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An Experimental investigation of metallurgical properties of thermally coated stainless steel 316l

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***Abstract-* Coating is one of the most important and basic feature of any components now a days. Because by applying the coating on the substrate material the performance of the components increases. The properties like as mechanical, optical, magnetic, optical & tribological properties very sharply. Physical vapour deposition (PVD) coating is one of good method of thermal coating. Physical vapour deposition (PVD) surface coatings make it possible to increase the surface hardness of treated components. Despite the good wear resistance of such coatings, the fatigue behavior of the bulk material may be affected by changes in the residual stress field and microhardness. This research discuss characterize the thermal and mechanical properties of coated substrate. The analysis of PVD coating on different stainless steel has been carried out. The objective of the analysis is to check properties of coated substrate with the help of different experiment.**

***Index Terms-* PVD coating, TiAlN, Stainless steel, metallurgical properties.**

I. INTRODUCTION

Surface engineering is one of the most growing area of research because of the high industrial demands for friction control and wear resistance. According to research and development in this period resulted in growth of product quality and reliability. The development of Nanotechnology based coating for their huge application such as UV blocking coating, anti scratch coating, anti corrosion coating, in paint industry and automobile industry.

Now a day coating is characterized not only by its thickness of layer and its adhesion to substrate, but also evaluation of its mechanical properties, thermal properties, hardness, toughness, fatigue resistance.[1]

Hard coating is one of the most important and basic feature of any components now a days. Because by applying the coating on the substrate material the performance of the components increases. The properties like as mechanical, optical, magnetic, optical & tribological properties very sharply. Coatings with Nano particles of hard material which enhances the surface properties such as it makes the component hard, wear resistant & also give refined grain microstructure. Hard coatings prepared by various deposition techniques and conditions exhibit the widest variety of microstructures among materials in terms of grain size, crystallographic orientation, lattice defects, texture, and surface morphology as well as phase composition.

Types of hard coating:-

- PVD (Physical Vapour Deposition) Coating
- CVD (Chemical Vapour Deposition) Coating
- HVOF (High Velocity Oxy Fuel) Coating

There are three step of formation of any deposition:

i) Transition from condensed phase (liquid or vapour) to vapour phase.
ii) Transport of vapour from source to substrate.
iii) Condensation of vapour followed by film nucleation and growth.

According to the industrial abbreviations, the PVD is a process carried out in high vacuum at temperatures in general between 150° C to 500°C.

There are different types of PVD:-

- Cathodic arc deposition
- Electron beam physical vapour deposition
- Pulsed laser deposition
- Sputter deposition

Microstructure developed uniform and dense which gives the best wear resistance, thermal shock resistance and also enhance the other thermal and mechanical properties. By providing only the Ti, TiN and other transition metal nitride we have observed that it can bear the thermal stresses at high temperature but their internal grain morphology were not become uniform and dense and also good adhesion to the substrate particle was no achieved. So that the investigation aimed to found out the best coating material with enhanced properties that can bear the thermal stresses in a high temperature environment.

II. LITERATURE REVIEW

In this paper few selected research paper related to coating. The studies carried out in these papers are mainly concerned with the different substrate and different coating material and how these affect the metallurgical and thermal properties.

Sveen et al. [1] has studied that Scratch adhesion characteristics of PVD TiAlN deposited on high speed steel, cemented carbide and PCBN substrates. According to this paper the practical adhesion, as determined from the critical normal load, corresponding to substrate exposure, of the TiAlN coatings to the underlying substrate material increases in order PCBN – HSS – CC. The only coating/substrate composite showing major adhesive fracture is the TiAlN coated PCBN. Besides the type of interatomic bonding present at the coating/ substrate interface the critical normal load depends on factors such as the substrate load carrying capacity (hardness) and the cohesive strength of the substrate surface and sub-surface region. It is more important the effect of surface finish processes in pre treatment of hard substrate and the amount and type of damage they can create.

Samir K. Khrais et al. conducted [2] Wear mechanisms and tool performance of TiAlN PVD coated inserts during machining of AISI 4140 steel. The turning test was conducted with variable high cutting speeds ranging from 210 to 410 m/min. Here they used cemented carbide as tool insert with TiAlN coating for turning of hot rolled SAE 4140H steels. The upper limit speed for this process was 410 m/min and any other increase in premature failure. Micro-abrasion and micro-fatigue behaviors were the dominant kinds of wear mechanisms in higher cutting speeds under dry cutting. Dry cutting is better than wet cutting for TiAlN coating inserts under high cutting speed. The best performance of TiAlN coated tool inserts under study is under dry cutting with any cutting speeds less than 260 m/min.

G. Skordaris et al. [3] having check the Brittleness and fatigue effect of mono- and multi-layer PVD films on the cutting performance of coated cemented carbide inserts. In this paper difference experiment are performed to check the brittleness, fatigue test, hardness and tool life. The brittleness and fatigue test is carried out by macro and nano impact test. Here they use cemented carbide as substrate and it was coated by TiAlN and TiN with mono and multi layer. Here they conclude that as coating layer increase hardness of substrate was improved. It is observed that in multilayer coating brittleness of substrate is better than monolayer coating because of good TiN layer resist the crack prorogation, which are characterized by enhanced ductility compared to TiAlN films. Tool life is increases when it is introduce with multilayer PVD coating.

A.I. Fernandez-Abia et al. [4] conducted behaviors of PVD coatings in the turning of austenitic stainless Steels. In this paper four coating materials AlTiSiN, AlCrSiN, AlTiN and TiAlCrN were tested. Here they analysed that nanocomposite AlSiTiN coating present higher wear resistance at high temperatures. AlTiN coating have high Al content (>67%) that confers high thermal resistance. AlTiSiN and AlTiN coatings have high chemical stability because of generation of protective layer of oxidation of aluminium. AlTiSiN coating was superior to AlTiN due to its nano crystalline structure. AlCrSiN and TiAlCrN provide protective layer of cromium oxide which is less stable than aluminium oxide layer. Roughness values were also lower for surface machined with AlTiSiN and AlTiN tool coating. AlTiSiN and AlTiN tool coating give best performance than other two coating in better tool flank wear, less tangential cutting force and less part roughness.

M. Antonov *et al.* [5] conducted investigations on the Assessment of gradient and nano gradient PVD coatings behaviour under erosive, abrasive and impact wear conditions. In this paper PVD coating by AlTiN/Si_3N_4 on cemented carbide substrate. Here they also test other coating materials which are TiN, TiCN, TiAlN, AlTiN. Erosive, abrasive and impact wear teste is conducted to obtain the insight into qualitative and quantitative aspects of PVD coatings resistance to wear. This coating possesses the highest hardness and proper microstructure of the nanometer sized AlTiN particles distributed throughout tough Si3N4 matrix that provide the increase in impact resistance. The nano composite gradient super hard AlTiSiN coating has better performance under wear conditions like erosive, abrasive and impact conditions than other coating tested. It was observed that at lower velocity and with less aggressive abrasive the performance of coating sufficiently increased. From relative material performance the order of wear resistance of different coatings are AlTiSiN(nACo) -AlTiN-G – TiAlN-ML – TiCN – TiN. It is important that TiN is best performance under erosive condition.

Mohammad Ahmed et al. performed **[6]** on Corrosion behaviors of nanocomposite TiSiN coatings on steel substrates. In this paper coating of TiSiN onto AISI M42 tool steel substrates by physical vapour deposition (PVD) using a reactive close-field unbalanced magnetron sputtering system was analysed. The effect of the coating microstructure and residual stress on the corrosion behaviour of TiSiN coated steels in acidic environments was investigated in this work. The microstructure of these coating have three sub layer, which are a nanocomposite TiSiN outer layer, a columnar-grained TiN transitional layer and a thin metallic Ti adhesion layer. All these three layers, while fulfilling their mechanical functions, also acted as physical barriers against potential corrosion attack on the steel substrates. Corrosion pitting was observed in TiSiN coating on steel substrate which originated from surface defect. Here thin oxidation layer of post deposition annealing process provide an overall protection of coated steel. Boundaries of columnar TiN grains reduce the compressive residual stress and maintain the structural integrity of TiSiN coated steel systems.

E.S Puchi-Cabrera et al. [7] carried out a study On the fatigue behavior of an AISI 316L stainless steel coated with a PVD TiN deposit. The effect of a TiN coating on the fatigue properties of an AISI 316L stainless steel has been investigated. The coating was approximately 1.4-μm thick and was deposited by means of filtered cathodic arc deposition. It has been determined that the application of such a coating to the steel substrate gives rise to a significant increase in both fatigue life and fatigue limit, in comparison with the uncoated steel. From the microscopic point of view, it has been observed that the coating remains well adhered to the substrate both in tension and during fatigue testing at low maximum alternating stresses (480 MPa). However, during fatigue testing at elevated maximum alternating stresses (510 MPa) the coating was observed to delaminate from the substrate. Also, it has been determined that the fatigue fracture of the substrate-coating composite is dominated by the fracture of the TiN coating since fatigue cracks have been observed to form first at the surface of the coating and subsequently to propagate towards the substrate.

L.A. Dobrza´nski et al. conducted investigations on properties of the multi-layer Ti/CrN and Ti/TiAlN coatings deposited with the PVD technique onto the brass substrate. This paper presents inspection results of structure, corrosion resistance, changes of the coating constituents' attention and mechanical properties of the CuZn40Pb2 brass coated by the thin Ti/CrN and Ti/TiAlN 1, 15 and 150-ply multi-layer coatings. It have been established that number of coating layer increase than it increase corrosion resistance. Here it is shown that multilayer PVD coating deposition on CuZn40Pb2 brass improves its corrosion resistance. The development in number of coating layer it improves corrosive resistance, decrease the mechanical properties, in case of adhesion test. Microhardness is also better in single layer and 15 layer coating.

Mohammad Ahmed et al. research on Corrosion behaviour of nanocomposite TiSiN coatings on steel substrates. Coating of TiSiN on AISI M42 tool steel substrates by material vapour deposition (PVD) by means of a reactive close-field unstable magnetron sputtering system was analysed. The result of the coating microstructure and residual stress scheduled the corrosion behaviour of TiSiN coated steels into acidic environments be investigated in this work. The microstructure of these coating include three sub layer, which be a nanocomposite TiSiN outer layer, a columnar-grained TiN intermediary layer with a thin metallic Ti adhesion layer. every these three layers, whereas fulfilling their mechanical functions, and acted as physical barriers against potential corrosion attack on top of the steel substrates. Corrosion pitting be observed in TiSiN coating on steel substrate which originated from surface defect. Here thin oxidation layer of post deposition annealing procedure provide an overall protection of coated steel. borders of columnar TiN grains decrease the compressive residual stress and maintain the structural integrity of TiSiN coated steel system.

E.S Puchi-Cabrera et al. research on the fatigue behavior of an AISI 316L stainless steel coated with a PVD TiN deposit. The effect of a TiN coating on the fatigue properties of an AISI 316L stainless steel has been investigated. The coating was approximately 1.4-µm thick and was deposited by means of filtered cathodic arc deposition. It has been determined that the application of such a coating to the steel substrate gives rise to a significant increase in both fatigue life and fatigue limit, in comparison with the uncoated steel. From the microscopic point of view, it has been observed that the coating remains well adhered to the substrate both in tension and during fatigue testing at low maximum alternating stresses (480 MPa). However, during fatigue testing at elevated maximum alternating stresses (510 MPa) the coating was observed to delaminate from the substrate. Also, it has been determined that the fatigue fracture of the substrate-coating composite is dominated by the fracture of the TiN coating since fatigue cracks have been observed to form first at the surface of the coating and subsequently to propagate towards the substrate.

- TiAlN have better adhesion and thermal resistance than other coating material at high temperature and pressure. As increase the layers of TiAlN coating properties of material also improve.
- We denoted that at higher temperature the micro porosity in the structure gradually removed and the particles could be distributed on to the surface in the well dispersed Manner. Hence they form the dense & uniform, isotropic structure on the topographical substrate surface.
- Machine tools have better performance in coated tool. Tool life is increases when it is introduce with multilayer PVD coating. Coating gives reduce tool flank wear, less tangential cutting force and less part roughness.

III. EXPERIMENT WORK

The substrate material is used as ASTM, A 240-2012, TYPE 316L. This material is generally used Stainless steel piping, stainless Steel vessels in oil and gas industry, refineries and chemical and petro-chemical plants.

	%	Std. Value
Carbon	0.029	0.03 Max
Silicon	0.39	0.75 Max.
Manganese	1.33	2.00 Max
Phosphorus	0.022	0.045Max
Sulphur	0.007	0.030 Max
Chromium	16.74	16.0-18.0
Nickel	10.05	10.0-14.0
Molybdenum	2.05	2.0-3.0

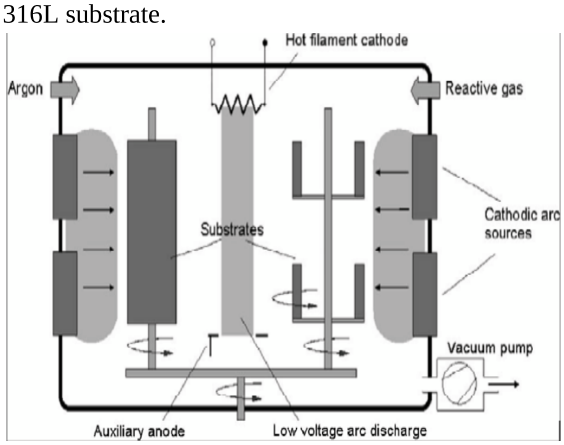
Chemical composition (wt %) of ASTM, A 240-2012, TYPE 316L

Basics of the Coating Material Details

Initiation phase the coating material used in machining industries as cutting tools was TiN. TiN is solid and improves the cutting performance compare to uncoated cutting tools**.** For the additional improvement in mechanical and thermal properties and the oxidation resistance some other materials contain been developed. Many material systems considered are based on the TiN system, where a third constituent is added to obtain for example TiCN or TiAlN. Today, TiAlN is the mainly common coating for cutting tools. The elevated hardness of TiAlN at high temperatures improve the cutting performance and enable higher cutting speeds.

Actual Experimental Procedure done in the Industrial Set Up.

A Front loading Balzer`s Rapid coating system (RCS) Machine has been used for the deposition of the coatings. The machine is equipped with eight cathodic arc sources. Four of the eight sources were used to deposit a thin TiN sub-layer. The remaining four sources were employed to deposit the main layer of the coatings, which was obtained using customized sintered targets. By using complex cathodes containing several elements the composition of the film is controlled in this work, Ti-Al complex cathodes have been used in adding to the elemental Ti cathodes. Nitrogen is supplied by a flow into the deposition chamber. This is the mainly ordinary way to introduce glow elements such as nitrogen. The temperature of the deposition on the substrate material should be started from 25°C to 750°C. Deposited film on the substrate material reveals the TiAlN Coated components on ASTM 240-12, TYPE 316L substrate.



Experimental set up for Cathodic Arc evaporation process at coating industry.

As shown from the specification the nitrogen deposition pressure applied on to the coating material was 3.5 Pa and the substrate bias voltage in between -40v to - 170 v and vacuum pressure was 10-6 torr applied such that perfect dispersion of evaporated particle on the substrate surface should be possible. Such that in the coating morphology the dense and uniform microstructure developed this can bear the higher thermal load.

IV. EXPERIMENTAL TESTING

The classical meaning of term analysis is: dissolution, separation, breaks up into the constitute elements.

Salt Spray Test

The salt solution shall be arranged by dissolving 5 ± 1 Parts by weight of NaCl in 95 part of distilled water or water containing not more than 200 PPM of total solids.

The period of the Test for our experiment is 24 hour in which we can consider that the corrosion on the specimen occurred or not. As per ASTM B117 also the 24 hour period of time of the tested specimen has been suggested.

The specimen should be carefully removed. The specimen should be gently washed or dipped in the clean running water not warmer than 38°C to remove the deposited salt on the surface& then immediately dried by stream of clean and compressed air provided by drier.

After these we shows that coating is improve corrosive resistance of substance. TiAlN have 28 % rust by corrosion by salt spray chamber for 24 hours. TiN coated sample have 32 % rust by corrosion by salt spray chamber for 24 hours. So, here we can say that TiAlN have better corrosion resistance than other coating.

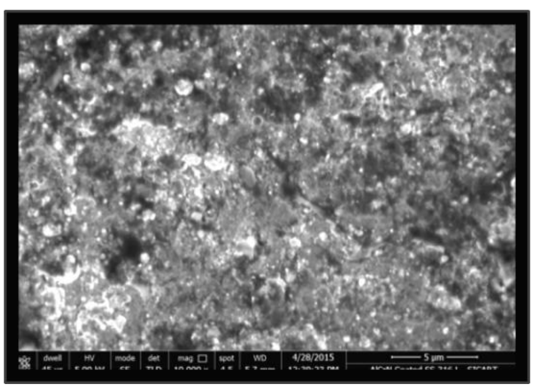
Field emission scanning electron microscopy (FESEM)

A FESEM is microscope that works with electrons (particles with a negative charge) instead of light. These electrons are liberated by a field emission source. The object is scanned by electrons according to a zigzag pattern.

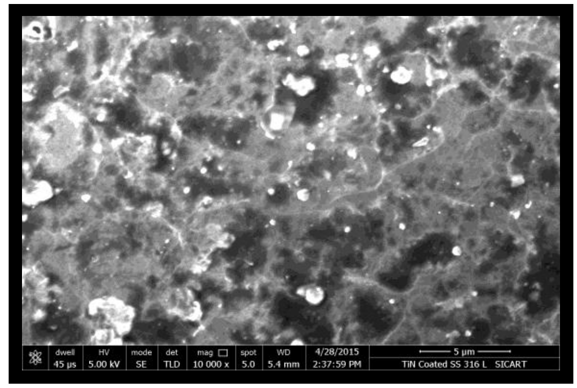
Another type of electron source (non-thermionic) is field emission. The filament used is usually a wire of single-crystal tungsten fashioned into a sharp point (tip radius about 100 nm or less) and spot welded to a tungsten hairpin. An electric field can be concentrated to an extreme level at the tip of the filament. The electric field at the tip is very strong (107 V/cm) due to the sharp effect. Thus, the potential barrier for e-s becomes reduced and the e-s leaves the cathode (filament) without requiring any thermal energy to lift them over the work function barrier. More than any cathode design the field emission tip is extremely sensitive to the size, shape surface condition. The anodes are also very sustainable to contamination.

The emission process itself depends on the work function of the metal which can be affected by adsorbed gases. This is the reason high vacuum is required. Sustaining high electrical field gradient is required to emission, so a tip that is well worn might not emit electrons at all. As with the tungsten filament gun, voltage difference or bias between the first anode and the accelerating voltage on the cathode determines the emission current. The second anode is at the ground potential& the voltage difference from the cathode determines the acceleration given the electrons. The shape of the anode is carefully selected for minimize the abreaction.

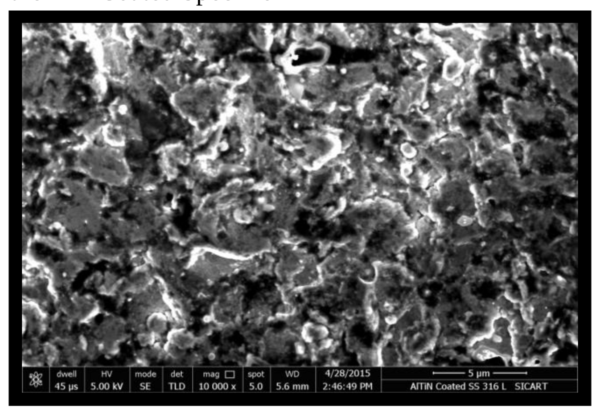
V. RESULT AND DISCUSSION



FEG SEM Image which shows the 10,000X Magnification and observing on the 5µm size of the AlCrN Coated Specimen



FEG SEM Image which shows the 10,000X Magnification and observing on the 5µm size of the TiN Coated Specimen



FEG SEM Image which shows the 10,000X Magnification and observing on the 5µm size of the AlTiN Coated Specimen

The image above shown uniform and dense morphology of the AlCrN,TiAlN and TiN films were observed with higher deposition temperature at 750°C on the substrate& this would be observed in FEG-SEM Characterization.

This denser morphology of grains investigated due to the higher temperature deposition because at higher temperature in CAE-PVD Method surface & bulk diffusivity occur by means of the higher energized evaporated atoms from the target material on to the substrate. The multi component (Ti,Al) N & gradient layer coatings were put behind uniformly on the investigate substrate material. The very good agreement for the adherence of CAE-PVD Method on ASTM, 240-12, TYPE 316L.

VI. CONCLUSION

Here we can see that TiAlN coating have hardness and enough to bear mechanical and thermal load because it has high content of titanium, TiAlN have also good adhesion to substrate properties than

CrAlN and TiN because of high content of Aluminium.

Here we also saw that coated substrate have better surface morphology than uncoated substrate. TiAlN provide better surface morphology than AlCrN and TiN.

The salt spray test was also performed for the investigation of the specimen condition in the marine environment. Here in present investigation the results revealed that in 5% NaCl (Sea Environment) condition ; some amount of the red spot were observed on to the specimen which showed that the corrosion should be proceed thought the specimen. TiAlN provide better corrosive and thermal shock resistance than AlCrN and TiN.

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