardness, altering the surface chemistry changing the surface roughness. Tribological behavior of coating system depends on many factors i.e. coating properties, counterparts, substrate interface and running conditions hence it is still difficult and complicated to choose appropriate coating for proper applications. There is no any particular rule for selection of coating. Additionally, many new deposition techniques and new coatings are being continuous are developed. In this work CrN, AlCrN and AlTiN coatings can be selected for investigation. Their behavior can be examined with respect to untreated AISI4140 steel material.

V. MECHANICAL CHARACTERISATION

In present work, following mechanical characteristics have been evaluated.

A. *Impact test*

A special dynamic loading in which sudden load is applied on specimen is called impact. Due to sudden load, fracture of sample takes place, this helps to study the resistance of material to sudden fracture. For such study notch impact test are widely used. In this test, the energy required to produce a rupture is determined to exhibit relative tendency of brittleness. Charpy and Izod test are mostly used in impact test.

1) Specimen Preparation

Izod specimen are machined with sq. 10X10 and length 75mm with V notch of angle 45 and depth of 2mm at 28mm from left face with notch radius 0.025mm using ASTM E23- 02a. The Izod specimens are shown in figure I. The specimens are nitrated and PVD coated with AlCrN, AlTiN and CrN with the thickness of 4 micron.

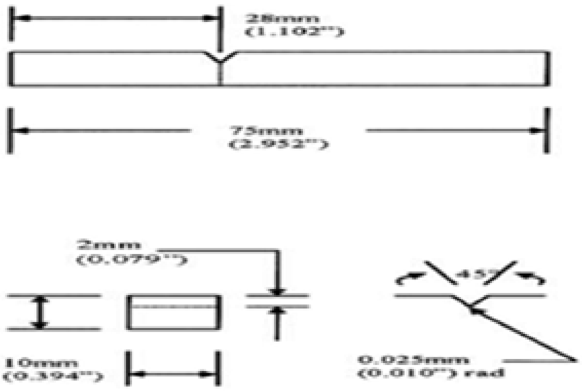


Fig. 1. Izod Specimen before test

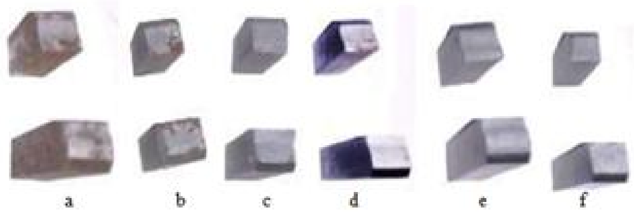


Fig. 2. Specimen after Izod test a) UN, b) N, c) N-B, d) N-B-AlCrN, e) N-B-AlCrN-B f) N-B-AlTiN, g) N-B-AlTiN-B, h) N-B-CrN i) N-B-CrN-B

B. Compression test

In mechanics, compression is the application of balanced inward ("pushing") forces to different points on a material or structure, that is, forces with no net sum or torque directed so as to reduce its size in one or more directions. It is contrasted with tension or traction, the application of balanced outward ("pulling") forces; and with shearing forces, directed so as to displace layers of the material parallel to each other. The compressive strength of materials and structures is an important engineering consideration.

In uniaxial compression the forces are directed along one direction only, so that they act towards decreasing the object's length along that direction. The compressive forces may also be applied in multiple directions; for example inwards along the edges of a plate or all over the side surface of a cylinder, so as to reduce its area (biaxial compression), or inwards over the entire surface of a body, so as to reduce its volume.

1) Specimen Preparation

The compression test specimens are prepared as per ASTM standard ASTM E9 89a by machining length 60 mm and diameter 20 mm with the ration of L/D equals to 3, as shown in Fig. 3.

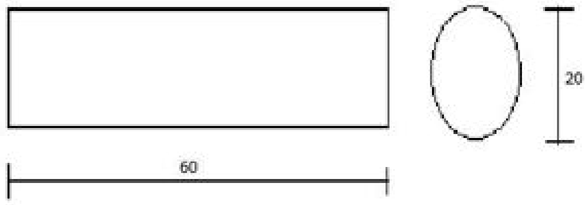


Fig.3. Compression test specimen (ASTM, E8-04, (2004) [11]

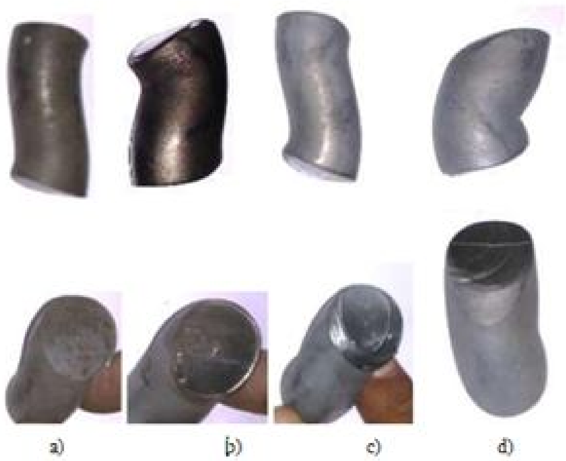


Fig. 4 Specimen after Compression test

a) N, b) N-B, c) N-B-CrN d) N-B-CrN-B

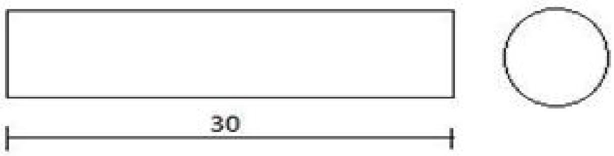


Fig.5. Wear test specimen

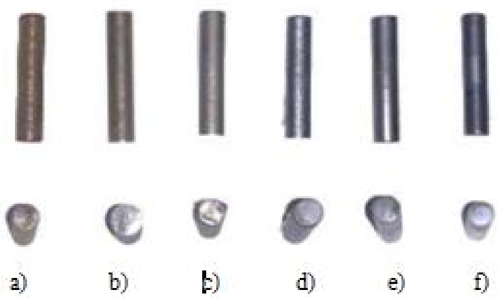


Fig. 6 Specimen after Wear test a) UN, b) N, c) N-B, d) N-B-AlCrN, e) N-B-AlCrN-B f) N-B-AlTiN

VI. TRIBOLOGICAL CHARACTERIZATION

A. *Wear test*

In the field engineering, wear is the most important consideration. Wear appears due to relative motion between two surfaces. Surface wear generally observed at outer surface of specimen. It is more effective and economical to make surface modification of existing alloy than using the wear resisting alloy. In this work, we have analyzed wear behavior of AISI4140 steel material with the help of wear testing machine. Wear can be measured by using Pin on Disc method, where pin on disc tribometer is equipment used to determine the sliding friction coefficient and wear resistance of surfaces. Wear of pin or disc can be tested with the help of pin- on- disc tester in which pin is stationary and disc rotates under applied load. The sample preparation and test procedure are carried as per ASTM G99 04 [11].

1) Specimen Preparation

The sample used in the experiment is a mid-carbon low alloyed AISI 4140 improve steel. The substrate is first machined and then finished with surface roughness of 0.4 micron. Then the Nitriding process is carried out on the substrate specimen. . After Nitriding process, micro blasting is done then various low friction coating materials are coated on the substrate by using Physical Vapour Deposition method, with Low friction coating materials like AlTiN, CrN, AlCrN.

VII. RESULT AND DISCUSSION

A. *Impact test*

In Izod impact test, specimen is placed as simply supported beam and the striker is released from 130˚, when stiker is released the specimen absorbs the impact strength of striker. As the impact strength of nitrided and coated specimen is more as compared to AISI4140 steel. The impact strength is indicated by the pointer with graduated scale and the lever is used to stop the motion of striker after the striker strikes the specimen which has simply supported orientation. Results indicate that as bought condition seems to have the energy absorbed by UN nitrided material is minimum and it increases after nitriding process as shown in Table III

TABLE III
ENERGY ABSORBED BY IZODE TEST

Sr. No	Category	Energy absorbed in Izod test [J]
1	UN	35.5
2	N	40.5

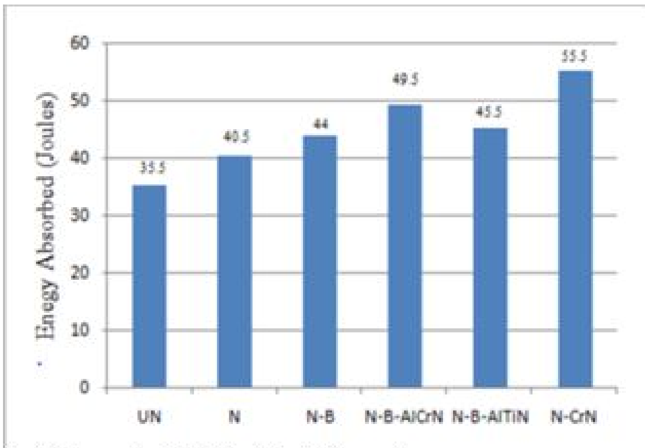


Fig. 7 .Energy absorbed in Izode test in bar graph.

The energy absorbed by un-nitrided material is 35 joule which is minimum. It is increased to 40 joule after nitriding process and further reached a value 44 joule. The energy absorbed by material after AlCrN coating is 49 joule and is further increased to 53 joule after post treatment. The energy absorbed by material after AlTiN coating is 45 joule and is further increased to 52 joule after micro-blasting. The energy absorbed by material after CrN coating is 55 joule which is maximum and is further increased to 60 joule.

The effect of surface treatment and different coating on impact specimen can be observed in the below given microstructure images. Fig 8 depicts SEM image of the

Untreated AISI 4140 steel. It shows abrasive wear mechanism. Fig 9 shows SEM micrograph of nitride-micro-blasted AISI 4140 steel which indicates very smooth surface without micro cracks as compared to micrograph of AlCrN and AlTiN. EDX spectrum of cross-section of nitrided 4140 indicates formation of fe_3N and Cr-N on the surface that clearly indicates the presence of nitrogen. Fe and Cr composition was found to be 96.86% and 1.04%, respectively, in addition to the presence of nitride layer as shown in Fig 12.

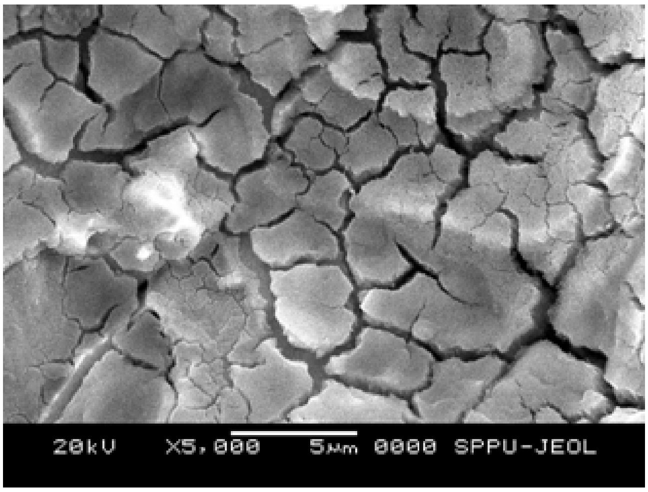


Fig.8. Fig SEM Micrograph of Uncoated Nitrided AISI

Fig.8. Fig SEM Micrograph of Uncoated Nitrided AISI 4140 steel.

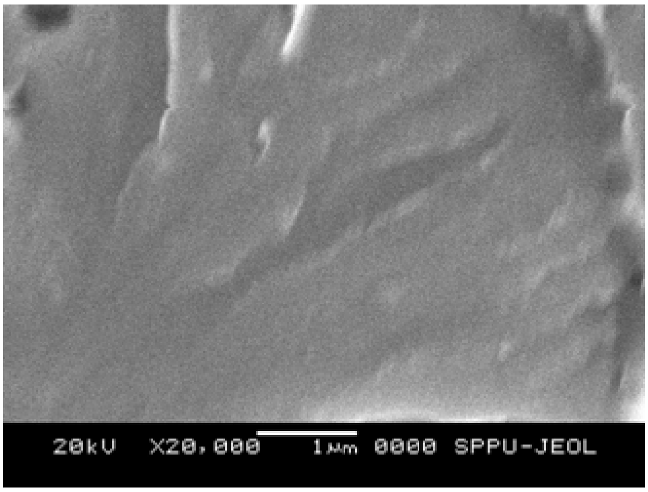


Fig. 9 . SEM Micrograph of Nitriding, Microblasting AISI 4140 steel.

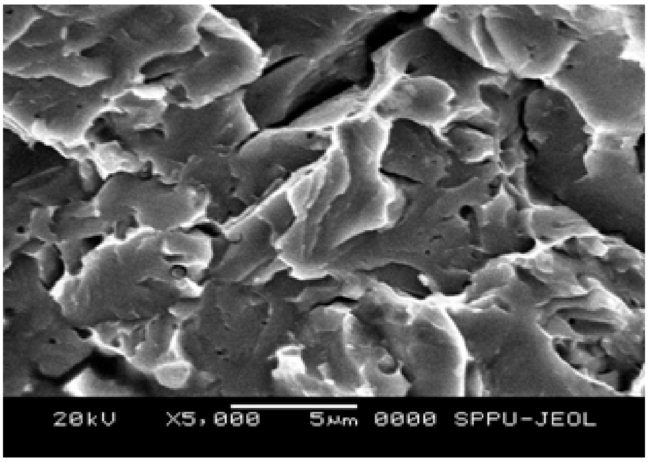


Fig. 10. SEM Micrograph of Nitrided ,micro blasting AlCrN AISI 4140

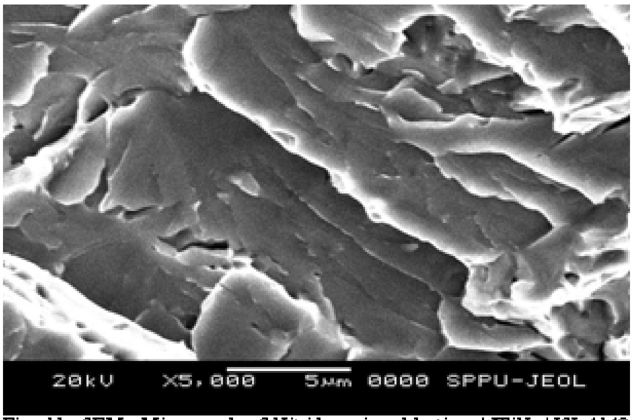


Fig. 11. SEM Micrograph of Nitride ,micro blasting AlTiN AISI 4140 steel

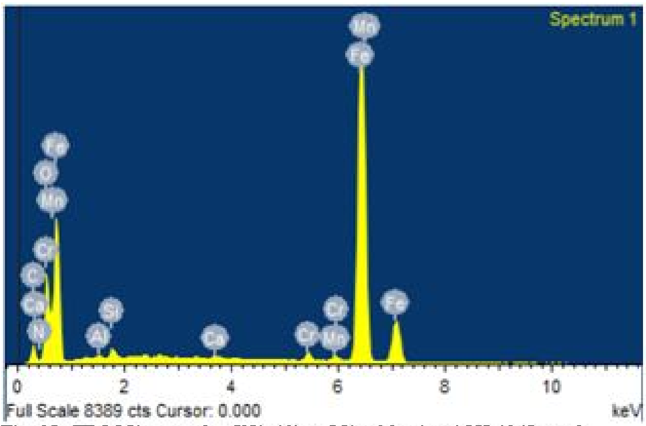


Fig. 12. EDS Micrograph of Nitriding, Microblasting AISI 4140 steel

B. *Compression test*

TABLE IV
COMPRESSIVE STRENGTH AND %RISE WITH RESPECT TO UN

Sr. No	Category	Failure load KN	Compressive Strength N/mm²	% rise in Compressive Strength
1	UN	266.5	848.30	-
2	N	272	865.80	40.93
3	N P	275	[illegible]	84.30

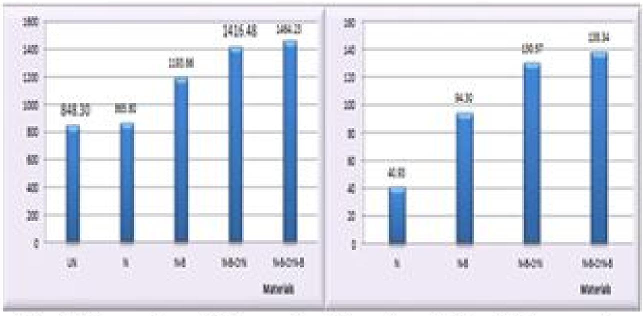
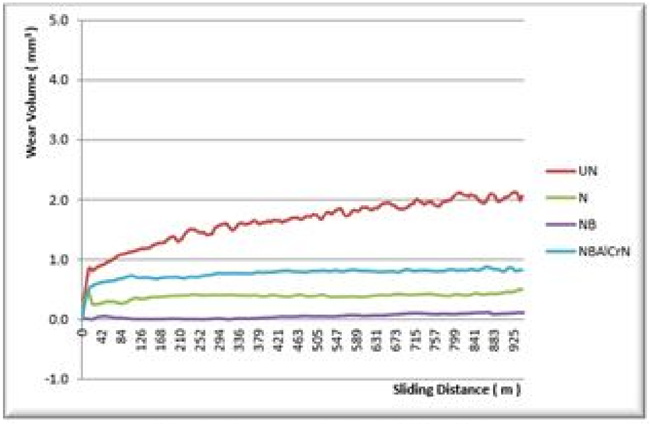


Fig. 13. Comparison of Compressive Strength and% rise in Compressive Strength for pre and post treated CrN

The compression strength of un-nitrided material is minimum. It is increased somewhat after nitriding. The compressive strength of material is improved due to micro-blasting and well increased after CrN coating. The compressive strength of N-B-CrN-B material is maximum and is equal to 1464.23 N/mm^2.

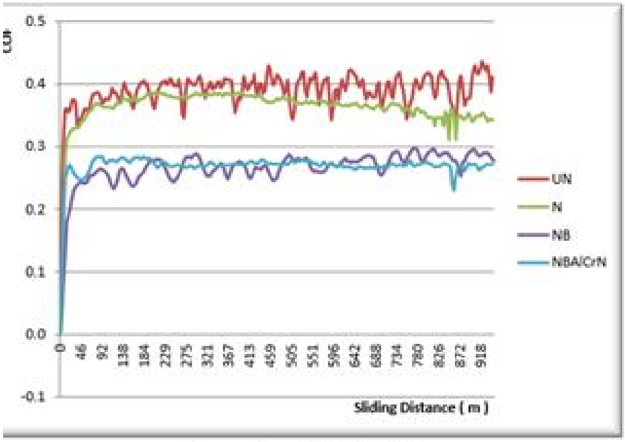
C. Wear test

Figures 14 to 19 show wear test results of various specimens.



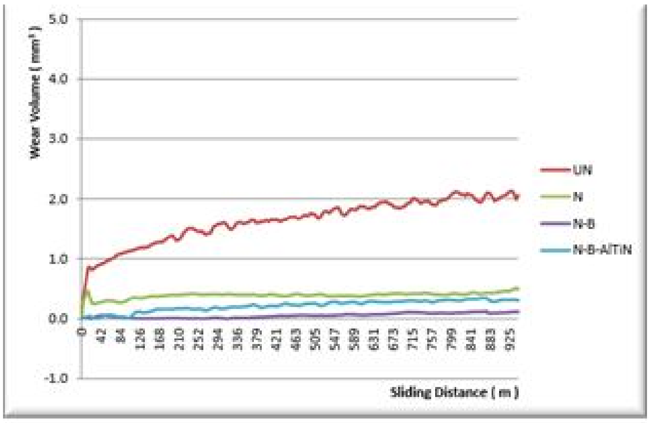
Wear volume comparison for 19.62 N, 950 m

Fig. 14.Wear Volume comparison for AlCrN



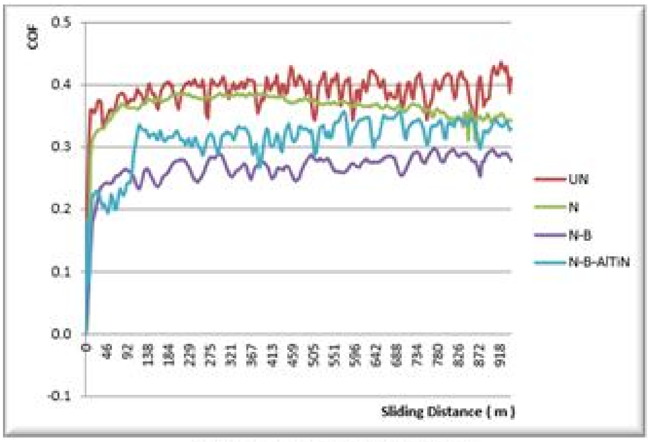
COF comparison for 19.62 N, 950 m

Fig. 15.COF comparison for AlCrN



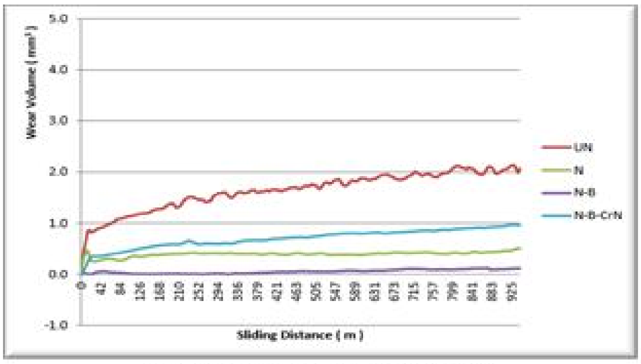
Wear volume comparison for 19.62 N, 950 m

Fig. 16. Wear Volume comparision for AlTiN



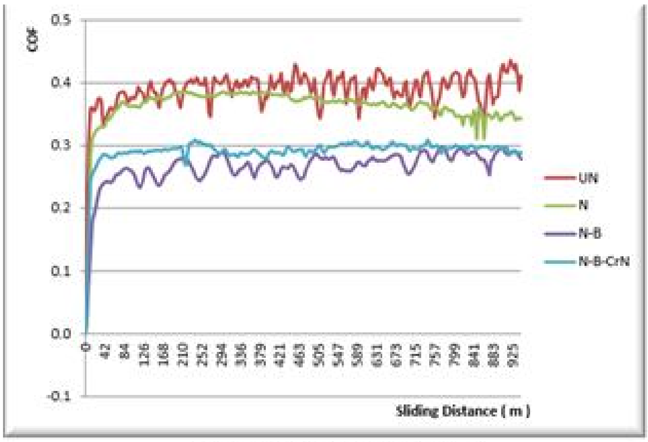
COF comparison for 19.62 N, 950 m

Fig. 17. COF comparision for AlTiN



Wear volume comparison for 19.62 N, 950 m

Fig. 18. Wear Volume comparision for CrN



COF comparison for 19.62 N, 950 m

Fig. 19. COF comparision for CrN

By comparing above results we can observe that COF increased with increasing load and sliding distance. It is observed that nitriding followed by microblasting finally results in lower COF value. Among all coated materials, AlCrN coated AISI 4140 steel which is pretreated with nitriding followed by microblasting and post treated by microblasting has shown best performance. The effect of surface treatment and different coating on impact specimen can be observed in the below given microstructure images.

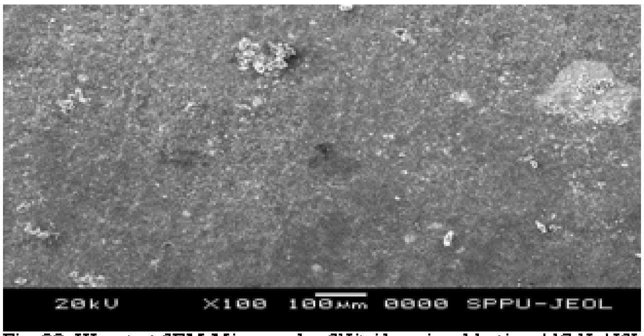


Fig. 20. Wear test SEM Micrograph of Nitride ,micro blasting AlCrN AISI 4140 steel

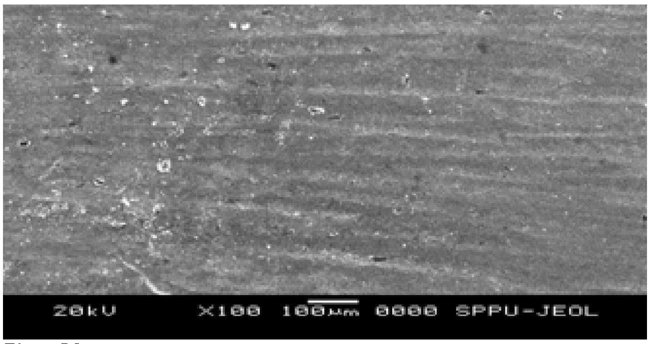


Fig. 21. Wear test SEM Micrograph of Nitride ,microblasting AlTiN AISI 4140steel

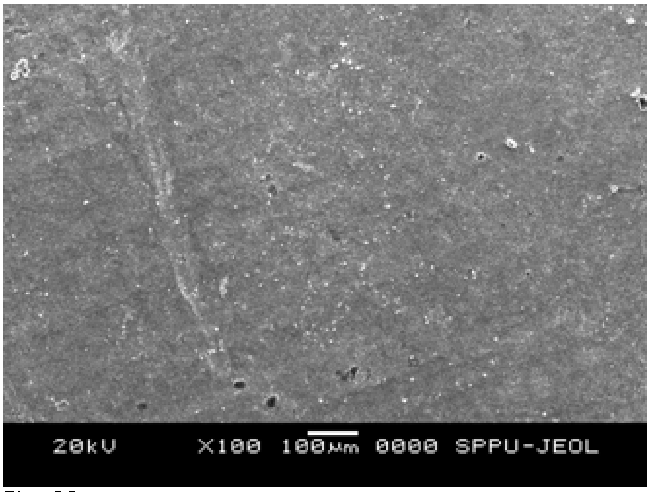


Fig. 22 Wear test SEM Micrograph of Nitride, microblasting CrN AISI 4140 steel

SEM micrographs of treated coated samples clearly indicate very smooth and homogeneous surface which has resulted in very low COF and wear as shown in Fig. 21-23.

VIII. CONCLUSION

In this work, various mechanical and tribological tests were conducted with different types of the coating materials. The tests were conducted on materials by varying load. Following conclusions are drawn.

1. It has been observed that the above tests provided considerably useful and informative results. Among the investigated materials, pre-nitrided and micro blasted CrN coated AISI 4140 steel has shown maximum compressive strength of 1464.23 N/mm^2 and 138.34 % rise in compressive strength as compared to untreated sample.
2. The energy absorbed by untreated steel is 55 J which is improved after CrN coating. It increases up to 60 J
3. From observation it has been concluded that COF has increased with increasing load as well as sliding distance.

4. Among the investigated materials, pre-nitrided and micro blasted CrN coated AISI 4140 steel has been found to be the best suitable coating material.

REFERENCES

[1] Gurumurthy, S. S. Sharma, Gowrishankar, Sowmith, Abhishek and Abhishek Devar," Study of Mechanical Properties of Dual Phase EN19 Steel (AISI4140)",Indian Journal of Science and Technology, Vol 9(37), October 2016,1-6

[2] Santosh V. Bhaskar1. Hari N. Kudal2 ," Investigation of Tribological Behaviour of Nitrided and Coated AISI 4140 Steel " , Journal of Materials Science & Surface Engineering, 5(5), 627-632

[3] Zhichaoliu ,Weillong cong, hoyeol kim, Fuda Ning,Qiuhong Jiang,Tao Li, Hong-cho Zhang and Yingge Zhou, "Feasibility Exploration of Super alloys for AISI4140 steel Repairing using Laser Engineered Net shaping",Procedia Manufacturing 10(2017) 927-632.

[4] Adnan Çalik, "Effect of cooling rate on hardness and microstructure of AISI 1020, AISI 1040 and AISI 1060 Steels", International Journal of Physical Sciences Vol. 4 (9), pp, September, 2009. . 514-518 .

[5] Abhishek Sharma , K. C. Swami, " A Study of Plasma Nitriding Process on the AISI 4140 Steel ",Journal of Materials Science & Surface Engineering Vol. 1 (3), 2014, pp 81-83

[6] A.E. Zeghni, M.S.J. Hashmi , "The effect of coating and nitriding on the wear behaviour of tool steels ", Journal of Materials Processing Technology155–156 (2004) 1918–1922

[7] J.L. Mo , M.H. Zhu , A. Leyland , A. Matthews, " Impact wear and abrasion resistance of CrN, AlCrN and AlTiN PVD coatings", Surface & Coatings Technology 215 (2013) 170–177

[8] Mustafa Ulutan, Osman N. Celik, Hakan Gasan and Umit Er, "Effect of Different Surface Treatment Methods on the Friction and Wear Behavior of AISI 4140 Steel ",J. Mater. Sci. Technol., 2010, 26(3), 251-257.

[9] J.L. Mo, M.H. Zhu, "Sliding tribological behaviors of PVD CrN and AlCrN coatings against Si3N4ceramic and pure titanium", Wear 267 (2009) 874–881.

[10] Mustafa Ulutan, Osman N. Celik, Hakan Gasan and Umit Er, "Effect of Different Surface Treatment Methods on the Friction and Wear Behavior of AISI 4140 Steel", J. Mater. Sci. Technol., 2010, 26(3), 251-257.

[11] Standard Test Method for Wear Testing with a Pin-on-Disk Appratus.