PERFORMANCE OF COATED CUTTING TOOLS IN MACHINING: A REVIEW

Rukmini Srikant Revuru[1]*, Vamsi Krishna Pasam[2] and Nageswara Rao Posinasetti[1]
[1,3] Department of Technology, University of Northern Iowa, Cedar Falls, IA, USA.
[2] Department of Mechanical Engineering, National Institute of Technology, Warangal, Telangana, India.
[1]Email: rukmini.revuru@uni.edu *(Corresponding author)
[2]Email: vamsikrishna@nitw.ac.in
[3]Email: posinasetti.rao@uni.edu

Abstract*:* Rapid advances in materials science have prompted the development of materials and alloys of enhanced properties like high strength, hardness, etc. Though these alloys are beneficial in their applications, their machining is difficult. For instance, Inconel 718, a nickel-based alloy, is used in several aerospace applications. This alloy can retain its strength at high temperatures up to 750°C. However, machining Inconel is a problem due to its poor machinability. Similarly, titanium alloys are not very hard but react with tools at high temperatures and lead to their premature failure. Carbide inserts are commonly used as cutting tools in the industry. Carbide tools are manufactured using powder metallurgy technique and possess high strength and hardness, even at elevated temperatures. However, these tools are not effective in machining of "difficult-to-machine" materials and have very short life. In light of this, coated tools have evolved. The cutting tools are coated using very hard, non-reacting material and sometimes a solid lubricant. The coatings are made usually by using PVD or CVD techniques. Often, intermediate layers are provided to improve adhesion between the substrate and the actual coating. Coated tools have better resistance to temperatures and hence, better tool life compared to the regular cutting tools. This paper deals with the evolution of the technology of coated tools. Different types of coatings, their advantages/limitations and efficacy of coated tools in machining are reviewed and discussed.

Keywords: Coatings, *cutting tools, properties, tool wear*

https://doi.org/10.47412/JSID9445

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1. Introduction

Machining is a major stakeholder of the world's economy and accounts to over 5% of GDP of developed nations [1]. If scrap and rework were considered, it would be still higher. Hence optimizing the process through proper selection of all the inputs involved in machining is critical for the growth of economy. As generally understood, machining involves metal removal with a cutting tool. The choice of workpiece material is generally decided by the functionality of the product or choice of the customer. Nevertheless, the choice of cutting tool lies with the machinist. In many cases, cutting tool is selected based on the hardness of the workpiece material, the general consideration being that the tool should be harder than the workpiece. Further, machining involves friction and hence high temperatures. At high temperatures, the cutting tool loses its strength and fails quickly. Most significant properties that influence the performance of tools in machining are hardness, wear resistance, chemical resistance and toughness [2].

Cutting tools are primarily designed to face the major challenges in machining like cutting temperatures and tool wear. Higher cutting speeds lead to high cutting temperatures. High temperatures have detrimental effect on various properties of cutting tools like hardness and strength [3]. Further, cutting tool materials react with workpiece at high temperatures causing failure of tools [4]. Beyond the critical temperature, some of the cobalt particles from the tool get diffused into the chip reducing the strength of tool leading to tool failure. At this temperature, the carbide particles from the tool are also separated from the matrix leading to tool failure [5]. At the tool/chip interface in machining, the composition of the tool changes leading to the separation of particles from the carbide tools. Carbon transfer from the tool is high at elevated temperatures and leads to tool failure. This phenomenon is termed as diffusion tool wear. In addition, tool loses its hardness at higher temperatures leading to plastic deformation. In case of materials like titanium alloys, tools react with the workpiece material and lose their properties. Further, thermal softening of the tools may result in high rates of tool wear. Hence, selection of tool material that is resistant to temperatures is critical for the tool for high speed machining.

Tool wear is another major challenge in the selection of cutting tool. The prolonged interaction of the cutting tool with work surface leads to the wearing of cutting tool. Tool wear affects the quality of products. Use of cutting tool beyond a certain limit may cause excessive chatter and may finally damage the machine tool and quality of machined product. Various mechanisms like abrasion, adhesion and diffusion lead to tool wear. Continuous rubbing of the cutting tool against the workpiece leads to abrasive wear.

Flank wear is because of the constant abrasion of the tool with the workpiece. This is mainly due to abrasive and adhesive wears. Crater wear is formed mainly because of adhesion, diffusion and plastic deformation. Notch wear forms due to the rubbing of the tool with the shoulder of workpiece. It leads to abrasion and removal of surface layers leading to total tool failure. In order to achieve a long tool life, cutting tool material should be resistant to the different wear mechanisms. Cutting tool technology is constantly developed to satisfy the needs of the machining industry.

Though cutting tool technology has evolved over the few centuries, rapid developments took place since the industrial revolution in 19th century [7]. Initially carbon tool steels were used as cutting tools until later half of 19th century when titanium was added to steel to make it harder. Later F.W Taylor developed a class of tools that could retain hardness at high temperatures. This is perhaps the first known high speed steel (HSS). Introduction of HSS tools made increased cutting speeds possible, as high as four times the existing speeds. HSS tools can be of different grades and types, though tungsten based tools are most commonly used. HSS tools dominated the industry for several years. In the beginning of 20th century, a new class of tools based on alloy of cobalt and chromium came into the market. The tools are known as cast cobalt alloys or stellites. These tools had superior wear resistance compared to HSS tools.

Cemented carbides became available around 1920. Carbide tools can be used at speeds about four times higher compared to HSS tools. Carbide tools are manufactured by binding hard carbides like tungsten carbide, titanium carbide, etc. using powder metallurgy technique [8]. Carbide tools have higher thermal conductivity and hardness even at high temperatures compared to most other tool materials [9]. This is an important characteristic required for a cutting tool to withstand the high temperatures encountered in high speed/high feed machining. The properties of carbide tools depend mainly on the hard carbides in the tool. For instance, tungsten increases the wear resistance but decreases tool strength; cobalt improves toughness but reduces hardness and strength [10]. Ceramic tools, which contain aluminium oxide and silicon nitride, retain their hardness at elevated temperatures [11]. However, ceramic tools cannot sustain shocks due to low toughness and chip easily. Apart from the above tools, several hard materials like diamond, cubic boron nitride (CBN) are also used as cutting tools due to their high hardness. However, the use of such tools is limited by their low toughness. Table 1 lists the properties about various cutting tools materials.

Table 1 Properties of cutting tool materials

Cutting tool material	Hardness, Knoop			Transverse rupture strength × 10^3 MPa
	Room temperature	540°C	760°C	
High speed steel	85 to 87	77 to 82	Very low	3.8 to 4.5
Cast cobalt	82 to 85	75 to 82	70 to 75	1.4 to 2.8
Carbides	89 to 94	80 to 87	70 to 82	1.4 to 2.4
Ceramics	94	90	87	0.5 to 0.4
Diamond	7000	7000	7000	---

As a recent development, cutting tools are coated with a variety of materials like titanium nitride, titanium carbide, chromium nitride and aluminium oxide. The coatings are metallurgically bonded to the cutting tool, known as substrate. Apart from protecting the tool from abrasion and adhesion, the coatings also provide protection from oxidation and diffusion wear [12]. Coated cutting tools often have two to three times the tool life compared to regular tools. Generally, the coating thickness is maintained between 2-10 µm [13].

In order to serve their functions, coatings should have high hot hardness, chemical stability and good bonding with the base material. Coating material is chosen based on the application of the cutting tool. Titanium nitride has low coefficient of friction, high hardness, better bonding with base material. Hence, these coatings can be used for machining at high speeds, but are not preferred at low speeds due to chip adhesion. Titanium carbide has high resistance to abrasion and hence low flank wear. Ceramic coatings resist flank and crater wear but do not bond strongly with base tool material and peel off. Of late, multiphase coatings are used, wherein, two or more coatings are applied on carbide tools to combine the advantages of different coatings (Fig. 1). Multiple coatings provide extended tool life and suitable for machining different materials. Commonly used multiple coatings are TiCN + Al_2O_3 + TiN; and TiN + TiC + Al_2O_3. Coated tools account to nearly about 40% of cutting tools in the industry [14].

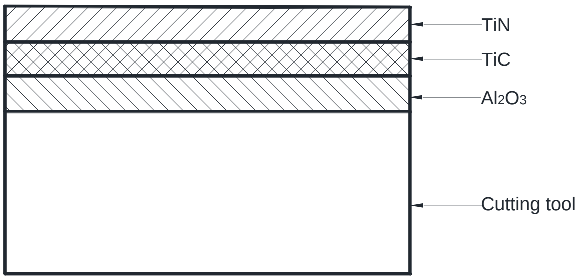

Fig. 1 Multiphase coatings on carbide tool

2. Coating techniques

The performance of coatings depends on the coating technique. Most commonly used methods are chemical vapor deposition (CVD) and physical vapor deposition (PVD). CVD technique is commonly used for multiphase coatings while PVD is used for TiN coatings. These techniques provide coatings with low porosity and good bonding with the substrate material.

CVD was introduced during 1970s and is carried out at high temperatures of about 980 ^{0}C in a reactor (Fig. 2). In this process, various reactions take place between the materials in gaseous phase and the heated substrate. The coating material is evaporated at high temperature inside the reactor. The material reacts or decomposes and deposits on the heated substrate. Since the material deposits on only the heated surface, waste is minimum in CVD process. The thicknesses of the coating layers can be precisely controlled.

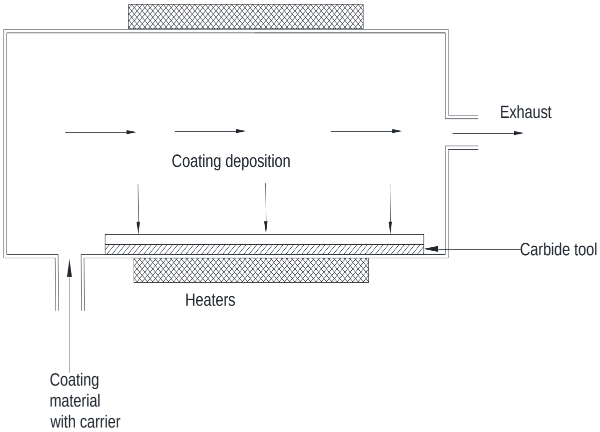

Fig. 2 Schematic of CVD

In PVD coating technique, which was introduced in 1980s, the coating material is vaporized and deposited by arc evaporation around 500°C. PVD process has different methods like sputtering, evaporation and molecular beam epitaxy (MBE). In the evaporation process, the material is gasified through heating. The gas diffuses through vacuum to the cutting tools to be coated. In the sputtering, plasma containing argon ions and electrons is generated. The sputtering chamber is a water-cooled vacuum chamber that houses the cathodes (Fig. 3). The atoms from the coating material are hit by the argon ions and are ejected. Substrates (cutting tools to be coated) are placed on a rotating holder plate. The atoms of coating material travel through plasma and deposit on the substrate. In MBE, cutting tools are placed in the chamber. It is then heated to remove any impurities on the surface. The molecular beams emit the coating material that deposits on the cutting tool. This process is costlier than other process but is very precise.

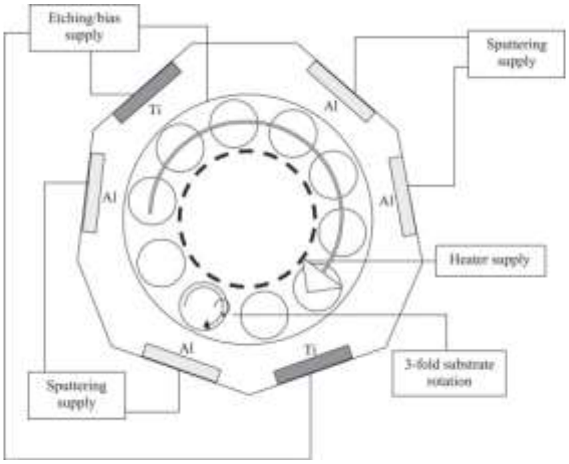

Fig. 3 Schematic of PVD- sputtering technique [15]

3. Performance of coatings

Coating materials are selected depending on the application of the parameters like workpiece material, cutting conditions, etc. Among the various coating materials, TiN, TiCN and TiAlN are popularly used. This section presents briefly the research reported on performance of various coating materials applied to cutting tools. Fig. 4 presents the thermal conductivities of the coatings at different temperatures. It may be noted that for the coating materials like TiN, TiCN and TiAlN, thermal conductivity increases with temperature. This property is helpful for high speed machining.

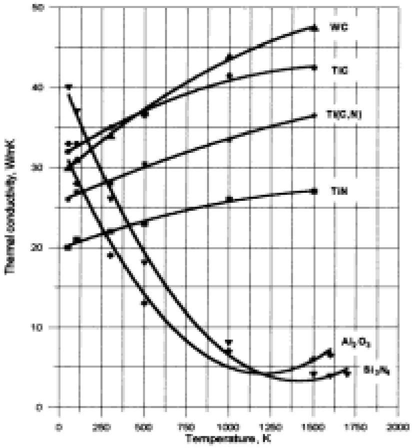

Fig. 4 Thermal conductivity Vs. temperature for coating materials [17]

3.1 TiN

A majority of the coated cutting tools available in the market are TiN coated tools. These coatings are applied on cutting tools using PVD (cathodic arc/high ionization magnetron sputtering process) and CVD processes. The coating is done on carbide insert tool substrate. Prengel et al. [18] used high-ionization magnetron sputtering PVD process. Monolayer coatings of TiN, TiAlN and TiB_2 were prepared and tested against Multi-layer coatings of TiN/TiCN/TiAlN. The coatings were 4 - 5 µm thick. Milling of ductile cast iron and turning of Inconel 718 was carried out using these coated tools.

It was observed that coatings improved the strength and even the substrate tool got harder compared to uncoated tools. The TiN/TiCN/TiAlN multilayer coating is harder than the TiAlN-monolayer coating. Further, it showed better resistance to micro-chipping compared to uncoated tools. However, TiN/TiCN/TiAlN multilayer coating showed no advantage compared to other coatings in milling. In addition, the debonding was higher in multilayer coatings, giving shorter tool life.

Grzesik [17] applied mono, bi and tri layer coatings on an uncoated grooved /flat carbide insert. The coating material is composed of TiC (one fold), TiC/TiN (two fold) and TiC/Al_2O_3/TiN (three fold). Tool life was improved with a single TiN layer (CVD). It was advocated that TiN layer prevented diffusion wear and supplied the required lubrication. This helped in reducing the adhesion of chips. TiC and Al_2O_3 reduces crater wear, while TiN reduces the friction. Further, TiN on TiC/Al_2O_3 helps in preventing crater wear at high/low cutting speeds. Coated tools also helped to reduce the contact length. For steel with 0.42% C, the contact length for a coated tool was 0.4 mm while for an uncoated tool, it was 1.2 mm. This reduces the tool temperature and moves the highest temperature towards the edge. Due to the above reasons, rake face of TiC/ Al_2O_3/TiN coated tool is smoother than TiC/TiN coating. Workpiece-coating combination with low thermal conductivity and specific heat reduces the contact length and prevents diffusion. It was found that the cutting temperatures decreased when machining with grooved tools having TiC/TiN and TiC/ Al_2O_3/TiN coatings. However, double and triple layers helped in reducing the temperatures further, particularly at high feed fates compared to flat tools.

3.2 TiCN

These coatings can be done with PVD and HT-CVD (High temperature-CVD) processes. The coating is done on substrate materials like Ti6Al4V, cemented carbide tools, etc. Sometimes, surface treatment is done with nitriding or carburizing process before coating while sometimes nano-structured CVD coatings are applied. The coating type and conditions significantly affect the cutting tool performance.

Jindal et al. [19] applied PVD TiCN coating (3 - 3.5 µm) using ion-plating technique on a WC-6wt%Co alloy tool insert. The coating was multi-layered with an FCC structure. No flanking was present confirming the proper adhesion of coatings to substrate. High residual stress growth and maximum compressive stress were observed in the coating. It was observed that TiCN coated tools perform better than TiC coated tools in machining of Inconel 718. In turning medium carbon steel (SAE 1045) the tool life of TiCN coatings has increased and thus was advantageous over TiN. TiCN coated tools had better resistance to crater wear, compared to TiN coated tools. Tool life of TiCN was longer than TiN tools while machining ductile cast iron as TiCN tool were more resistant to flank wear. Overall, TiCN increased the tool life compared to TiN coatings at higher cutting speeds.

Köpf et al. [20] produced nano-structured multi-layered TiCN CVD coating by altering the temperature during CVD process. All the coatings were prepared a CVD reactor between 900 and 1050°C (TiCN) respectively and pressures between 70 and 150 mbar (TiCN) respectively. The reaction gas was a mixture of $TiCl_4$, N_2, CH_4. H_2 was used as carrier gas. Carbon and nitrogen distributed uniformly at medium temperature, however, TiCN, formed a “core-rim” microstructure at high temperature. The microstructure presented a nitrogen rich core and a carbon rich rim. Ti(C,N) phase had a composite structure in terms of both chemical composition and crystal morphology. Two different Ti(C,N) structures, namely, star and lenticular shaped crystallites co-existed in the layer. The defect density varies though their basic crystal structure is still cubic. It was found that owing to mechanical anchoring, the roughing-effect helps the adhesion of subsequent layers, like Al2O3. The nitrogen-rich TiCN layer may reduce crater wear due to the oxide layers on crystal surface In the coating of Ti(C,N) layer. Al_2O_3 coating has better adhesion because of the formation of needle-like transition structure. This leads to better performance of the cutting tools.

3.3 TiAlN

TiAlN coatings are deposited mostly by the PVD process. The coatings are applied in the form of monolayered, multi-layered, nanostructured or nano-composite where each of them has their own advantages. To improve the performance of the coated tools, pre, intermediate, post and surface treatments are required.

Devillez et al. [21] deposited TiAlN coatings on the carbide K20 tool substrate using PVD process. The nano-structured coating has nano-crystalline globular morphology. In this study, TiAlN coatings were subsequently coated with a solid lubricant layer. This gave the tool required hardness and also lubrication. TiAlN coating was followed by a thin interlayer and WC/C topmost layer. It may be noted that TiAlN retains its hardness and thermal/chemical stabilities at high temperatures. Due to the oxidation stability of the coatings, a very thin oxidation layer is formed compared to other coatings. Furthermore, grain refinement leading to nano sized particles helped in better wear resistance. This increased the tool life of the coated tools.

Prengel et al. [18] deposited monolayer PVD TiAlN and different TiAlN multilayer coatings on tungsten carbide inserts with coating thickness of 4-5 µm. The coatings were applied using PVD process (cathodic arc/ high-ionization magnetron sputtering process). The layers of PVD coatings are shown in the Fig.7. TiN/TiCN/TiAlN coating was found to be harder compared to TiAlN-multilayer which was harder than TiAlN-monolayer. It was found that TiAlN-monolayer tools were best for wet milling, while multilayer tools were better for dry milling. TiAlN-multilayer coating gave 70% and 50% longer tool life while machining ductile and grey cast irons respectively, compared to monolayer tools in dry milling. However, in wet milling mono layer tools were better.

Çalışkan et al. [22] studied the performance of nanocomposite multilayer TiAlSiN/TiSiN/TiAlN coatings on carbide tools using PVD process. The thickness of the deposition is ~3.6 µm. the deposition of each layer of TiAlSiN/TiSiN/TiAlN coating is (~0.2/~2.3/~1.1) µm respectively. TiAlSiN/TiSiN/TiAlN coatings were deposited using an industrial magnetron sputtering system. Four magnetron sources were used for the four corners of the insert. The samples were rotated thrice to get the required nano structures and uniform thickness of the films. It was observed that TiAlSiN/TiSiN/TiAlN coating has maximum hardness and lesser plastic deformation among the considered coatings. However, the coating delaminated from the rake face after certain time. This was due to the abrasion, oxidation and adhesion of the work material.

Sprute et al. [23] studied TiAlN coating on pre-treated X37CrMoV5-1 tool substrates by PVD process. Nitrogen was taken as reaction gas and was supplied under constant pressure. Three TiAl and one pure Ti targets were placed as cathodes. Mono-layers of TiAlN and multilayers of Ti/TiAlN were deposited on the different substrates. Three pre-treatments are performed on the substrate material. Though residual stresses were observed due to plastic deformation, compressive stresses reduced due to the temperature. TiAlN monolayer and Ti/TiAlN multilayer had reduced wear with increase in showed a reduction of the wear coefficient with different pre-treatments (Fig. 5). It was noted that adhesion of coatings was better for harder substrates. However, it was observed that low residual stresses in the substrate affect the tribological properties of coatings due to the elastic and plastic deformations.

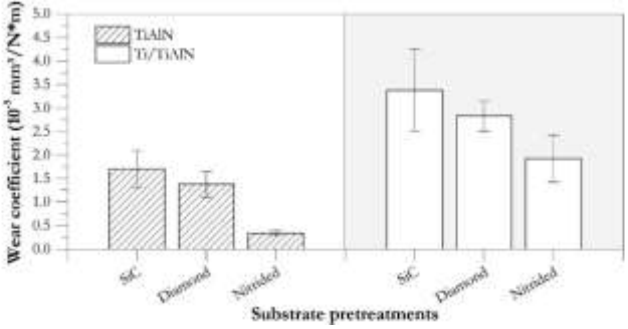

Fig. 5 Wear characteristics of TiAlN and Ti/TiAlN coatings on different substrates [23]

3.4 $Ti_{45}Al_{55}N$ coatings

Skordaris et al. [24] studied the performance of $Ti_{45}Al_{55}N$ coatings deposited on cemented carbide inserts (94 wt.% WC + 6 wt.% Co) by PVD process. The thickness of the coating is 2 µm. The coatings were made using DC arc evaporation method using three-fold substrate fixture rotations in the presence of N_2 gas. Before coating, the cemented carbide inserts were etched by Ar-ions. Different substrate bias voltages were used to obtain different properties of the coating. These coatings induce compressive residual stresses. Higher substrate bias voltage results in the development of larger coating residual stresses. Some inserts are heat treated at 700°C after the coating deposition, in order to obtain residual stresses causing an increase in yield stress and compressive stress of the coating. Higher compressive stresses improve the hardness of coating and thus tool life. The coated tools were used in turning hardened steel. However, beyond a particular value, residual stresses reduce the coating adhesion and make it brittle. This leads to increased tool wear.

3.5 AlCrSiN/CrAlSiN/TiAlSiN

These coating can be done using cathodic arc physical vapour deposition (CAPVD) technique. These are coated on WC tool substrates to improve performance and life time of PVD coated cutting tools. The coating films may be either micro thin films or nano composite thin films.

Abusuilik [25] studied AlCrSiN (Al-64%, Cr-33%, Si-3% by weight) coatings made using a standard arc-PVD method. Two circular targets were coated while another target was used for metal ion cleaning. The substrates were heated and cleaned by etching with argon plasma and bombarding with titanium ion. Nitrogen was used as reactive gas. Chamber pressure, substrate temperature and arc current at which deposition was performed are set according to the requirement. The coating is deposited to a thickness of 3 - 4 µm. Pre-treatment of substrates was done by shot peening, grinding. First intermediate treatments like micro-blasting and plasma etching were performed, followed by shot blasting. It was observed that pre-treatment of substrates with plasma nitriding resulted in superior adhesion strength. Resistance to erosion and corrosion resistance improved with the intermediate/ post-treatment process. This helped to improve the machining performance of the cutting tools. Further, delamination was not observed, indicating strong adhesion of the coating. However, the ground surface showed partial delamination because of the substrate surface was very rough.

Puneet et al. [26] developed nanocomposite films of CrAlSiN with different chemistry using c-CAPVD (cylindrical cathodic arc physical vapor deposition) technique. 99.99% pure Cr and AlSi (82:18) cylindrical cathodes were used for deposition. Different ratios (R) were computed as:

$$R = Cr/(Al+Si) \tag{1}$$

The change in R values was achieved by independently controlling the power to the two cathodes. Deposition parameters such as substrate temperature, bias voltage, and reactive gas pressure were kept constant. The coating deposition time was controlled to achieve a constant coating thickness of 4 µm. CrAlSiN coating has major influence on adhesion strength, stress and hardness. It was advocated that there exists a critical ratio of R = 1.2 at which best mechanical and tribological properties can be achieved. This ratio resulted in highest plasticity index, hardness, temperature stability, wear resistance and toughness.

The prepared tools were compared with regular tools and TiAlSiN coated tools while machining AISI 1024 steel. The tool life for tools with CrAlSiN coatings was found to have improved over other tools. This was attributed to the near-perfect nanocomposite formed due the crystalline CrAlN surrounded by Si_3N_4, which is in amorphous phase. However, the adhesion strength was observed to decrease with decrease in R (Cr/(Al+Si)). The surface roughness of the coatings is significantly higher than that of the bare substrate. Further, at very low Cr contents, the coatings tend to grow in an amorphous structure, with an additional major amorphous phase of Si_3N_4.

3.6 AlTiN

Arndt and Kacsich [27] applied AlTiN-Saturn coating with and without W-C: H coatings on HSS, micro blasted carbide inserts and cemented carbides using cathodic arc PVD process. Coatings of 2 - 5 µm thickness were deposited. W-C:H comprises of a chromium bond coat on which Me-C transition film is coated. W-C: H was deposited on AlTiN-Saturn coated end mills of HSS using magnetron sputtering method. Due to its fine structure and smooth surface, AlTiN-Saturn coating has good adhesion. This makes it suited for machining applications. In some instances, adding a low friction layer on a hard coating is useful to reduce friction and tool wear. The coatings had small percentages of nitrogen. Tool wear considerably reduced compared to other TiAlN films.

Endrino et al. [28] deposited fine grain (Fig) and nanocomposite AlTiN on carbide tools. All coatings were 3.5±0.2 µm thick. The coatings were made with a Rapid Coating System (RCS) deposition machine in C-PVD mode. Fine-grained (fg) and nano-crystalline (nc) AlTiN were obtained with the $Al_{67}Ti_{33}$ target with nitrogen as reactive gas. The coatings showed similar micro-hardness but the Young's Modulus is higher for fg-AlTiN than AlTiN coating. Nitride coatings having high content of aluminium (AlCrN/AlTiN) were more wear resistant at higher temperatures compared to coatings without aluminium (CrN/TiN). This was due to the ability of those coatings to retain hardness at high temperatures, better resistance to oxidation and low thermal conductivity. nc- AlTiN had better performance compared to fg-AlTiN and resulted in double the tool life. Surface post-treatments of the tools before coating deposition resulted in longer tool life. (Fig. 6).

Köpf et al. [20] applied AlTiN coatings on cemented carbides, sapphire, polished HSS and cemented carbide inserts. Different CVD and PVD processes were used for preparing the coatings. The coatings may be monolayer, multilayer or nano structured. Coatings were made in a CVD reactor between 800- 900℃ and pressure between 15-25 m bar (AlTiN). The reaction gas mixture consists of $AlCl_3$, $TiCl_4$, N_2 and NH_3 for AlTiN. H_2 was used as carrier gas. The nanostructured AlTiN coating was made in a commercial reactor. It consists of a unique lamellar structure. The lamellae has coatings of w-AlN and fcc-Ti(Al)N, 10 and 3 nm, respectively. Slight compressive stress is present in the Al0.8Ti0.2N coating. AlTiN coatings were observed to have higher hardness – toughness relationship than PVD coatings. compared with their PVD counterparts. Al0.8Ti0.2N coating reduced the machining time as it could withstand higher feeds.

3 µm thick nano-structured coating was applied on the cemented carbide substrate using PVD process. The coating had hardness of 3300-3500 HV. Due to the stable films formed on surface, these coatings are highly

resistant to oxidation. Adhesion wear was observed in dry machining of Inconel 718 at the tool flank and rake faces. Abrasion wear was also observed as the hard particles present in the work material were welding and adhesion of work piece material onto the rake and flank faces. However, TiN/AlTiN nanolayer coating had better resistance to abrasion and adhesion than the regular coatings. In addition, the formation of BUE was less due to ability to withstand high temperatures.

Çalışkan et al. [22] coated carbide insert is coated with a nanolayer AlTiN/TiN having an overall coating thickness of ~3.2 µm using magnetron sputtering process. Four magnetron sources were located at the corners of the substrate. nl-AlTiN/TiN coating was deposited using segmental TiAl and Ti targets. Uniform film thickness was obtained.

The n-AlTiN/TiN coated tool had the highest adhesion, wear resistance and hence the better lifetime. The life of tool coated with the n-AlTiN/TiN was longer than nc-TiAlSiN/TiSiN/TiAlN, commercial TiN/TiAlN coated tools and regular tools. However, the coatings delaminated after a specific cutting length resulting in increased abrasion, adhesion, oxidation and notch wear.

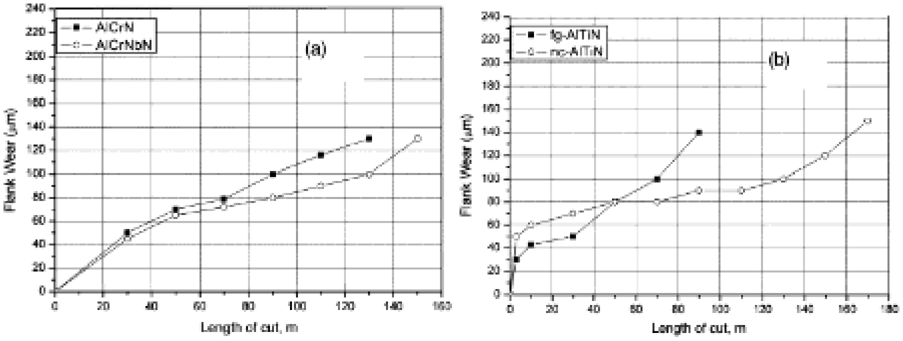

Fig. 6 Performance coated carbide tools in machining of AISI 316 steel using (a) AlCrN and AlCrNbN, (b) fine-grained AlTiN and nano-crystalline AlTiN [28]

3.7 Nickel based carbon nanotube coatings

Suzuki and Konno [29] applied Ni-based carbon nano tube (CNT) coatings on diamond tools. CNT is easy to conglomerate but is difficult to disperse in metal matrix composite homogeneously. Ni based CNT has superior properties like low density, high strength, and high thermal conductivity. Further, these coatings improve the bonding strength of the tools. The coating was carried out by electroplating process using a nickel sulphamate plating bath under galvanostatic conditions. Two layers of coating were done, one is the undercoat layer made of Ni coatings arranged on a short surface. The other layer of Ni-CNT coating was applied over the undercoat layer as topcoat layer. Both layers were 15 µm thick. It was observed that the electroplated tools had eight times the life than regular tools.

4. Summary

Cutting tool manufacturers aim to produce tools with high thermal resistivity, wear resistance and to give longer life and better surface finish. For this reason, several cutting materials have evolved to reach the expectations. In order to improve the properties of the cutting tools, coatings are often applied. In this context, the machining performance of various coating materials are discussed in this paper. TiN, TiCN, TiAlN, AlTiN, Ni based CNT composites and AlCrSiN/CrAlSiN are discussed. Coated tools exhibit better wear resistance compared to uncoated tools. With almost all the coatings, tool life improvements and better thermal resistance are reported. However, there are some challenges with the coating of cutting tools. In the case of TiAlN coatings, delamination is the major limitation whereas, in case of AlCrSiN/CrAlSiN coating, surface roughness of machined component may be higher compared to other tool materials. Hence, the choice of the coating material and coating technique should be made considering the limitations and advantages. Though coatings are advantageous in terms of machining, the sustainability aspects are not much studied. Future work may be carried out to study the sustainability of the machining process while using coated tools.

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