

Lifetime and Performance Improvement of HSS Drill Bit by Titania (TiO₂) Nano-Coatings and Cryogenic Treatment

Prabhu Kiran Martha, K. Kishore, Gokarakonda Ramadevudu

Abstract: The small and medium scale industry in drilling and cutting sector widely use cutting tools made by High Speed Steel (HSS). The improvement of lifetime of HSS drill bits helps these establishments to achieve product economy. The improvement in the performance and service lifetime of high-speed steel (HSS) twisted drill bits are studied by depositing Titanium dioxide (TiO₂) nano-coatings using reactive dc magnetron sputtering Method. Pure titanium (99.99%) metal is used as target material for making nano-coatings in oxygen atmosphere. X-ray diffraction studies indicated change of phase of annealed samples compared to as-deposited coatings. X-ray reflection (XRR) measurements estimated nanocoating thickness on the HSS drill bit around 100nm. The lifetime of TiO₂ nano-coated, and cryogenically treated nano-coated tools significantly improved compared to uncoated (bare) HSS drill bit. The tool life has been enhanced by about 16% when TiO₂ nano-coatings were made on HSS drill bits. Further lifetime enhancement of 10% was observed when the nanocoated drill bit is given cryogenic treatment in liquid nitrogen. SEM images and EDS profiles are reported. The minimum surface roughness measured as 7.296x10⁻⁶m for TiO₂ coated and cryo-treated HSS drill tool.

Index terms: Cryo-treatment, d.c. Magnetron Sputtering, Nano-coatings, Surface Finishing, Titanium Oxide, Twist drill bit.

I. INTRODUCTION

High Speed Steel (HSS) twist drill bits are widely used metal removing tools in the mechanical, electrical and electronic industries. Improvement of their lifetime and performance is one of the important aspects of research in the area of metal cutting and drilling. The materials used to fabricate tools should have good wear resistance, hardness and toughness. The frequently used tools for metal removal from the work pieces in small and medium scale industries are manufactured from high speed steel (HSS), sintered tungsten carbide (WC), ceramics, polycrystalline cubic nitride (PCBN), polycrystalline diamond (PCD) etc.

The widespread use of HSS drill bits is due their low cost, high toughness and capability of withstanding high loads. Several researchers reported tool life improvement

using various methods viz cryogenic treatment, thin film protective layers, nano-coatings etc. These coatings help to decrease wear and tear of the drill bit during machining. Many process parameters and external parameters such depth of cut, wet or dry machining, speed of cutting, temperature, materials used for making drill bits and work pieces etc.

S.K. Mishra et al [1] studied multilayered SiCN coatings deposited by magnetron sputtering. In their study, they achieved a hardness of 37 GPa with elastic recovery of 62% by alternate hard and soft layers of Si-C-N coatings. Damian Wojcieszak et al [2] studied mechanical and structural properties of titanium dioxide nano-coatings using both conventional and pulse magnetron sputtering technique. According to their results TiO₂ coatings fabricated by magnetron sputtering have shown best results in improving the hardness. The enhancement of corrosion resistance, durability, corrosion resistance by depositing coatings of chromium nitride, titanium-aluminum nitride etc., were also reported several research workers [3-5] Hafedh Dhiflaoui et al [6] reported an increase of wear resistance of 316L stainless steel when coated with TiO₂ nano-coatings. Das et al [7] reported wear, hardness and the microstructural characteristics of AISI D2 steel cryo-treated at 77K for various soaking times and reported that best wear resistance is observed for specimens cryogenically treated for 36 hours.

The multilayer coatings such as TiAlN/CrN have shown excellent pore resistance and corrosion resistance [4]. The nano crystalline-amorphous composite coatings due to their structural advantages can offer high cohesive energies which limit crack growth and thus offer high toughness and low friction [1,8]. In addition, thin and nano-coatings on drill bits and other cutting tools, cryogenic treatment is also gained importance in the improvement of tool life since cryogenic treatment is one-time application and increase the wear resistance further [9-10].

The review of the literature reveals availability of performance and lifetime improvement studies on HSS steels and other steels due to nitride, carbide coatings, but oxide nano-coatings of TiO₂ and cryo-treatment of TiO₂ nano-coatings are limited. In this paper, we report studies on lifetime and performance parameters of HSS drill bits and HSS a comparative study has been done on the performance of bare tool, TiO₂ nano-coated and cryogenically treated TiO₂ nano-coatings on high-speed steel twist drill bit tools.

II. MATERIALS AND METHODS

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8.5 mm and 10mm diameter HSS twisted drill bits of ADDISON brand are purchased for the present study. The general chemical composition of High-Speed Steel drill bit contains (in weight %) carbon (0.65-0.80%), chromium (4%), tungsten (18%), vanadium (1%), manganese (0.1-0.4%) and silicon (0.2-0.4%). Some important mechanical properties of HSS (Mild steel) are Rockwell

and 22 m/min respectively for 8.5mm and 10 mm drill bits. The feed rate is 0.2 mm/rev and dept of the hole is 10mm for both the drill bits. At the beginning, holes are drilled on the workpiece using uncoated HSS drill bit under dry conditions and lifetime of the bare drill bit was estimated. Subsequently, TiO₂ nano-coated HSS drill bit and cryo-treated nano coated HSS drill bits are used to make



Figure 1. Reactive DC Magnetron Sputtering vacuum chamber, loaded HSS drill bits and deposition

Hardness 65 (60), ultimate tensile strength 380 MPa (440Mpa) and Young’s modulus 233 GPa (200GPa). The drill bits were cleaned initially with acetone and then vacuum dried. Before start of actual deposition, sputtering process parameters such as substrate temperature, operating pressure, target power etc. were optimized for best coating results. The cleaned drill bits were introduced into the vacuum chamber of Reactive DC Magnetron Sputtering machine to coat TiO₂ nano-coatings. The instrument base Pressure was kept at 1x10⁻⁶ Torr and operating pressure was kept at 4.95x10⁻³ Torr. The purity of the target titanium metal is 99.99%. The density of titanium is 4.506 g/cm³. The deposition is carried out under inert atmosphere by passing argon gas at a flow rate of 49.5 standard cubic centimeter per min (SCCM). The deposition is carried in oxygen atmosphere (0.5 SCCM flow rate) to form Titania (TiO₂) nano coatings. Figure.1 shows Reactive DC Magnetron Sputtering vacuum chamber, loaded HSS drill bits and deposition on a quartz slab to carried out characterization. Thin film deposition was carried out simultaneously on the drill bits and a small quartz slab at a deposition rate of 80Å/sec for about 56 min 48 sec using 2-inch target of pure titanium. The TiO₂ nano-coated quartz slab is used for X-ray diffraction (XRD) and X-Ray Reflectivity (XRR) studies. Figure.2 depicts the Scanning Electron Microscope images of TiO₂ coatings and the profiles of elements present in the coatings. The TiO₂ coatings were characterized by x-ray diffraction using Bruker D8 Advance X-Ray Diffractometer equipped with Cu-Kα X-ray source. The diffractometer is fitted with one dimensional position sensitive silicon drift detector. The X-ray diffractogram of as-deposited TiO₂ nano coating is peak free. After annealing for 2 hours at 400°C, the sample developed X-ray diffraction pattern Bragg peaks. Scanning Electron Microscope (SEM) and EDS profiles are recorded on Zeiss instrument. Mild steel bright materials were chosen as workpiece and HSS twist drill bits of 8.5mm and 10mm are used to drill holes on the workpiece by a pillar drilling machine under dry conditions. The spindle speed fixed at 680 rpm for both 8.5mm and 10 mm drill bits. The cutting speed was maintained at 18 m/min

holes on separate mild steel workpieces. A dynamometer fitted with stain gauges is used to measure thrust force, torque developed during machining. The TiO₂ nano coated drill bits were soaked by immersion method in liquid Nitrogen at 77K (-196°C) for 24 hours at (77K) for cryogenic treatment.

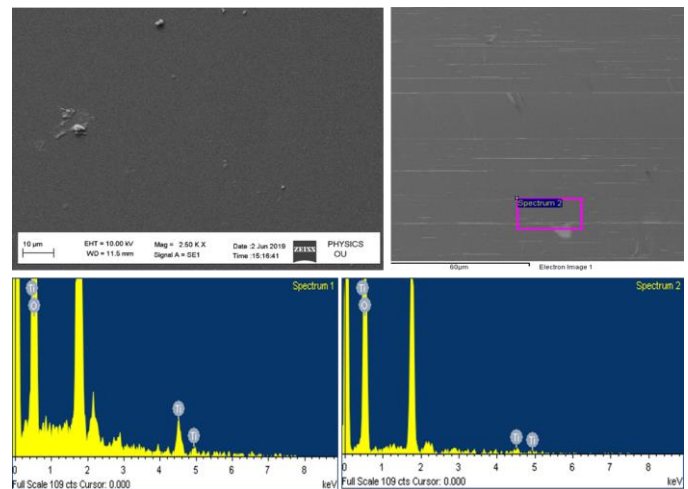


Figure 2. SEM images and EDS profile of surface of TiO₂ coatings

The improvement in the tool life of TiO₂ coated and coated cryo-treated drill bit were estimated and compared with bare drill bit results. The surface roughness was checked by using Taly Surf instrument for drilled holes on bar TiO₂ coated and TiO₂ coated and cryo-treated drill bits.

III. RESULTS AND DISCUSSION

a. X-Ray Diffraction:

Figure.3 shows X-ray diffraction patterns of as-deposited TiO₂ nano-coating and annealed TiO₂ coating. The x-ray diffraction pattern of as-deposited TiO₂ nano coating is peak free confirming the amorphous nature of as-deposited coatings on the HSS drill bit. Weak Bragg's peaks appeared in the X-ray diffraction pattern after annealing TiO₂ coatings at 400°C for 2 hours.

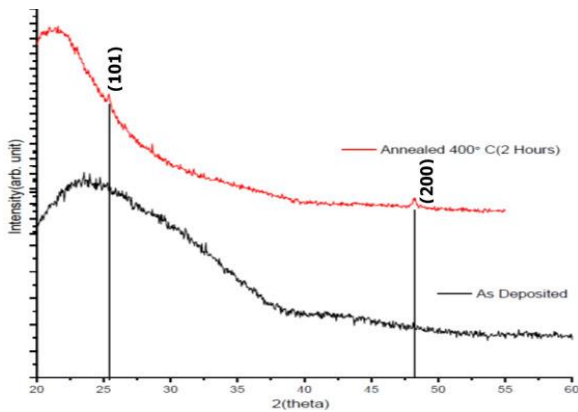


Figure 3. X-Ray diffraction patterns of TiO₂ nano-coatings as-deposited and annealed

After annealing, the amorphous nature of as-deposited coatings is converted into poly-crystalline structure. The Bragg peaks were observed 2θ values around 25.4° and 48.18°. The Bragg peaks depicted by X-ray diffractogram confirmed the existence of anatase phase of TiO₂ after annealing at 400°C. The diffraction patterns clearly indicated anatase structure and no rutile phase is observed [11-12]. In general, TiO₂ films annealed above 900°C exhibit rutile structure [13]. The change from amorphous state of the film to poly-crystalline state of deposited TiO₂ films may be attributed to thermal stability. With increase in temperature during annealing titanium and oxygen atoms might have rearranged themselves due the available thermal energy and thereby TiO₂ unit cell acquired stable configuration as well as defect free [14]. The anatase phase belongs to tetragonal structure.

b. X-ray Reflectivity (XRR)

X-Ray Reflectivity technique is one of the widely used technique to measure thickness of deposited films up to 1000 nanometers. X-ray reflectometry (XRR) measures total external reflection of x-rays to estimate the thickness, density and surface roughness of thin coatings. Reflectometry data obtained from the experiments is used to estimate the thickness of the coatings. Figure.4 shows X-Ray Reflectivity pattern of TiO₂ deposited film. The approximate thickness of the deposited TiO₂ coatings on the HSS drill bit is around 100nm.

c. Lifetime and the Performance of tools

Drilling of holes has been carried out on a mild steel workpiece using bare, TiO₂ coated and TiO₂ coated and cryo-treated HSS twisted drill bits of 8.5mm and 10mm diameter using pillar drilling machine without any coolant support. To calculate lifetime of the drill bit, holes are made

on a mild steel plate until 1mm flank wear observed. The tool life is evaluated by multiply the time take for making on hole with number of holes drilled. Table.1 presents the time taken, number of holes drilled and other parameters like thrust force, torque and surface roughness. Table.2 gives EDS profile values of the TiO₂ nano-coatings from two iterations.

We observed enhancement of machining time when the bare tool is immersed in liquid nitrogen. A significant improvement in the lifetime is observed when HSS drill bit is

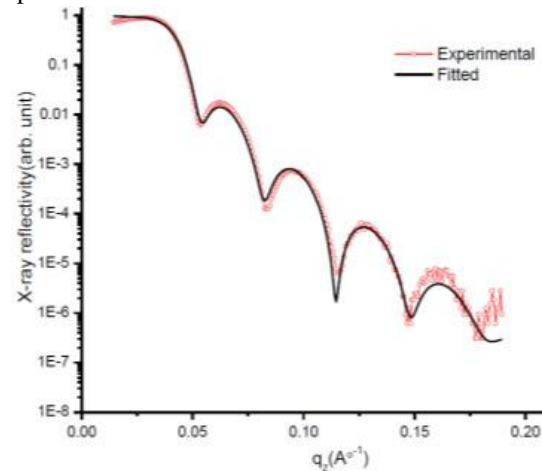


Figure 4. shows X-Ray Reflectivity pattern of TiO₂ deposited film.

coated with TiO₂ nano-coatings and subsequent cryogenic treatment further improved the life of the tools. Compared to bare drill bit, TiO₂ nano-coating on the HSS drilling tool improved the tool life around 16%. A further improvement of 10% is gained when TiO₂ nano-coated HSS drill bit is cryogenically treatment in liquid nitrogen.

The variation of tool life of uncoated, TiO₂ nanocoated and nanocoated cryo-treated tools is shown in figure 5. It is clear from figure that TiO₂ nano-coatings and subsequent cryo-treatment improved the lifetime of the tool for both 8.5mm and 10mm diameter HSS drill bits. The lifetime of 8.5mm HSS drill bit is increased from 30.37 min (bare) to 36.06 min with TiO₂ coating and a further increase to 40.64 min when the nano coated HSS drill bit is cryo-treated.

Table.1 Drill tool dynamometer and Taly Surf parameters

Tools	Tool diameter (mm)	No. of Holes	Tool life (min)	Thrust force (N)	Torque (Nm)	Surface Roughness (μm)
Bare	8.5	303	33.80	147.66	0.136	8.568
TiO ₂ coated	8.5	352	39.30	105.60	0.056	7.357
TiO ₂ coated and Cryo-treated	8.5	401	44.70	108.30	0.060	7.296
Bare	10	272	30.37	107.83	0.181	8.710
TiO ₂ coated	10	323	36.06	129.83	0.215	7.788
TiO ₂ coated and Cryo-treated	10	364	40.64	110.00	0.250	7.571

Figure.6 represents variation of thrust force with uncoated, TiO₂ nanocoated and nanocoated cryo-treated tools. A sharp fall in the thrust force is observed for both 8.5mm and 10 mm HSS twisted drill bits when the bits are TiO₂ nanocoated, nanocoated and cryo-treated.

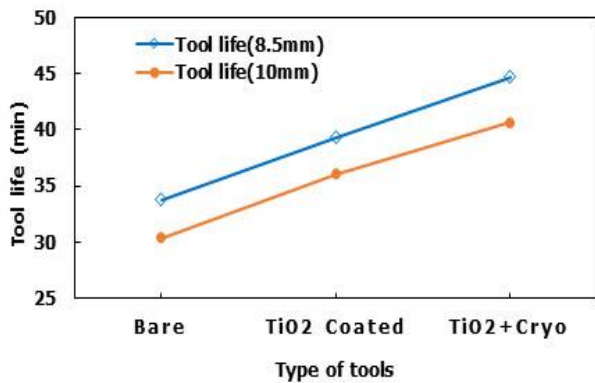


Figure 5. Variation of tool life of uncoated, TiO₂ nanocoated and nanocoated cryo-treated tools

The variation of torque with uncoated, coated and cryo-treated tools is shown in figure 7. Both the drill bits (8.5mm and 10mm) have shown an increase in the torque with nano coatings and cryo-treatment.

The surface finishing of uncoated, coated and cryo-treated tools is shown in figure 8. There is a good improvement in the surface finish with the nano coatings and cryo-treatment. Drill tool dynamometer and Taly Surf parameters are presented in table 1.

The TiO₂ coatings on the drill bit diminished the friction

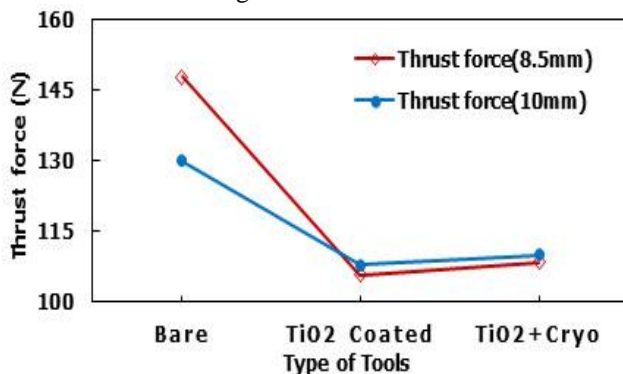


Figure.6 Variation of thrust force with uncoated, TiO₂ nanocoated and nanocoated cryo-treated tools

between the drill bit and the workpiece surface so that smooth chipping is achieved. Due to this factor wear of the drill bit is reduced and life of tool has increased. It can also be seen from table.1 that the thrust force of bare drill bit

decreased when it is coated with TiO₂ and at the same time torque also decreased.

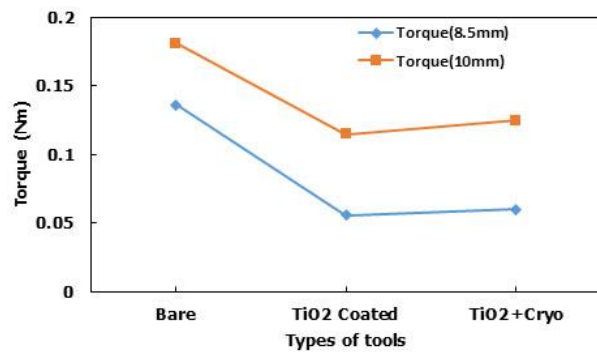


Figure 7. Torque variation during drilling with different tools

The decrement in the torque and the thrust force improves sliding during drilling and thus the performance of the drill bit is improved. The surface roughness also improved with TiO₂ coatings and with cryo-treatment. The minimum surface roughness of 7.296 micrometers is observed for TiO₂ coated and Cryo-treated HSS drill bit. Improvement of surface roughness results in good finishing of the cut.

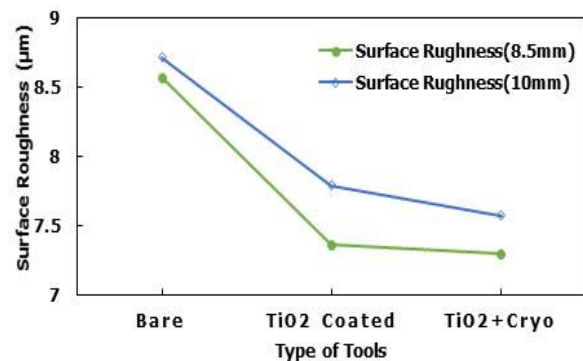


Figure 8. Surface Roughness measured for drilled holes with different drill bits

It is known from the literature cryogenic treatment significantly improves abrasive wear resistance, tensile strength and reduce the brittleness, fatigue resistance of the tool materials due to microstructural changes in the tool material [15-17]. Similar findings are observed with cryo-treated TiO₂ nano coatings on the HSS twisted drill bits in our study.

Table.2 EDS profile values of the TiO₂ coatings from two iterations

Element	Iteration-1		Iteration-2	
	Wt%	Atomic%	Wt%	Atomic%
O	89.21	96.12	92.43	97.34
Ti	10.79	3.88	7.57	2.66

IV. CONCLUSIONS

In this paper, we reported the performance and lifetime improvement of 8.5mm and 10mm high-speed steel drill bits by nano TiO₂ coatings and cryogenic treatment. Considerable improvement in the performance of the tool has been observed due to TiO₂ nano-coatings and cryo-treatment. The TiO₂ nano-coatings are deposited on the high-speed steel twist drill bit using reactive dc magnetron sputtering technique with 99.99% pure titanium metal in oxygen atmosphere and argon gas flow. The significant conclusions of the study are:

- Post deposition annealing at 400°C for 2 hours converted the amorphous films TiO₂ into polycrystalline anatase phase.
- The X-ray Reflection measurements have shown that the thickness of TiO₂ deposited nano-coatings on the HSS drill bit is around 100nm.
- A lifetime improvement of 16% is observed when the HSS drill bit is TiO₂ nanocoated. A further improvement of 10% lifetime is observed when the coated drill bit is given cryo-treatment in liquid nitrogen.
- TiO₂ coated and cryo-treated tools developed less torque and thrust force during the drilling which is attributed to improvement in the sliding of the tool into the workpiece.
- The holes drilled with TiO₂ nanocoated and TiO₂ coated and cryo-treated drills have shown better surface finish than drilled with uncoated bare drill bits.
- Both 8.5 mm and 10 mm diameter drills have shown a sharp decrease in thrust force, torque and improved surface finish.
- The enhancement of performance and increase in service lifetime of TiO₂ nanocoated HSS twist drill bit are attributed to reduced friction between the tool and the workpiece because due to TiO₂ nano-coatings and cryogenic treatment.

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