EFFECT OF PRE AND POST MECHANICAL TREATMENT ON PVD COATED TOOLS' CHARACTERISTICS AND MACHINING PERFORMANCE

Thesis Submitted in Partial Fulfillment

of the Requirements for The Degree Of

MASTER OF TECHNOLOGY

In

PRODUCTION ENGINEERING

By

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CERTIFICATE

This is to certify that the thesis entitled, **"Effect of Pre and Post Mechanical Treatment on PVD coated tools Characteristics and Machining Performance"** submitted by **Mr. Abhishek Singh** bearing roll no. **212ME2301** in partial fulfillment of requirements for the award of Degree of Master of Technology in **Mechanical Engineering** with specialization in **"Production Engineering"** at National Institute of Technology, Rourkela is an authentic work carried out by him under my guidance and supervision. To the best of my knowledge the matter embodied in the thesis has not been submitted to any other University or Institute for the award of any Degree or Diploma.

Date: 02-06-2014

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Dedicated to My Parents

& Brother

ACKNOWLEDGEMENT

Successful completion of work can never be one man’s task. It requires hard work in right direction. There are many who have helped to make my experience as a student a rewarding one.

In particular, I express my gratitude and deep regards to my guide **Prof. S. Gangopadhyay** for his valuable guidance, constant encouragement and kind cooperation throughout the period of work which has been instrumental in the success of thesis.

I also express my sincere gratitude to **Prof. K.P. Maity,** Head of the Department, Mechanical Engineering for his continuous support and insightful ideas. I am also indebted to Prof. S.K. Sahoo, and Prof. M. Masanta for providing valuable departmental facilities.

I am grateful to Prof. S.K. Patel for encouraging the use of correct grammar and consistent notation in technical writings.

Last but not the least; I wish to express my sincere thanks to Mr. Kunal Nayak, Sr. Lab Assistant (Production Engineering Laboratory) and to all those who directly or indirectly helped me at various stages of this work.

Many friends have helped me stay sane through these difficult years. Their support and care helped me overcome setbacks and stay focused on my research work. I greatly value their friendship and I deeply appreciate their belief in me.

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ABSTRACT

Recent advancement of high performance engineering materials has been imposing more stringent requirements on the cutting tools. Although last two decades have witnessed major improvement in physical vapour deposition(PVD)-based coatings for cutting tools, it is still a challenge on the researchers working in the field of development of advanced PVD coatings to further augment the performance of the PVD coatings for cutting applications. Substrate treatment prior to coating deposition (i.e. pretreatment) as well as treatment of PVD coated surface exhibited promise in improving the physical and mechanical properties of the PVD coating. The current study investigates the influence of micro blasting as pre-treatment and post treatment technique separately and also in combined way on various characteristics of multilayer AlTiN and dual layer AlCrN/TiAlN coatings and compared the results with as deposited coating i.e. without any micro blasting either of substrate or coating. Pre and post micro blasting were carried out using Al_2O_3 granulates at different pressure for both the treatments.

The changes in the microstructure, elemental composition and crystallographic phases of pre-treated, post-treated as well as combined in comparison with as deposited coated tools were examined using Scanning electron microscopy, Energy dispersive X-ray spectroscopy and X-ray diffraction test. Micro hardness test was carried out using Vickers hardness tester to determine the changes in the hardness value of the samples after surface treatment.

The results revealed that both pre and post blasting have significant effect on physical, mechanical and machining characteristics of multilayer AlTiN and dual layer AlCrN/TiAlN coated tools. The results during dry turning of AISI 316L grade austenitic stainless steel with various pre and post treated coated tools revealed that reduction in flank wear upto maximum of 23.426 % and decrease in cutting force upto 32.315 % was observed for combined pre and post treated tool having layers of TiAlN/AlCrN and AlTiN coatings respectively.

Keywords: austenitic stainless steel, micro blasting, physical vapour deposition (PVD), pre-treatment, post-treatment.

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CHAPTER 1

Introduction

1. Introduction

More than hundred years have passed since the development of the first cutting-tool material i.e. carbon steel which is suitable for use in metal cutting (Smith, 1989). But the demand for cost efficiency in production and the development of variety of new products ranging widely in complexity, material composition, size, and surface finish have required industry to develop new cutting materials. Since then cutting tool materials have been undergoing continuous assessment. New materials have been developed and utilized for performance and cost optimization in high-speed machining conditions (HSM), especially during high cutting speed and higher feeds.

1.1 Different cutting tool materials

1.1.1 High Speed Steel (HSS)

These are the most commonly used cutting tool cutting material where high speed machining is not required. Advent of HSS is in early 1900. High speed steel (HSS) is a high carbon ferrous alloy consisting of W, Mo, Cr, V, and Co. HSS is generally available in cast, wrought and sintered (obtained by using powder metallurgy technique) form. These tools can be hardened to various depths however they can be used for low cutting velocities 20 m/min to 50 m/min due to thermal and chemical stability. HSS tools are basically of two types i.e. M Series (Molybdenum as primary alloying element) and T series (Tungsten as primary alloying element). M Series HSS tools provides better abrasive resistance and less distortion as compared to other.

1.1.2 Ceramics

These tools are generally used with high cutting speeds for finish machining of cast iron or ferrous alloys work-pieces. However they are also used for machining of very hard materials (hardness upto HRc 63) but at low to medium range cutting velocity and at very rigid machinery. Two popularly used ceramics materials are combination of Aluminum oxide with 40% TiC and Aluminum oxide with 30% ZrO_2. The combination of aluminum oxide with TiC and ZrO_2 increases its stability, thermal conductivity and toughness.

1.1.3 Cermets

These tools are produced by making use of the materials that are used to coat the carbide varieties i.e. the titanium carbides and the nitrides. They are basically the ceramic binder in metal matrix. They are generally useful in chemically reactive machining environment for finishing and semi-finishing operations. Uncoated cermets are recommended for dry machining at medium cutting speeds, but only at low machining parameters and low cutting force. Cermet grades with TiCN, TiC, TiN and Co, Ni and Mo as a binder are more suitable for dry cutting and high cutting speeds, especially in finishing conditions. They avoid built-up-edge, but are not suitable for machining very hard materials and in semi-roughing and roughing conditions.

1.1.4 Cemented carbide

Cemented carbide tools are the modern cutting tool material produced by mixing, compacting and sintering mainly tungsten carbide (WC) and cobalt (Co) powders. In this cobalt act as a binder for the tungsten carbide grains. These tool materials have excellent red hardness capabilities and can remove large amount of material in very short duration of the time interval. They are capable of CS 3−4 times costlier than HSS tools are brittle in nature. These tools are generally used for machining of stainless steel. Cemented carbide tools are generally available in three grades P grade, K grade and M grade. K grade also known as straight grade does not consists any alloying carbides. These grades are recommended for machining of non-ferrous and non-metallic material. P grade consists of alloying material such as TiC, TaC and NbC and are generally used for machining variety of steels. These grades are rated from P01 to P50, M grades from M10 to M40, and K grades from K01 to K40. Cobalt percentage and gain size of the carbides determines the performance of these grades. The percentage contribution of these tools in the machining operations is shown in Figure 1.

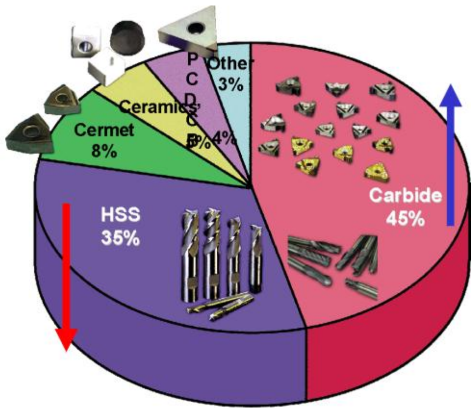

Figure 1. Percentage usage of the various cutting tools in machining operation

1.2 Tool Coatings

1.2.1 Need of coating

During high speed machining heat is generated from plastic deformation energy of the workpiece in the primary shear zone and at chip/tool interfaces in secondary shear zone (shown in Figure 2.). Some amount of heat is also generated at machined tertiary shear zone. This large amount of heat generation leads to deformation of the cutting edges. So the surface of the tools need to be hard, chemically inert, abrasion resistant, having low thermal conductivity, and low coefficient of friction whereas bulk should be tough having high thermal conductivity to avoid deformation of tool form and geometry. This combination of the material properties can be achieved with the help of coating. Coatings act as a chemical and thermal barrier between the tool and workpiece. They increases the wear resistance of tool, prevent chemical reactions between the tool and work material, reduce built-up edge formation, decrease friction between the tool and chip, and prevent deformation of the cutting edge due to excessive heating. Coatings thus improves the performance of the cutting tools as compared to uncoated tools during the machining operation.

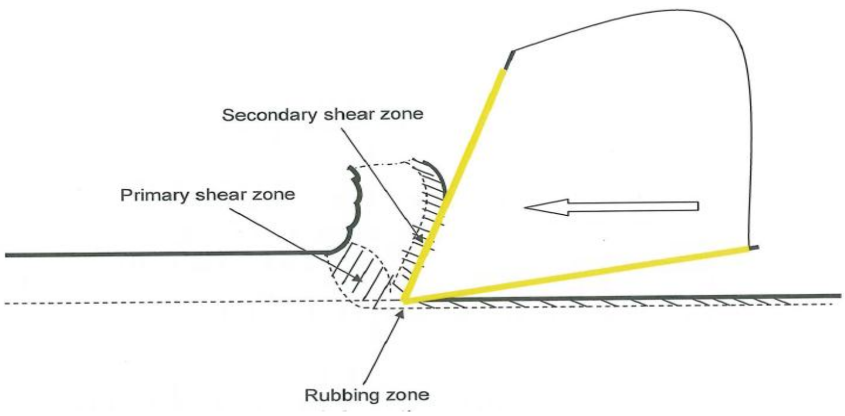

Figure 2. Primary and secondary shear zones during plastic deformation of material

However their performance is dependent on working condition and the parameters at which the operation is performed. Coating materials need to be selected on the basis of tool material and their application.

1.2.2 Types of coatings

Different types of coatings are used on cutting tools for enhancing their performance during machining operations. On the basis of composition, structure and nature these coatings can be classified as follows:

(1) Conventional hard coatings

(2) Multicomponent alloy coatings

(3) Multilayer coatings

(4) Super lattice coatings

(5) Super hard coatings

(6) Composite coatings

(7) Soft coatings

These coatings along with their examples is shown in Table 1.

Table 1. Classification of various types of coating along with their examples.

Coating	Examples
Conventional hard coatings	TiC, TiN, TiCN, Al_2O_3, HfC ,HfN
Multicomponent alloy coatings	TiAIN, TiCrN, TiVN
Multilayer coatings	TiC/TiCN/TiN, TiC/TiN/Al_2O_3, TiC/TiCN/TiN/Al_2O_3
Superlattice coatings	TiN/NbN, TiN/VN
Superhard coatings	Diamond and CBN
Composite coatings	Ti + MoS_2, TiN + MoS_2
Soft coatings	MoS_2, WS_2

1.3 Coating processes

Coatings can be deposited on the tool substrate by vapour deposition processes. These processes helps in achieving the desired degree of accuracy in terms of uniformity of coating material over the substrate and coating thickness. The various types of processes that are used for depositing the tool coatings are as follows:

(1) Chemical vapour deposition process (CVD)

(2) Physical vapour deposition process (PVD)

1.3.1 Chemical vapour deposition (CVD)

Chemical Vapour Deposition (CVD) of films and coatings involve the chemical reactions of gaseous reactants on or near the vicinity of a heated substrate surface. In this process dissociation and/or chemical reactions of gaseous reactants in activated (heat, light, plasma) environment, followed by the formation of a stable solid product take place. The deposition involves homogeneous gas phase reactions, which occur in the gas phase, and/or heterogeneous chemical reactions which occur on/near the vicinity of a heated surface leading to the formation of powders or films, respectively. These reactions takes place at the temperature varying from 200˚C to 2000˚C and pressure of 10^5 bar (generally). Different variations of CVD process are used in industries now days. These process can be classified on the basis of operating pressure range, physical characteristics of the vapour. One of these is plasma assisted chemical vapour deposition process (PACVD) which is generally used for depositing TiN coatings. This process utilizes a glow discharge and can produce coatings at temperatures in the range 400 – 700 ^{o}C and pressures in the range of 50 – 550 Pa. The plasma used in PACVD can be generated either by DC voltage or by RF voltage. The main advantage of using PACVD process is their ability to deposit the coating at low temperature with minimum usage of the gas.

1.3.2 Physical vapour deposition (PVD)

Physical vapour deposition makes use of variations of vacuum deposition techniques for depositing thin films on the tool substrate by condensation of vaporized form of the desired material. The material deposited by PVD process has excellent adhesion properties. This process involves atom to atom transfer of material from the solid phase to the vapor phase and back to the solid phase, gradually building a film on the surface to be coated. Steps involved in the physical vapour deposition process is described with the help of flow diagram in Figure 3.

Figure 3. Stages involved in PVD coating deposition

The various variants of PVD process that are used for depositing the thin films are as follows:

(1) Cathodic arc evaporation

(2) Electron beam deposition

(3) Pulsed laser deposition

(4) Sputter deposition

The main reasons for depositing the PVD coatings are they exhibit improved hardness and wear resistance, reduced friction and improved oxidation. However high capital cost involvement and low deposition rates makes them unfit for use where there is restriction in terms of time and money.

1.4 Commonly used PVD deposition techniques for cutting tools

1.4.1 Magnetron Sputtering

Sputtering is defined as the process in which atoms are dislodged from the surface of a material as a result of collision with high-energy particles. These ejected atoms then travel some distance until they reach the substrate and then condensed to form thin films.. The schematic for the basic sputtering process is shown in Figure 4.

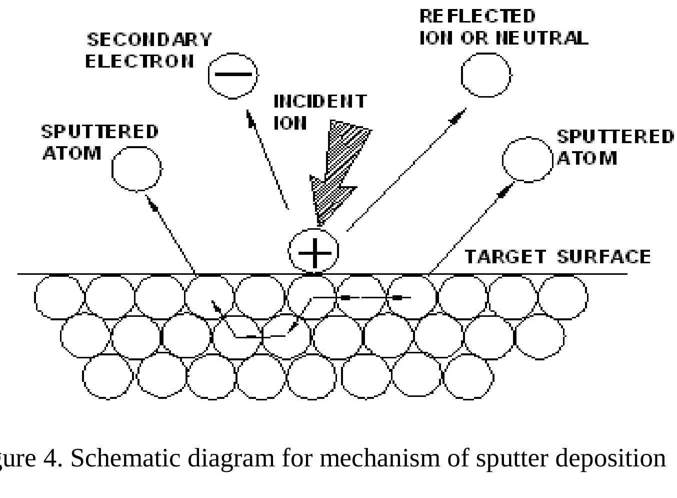

Figure 4. Schematic diagram for mechanism of sputter deposition

In the basic sputtering process, positive gas ions (usually Ar ions) produced in a glow discharge (gas pressure: 20 – 150 mTorr) bombard the target materials (cathode) which is at high negative potential (0.5 – 5 kV) dislodging groups of atoms which then pass into the vapour phase and deposit onto the substrates. Ejection of the atoms from the material surface is due to the momentum transfer from high energy Ar ions to material atoms

The basic sputtering process has several limitation despite of which it is used for so long. The introduction of the magnet in sputtering technique makes this technique popular and effective. These magnetrons confine the motion of secondary electrons emitted during the sputtering process near the target by making use of the magnetic field configured parallel to the target surface. Arrangement of the magnets around the target is done in such a way one pole is positioned at the central axis of the target and the second pole is formed by a ring of magnets around the outer edge.

Such type of arrangement increases the possibility of collision between electron and atom. The increase in the ionization efficiency of magnetron leads to denser plasma near the target material which in turn results in increased ion bombardment of the target, giving higher sputtering rates and, therefore, higher deposition rates at the substrate. In magnetron sputtering discharge is maintained at low operating pressure (typically, 10~3 mbar) and lower voltage of -500 V as compared to basic sputtering process.

Magnetron sputtering is classified into two types on the basis of strength of inner and outer race magnets.

(i) Balanced magnetron sputtering

(ii) Unbalanced magnetron sputtering

These two sputtering techniques are very much similar in design but vary significantly in terms of performance. Balanced sputtering process is defined as the one in which the strength of both magnets in inner and outer race are same. This balanced magnetron was mainly developed for microelectronic applications, where bombardment of growing film by energetic particles was to be avoided. The limitation of balanced magnetron sputtering to deposit films of higher density without introducing excessive intrinsic stress, a high flux (>2 mA/cm^2) of relatively low energy lead to make use of unbalanced magnetron sputtering process. Unbalanced magnetron is defined as the one in which the strength of inner and outer race magnets are not same. Basic balanced and unbalanced magnetron sputtering process is shown in Figure 5.

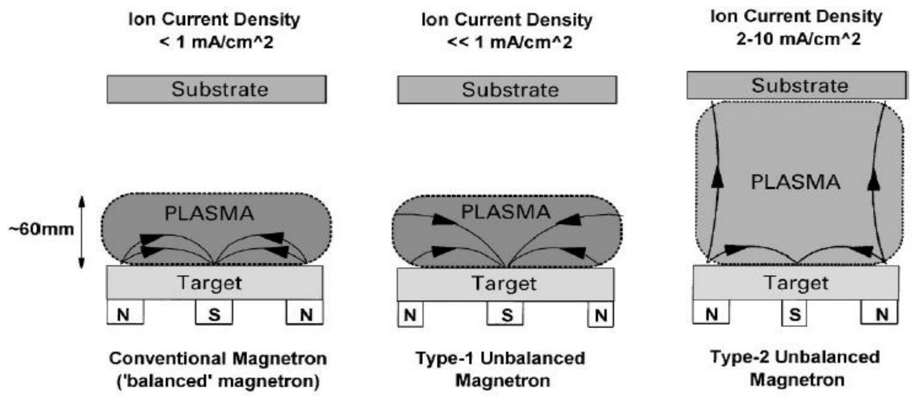

Figure 5. Balanced and unbalanced magnetron sputtering techniques [1].

Unbalanced magnetron sputtering is available in two types of configuration.

(i) Type I - inner pole is stronger than the outer pole.

(ii) Type II – outer pole is stronger than inner pole

Type I configuration cannot be used for depositing films over cutting tool substrate due to very low substrate ion current densities.

1.4.2 Cathodic arc evaporation

Cathodic arc evaporation is a physical vaporization process used to deposit thin films by vaporizing the material through electric arc and then its condensation onto the substrate material. This process is generally used for synthesizing hard coatings so as to increase the tool life. In this process high current, low voltage arc on the cathode surface give rise to highly energetic emitting area known as cathode spot. The schematic for the cathodic evaporation process is shown in Figure 6.

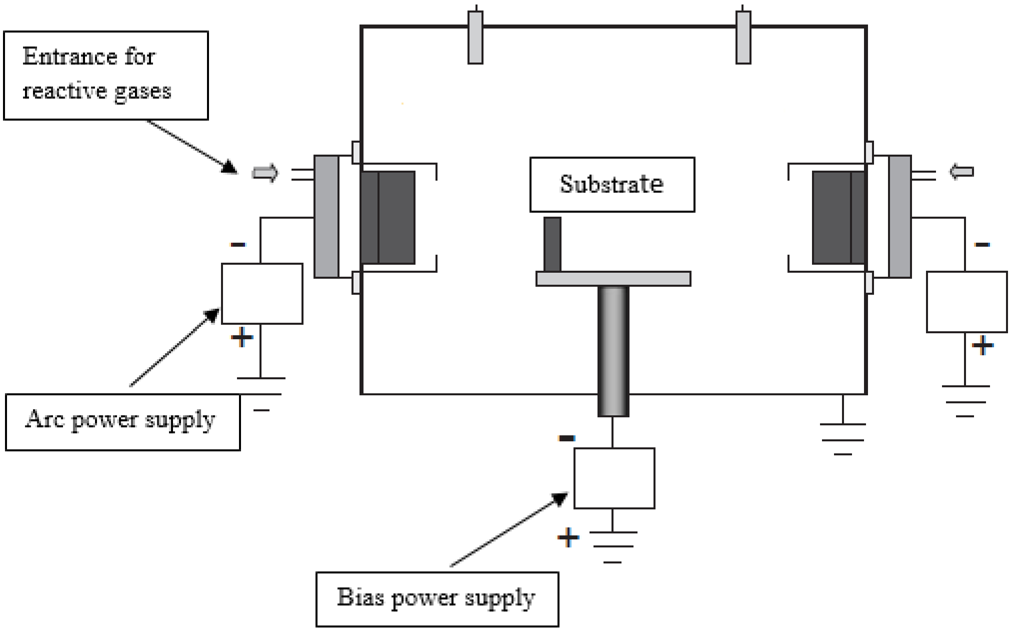

Figure 6. Schematic diagram for CAE-PVD process.

In this process the temperature near to the cathode spot is around 15,000 ˚C which leads to high velocity of vaporized cathode material, thus leaving carters on the surface of the cathode. These cathode spots are of very high current density (of order 10^{12} A/m ^{2}) and are only active for a short period of time, then it self-extinguishes and re-ignites in a new area close to the previous crater. This behaviour causes the apparent motion of the arc. The high current density of the cathode spots is associated with the high areal power which provides localized phase transformations i.e. from solid phase to fully ionized plasma.

Application of electromagnetic fields effects the arc i.e. cathode which travels across entire surface of the cathode causing surface erosion. Reactive gas is introduced during the evaporation process causing dissociation, excitation and ionization with ion flux. This process of dissociation, excitation and ionization leads to formation of thin film of the compound. The ion flux is significantly larger as compared to the flux of the neutral metal vapour thus traditional term deposition of “arc evaporation” is misnomer and hence the better term for the process is “cathodic arc plasma deposition”.

This process has certain limitation i.e. if cathode spots remains at the evaporative point for large interval of time it will eject large number of droplets. These droplets determines the adhesion property of the coatings. Larger the droplets poorer the adhesion.

1.5 Surface modification techniques for improving performance of coated tools

Accessing the entire benefits of the coating for high-performance applications requires specialized methods and knowledge of surface preparation so pre-treatments and post-coating treatments are adopted.

These treatments helps in improving various properties before as well as after the coating deposition which are as follows:

(i) Improving adhesion between coating material and substrate before coating.

(ii) Improving wear resistance

(iii) Improving hardness

(iv) Controlling friction

(v) Improving corrosion resistance

(vi) Improving aesthetics.

The type of surface treatment is adopted on the basis of its application. The various types of surface treatment that are used now days are described below.

1.5.1 Polishing

Polishing is defined as the process of smoothening the surface of the work-piece by making use of abrasives. The abrasives used in this process are glued to the work wheel. This process is generally used for enhancing the aesthetics of the material, preventing contamination of instruments, prevent oxidation, and improving corrosion resistance. Polishing is used both as pre-treatment and post-treatment process in metal working operation. Application of abrasive type is dependent on the condition of the work-piece. Figure 7 represents the polishing schematic for a polishing machine.

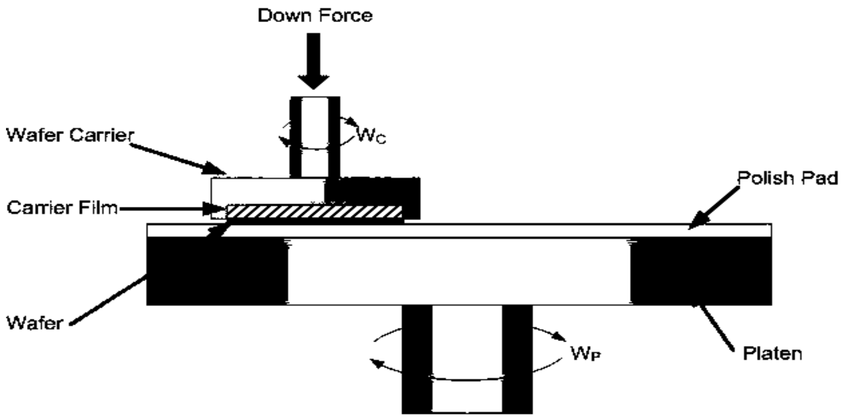

Figure 7. General setup used for the polishing process [2].

The process is started first by making use of rough abrasive of grit size 60-80 followed by the 120, 180, 220/240, 320, 400 and higher grit abrasives at subsequent stages until the desired degree of accuracy is achieved. Rough abrasive first removes the imperfection like pits, nicks, lines and scratches on the metal surface. Finer abrasives gives smoothing to the surface leaving marks which are not visible by naked eye. In order to achieve mirror finish diamond polishing is preferred. Although it is costly as compared to the general abrasive polishing process. Diamond cuts faster thus reduces the time for achieving the desired surface finish. This process is carried out on the polishing cloth with application of diamond paste.

1.5.2 Chemical etching

This process involves the removing layer of contamination on the metal surface through chemical erosion. It includes treatments which etch the surface to form highly adhering oxides, or deposit complex coatings. Chemical cleaning, where applicable, provides the best surface for adhesion. The process makes use of the mask for the purpose of selective etching of the material. The masks are deposited and patterned by lithography technique over the wafers in the initial stage. Original reactants are consumed during multiple chemical reactions and new reactants are produced. The process of etching involves basically three steps:

a) Diffusion of the liquid etchant.

b) Reaction between the liquid etchant and material that is etched away.

c) Diffusion of the by products produced during the chemical reactions.

1.5.3 Micro Abrasive Blasting (MAB)

Micro abrasive blasting is a mechanical treatment process that is used to structure and perforate brittle and hard materials [3-5]. It is significantly used in the realization of micro electro mechanical systems. Micro-blasting on PVD films is an efficient method for improving the adhesion between the coating substrate and material, inducing compressive stresses, thus for increasing the coating hardness and toughness as well as tool life of coated hard metal tools. Micro abrasive blasting parameters such as pressure and time are pivotal in terms of performance of the coated cutting tools [4-6]. MAB process makes use fine and hard abrasives, feeding device and masking technology i.e. concept of precision machining through conventional abrasive blasting technique.

Before the processing the substrate is shielded with the erosion resistant mask where blasting is not desired. This is because whole substrate is exposed to the erosive action the particle. Removal of material takes place in the area where mask is not applied. In this process mask determines the accuracy of the material removal. Micro abrasive blasting can be used both as the pre-treatment as well as post-treatment technique. The process is generally carried out by making use of either sharp edged $Al_2 O_3$ particles or round shaped ZrO_2 particles with diameter varying from 10 µm to 100 µm. Blasting pressure is kept in the range from 0.2 MPa to 0.9 MPa. Figure 8 represents the changes in surface using different types of grain particles.

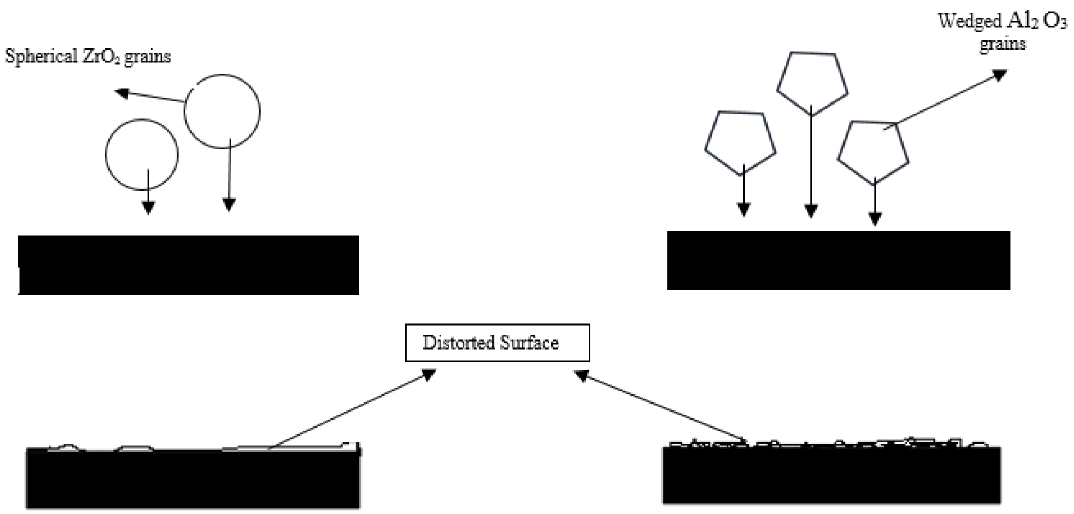

Figure 8. Distortion on the substrate surface using wedge shaped Al_2O_3 particles and round shaped ZrO_2 during micro blasting

1.5 Need for Machinability Study of Stainless Steel

Machinability is defined as the process of assessing the performance of the material and cutting tool. It is also define as the ease with which material can be machined to a desired surface finish. Machinability depends on the chemical composition of the work material, cutting conditions, cutting parameters, tool shape and geometry, and tool material. Ease of machining can be judged with the help of power requirement, cutting forces, surface finish, and tool life.

It has been always a challenging task to machine ‘difficult to cut’ material due to difference in their properties and chemical composition as compared to the others. Stainless steel falls in the category of these ‘difficult to cut’ material due to variation in their chemical composition in terms of carbon content as compared to other carbon steels. Machining of high carbon steel is difficult due to their high toughness and whereas low carbon steel cannot be easily machined due to their softness. Steel has the best machinability with medium amounts of carbon, about 0.20%. Different alloying metals such as chromium, molybdenum are often added to steel to improve its strength. However, most of these metals results in decrease in its machinability. Machinability of stainless steel is less as compared to other carbon steel because of its tougher, gummier and rapid work hardened nature. However slight hardening makes it easy to cut.

Austenitic grade of stainless steel is regarded as amongst the tougher grade to machine because of the tendency of γ-ss to work-harden and it's relatively low heat conductivity. Due to this work hardening property more heat generation will take place during the machining operation which in turn increases adhesion in terms of chip-tool interaction [7]. This increased temperature also promotes higher interactive forces and mechanical wear i.e. adhesion wear.

1.6 Different types of stainless steel

Stainless steel is classified into four types on the basis of their crystal structure.

1.6.1 Ferretic stainless steel

This group of stainless steel is corrosion and oxidation resistant as well as resistant to stress corrosion cracking. These steels are magnetic but cannot be hardened or strengthened by heat treatment process. They can be cold worked and softened by annealing. They are plain chromium steel having chromium percentage variation from 11 % to 18% and low carbon content. These grades are generally expensive as compared to other. Molybdenum, aluminum or titanium is generally present in most of their composition. Common ferritic grades include 18Cr-2Mo, 26Cr-1Mo, 29Cr-4Mo, and 29Cr-4Mo-2Ni. These alloys can be degraded by the presence of intermattilc phase of chromium which can precipitate upon welding.

1.6.2 Austenitic stainless steel

This is the most commonly used grade of the stainless steel. It consists of 19 % chromium and 9 % nickel. These steel have face centered cubic crystal structure and exhibits excellent corrosion resistance, weld-ability, formability, ductility, clean-ability and cleanliness characteristics. They can retain their structure from the cryogenic region temperature range to the melting point of the alloy. These grades cannot be hardened by heat treatment process but can be significantly hardened by cold working operation. Different grades of austenitic steel that are used now days are:

(i) Type 304: Excellent corrosion resistance in unpolluted and fresh water environment. Contain 18% chrome and 8% nickel.

(ii) Type 321: A variation of type 304 with Ti added in proportion to the carbon content.

(iii) Type 347: Uses Niobium instead of Titanium.

(iv) Type 316: Addition of 2-3% molybdenum gives increased corrosion resistance in off shore environments

(v) Type 317: Similar to 316 but the 3-4% molybdenum gives increased pitting resistance when immersed in cold sea water.

1.6.3 Martensitic stainless steel

This grade of stainless consists of high percentage of carbon (nearly 1 %), 19 % chromium, molybdenum (0.25–1%), and nickel (less than 2%). The high carbon content makes this harder but bit brittle too. Addition of the nickel and molybdenum increases the strength of the steel. They are magnetic and can be hardened by heat treating. The martensitic grades are mainly used where hardness, strength, and wear resistance are required.

1.6.4 Duplex stainless steel

This grade of stainless consists of relatively higher percentage of chromium (18% to 29%) and moderate nickel percentage (4.5% to 8%). This amount of nickel content is insufficient in generating fully austenitic structure and results in mixed structure of ferrite and austenite which is called as ‘duplex’. Molybdenum percentage in duplex steel is about

5 %. These steels are commonly used in marine applications, desalination plants, heat exchangers and petrochemical plants.

1.7 Austenitic stainless steel: AISI 316

Austenitic steel is most commonly used stainless steel as its finds application in various industries due to good combination of physical and mechanical properties. These properties depends on the nature and quality of the alloying elements. Austenitic steel is graded on the basis of metallurgical structure and percentage of the alloying elements.

Grade 316 is the standard molybdenum grade second in importance to Grade 304 amongst the austenitic stainless steel. Presence of molybdenum in this grade gives better overall corrosion properties as compared to Grade 304 particularly higher resistance to crevice corrosion and pitting in chloride environment. This grade has excellent welding and forming characteristics. It can be readily roll formed into various shapes for applications in the industrial, transportation and architectural field. For this grade post weld annealing is not required when welding thin sections.

Grade 316L is the low carbon grade of the 316 and is immune from grain boundary carbide precipitation. And hence used in heavy gauge welding components (over about 6 mm). Grade 316H is the higher carbon content grade of 316 and is used at elevated temperature. Various mechanical properties for 316 grade is described in Table 2.

The various alternatives for 316 grade are as follows:

316Ti – Better resistance to temperature of around 600-900˚C is needed.

316N – Higher strength than standard 316.

317L - It have higher resistance to chlorides than 316L, but with similar resistance to stress, corrosion cracking.

904L – Much higher resistance to chlorides at elevated temperatures, with good formability.

220S – Much higher resistance to chlorides at elevated temperatures and higher strength than 316.

Table 2. Mechanical properties of AISI 316

Grade	Tensile Strength (MPa) min	Yield Strength 0.2% Proof (MPa) min	Elongation (% in 50mm) min	Rockwell B (HR B) max	Brinell (HB) max
316	515	205	40	95	217
316L	485	170	40	95	217
316H	515	205	40	95	217

1.7.1 Applications of AISI 316

Good mechanical and physical properties increases it demand in various industries. The various industries in which AISI 316 is used are as follows:

- **(i)** Food industry
- **(ii)** Fertilizers industry
- **(iii)** Chemical industry
- **(iv)** Heat exchangers
- **(v)** Boat fittings
- **(vi)** Springs
- **(vii)** Laboratory benches and equipments.

***

CHAPTER 2

Literature Review

2. Literature Review

2.1 Effect of micro abrasive blasting on characteristics of coated cemented carbide inserts

Micro abrasive blasting is a mechanical surface treatment technique which is used to enhance the properties of the coated tools. Micro abrasive blasting on the tool inserts before as well as after the coating has significant impact on its performance. Some researchers studied the effect of micro abrasive blasting on the performance of coated cutting tools [8-11].

2.1.1 Effect of micro abrasive blasting as pre-treatment on various characteristics of coated cutting tools

(I) Physical characteristics

Micro abrasive blasting of the cemented carbide inserts effects the various physical characteristics of the cutting tool. It causes changes in the micro structure, diffraction pattern, and the geometry of the cutting edges [12, 13]. Abia et al. [12] observed that the pre-treatment of the tool using glass microspheres for 30 s causes changes in the geometry of the cutting edges which in turn effect the efficiency of the coating deposition. The cutting edges of these samples shown more roundness as compared to the untreated sample. Denkena et al. [13] analyzed that these changes in the geometry of cutting edges were due to pressure exerted by the impingement of the abrasive particles. Controlled radius of the cutting edge is required for achieving good adhesion strength and reduced residual stress. Accumulation of high value of the residual stress at the cutting may cause detachment of the coating which in turns effects the performance of coated tool during machining operation [14].

Micro abrasive blasting of the substrate results in change in the micro topography as well as the surface integrity. During the micro structural analysis of the micro blasted substrates Abia et al. [12] observed small depressions and inter-granular hollows on the surface due to impingement of the glass microspheres used for the process.

Micro abrasive blasting of the substrate causes material removal however the amount of the material removal is dependent on the grain size and blasting pressure. It was also observed that strong plastic deformation is induced by the grains having larger diameter as compared to WC grains whereas smaller grains in the blasting increases the abrasive effect of micro blasting [15, 16].

(II)Mechanical characteristics

Micro abrasive blasting is generally carried out by Al_2O_3 or ZrO_2 grains and is used for altering the micro geometry, adhesion, hardness and residual stresses of the substrate [17, 18]. However, the nature of variation in these properties is dependent on the proper selection blasting parameters such as size of the abrasive and blasting pressure. Bouzakis et al. [19, 20] observed that the adhesion strength of the coating material and substrate can be improved by impingement of particles inferior to 90 μm diameter and at blasting pressure of 2 bar. The capacity of the adhesion can be evaluated by measure of the superficial roughness where low value of roughness corresponds to good adhesion strength [21]. Abia et al. [12] investigated that pre-treatment of the substrate by glass microspheres has increased the surface roughness value of the substrate surface due to the impact of the microspheres that produces superficial micro-cracks in the substrate. During the investigation of the adhesion strength of the pre-treated samples it was found that Rockwell hardness test on the pre-treated samples shows the presence of radial fissures which corresponds to poor adhesion, this is due to removal of Co binder from the substrate due to impingement of the particles. Contrary to this Klocke et al. [17] observed that micro abrasive blasting as the pre-treatment improves the adhesion quality. Similar observation was also made by other researchers [18, 22]. The value of the surface roughness for the pre-treated samples increase coating deposition. The main reason for this is the escalation of the gains with increase in the coating thickness [23]. Low value of surface roughness favours adhesion which results in high performance of the tool coating during the machining operation because of the ease in the chip flow [24]. Bouzakis et al. [19, 26] reported that micro abrasive blasting of the ground surface results in growth of the surface roughness while the mean spacing between the profiles decreases, this contributing to the enhancement in the interlocking of the coating-substrate. The effectiveness of the nano interlayers is dependent on the layer material and surface integrity of the substrate. Bouzakis et al. [27] observed that polished/micro-blasted substrate shows significant film fracture resistance as compared to ground/micro-blasted substrate due to improvement in the film adhesion caused by reduction of WC grains and enlargement of Co binder. Bouzakis et al. [28] reported that the micro abrasive blasting of the carbide substrate before coating leads to increased adhesion properties between the coating material and the substrate. This is mainly due increase in the nucleation rate at earlier formed transient junction of TiAlN on WC substrate of W and C atoms. Similar observation during the deposition of diamond films on the WC substrate was made by other researchers [10, 11].

Residual stresses generated on the surface of the substrate can be directly correlated to the plastic deformation. Micro abrasive blasting of the substrates induces residual stress which are used for compensating the compressive stresses generated by PVD process during deposition [28]. The residual stresses are induced into the substrate due to Co binder removal by impingement of the hard abrasive particles.

Surface energies is the direct measure of the adhesiveness of the surface and can be determined measuring the angle of contact in case of solid bodies. The surface energy of the surfaces can be altered by means of mechanical pre-treatments. Micro abrasive blasting of the surface increases its surface free energy [29].

(III) On machining performance

Performance of the cutting tool is evaluated by means of various characteristics such as tool life, surface finish, power consumption, cutting force and machinability rate. Coating on the tool surface improves its properties in terms of thermal conductivity, tool wear, reduction in friction etc. But to extract all the benefits of the coating surface treatment techniques like micro abrasive blasting are adopted. However, the results on machining performance of the tools subjected to pre-treatment prior to coating deposition have been contradictory [30, 31]. Abia et al. [12] reported that tool subjected to drag-grinding shows better adhesion and gradual wear during machining operation on austenitic stainless steel while micro blasted tools suffered edge breaking. This is because micro abrasive blasting pre-treatment was not able to sustain at rapidly increasing cutting forces. The coating that were deposited on these tool is AlTiSiN. Tonshoff and Mohlfeld [15] reported that micro blasted TiAlN tool performed better as compared to untreated samples during drilling operation due to the improvement in the film adhesion. Untreated coated tools underwent inhomogeneous wear in spite of optimized coating conditions. Cutting performance of the coated is largely dependent on the subsurface properties. Tonshoff et al. [28] reported that micro blasted tools performed better in comparison to the unblasted tools during dry drilling operation of the tempered steel. It was observed that micro blasted tools exhibits high interface strength which was correlated to the micro-hardness and wear resistance of HIS[@] coatings which showed better result as compared to MSIP coating. Bouzakis et al. [32] observed that the pre-treated coated inserts with graded Cr/CrN-nanointerlayer exhibits high wear resistance. The tool life of approximately 140,000 cuts, at a flank wear width VB of 0.2 mm and coating thickness 200 nm was achieved during milling operation on

42CrMo4 QT workpiece as compared to tool with same coating but of thickness 50 nm. It was also observed that the tool life of the micro blasted samples had increased with growth of nano-interlayer and the difference is caused due to changing coating adhesion. The interlayer thickness for the micro blasted sample was found to be of optimum value. Bouzakis et al. [27] observed that there is reduction in the tool life of the sample subjected to micro abrasive blasting as compared to samples subjected to honing for cutting edge roundness manufacturing, despite exhibiting the good cutting performance of large cutting radii during the milling operation. Bouzakis et al. [33] observed that polished/micro-blasted samples shown significant improvement in the tool life compared to the ground/micro-blasted samples. Tool life of the ground/micro-blasted samples with (TiAl)N coating has increased by 300 % by polished/micro-blasted as compared to ground/micro-blasted samples. This improvement in the tool life is due to solubility of Ti material in Co binder which in turn improves its adhesion.

2.1.2 Effect of micro abrasive blasting as post-treatment on various characteristics of coated cutting tool

(I) Physical characteristics

Micro abrasive blasting post treatment is generally carried out at low pressure as compared to micro abrasive blasting pre-treatment. This is because of prevent significant changes in the grain morphology. The process also causes change in other characteristics such as cutting edge geometry, composition and crystallographic structures.

Bouzakis et al. [34] observed that enlargement of cutting edge takes place with increase in micro abrasive blasting pressure using fine and coarse Al_2O_3 grains. This value of enlargement is more prominent by coarse Al_2O_3 grains at blasting pressure of 0.2 MPa. The changes in the cutting edge geometry is due to abrasion during the micro abrasive blasting process.

Micro abrasive blasting on the coated substrate lead to removal of coating on the rake surface while the flank surface remains unaffected thus changing the thickness of the film deposited. The reduction in film thickness is due to the erosion caused by impingement of high pressure (0.4 MPa) abrasive particles on the coating surface.

(II) Mechanical characteristics

Micro abrasive blasting on the coated substrate causes change in its mechanical properties. Bouzakis et al. [34] reported that micro abrasive blasting using Al_2O_3 grains induces stresses in the substrate of TiAlN coating which deteriorates the film ductility thus increasing its brittleness and hardness. These stresses can be induced in the surface of the substrate upto a certain depth. The amount of the induced stresses can be controlled by proper adjustment of the micro abrasive blasting parameters such as blasting pressure and time.

Coatings subjected to wet micro-blasting by fine Al_2O_3 grains are expected to possess higher roughness and smaller nano-hardness, compared to the corresponding ones, micro-blasted by coarser grains under the same conditions. This is because of easily dragging of the fine grains on to the film surface by flowing water as compared to coarse grains thus causing intense deterioration of surface. Coarse grains of Al_2O_3 at high blasting pressure causes diminution of indentation depth (caused by nano hardness indenter) thus improving the TiAlN film hardness. It was also observed that these grains causes significant increase in residual stress upto a pressure of 0.3MPa [5, 34]. Bouzakis et al. [8] reported that micro abrasive blasting of the specimen by ZrO_2 particles at 0.4 MPa pressure results in enhanced coating properties such as brittleness and it also causes local substrate revelations.

Bouzakis et al. [22] observed that higher pressure micro blasted samples performed better as compared to low pressure blasted samples in removing large surface roughness peaks and increasing the number of newly revealed carbide grain edges. It was reported that surface treatment such as polishing and micro abrasive blasting can cause defamation of the coating for rough specimen surfaces and hence should be performed on specimens with high surface integrity. In terms of adhesion strength, micro blasted samples at high pressure performed better among polished and low pressure blasted samples and causes improvement of the cutting performance of the tool during milling operation. Bouzakis et al. [4] reported a method for determination of the coating strength and improvement in other properties after micro blasting. The method was based on the measurements of residual stresses by XRD and FEM based analysis.

Wallgram et al. [35] reported that the metal blasted samples shown inferior wear characteristics as compared to as deposited and polished samples. However, these samples performed better in terms of tool life improvement for some machining operation. The increased value of the wear value for metal blasted samples is due to crushing of coating asperities and oxidized metal transfer.

(III) On machining performance

Cutting performance of tools can be increased by post- treatment of the coatings. The increased tool life is a result of reduced surface roughness, introduction of compressive stresses or enhanced sliding properties by reduced friction between work- piece and coating [6]. Bouzakis et al. [32] observed that the micro abrasive blasting by Al_2O_3 at 0.2 MPa resulted in improved cutting performance of the TiAlN coated tool during milling operation on 42CrMo4 QT as compared to its untreated counterpart. While the tools micro blasted with ZrO_2 particles shown better results when the blasting pressure was 0.4MPa. This variation in the blasting pressure is due to different grain kinematics and film deformation during the micro abrasive blasting process. Bouzakis et al. [35] also made similar observation during cutting performance evaluation of micro blasted TiAlN coated tools in milling operation and suggested that this improvement in the performance of the micro blasted tools is due to enhanced film strength properties. Bouzakis et al. [22] reported that surface treatment such as micro abrasive blasting and polishing diminishes the performance of the cutting tool during milling operation however enhancement in the cutting performance can be done achieved by proper micro abrasive blasting on the substrate. This is due to decrease in local coating failure. Bouzakis et al. [32] investigated the performance of the micro blasted TiAlN coated tools and found that micro blasted performed better at blasting pressure of 0.2 MPa as the tool life of 1,70,000 cuts was obtained at 0.2 mm flank as compared to untreated sample during machining operation. It was also observed the performance of the micro blasted samples decreases with increase in blasting pressure. Tool life had reduced up to 15 % at blasting pressure of 0.6 MPa. So proper selection of the parameters need to done in order to avoid tool failure. Similar observation regarding proper of selection of maters was made by Klocke et al. [38] for improving the performance of micro blasted coated cutting tool.

2.1.3 Effect of micro abrasive blasting as combined pre-treatment as well as post-treatment on various characteristics of coated cutting tool

Micro blasting as pre-treatment improves adhesion strength, induces residual stresses and increases sites for nucleation of coating while as post-treatment it causes grain flattening and increases the hardness of coating. But with combined pre-treatment and post-treatment coated samples shows variation from these properties.

Klocke et al. [38] reported that substrate treatment of the samples by Al_2O_3 and ZrO_2 particles resulted in the increase in the roughness value due to growing of the coating while when these samples are again subjected to micro abrasive blasting, a slight decrease in its value is observed concerning mean roughness depth. It was also found that spherical shaped ZrO_2 particles resulted in low surface roughness as compared to Al_2O_3 due to less material erosion (less depth of penetration on the surface). However the value of the residual stresses remain same for both types of particles. For achieving desired values of all the outputs proper selection of the micro abrasive blasting parameters is required. There was also a significant variation in terms of tool wear for both types of particles.

Bouzakis et al. [20] reported that spherical shape ZrO_2 causes less abrasion during micro blasting as compared to wedge shaped Al_2O_3 particles. However, at blasting pressure above 0.4 MPa they can enhance the properties of the coating.

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CHAPTER 3

Objective

3. Objective

From the literature review it was found that micro blasting has prodigious potential in improving the performance of cutting tool during the machining operation. This process can be utilized both as pre-treatment as well as post-treatment. Though sustainable work has been reported on effect of surface treatments on different characteristics of PVD coating with primary emphasis on coating adhesion, hardness and residual stress, microstructural modification of coating due to prior or post-deposition micro blasting has hardly been reported so far. Moreover, the correlation of different treatment techniques on various aspects of machinability like cutting force, chip characteristics and tool wear has not been studied in detail so far. While tool wear during milling operation has been given major emphasis, the effect of pre-treatment as well as post-treatment on performance of PVD coated tools during turning operation is still unknown. Multilayer AlTiN and dual layer TiAlN/AlCrN deposited using PVD technique have strong potential in machining advanced grades of steel and other difficult-to-cut alloys. However, the effect of micro blasting as pre-treatment as well as post-treatment technique on these promising PVD coatings has hardly been reported so far. Moreover, there is a great deal of contradiction on effect of pre-treatment and post-treatment techniques on machining performance of coated tools

In order to get in deep insight into the actual role of micro blasting as pre-treatment as well as post-treatment technique and with an attempt to clarify incomplete and contradictory results the following objectives of the current research work have been formulated

(i) To study the effect of micro blasting as pre-treatment, post-treatment as well as combine pre and post-treatment (i.e. micro blasting of PVD coating deposited on prior micro blasted carbide substrate) on different physical as well mechanical characteristics of coatings i.e. microstructure and crystallographic phases, chemical composition and hardness.

(ii) To investigate the influence micro blasting as pre-treatment, post-treatment as well as combine pre and post-treatment on characteristics of different types of PVD coatings namely multilayer AlTiN coating and dual layer TiAlN/AlCrN coatings.

(iii) To analyze the effect of micro blasting as pre-treatment, post-treatment as well as combine pre and post-treatment on the machining performance of the coated tools during dry turning of stainless steel AISI 316L in terms of cutting force, chip characteristics and tool wear.

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CHAPTER 4

Experimental Details

4. Experimental Details

4.1 Detail of cutting tool substrate

Cemented carbide cutting tool insert of ISO P30 designation and geometry SCMT 120408 was selected as the tool substrate material. This is basically a turning grade and is mainly used for performing machining of stainless steel. These tool materials have excellent red hardness capabilities and can remove large amount of material in very short duration of the time interval. The geometry of the cutting insert is described in the Table 3.

Table 3. Geometry of the cutting insert

S – Shape of the insert	90˚
C – Clearance angle	7˚
M – Medium Tolerance	+/- 0.005”
T – Hole	(40-60° double countersink)
12 – Cutting edge length	12 mm
04 – Nominal thickness of the insert	4 mm
08 – Nose radius	0.8 mm

The substrate of the selected cutting inserts consists of WC, Co, TiC, TaC and NbC.

4.2 Substrate cleaning

Prior to any surface treatment or coating the substrate of the inserts undergoes cleaning process so as to achieve high quality of coated surface. Clean surface improves the coating adhesion. The cleaning process involves the ultrasonic cleaning of the substrate in a multi-stage cleaning line using aqueous alkaline solution followed by acetone and rinsed with alcohol before being dried in the degasifying furnace and placed into the chamber for surface treatment process as well as deposition of the coating material by PVD process.

4.3 Micro blasting as pre-treatment and post-treatment

The working principle of micro blasting is very much similar to the abrasive jet machining process. Micro blasting is used as the surface treatment technique and hence causes modifications in physical as well as mechanical characteristics of the tool. In this study dry micro blasting was carried on the cemented carbide inserts by making use of sharp edged Al_2O_3 grains before as well as after the coating deposition. Impingement of these fine abrasive particles of 50 µm average diameter was carried out through small nozzle of diameter 0.25 mm. The various conditions for micro blasting is described in Table 4.

Table 4. Conditions for micro blasting pre and post treatments.

Particle	Al_2O_3 grains
Process duration	15s
Nozzle diameter	0.25 mm
Diameter of the abrasive	50 µm
Blasting pressure during Pre-treatment	0.6 MPa
Blasting pressure during Post-treatment	0.3 MPa

4.4 Coating deposition

AlTiN multilayer layer and TiAlN + AlCrN dual-layered coating were deposited on the cutting insert substrate of 12 x 04 x 08 geometry by using PVD cathodic arc deposition technique at Oerlikon Balzer coating plant using RCS coating system. Figure 9 represents the structure of the deposited films.

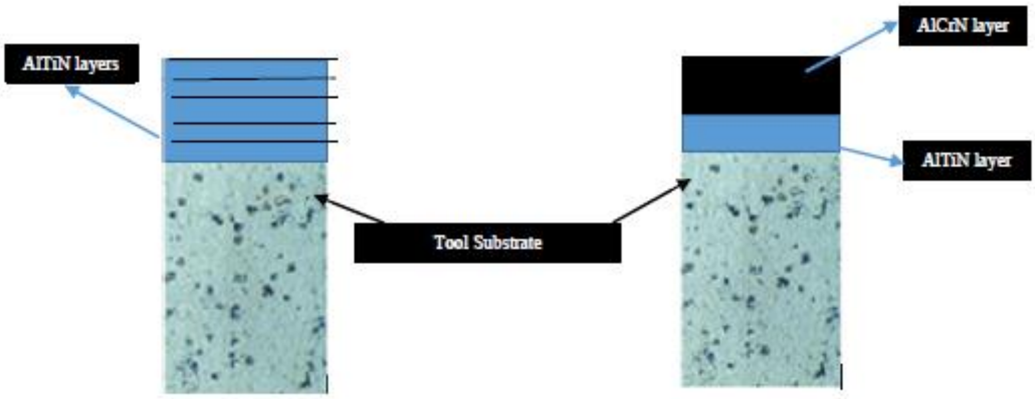


Figure 9. Basic structure of the deposited AlTiN and TiAlN/AlCrN films

For deposition N_2 was used as the reactive gas and was introduced in the coating chamber by means of conducting ducts near the target so as to reduce the formation of the droplets on the coating surface. The deposition pressure was kept at 3.5 bar and duration for deposition is 3 h. The thickness of the deposited film were 2.570 µm for AlTiN coating and 1.662 µm/0.705 µm for TiAlN and AlCrN respectively in TiAlN + AlCrN coating. The RCS system used for the coating deposition is shown in the Figure 10.

Figure 10. RCS system for coating deposition(Source : Oerlikon Balzer)

Pure AlTi cathodes were used for AlTiN coating deposition whereas AlCr and TiAl were used for TiAlN + AlCrN coating. AlTiN multilayer consists for different layers of AlTiN with varying composition of Al and Ti. In dual layer TiAlN/AlCrN, TiAlN was deposited as the inner layer while AlCrN is the outer layer in case of dual layer coating. The different properties of the coatings and their deposition conditions are described in Table 5 and Table 6 respectively.

Table 5. Properties of AlTiN and TiAlN/AlCrN coatings.

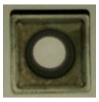
Properties	AlTiN Coating	TiAlN + AlCrN Coating
Coating Colour	 Grey	 Blue-grey
Microhardness (HV 0.05)	3,000	3,300
Coefficient Of Friction Against Steel	0.35	0.35-0.40
Max. Service Temperature (˚C)	1000	>1100
Residual compressive stress (GPa)	-3.0	-3.0
Coating temperature (˚C)	< 500	< 600

Table 6. Coating deposition parameters.

Target	TiN, AlN, Cr, Ti
Target power (kW)	3.5
Substrate	Cemented carbide insert
N_2 pressure (Pa)	3.5
Substrate temperature (˚C)	450
Deposition time (h)	3
Base pressure (Pa)	1.5×10^{-3}

4.5 Coating thickness measurement

The thickness of the deposited coating was measured under Fischer X-RAY XDL. This uses the x-ray fluorescence method (XRF), where the secondary x-ray emission intensity of a material is related to thickness when the energy and intensity are calibrated against a known standard. Four measurements was made for each type of coating.

4.6 Samples description

Four types of samples with different conditions were used for both the coating. These samples were prepared for the comparative analysis of micro abrasive blasting as pre-treatment and post-treatment. Table 7 and Table 8 represents the conditions of the samples used in this analysis for different types of coatings.

Table 7. Description of AlTiN coated samples conditions and name.

Sample Name	Condition
L1	AlTiN coated insert without any surface treatment. (Only Coating)
L2	AlTiN deposited substrate subjected to micro abrasive blasting as post-treatment. (Coating + Micro blasting)
L3	Micro abrasive blasting pre-treatment on the carbide substrate followed by AlTiN coating deposition.(Micro abrasive blasting+ Coating)
L4	Pre-treatment + AlTiN Coating + Post-treatment.

Table 8. Description of TiAlN/AlCrN coated samples conditions and name.

Sample Name	Condition
A1	TiAlN/AlCrN coated insert without any surface treatment. (Only Coating)
A2	TiAlN/AlCrN deposited substrate subjected to micro abrasive blasting as post-treatment. (Coating + Micro blasting)

A3	Micro abrasive blasting pre-treatment on the carbide substrate followed by TiAlN/AlCrN coating deposition.(Micro abrasive blasting+ Coating)
A4	Pre-treatment + TiAlN/AlCrN Coating + Post-treatment.

4.7 Physical characterization

4.7.1 Scanning Electron Microscopy (SEM)

Surface morphology and microstructural analysis of cemented carbide inserts substrates before and after surface treatment was carried out under scanning electron microscopy (SEM) using SEM-JEOL-JSM-6480 LV machine (shown in Figure 11) operated at an acceleration voltage of 15 kV. SEM makes use of the focused beam of the high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals obtained from the electron beam and surface interaction gives the information about its morphology or texture. Generally the beam is focused onto a specified area of the specimen. The analysis of the samples was done at 100x and 5000x.

Figure 11. SEM machine setup

Elemental composition of the substrate was determined by EDS (INCA, Oxford Instruments, UK) microanalysis coupled with the SEM. EDS detector that was used for analysis is equipped with ultra-thin window and is capable of detecting the elements heavier than beryllium. Bulk and point EDS was carried out at an accelerating voltage of 20 kV on specific sites of the samples to know the possible variation in the composition.

4.7.2 Field Emission Scanning Electron Microscopy (FESEM)

The working principle of the FESEM is very similar to the SEM. Field-emission cathode in the electron gun of a scanning electron microscope provides narrower probing beams at low as well as high electron energy, resulting in both improved spatial resolution and minimized sample charging and damage.

Samples were analyzed using FESEM machine NOVA NANO SEM 450 machine at magnifications of 10,000x, 20000x and 30000x so as to examine the microstructures, surface texture as well the coating growth. Analysis of both treated and untreated samples were carried out an accelerating voltage of 5 kV.

4.7.3 X-Ray Diffraction (XRD)

X-ray diffraction technique was adopted for the phase identification of various samples for both types of coating. Diffraction measurements were performed on a high resolution Philips, PANalytical PW 3040/60 X'Pert PRO machine (shown in Figure 12) using Cu Kα radiation of wavelength 0.15418 nm with. XRD makes use of the X-rays generated from Cu cathode ray tube to produce monochromatic radiations collimated to concentrate at the sample. The interaction the incident rays with the sample produces constructive interference (and a diffracted ray) when conditions satisfy Bragg's Law ($n\lambda=2d \sin \theta$).

Figure 12. Outer and Inner view of the XRD machine setup

The produced diffracted X-rays during the process detected are processed and counted. By scanning the sample through a range of 2θ angles, all possible diffraction directions of the lattice should be attained due to the random orientation of the powdered material. Conversion of the diffraction peaks to d-spacing allows identification of the element because each element has a set of unique d-spacing.

The parameters that were selected for the XRD involves: Scanning range – 30˚ - 80˚, Step size (2 θ) – 0.05˚ and Count time – 2 s/step. Voltage and current were kept at 30 kV and 20 mA respectively. Analysis of the data was later done with X'pert High score software (Philips Analytical B.V., Netherlands).

4.8 Mechanical characterization

4.8.1 Hardness testing

Hardness of the bulk material is generally measured by measuring the size of the indentation. This procedure is simple and fast. However for the measurement of the coating thickness very small indentations are made. The maximum indentation depth should be less than 10 % of the coating thickness [39]. So microhardness of the samples is generally measured using Vickers micro hardness tester. The test method consists of indenting the samples to be tested by means of diamond indenter, in the form of a right pyramid with a square base. The angle between the opposite faces is 136˚. Generally a load of 1 to 100 kgf is applied for 10 to 15 s to test the microhardness of the sample. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation.

The Vickers hardness number is given as:

$$HV = \frac{2P\sin(\alpha/2)}{d^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where P is the applied load in kgf, α is the angle between opposite faces of the diamond indenter, 136° and d is the mean diagonal of the indentation in mm. In this study composite hardness of the coating and the substrate material was determined by making use of the Vickers micro-hardness tester (Make: LECO LM 700).

Testing was under at a load of 50gf and dwell time of 15 s. The diagonal length of the indention marks on the substrate was measured at a magnification of 500x. For each sample five readings were taken so as to obtain the efficient results. Figure 13 shows the photographic view of the Vicker’s micro hardness tester.

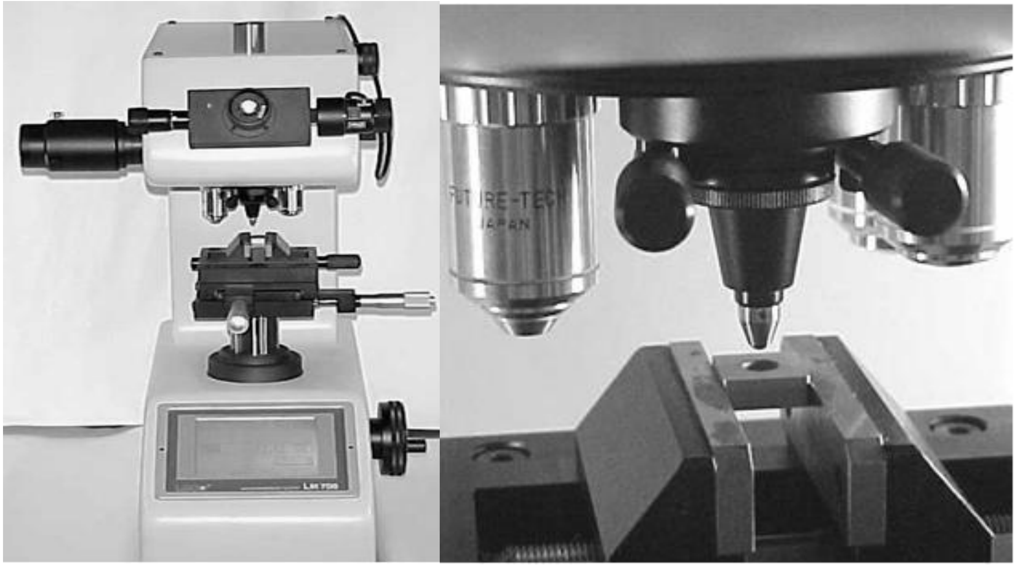


Figure 13. Photographic views of Vicker's Micro hardness tester

4.9 Machining performance evaluation

Machining operation i.e. turning was performed on the austenitic stainless steel 316L to examine the performance of the micro blasted AlTiN and TiAlN/AlCrN cemented carbide inserts.

Since austenitic steel is 'difficult to cut'' material and its machining is quite a challenging task so it was taken as the workpiece as its machinability helped in judging the desired outputs with the help of the cutting tools. Elemental composition and properties of the austenitic stainless steel 316L are shown in Table 9 and Table 10.

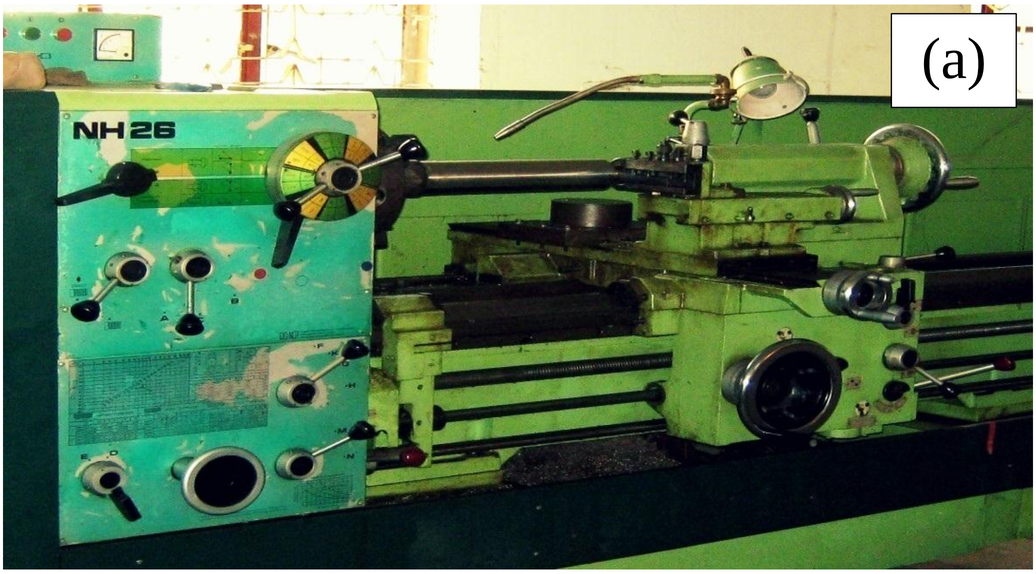
Table 9. Percentage elemental composition of AISI 316 austenitic stainless steel

Elements	C	Mn	Si	P	S	Cr	Mo	Ni	N
%	0.03	2.0	0.75	0.045	0.03	16.0-18.0	2.00-3.00	10.0-14.0	0.10

Table 10. Mechanical and physical properties of AISI 316 austenitic stainless steel

Property	**Value**
Tensile Strength (MPa) min	485
Yield Strength 0.2% Proof (MPa) min	170
Elongation (% in 50mm) min	40
Rockwell B (HR B) max	95
Brinell (HB) max	217
Specific Heat 0-100°C (J/kgK)	500
Density (kg/m^3)	8000
Thermal Conductivity (W/mK) at 500 °C	21.5

Tuning operation was performed on a heavy duty lathe (Make: Hindustan Machine Tools (HMT) Ltd., Bangalore, India; Model: NH26) fitted with variable spindle drive (Make: ABB). The workpiece used for the operation was 650 mm in length and 75 mm in diameter. Machining operation was carried out under dry environment at three levels of cutting speed: low speed, medium speed and high speed with constant value of feed (0.2 mm/rev) and depth of cut (1.5 mm). The duration of each run is 60 s. Tool holder with ISO designation of SSBCR 2020K12 (Kennametal, India) was used for all coated cutting tools. For each cutting velocity fresh tip of the cutting tool was used. Forces were measured with the help of attached dynamometer. The setup used for carrying the turning operation is shown in Figure 14.



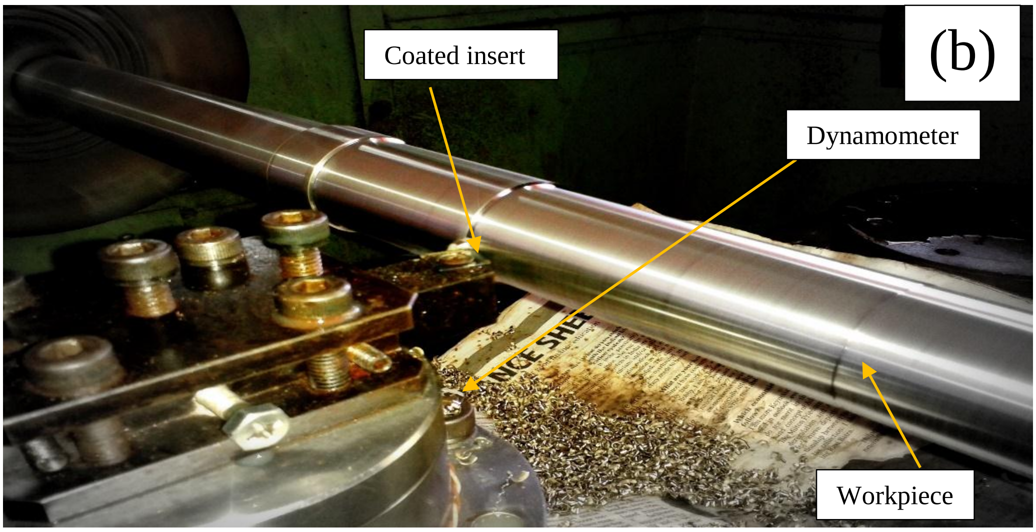


Figure 14. Setup used for performing the machining operation (a) Lathe, (b) Dynamometer-tool holder attachment.

After 60 s of machining, the condition of the cutting tools was studied stereo zoom optical microscope shown in Figure 15. (Make: Radical Instruments). Four runs was performed on each tool i.e. for durations 60 s, 120 s, 180 s, and 240 s to examine the tool wear during the machining operation. The various cutting conditions and parameters on which machining was performed are shown in Table 11.

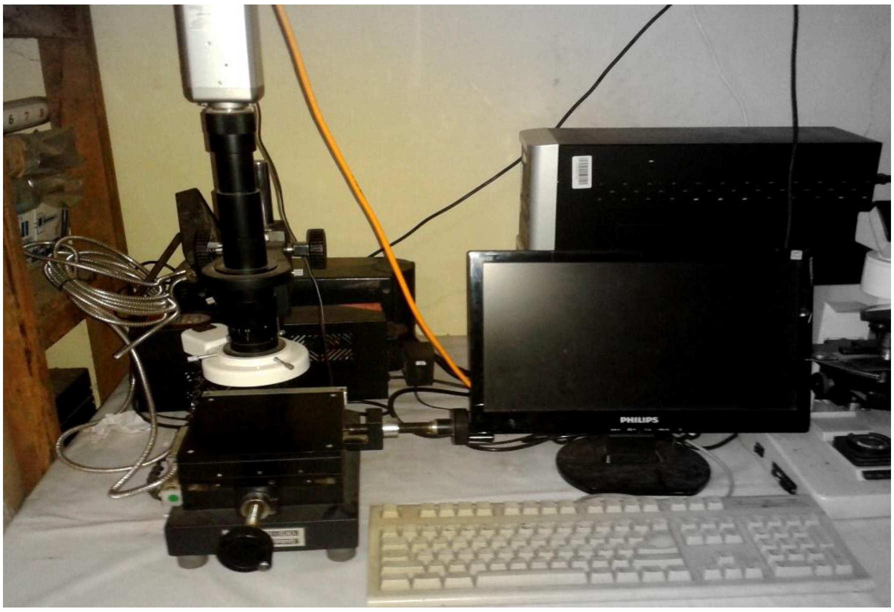


Figure 15. Sterio zoom optical microscope with attachment for viewing images

Table 11. Parameters and conditions for turning operation.

Workpiece	Austenitic stainless steel 316L
Cutting velocity (m/min)	100, 130, 180
Feed (mm/rev)	0.2
Depth of cut (mm)	1.5
Environment	Dry
Tool designation	SCMT 120408
Coatings on the cutting tool	AlTiN and TiAlN/AlCrN
Tool geometry	−6°, −6°, 6°, 6°, 15°, 75°, 0.8 (mm)

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CHAPTER 5

Results & Discussion

5. Results and Discussion

5.1 Coating thickness measurement

The thickness of the both types of deposited coating i.e. AlTiN as well as TiAlN/AlCrN was measured so as to verify the values desired for the investigation. The observed values of the thickness are shown in Table 12 and Table 13.

Table 12. Measured thickness value for multilayer AlTiN film.

Readings	Thickness (μm)
1	2.647
2	2.617
3	2.594
4	2.420
Average thickness: 2.570 μm	

Table 13. Measured thickness value for dual layer TiAlN/AlCrN film.

Readings	TiAlN layer thickness (μm)	AlCrN layer thickness (μm)
1	1.728	0.731
2	1.674	0.683
3	1.627	0.700
4	1.620	0.706
Average thickness	1.662	0.705
Total thickness of TiAlN/AlCrN: 2.367 μm		

From the obtained values the film thickness of 2.570 µm and 2.367 µm was found for AlTiN coated and TiAlN/AlCrN coated inserts respectively. However deviations of 0.102 µm and 0.070 µm was found in film thickness values for AlTiN coated and TiAlN/AlCrN coated inserts respectively but they were very much within the desired limit.

5.2 SEM Analysis

5.2.1 Effect of post-treatment on microstructure and chemical composition of coated cemented carbide inserts

The micrographs for as deposited and post-treated samples of AlTiN coating is shown in the Figure 16 along with EDS spectrum. During the microstructural analysis it was found that coating shows good adhesion in post treated samples which is correlated to less pores or holes on the surface. The typical cracks on the surface of the untreated surface is due to consequence of the different thermal expansion coefficients between the substrate and the coating and cannot really be avoided in commercial PVD cutting inserts. Since post-treatment of the coating is done at significantly low pressure of 0.3 MPa to avoid high surface roughness on the surface so not much significant changes in the surface topographies of both the samples was found in both types of coatings. However micro abrasive blasting of the samples causes grain flattening due to strong abrasive effect of the impinged abrasive of Al_2O_3. Post treatment of the coated samples also causes removal of the coating in the localized areas which results in smoothening of the protruding irregularities. These changes in the surface of the micro blasted samples decreases the mechanical contact between asperities of the tribological pair tool-work piece. This leads to a lower friction coefficient and thus, a contribution for extended tool life of the inserts.

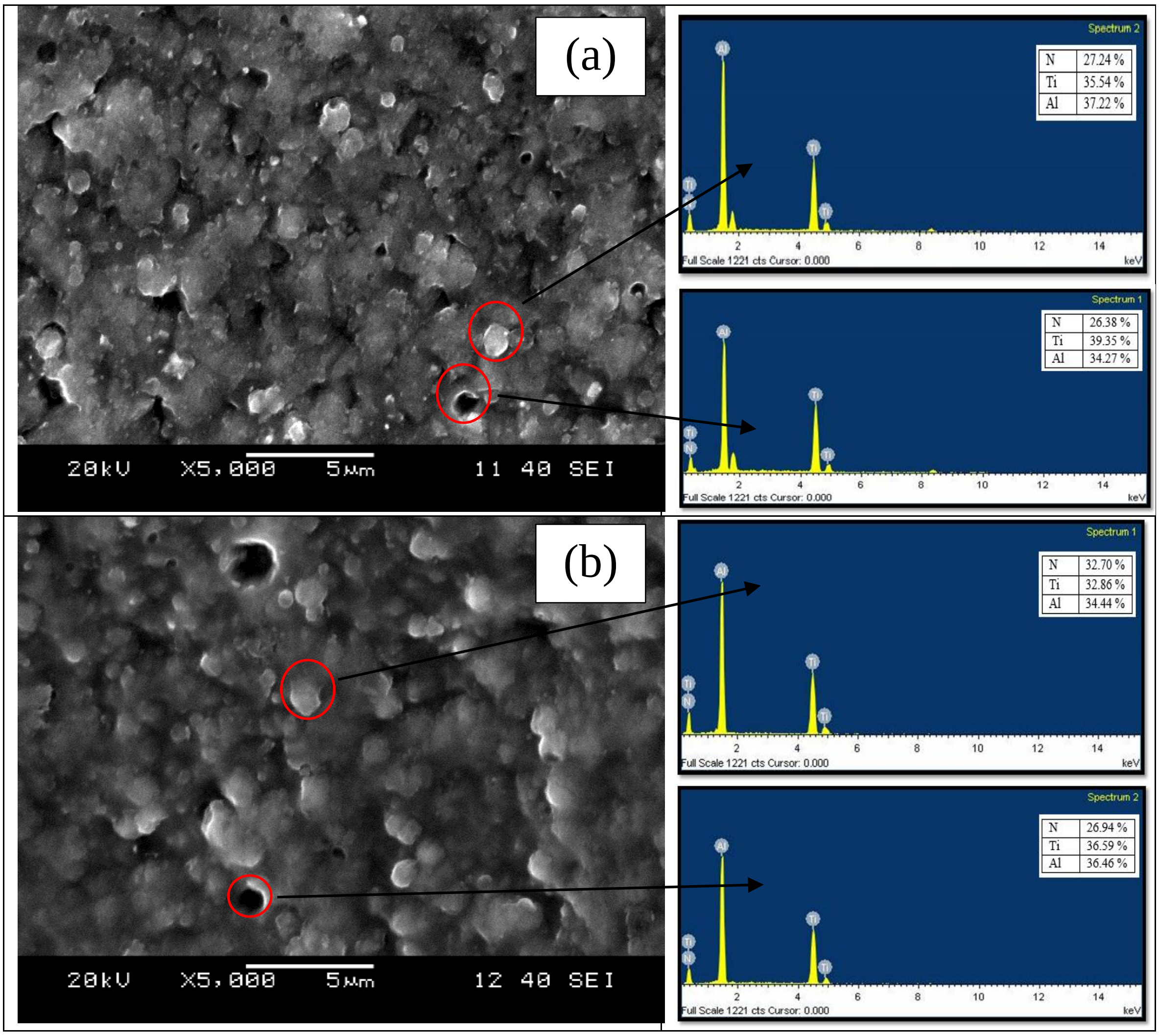


Figure 16. Micrographs and EDS for (a) as deposited, (b) post-treated AlTiN coated samples.

On comparing the micrographs of AlTiN coated samples with TiAlN/AlCrN coated samples it was also found that the surface texture of TiAlN/AlCrN coating is denser as compared to AlTiN. This is due to the dual layer of the coating material on the substrate which in turn not only reduces the crack or pores on the surface but also improves other surface characteristics of the coating. The micrographs for TiAlN/AlCrN samples along with EDS spectrum is shown in Figure 17.

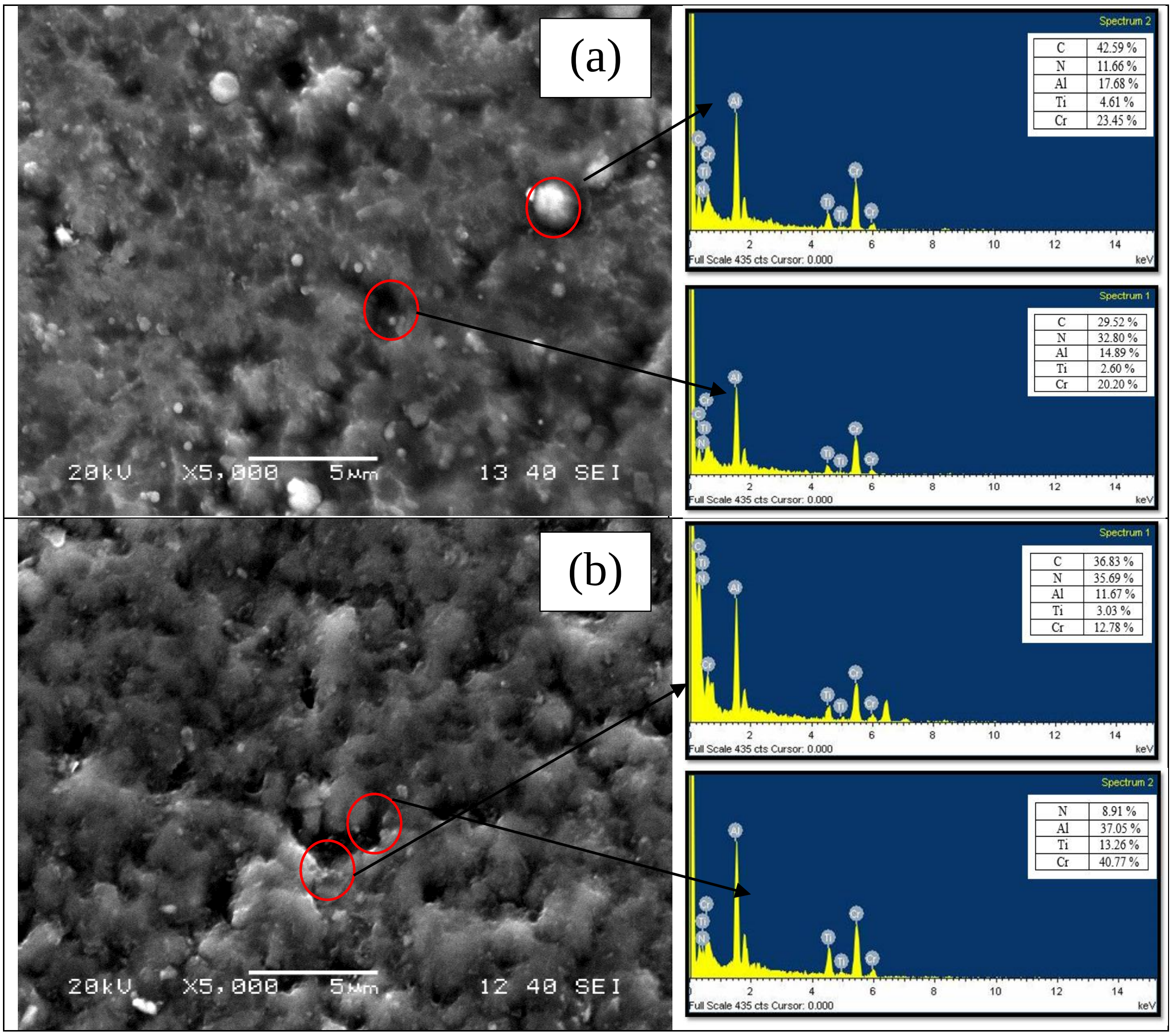
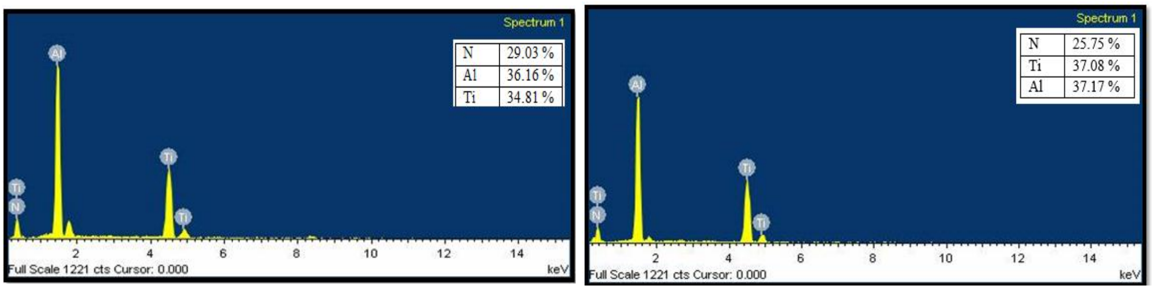


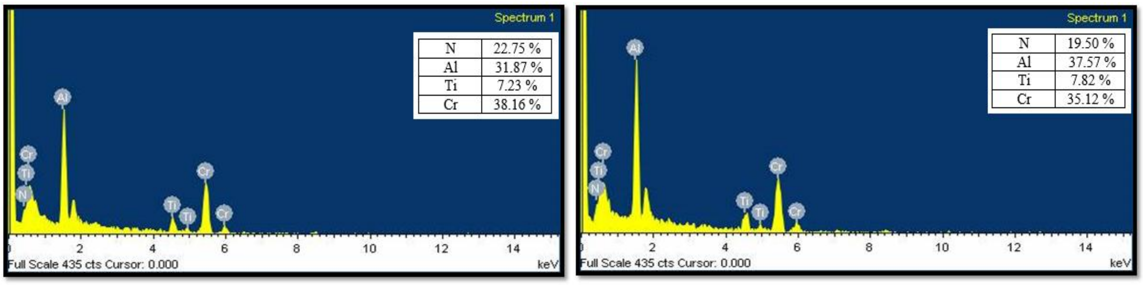
Figure 17. Micrographs and EDS for (a) as deposited, (b) post-treated TiAlN/AlCrN coated samples.

Electro dispersive spectroscopy results reveal variation in elemental composition for AlTiN as well as TiAlN/AlCrN coating in case of as deposited condition and for post-treated condition. During bulk EDS of AlTiN coating it was observed that the percentage of Al and Ti has increased in case of post-treated sample as compared to as deposited which is compensated with the decrease in the N percentage. The spectrum for bulk EDS of AlTiN and TiAlN/AlCrN coated samples is shown in Figure 18 and 19.



(a) **(b)**

Figure 18. Bulk EDS for (a) as deposited, (b) post-treated AlTiN coated samples



(a) **(b)**

Figure 19. Bulk EDS for (a) as deposited, (b) post-treated TiAlN/AlCrN coated samples

On comparing the local sites i.e. white and black points in both case it was found that Al percentage had increase in the black region as compared to white region while Ti percentage has decreased and in as deposited sample and increased in micro blasted sample. This variation is shown due to in uniformity in the coating and impinged abrasive particles which causes local subsurface deformation. EDS spectrum.

During the point EDS analysis of TiAlN/AlCrN some percentage of carbon was obtained in as deposited as well as post treated samples may be due to presence of voids and pores on the coating surface due to removal of localized coating material (in atomic level) during micro abrasive blasting. The presence of carbon due to voids and pores was confirmed by the fact that high percentage of carbon was found in the black region (pore) as compared to white region in as deposited sample.

5.2.2 Effect of pre-treatment and combined pre-treatment as well as post-treatment on microstructure and chemical composition of coated cemented carbide inserts

The micrographs for as deposited, pre-treated and pre-treated + post-treated samples of AlTiN and TiAlN/AlCrN coating are shown in the Figure 20 and Figure 21 respectively along with EDS. EDS spectrum was taken at various interstial sites in order to examine the variation in elemantal condition.

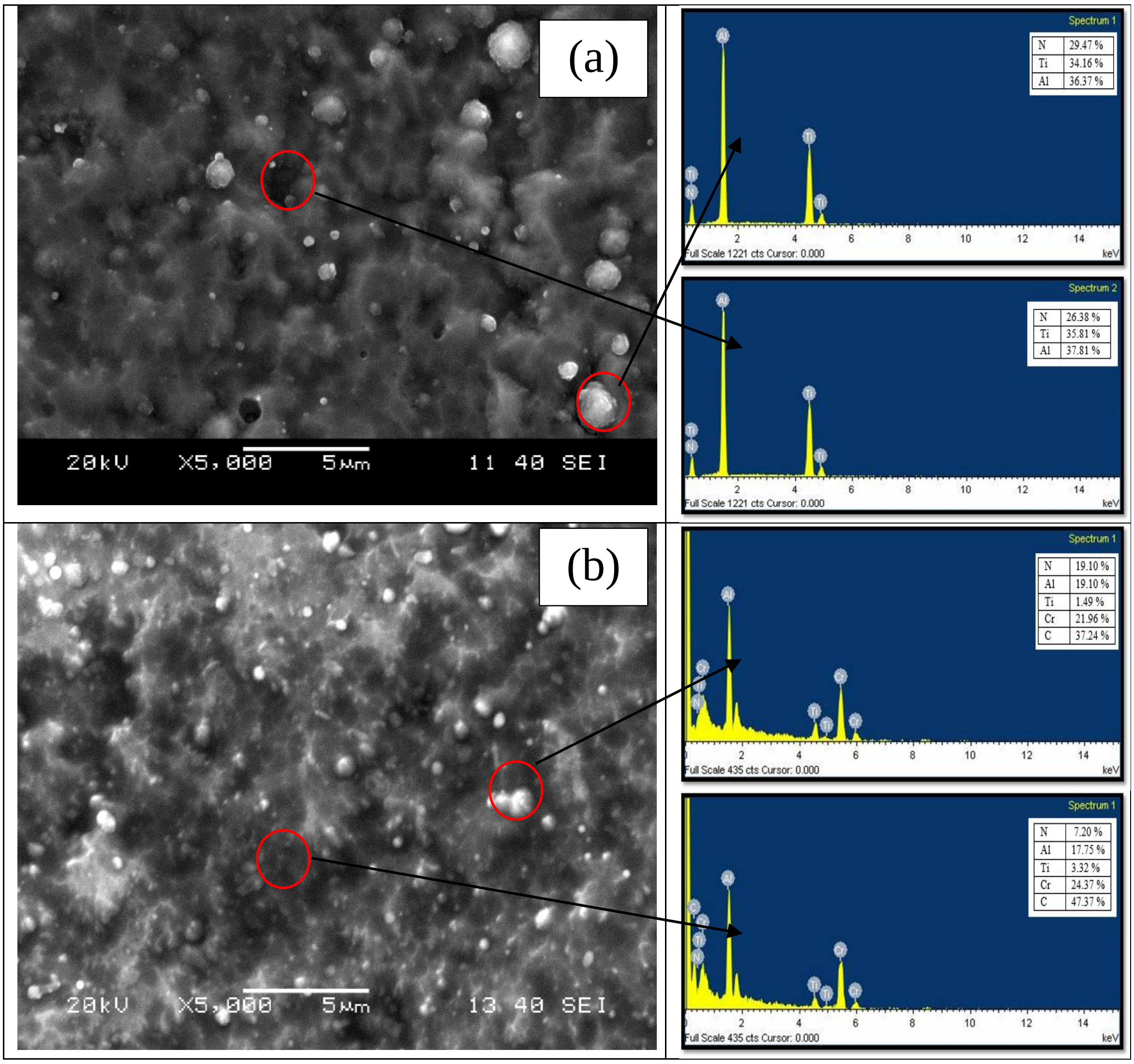


Figure 20. Micrographs and EDS for pre-treated (a) AlTiN, (b) TiAlN/AlCrN coated samples

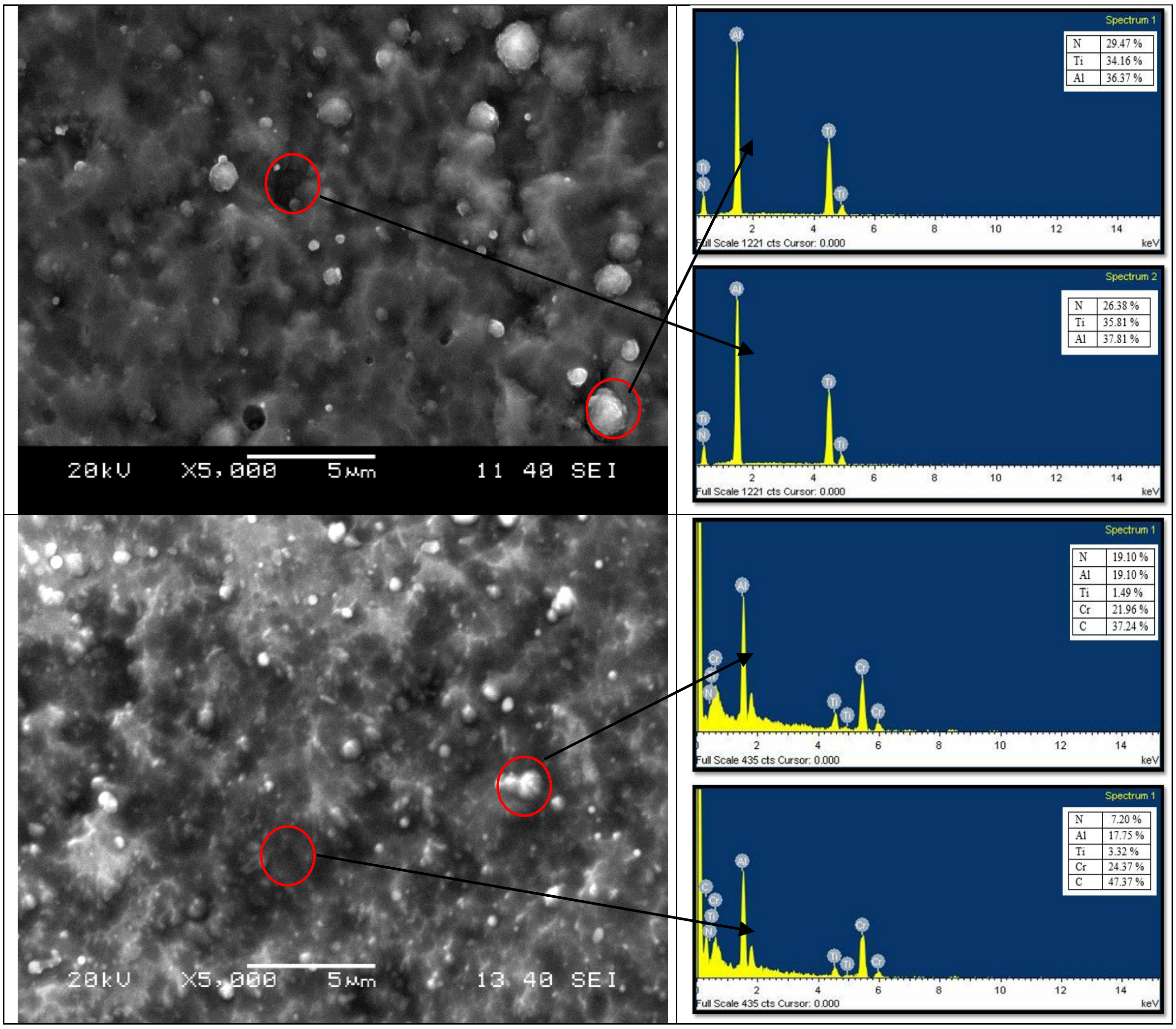
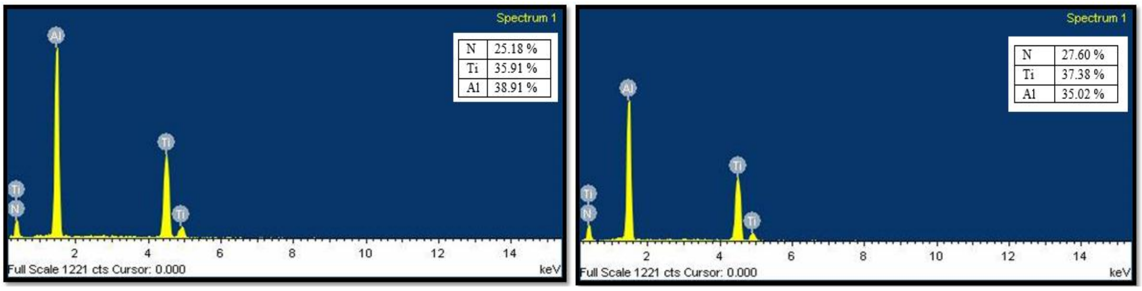


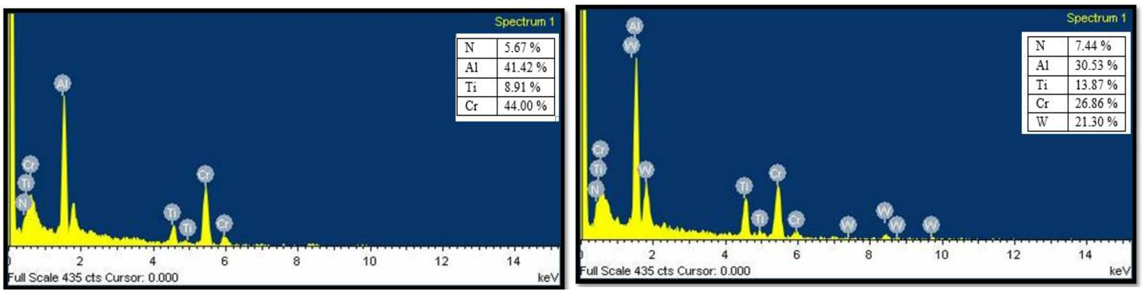
Figure 21. Micrographs and EDS spectrum for combined pre-treated as well as post-treated (a) AlTiN, (b) TiAlN/AlCrN coated samples.

On comparing the surface topography of the pre-treated samples with as deposited samples it was found that the coating is much firmly adhered to the substrates. This is due to the fact that micro abrasive blasting of the uncoated inserts increases its surface roughness thus increasing the adhesion strength between the coating material and the substrate. However the adhesion of the coating will be better judged by performing adhesion tests. Micro abrasive blasting removes the Co binder phase of the material and hence causes significant changes in the surface topography of the samples. When the size of the grains is bigger than the carbide grains it causes plastic deformation while the vice-versa of this increases the abrasive effect. This can be examined and correlated with the help of the EDS data which reveals that pre-treatment had caused increase in the Al content from 36.16 % in as deposited to 38.91 % in pre-treated samples due to increase in the density of the nucleation sites for growth of Al. Bulk EDS for both pre-treated as well as combined pre and post treated samples of AlTiN and TiAlN/AlCrN coatings are shown in Figure 22 and Figure 23 respectively. For both the coatings the surface morphology variations in the per-treated sample from the as deposited more or less remains same. Point EDS of the samples at the coating surface revealed variation in the composition of the interstitial sites. Similar to post treated samples carbon percentage was found in the samples. This percentage increased in the black spots.



(a) **(b)**

Figure 22. Bulk EDS for (a) pre-treated and (b) combined pre as well as post-treated samples with AlTiN coating.



(a) **(b)**

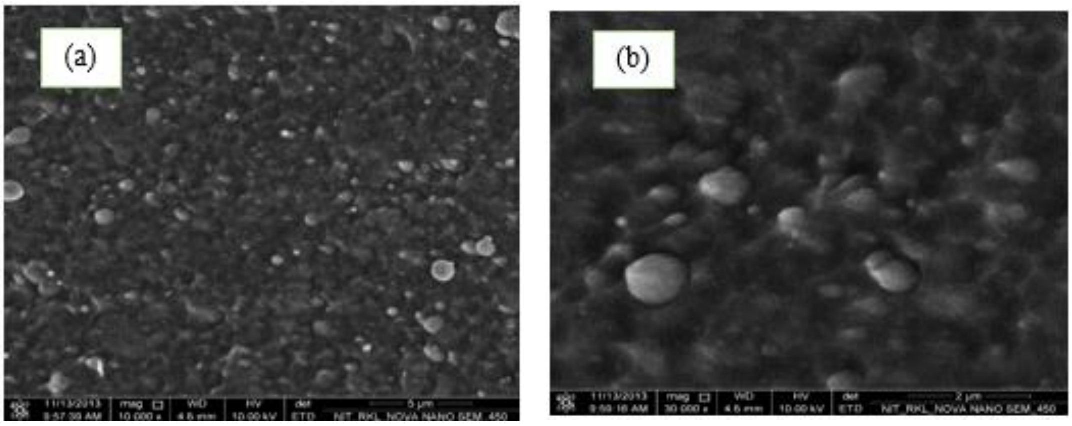
Figure 23. Bulk EDS for (a) pre-treated and (b) combined pre as well as post-treated samples with TiAlN/AlCrN coating.

Samples subjected to both pre-treatment as well as post-treatment showed significant variation in the surface morphology as compared to other samples. Micrographs for combined pre-treatment and post-treatment showed high percentage of Al at some sites. This suggested that the nucleation of Al might have taken place over their due to impinged Al_2O_3 particles Point EDS of the TiAlN/AlCrN shows the presence of the W in the local sites. This was due to the removal of the coating grains during post-treatment process. However, no such observation was made in case of AlTiN coated surface with same combination of the surface treatment.

5.3 FESEM Analysis

5.3.1 Effect of micro abrasive blasting as post-treatment on microstructure of coated cutting tool

Surface micrographs for the TiAlN/AlCrN coating in as deposited as well as post treated conditions is shown in Figure 24. These obtained micrographs were closely studied and later correlated to the surface conditions of the samples.



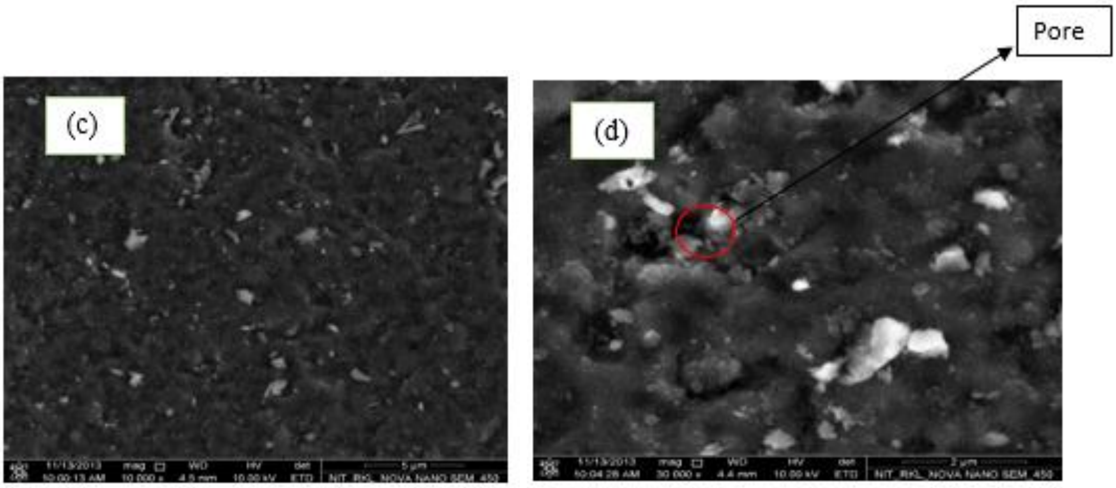


Figure 24. Micrographs for TiAlN/AlCrN coated samples (a), (b) as deposited and (c), (d) post-treated conditions.

On comparing Figure 24 (a) and (c) it was observed that micro blasting of the samples resulted the grains flattening. This flattening of grains is caused due to overlapping of the several localized deformations caused by the impact of the alumina shots on the surface.

Micro blasting of the coated substrate cause's material erosion so pores appear on the upper layer on the coating. So it can be concluded that at high blasting pressure the density of these pores and cracks increases and causes extensive loss of the coating grains at the localized areas. The removal of top coating material causes an increase in the line intensity of the WC reflections, since more contribution from the substrate will be registered. Segregated particles of Al_2O_3 were obtained on the surface of the micro blasted samples. The presence of Al_2O_3 in these segregates was confirmed with the point EDS analysis on these interstitial sites.

5.3.2 Effect of pre-treatment and combined pre-treatment as well as post-treatment on microstructure of coated cemented carbide inserts

Figure 25 represents the surface micrographs for the TiAlN/AlCrN coating in pre-treated and combined pre as well as post treated conditions. FESEM analysis was done as so to closely analyze the samples the samples to micro blasting before the coating deposition.

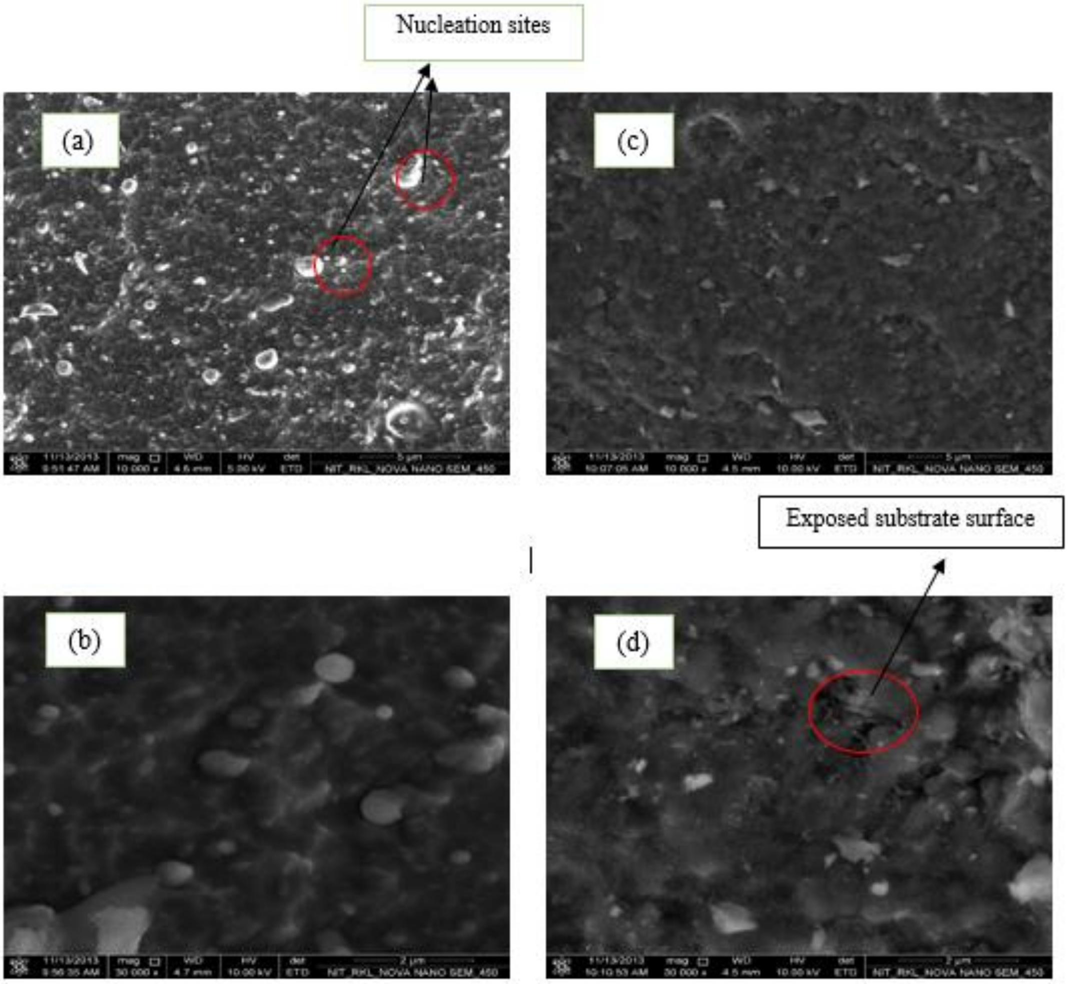


Figure 25. Micrographs for TiAlN/AlCrN samples under (a), (b) pre-treated and (c), (d) combined pre as well as post-treated conditions.

At higher resolution i.e. 30000x not much significant changes in the surface topographies of both the samples were observed however the at magnification of 10000x it was observed the micro blasting before coating has increased the coating nucleation sites on the surface of the substrate. This is due to abrasive action of the blasted samples. The surface texture of the pre-treated samples appears to be smooth as compared to as deposited samples with no signs of pores, cracks or spallation's.

On comparing the micrographs of pre-treatment as well as post treatment samples with as deposited samples micrographs it was observed pre-treatment as well as post treatment of the coated surface lead to the exposed coating surface due to material removal. The removed layer of the coating was clearly visible the micrographs obtained for the sample.

5.4 XRD Analysis

X-ray micro-area diffraction of the AlTiN coating was performed to analyze the variation in the phase structures of the coated surface due to surface treatment. The coating showed a cubic AlN structure which was responsible for high hardness and wear resistance of the coating. The structure was cubic at miller indices (111) and (200) of the coating. The diffraction pattern for various samples of AlTiN multilayer coating is shown in Figure 26.

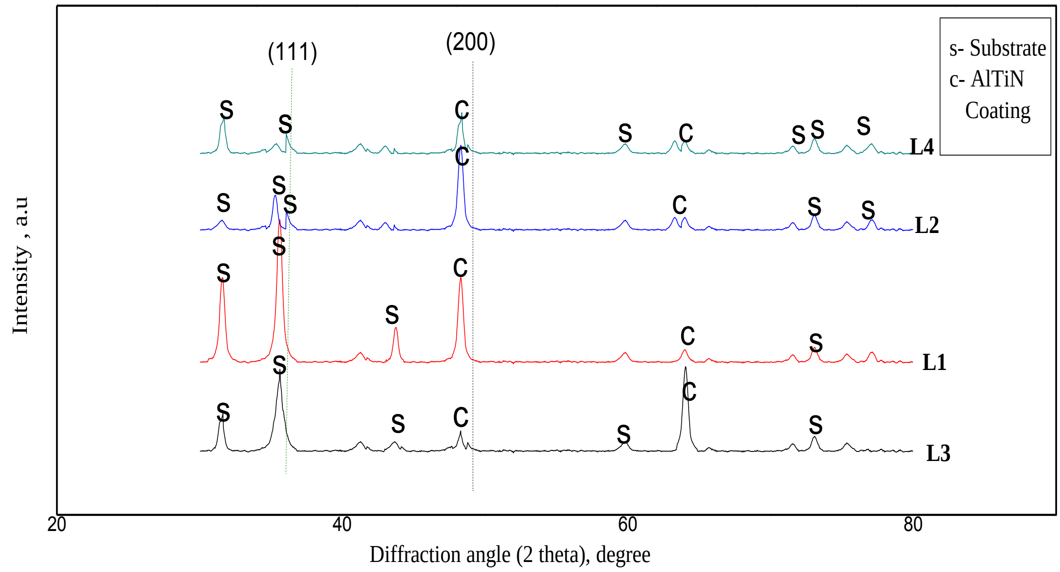


Figure 26. X-ray diffraction pattern for various samples with AlTiN coating.

5.4.1 Effect of post-treatment on diffraction pattern of coated cemented carbide inserts

On comparing the diffraction pattern of post-treated samples (L2) with as deposited samples (L1) it was found that shifting in the position has occurred on the left side of the curve due to compressive residual stresses which is necessary for improving toughness of coating. The peaks obtained for the substrate as well as coating also showed variation in their intensity. The broadening of the peaks in the diffraction pattern of post-treated sample was attributed to the grain refinement of the coating due to subsequent micro abrasive blasting.

The XRD pattern for the TiAlN/AlCrN also showed the same variation in diffraction pattern.

5.4.2 Effect of pre-treatment and combined pre-treatment as well as post-treatment on diffraction pattern of coated cemented carbide inserts

Pre-treated sample (L3) had caused shifting of the diffraction pattern slightly at right side of the curve at some values on the scanning range as compared to as deposited sample (L1). This was correlated to relieved stresses during micro abrasive blasting pre-treatment. Micro abrasive blasting as a pre-treatment also induces large number of defects at substrate surface, this caused larger number of nucleation sites. Thereby, decreasing grain size of the coating. This was the cause for peak widening.

The combined pre-treatment and post-treatment sample does not underwent any variation in position as compared to as deposited samples. However the intensity variation was observed in this case.

5.5 Microhardness Test

5.5.1 Effect of post-treatment on microhardness of coated cemented carbide inserts

Vickers microhardness test was performed on the AlTiN and TiAlN/AlCrN coated cemented carbide inserts with both as deposited as well as post treated conditions so as obtain their composite hardness. For each sample five readings were taken so as to the compute exact values. The average obtained value hardness for both the coatings is shown in the Table 14 and Table 15 and their corresponding graphs are shown in Figure 27.

Table 14. Microhardness values for (1) as deposited, (2) post-treated samples with AlTiN and TiAlN/AlCrN coatings.

Sample Number	TiAlN/AlCrN coating (A)	AlTiN coating (L)
1	2562.775	2258.625
2	2619.4	2499.35

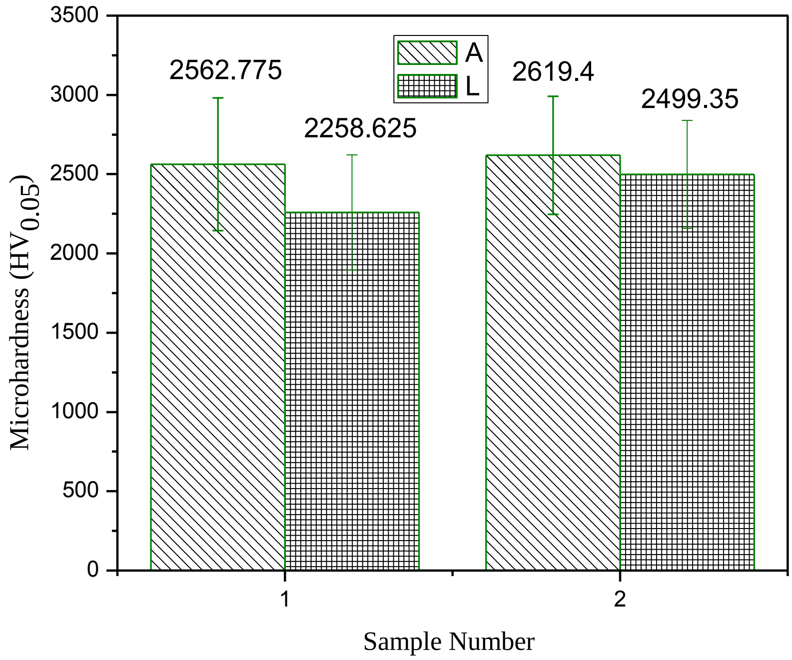


Figure 27. Graphs representing microhardness values variation for (1) as deposited, (2) post-treated samples having AlTiN and TiAlN/AlCrN coatings.

From the plotted graphs for the hardness value it was found that the post-treated samples shown some improvement in their composite hardness values as compared to as deposited samples in both type of coatings. The value of the post-treated samples had increased to 2619.4 and 2499.35 from 2562.775 and 2258.625 in case of TiAlN/AlCrN and AlTiN samples respectively. This is because micro abrasive blasting causes generation of residual stresses which in turn improves the hardness [8]. It was also observed that the

TiAlN/AlCrN have higher composite hardness value under same load conditions as compared to AlTiN coating may be due dual structure of the coating.

5.5.2 Effect of pre-treatment and combined pre-treatment as well as post-treatment on diffraction pattern of coated cemented carbide inserts

The obtained values for composite hardness of pre-treated and combination of pre-treated as well as post-treated samples is shown in Table 15 and their corresponding graphs are represented in Figure 28.

Table 15. Obtained microhardness values for (1) as deposited, (3) pre-treated, (4) combined pre as well as post-treated samples with AlTiN and TiAlN/AlCrN coatings.

Sample Number	**TiAlN/AlCrN coating (A)**	**AlTiN coating (L)**
1	2562.775	2258.625
3	2697.575	2502.32
4	2986.875	2863.975

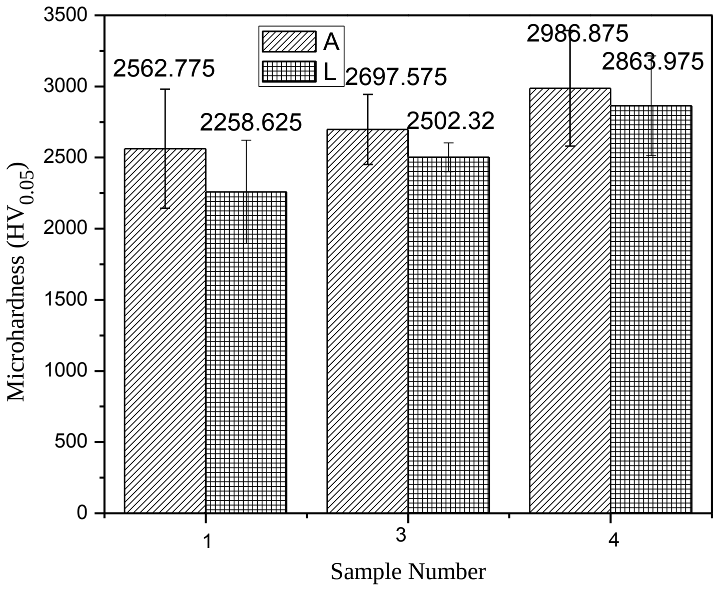


Figure 28. Graphs representing microhardness values variation for (1) as deposited, (3) pre-treated, (4) combined pre and post treated samples having AlTiN and TiAlN/AlCrN coatings.

From the obtained result it was found that the hardness value had shown variation as compared to as deposited samples. For pre-treated sample there is slight improvement in the value i.e. from 2562.775 and 2258.625 to 2697.575 and 2502.32 for TiAlN/AlCrN and AlTiN coatings respectively. And for sample 3 the value had increased significantly i.e. up to 2986.875 and 2863.975 for TiAlN/AlCrN and AlTiN coatings respectively. This improvement in hardness value of sample 3 was due to improved brittleness of the surface and good adhesion of the coating material to its substrate.

5.6 Machining performance evaluation

Micro blasting has significant effect on the physical as well as mechanical characteristics of AlTiN and TiAlN/AlCrN coated cemented carbide inserts. These effects were well examined by various tests that were conducted on the samples. However, in order to investigate the performance of surface treated cutting tools, machining operation i.e. turning was performed on austenitic stainless steel 316L at various machining parameters.

5.6.1 Effect of post-treatment on cutting performance of coated cemented carbide inserts in terms of machinability characteristics

(I) Cutting force

Figure 28 shows the variation of cutting force as a function of machining duration during turning operation using AlTiN and TiAlN/AlCrN coated inserts with and without surface treatment. From the obtained graphs it was found that the force values are higher at low cutting velocities. The value of cutting force increases with increase in the machining duration except at some points. This variation was shown due to progressive wear of the tool at the rake and flank surfaces.

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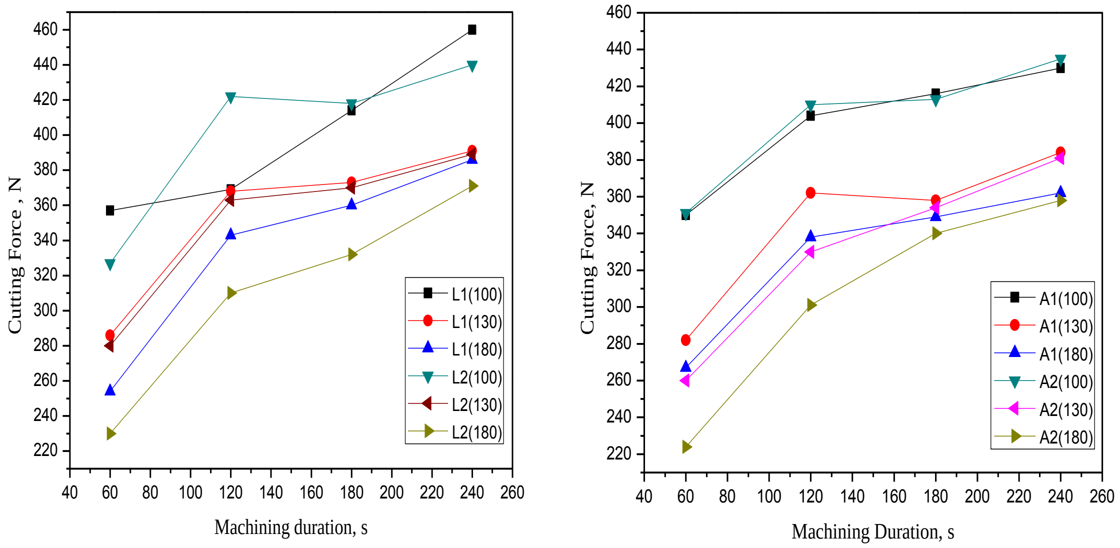


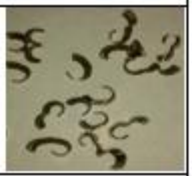
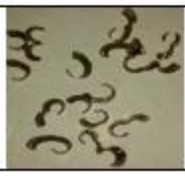
Figure 29. Variation of cutting force with machining duration for as deposited and post-treated AlTiN and TiAlN/AlCrN coated samples

On comparing the values of cutting force for post-treated and as deposited samples it was observed that the value is always less in the previous as compared to later. This was correlated to the less wear in case of post-treated tools. At low cutting velocity, post-treated tools were subjected to large cutting force as compared to higher velocities because of large friction between the tool and workpiece interface which in turn causes wear.

Similar trend was observed for both types of coatings. However, the values of cutting forces were less in case of dual layer TiAlN/AlCrN coated tools because of its high hardness value

(II) Chip characteristics

During the machining operation i.e. turning the effect of micro blasting on PVD deposited AlTiN and TiAlN/AlCrN tools cutting performance in terms of chip characteristics was examined. The various chip characteristics that were examined includes chip macro morphology, chip nature and chip reduction coefficient. For both types of coating the post-treated tools yielded discontinuous chips similar to as deposited conditions. High value of depth of cut attributed to formation of this type of chips. Figure 30 represents the chip macro morphology at various cutting conditions.

V = 100 m/min				
Samples Name/Time duration	**L1**	**L2**	**A1**	**A2**
60				
Chip type	Discontinuous	Discontinuous/Snarled	Discontinuous	Discontinuous
240				
Chip type	Discontinuous	Discontinuous	Discontinuous	Discontinuous
V = 130 m/min	**L1**	**L2**	**A1**	**A2**
60				
Chip type	Discontinuous	Discontinuous/Snarled	Discontinuous	Discontinuous
240				
Chip type	Discontinuous	Discontinuous	Discontinuous	Discontinuous

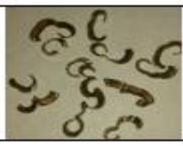
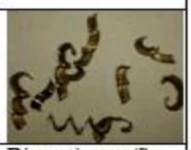
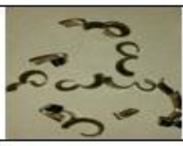
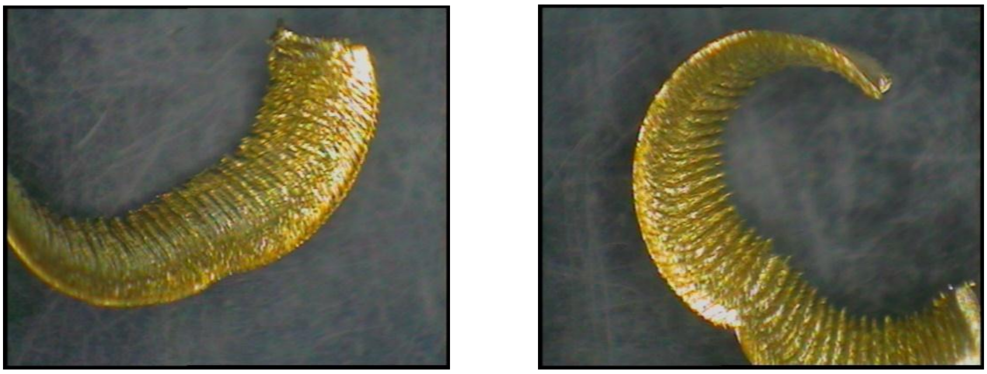
V = 180 m/min				
Samples Name/Time duration	**L1**	**L2**	**A1**	**A2**
60				
Chip type	Discontinuous	Discontinuous	Discontinuous	Discontinuous/Snarl
240				
Chip type	Discontinuous	Discontinuous	Discontinuous	Discontinuous

Figure 30. Macro morphology of chips obtained using as deposited and post-treated AlTiN and TiAlN/AlCrN coated samples during turning of AISI 316

Chips obtained from cutting of AlTiN coated tools had very less length as compared to cutting by TiAlN/AlCrN coated tools. However the chip curling was more in case of AlTiN coated samples. Chip curling during the machining operation is always associated with the stress state of the chip layer next to the cutter. On examining the chips at higher magnification (as shown in Figure 31) it was found that the chip serration spacing decrease at later stage of machining i.e. when tool begins to fail. Chips obtained by cutting from post-treated samples appeared to have large chip serration as compared to chips obtained by cutting from as deposited. This may be due to less tool wear of the post-treated samples which exhibit high hardness value.



(a) **(b)**

Figure 31. Magnified images of chips for examining chip serration for (a) as deposited and (b) post-treated samples.

Chips obtained by cutting from post-treated samples appeared to have large chip serration as compared to chips obtained by cutting from as deposited coating. This may be due to less tool wear of the post-treated samples.

Chip reduction coefficient is a function of chip thickness and is given by ratio of chip thickness to uncut thickness. On comparing the chip reduction coefficient value for sample L2 and L1 it was found its value was generally less for sample L2 except at some points. This can be attributed to the fact that sample L2 had undergone less wear at the cutting edge because of its high hardness. Wear on the rake surface and coating removal at lower cutting speeds due to high drag force changed the trend 6of variation of chip reduction coefficient with machining duration.

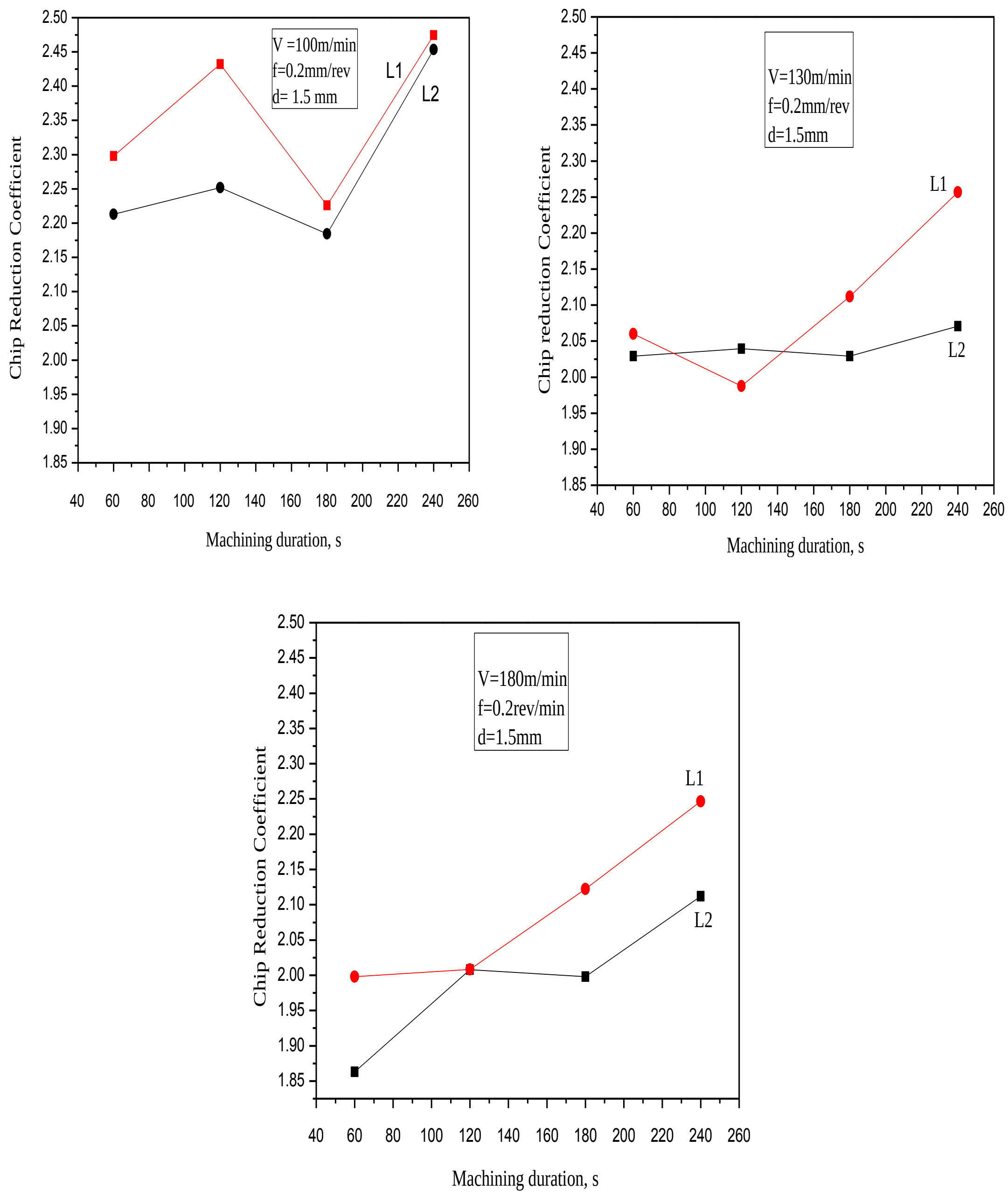


Figure 32. Variation of chip reduction coefficient with machining duration for as deposited (L1) and post-treated (L2) conditions

In case of dual layer coating, similar trend was obtained for chip reduction coefficient. However, at some points the chip relation coefficient value related to post-treated sample decreased because of contribution of localized coating removal on rake surface.

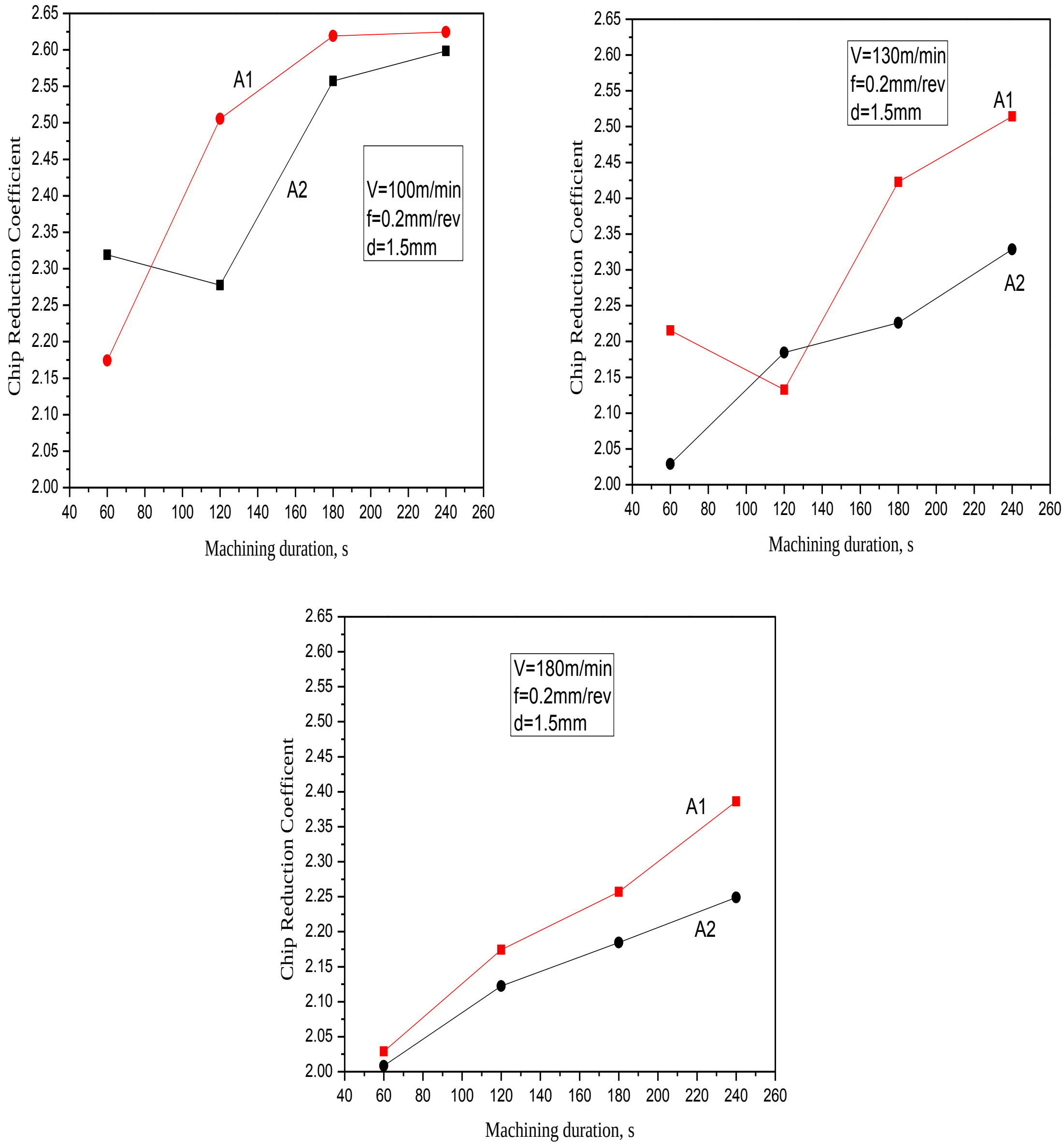
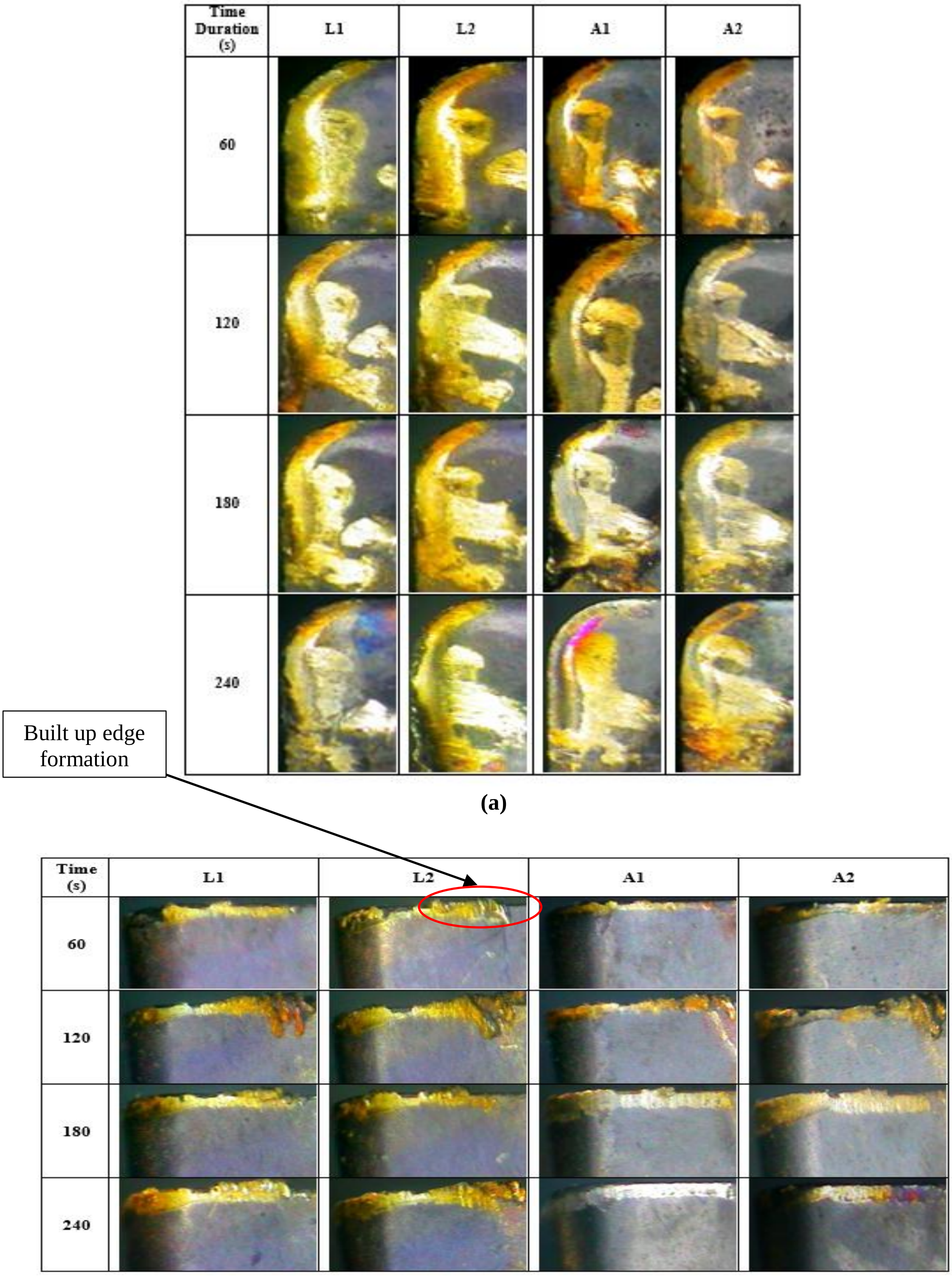


Figure 33. Variation of chip reduction coefficient with machining duration for as deposited (A1) and post-treated (A2) conditions

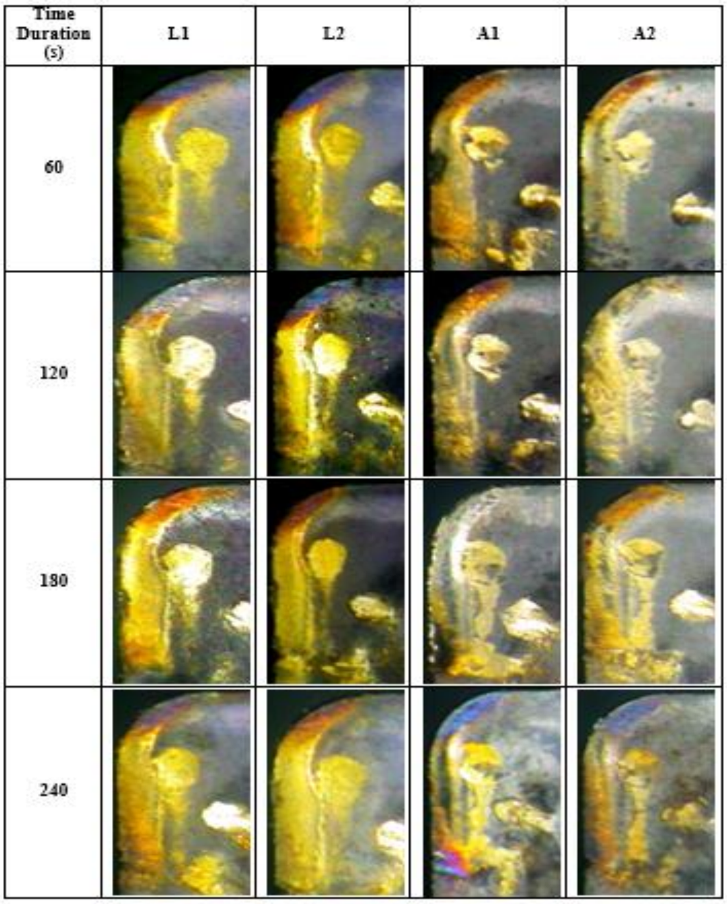
(III) Tool wear

Machining was performed with three levels of velocities in order to examine the tool wear at different intervals of time i.e. at 60 s, 120 s, 180 s and 240 s at constant value of feed (0.2 mm/rev) and depth of cut (1.5 mm). The growth of rake and flank wear for AlTiN and TiAlN/AlCrN coated tools at cutting velocity of 100 m/min, 130 m/min, and 180 m/min are shown in Figure 34- Figure 36.

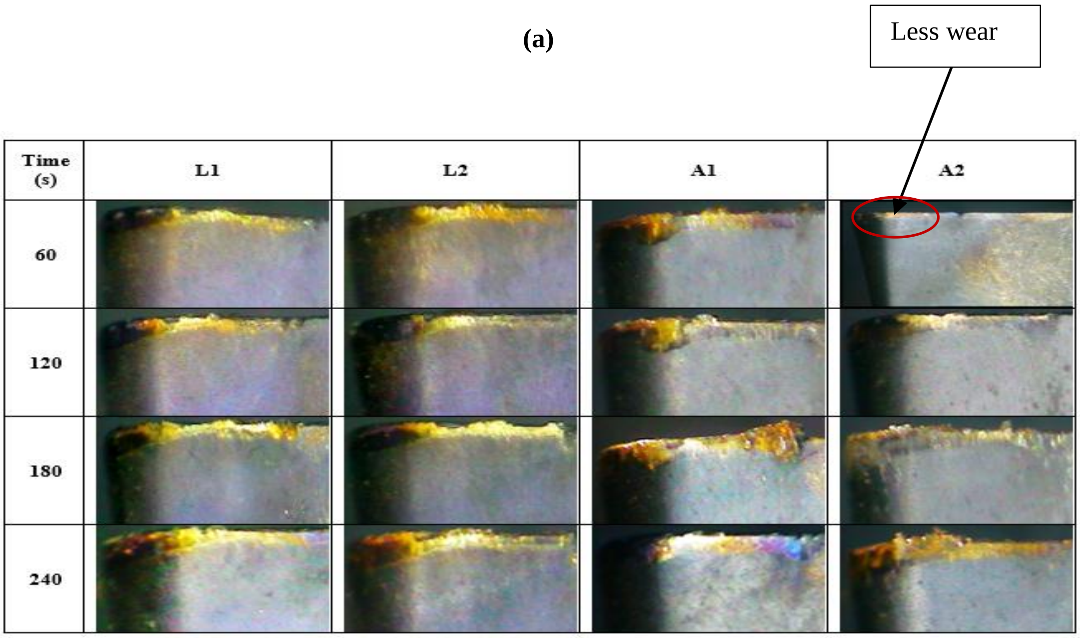


(b)

Figure 34. Growth of (a) rake and (b) flank wear of as deposited (L1, A1) and post-treated (L2, A2) samples with AlTiN and TiAlN/AlCrN coatings at V= 100 m/min.

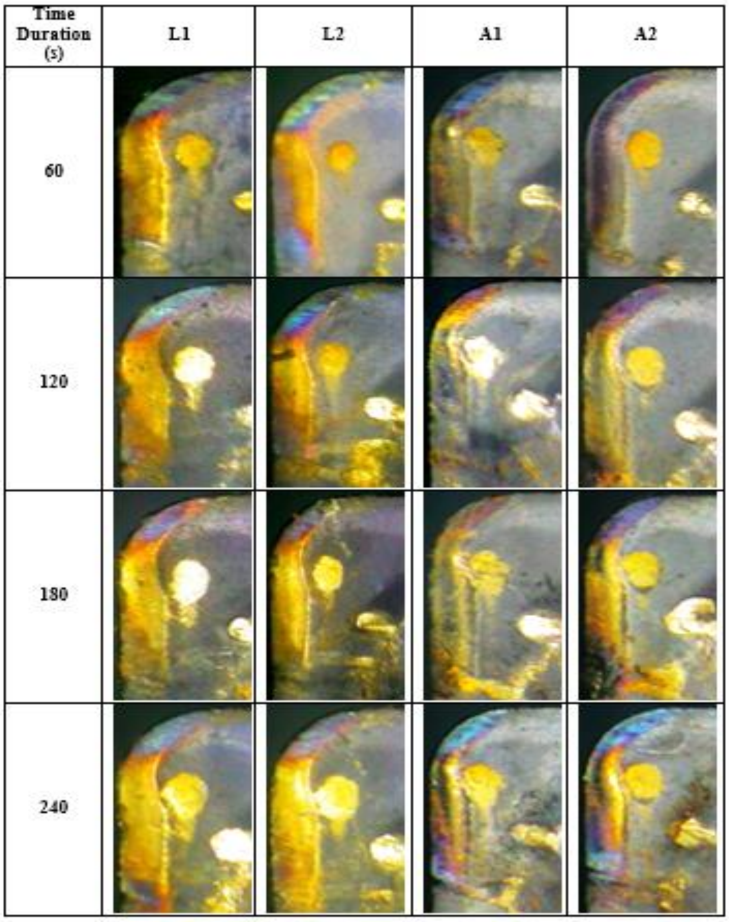


(a)

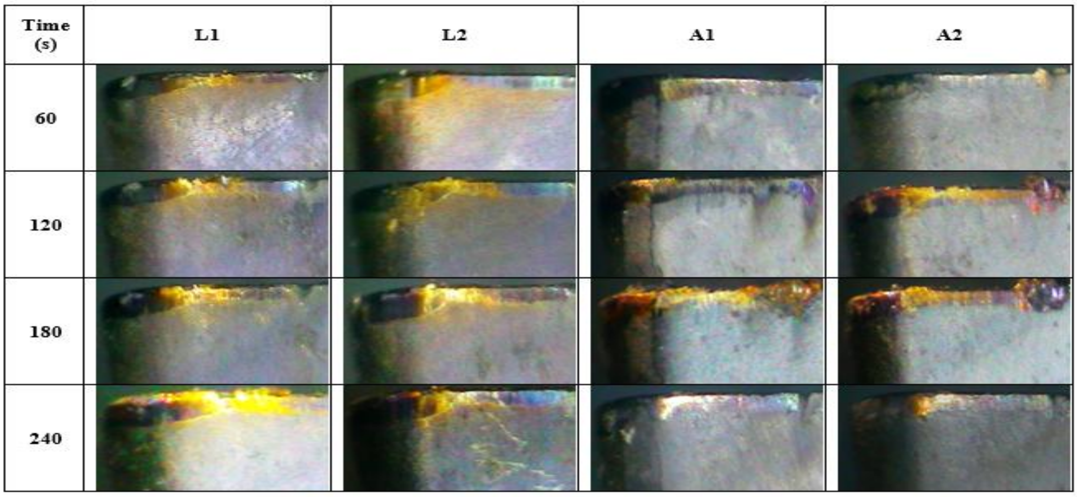


(b)

Figure 35. Growth of (a) rake and (b) flank wear of as deposited (L1, A1) and post-treated (L2, A2) samples with AlTiN and TiAlN/AlCrN coatings at V= 130 m/min.



(a)



(b)

Figure 36. Growth of (a) rake and (b) flank wear of as deposited (L1, A1) and post-treated (L2, A2) samples with AlTiN and TiAlN/AlCrN coatings at V= 180 m/min.

The growth of wear at rake and flank surfaces can be easily examined with the help of the optical microscopic images. The wear of the tool is generally judged with by examining the flank wear values. A tool is said to be failed when the value of flank wear VB reaches 0.3 mm. So to examine tool wear analytically, graphs were plotted (shown in Figure 37 and Figure 38) for both types of coated samples at varying velocity

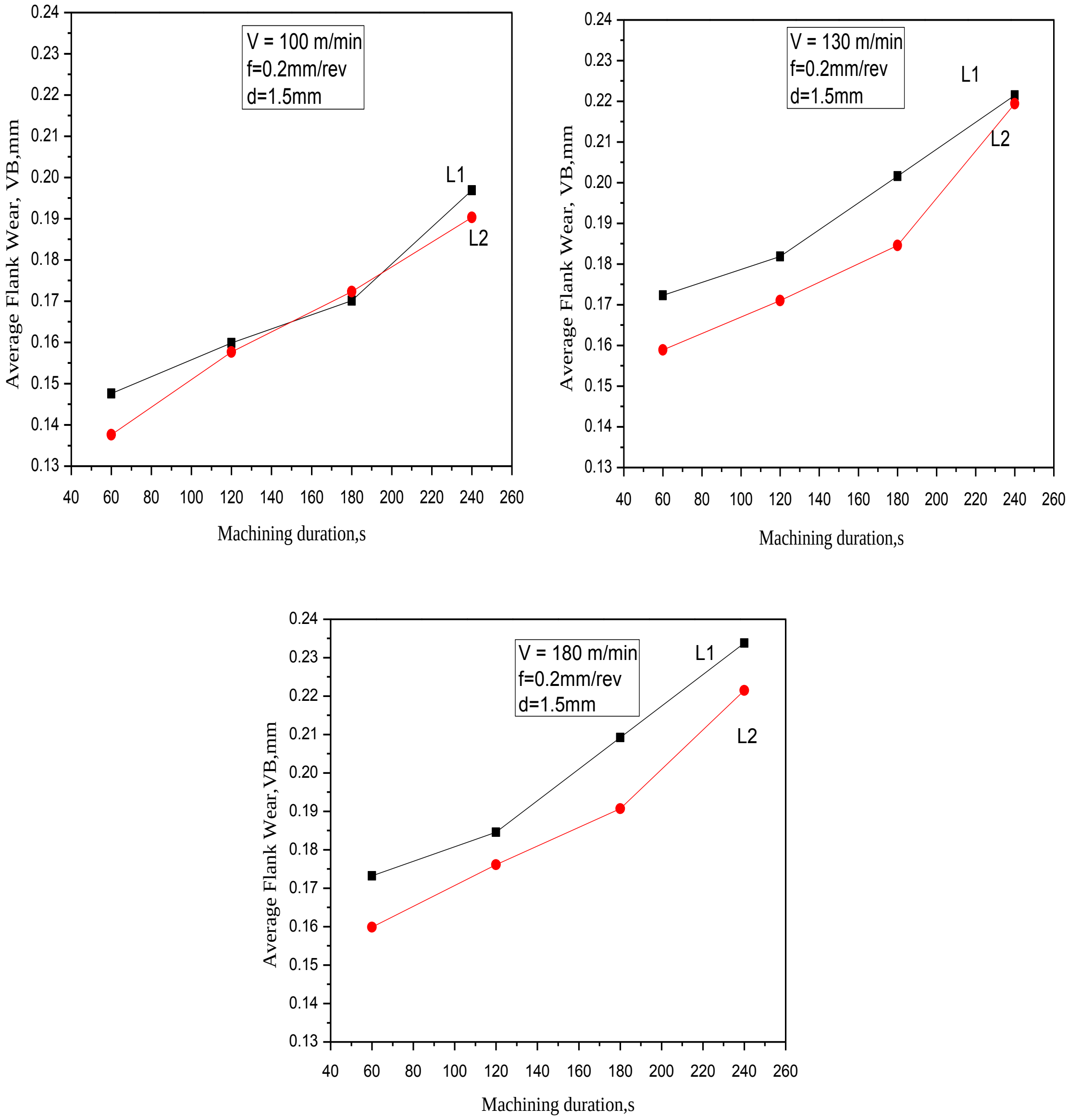


Figure 37. Variation of flank wear with machining duration in case of AlTiN coated tools with as deposited (L1) and post-treated (L2) conditions

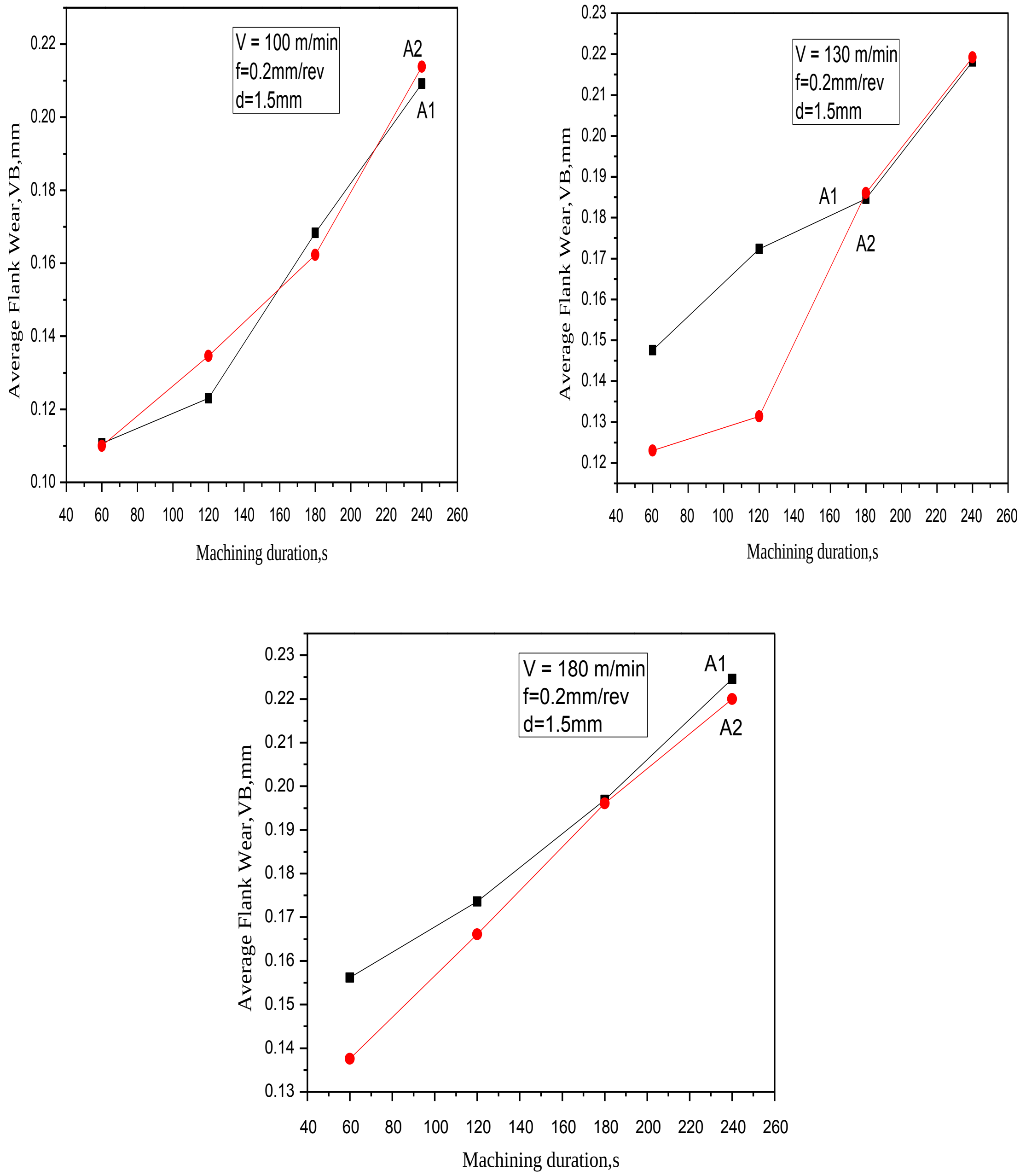


Figure 38. Variation of flank wear with machining duration in case of TiAlN/AlCrN coated tools with as deposited (A1) and post-treated (A2) conditions

During the analysis it was found that post-treated sample had undergone less wear at the flank surface as compared to as deposited samples in both types of coatings. This was correlated to increased hardness value of the samples after post-treatment. However at some instances abnormal behaviour was observed for wear due to built-up edge formation. At cutting velocity of 100 m/min and time duration of 120 s, post-treated coated tools suffered from removal of coating at selective locations resulting in formation of built up edge which was later removed by etching using sulfuric acid solution.

It was also observed that the dual layer TiAlN/AlCrN coated samples for both conditions had underdone less wear as compared to the multilayer AlTiN coated samples because of high hardness value of dual layer coated samples. After certain duration of time interval, the value of flank wear for TiAlN/AlCrN coated samples had increased rapidly and approximately same flank wear values were obtained in both the samples (i.e. in A1 and A2). Local substrate revelations at the cutting edge and flank surface caused by increased mechanical and thermal loads led to this type of behaviour of the coating which in turn decreased its cutting performance. Even though, the wear values obtained at 240 s for TiAlN/AlCrN samples were found to less as compared to AlTiN coated samples which had undergone gradual wear.

5.6.1 Effect of pre-treatment as well as combined pre-treatment and post-treatment on cutting performance of coated cemented carbide inserts in terms of machinability characteristics

(I) Cutting force

Variation of cutting force as a function of machining duration during turning operation using AlTiN and TiAlN/AlCrN coated inserts (with different conditions) is shown in Figure 39 and Figure 40. From the obtained graphs it was found that force showed an increasing trend with machining duration for all types of samples. However there was variation in the force value for each type of sample. Since as deposited sample underwent inhomogeneous wear at its cutting edge as well as its rake surface so friction value increased between tool and workpiece, thus results in higher application of force.

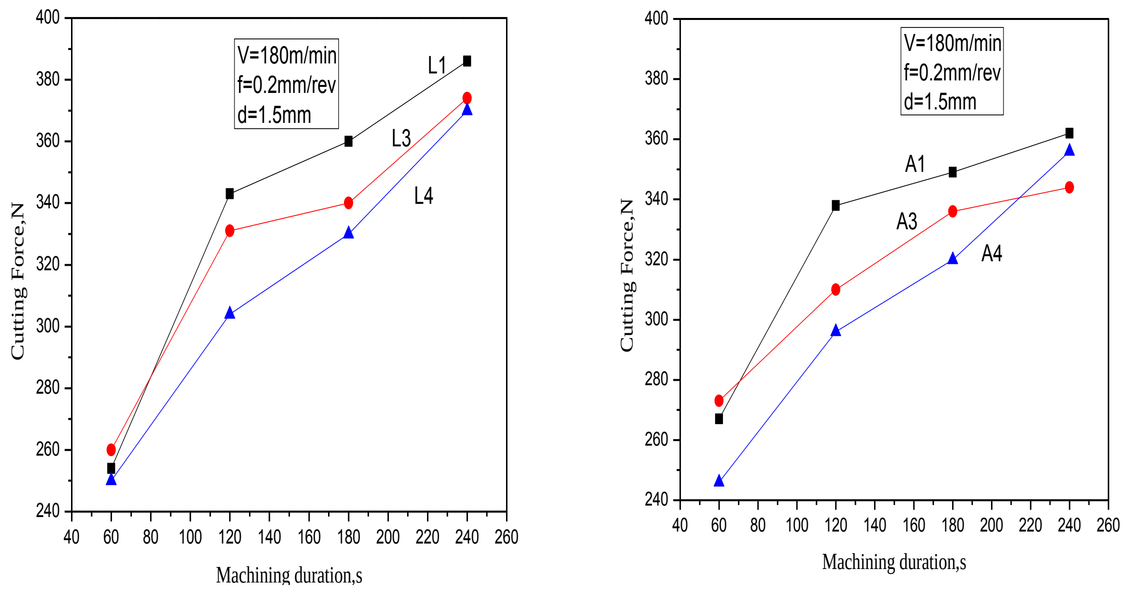


Figure 39. Variation of cutting force with machining duration for as deposited, pre-treated and combined pre as well as post treated AlTiN and TiAlN/AlCrN coated samples

But in case of pre-treated sample the wear was less as compared to as deposited because of high adhesion and low value of superficial surface roughness which in turn reduces the friction as well as cutting force between tribological pair i.e. tool and workpiece. The cutting force variation for pre-treated samples with machining duration were very much similar in both types of coating except its value. Cutting force value for pre-treated samples with TiAlN/AlCrN (A3) coating was less as compared to pre-treated samples with AlTiN coating (L3) due to its high strength and less wear.

The samples with combined pre-treatment as well as post-treatment have also shown similar trend as that of other two samples. Cutting force value obtained for the sample L4 was less as compared to L1 because prior micro abrasive blasting has increased adhesion strength of coating while the post blasting has increased it hardness. For sample A4 large value of force was very much similar to A1 at machining duration 240s. The variation in the force value at some points is due to removal of coating grains.

(II) Chip characteristics

During the machining operation i.e. turning the effect of micro blasting on PVD deposited AlTiN and TiAlN/AlCrN tools cutting performance in terms of chip characteristics was examined.

Figure 40 represents the chip quality and chip morphology for the chips obtained by using various cutting tools at start and end run of machining operation. From the study it was found that discontinuous chips was produced in all the cases. Though there was not much difference in the chip type but a significant difference in the chip quality in terms of chip length and chip curling was found for different types of samples.

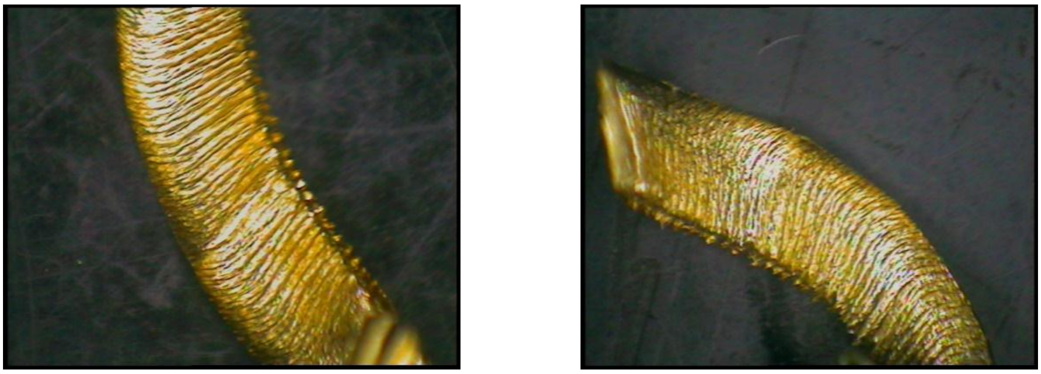
Chips obtained by using pre-treated tool were larger in length and were having more curling as compared to chips from as deposited tool. There was an increase in chip curling with increased cutting velocity which in turn reduces the chip tool contact area (less chip tool contact area was obtained in pre-treated as well as combined pre-treated and post-treated samples.

V = 180 m/min			
Samples Name/Time duration(s)	**L1**	**L3**	**L4**
60			
Chip type	Discontinuous	Discontinuous	Discontinuous
240			
Chip type	Discontinuous	Discontinuous	Discontinuous

Samples Name/Time duration	A1	A3	A4
60			
Chip type	Discontinuous	Discontinuous/Snar led	Discontinuous
240			
Chip quality	Discontinuous	Discontinuous	Discontinuous

Figure 40. Macro morphology of chips obtained using as deposited, pre-treated and combined pre as well as post-treated AlTiN and TiAlN/AlCrN coated tools during turning

Figure 41 represents the chip cross-sections for chips obtained by using pre-treated tool (L3) and combined pre-treated as well as post treated tools (L4) which have difference in their chip segregation as compared to as chips obtained using as deposited tools.



(a) **(b)**

Figure 41. Magnified images of chips for examining chip serration for (a) pre-treated and (b) combined pre as well as post-treated samples.

The trend obtained for variation of chip reduction with machining duration is shown in the Figure 42. From the plotted graph it was found that the chip reduction value for pre-treated as well combined pre-treated and post-treated was less as compared to as deposited in both types of coatings except at some points. The trend obtained was due to the low friction offered by these samples as compared to as deposited which underwent high wear due to defamation of the coating material from the cutting edge.

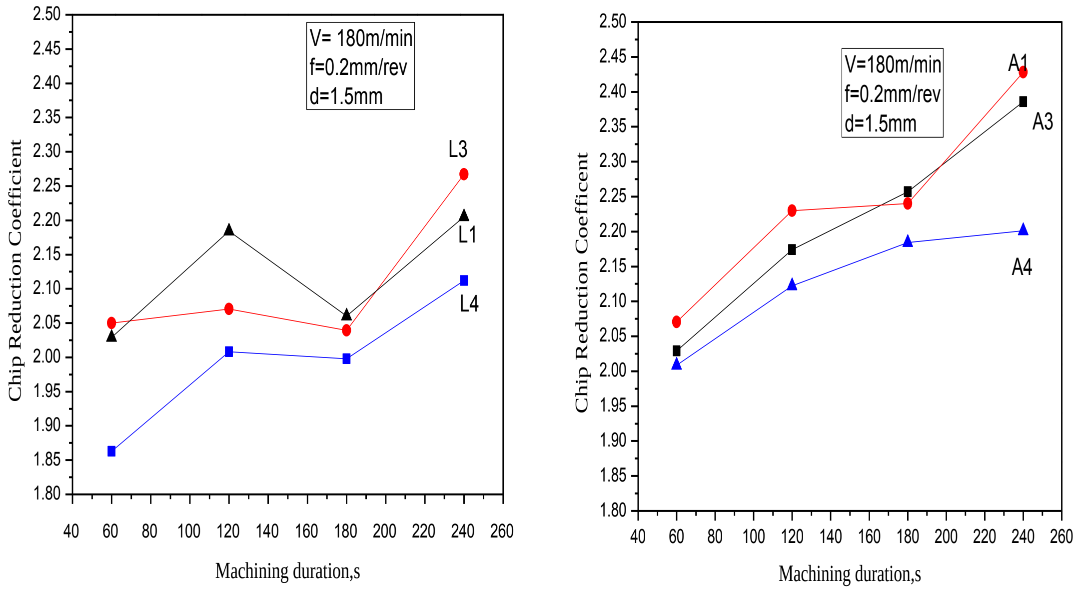
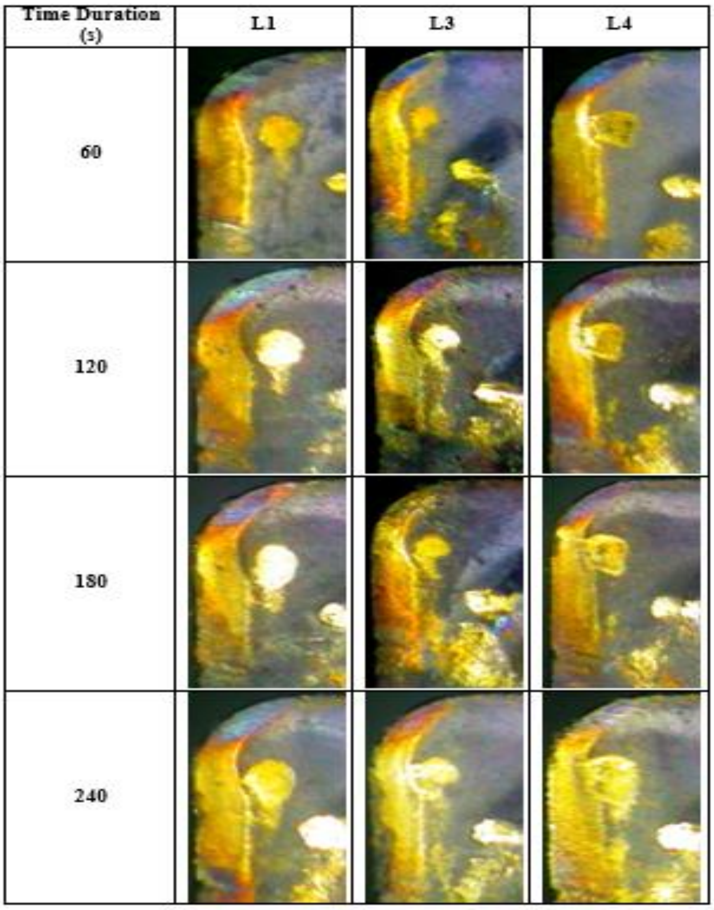


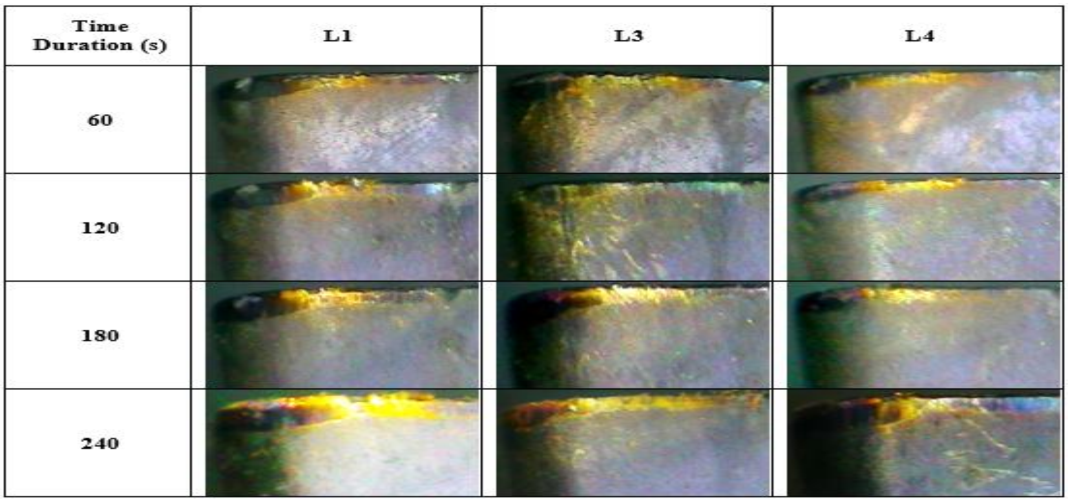
Figure 42. . Variation of chip reduction coefficient with machining duration for as deposited (L1, A1), pre-treated (L3, A3) and combined pre as well as post treated (L4, A4) conditions

(III) Tool wear

Machining performance of the tools in terms of tool wear was examined at higher cutting velocity value i.e. at 180 m/min at different intervals of time i.e. at 60 s, 120 s, 180 s and 240 s at constant value of feed (0.2 mm/rev) and depth of cut (1.5 mm). Figure 43 and Figure 44 represents growth of rake and flank wear of AlTiN and TiAlN/AlCrN coatings at cutting velocity of 180 m/min. On comparing the optical micrographs of the pre-treated samples with as deposited samples for both the coatings it was found that pre-treated samples had shown less flank and rake wear compared to the as deposited coated tools. This improvement in performance of the pre-treated samples was due to improvement in the adhesion strength between the coating material and substrate due to the micro blasting.

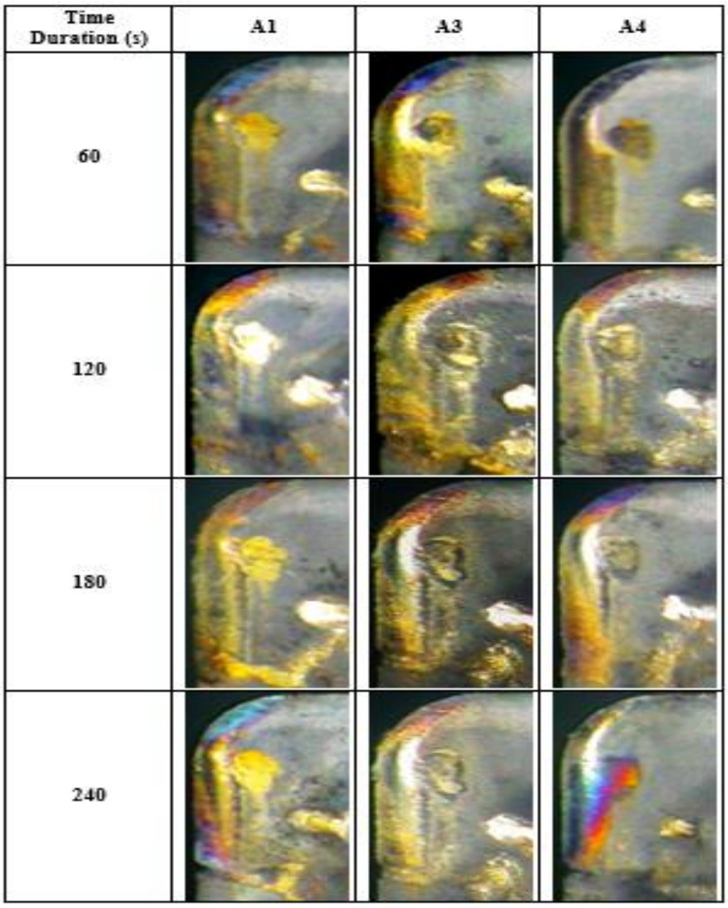


(a)

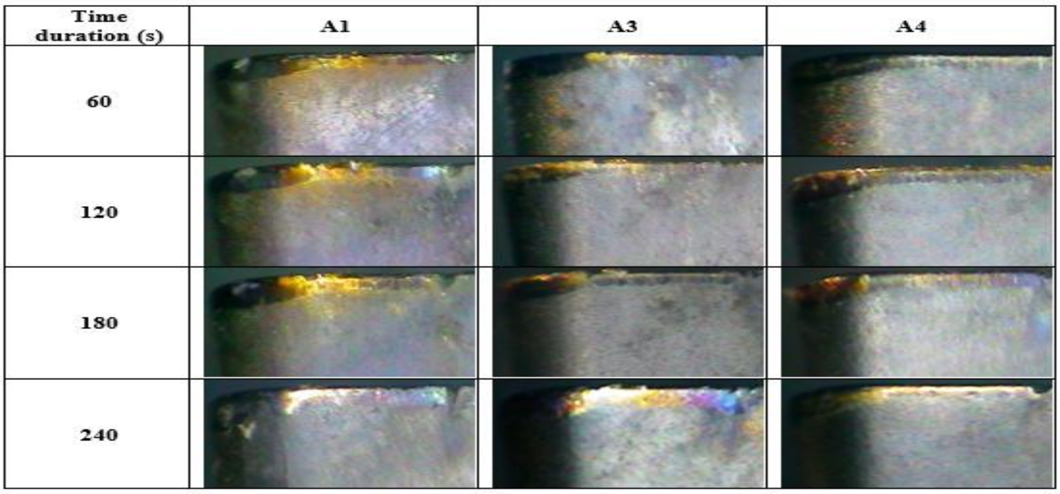


(b)

Figure 43. Growth of (a) rake and (b) flank wear for as deposited, pre-treated as well as combined pre-treated and post-treated AlTiN coated tools with machining duration



(a)



(b)

Figure 44. Growth of (a) rake and (b) flank wear for as deposited, pre-treated as well as combined pre-treated and post-treated TiAlN/AlCrN coated tools with machining duration

These obtained results also shown correlation with the less values of the cutting forces in case of pre-treatment. Combined pre-treated as well as post-treated samples had undergone least wear in comparison with pre-treated, as deposited and post-treated samples in both types of coatings. This is due to improvement of the mechanical properties i.e. adhesion, hardness, strength of the tool.

Variation in the flank wear for different samples can be examined analytically through the plotted graphs in Figure 45. In case of pre-treated AlTiN samples it was found that at initial stage flank wear was very much similar to as deposited condition. However at later stage pre-treated samples had shown less wear which resulted in improved tool life. For combined pre-treated as well as post-treated samples the less wear can also be examined through the graphs obtained for both types of coating i.e. AlTiN and TiAlN/AlCrN.

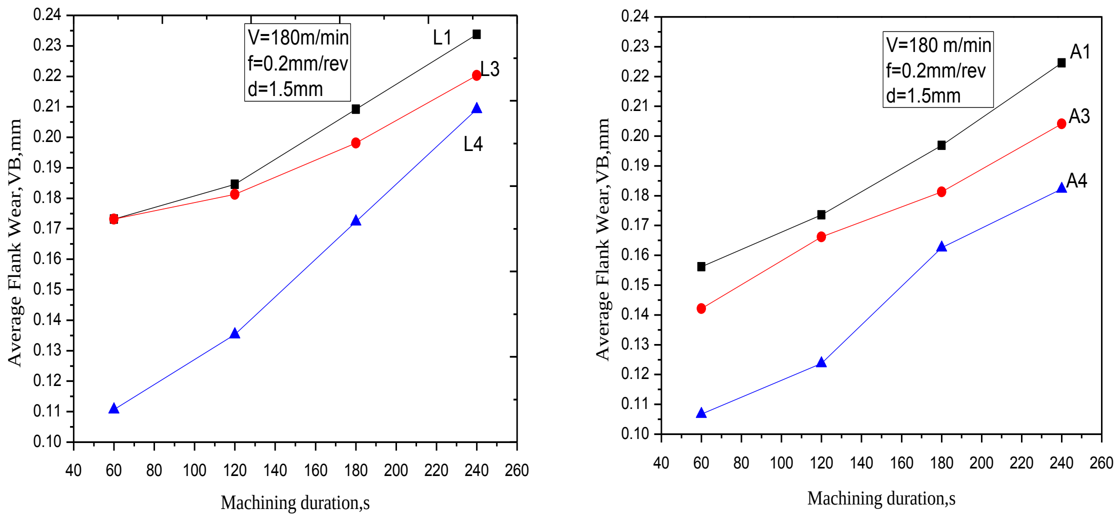


Figure 45. Variation of flank wear with machining duration for as deposited and surface treated AlTiN and TiAlN/AlCrN coated samples

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CHAPTER 6

Conclusion

6. Conclusion

The current research work investigated the influence of micro blasting as pre-treatment (i.e. substrate treatment prior to coating deposition) and post-treatment (i.e. treatment of coated surface) technique on various characteristics of two different PVD coatings namely multilayer AlTiN and TiAlN/AlCrN. The effect of pre and post treatment along with combination of both has also been studied during machinability characteristics of austenitic stainless steel AISI 316l under dry environment. The following conclusions can be made from current study.

(i) Microstructure indicated substrate blasting prior to coating deposition resulted in dense and compact structure. The presence of pores and voids was remarkably less as compared to that in as deposited and post-treated samples. The post treatment technique caused maximum number of pores and voids resulting in exposure of under layers or substrate. Post treatment also lead to flattening of coating grains

(ii) XRD study revealed broadening of peaks for both pre-treated and post-treated samples. It also showed shifting of peaks towards higher angle for pre-treated sample and towards lower angle for post-treated sample.

(iii) The composite hardness was found to be higher for TiAlN/AlCrN coating as compared to AlTiN coating. Micro abrasive blasting used both as pre-treatment and post-treatment technique appeared to enhance composite coating hardness for both type of coatings. The post-treatment was found be more effective in increasing the hardness compared to pre-treatment technique. Maximum composite hardness was obtained for samples where both blasting of substrate as well as coating was carried out (i.e. combined pre and post-treatment).

(iv) Resistance to flank wear during machining of AISI 316 austenitic stainless steel could be improved by pre-treatment as well as post-treatment for both types of coatings. Reduction of flank wear upto a maximum of 21.64 % and 23.426 % was observed for combined pre and post treated sample having AlTiN and TiAlN/AlCrN coatings respectively.

(v) Combined pre and post treatment techniques was also beneficial in reducing the cutting force. Decrease in cutting force upto a maximum of 32.315 % and 7.4468 % was observed for combined pre and post treated sample with AlTiN and TiAlN/AlCrN coatings respectively.

(vi) Promising potential of combined pre and post treatment could also be reflected in decrease of chip reduction coefficient during machining of austenitic stainless steel AISI 316l.

6.1 Contribution

The current study carefully investigated the influence of micro blasting as pre-treatment and post treatment technique separately and also in combined way on various characteristics of multilayer AlTiN and dual layer AlCrN/TiAlN coatings and compared the results with as deposited coating i.e. without any micro blasting either of substrate or coating. Further attempt was also made to study the influence of these different treatments on various machinability characteristics of AISI 316L austenitic stainless steel using tools coated with the above mentioned PVD coatings. Reduction in flank wear upto maximum of 23.426 % and decrease in cutting force upto 32.315 % was observed for combined pre and post treated sample having TiAlN/AlCrN and AlTiN coatings respectively. The results obtained from the current research would therefore would be of utmost relevance and importance to both researchers working in the area of tool coating, industries providing coating solution as well as tool manufacturers.

6.2 Recommendation

The research work clearly revealed the supremacy of combined pre and post treatment through micro blasting of coated tools in terms of superior properties and machining performance. Therefore, it is recommended to utilize micro blasting both as pre and post treatment technique for PVD coated tools after carefully choosing the parameters for micro blasting for both techniques. Future attempt may be made in the following areas to generate further knowledge in the current research topic

1. In depth micro structural analysis of pre-treated and post treated samples using high resolution FESEM and TEM in order to understand the phenomena occurring at the atomic level due to pre and post treatment along with their combined influence.
2. Optimization of parameters for micro blasting for both pre as well post treatment operation to obtain still improved synergistic effect on the machining performance of coated tools
3. Effect of pre and post treatment along with their combination on the tribological properties of the PVD coatings
4. Influence of pre and post treatment techniques on the substrate materials.

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