

Mechanical, Tribological Properties and Micro-Structural Analysis for Coated Steel Material using Green Coating Technique: A Review

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Abstract

The coating is a layer of material deposited onto a substrate, enhancing surface properties like corrosion and wear protection. There is a wide range of coating methods to deposit many different material types at thicknesses ranging from just a few microns to several millimetres. In this paper, literature on why the PVD process is suitable, types of PVD methods, their process, application and challenges have been reviewed. There are many coating processes available, but it has limitations to coat few materials only. PVD process covered a wide range of coating materials, and it is also called green coating technology, focus on environmental protection. Many parameters affect the experimental work of PVD (sputtering process) like coating thickness, sputtering gas, gas flow rate, sputtering power etc. A carbon nanotube (CNT) is a carbon allotrope, intermediate between fullerene and flat Graphene sheets. Its structure consists of carbon atoms arranged in cylindrical layers, joined by covalent bonds in a hexagonal pattern that forms a hollow tube. Due to this structure, CNTs provide a very high tensile strength, wear-resistance, and thermal conductivity.

Keywords: - Coating cutting tool, Carbon nanotubes (CNT), Green coating technique, HSS cutting tool, PVD sputtering process.

INTRODUCTION

The coating is a layer of material deposited onto a substrate, enhancing surface properties like corrosion and wear protection. The service environment, life expectancy, compatibility of the substrate material, part shape and size, and cost influence the choice of a coating. There is a wide range of coating methods to deposit many different

material types at thicknesses ranging from a few microns to several mm. The different types of coatings can be categorised in many ways, as mentioned ahead. Green coating Technologies is highly focused on environmental protection. The green coating process does not create any hazardous waste compared to other types of coating, such as electroplating or painting. As

described above, the various types of coatings can be classified in several ways;

1. Spraying processes.
2. Chemical and electrochemical techniques.
3. Roll-to-roll coating processes.
4. Physical coating processes.
5. Vapour deposition.
 - a. Physical vapour deposition (PVD).
 - b. Chemical vapour deposition (CVD).

Generally, PVD processes are categorized into two ways: evaporation and sputtering process. There is a wide range of applications like high-temperature superconducting films, very high deposition rates (25 $\mu\text{m}/\text{sec}$), and the thickness of the deposits can vary from angstrom to millimetres. Many materials can be deposited using PVD technologies [1]; more group sub-groups and methods are shown in table 1.

Table 1 Coating methods

Group	Sub-group	Methods
Physical vapour deposition (PVD)	Thermal evaporation (TE)	Pulsed laser deposition (PLD)
		Electron beam deposition (EB-PVD)
	Sputter deposition	Magnetron sputtering Ion
		Iron-beam sputtering
	Arc vapour deposition	Vacuum arc deposition
		Filtered arc deposition
	Ion implantation	Ion beam deposition (IBD)
Chemical vapour deposition (CVD)		Plasma enhanced CVD (PECVD)
		Plasma assisted CVD (PACVD)
		Electron cyclotron resonance CVD (ECR-CVD)

PVD SPUTTERING SYSTEM

Sputtering, also called cathodic bombardment, has been intensively investigated and is now widely used for coating processes. The basic sputtering principle is most easily explained concerning direct current sputtering and is shown diagrammatically in Figure (1). The chamber contains a gas (almost argon) at low pressure. A potential of the order of several hundred volts is established between the anode and the thermionic filament cathode, and the latter is heated to emission temperature. The resulting flow of electrons through the low-pressure argon creates a glow discharge and a plasma of ionised argon atoms. The negative potential of 2 to 4 kV is then applied to the specimen to be coated [2]. Positive argon ions from the plasma bombard the specimen substrate, and then this high-energy bombardment generates a clean surface.

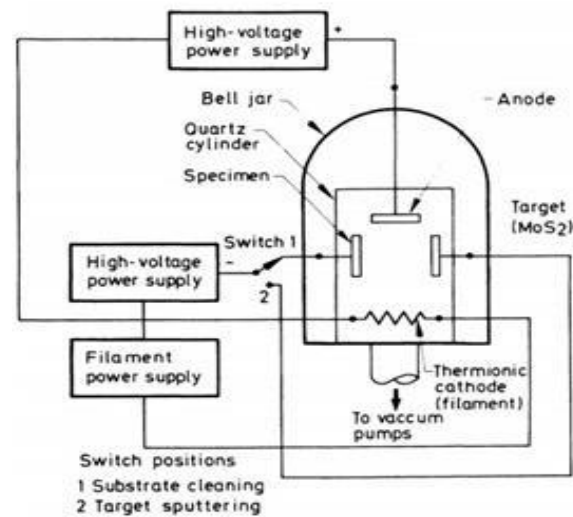


Figure 1 Diagram of a typical D-C sputtering system.[2]

The high negative potential is then switched to the target, which consists of the material used for coating. After the ion bombardment of the target causes sputtering, with the emission of particles of atomic or molecular dimensions from the target

surface. Sputtered particles are deposit on the substrate surface, and then the sputtering process is continued until a coating of the required thickness is obtained [2].

These steps are carried out inside a vacuum chamber, so evacuation of the chamber always precedes the PVD process, as shown in figure 2 [2-6].

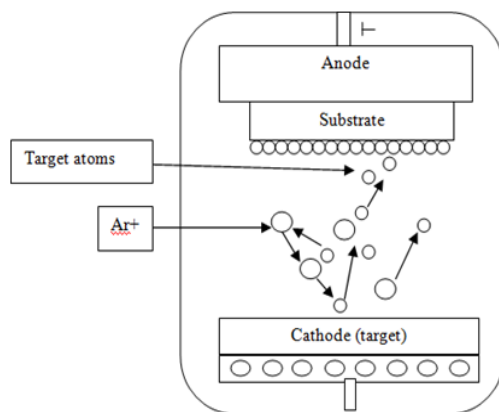


Figure 2 PVD process vacuum chamber diagram.[6]

LITERATURE REVIEW

A. Mubarak et al. 2005 [2] Reviewed hard coatings deposition using different PVD techniques, including a summary of target/cathode materials and various synthesis techniques. Deposition parameters for the method of cathodic arc deposition and magnetron sputtering were different. From the analysis, it was noted that the best technique, but at the same time the most costly, is the ABS technique for PVD hard coating, and it is concluded that the process parameters in PVD hard coating played an important role in optimising the properties for a particular application.

Daria Sidorenko et al. 2017 [3] Due to their specific structures, high mechanical properties, and wear resistance, the explained nanocomposites attract broad attention concerning modern tool materials. Ceramics, cemented carbide and carbon nanotube

modified metallic binders and HBN nanoparticles have a particular function. The machining tool industry is rapidly evolving; manufacturers are still working on novel materials that are reasonably priced, solid, and can replace the best benchmark specimens of today successfully. All these efforts are aimed at obtaining materials that can provide the highest possible levels of productivity.

Mahmud Abdulmalik Abdulrahman et al. 2017 [4] Investigated the mechanical properties and corrosion behaviour of mild steel coated with MWCNTs at different coating conditions. The HRSEM/HRTEM analyses and multi-walled carbon nanotubes were successfully prepared from a bimetallic catalyst of FeNi supported on gamma-alumina support via a conventional chemical vapour deposition reactor acetylene carbon source. The coated mild steel samples at the temperature of 950 °C for 90 min holding time showed the best combination of hardness, yield strength and tensile strength values, which however resulted in having a slightly lower impact energy value as compared to samples treated at other different conditions.

Atiqah Badaluddin et al. 2018 [5] Analysed that Most of the cutting tools used are cemented tungsten carbide. However, cemented tungsten carbide is inadequate when it comes to wearing and has a short lifetime. Different materials and thicknesses of the layers can be combined to achieve a maximum level of performance for the cutting tools. Hierarchical structure can improve the strength and hardness of the coating, reduce wear and prevent crack propagation and investigate the effectiveness of a hierarchical structure concerning the mechanical and tribological properties of cutting tool materials.

Andrea Baptista et al. 2018 [6] Physical vapour deposition (PVD) is a well-known technology commonly used to deposit physical vapour. Deposition of thin films concerning many requirements, namely the improvement of tribological behaviour, optical improvement, visual/aesthetic upgrade, and several other areas, with a wide selection of already perfectly designed applications.

Table 2 Typical features of the PVD process.

Parameters	Sputtering	Evaporation
Vacuum	Low	High
Deposition rate	Low (except for pure metals and dual magnetron)	High (up to 750,000 Å min ⁻¹)
Adhesion	High	low
Absorption	high	Less absorbed gas into the film
Deposited species energy	High (1–100 eV)	Low (~0.1–0.5 eV)
Homogeneous film	More	Less
Grain size	Smaller	Bigger
Atomized particles	More Dispersed	Highly directional

Using chemical vapour deposition (CVD) to increase their lifetime, minimise friction and improve thermal efficiency. Assets The CVD process, however, is carried out at higher temperatures, generating higher stresses, used only when the necessary coating is needed in the coatings and substrate. Deposited using this mechanism Several experiments have been carried out to develop this methodology.

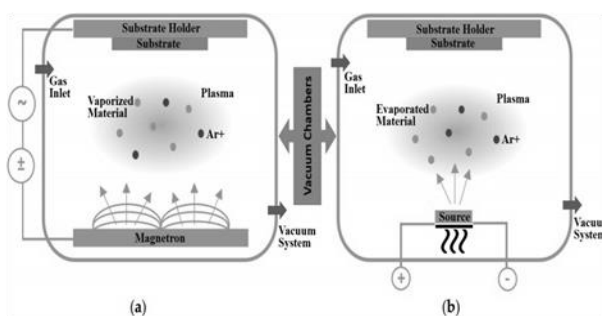


Figure 3 schematic drawing of two conventional PVD processes: (a) sputtering (b) evaporating using ionised argon (Ar⁺) gas. [6]

Optimisation of the PVD system by increasing plasma ionisation and reducing dark areas (zones Improving the use of objectives, improving atomic bombardment if there is no deposition in the reactor), Performance, or even increasing the rate of deposition and optimising gas selection. Such experiments show an enormous potential to adjust parameters to improve the quality of the thin film and increase The substrate's adhesion.

H. Caliskan et al. 2017 [7] Reviewed the effect of hard coatings on surface finish in machining applications. Main hard coatings designs were introduced, and the required properties from a hard coating were summarised and shown that the cutting performance of cutting tools and surface finish can be significantly improved by deposition of a hard coating on cutting tool materials. The relation of hard coatings with tool wear and cutting temperature, chip formation and surface roughness was discussed in detail. P Srinivas Reddy et al. 2017 [8] Analysed The machining performance of HSS cutting tool inserts in turning EN-24 steel. Before that, HSS tool bit nomenclature shaped on grinding machine and Measure tool bit angle using bevel gaugeprotractor.



Figure 4 HSS tool shaped on grinding machine. [8]

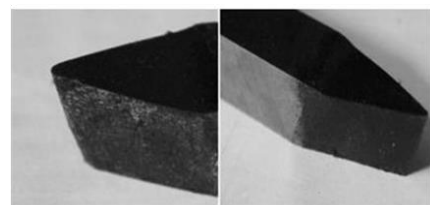


Figure 5 MWCNT coated HSS cutting tool bit. [8]

Substrate material HSS cutting tool coated, using Electroplating deposition coating process and Uncoated tool and MWCNT coated tools were examined and their flank wear and the resultant machined work piece surface finish and metal removal rate.

F.C. Sousa [9] Collected information on coating methods. By using these coatings, there is a significant improvement in the tool's life and machining quality. The deposition process is also an important factor when choosing a coating for a milling application. PVD and CVD processes achieve different types of coating. For example, PVD coatings are usually thinner. These thin coatings provide an excellent choice when it comes to finishing operations. On the other hand, CVD coatings are generally thicker and more oriented for roughing operations. Also, it is important to note that these deposition methods confer the coating with different types of residual stress (tensile and compressive) that impact the coating's behaviour when cutting.

Yunfeng Wang et al.2012 [10] experimented with Nanocomposite TiC(Ag)/AC: H coatings were successfully fabricated by mid-frequency dual-magnetron sputtering on silicon wafer substrates. after that analysed low friction coefficient and long lifetime of the TiC(Ag)/a-C: H coatings were attributed to the presence of low shear Ag clusters on the surface and the diffusion of the Ag in the coatings to the work area to improve the anti-wear properties.

Yu-Chu Kuo et al.2007 [11] prepared Cr– Cu–N thin films with different Cu content by a bipolar asymmetry pulsed DC reactive magnetron sputtering system, and a combination of sufficient

hardness and good antibacterial properties are observed in the Cr–Cu–N nano composite thin films, which make them be promising candidates applied on the surface of medical and food processing equipment.

Harish C. Barshilia et al.2006 [12] prepared Super hard nanocomposite coatings of TiN/Si₃N₄ by reactive DC unbalanced magnetron sputtering at different silicon contents. About 1.5- μ m thick TiN, Si₃N₄ and TiN/Si₃N₄ nanocomposite coatings deposited on stainless steel substrates demonstrated good corrosion resistance in 3.5% NaCl solution, and the nanocomposite coatings showed better corrosion resistance as compared to the single-phase TiN coatings.

The wear data showed that TiN/Si₃N₄ nanocomposite coatings exhibited better wear resistance than TiN coatings.

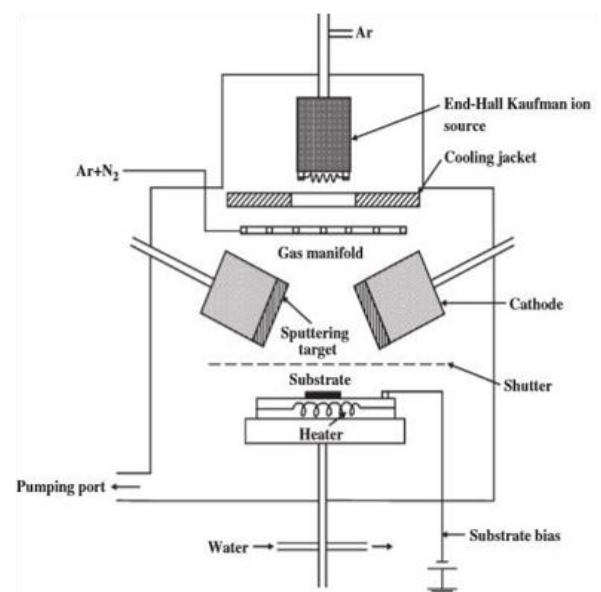


Figure 6 Schematic diagram of the reactive unbalanced DC magnetron sputtering system.[12]

M. Stuber et al.2001 [13] Analysed TiC–C nanocomposite coatings of various chemical compositions showing promising tribological properties were presented. TiC–C nanocomposite

thin films deposited from a target of a composition of 70 mol.%TiC and 30 mol.% carbon show similar Vickers hardness compared to pure PVD-TiC coatings. Superhard TiC–C nanocomposite coatings sputtered from a target composed of 50 mol.% TiC and 50 mol.% carbon can be obtained and Variation of thin-film preparation parameters, analysis by XPS, XRD, TEM and mechanical testing provide nanocomposite thin film optimization

E. Martinez et al.2004 [14] Experimented Nanocomposite CrN_y-SiN thin films can be deposited by reactive magnetron sputtering from the deposition of Cr and Si targets in the presence of the reactive gas mixture and from the alternating deposition of CrN and a-SiN as multilayered structures and the case of CrN_y-SiN_x multilayered films, the presence of a thin amorphous layer (thickness f1 nm) as well as the small CrNcrystallite size (f4 nm) results in high hardness values.

Sam Zhang et al.2002 [15] prepared Superhardnano-crystalline (Ti, Cr)CN_yDLC coatings by co-sputtering Ti, Cr and graphite targets in an argon nitrogen atmosphere. Results from both TEM and GIXRD indicated that the grain size of the (TiCr)C N crystals was approximately xy 10–20 nm. XPS results confirmed that an increase in the sputtering power at the Ti target increased the Ti composition in the film and brought about an increase in sp bonding in the DLC matrix, in agreement with the raising hardness with Ti sputtering power. Film hardness and elastic modulus were measured with a nano-indenter. Under the experiment conditions, the film hardness fell within 18–40 GPa. The tribological behaviours of the films were evaluated

using a ball-on-disk tribometer, and the films demonstrated properties of low friction and good wear resistance.

Kamlesh V. Chauhan et al.2014 [16] analysed frictional behaviour of TiN/TiAlN coatings under a normal load of 3.924N at room temperature shows a relatively lower value of about 0.25 compared to the 0.40 and 0.45 for the single-layer coatings and bare substrate. Tin/TiAlN multilayered coatings show the lowest coefficient of friction compared to a single layer and bare substrate. When tested on a pin-on-disc test against Counter bodies WC–Co pin, the friction coefficients of TiMoN coatings were found to decrease with the increase in Mo atomic fraction, with the lowest friction coefficient values of 0.4 to 0.5 one-half that of TiNcoating.

Anantha Kumar R. et al.2011 [17] prepared TiN/TiAlN multilayered coatings with 20–30nm bilayers lengths and thickness of 2µm by DC reactive magnetron sputtering and Substrates were cleaned in an ultrasonic bath using acetone and trichloroethylene. Using pure titanium and titanium aluminium alloy target. The frictional behaviour of the coatings under an average load of 3.924N at room temperature is shown in figure 7. In figure 8, a large difference can be seen in wear rate and the lowest for the TiN/TiAlN multilayer coatings. Sliding friction for TiN/TiAlN coated the 0.40and 0.45forthesingle-layer coatings and bare substrate. TiN/TiAlN multilayered coatings show the lowest coefficient of friction compared to a single layer and bare substrate.

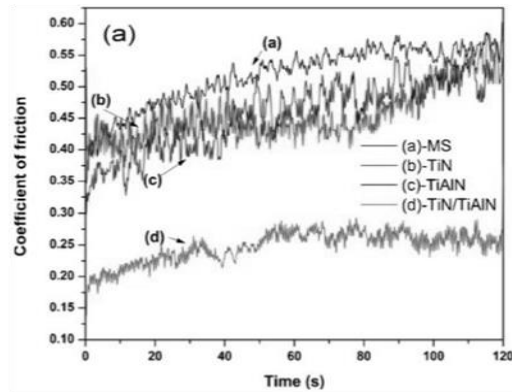


Figure 7 friction co-efficient of the TiN/TiAlN multilayer coatings.[17]

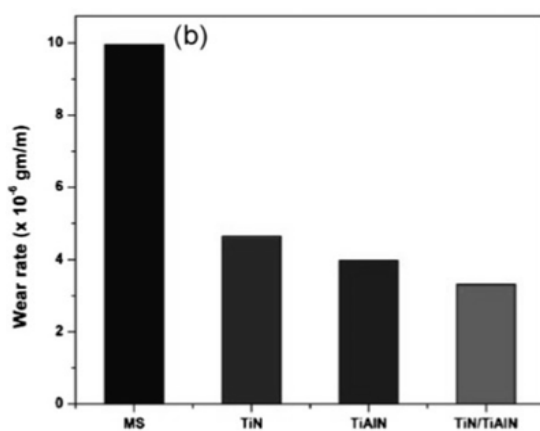


Figure 8 wear rate for TiN/TiAlN multilayer coating.[17]

Firoozeh Danafar et al.2009 [18] Carbon nanotubes (CNTs) are pure carbon in nanostructures with unique properties (physicochemical). They have brought significant breakthroughs in different fields such as materials, energy storage, separation, electronic devices, sensors, etc. optimise process productivity and scale -up the process and dominating process parameters that impact the CNT nucleation and growth need to be understood control product morphology. This paper discusses a general overview of the critical parameters in the CVD formation of CNT.

Chu K. et al.2006 [19] prepared SS (Ti, Al)N films on Si wafers and AISI M42 tool steels only for tribological measurements. They have studied on

mechanical and tribological properties of SS (Ti, Al)N films as a function of negative bias voltage prepared at room temperature by reactive close-field unbalanced magnetron sputtering in an argon and nitrogen gas mixture. So it was found that the nano hardness and residual stress were related to the negative bias voltage Kamat P. 2006 [20] analysed that class of carbon nanomaterials with properties that vary greatly from other types of carbon, such as graphite and diamond, are carbon nanotubes, fullerenes, and mesoporous carbon structures. The ability to custom synthesise nanotubes with functional groups attached or assemble fullerene (C60 and analogue) clusters into three-dimensional (3D) arrays has opened new avenues for the design of high-surface catalyst supports and high-photochemical and electrochemical materials.

SUMMARY OF LITERATURE REVIEW:

- 1) Various types of coating techniques are reported, which can be used for coating purposes. PVD process is reported as a green coating technique.
- 2) It is found from past research that Nickel Chrome (NiCr), Nickel Aluminum (NiAl), Aluminum Bronze (CuAl), Aluminum Oxide (Al₂O₃), Chrome Oxide (Cr₂O₃), Zirconium Oxide (ZrO₂), Titanium Oxide (TiO₂), etc. are most popularly used coating materials and nanocomposites serve as a unique coating material.
- 3) Researchers have worked on various coating process parameters such as “coating thickness, sputtering gas, gas flow rate, sputtering power”, etc.
- 4) It is also reported that selecting appropriate substrate and coating materials leads to

enhanced thermal, mechanical, and wear resistance. Few researchers have also reported the use of multilayer coating deposition on HSS cutting tools.

CONCLUSION

Coating thin films deposition on cutting tools plays a vital role in industrial applications. It gives better properties like high hardness, low coefficient of friction, good wear resistance, excellent corrosion protection, etc. In this review paper, the various methods used for deposition such as sputtering, DC magnetron sputtering system, electroplating deposition, electron beam evaporation are studied, and it is found that out of all these techniques, sputtering is most widely used for a deposit. The parameters of the sputtering process, materials properties, preparation techniques are presented in this review.

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