PERFORMANCE EVALUATION OF TiAlSiN COATED AND CRYOGENICALLY TREATED END MILLING TOOL

PROJECT REPORT

Submitted by

NANDU B
Reg. No: TKM21MEIR08

to

the APJ Abdul Kalam Technological University
in partial fulfilment of the requirements for the award of the Degree
of
Master of Technology

in

Mechanical Engineering

Specialization*: Industrial Refrigeration and Cryogenic Engineering*

DEPARTMENT OF MECHANICAL ENGINEERING
THANGAL KUNJU MUSALIAR COLLEGE OF ENGINEERING
KOLLAM
MAY 2023

DEPARTMENT OF MECHANICAL ENGINEERING
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CERTIFICATE

This is to certify that the report entitled **"PERFORMANCE EVALUATION OF TiAlSiN COATED AND CRYOGENICALLY TREATED END MILLING TOOL"** submitted by **NANDU B** Reg. No: **TKM21MEIR08** during **2022- 23** to the APJ Abdul Kalam Technological University in partial fulfilment of the requirements for the award of the Degree of Master of Technology in Industrial Refrigeration and Cryogenic Engineering is a bonafide record of the project work carried out by him under my guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

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DECLARATION

I **Nandu B**, hereby declare that the project report "Performance evaluation of TiAlSiN coated and cryogenically treated end milling tool", submitted for partial fulfillment of the requirements for the award of degree of Master of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of **Dr. Ajukumar V N.** This submission represents my ideas in my own words and where ideas or words of others have been included, I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma, or similar title of any other University.

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MAY 2023

ABSTRACT

The research focuses on the machining performance of a Titanium Aluminum Silicon Nitride (TiAlSiN) coated tungsten carbide tool during end milling of maraging steel C300. End milling experiments are performed at various spindle speeds using uncoated tool, coated tool, shallow treated coated tool and deep treated coated tool to determine surface roughness and characterize cryogenic treated and untreated tools. The tool's Scanning Electron Microscope (SEM) image can be used to determine the variation in surface characteristics. The Energy Dispersive X-ray Spectroscopy (EDS) analysis can be used to get the composition of the coating. Using a 4 flute-6mm end milling tool in a Computer Numerical Control (CNC) milling machine, a slot with a depth of 0.2mm is cut into the plate at a feed rate of 320mm/min. The process is carried out at varying speeds of 1000, 2000, 3000, and 4000rpm. It has been observed that with an increase in rpm, the surface roughness decreases in all cases. Better surface finish is observed in Shallow Cryogenic Treatment (SCT6) tool followed by Deep Cryogenic Treatment (DCT24), untreated coated tool and untreated uncoated tool. Variation in microhardness was measured using Vickers hardness testing machine. Mass loss rate from the tool wear for three conditions has been determined. SCT shows a reduction in mass loss rate and an increase in microhardness compared to untreated and DCT.

Keywords: Cryogenic treatment, surface roughness, shallow cryogenic treatment, deep cryogenic treatment, end milling, CNC milling.

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ABBREVIATIONS

UT	Untreated Tool
SCT	Shallow Cryogenic Treatment
DCT	Deep Cryogenic Treatment
LN_2	Liquid Nitrogen
SEM	Scanning Electron Microscope
EDS	Energy-Dispersive X-ray Spectroscopy
WC	Tungsten Carbide
TiAlSiN	Titanium Aluminium Silicon Nitride
CNC	Computer Numerical Control
BUE	Built-Up Edge

CHAPTER 1

INTRODUCTION

Machining is a manufacturing process that involves removing material from a workpiece using various cutting tools to create a desired shape or finish. This process is used to create precision parts and components for a wide range of industries, such as automotive, aerospace, medical, and electronics.

There are several types of machining processes, including turning, milling, drilling, grinding, and boring. Each of these processes involves using different types of cutting tools and techniques to remove material from the workpiece in a specific way.

Machining is typically performed on metal, but it can also be used on other materials such as plastic, wood, and composites. CNC (Computer Numerical Control) machining has become increasingly popular in recent years, which uses computer-controlled machines to perform precise and complex machining operations.

Machining is a crucial operation in the manufacturing industry, and it plays an important role in producing high-quality, precision parts and components for a wide range of applications. Here are some of the key reasons why machining is important:

1. *Precision and accuracy:* Machining processes can produce parts and components with extremely high precision and accuracy, which is essential for many applications, such as aerospace, medical, and automotive industries.
2. *Flexibility:* Machining processes are versatile and can be used to create a wide range of shapes and features, including complex geometries and tight tolerances.
3. *Efficiency:* Machining processes can be automated, which can improve efficiency and reduce production time and costs.
4. *Quality control:* Machining processes can be tightly controlled and monitored, allowing for rigorous quality control and inspection of parts and components.
5. *Material compatibility:* Machining can be used to work with a variety of materials, including metals, plastics, and composites, which allows for flexibility in material selection for different applications.
6. *Customization:* Machining processes can be tailored to specific requirements, allowing for customization of parts and components to meet the unique needs of different industries and applications.

1.1 MILLING

Milling is a type of machining operation that involves the use of a rotating cutting tool to remove material from a workpiece.

During milling, the workpiece is securely clamped to a machine table, and a cutting tool with multiple teeth is rotated at high speeds. As the cutting tool rotates, it removes material from the workpiece, creating a desired shape or surface finish.

Milling machines can be either manual or automated, with computer numerical control (CNC) machines being widely used in modern manufacturing facilities. CNC milling machines can be programmed to perform complex milling operations with a high degree of accuracy and consistency.

Overall, machining and milling operations play a critical role in modern manufacturing, enabling the production of a wide range of complex components used in various industries.

1.1.1 TYPES OF MILLING OPERATIONS

1. *Face milling:* This involves cutting the surface of a workpiece with a milling cutter that has teeth on its periphery. It is used to create a flat surface, a step, or a groove on the workpiece.
2. *Peripheral milling:* In this operation, the cutter rotates on its axis while it moves along the periphery of the workpiece. It is used to create a slot, a contour, or a flat surface on the workpiece.
3. *End milling:* This operation involves cutting the surface of the workpiece with a milling cutter that has teeth on the end of its periphery. It is used to create a flat surface or a contour on the end of a workpiece.
4. *Chamfer milling:* In this operation, the milling cutter is used to create a beveled edge on the workpiece.
5. *Slot milling:* This operation involves cutting a slot into the workpiece using a milling cutter. The slot can be straight or curved, and can be used to create a variety of shapes and features.
6. *Gear milling:* This operation is used to create gears using a specialized milling cutter that has teeth on its periphery. It is used in the manufacturing of gears for various applications.
7. *Thread milling:* In this operation, a specialized milling cutter is used to create threads on the surface of the workpiece. It is used in the manufacturing of threaded components.

8. *Face milling with a radius cutter:* This operation is similar to face milling, but it uses a milling cutter with a radius on its periphery. It is used to create a contoured surface on the workpiece.

1.1.2 REQUIRED PROPERTIES OF CUTTING TOOL MATERIAL

The properties required in cutting tool materials depend on the type of cutting operation, workpiece material, and desired outcome. However, some general properties required in cutting tool materials include:

1. *Hardness:* Cutting tool materials should be hard enough to withstand the cutting forces and temperatures generated during the cutting process. Hardness is typically measured using the Rockwell or Vickers hardness scale.
2. *Wear resistance:* Cutting tool materials should have good wear resistance to prevent premature tool failure and extend tool life. Wear resistance is typically improved by adding carbides, nitrides, or other hard compounds to the tool material.
3. *Toughness:* Cutting tool materials should have good toughness to resist chipping or cracking under the high stresses encountered during cutting. Toughness is typically improved by adding metals such as cobalt or nickel to the tool material.
4. *Thermal stability:* Cutting tool materials should have good thermal stability to maintain their hardness and wear resistance at high temperatures. Thermal stability is typically improved by using materials with high melting points, such as tungsten carbide or ceramic.
5. *Chemical stability:* Cutting tool materials should have good chemical stability to resist corrosion and oxidation. Chemical stability is typically improved by using materials that form protective oxide layers, such as titanium or aluminum.
6. *Machinability:* Cutting tool materials should be easily machinable to produce the desired tool geometry. Machinability is typically improved by using materials that are easy to machine, such as high-speed steel or cobalt.

1.1.3 TOOL LIFE

Tool life refers to the length of time a cutting tool can be used before it becomes worn out and needs to be replaced. A longer tool life can provide benefits such as reduced downtime, increased productivity, and lower tooling costs. To extend the tool life of a cutting tool, it is important to optimize the cutting conditions and use the appropriate cutting tool for the specific application.

The tool life of a cutting tool depends on various factors, including:

1. *Cutting speed:* The cutting speed is the speed at which the workpiece moves past the cutting tool. Higher cutting speeds can increase the temperature at the cutting edge, leading to faster tool wear.
2. *Feed rate:* The feed rate is the rate at which the cutting tool advances into the workpiece. Higher feed rates can cause increased tool wear due to higher cutting forces.
3. *Depth of cut:* The depth of cut is the distance between the tool and the workpiece. Higher depths of cut can cause increased tool wear due to higher cutting forces.
4. *Workpiece material:* The properties of the workpiece material, such as hardness and toughness, can affect the tool life. Harder materials can cause faster tool wear due to increased cutting forces and higher temperatures.
5. *Cutting fluid:* The type and application of cutting fluid can affect tool life. Proper application of cutting fluid can improve tool life by reducing friction, lowering temperatures, and removing chips.
6. *Tool material:* The properties of the tool material, such as hardness, toughness, and wear resistance, can affect tool life. Higher-quality tool materials can withstand higher cutting speeds and feed rates, leading to longer tool life.
7. *Tool geometry:* The geometry of the cutting tool, such as rake angle and clearance angle, can affect tool life. Proper tool geometry can reduce cutting forces and temperatures, leading to longer tool life.

   The aim of the work is to find ways to improve the tool life and surface quality of milled surfaces at low rpm without the use of any lubricants. This can be achieved through various methods, such as using high-quality cutting tools with specialized coatings or by cryogenic treatment. Improving the tool life and surface quality of milled surfaces at low rpm can have significant benefits, including reducing production costs, improving product quality, and increasing the efficiency of the milling process. This project could have a significant impact on the manufacturing industry by providing new methods for optimizing the milling process and improving the performance of milling machines.

Different types of cutting tool materials are mentioned in the table 1.1.

Table 1.1 Different type of cutting tool materials

Tool Material	**Properties**	**Applications**
High-Speed Steel (HSS)	HSS is a type of tool steel that can withstand high temperatures without losing its hardness. It is suitable for cutting ferrous and non-ferrous materials.	It is commonly used for milling cutters, drills, and taps.
Carbide	Carbide is a composite material made of tungsten carbide and cobalt. It is very hard and wear-resistant and is suitable for cutting hard materials like stainless steel and titanium.	Carbide is commonly used for cutting inserts, end mills, and reamers.
Ceramics	Ceramics are inorganic materials that are very hard and wear-resistant. They are suitable for cutting hard materials at high speeds, such as superalloys, hardened steels, and ceramics. The	Ceramic cutting tools are commonly used for turning, milling, and drilling.
Cubic Boron Nitride (CBN)	CBN is a synthetic material that is second only to diamond in hardness. It is suitable for cutting hardened steels and difficult-to-machine materials like cast iron.	CBN cutting tools are commonly used for turning, milling, and grinding.
Diamond	Diamond is the hardest material known and is suitable for cutting abrasive materials like glass, ceramics, and composites.	Diamond cutting tools are commonly used for grinding, cutting, and drilling.
PCD (Polycrystalline Diamond) Tools	PCD tools are made from a composite material consisting of diamond particles and a binder. They are extremely hard and wear-resistant and	PCD tools are commonly used for milling, turning, and drilling.

	are suitable for cutting non-ferrous materials like aluminum, copper, and plastics.	
Cermet Tools	Cermet tools are a composite material made of ceramic and metallic particles. They exhibit high wear resistance and toughness and are suitable for cutting hard materials like cast iron and hardened steel.	Cermet tools are commonly used for turning, milling, and drilling.
HSS-Co (High-Speed Steel with Cobalt) Tools	HSS-Co tools are made by adding cobalt to high-speed steel, which increases its hardness and wear resistance. They are suitable for cutting ferrous and non-ferrous materials.	HSS-Co tools are commonly used for milling, drilling, and reaming.
Alumina tools	Alumina is a ceramic material that has high hardness, excellent wear resistance, and good chemical stability.	It is suitable for cutting a wide range of materials and is commonly used for turning and milling.
Carbon tool Steels	Unstable, very expensive, extremely sensitive to heat.	It is commonly used for drill bits, taps, dies, reamers.

Various types of wear types at cutting edge are represented in table 1.2.

Table 1.2 Wear mechanism and wear types at cutting edge

Wear type	**Location on the tool**	**Typical wear mechanism**
Thermal deformation Flank	Nose	Plastic deformation of the nose due to insufficient thermal strength of the substrate at the specified cutting conditions.
Thermal cracks	Nose & flank face	Surface and material fatigue due to thermal cycling of the tool.

Depth-of-cut notch	Flank and rake face	Abrasive wear, a deep notch at an approximately depth-of-cut distance for the nose, due to extreme abrasion by the work hardened surface of the workpiece.
Built-up edge	Nose–rake face	Adhesion of chips due to chemical reaction and solubility with the workpiece, typically at low cutting speed.
Cratering	Top surface	Diffusion and chemical wear due to severe friction and chemical interaction between the hot chip and the rake face of the tool.
Mechanical wear	Nose, flank and clearance face	Abrasive wear: mechanical abrasion between tool and workpiece.

1.2 OBJECTIVES

The aim and objectives of the project are;

- To evaluate the variation in hardness of TiAlSiN coated tool in untreated, deep cryogenic treated and shallow cryogenic treated condition.
- To characterize the Cryogenic Treated and Untreated Tool.
- To compare the surface roughness during milling using uncoated, coated, shallow treated and deep treated end milling tool.
- To evaluate the tool wear of untreated, shallow treated and deep treated tools.

1.3 METHODOLOGY

The methodology of the work is depicted in the fig 1.1

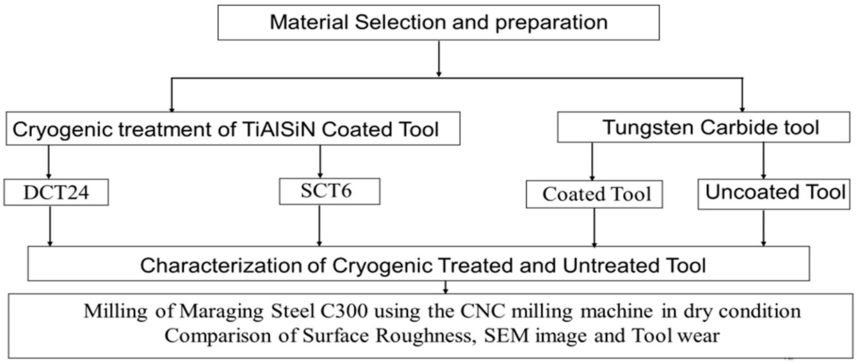


Fig 1.1 Methodology of work

CHAPTER 2

LITERATURE SURVEY

2.1 RECENT DEVELOPMENTS IN MILLING OPERATIONS

- A.Molinari et al.(2001) carried out an experiment to determine the effect of deep cryogenic treatment on the mechanical properties of tool steels, and it was discovered that deep cryogenic treatment on quenched and tempered high speed steel tools improves their properties such as increasing hardness and improving hardness homogeneity, reducing tool consumption and down time for equipment setup, resulting in a 50% cost reduction.
- Hui-Bo He, Wen-Qiang Han, Hua-Ying Li, Dong-Yang Li, Jun Yang, Tao Gu, and Tao Deng (2014) carried out an experiment on deep cryogenic treatment (DCT) at -196°C for 30 hours on TiAlN coated YT15 tungsten carbide inserts. On AISI 5140 steel, dry turning experiments using uncoated, NCT TiAlN coated, and DCT TiAlN coated tools were conducted by varying the cutting speeds, and at constant depth of cut and feed rate.During the dry turning of AISI 5140 steel, the DCT tool looked impressive in terms of cutting force, cutting temperature, surface roughness, tool life, and tool wear, particularly at higher cutting speeds.
- Yin-Yu Chang, Hsing-Ming Lai, (2014), study found that nanocrystalline TiAlSiN coatings are more effective in reducing tool wear compared to TiAlN coatings. At high cutting speeds of 350 m/min, the CrAlSiN coating exhibited the highest wear resistance, surpassing TiAlSiN, TiAlN, and uncoated tools by 2.9, 4.2, and 9.5 times, respectively. The results suggest that the CrAlSiN coatings demonstrate the best cutting performance in dry machining of Ti–6Al–4V alloys.
- C.Y. Wang, Y.X. Xie, Z. Qin, H.S. Lin, Y.H. Yuan, Q.M. Wang (2015) carried out research into the relationship between tool wear and tool coating materials, TiSiN and TiAlN coatings are used in the high-speed milling of hardened steels of varying hardnesses. It is found that the most common types of tool wear and breakage when using TiSiN- and TiAlN-coated carbide tools for the high-speed milling of hardened steel were flank wear, rake face wear, coating peeling, and chipping.The tool life of cutting tools coated with TiSiN were found to be around four times as long as than that of tools coated with TiAlN. The peeling of the coating, chipping, and tip breakage are the forms of tool breakage that happened during the high-speed milling of hardened steel using coated carbide tools.

- Vinothkumar Sivalingam, Jie Sun, Bin Yang, Kai Liu, Ramesh Raju(2018)conduct an experiment to study the machinability of Ti-6Al-4 V alloy with a PVD TiAlN/NbN coated tungsten carbide insert under cryogenic treated (i.e. 24 h & 48 h) and untreated conditions. The experimental findings revealed that, when compared to an untreated insert under a given set of working conditions, an insert that has undergone cryogenic treatment exhibits greater machinability and increased tool life.
- Vishnu Vardhan Mukkoti, G. Sankaraiah, M. Yohan. (2018) study found that cryogenic soaking duration had the most significant effect on cutting forces and power consumption, followed by cutting speed, feed, and depth of cut. The results showed that DCT tools soaked for longer durations minimized cutting forces and power consumption compared to untreated tools.
- Abdullah Sert, Osman Nuri Celik, (2019) conducted X-ray diffraction (XRD) analysis on samples of a Co-based alloy with different cryogenic treatment and tempering conditions. They observed a martensitic transformation of the α-Co (fcc) phase to the ε-Co (hcp) phase in the binder Co element of the alloy, as confirmed by the Rietveld analysis of the XRD data. The ε-Co ratio was found to be higher in the deep cryogenic treatment samples compared to shallow cryogenic treatment and the untreated samples.
- Vinay Varghese, Akhil K, M.R. Ramesh, D. Chakradhar (2019) had done an experiment to compare the machining performance of AlCrN and AlTiN coated cemented carbide inserts when end milling MDN 250 maraging steel. Compared to AlTiN coatings, AlCrN coatings offer higher machinability. AlCrN coatings have higher micromechanical properties than AlTiN coatings, such as a higher hardness and plasticity index. AlCrN has better wear resistance and decreased thermal conductivity due to the chromium oxide and aluminium chromium oxide coatings that are formed through oxidation. Using coated inserts significantly reduced the workpiece's surface roughness. A better surface finish was achieved due to the decreased tool wear and cutting temperature.
- Vinay Varghese, M.R. Ramesh, D. Chakradhar (2019) carried out a study to compare the performance of the two types of inserts in terms of tool wear, surface roughness, and cutting forces. The results showed that cryogenic treatment was effective in reducing tool wear, even at high spindle speeds. The cryogenically treated inserts demonstrated higher tool life, improved surface finish, and lower cutting forces during machining at various spindle speeds. The study also determined the optimum soaking time for cryogenic treatment of

WC-Co inserts to be 24 hours (CT-24). Beyond this duration, no significant improvement was observed in terms of microhardness and wear resistance.

- Neeraj Sharma, Kapil Gupta (2019) found that The quality of the machined surface enhanced with the increase in cutting speed, but deteriorated with feed rate and depth of cut. Due to better tribological properties of the TiN/TiAlN multi-layer coating, the quality of machined surface is better when using coated tools.
- Nursel Altan Özbek (2020) carried out a study the effects of cryogenic treatment on cutting tool performance when turning AISI H11 using TiCN/Al2O3/TiN-coated tungsten carbide tools. In this work Shallow cryogenic treatment was applied for 6 h for −80°C (SCT6), deep cryogenic treatment at −196°C for 6 h (DCT6), and deep cryogenic treatment at −196°C for 24 h(DCT24) were done. The cryogenic treatment enhanced the hardness of the cutting tools. The highest hardness occurred in the tools with deep cryogenic treatment applied at −196°C for 24 h followed by deep cryogenic treatment applied at −196°C for 6 h, and by tools that had shallow cryogenic treatment applied at −80°C for 6 h. Tools that were deep cryogenic treated performed better in terms of wear and surface roughness.
- Anshuman Das, Miyaz Kamal, Sudhansu Ranjan Das (2021) carries out a comparative study and found that the newly developed nanocomposite (SPPP-TiAlSiN) coated carbide tool promises a better surface finish, reduced cutting force, longer tool life due to lower crater and flank wears, and a significant improvement in tool life. Higher cutting speeds increase crater wear length and flank wear while decreasing surface roughness, crater wear width, and cutting force.
- Vitor F.C. Sousa, F.J.G. Silva *et.al.*(2022) had done a study to analyze the wear behavior of various PVD-coated tools with different geometries while milling pre-hardened tool steel. The tools used in the experiment had two distinct geometries, namely ball nose end mill and end mill tools, and were coated with two different PVD coatings, TiAlSiN and TiAlN. The milling operations were conducted on W 1.2711 pre-hardened tool steel. Both coatings exhibited similar wear mechanisms, but TiAlSiN coatings had less flank wear than TiAlN coatings, especially for ball mills. TiAlSiN coated tools produced better-quality surface roughness on the machined material compared to TiAlN coated tools, with the ball mill having the most significant effect.

2.2 SUMMARARY OF THE LITERATURE SURVEY

In summary, various experiments have been conducted to study the effects of deep cryogenic treatment, coatings, and cutting conditions on tool performance during machining. A.Molinari et al. discovered that deep cryogenic treatment on quenched and tempered high-speed steel tools improves their properties, resulting in a 50% cost reduction. Hui-Bo He, Wen-Qiang Han, Hua-Ying Li, Dong-Yang Li, Jun Yang, Tao Gu, and Tao Deng found that deep cryogenic treatment on TiAlN coated YT15 tungsten carbide inserts improved their cutting force, temperature, roughness, tool life, and wear. Wang et al. (2015) and Vinothkumar et al. (2018) found that the type of coating and cryogenic treatment affect tool wear and surface finish. Vinay Varghese et al. (2019) found that AlCrN coatings offer higher machinability and better wear resistance than AlTiN coatings. Cryogenic treatment was effective in reducing tool wear and improving surface finish, and the optimum soaking time for cryogenic treatment was 24 hours. Neeraj Sharma and Kapil Gupta (2019) found that the quality of the machined surface is better when using TiN/TiAlN-coated tools. Nursel Altan Özbek (2020) found that cryogenic treatment enhanced the hardness of cutting tools and improved their wear and surface roughness. Anshuman Das et al. (2021) compared the performance of different coatings and found that nanocomposite coatings outperform other coatings in terms of tool life, surface finish, and wear resistance. Overall, these studies provide insights into the various factors that affect tool performance during machining and highlight the importance of selecting appropriate coatings and cryogenic treatments to improve tool life, surface finish, and machining efficiency.

CHAPTER 3

EXPERIMENTAL WORK MATERIALS

3.1 WORK MATERIAL

Maraging steel is a tough material that finds wide application in formula 1 drive shafts, missile casings, ordinance breech blocks and tooling. For the purposes of this study, the work material used is hardened maraging steel C300, which has been forged and annealed and has dimensions of 200 x 100 x 8mm. This material has been sourced from Neptune Alloy Limited in Mumbai, India. The company has provided the chemical composition and mechanical properties of Maraging steel C300, which are presented in Table 3.1 and Table 3.2, respectively. An EDS analysis has been conducted to determine the chemical composition of Maraging Steel C300, and the results are shown in Fig 3.2.

Fig 3.1 200*100*8mm maraging steel plate

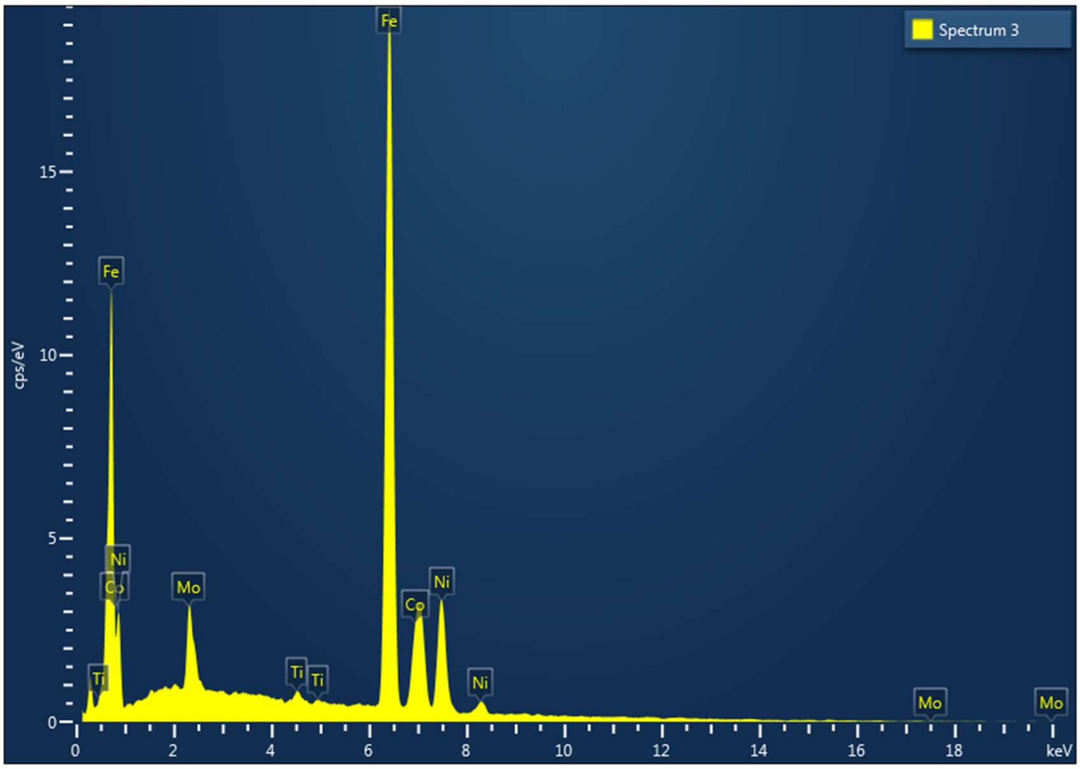


Fig 3.2 EDS analysis of maraging steel C300

Table 3.1 Chemical composition of maraging steel C300

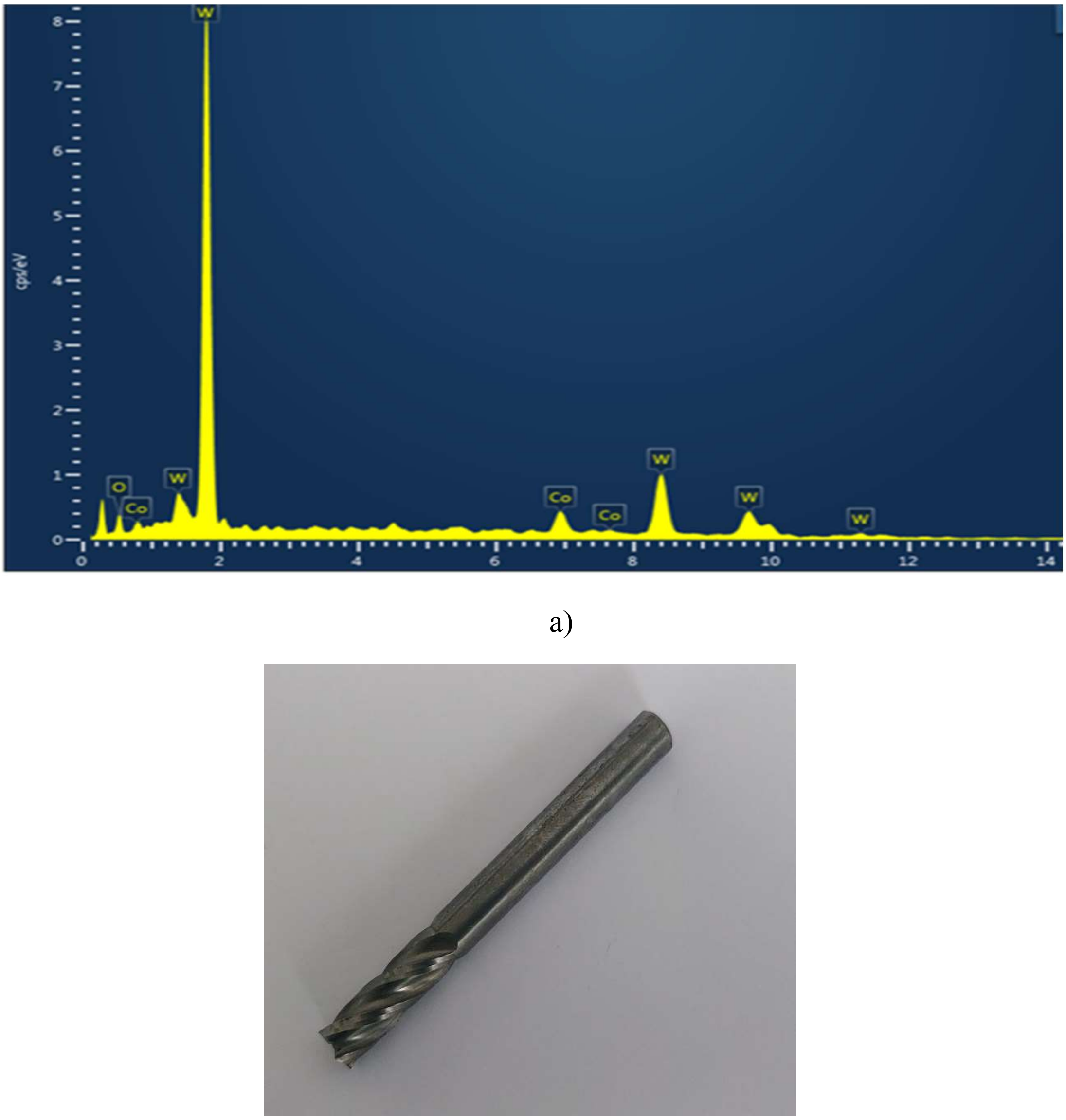
Element	Ti	Fe	Co	Ni	Mo
Weight%	0.48	68.01	8.16	17.33	6.02

3.2 UNCOATED CUTTING TOOL MATERIAL

In the experiment, a cutting tool with a diameter of 6 mm and four flutes was used, supplied by NVK Metals and Tools Pvt. LLP. An image of the cutting tool used in the experiment is shown in Fig 3.3b. An EDS analysis revealed that the composition of the WC-Co alloy used in the cutting inserts, Fig 3.3a shows the EDS analysis of the WC-Co cutting inserts. Table 3.2 provides a detailed specification of the cutting tool used in the experiments.

Table 3.2 Chemical composition of uncoated tool

Element	Line Type	Weight%	Atomic %
O	K series	5.16	35.36
Co	K series	10.38	11.88
W	L series	84.46	52.76
Total:		100	100



a)

b)

Fig 3.3 Chemical composition analysis of WC-Co cutting inserts using a) EDS analysis b) 6mm uncoated tool

3.3 TiAlSiN COATED TOOL MATERIAL

TiAlSiN coated tool material is a type of cutting tool material that is commonly used in metal cutting applications due to its excellent performance characteristics. TiAlSiN stands for Titanium Aluminium Silicon Nitride, which is a hard ceramic coating that is applied to the surface of the tool material using a physical vapor deposition (PVD) process.

The TiAlSiN coating provides the cutting tool with several advantages, including high wear resistance, good adhesion to the substrate material, and low friction. This results in improved tool life, higher cutting speeds, and better surface finish. TiAlSiN coated tool materials are commonly used in machining applications that involve high-temperature metals, such as titanium, nickel, and stainless steel.

In addition to its excellent performance characteristics, TiAlSiN coated tool materials are also environmentally friendly, as they do not contain any toxic or hazardous substances. This makes them an ideal choice for companies that are committed to sustainability and environmental responsibility.

Fig 3.4 TiAlSiN coated tool

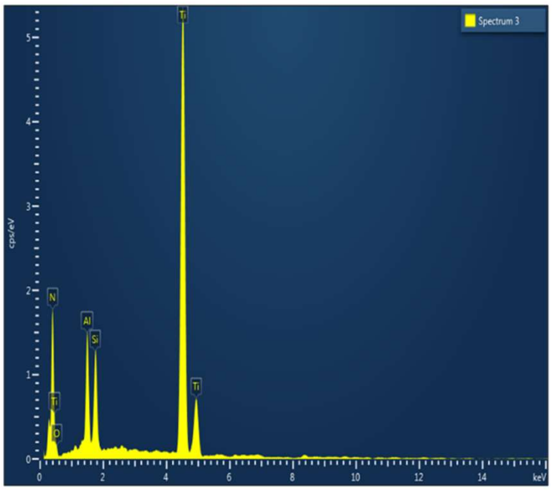


Fig 3.5 EDS analysis of coated tool

Table 3.3 Chemical composition of TiAlSiN coated tool

Element	Line Type	Weight%	Atomic %
N	K series	19.19	36.43
O	K series	12.48	20.75
Al	K series	6.64	6.55
Si	K series	5.14	4.86
Ti	K series	56.55	31.4
Total:		100	100

CHAPTER 4

CRYOGENIC TREATMENT

4.1 INTRODUCTION TO CRYOGENIC TREATMENT

Cryogenic treatment is a process that involves exposing materials to very low temperatures, typically below −150 °C (−238 °F), for an extended period of time. The process is designed to enhance the physical and mechanical properties of the material, resulting in improved performance and durability.

Cryogenic treatment is commonly used in the manufacturing of cutting tools, as it can improve the tool's performance and extend its life. Additionally, the process is also used in other industries, such as automotive, aerospace, and medical, to improve the strength and durability of materials used in various components and parts.

Overall, cryogenic treatment has become a popular method for enhancing the properties of various materials, offering improved performance and extended service life, resulting in cost savings and improved efficiency.

4.2 CRYOGENIC TREATMENT USING LIQUID NITROGEN

Cryogenic treatment using liquid nitrogen is a popular method for exposing materials to extremely low temperatures. Liquid nitrogen is a colourless, odourless, and non-toxic liquid that is obtained by cooling and compressing air. It has a boiling point of -196°C and is often used in cryogenic applications due to its ability to rapidly cool materials to very low temperatures.

In cryogenic treatment using liquid nitrogen, the material is typically placed in a specially designed chamber and cooled using liquid nitrogen. The material is held at the low temperature for a specified period of time, usually several hours, to allow for the molecular changes to take place. The temperature is then slowly raised, and the material is allowed to return to room temperature over a period of hours or days.

Cryogenic treatment using liquid nitrogen is often used in the manufacturing of cutting tools, where it can improve the wear resistance and lifespan of the tool. It is also used in the automotive industry to improve the performance and durability of engine components. In addition, it can be used to treat materials such as plastics, ceramics, and composites to improve their properties.

While cryogenic treatment using liquid nitrogen can be an effective method for enhancing material properties, it is important to note that it must be carried out carefully and with proper equipment to avoid thermal shock or other damage to the material.

The temperature is measured using a T-type thermocouple connected to DAQ. A T-type thermocouple is a type of thermocouple that is commonly used to measure temperature in a variety of applications. The T-type thermocouple is composed of two different metal wires, typically copper and constantan. The two wires are joined together at the sensing end to form the thermocouple junction, have a temperature range of -200°C to +350°C (-328°F to +662°F).

One of the main advantages of the T-type thermocouple is its high accuracy, which is typically within 0.5% of the measured temperature. It is also relatively inexpensive and easy to use, making it a popular choice for a wide range of applications.

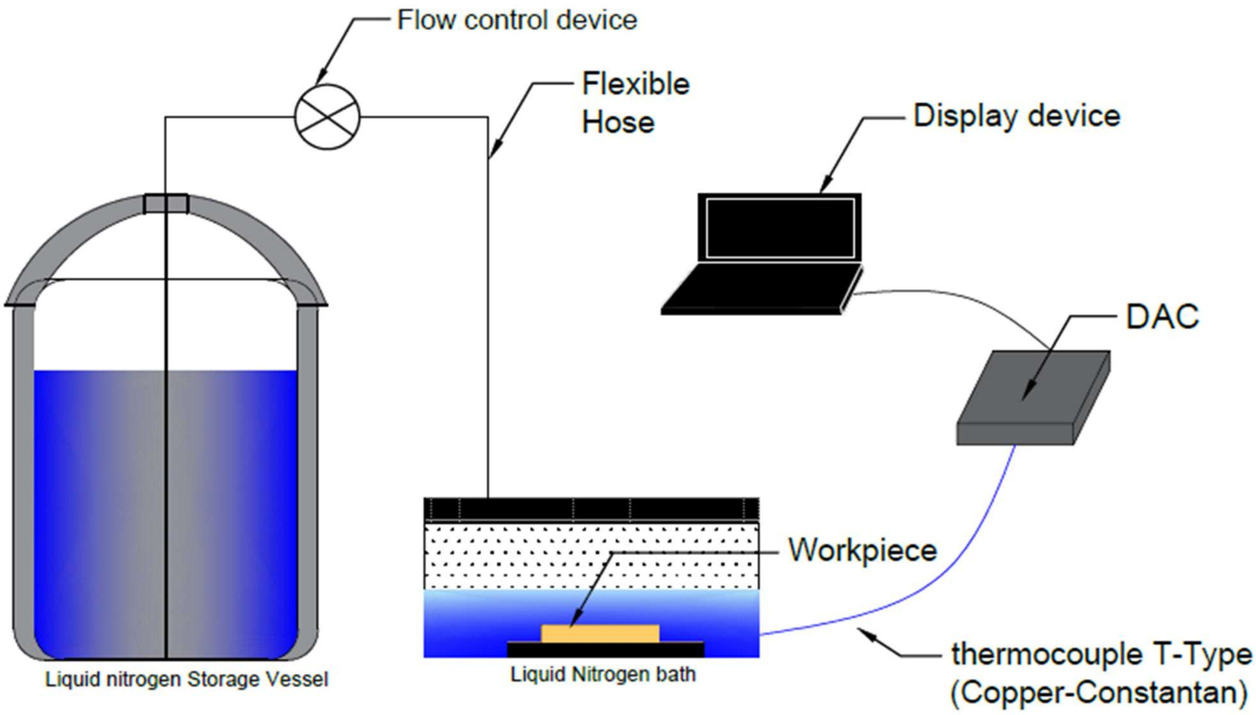


Fig 4.1 Cryogenic Treatment Setup

4.2.1 DEEP CRYOGENIC TREATMENT

Deep cryogenic treatment is a type of cryogenic treatment that involves exposing a material to extremely low temperatures for an extended period of time, typically 24-48 hours. During this process, the temperature of the material is gradually lowered to below -190°C using liquid nitrogen or another cryogenic coolant, and then held at this temperature for the duration of the treatment.

The low temperature causes a number of physical and chemical changes in the material, such as the transformation of retained austenite to martensite, the precipitation of fine carbides, and the reduction of residual stresses. These changes can result in significant improvements in the material's mechanical properties, such as increased hardness, wear resistance, and fatigue strength.

4.2.2 SHALLOW CRYOGENIC TREATMENT

Shallow cryogenic treatment is a type of cryogenic treatment that involves exposing a material to low temperatures for a shorter period of time than deep cryogenic treatment. Typically, materials are exposed to temperatures between -120°C and -150°C for several hours, as opposed to the temperatures below -190°C used in deep cryogenic treatment.

The goal of shallow cryogenic treatment is to improve the toughness and resistance to cracking of the material, rather than its wear resistance and durability like deep cryogenic treatment. During the process, the low temperature causes the material's microstructure to change, which can help to reduce internal stresses and improve its ability to withstand external stresses without cracking or breaking.

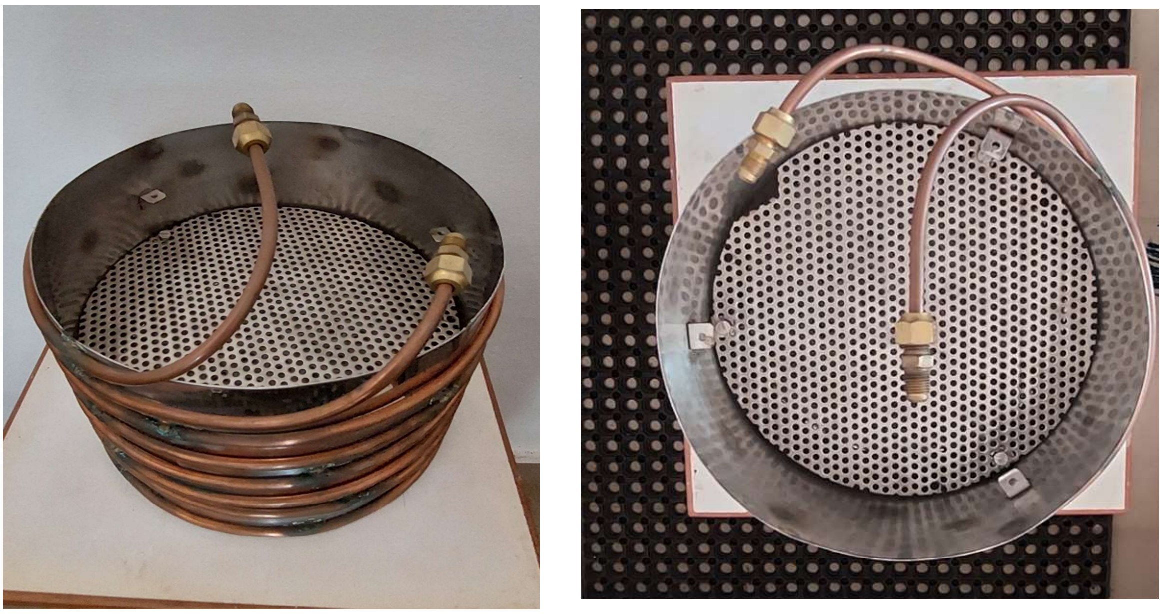


Fig 4.2 Setup for shallow cryogenic treatment

4.3 TEMPERATURE PROFILE

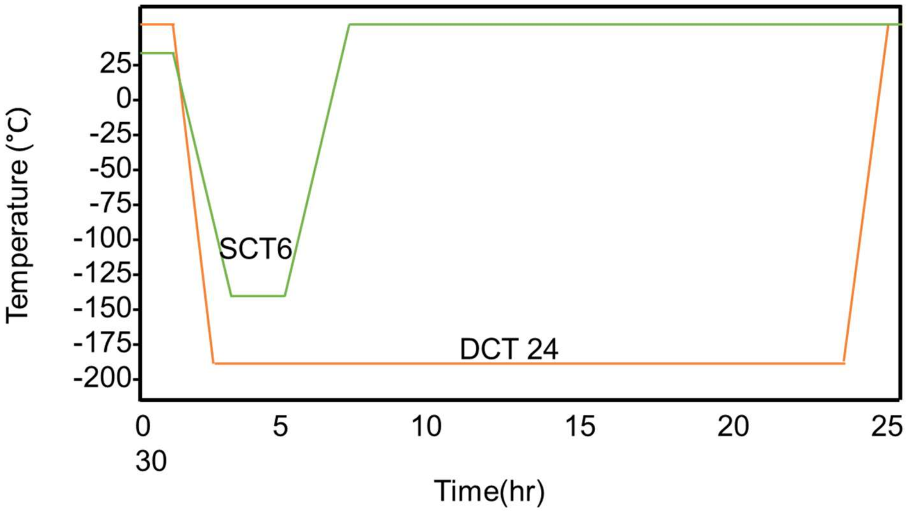


Fig 4.3 Temperature profile of cryogenic treatment

The figure depicts how the temperature changes over time for two different cryogenic treatments, deep cryogenic treatment (DCT) and shallow cryogenic treatment (SCT), on a tool.

In the case of DCT, there is a significant and rapid drop in temperature, meaning the temperature decreases quickly and sharply. This could be due to the tool being subjected to extremely low temperatures for a prolonged period. This type of treatment is generally more intense and involves exposing the tool to temperatures below -100°C for an extended period. On the other hand, SCT shows a more gradual drop in temperature. This could be because the tool is subjected to lower temperatures for a shorter period, resulting in a slower rate of temperature change. This type of treatment is generally less intense and involves exposing the tool to temperatures just below -100°C for a shorter period. The variation of temperature over time is an important factor to consider in cryogenic treatment because it can affect the resulting properties of the tool. The rate of cooling and the final temperature achieved can impact the microstructure and hardness of the tool. Therefore, it is important to carefully control the cryogenic treatment parameters to achieve the desired outcomes.

CHAPTER 5

EXPERIMENTAL WORK

5.1 MACHINING PERFORMANCE CHARACTERISTICS

The performance characteristics observed during the experiments are evaluated through various methods, and are listed as follows:

5.1.1 Surface Roughness

The Mitutoyo Surftest SJ 210 was employed in measuring the surface roughness of the machined surface. The cut-off length used was 4 mm, and average surface roughness (R_a) was measured at four different locations for each trial. Average surface roughness (R_a) is considered for roughness measurement, other method is: R_q root mean square roughness, Fig 5.1 presents the surface roughness tester used in the experiments.

Fig 5.1 Surface roughness tester (Mitutoyo SJ 210) used in the experiment

5.2 CHARACTERISATION OF CUTTING TOOL

5.2.1 MICROSTRUCTURE AND ELEMENTAL COMPOSITION ANALYSIS (SEM/EDS)

SEM/EDS stands for scanning electron microscopy/energy dispersive X-ray spectroscopy. It is a technique used in material science and other fields to obtain information about the composition and structure of a material at a microscale level.

In SEM, a beam of electrons is focused onto the surface of the material being studied, causing it to emit secondary electrons that are collected and used to create an image of the surface topography. This allows researchers to visualize the microstructure of the material, including its surface features and defects.

EDS is a complementary technique that is often used in conjunction with SEM. It works by detecting the characteristic X-rays emitted by elements in the material when they are bombarded with the electron beam. By analyzing the energies and intensities of these X-rays, researchers can identify the elemental composition of the material and obtain information about its chemical bonding and crystal structure.

Fig 5.2 SEM-EDS machine used in the experiment

5.2.2 MICROHARDNESS TESTING

A Vickers microhardness tester is a type of instrument used to measure the hardness of a material at a microscopic level. The Vickers microhardness tester works by applying a small force to the surface of the material being tested using a diamond indenter in the shape of a pyramid with a square base. The indentation made by the diamond is measured using a microscope, and the size of the indentation is used to calculate the hardness of the material.

The Vickers microhardness tester is capable of measuring the hardness of a wide range of materials, including metals, ceramics, plastics, and composites. It is particularly useful for measuring the hardness of thin films and coatings, as well as for evaluating the hardness of small regions within a larger sample. Vickers microhardness is carried out to find microhardness variation for different cryogenically treated samples and machined samples. A load of 0.5kgf is applied for 5 seconds on each sample and is repeated at 5 different locations for accuracy. Fig 5.3 shows the microhardness tester used in the experiment.

Fig 5.3 Microhardness tester used in the experiment

The Vickers microhardness is typically calculated using the following equation:

$$HV = \frac{1.8544}{d^2}$$

where HV is the Vickers hardness number, F is the applied force in Newtons, and d is the mean diagonal length of the indentation in micrometers.

5.3 MILLING OPERATION

A three-axis CNC vertical milling machine is used for milling experiments on maraging steel C300. The specifications of the milling machine are presented in Table 5.1. The milling machine used in the experiment is displayed in Fig 5.4.

Fig 5.4 CNC Milling Machine

Table 5.1 Specifications of milling machine

Description	**Specification**
Machine	Vertical Milling Machine
Model	TM1
Table Area	1220 x 267mm^2
Rapid traverse	2250mm/min
Max. Spindle speed	4000 rpm
Spindle	7.5kW
Spindle taper	CAT40
Net weight	1800kg (approx.)

5.3.1 PREPARATION OF WORK PIECE

Edge sizing refers to the process of removing a very thin layer of material from the edges of a workpiece in order to achieve a specific dimension or tolerance. This is typically done using a finishing pass with a small diameter tool that is run around the perimeter of the workpiece.

The goal of edge sizing is to ensure that the workpiece has consistent dimensions along all of its edges, which is important for achieving a precise fit or finish.

Fig 5.5 Edge Sizing

Facing refers to the process of creating a flat surface on the top of a workpiece by removing material using a cutting tool. The facing operation is typically performed at the beginning of a machining process to prepare the workpiece for subsequent operations such as drilling, boring, or slotting.

During the facing operation, the cutting tool is positioned perpendicular to the surface of the workpiece and is moved across the material in a back-and-forth motion. This removes material from the top of the workpiece, creating a flat and level surface. The depth of cut is typically shallow, with the goal of removing only enough material to achieve the desired surface finish.

Fig 5.6 Facing Operation

5.3.2 SLOTTING OPERATION

In milling, slotting refers to the process of machining a narrow, flat-bottomed groove in a workpiece. In this work slotting was done using 4 flute end milling tool.

To perform a slotting operation, the workpiece is typically clamped securely to a milling machine table. The cutter is then positioned above the workpiece and slowly lowered into it, making a series of cuts that gradually form the slot.

The milling operations were carried out using uncoated tool, coated tool, deep treated tool and shallow treated tool, each at running rpm of 4000, 3000, 2000 and 1000rpm at a feed rate of 320mm/min to a depth of 0.2mm in dry condition.

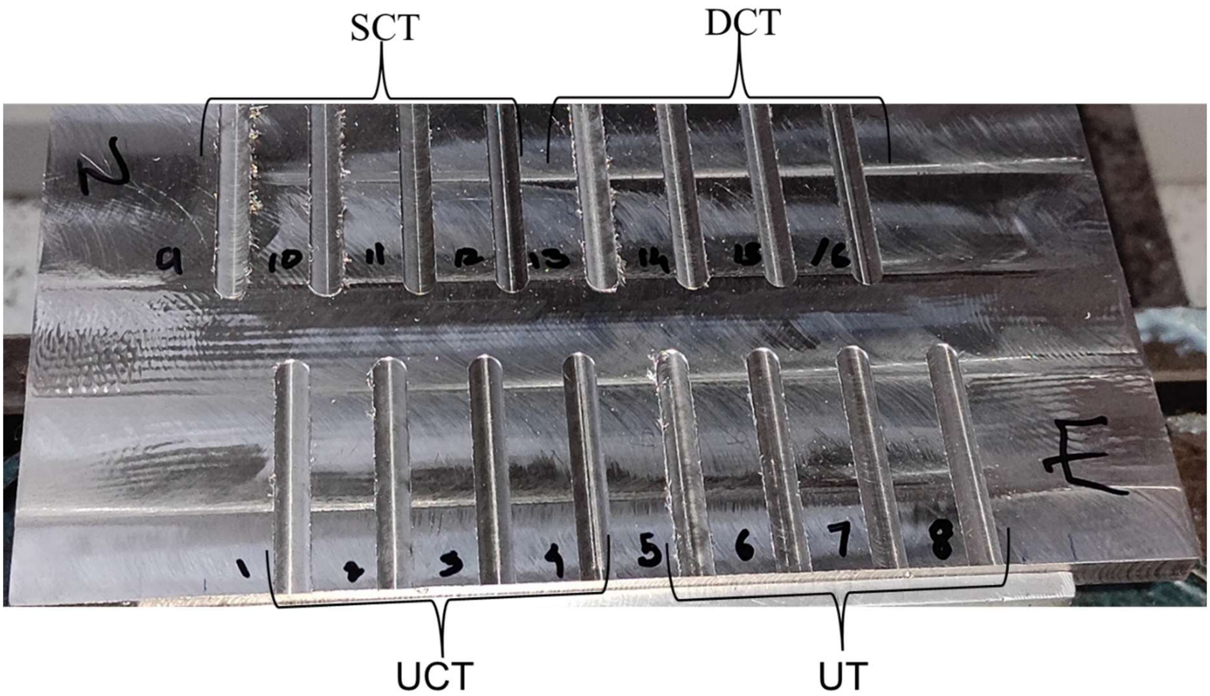


Fig 5.7 Slotted plate at various rpm for different tools

Slots indicated as 1,2,3 and 4 represents 4000,3000,2000 and 1000rpm respectively using uncoated tool, similarly consecutive four numbers for untreated coated tool, shallow cryogenic treated and deep cryogenic treated tool.

5.3.2.1 CNC PROGRAM FOR MILLING OPERATION

```
O00002;
G28;
T1 M06;
G54 G40 G21 G90;
M03 S4000;
G00 X14, Y-10;
G00 Z10;
G01 Z-0.2 F100;
G01 X14 Y40 F320;
G00 Z10;
M03 S3000;
G00 X31 Y-10;
G01 Z-0.2 F100;
G01 X31 Y40 F320;
G00 Z10;
M03 S2000;
G00 X48 Y-10;
G01 Z-0.2 F100;
G01 X48 Y40 F320;
G00 Z10;
M03 S1000;
G00 X65 Y-10;
G01 Z-0.2 F100;
```

```
G01 X65 Y40 F320;
G00 Z10;
G28;
M05;
M30;
```

The above program was used for slotting using uncoated tool namely slots 1,2,3&4. And by changing the tool and the coordinates other consecutives slots were cut by using the program.

CHAPTER 6

RESULTS AND DISCUSSION

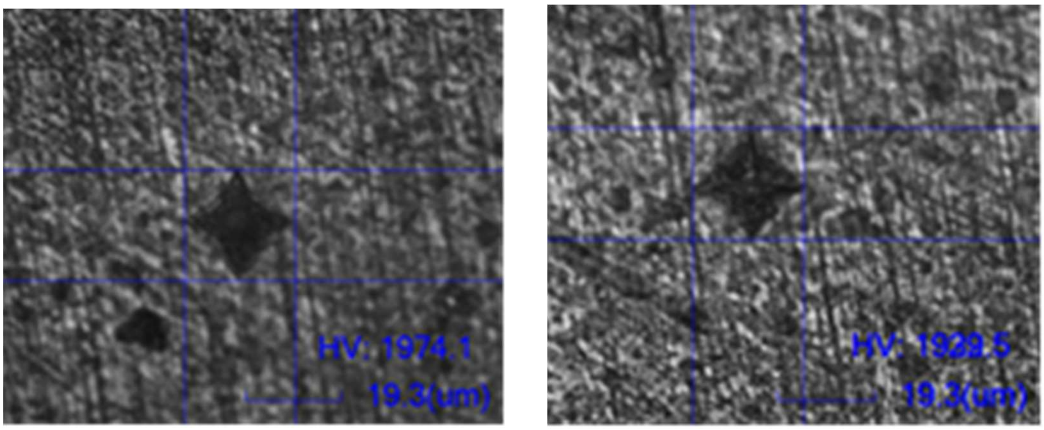
6.1 VICKERS MICROHARDNESS TEST

6.1.1 UNTREATED TiAlSiN COATED TUNGSTEN CARBIDE TOOL

Table 6.1 Microhardness for Untreated TiAlSiN coated Tungsten carbide tool

Sl No.	D_1(µm)	D_2(µm)	D_avg(µm)	Hardness type	Hardness value
1	20.81	22.15	21.48	HV	2010.0
2	22.15	21.77	21.96	HV	1922.5
3	21.96	21.77	21.86	HV	1939.5
4	21.58	21.77	21.67	HV	1974.1
5	21.19	22.15	21.67	HV	1974.1

Untreated TiAlSiN tool hardness=*1964.04 HV*



1974.1HV 1939.5HV

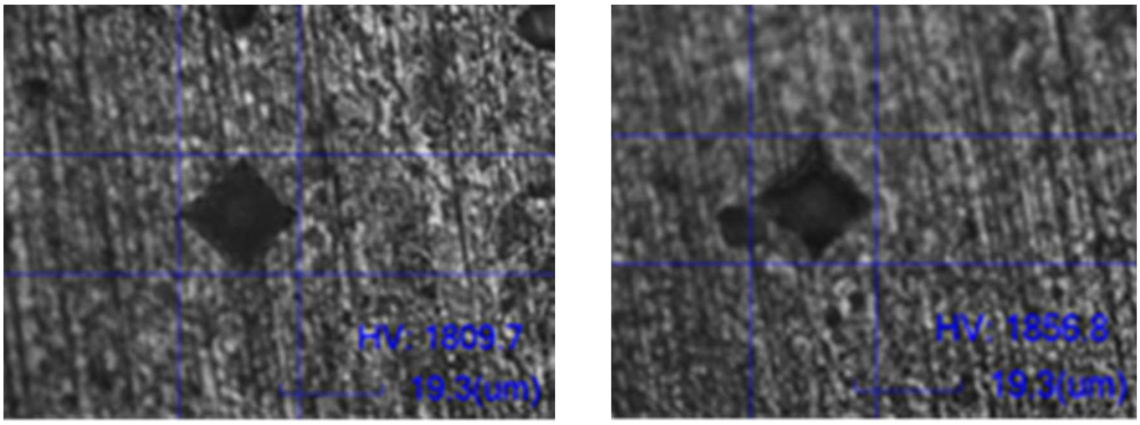
Fig 6.1 Nano indenter used in the experiment for untreated TiAlSiN coated tungsten carbide tool

6.1.2 DEEP CRYOGENIC TREATED TiAlSiN COATED TOOL

Table 6.2 Microhardness for Deep cryogenic treated TiAlSiN Coated Tool

Sl No.	D_1(µm)	D_2(µm)	D_avg(µm)	Hardness type	Hardness value
1	22.35	22.92	22.64	HV	1809.7
2	22.73	22.54	22.64	HV	1809.7
3	22.73	21.96	22.35	HV	1856.8
4	21.96	22.54	22.25	HV	1872.9
5	21.77	22.73	22.25	HV	1872.9

Deep cryogenic treated TiAlSiN Coated Tool hardness=1844.4HV



1809.7HV 1856.8HV

Fig 6.2 Nano indenter used in the experiment for deep cryogenic treated TiAlSiN coated tool

6.1.3 SHALLOW CRYOGENIC TREATED TiAlSiN COATED TOOL

Table 6.3 Microhardness for Shallow cryogenic treated TiAlSiN Coated Tool

Sl No.	D_1(µm)	D_2(µm)	D_avg(µm)	Hardness type	Hardness value
1	21.19	20.23	20.71	HV	2162.0
2	21.58	21.58	21.58	HV	1991.8
3	21.96	21.96	21.96	HV	1922.5
4	21.77	21.38	21.58	HV	1991.8
5	22.54	22.15	22.35	HV	1986.8

Table 6.3 Microhardness for Shallow cryogenic treated TiAlSiN Coated Tool

Shallow cryogenic treated TiAlSiN Coated Tool hardness=2010.98HV

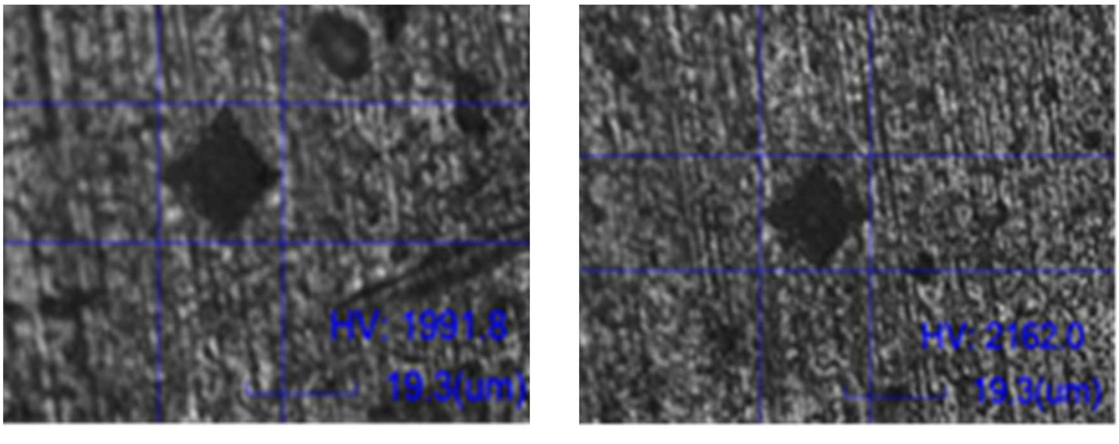


Fig 6.3 Nano indenter used in the experiment for shallow cryogenic treated TiAlSiN coated tool

The microhardness on three different TiAlSiN coated tools; UT, DCT24, and SCT6, were evaluated for their hardness. The hardness of UT tool was found to be 1964.04HV, while the hardness of DCT24 tool was 1844.4HV, and the hardness of SCT6 tool was 2010.98HV.

Comparing these results, it can be seen that the SCT6 tool exhibited the highest hardness with an increase of 2.4% compared to the UT tool. On the other hand, the DCT24 tool showed a decrease in hardness of 6.1% compared to the UT tool.

6.2 SURFACE ROUGHNESS

6.2.1 TiAlSiN COATED TOOL IN DRY CONDITION

In this work, the TiAlSiN coated tool is being used with a feed rate of 320mm/min and a depth of 0.2mm in a dry condition.

Table 6.4 Surface roughness of TiAlSiN coated tool in dry condition

Sl No.	**RPM**	**Surface Roughness(µm)**	
		R_a	R_q
1	4000	0.524	0.737
2	3000	0.601	0.835
3	2000	0.857	1.037
4	1000	1.141	1.348

6.2.2 SHALLOW CRYOGENIC TREATED TiAlSiN COATED TOOL IN DRY CONDITION

In this work, shallow cryogenic treated TiAlSiN coated tool is being used with a feed rate of 320mm/min and a depth of 0.2mm in a dry condition.

Table 6.5 Surface roughness of SCT TiAlSiN coated tool in dry condition

Sl No.	**RPM**	**Surface Roughness(µm)**	
		R_a	R_q
1	4000	0.454	0.56
2	3000	0.517	0.63
3	2000	0.809	0.927
4	1000	0.897	1.104

6.2.3 DEEP CRYOGENIC TREATED TiAlSiN COATED TOOL IN DRY CONDITION

In this work, deep cryogenic treated TiAlSiN coated tool is being used with a feed rate of 320mm/min and a depth of 0.2mm in a dry condition.

Table 6.6 Surface roughness of DCT TiAlSiN coated tool in dry condition

Sl No.	**RPM**	**Surface Roughness(µm)**	
		R_a	R_q
1	4000	0.683	0.829
2	3000	0.701	0.858
3	2000	0.734	0.929
4	1000	1.062	1.247

6.2.4 UNCOATED TOOL IN DRY CONDITION

In this work, uncoated tool is being used with a feed rate of 320mm/min and a depth of 0.2mm in a dry condition.

Table 6.7 Surface roughness of uncoated tool in dry condition

Sl No.	**RPM**	**Surface Roughness(µm)**	
		R_a	R_q
1	4000	0.654	0.895
2	3000	0.682	0.904
3	2000	0.928	1.072
4	1000	1.787	1.985

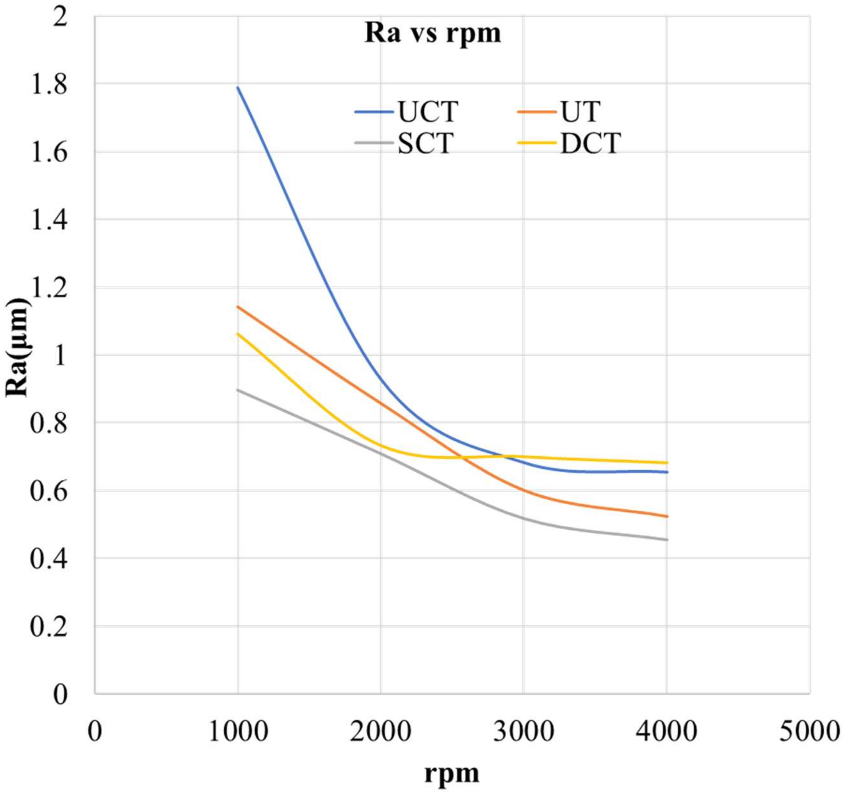


Fig 6.4 R_a vs rpm

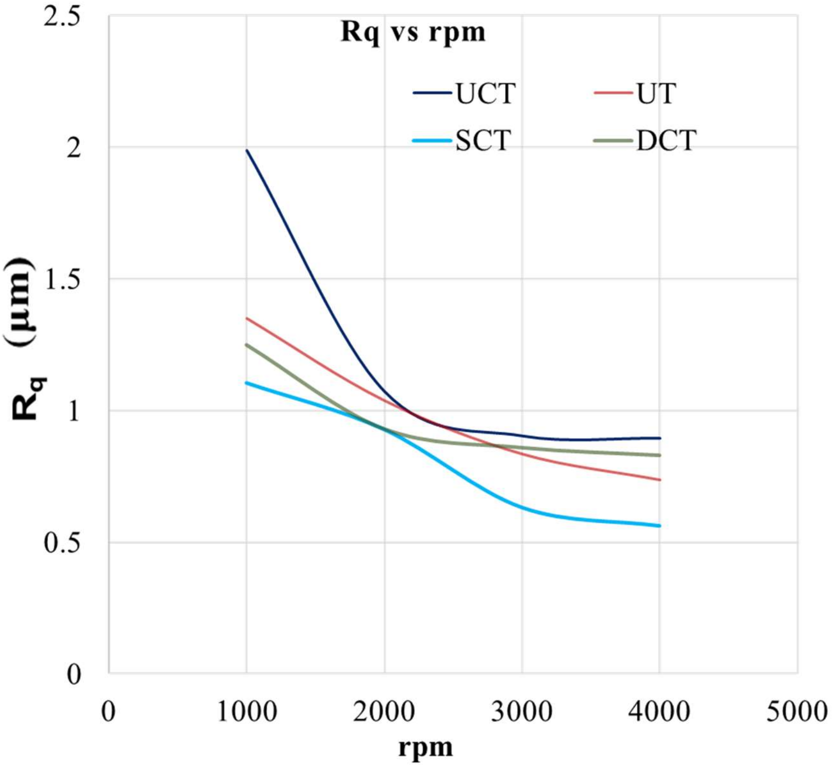
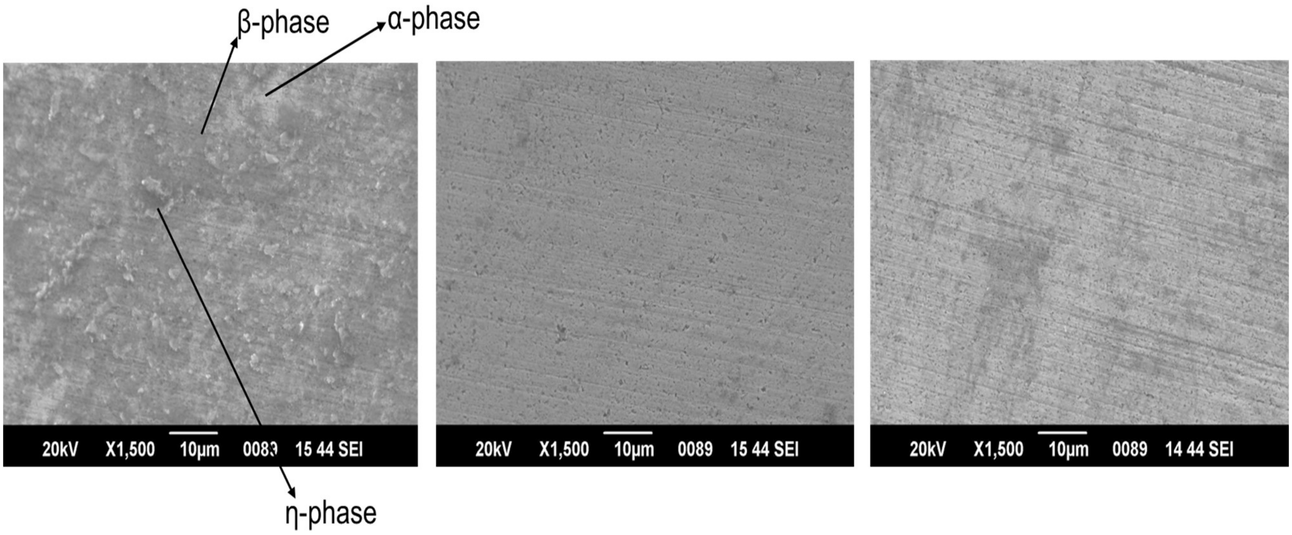


Fig 6.5 R_q vs rpm

The surface roughness decreases as the rpm increases for all types of tools, including coated, uncoated, SCT6, and DCT24. However, the uncoated tool has very high surface roughness. In contrast, SCT6 demonstrates the best improvement in surface quality compared to all other cases, particularly at lower rpm. At lower rpm, the SCT6 tool reduces the roughness value by approximately 49.8% when compared to an uncoated tool, 21.3% compared to a coated untreated tool, and 15.6% compared to a DCT24 tool. At higher rpm, the SCT6 tool still reduces the roughness value by about 30.6% when compared to an uncoated tool, 13.3% compared to a coated untreated tool, and 33.5% compared to a DCT24 tool.

6.3 CHARACTERISATION OF TOOL SURFACES (SEM-EDS)

6.3.1 TUNGSTEN CARBIDE TOOL



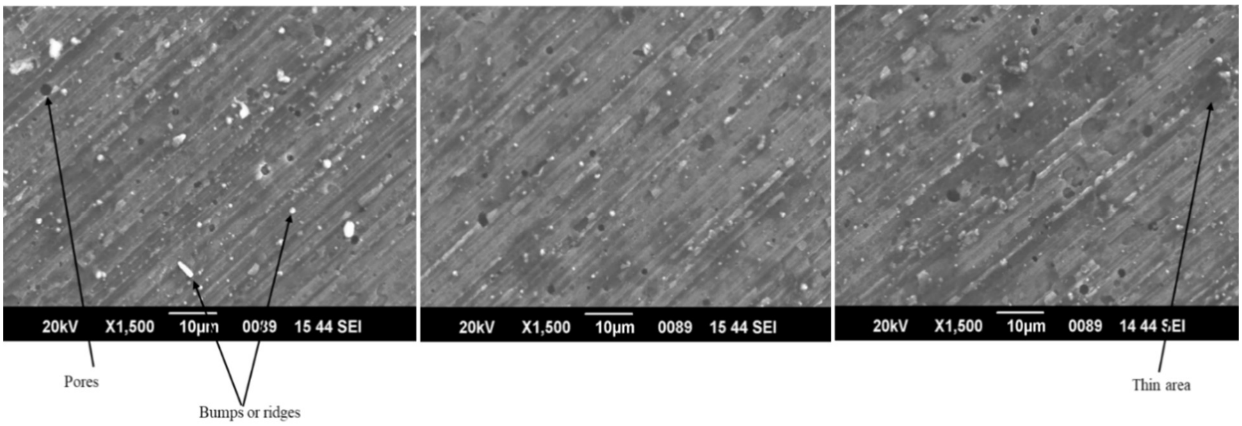
UT SCT DCT

Fig 6.6 Surface of tungsten carbide tool [9]

- There are three main phases in the microstructure of WC–Co inserts, namely, α-phase (WC), β-phase (Co), and η-phase (Co3W3Cand Co6W6C)[8].
- α, β and η-phases are identifiable from the SEM image.
- Hard α-phases form continuous structure throughout the sample.
- Hard α-particles of tungsten carbide are refined into most stable form after CT.
- It is evident from the SEM images that the particle size get reduced after DCT and SCT compared to UT material.
- The microscopic surface defects reduced and surface integrity improved under cryogenic treatment.

- It is reported that the cryogenic treatment refined coarser, randomly-distributed η-phase particles into the most stable form.

6.3.2 TiAlSiN COATED TUNGSTEN CARBIDE TOOL



UT SCT DCT

Fig 6.7 Surface of TiAlSiN coated tungsten carbide tool

A. Dark region: Dark regions in a SEM image indicate areas where fewer electrons are being emitted from the surface of the sample. This can be caused by several factors, such as:

1. *Porosity*: Porosity refers to the presence of voids or empty spaces within the coating, which can lead to darker regions in the SEM image.
2. *Grain boundaries*: Grain boundaries refer to the areas where the TiAlSiN coating is made up of multiple grains or crystals, and can also cause darker regions in the image.
3. *Thin areas*: The areas of the coating, where the coating is thinner than other areas, can also cause darker regions in the image. Fig 6.7 Surface of TiAlSiN coated tungsten carbide tool

B. Light regions: Light regions in a SEM image generally indicate areas where more electrons are being emitted from the surface of the sample. This can be caused by several factors, such as:

1. *Surface features*: The TiAlSiN coating has any surface features like bumps or ridges, the electrons may be reflected back in a way that causes these areas to appear brighter.
2. *Smooth areas*: The TiAlSiN coating is relatively smooth in some areas, the electrons may be emitted more easily and cause those areas to appear brighter.

- Compared to tungsten carbide material surface TiAlSiN surface appears smoother and the grain size of TiAlSiN is small compared to that of tungsten carbide when observing the untreated tool.

- The small grain size of TiAlSiN hinders the dislocation movement and dislocations are generally absent at very small grains resulting in high hardness.

6.3.3 EDS RESULT OF NON-CUTTING EDGES

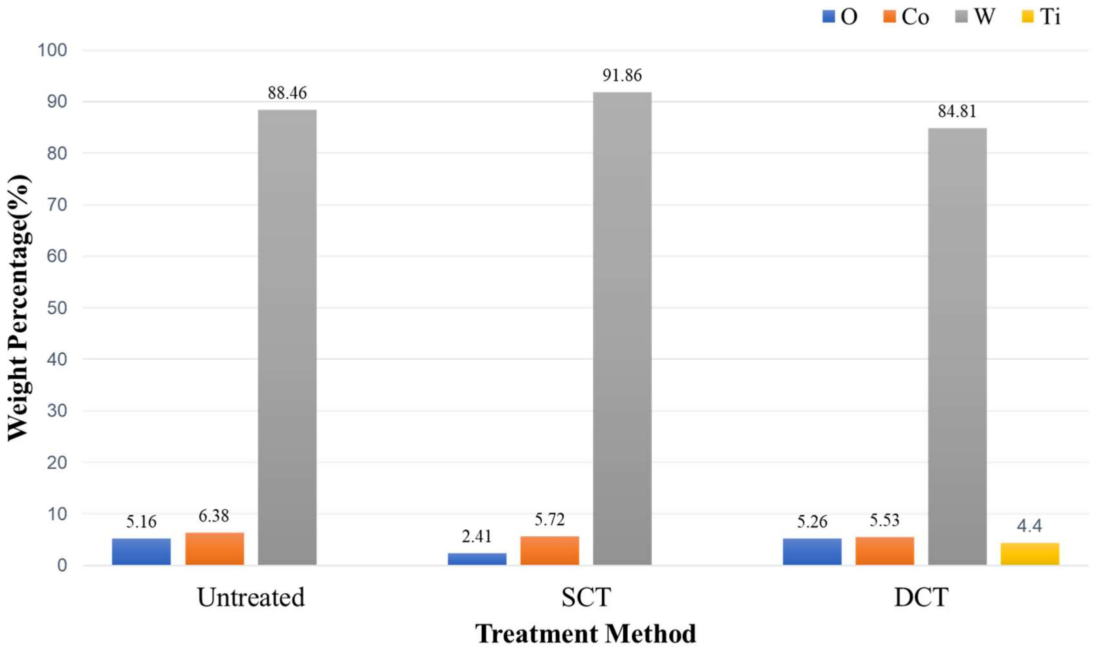


Fig 6.8 EDS result of non-cutting edges

During the deposition of TiAlSiN coatings, residual stresses can be introduced into the coating due to a variety of factors, including differences in the thermal expansion coefficients of the coating and substrate, differences in the crystal structure between the coating and substrate, and ion bombardment during the deposition process. These residual stresses can have a significant impact on the performance of the coating and the substrate, including affecting adhesion, wear resistance, and fracture resistance.

Cryogenic treatment (DCT) is a post-treatment process that involves cooling the coated tool to a low temperature typically below -190°C, and then allowing it to warm up slowly to room temperature. During this process, the residual stresses in the coating and substrate can be relaxed, resulting in improved mechanical properties and enhanced performance.

There is a risk that the stresses relaxation process may cause cracking or delamination of the coating. This is because during DCT, the thermal stresses that were present in the coating are reduced and this relaxation can lead to a mismatch in stress between the coating and the substrate, leading to cracking and delamination, by which coating gets deposited onto the non-cutting edge of the tool.

6.3.4 EDS RESULT OF CUTTING EDGES

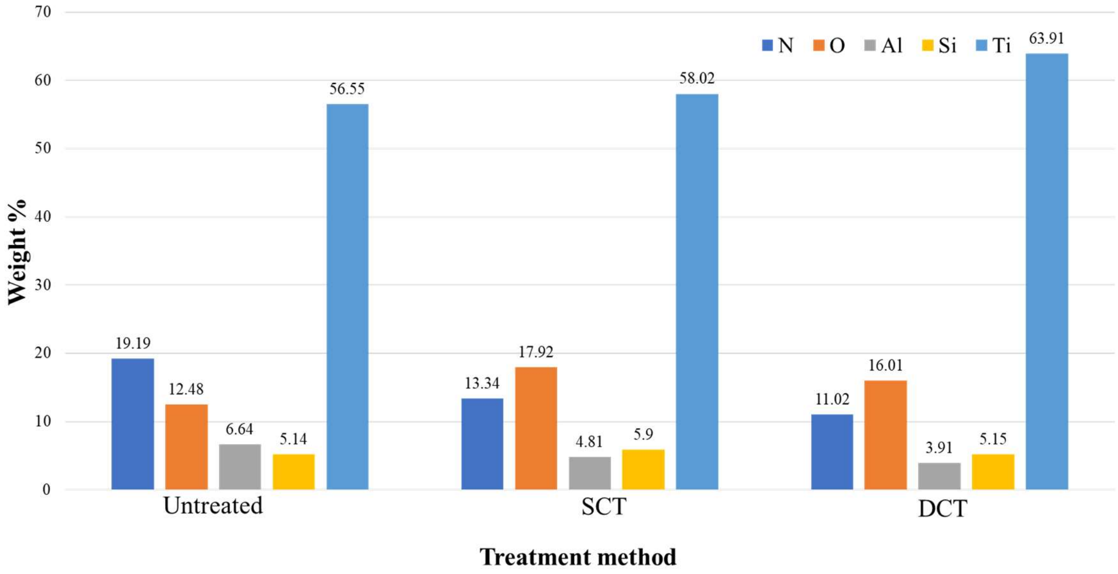


Fig 6.9 EDS result of cutting edges

By the presence of Si in TiAlSiN coatings, it is possible to achieve superior mechanical properties and enhance bonding between atoms. One of the key factors in determining a material's resistance to local plastic deformation is its hardness.

The incorporation of Al into TiAlSiN coatings can also contribute to their high levels of hardness. Additionally, tribo oxide films such as TiO_2, SiO_2, Al_2O_3, and $Al_xSi_yO_z$ can offer protection to the TiAlSiN coating.

EDS results of the coatings have shown the presence of oxygen, indicating the formation of oxide films on the coatings. The formation of alumina and silica tribo films on the coatings has been found to significantly increase their wear resistance.

These tribo films are also responsible for the wear protection of the TiAlSiN coatings and can result in a better finish on materials such as maraging steel. Overall, the incorporation of Si and Al and the formation of tribo films are key factors in improving the mechanical and wear properties of TiAlSiN coatings[12].

6.3.5 UNTREATED TiAlSiN COATED TOOL AFTER MACHINING

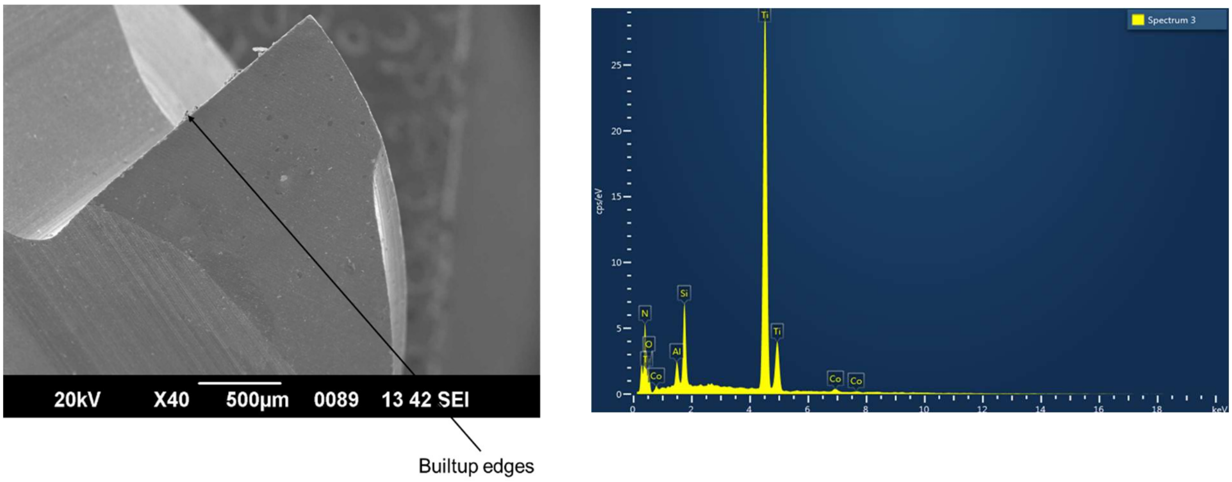


Fig 6.10 SEM image of cutting edge in UT tool

Table 6.8 Chemical composition of cutting edge of TiAlSiN coated UT tool

Element	Line Type	Weight%
N	K series	11.25
O	K series	15.34
Al	K series	1.67
Si	K series	6.01
Ti	K series	65.05
Co	K series	0.66
Total:		100

The built-up edge (BUE) of cobalt is a phenomenon that occurs during cutting operations when work material welds onto the edge of the cutting tool due to the high cutting pressure. This welding action can cause a buildup of material on the tool edge, which can negatively impact the cutting performance of the tool.

However, the flow of chips generated during the cutting process can help to remove the built-up edge over time. As the chips flow over the surface of the tool, they can gradually remove the material that has accumulated on the tool edge.

6.3.6 SHALLOW CRYOGENIC TREATED TiAlSiN COATED TOOL AFTER MACHINING

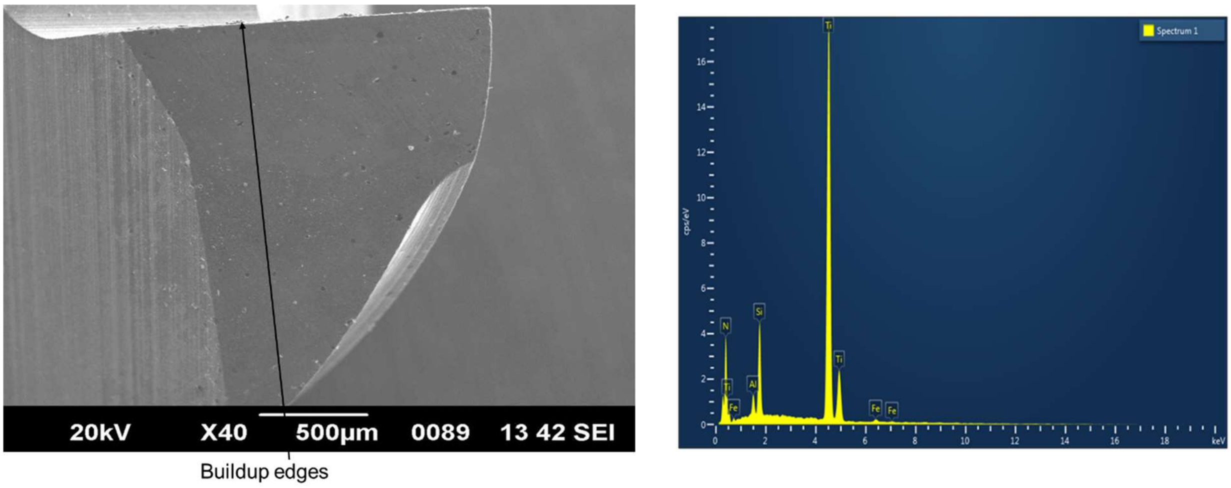


Fig 6.11 SEM image of cutting edge in SCT tool

Table 6.9 Chemical composition of cutting edge of TiAlSiN coated SCT tool

Element	Line Type	Weight%
N	K series	19.82
Al	K series	1.69
Si	K series	6.95
Ti	K series	70.61
Fe	K series	0.93
Total:		100

In the case of a shallow cryogenic treated tool, the BUE removal process can be more efficient due to the improved wear resistance of the tool. Additionally, the reduction in BUE can help to mitigate the development of crater wear, chipping, and notch wear, resulting in improved tool life and performance.

The development of BUE and wear during metal cutting processes can have a significant impact on the performance and lifespan of cutting tools made from iron. The use of surface treatments such as shallow cryogenic treatment can help to improve the wear resistance and reduce the negative impact of BUE and wear on the performance of cutting tools.

6.3.7 DEEP CRYOGENIC TREATED TiAlSiN COATED TOOL AFTER MACHINING

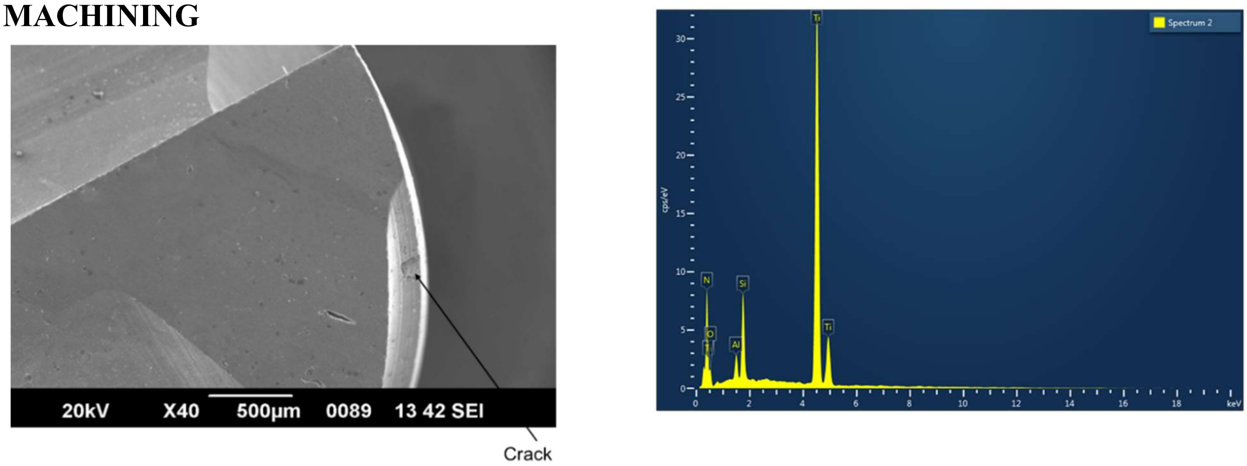


Fig 6.12 SEM image of cutting edge in DCT tool

Table 6.10 Chemical composition of cutting edge of TiAlSiN coated DCT tool

Element	Line Type	Weight%
N	K series	16.53
O	K series	14.62
Al	K series	1.88
Si	K series	5.85
Ti	K series	61.12
Total:		100

In the case of DCT, the tool's improved toughness and wear resistance can help prevent the formation of built-up edge (BUE) during cutting. BUE is a common problem encountered during metal cutting processes, where work material adheres to the cutting edge of the tool, leading to poor surface finish, dimensional inaccuracies, and increased tool wear. The improved toughness and wear resistance of the DCT-treated tool can help to mitigate the development of BUE.

The development of cracks in the cutting edge of TiAlSiN coated tools after DCT could be due to a variety of factors. One potential reason could be the residual stresses induced during the DCT process. Although DCT can improve the mechanical properties of the tool, it can also introduce residual stresses that can lead to cracking during the machining process.

6.4 TOOL WEAR

Milling operation using UT, SCT and DCT tools were carried for 20min under dry condition in a maraging steel plate at 4000rpm for depth of 0.2mm.

The decrease in mass represents the measure of wear rate of tool.

It was observed that maximum wear rate takes place at higher rpm. As per F.W. Taylor, the relationship between Cutting Speed and Tool Life can be expressed as

$$VT^n = C$$

T-Tool life

Table 6.11 Mass Loss in each type of tools

Treatment method	Initial weight (gm)	Final weight (gm)	Mass loss
Untreated Tool	18.4898	18.4895	0.0003
Shallow Treated Tool	18.4873	18.4872	0.0001
Deep Treated Tool	18.2486	18.2477	0.0009

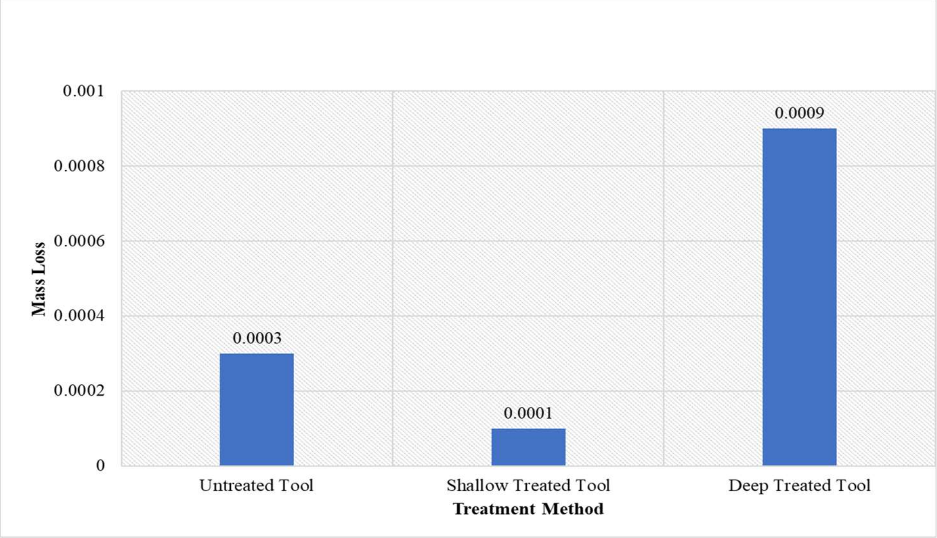


Fig 6.13 Mass loss vs Treatment method

In the case of the SCT6 tool, it has been observed that the tool wear is less compared to the untreated and DCT24 tools. This can be attributed to the improved mechanical and physical properties of the SCT6 tool resulting from the cryogenic treatment. Cryogenic treatment can refine the microstructure of the tool, leading to improvement in wear resistance.

CHAPTER 7

CONCLUSION

Based on the studies conducted it can be seen that the SCT6 tool exhibited the highest hardness with an increase of 2.4% compared to the UT tool. On the other hand, the DCT24 tool showed a decrease in hardness of 6.1% compared to the UT tool.

The hardness of a tool is an important factor in its performance and durability, as it affects its ability to withstand wear and deformation during use. Therefore, the increase in hardness observed in the SCT6 tool is a positive result, indicating that it may perform better than the UT tool in certain applications. However, the decrease in hardness observed in the DCT24 tool may indicate that it may not be as durable or long-lasting as the UT tool.

The study found that surface roughness is affected by the rpm and tool type used in the machining process. The uncoated tool had the highest surface roughness, while the SCT6 coated tool demonstrated the best improvement in surface quality, especially at lower rpm. At lower and higher rpm, the SCT6 tool showed a significant reduction in roughness compared to the uncoated tool, coated untreated tool, and DCT24 tool. The findings suggest that the SCT6 coating can improve surface quality and reduce the need for additional finishing processes.

The microstructure of WC-Co inserts consists of α, β, and η-phases, which can be identified through SEM imaging. Cryogenic treatment can refine coarser, randomly-distributed η-phase particles into their most stable form and reduce microscopic surface defects, thereby improving surface integrity. TiAlSiN coatings have a smaller grain size compared to tungsten carbide, which results in higher hardness due to hindrance of dislocation movement. Residual stresses can be introduced during the deposition process of TiAlSiN coatings, and cryogenic treatment can relax these stresses, leading to improved mechanical properties and performance. However, there is a risk of cracking or delamination during the stress relaxation process. The incorporation of Si and Al into TiAlSiN coatings can enhance their mechanical and wear properties, and the formation of tribo films such as alumina and silica can significantly increase their wear resistance.

The builtup edge (BUE) is a common issue during metal cutting operations that can negatively impact tool performance and lifespan. Surface treatments such as shallow cryogenic treatment and Deep cryogenic treatment can improve the wear resistance and toughness of cutting tools, reducing the development of BUE and other wear-related issues. However, the DCT process can also induce residual stresses that may lead to cracking in the cutting edge of TiAlSiN coated tools, highlighting the importance of carefully considering the post-treatment process for cutting tools.

The SCT6 tool had less wear than the DCT24 and untreated tool, indicating that cryogenic treatment improved its wear resistance. Cryogenic treatment involves subjecting the tool to very low temperatures to refine its microstructure and improve its mechanical and physical properties. As a result, the SCT6 tool had a more refined microstructure, which contributed to its improved wear resistance. The improved wear resistance is due to the cryogenic treatment reducing the size of the tool's grains and improving the tool's hardness, toughness, and strength.

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