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A Comprehensive Review on Effect of Zinc, Chromium, Titanium Nanoparticle Coating on Mechanical Properties of EN24T Steels

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A comprehensive review on effect of Zinc, Chromium, Titanium nanoparticle coating on mechanical properties of EN24T steels.

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Abstract:

Industrial punch and die tool steel has been a major part of manufacturing unit and is widely used method of production. As a material EN24T steel is used in punch and die application, this review is carried out to find the recent trends in coating and its properties. The NPs are the type of materials that show an increase in properties of tool steel materials. The main reason to coat this tool is to increase surface hardness, improve tool life. Various coatings like Zinc (Zn), Carbon (C), Nickel (Ni), Chromium (Cr), Vanadium (V), etc. are coated. The processes of coating NPs differ according to the properties required. SILAR, Spray pyrolysis, Chemical Bed Deposition, Physical Vapor deposition, Screen printing, etc. are the amongst them. Coating the NPs show increase in surface hardness, impact strength, reduce wear rate and hence increase tool life. Here we outline the new improvements around by investigating the different strategies for depositing the film of a nanoparticle compound on EN24T punch and die tool steel.

Keywords: Nanoparticle (NPs), Tool Steel, Coating, Hardness, Impact strength, Wear resistance.

1. Introduction

Steel is considered as the most complex and generally utilized designing material because of the accessibility of iron in earth core, high melting temperature, a scope of mechanical properties and the change stage by varying its cooling rate. Steel is broadly utilized in numerous application areas like structural designing, transport and the oil and gas industry. Nonetheless, steel has a few basic issues attributable to its corrosion properties particularly in marine conditions that ordinarily have high saltiness and high humidity, two factors that seriously influence steel's mechanical properties. An expected 20% of world steel creation is lost every year as rust. The hardness of the steel is its main parameter on which it can be selected for various works or production process. Tool steel material requires the highest hardness as it has to go through toughest work amongst all the working instruments used in manufacturing process. The study of various tool steel materials that are used at ground level in the industrial sector of Aurangabad, MH, India is thoroughly done. The main reason of this study is to improve the material impact hardness, surface topography, decrease tool wear, reduces the shock generated while machining. The issue of composites has gotten impressive basic consideration. Ongoing improvements in the field of cold work apparatus steel have prompted a

recharged interest in the modified adaptation of the steel. Until this point, different strategies have been created and acquainted with increasing tooling life by coating the surface to increase the life without altering the compositing of the tool steel. Shockingly, very little data is accessible in literature related with its mechanical properties and microstructure conduct through machining processes for nano-coating on tool steel. Various parameters are modified using coating on tool steel. The most important of all are the friction, surface roughness, hardness, impact strength that is affected by NPs coating. The contact between the tooling surface and the sheet metal produces friction that gives rise to tool and die wear.

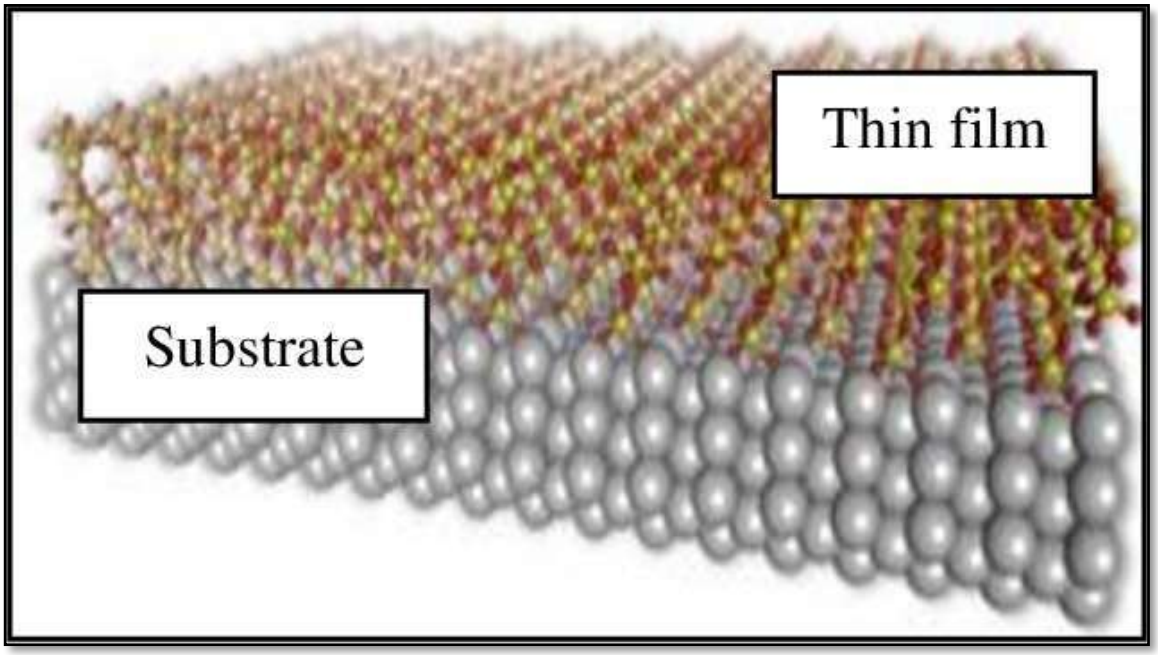

Fig.1 Sol gel coating stainless steel [1].

The tool steel studied all requires an effectively high toughness and impact properties increasing the micro hardness and decreasing the coefficient of friction. The review covered the study of tool steel like EN24T steel. It is a very high hardness value tool steel and is used in various high pressure works. The steel has been coated many times by research and undergone hardness test, impact test, corrosion resistance test. EN24T steel has been abundantly used in industries and studied a lot. All of these materials were coated by various NPs that include Zinc, Chromium, Silica, Tungsten, Titanium, etc. All of these NPs show increase in the mechanical properties like hardness, surface roughness, impact strength, physical characteristics, Anti-corrosive property, chemical resistivity, hardness, thermodynamic stability and other properties. Various coating methods show a good way of coating NPs like chemical & physical deposition, electro deposition, physical vapor deposition, spray pyrolysis, SILAR, etc. These techniques give an advantage over other methods and are readily available nearby. Hardness properties, Surface properties, friction properties, wear properties and impact properties are studied using Vickers Hardness tester, Tribometer, & Scratch tester.

The main reasons for coating tool steel are:

- Increase of wear resistance
- Increase of oxidation resistance
- Reduction of friction
- Increase impact and fatigue strength.
- Increase tool life.

Tool wear and tool life of any tool for any work material is ruled specifically through the extent of the machining parameters i.e. V_c cutting velocity, (t) depth of cut and (f) feed. Cutting speed impacts the most. The paper concludes the method of coating NPs that haven't been coated using metallic NPs on steel substrate. Therefore, a review of the micro structural properties of the process is very useful for both production and R & D. This paper summarizes the principles, advantages, and limitations of the various coating processes for tool steel.

2. EN24T Tool Steel.

EN24 is an exceptionally well known grade of through-solidifying combination steel, which is promptly machinable in the ' T 'condition. The ' T ' condition is the high tensile condition ranging upto 1000 N/mm^2. EN24T is generally appropriate for the assembling of parts like uncompromising shafts and axles, cog wheels, studs and bolts. EN24T can be hardened ordinarily to 58-60 HRC by induction process or nitride processes, creating parts along with improved wear resistance. As above mentioned, EN24T is equipped for holding great effect at low temperatures, subsequently it is as often used in applications like pressure driven bolt tensioners and ship borne mechanical dealing with gear. [2]

Table.2.1. Chemical Composition of EN24 Tool Steel [3].

C	Mo	Si	P	Mn	Cr	S	Ni	Fe
0.5	0.2	0.26	0.02	0.5	1	0.012	1.4	As required

The EN24T grade is a nickel chromium molybdenum blend – it provides high malleable strength to the steel, with great flexibility and wear opposition qualities. With moderately great effect properties at minimum temperature, EN24T is additionally reasonable for an assortment of high temperature applications. P Tamilarasui in his research work gave the idea about the physical properties of EN24T steel while studying it for a pinion use. The data is articulated in a table format below

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Table.2.2 Physical properties of EN24T [4].

Vickers hardness	Impact strength KCV	Tensile strength	Elongation
252-303	35 J	850-100 N/mm^2	13 %

It is drawn nickel chromium molybdenum obtained by hardening steel which can produce a wide range of strengths by heat treating. On a scale of minimum surface scaling tempering and heat can both can be achieved.

A good wear resistance and even high strength is offered by high tensile alloy EN24T steel. EN24T is used in components which show high stress and depict large cross section. In order to get hardened the crystalline structure of mild steel must change, which in usual cases does not happen. This is because the carbon % in mild steel ranges from 0.05 to 0.25% which is not sufficient to change their crystalline structure and hence cannot be tempered or hardened. Its high Cr % gives it the property of corrosion resistance to a certain limit when hardened. EN24T also show good hardness properties and wear resistance. EN24T is an ideal material for production process of punch and die. Due to its hardness properties, EN24T is used in heavy duty applications where wear resistance, hardness and tensile strength are of prime importance. Another feature of EN2T tool steel is the good impact strength values at low temperatures making it popular in offshore applications like hydraulic bolt tensioners. As per N.V Londe [5] EN24 designing steel is not difficult to treat and treat and is provided solidified and tempered. The composite offers a decent blend of solidarity, flexibility and wear resistance. It is an extremely high strength composite for designing steel. EN24T tool steel is a long running tooling applications where the important parameter is wear resistance similar to forming dies or blanking and thread rolling dies. EN24T is more difficult to machine and use of carbide in the machining process is essential. It can be machined when hardened with stainless tip tools. EN24T tool steel has incredible wear resistance and is generally utilized in cold work applications that need sharp edges, abrasive resistance, and compressive strength. It is widely used in the Maharashtra Industrial Development Corporation (MIDC) Waluj, Aurangabad MH for the production and manufacturing of heavy work machine components.

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EN24T Tool Steel Application:

EN24T steel shows application in pinions, gears, shafts and spindles in the automotive and machine tool industries.

EN24T offers a good combination of hardenability, strength and wear resistance.

- Power transmission gears and cams
- Hydraulic bolt tensioners
- Marine mechanical handling equipment
- Dies and punches
- Heavy duty axles
- Shafts, bolts and stud

Heat treatment is also performed to see the change in hardness and machining properties of EN24T to date by J Jones Praveen [6]. According to the authors research EN24 possess high Ni & Cr content which serve as anti-failure properties. It was also found that gas nitriding was also a method to increase its hardness. But nano-coating on EN24 is still to be studied on a major basis. However, AISI36 stainless steel coatings and other steel coatings are prominent on EN24 tool material. The process parameters of EN24 were greatly improved by the coatings, hence a coating on the surface can give rise to increased quality in performance. It was all concluded from the research of George Sahaya Nixon [7].

EN24T steel has different properties better than other steel materials. EN24T has Cr, Mo, Ni content which is not present in EN8 steel. EN8 tool steel rather bearing good hardness value has high per kg cost. Same is the case with other tool steels. The cost of EN24T is 30-67 INR while EN8 costs 75-375/kg, D2 600-900/kg, A2 300-400/kg.

But how does EN24T get affected by various parameters? All the parameters have been taken into consideration as mentioned below:

Effect on hardness: A major component influencing wear resistance is "hardness". As a general rule, the wear resistance increases as the material itself becomes harder. Nonetheless, it isn't right to expect that making the material hard by treating it, since it is better that the inside leftover pressure in the steel material is low not withstanding higher hardness of the material. This is the justification for why treating and toughening are done together. But excessive addition of carbon leads to increase in brittleness and reduces weldability if carbon is more than 0.25%it can later form martensite.

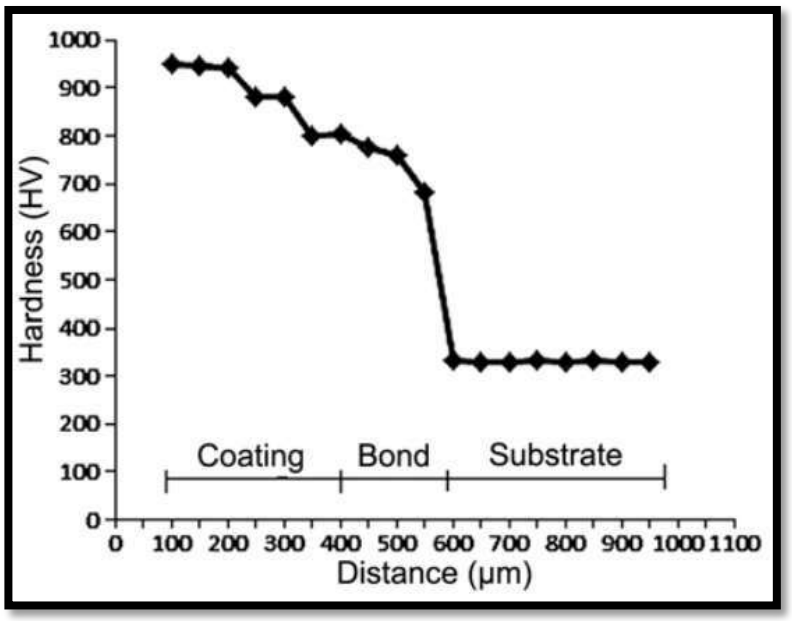

Fig.2.1 Effect of coating on hardness of steel [8]

Effects on the Constituents: If the carbon content surpasses 0.6%, the tempered hardness does not increase and remains constant. But when the hardness becomes constant the wear resistance does not remain stable at the same point [9].

Effect on the Material Structure: After steel material tempering, carbon (C) and iron (Fe) bind together and the material changes into a martensite. This martensite change is effective for wear resistance property. However, not all of the material conversion to martensite takes place in high carbon steel or high alloy tool steel (SKD, etc.), and about 20 to 30% of the material remains as austenite. This austenite remnant is not good for wear resistance. The residual austenite is converted into martensite. As a method of converting the residual austenite into martensite, there is the sub-zero processing.

Effect on Impact strength: Impact strength increases with increasing temperature.

Material thickness: Thickness reduces with increase in the impact strength

Notch radius: Impact strength decreases with use of small notch tip radius.

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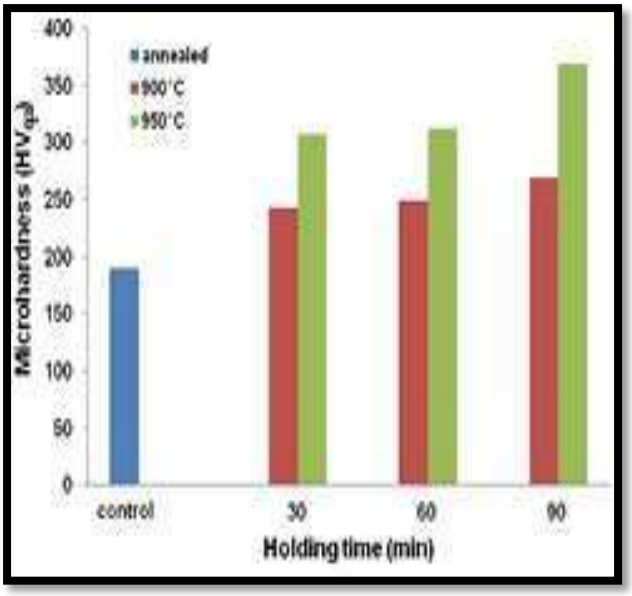
3. Importance of Coating nanoparticles.

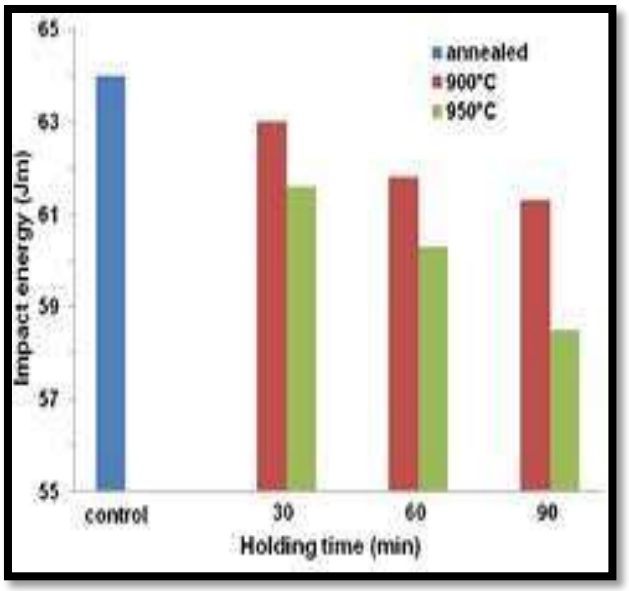
The hardness of a material is the main parameter that defines the life of the tool. Coating tools can be an alternative to adding metallic components in the process of manufacturing tool steel. As excess addition of quality increasing materials can lead to brittleness of the tool steel, coating the surface that is subjected to high work load can make the composition be intact as well increase the material properties.

When cutting instruments are appropriately covered and proceed as planned, the outcome for the end client is higher cutting information, longer device life and the chance of dry machining. The five main parameters and reasons for coating tool materials are:

- To increase wear resistance
- Oxidation resistance increases
- Reduces friction
- Adhesion wear
- Diffusion wear
- Friction reduces
- BUE formation occurs
- Build up in quality of product.
- To increase resistance to thermal shock.
- Reduction of cutting forces and power consumption
- Tool life increases by 200%-500%(VC remains same)
- VC increases by 50%-150% for similar life of tool
- Build up in quality of product
- Effective machining of numerous work materials
- Heat resistance and thermal cracking reduces and plastic deformation occurs.
- Increases resistance over fatigue of metal [10].



a) Fig.3.1 a) Variation of micro hardness



b) Variation of impact energy due to coating [11].

4. Properties of different Nanoparticles

4.1 Zinc Nanoparticles.

Zinc NPs are available in the form of Zinc Oxide (ZnO), Zinc peroxide (ZnO_2). Zinc Oxide nano powders are accessible as powders and scatterings. Zinc Oxide show antibacterial, anti-destructive, antifungal and UV screening properties. Zinc is amongst D-Block, Period IV component, while Oxygen belongs to P-Block, Period II component. ZnO shows high toughness, strength, optical, electrical conductivity, and bacterial resistance [12].

Table.4.1 Chemical Properties of Zn NPs [13]

Group	Zinc 12, O 16
Chemical symbol	ZnO

According to Ramdziah Bt. Md Nasir [12] due to the addition of ZnO NPs there can be seen an increase in the micro hardness value and due to this the volume loss also occurs. This is on the grounds that the plastic contact region of composite surface to rough surface will decrease with expanding composite hardness.

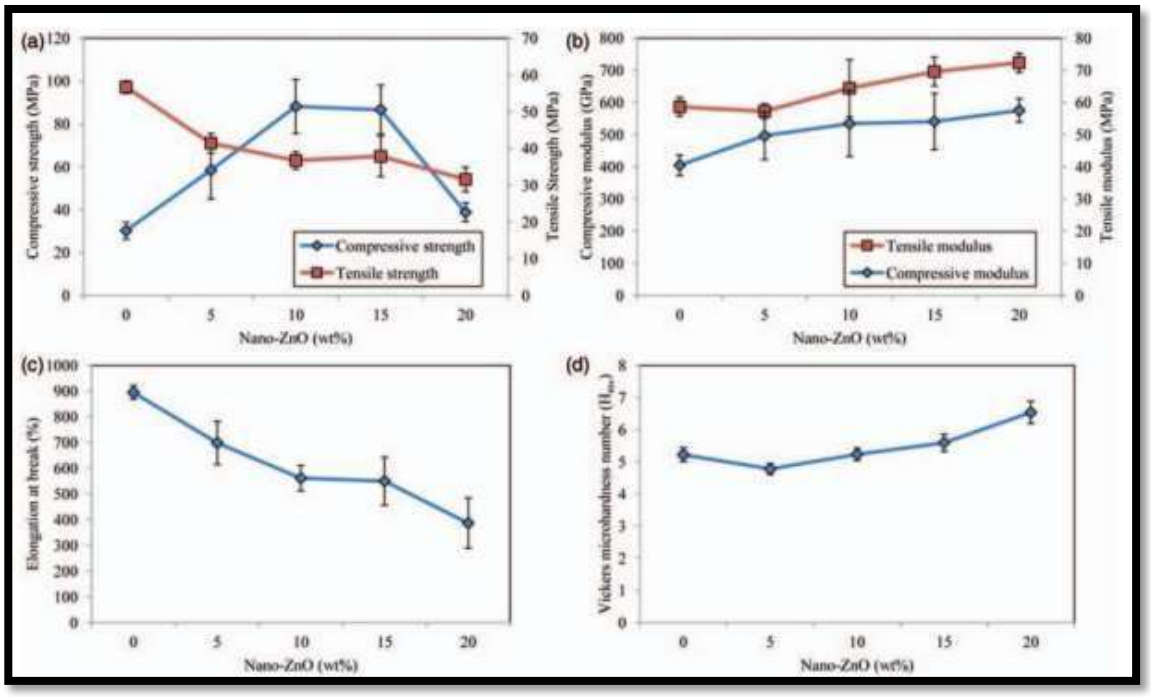


Fig.4.1 Zinc Oxide Mechanical Properties [12]

Also Zinc NPs coating showed improvement in the frictional force values. Spherical shape NPs of Zn for reducing frictional forces in sliding teeth movements of gear were tested and were found to be better than non-coated. Due to the positive impact shown by the coating of Zn NPs, the author Baharak Divband in the paper titled "The effect of zinc oxide NPs deposition for friction reduction on orthodontic wires" [14]. said that these NPs may offer a brilliant opportunity reduce friction wear of any material including wire.

Table.4.2 Chemical Composition of Zinc Oxide

Element	**% Composition**
Zinc	80.34
Oxygen	19.66

The thermal properties of ZnO are that it has melting point in the range of 1970-1975°C and boiling point temperature of nearly 2400°C. Even the Young's Modulus of the steel is found to be improved due to the coating of Zn NPs. So the coating of Zn as Zinc Oxide NPs is done on various tool steel until now and show a very good results in the metallurgical properties has been noticed all along. Zn is coated along with Si even Fe, dipped in electrolyte of 0.3% to 3.0 wt % of Sodium Chloride [15].

Abeer Shmait [16] has his say after coating on the surface of steel using polyurethane by adding Zn NPs. The conclusive evidence shows that ZnO NPs enhance the anti corrosion properties of the steel it was applied on, even recommended the use of NPs while coating on the surface of steel to give rise to

better mechanical as well as tribological properties. Zinc rich coatings on the surface of steel along with Aluminium gave a good anti-corrosion property and were proven by M. Bu¨tefu¨hr [17].

Zinc Oxide Nanoparticles Application:

Iron must be covered with zinc oxide since its high reactivity rate with natural coatings prompts an absence of grip and weakness. In this way, it holds the adherence and adaptability on a superficial level where natural coatings are futile to apply. Another benefit of utilizing zinc oxide for coating steel is that the coating stays flawless for long years.

4.2 Chromium Nanoparticles.

Chromium NPs are obtained in the form of Cr_2O_3 . Amongst the metal oxides, Cr_2O_3 is more perceptible due to its thermodynamic dependability, synthetic opposition, hardness, and anti-ferromagnetic qualities. Cr_2O_3 NPs are used as thermal spray materials in order to protect the surface and act as corrosion resistant and even as a wear resistant material. It has applications in coating of bearing [18]. They can combine in formation of various compounds that show their applications in thermal spraying and thermal spraying; this material shows environment friendly properties regarding hard plating [19].

N. GIDIKOVA [20] did composite coating of Chromium NPs and Diamond NPs on the steel and carried out X-ray analysis on chromium steel plated along etched section. The result showed that deposition of Cr NPs brought an increase in micro hardness of the surface with the addition of diamond NPs. Hybrid Chromium coatings can result in the well versed of the properties of steel surface. Shell formation was seen on chromium coated surface, hence change in the properties was noted.

Table.4.3 Chemical Properties of Cr NPs [21].

Chemical Symbol	Cr_3C_2
Electronic configuration	Chromium [Ar]. $3d^5 4s^1$
	Carbon [He]. $2s^2\ 2p^2$
Group	Chromium 6
	Carbon 14

Blend containing Fe-Cr was used to produce a surface coating of Chromium carbide on stainless steel by Thermo-Reactive Deposition (TRD). The layer deposited was in the range of 3-8 μm. The hardness of the steel before coating was approximately 700 HV and this value hit the mark in between of 1700-1900 HV.

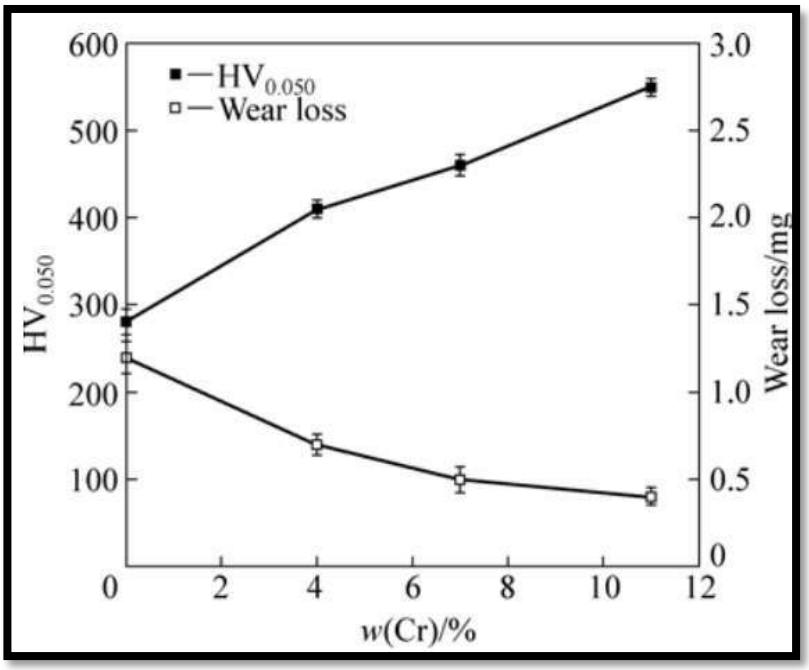


Fig.4.3 Hardness value & wear Loss Against Cr % (wt) coating. [22].

In fig.4.3 ZHOU Yue-bo [22] research gave us this evidence that as the concentration of Cr percent wise increases the wear loss decreases and the hardness value of the surface coated increases.

Applications of chromium carbide:

- Metal surface bed protected by thermal spray of material.
- Increase wear and corrosion-resistance of tool materials.

Corrosion resistance is used as a mix in various coatings to increase hardness.

The author, Xiaoming ZONG [23] also mentions that Cr7Cr3 provide extreme hard coatings. Even the coefficient of friction was observed to be improved from a particular value of 0.5 to 0.3 and the weight loss in wear decreased by a net value of 89%.

The composite coating of Cr-Graphene on the surface of the steel by Rekha M. Y [24] and stated that " Graphene incorporated Cr coating is nobler towards the aggressive environment ". Even chromium as Cr2O3 is used to improve the characteristics of epoxy coatings on tool steel and improved the performance barrier that Fe brought in the form of corrosion. [25].

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4.3 Titanium Nanoparticles.

Titania existing as oxide of titanium is perceived as NPs of metal oxides establishing interesting optical, warm, electric, and attractive properties. Under ordinary condition, Titanium dioxide is insoluble in water and is profoundly steady. These NPs can be green manufactured also. It is available in the form of Titanium dioxide that is readily available in the form of nanodots, nanocrystals or substrate particles.

The study from the research of Dongdong Zhang [26] consisted of Ti NPs when incorporated to Sn-Co as Sn-Co-TiO_2show significant increase in the micro hardness, microstructure, mehcnaical properties and corrosion resistance. Ti NPs has high surface area and high magnetic properties depending emphatically on qualities of these NPs that incorporate thermal resistant properties, mechanical properties, biodegradability, optical properties, penetration as concluded by H.Salehian [27].

Titanium is a Period IV, D block element whereas oxygen as previously mentioned is a P block, period II element. TiO_2 is otherwise called flamenco, titanium dioxide, rutile, and dioxotitanium. TiO_2 NPs coating has been successfully done on mild steel before by A. Shanaghi [28]. using sol-gel method. Crack less coating of the NPs resulted in the improvement in corrosion resistance, by increasing the thickness of coating by 555 – 565 nm improves the corrosion properties of the metal sample.

Table.4.4 Chemical Properties of Ti NPs [29].

Chemical Symbol	TiO_2
Group	Titanium 4 Oxygen 16

Hua, Y. [30]., noted that Titanium nitride (TiN) coatings improve the corrosion resistance, conductivity, shear modulus, wear resistance and creep performance of tool steel material.

Good thermal and electrical properties and coatings possess and resistant to oxidation, erosion , corrosion and wear in high temperature environments is seen in TiO_2 nanoparticles. This property is very important factor in the applications such as pipelines, castings and automotive industry.

The increase in corrosion resistance due to the coating of TiO_2 NPs on the surface of mild steel using Tafel polarization was observed and noted by A. Shanaghi [31]. The result output shows the decrease in i_{corr} value from 18 to 0.2 $\mu A/cm^2$.

The packing factor and the texture coefficient are the factors that affect the film thickness and thus the hardness of TiN NPs coated surface also increases [32]. This is the study of Wen-Jun Chou who also gave the change in hardness value due to the coating thickness in µm as shown in fig 4.4 below.

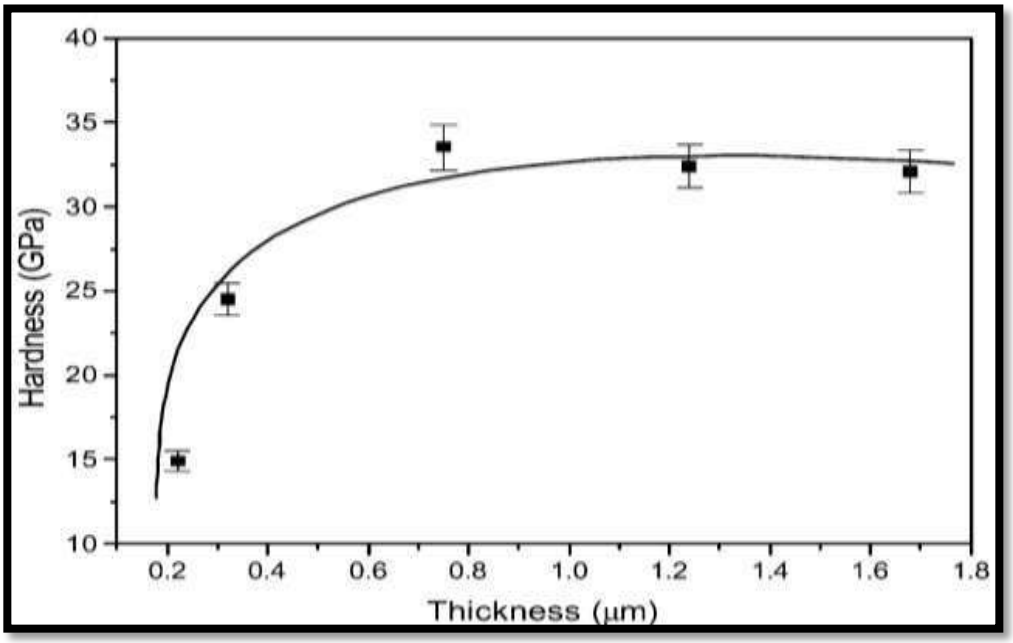

Fig.4.4 Effect of TiN Coating on 304 Stainless Steel [32].

Table.4.5 Effect of TiO_2 on the impact strength of steel [33].

Sr.No	W	0.75% NPs	1.5% NPs	2% NPs
1	172	204	224	156
2	158	210	210	184
3	164	216	250	172
4	162	194	224	196
5	156	202	248	148
AV	162.4	205.2	231.2	171.2
Improvement ratio	0.0%	24.35%	42.36%	5.41%

The change in value of impact strength before coating and after coating TiO_2 NPs was studied by Ali Sadiq AlIthari [34]. The result depict that the average impact strength of a sample without coating TIO_2 was around 163 J, although with the coat of TiO_2 under sudy show the impact strength to be around 232 J. It is a straight increase of 1.5% in the impact strength. Also increase in impact hardness/resistance of the joints that are welded due to cultivation of TiO_2 was seen. Results showed an improvement in the impact strength of the steel specimen by 40-50% under a certain amount of NPs quantity utilized.

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5. Conclusion:

The composition of the tool steel material plays a vital role in coating the NPs. Figure 1. Gives a comparative study that when the tool steel is heat treated, plasma nitrated 7 when coated. The study concluded that various tool steels have different properties and these properties give them a different application. D2 has hardness of 60 HRC, while EN24T has hardness value 58-60 HRC. Zinc NPs show increment in hardness value and decrement in surface roughness. With increase of coating thickness of Titanium NPs the hardness value increases, impact strength increase and wear factor decreases. The tool steel EN24T that has still work to be done on. As D2 steel is eventually hardest that doesn't need any coating further but EN24T needs to improve a bit. The main result that came out is the cost of steel. EN24T even after getting coated does not exceed the basic cost of other tool steels. All the coating methods are reliable and coat specifically on metals and wide spread use of them is still done on the industrial level of Aurangabad. Hardness testing for these steel materials shows a rise from 70-170 HRC due to coating.

Future scope:

The thickness of coating can be improved using various different methods of coating. EN24T is a cheap material that can be treated and can be used as an alternative to many steels of high cost and same composition.

Conflicts of interests: There are no conflicts of interests amongst the authors.

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