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Characterization of Multilayer Nano-coating of Piston Ring

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Abstract. Nano-structured coatings can be used to reduce surface roughness, improved hardness and to protect against wear of the components. In this, research article the AISI 440C Stainless Steel is considered for coating Nano-particles and different materials such as Nickel, Titanium dioxide and Aluminium dioxide. The deposition of Nano-particles on piston ring by physical vapor deposition (PVD) process namely Electron Beam physical vapor deposition (EB-PVD). The surface morphology and crystallographic texture of the coatings were analyzed by means of the non-contact surface measurement device and XRD. Mechanical properties of the coated substrate namely hardness, friction and wear resistance are evaluated using micro-Vickers hardness and pin on disc test equipment. A major part of the power produced by the engine lost in overcoming friction between the reciprocating parts. Heat lost to the surroundings is a major factor reducing engine efficiency. Nano-coating can be used to reduce the surface roughness of the engine components and to act as a protective coating against friction and wear of the components. The comparison of tribological related properties of the coated material with uncoated AISI440C piston ring material revealed improved hardness and better wears resistance. Also, this paper deals with the deposition Nano-coating on AISI440 C SS piston ring material and further the characterization of nano-coating are carried out through Noncontact surface roughness, XRD, Micro-Vickers hardness and pin on disc tribometer test. Finally, the best coating material are identified for reducing the friction and wear and thereby increasing the performance of piston ring, these experimental results are validated with numerical results.

1 Introduction

Nanotechnology is an engineering functional system at the molecular scale. It involves the creation and/or manipulation of materials at the nanometre (nm) scale either by scaling up from single groups of atoms or by refining or reducing bulk materials. A nanometre is 1 x 10-9 m or one-millionth of a millimeter. To give a sense of this scale, a human air is of the order of 10,000 to 50,000 nm, a single red blood cell has a diameter of around 5000nm, viruses typically have a dimension of 10 to 100 nm and a DNA molecule has a diameter of 2–12 nm. The use of the term "Nanotechnology" can be misleading since it is not a single technology or scientific discipline. Rather it is a multidisciplinary grouping of physical, chemical, biological, engineering electronic process, materials, application and concepts in which the defining characteristic is one of size. Nanotechnology is a broad interdisciplinary area of research, development and industrial activity which has been growing rapidly worldwide for the past decade. New companies, often spin-outs from university research departments are being formed and are finding no shortage of investors willing to back their ideas and products, new materials are being discovered or produced and astonishing claims are being made concerning their properties, behaviours and applications.

Two main approaches are used in Nanotechnology. In the "bottom-up" approach, materials and devices are built from molecular components which assemble themselves chemically by principles of molecular

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recognition. In the "top-down" approach, Nano-objects are constructed from larger entities without atomic-level control. The impetus for nanotechnology comes from a renewed interest interface and colloid science, coupled with a new generation of analytical tools such as the atomic force microscope (AFM) and scanning tunneling microscope (STM). Combined with refined processes such as electron beam lithography and molecular beam epitaxial, these instruments allow the deliberate manipulation of Nanostructures and lead to the observation of novel phenomena.

Nano coating is a surface modification technique to create the Nano-layer on the surface to improve the physical and mechanical performances: Increase the hardness, Superior wear resistance, Oxidation resistance, Friction resistance. This coating is widely used for cutting and forming tools, bearings, I.C engine components, seals, valves, glass etc. The function of a piston ring is to seal off the combustion pressure, to distribute and control the oil to transfer heat, and to stabilize the piston.

The piston is designed for thermal expansion, with a desired gap between the piston surface and linear wall. The rings and the ring grooves form a labyrinth seal, which relatively well isolates the combustion chamber from the crankcase. The position and design of the ring pack is shown. The ring face conforms to the linear wall and moves in the groove, sealing off the route down to the crankcase. The sealing ability of the ring depends on a number of factors, like a ring and linear conformability, the pretension of the ring and gas force distribution on the ring faces. Some of the combustion chamber heat energy is transferred through the piston to the piston boundaries i.e. the piston skirt and rings, from which heat transfers to the linear wall. Furthermore, the piston rings prevent excess lubrication oil from moving into the combustion chamber by scrapping the oil from the linear wall during the down stroke. The piston rings support the piston and thus reduce the slapping motion of the piston, especially during cold starts where the clearance is greater than in running conditions. The rings are generally open at one location, at the ring gap, hence easily assembled on the piston.

1.1 Literature review

Ti_Y_O_N films were deposited by reactive magneto sputtering and formation of yttrium oxide improved the toughness significant. The incorporation of Y (> 10.2 at. %) improved the load capacity [1]. By thermo-mechanical coupling analysis of exhaust manifold assemblage, to get the increase in stress vonmises by 55.9% and contact pressure by 44.5% due to thermal load than the mechanical load, contact between the abutments opens more under thermal loading than the bolt preloading [2]. The high refractoriness and high lubricant are necessary to the coating to be prepared for it, multilayer coating consisting calcia-Partially Stabilized zirconia, magnesia-Partially Stabilized zirconium, Silicon Dioxide, diamond-like carbon which sounds to be effective under such extreme conditions [3].

The characterization of TiCN and TiCN/ZrN coatings for cutting tool application is the coating deposition parameters used in this experiment could successfully deposit TiCN and ZrN on commented WC substrates. However, the gas flow rate of CH4 should be further increased to increase the formation rate of TiCN. The coefficient of friction of the in-house developed TiCN was slightly lower than the commercial TiN coating. The coating could significantly reduce the coefficient of friction and improve the abrasive wear resistance of carbide inserts [4]. The M-Ni has been successfully prepared by ultrasonic-assisted electro deposition process. Based on the results, the M-Ni coating showed the superior wear resistance than the O-Ni coating due to its multilayered microstructure. And its wear mechanism is adhesive wear. By contrast, the O-Ni coating failed quickly under wear conditions owing to the microstructure of columnar gain with poor adhesion, low micro-hardness. And its wear mechanism is the compound fatigue and adhesive wear. To sum up, multilayered microstructures remove the defect of the columnar grains in the O-Ni coatings, making the mechanism of coating failure transform enormously under the wear condition [5].

1.2 Nano coating methods

Thin-film deposition is any technique for depositing a thin film of material to a substrate or on to previously deposited layers. This is a relative term, but most deposition techniques allow layer thickness to be controlled within a few hundred nanometers and some allow one layer of atoms to be deposited at a time:

1.2.1 Electron Beam Physical Vapour Deposition:

- The AISI 440^{0}C material is held into the substrate holder.
- The rotation of the substrate is achieved by means of AC Geared motor with AC drive. The rpm of the control is between 2-30 rpm.
- Vacuum pumping system is used to achieve the high vacuum in the coating chamber. This can give an ultimate vacuum of 5x10^-7 m.bar.
- The water-cooled magnetically focused bent beam gun evaporation sources have to be used in vacuum chambers for deposition of high purity metal films.
- This gun should have self-accelerated electron bent beam source.

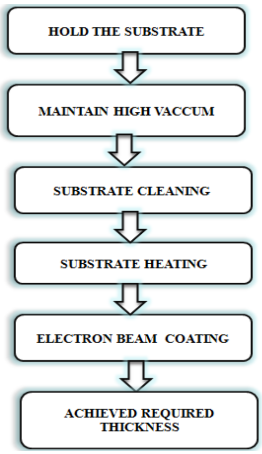

Fig. 1. Flowchart of Nano coating methods

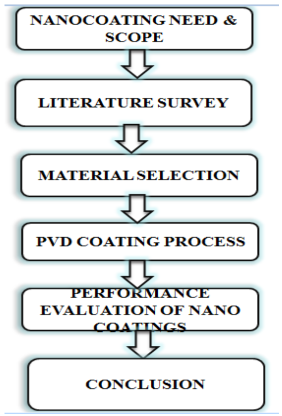

Fig. 2. Process flowchart

Table 1. Electron Beam Coating Conditions

SUBSTRATE	AISI 440 C SS
COATING MATERIAL	Nickel, Aluminum dioxide& Titanium dioxide
VACUUM PRESSURE	5 x 10^-6 m.bar
SUBSTRATE TEMPERATURE	250 deg celsius
SUBSTRATE ROTATION	15 rpm

Table 2. Operating parameters

OPERATING PRESSURE	BELOW 5X10^-4
POWER RATING	8 to 10 KW
BEAM VOLTAGE	4-10 KV DC
BEAM CURRENT	0-1Amp
FILAMENT VOLTAGE	0-10 Volt Ac
FILAMENT CURRENT	0-50 amps max
BEAM DEFLECTION	270deg deflection
BEAM SPOT SIZE	Tight beam approx 6mm(W) x 10 mm(L) oval spot size

2 Methodology

A specially designed doom shaped heater is provided to heat the substrate to the maximum temperature of 350 deg Celsius. The temperature measurement and control is by means pf PID controller with K type thermocouple. The power to the heater is smoothly controlled by means of thyristor power controller.

2.1. Selection of Materials

AISI 440^{0}C SS piston ring is selected as a substrate material. The material is characterized by high tension, high breaking resistance and high heat resistance. To increase the life of high-speed steel, tools are sometimes coated.

Table 3. Coating material properties of Grade440^{0}C

Ingredients	Min.	Max.
Carbon	0.95	1.20
Manganese	-	1.00
Silicon	-	1.00
Phosphorus	-	0.040
Sulphur	-	0.030
Chromium	16.00	18.00
Molybdenum	-	0.75
Iron	Balance	

One such coating is TiN (titanium nitride). Most coatings generally increase a tool's hardness and/or lubricity. A coating allows the cutting edge of a tool to cleanly pass through the material without having the material gall (stick) to it. The coating also helps to decrease the temperature associated with the cutting process and increase the life of the tool. Titanium (Ti) is an extremely hard ceramic material, often used as a coating on titanium alloy, steel, carbide to improve the substrate's surface properties. Aluminum and aluminum alloys are lightweight, non-ferrous metals with good corrosion resistance, ductility, and strength. Nickel and nickel alloys are non-ferrous metals with high strength and toughness, excellent corrosion resistance, and superior elevated temperature properties.

2.2 Experimentation

Surface roughness, often shortened to roughness is a measure of texture of a surface. Roughness plays an important role in determining how a real object will interact with its environment. The most commonly used parameters to quantify the roughness of a surface in engineering are the **Ra** value. Surface morphology of coated and uncoated substrate is measured with Taylor Hobson CCI System surface roughness measuring equipment to compare the surface properties. The 20X magnification LED is used to measure the surface roughness.

The unit consists of the gimbaled arm to which the pin has attached a fixture which accommodates disks up to 165mm diameter& 10 mm thickness

Fig. 3. Pin On Disc Tribometer (Wear & Friction Test)

The hardness value of coated and uncoated substrate compared to uncoated AISI440C SS substrate 60% hardness increased in Al2O3 substrate and 30% hardness increased in TiO2 substrate.

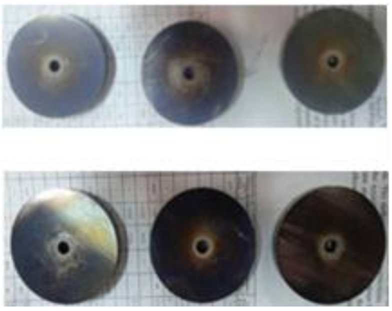

Fig. 4. Coated specimen TiO_2 & Al_2O_3

The 50 mm dia AISI 440C Stainless steel disc and the friction reduced in the coated specimen friction reduced in the encircled position of the disc and load applied on the pin is mesh with the disc is shown in 3D geometry.

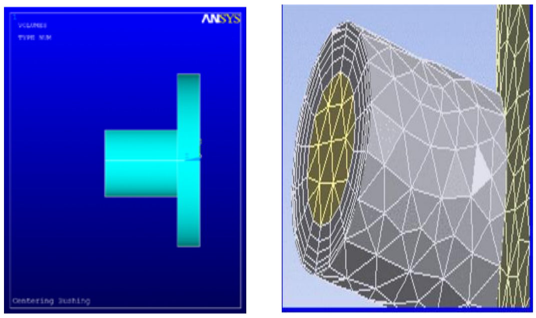

Fig. 5. Modelling and Meshing

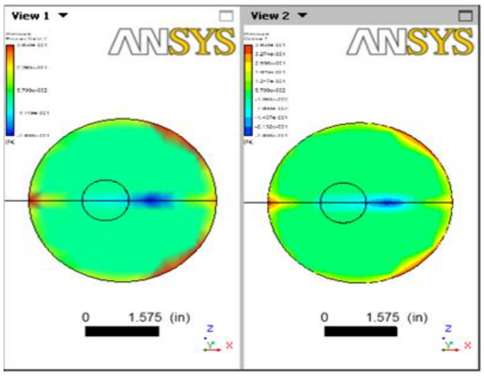

Fig. 6. FEA Frictional analysis

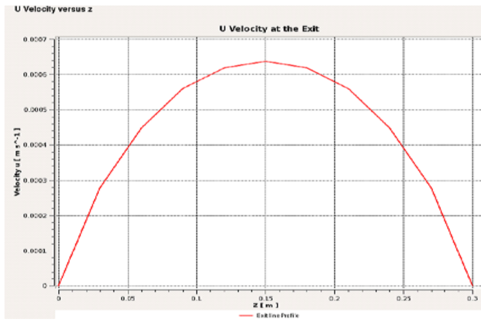

Fig. 7. velocity graph for coated and uncoated friction value

The friction increased in the uncoated specimen from 0 to 0.15 velocity and also the friction reduced in the coated specimen 0.15 to 0.3 velocity.

3 Results and Discussion

3.1 Surface Roughness of Uncoated and Coated Piston Ring

Surface morphology of coated and uncoated substrate are measured with Taylor Hobson CCI system surface roughness measuring equipment to compare the surface properties. Fig 8 shows the 2D roughness profile of coated and uncoated samples.

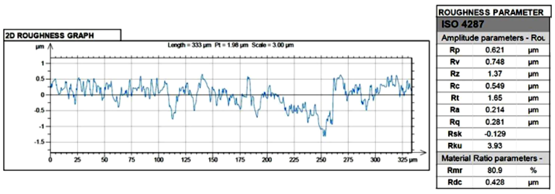

Fig. 8. 2D Roughness profile of uncoated piston ring

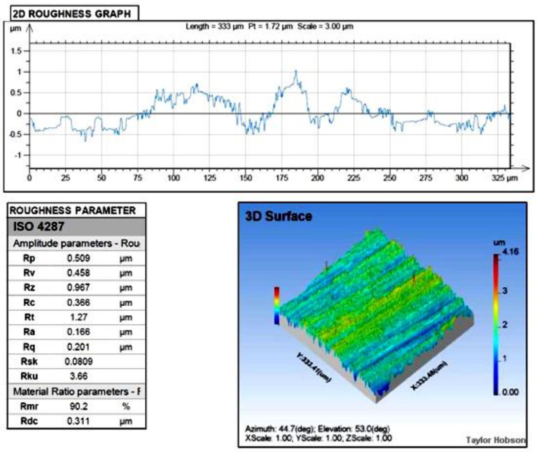

Fig. 9. 2D Roughness Profile of TiO_2 coated piston rings

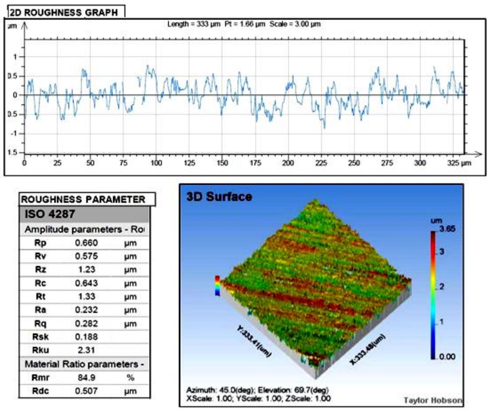

Fig. 10. 2D Roughness Profile of Al_2O_3 coated piston ring

The Ra value of the coated and uncoated samples is:

- Uncoated - 0.214 micron
- TiO2 - 0.166 micron
- Al2O3 - 0.232 micron

From these results, the surface roughness coated samples are reduced due to the uniformity of coating further the coating performances are improved because of its lower surface roughness compared to the uncoated surface.

3.2 Frictional wear properties

Friction and wear properties of coated and uncoated substrate are evaluated using a pin on disc tribometer. A comparison of the coefficient of friction values with time at room temperature is displayed. The operating conditions of TiO_2, Al_2O_3 and Ni are 1 Kg 1.5 Kg and 2Kg with constant 550 rpm. The coated material is running against the cast iron material disc.

Table 4. Coefficient of friction with respective load

S.NO	MATERIAL	LOAD 1 kg	LOAD 1.5 kg	LOAD 2kg
1	Un coated	0.341	0.598	1.112
2	TiO_2	0.760	0.6685	0.6395
3	Al_2O_3	0.7343	0.8617	0.5020

From the above chart, it is evident that the coefficient of friction Al_2O_3 is increased compared to the TiO_2 for the same operating condition.

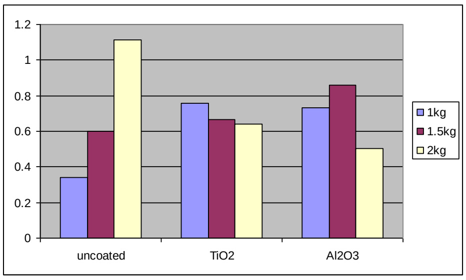

Fig. 11. Friction chart

Frictional heating in the contact results in oxidation of the layer and surface. Because of it exhibits a low coefficient of friction

Table 5. Coefficient of friction with weight loss

S.NO	MATERIAL	Wt loss at 1 Kg	Wt loss at 1.5 Kg	Wt loss at 2Kg
1	TiO_2	0.012	0.014	0.014
2	Al_2O_3	0.03	0.08	0.012
3	Un coated	0.016	0.028	0.024

The weight loss of coated and uncoated materials. The result shows the weight loss comes in minimum range.

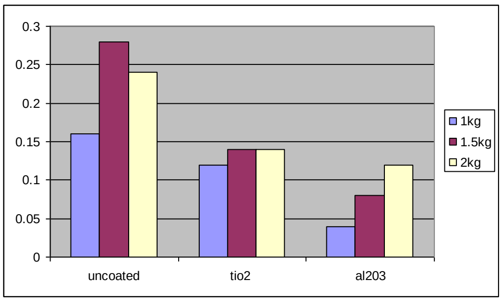

Fig. 12. Weight loss chart

It shows the time limit and runs the experiment but when compared to the uncoated material, the coating material having less weight loss for same running condition aluminum dioxide proves better to wear resistance compared to titanium dioxide.

Table 6. Wear rate

S. NO	MATERIAL	1 KG 10 min,550 rpm	1.5 KG 10 min,550 rpm	2 KG 10 min,550 rpm
1	TiO_2	2.314X 10^{-7}	2.700 X 10^{-7}	3.472 X 10^{-7}
2	Al_2O_3	7.716 X 10^{-8}	1.543 X 10^{-7}	2.314 X 10^{-7}
3	Un coated	3.086 X 10^{-7}	4.629 X 10^{-7}	5.401 X 10^{-7}

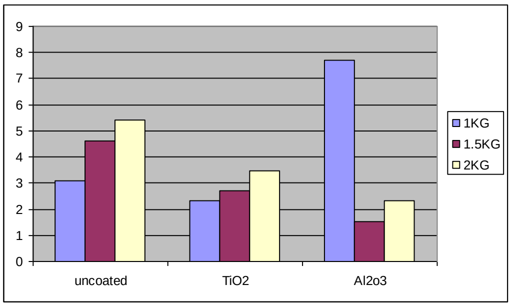

Fig. 13. Friction chart

From the above Fig 13 wear rate of the coated specimen is reduced compared to the uncoated specimen in Al_2O_3 coated specimen has less wear rate compared to TiO2 at 1.5 kg load applied in 10 min at 550 rpm

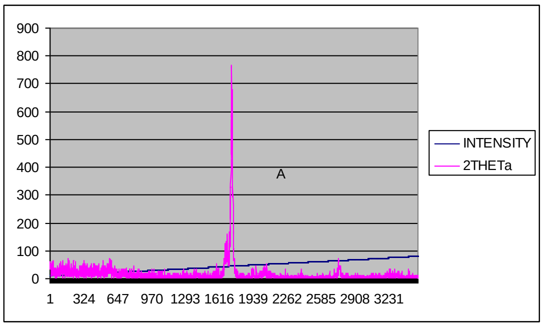

Fig. 14. Chart for AISI 440C SS

From the above Fig 14. The graph is plotted between Intensity and 2 Theta the peak obtained in 750 2Theta at an intensity level between 1616 and 1939. The highest peak shows the AISI 440C Stainless Steel is presented

Table 7. Hardness for coated and uncoated samples

S.NO	LOAD	SUBSTRATE	TiO_2	Al_2O_3
1	25	297	242	159.50
2	50	154	178.50	189.50
3	100	141	155.50	233
4	200	128	130	256.50
5	300	120.50	142.50	309.50
Avg		168.10	169.70	229.60

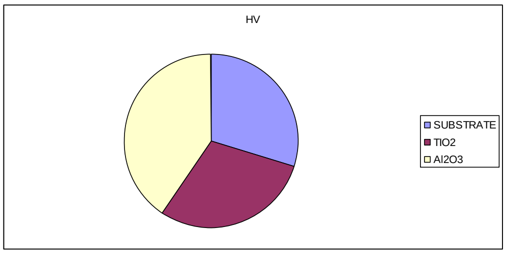

Fig. 15. Vicker hardness for coated and uncoated samples

The hardness value for coated and uncoated piston ring is measured by using micro vicker hardness and the values are tabulated in table 7. From the above Fig 15 shows the hardness value of coated and uncoated substrate compared to uncoated AISI440C SS substrate 60% hardness increased in Al2O3 substrate and 30% hardness increased in TiO2 substrate.

CONCLUSION

The present work has been carried out to investigate the coating performance of piston ring. The coating materials are TiO_2, Al_2O_3 and Ni selected based on its properties. The coating materials are successfully deposited on AISI 440C stainless steel material by EB-PVD and following conclusions are arrived. The surface roughness of the coated AISI440C stainless steel material is reduced compared to the uncoated material. Further, the coating performances are improved of its lower surface roughness compared to the uncoated surface. Compared to the uncoated material, the hardness of the Aluminium dioxide coated substrate is increased by a 33% and with Titanium dioxide by 5%. The coefficient of friction and wear rate of coated material are reduced when compared to the uncoated material. Al_2O_3 Proves better wear resistance compared to TiO_2. The XRD analysis reveals the AISI 440 C Stainless Steel material present in the substrate. Simulate the friction results of coated and uncoated surface of the sample. Friction is increased in the uncoated substrate and also the friction is reduced in the coated sample.

References

1. HongboJuLihuaYuShengHeIsaacAsempahJunhuaXu. *The enhancement of fracture toughness and tribological properties of the titanium nitride films by doping yttrium* Surface and Coatings Technology-ScinceDirect 321 (2017).
2. Eriki Ananda, K, K.M. Abubacker, S.M. Walke, Y.D. Kumar. *Thermo Coupled Stress Analysis of Exhaust Manifold Assemblage using ABAQUS.* Int. Journal of Civil, Mechanical and Energy Science 2, 1 (2016).

3. S. Parthiban, A. Mohd. Gani, R. Vasudevan, Naveen Kumar. *Design and Performance Analysis on Piston Ring*. Int.J. Eng. Research and General Science **3**, 5 (2015).
4. Ping Chuan Siowa, Jaharah, Ghani, Mariyam Jameelah Ghazali, Talib Ria Jaafar, Mohamad Asri Selamat, Che Hassan Che Haron. *Characterization of TiCN and TiCN/ZrN coatings for cutting tool application*. Ceramics International-ScinceDirect 39, 2 (2013).
5. Yunsong Niu, Jie Wei, Ying Yang, Jiaxiu Hu, Zhiming Yu. *Influence of microstructure on the wear mechanism of multilayered Ni coating deposited by ultrasound-assisted electrodeposition*. Surface and Coatings Technology-ScinceDirect 210 (2012).