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Machinability Studies of Monel 400 in Cnc Turning Operation Using Treated Tools

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ABSTRACT
Monel 400 is widely used material for construction of equipment and which requires corrosion resistance, heat resistance, strength, and stability. These properties make them potential material for components in aerospace industries, gas turbine, chemical industry etc. The conventional machining in Monel 400 become uneconomical because of low productivity, poor surface finish, and rapid tool wear. Cryogenic tool treatment, is one such process which can increase surface finish, increase tool life, thus improving overall productivity and reducing the surface roughness. This project is an experimental study on CNC turning of Monel 400 using Cryo-treated tools. The workpiece is machined in CNC using three different types of cutting tools, Uncoated WC, TiAlN Coated WC and TiN Coated WC. The experimental runs were carried out using L16 orthogonal array and result were analysed using Taguchi's methodology. Speed, Treatment and Lubrication are considered as the factors for machining which varies by 2 levels. Following parameters Surface Roughness and Chip Curl diameter were found out during the experiment.

I. INTRODUCTION

Nickel-base alloys are the widely used nowadays in aerospace, nuclear, marine, and automobile sectors due to high corrosion resistance, lightweight, and ability to retain at high temperature, etc. Nickel base alloys are known as hard material or difficult-to machine material due to low thermal conductivity, chemical reactivity with tool material at high temperature, high hardness, and low elastic modulus, etc. Generally, in nickel base alloys, the formation of second phase particles makes the alloys stronger, abrasive and difficult to machine. Due to the tendency of formation of strain hardening, a vast amount of heat generated in the process zone and increase the thermal stresses at the tool, hence the formation of rapid tool wear. Though many techniques were successfully already applied for hard machining materials like hard turning, grinding, non-conventional machining process such as EDM and m-EDM. However, the only demerit is high investment cost, high skill operator, and less material removal rate, etc.

Cryogenic machining,which uses liquid nitrogen as the cooling media, is considered a sustainable alternative to conventional flood cooling application used in the machining process. Though the benefits of cryogenic machining in various aspects have been studied in previous researches, the lack of a real-world implementation generates uncertainties in its application. A cryogenic treatment is the process of treating workpieces to cryogenic temperatures (i.e., below −190 °C (−310 °F)) in order to remove residual stresses and improve wear resistance in steels and other metal alloys, such as aluminium. In addition to seeking enhanced stress relief and stabilization, or wear resistance, cryogenic treatment is also sought for its ability to improve corrosion resistance by precipitating micro-fine eta carbides, which can be measured before and after in a part using a quantimeter. The process has a wide range of applications from industrial tooling to the improvement of musical signal transmission. Some of the benefits of cryogenic treatment include longer part life, less failure due to cracking, improved thermal properties, better electrical properties including less electrical resistance, reduced coefficient of friction, less creep and walk, improved flatness, and easier machining.

Asit and Kalipadaanalyzed and compared the machinability characteristics of Monel 400, Inconel 625 and 718 with carbide insert under flame heating of workpiece over room temperature. It reported that hot turning substantially improves the machinability characteristics of mentioned materials. Asit and Kalipada studied the effect of machining parameters and temperature of flame heating when turning Monel-400 with uncoated carbide inserts. The reduction in forces and improvement in tool life was observed under hot machining than room temperature in all machining conditions. Asit and Kalipadainvestigated experimentally and developed the mathematical model for hot turning of Monel-400. It found that the developed regression equation of flank wear and surface roughness showed good fitment with the experiment results. In addition, only few researchers were carried out electrical discharge machining of Monel 400 alloy.

Parida and Maity studied the effect of heating on machinability of three nickel base alloy in hot machining processes. They concluded that heating improves machinability in terms of increase tool life, better surface finish, less tool wear etc. Ansari et al. prepared CuFe12O19 nano-composite using sol-gel-auto combustion process. They studied facial synthesis, characterization and magnetic properties of the material. They observed that the presence of hexaferrite plays major biological role, which reduce low energy consumption and environment-friendly. The advantage of using gas flame as a heating source is it is low cost and simple, but it cannot use for machining Ti-base alloy due to carbon particles deposition and formation of oxide. Lee et al. studied machining of high strength material using hybrid machining processes. They used both heating and cryogenic cooling to improve the tool life. It was observed that the cutting force decreased by 65% with heating conditions and slightly increase in the cryogenic machining process. Compared to single machining processes, the hybrid technique (both cryogenic and heating) machining process increase tool life around 90%.

Cryogenic treatment is the process of cooling materials to cryogenic temperatures temporarily to improve their material properties at room temperature. This is distinct from cooling materials down to cryogenic temperatures to take advantage of phenomena such as superconductivity that only occur at cryogenic temperatures. Cryogenic treatment, sometimes also referred to as deep cryogenic treatment, is best thought of as an adjunct to other material processing steps such as heat treatment, quenching and cold work. Depending on both the process applied and the material used, a number of material properties may be improved, including hardness, wear resistance (thus increasing lifetime), fatigue life and electrical conductivity. As an example, Barron (1982) described an increase of wear resistance of tool steel treated down to 77 K and ascribed the cause to a more complete transition from the austenite phase to the harder martensite phase. While steel was one of the first materials to undergo cryogenic treatment—and the use of this technique to increase the lifetime of machine tools is one of its major applications—cryogenic treatment has been applied to a wide range of materials including aluminium, brass, titanium, nickel alloys, some plastics and even carbon nanotubes.Cryogenic treatment generally occurs at roughly 77 K (liquid nitrogen temperatures). Some processes use dry ice temperatures (189 K) which, while above the nominal 120 K limit of cryogenics, are also sometimes referred to as cryogenic treatment.

Cryogenic treatment is a very active area of research that has produced many reproducible and industrially useful results. However, cryogenic treatment is not a panacea and not all claims can be scientifically verified. Care must be taken in interpreting results in this area.

In the literature survey, only few studies were carried out on turning of Monel 400 alloy. In addition, only few studies based on the effect of cutting tool material performance in turning of Monel 400 alloy. Therefore, an attempt has been made in this study to investigate the finish of the turned Monel 400 alloy with TiAlN coated, TiN coated and uncoated tungsten carbide tool.Also, recent studies done on Monel 400 alloys doesn't have these many combinations of cold and cryo treated cutting tools used. Therefore, we are able to obtain a lot of different comparisons and conclusions.

II. MATERIALS AND METHOD

2.1 Methodology

The research focuses on using a CNC machine for machining Monel 400 alloy utilizing cutting tool of tungsten carbide coated and uncoated. It is determined as to which response variables and parameters to use. The optimum values are determined using a Taguchi design. Secondary experimentation is conducted to evaluate different tools to improve performance characteristics and life of tool.

2.2 Workpiece material

MONEL nickel alloy is a solid solution alloy that can be hardened by the process of cold working The Monel 400 alloy is also known as super alloy Monel. This alloy is available in some standard shapes such as hexagon, round, tube, pipe, plate, strip, sheet and wire. The proportions of copper and nickel used to make Monel are the same as that found in the nickel ore found in Ontario mines. This alloy exhibits good corrosion resistance. This datasheet will look into the chemical composition, properties and applications of MONEL 400 alloy.

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Table1Chemical Composition of Monel-400 Alloy

Trade Name	%Cu	%Fe	%Mn	%Si	%Ni
Monel 400	28–34	2.5 max	2.0 max	0.5 max	63 min

Table1Chemical Composition of Monel-400 Alloy

2.3 Tool Material

TiN - Titanium Nitride - basic general-purpose wear resistant coating

TiN is the most common wear and abrasion resistant hard coating. It decreases the friction, increases chemical and temperature stability and decreases sticking of material often occurring during machining of soft steels. TiN is suitable for coating of tools made of cemented carbides– drill bits, milling cutters, cutting tool inserts, taps, reamers, punch knives, cutting tools, shear and flexion tools, matrices, forms, etc.

TiAlN – Titanium Aluminium Nitride – wear resistant coating for high-speed cutting

TiAlN is a coating with excellent hardness and high thermal and oxidation resistance. Incorporation of aluminium resulted in an increase of the thermal resistance of this composite PVD coating with respect to the standard TiN coating by 100°C. TiAlN is typically coated on high-speed cutting tools used on CNC machines for machining of materials of higher toughness and at severe cutting conditions. TiAlN is suitable especially for monolithic hard metal milling cutters, drill bits, cutting tool inserts and shaping knives. It can be used in dry or near-dry machining applications.

III. EXPERIMENTAL WORK

3.1. Design of experimentation table

The DOE is used to assess the system's output according to a collection of parameters. DOE is a relevant data collection and analysis tool utilized in large number of experimental situations. Factors, factors at different levels, and response are the three aspects that are analysed by a designed experiment.

Factors	Level 1	Level 2
Speed	40 m/s	80 m/s
Treatment	Cold	Cryo
Lubrication	Dry	Flood

Table 2Parameter selection table

3.2Experimentation

The turning of Monel 400 was subjected to a series of tests with TiN Coated, TiAlN Coated and uncoated tungsten carbide cutting inserts. Experiments were done with two levels of input values for each of the three input parameters, totalling 48 trials. Values for surface roughness, and Chip Curl diameter were seen for each combination of factor levels and the optimum valuewere evaluated.

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IV. RESULTS AND DISCUSSIONS

TiN Coated				
Speed (m/min)	Treatment	Lubrication	Ra (μm)	Chip Curl Diameter (mm)
40	Cold	Dry	1.772	5.02
40	Cold	Dry	1.762	5.20
40	Cold	Flood	1.683	5.70
40	Cold	Flood	1.612	5.30
40	Cryo	Dry	1.446	3.70
40	Cryo	Dry	1.522	4.00
40	Cryo	Flood	1.183	3.74
40	Cryo	Flood	1.196	3.89
80	Cold	Dry	1.522	3.70
80	Cold	Dry	1.433	3.64
80	Cold	Flood	1.403	5.02
80	Cold	Flood	1.393	5.06
80	Cryo	Dry	1.025	5.10
80	Cryo	Dry	1.118	5.20
80	Cryo	Flood	0.586	4.30
80	Cryo	Flood	0.570	4.60

TiAlN Coated				
Speed (m/min)	Treatment	Lubrication	Ra (μm)	Chip Curl Diameter (mm)
40	Cold	Dry	1.691	3.00
40	Cold	Dry	1.675	3.02
40	Cold	Flood	1.645	3.60
40	Cold	Flood	1.651	3.40
40	Cryo	Dry	1.236	2.30
40	Cryo	Dry	1.322	2.50
40	Cryo	Flood	1.093	2.20
40	Cryo	Flood	1.036	2.02
80	Cold	Dry	0.737	4.00
80	Cold	Dry	0.715	3.80
80	Cold	Flood	0.649	3.80
80	Cold	Flood	0.634	3.60
80	Cryo	Dry	0.649	2.80
80	Cryo	Dry	0.657	2.60
80	Cryo	Flood	0.506	3.20
80	Cryo	Flood	0.510	3.00

Table 4Experimental Results TiAlN Coated Tool

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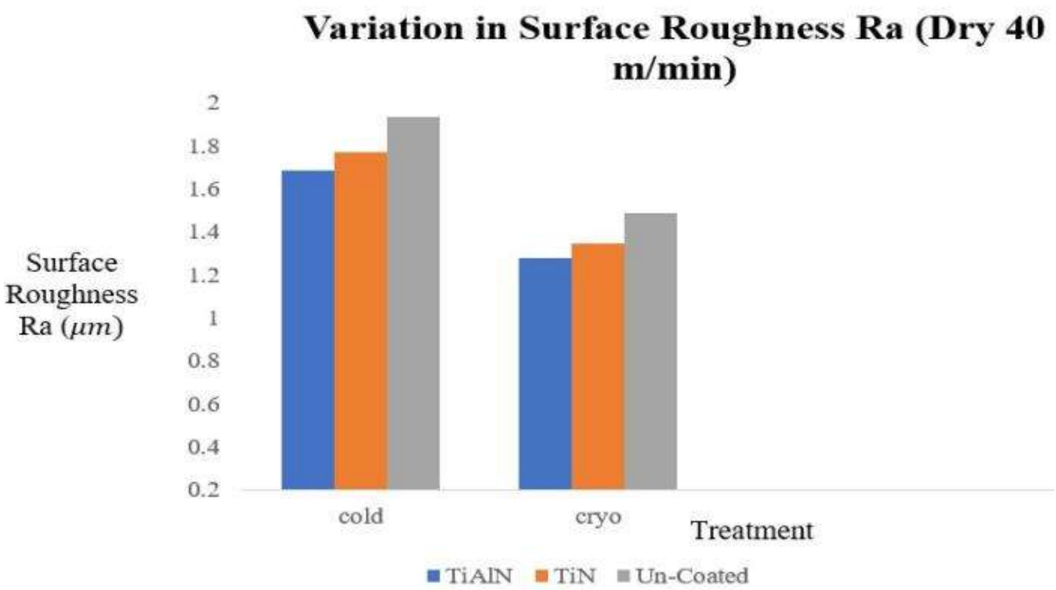
Un-Coated				
Speed (m/min)	Treatment	Lubrication	Ra (μm)	Chip Curl Diameter (mm)
40	Cold	Dry	1.972	5.00
40	Cold	Dry	1.892	5.02
40	Cold	Flood	1.883	6.20
40	Cold	Flood	1.792	6.40
40	Cryo	Dry	1.356	6.80
40	Cryo	Dry	1.327	6.60
40	Cryo	Flood	1.200	5.40
40	Cryo	Flood	1.327	5.80
80	Cold	Dry	1.722	8.80
80	Cold	Dry	1.543	9.00
80	Cold	Flood	1.503	9.00
80	Cold	Flood	1.583	8.80
80	Cryo	Dry	1.145	7.80
80	Cryo	Dry	1.178	8.00
80	Cryo	Flood	0.966	8.50
80	Cryo	Flood	0.970	8.80

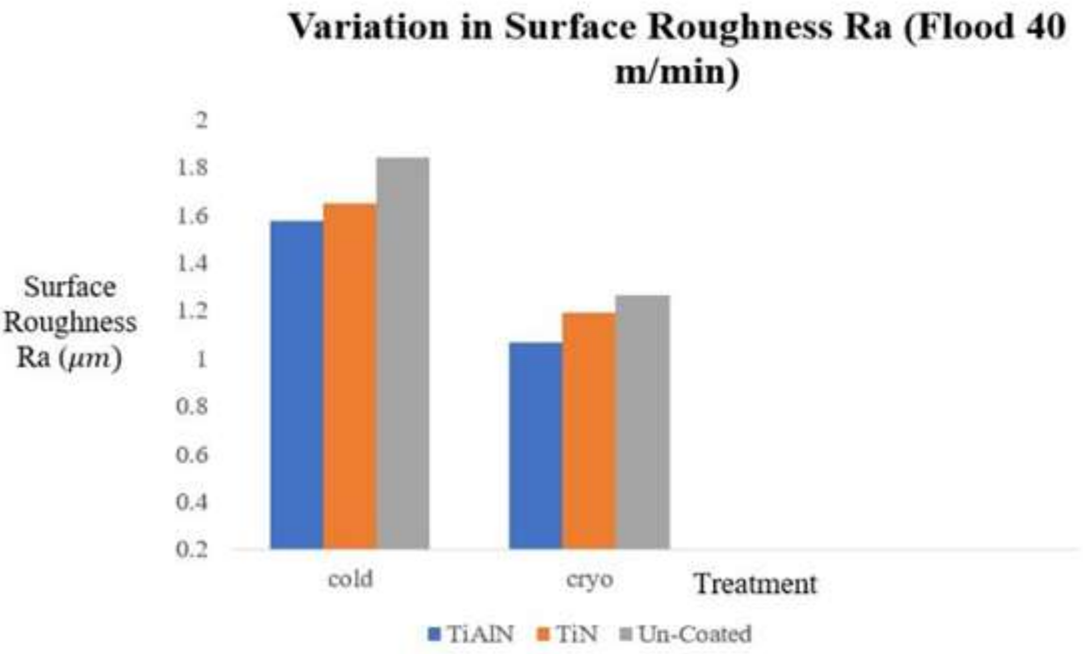
Table 5Experimental Results Un-Coated Tool

4.1 Discussions
4.1.1 Variation in Surface Roughness



Graph 1Variation in Surface RoughnessDry (40 m/min)

Here a comparison of variation in Surface Roughness is done for Both Cryo Treated and Cold treated cutting inserts at speed 40 m/min without lubrication. We can observe a reduction of surface roughness while using cryo treated tools compared to that of cold treated tools. Also, we can observe that TiAlN coated tool gives lesser surface roughness compared to TiN coated and Uncoated tools



Graph 2Variation in Surface RoughnessFlood (40 m/min)

Here a comparison of variation in Surface Roughness is done for Both Cryo Treated and Cold treated cutting inserts at speed 40 m/min with lubrication. We can observe a reduction of surface roughness on using cryo treated tools compared to that of cold treated tools. Also, we can observe that TiAlN coated tool gives the lesser surface roughness compared to TiN coated and Uncoated tools. Another observation is that surface roughness is reduced for each tool with introduction of lubricant.

Surface Roughness Ra (μm)

Graph 3Variation in Surface RoughnessDry (80 m/min)

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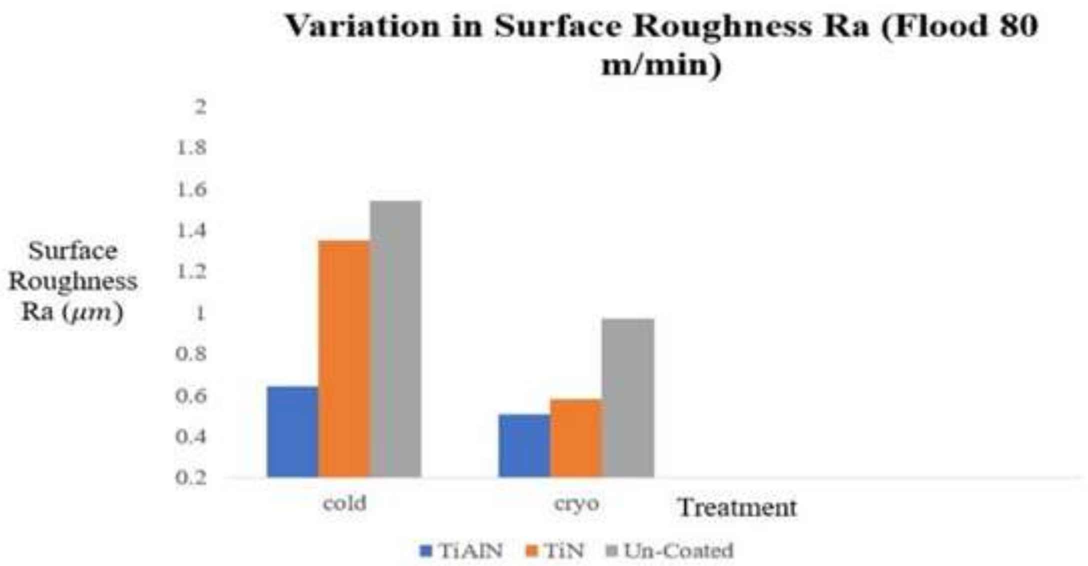
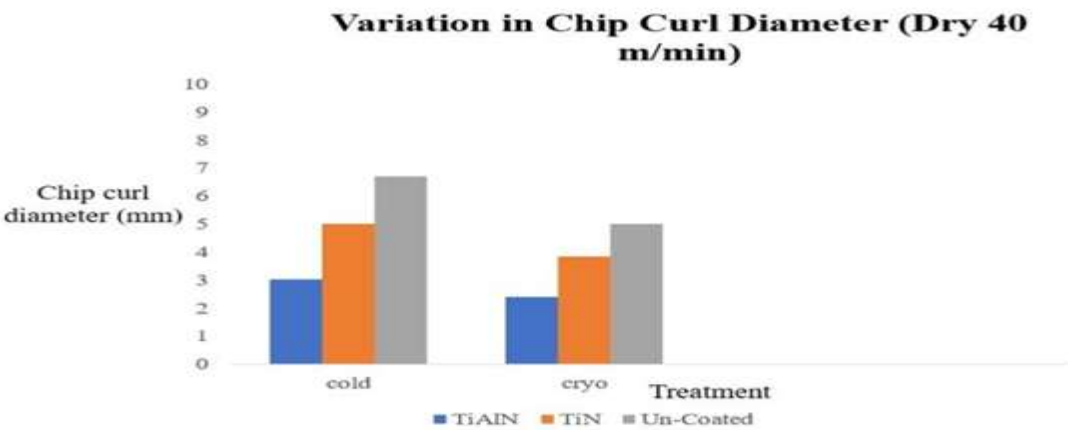
Here a comparison of variation in Surface Roughness is done for Both Cryo Treated and Cold treated cutting inserts at speed 80 m/min without lubrication. We can observe a reduction of surface roughness on using cryo treated tools compared to that of cold treated tools. Also, we can observe that TiAlN coated tool possess the lesser surface roughness compared to TiN coated and Uncoated tools. Another observation is that surface roughness is reduced for each tool with increase in cutting speed.



Graph 4Variation in Surface RoughnessFlood (80 m/min)

Here a comparison of variation in Surface Roughness is done for Both Cryo Treated and Cold treated cutting inserts at speed 80 m/min with lubrication. We can observe a reduction of surface roughness on using cryo treated tools compared to that of cold treated tools. Also, we can observe that TiAlN coated tool possess the lesser roughness compared to TiN coated and Uncoated tools. Another observation is that surface roughness is reduced for each tool with introduction of lubrication and increased cutting speed.

4.1.2 Variation in Chip Curl Diameter



Graph 5Variation in Chip Curl Diameter Dry (40 m/min)

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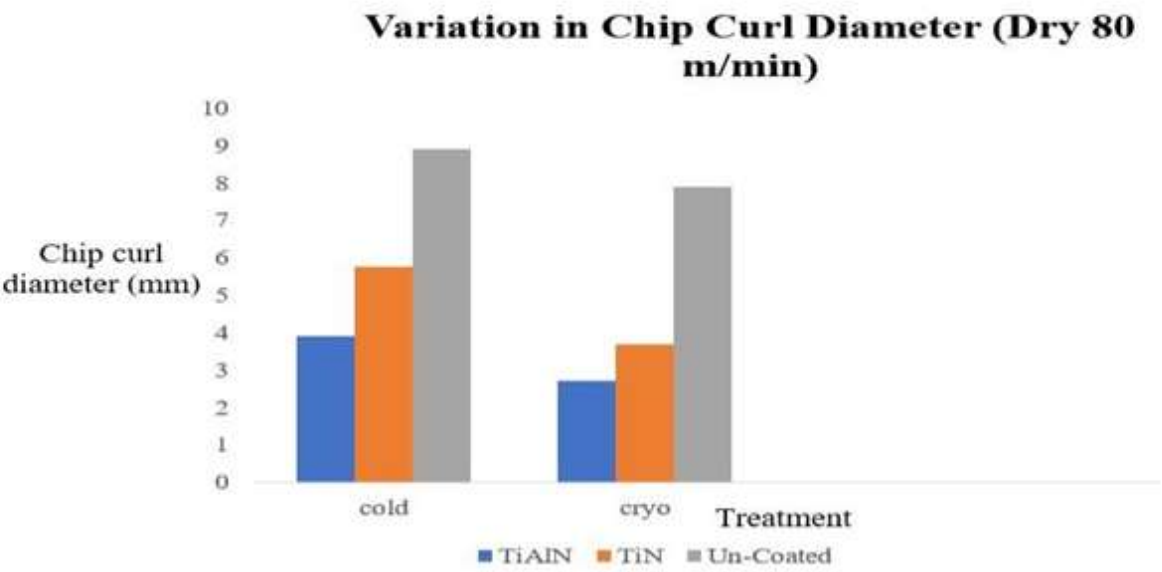
Here a comparison of variation in Chip curl diameter is done for Both Cryo Treated and Cold treated cutting inserts at dry 40 m/min without lubrication. We can observe a reduction of chip curl diameter on cryo treated tools compared to that of cold treated tools. Also, we can observe that TiAlN coated tool produce lesser chip curls compared o TiN coated and Uncoated tools.

Chip curl
diameter (m

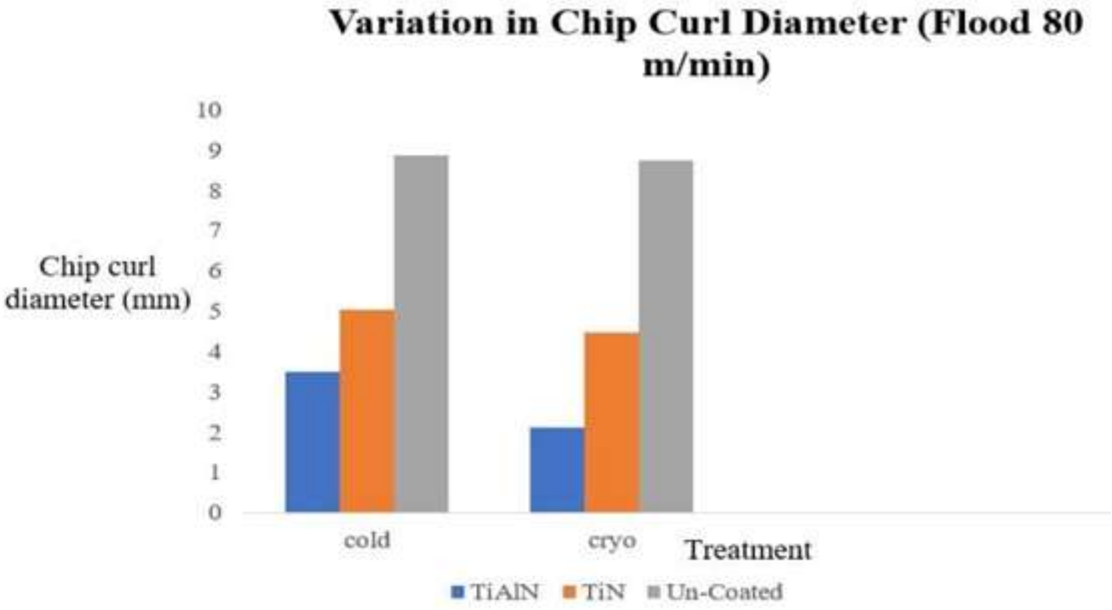
Graph 6Variation in Chip Curl Diameter Flood (40 m/min)

Here a comparison of variation in Chip curl diameter is done for Both Cryo Treated and Cold treated cutting inserts at dry 40 m/min with lubrication. We can observe a reduction of chip curl diameter on cryo treated tools compared to that of cold treated tools. Also, we can observe that TiAlN coated tool produce lesser chip curls compared to TiN coated and Uncoated tools.



Graph 7Variation in Chip Curl Diameter Dry (80 m/min)

Here a comparison of variation in Chip curl diameter is done for Both Cryo Treated and Cold treated cutting inserts at dry 80 m/min without lubrication. We can observe a reduction of chip curl diameter on cryo treated tools compared to that of cold treated tools. Also, we can observe that TiAlN coated tool produce lesser chip curls compared to TiN coated and Uncoated tools. We can observe an increase in chip curl diameter mainly for uncoated tool but TiAlN coated tool doesn't have much variations.



Graph 8Variation in Chip Curl Diameter Dry (80 m/min)

Here a comparison of variation in Chip curl diameter is done for Both Cryo Treated and Cold treated cutting inserts at dry 80 m/min with lubrication. We can observe a reduction of chip curl diameter on cryo treated tools compared to that of cold treated tools. Also, we can observe that TiAlN coated tool produce lesser chip curls compared to TiN coated and Uncoated tools. We can observe an increase in chip curl diameter mainly for uncoated tool but TiAlN coated tool doesn't have much variations.

4.1.3 Chip Morphology

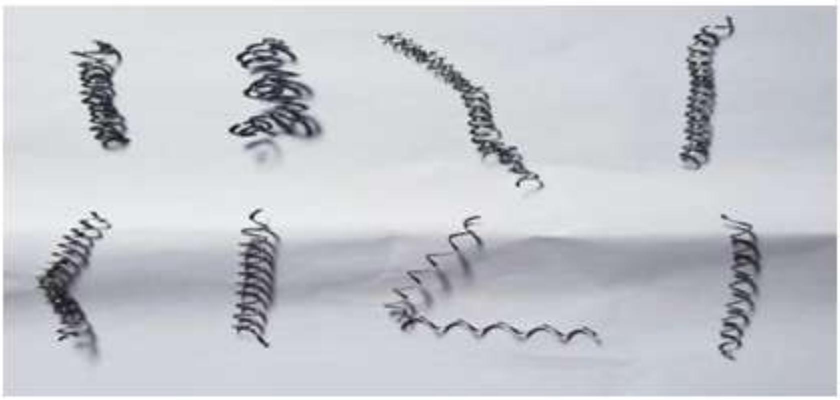


Fig 1Chips formed during machining (TiN Coated tool)

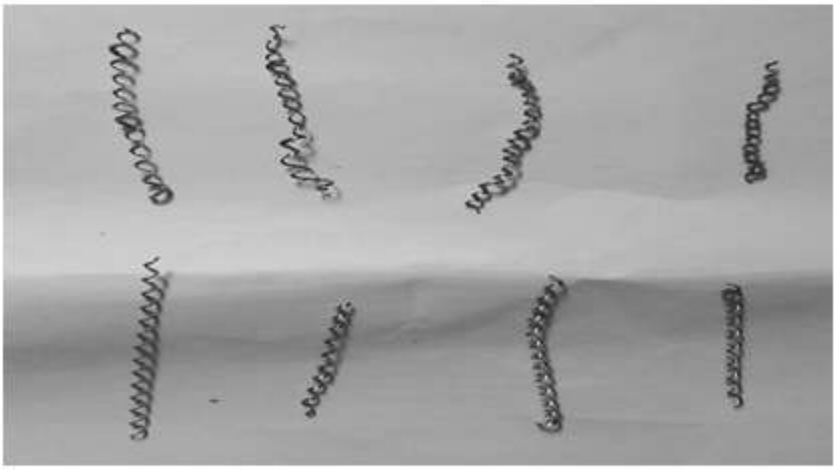


Fig 2Chips formed during machining (TiN Coated tool)

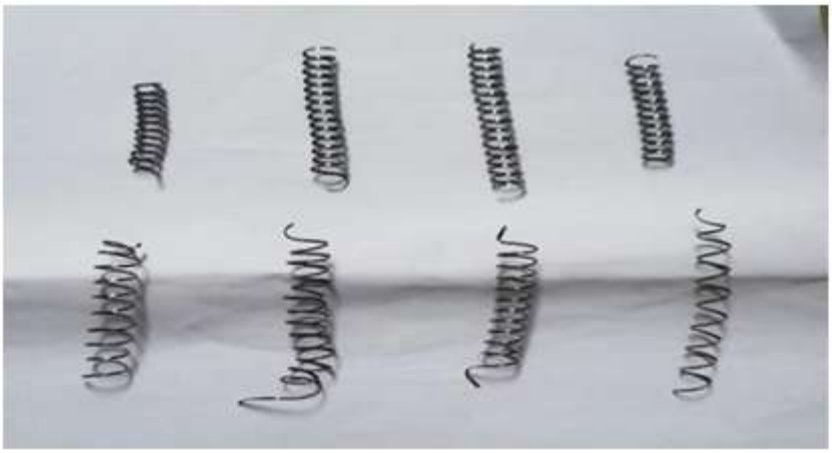


Fig 3Chips formed during machining (TiN Coated tool)

Chips formed during turning operations using different cutting tools are shown in Fig 1, Fig 2 and Fig 3. While observing the chips we can see that smaller chip curling is for TiAlN tool and higher chip curl diameter is obtained for un-coated tool.

During cutting operation, the layers adjacent to the tool get deformed, this cause curling of chip into the spiral shape. The force applied during the cutting processes deform the layer that in contact with the tool and this layer become thicker finally results in the curling.

The significance of chip curl diameter is that better machinability will obtain with lower chip curls.The lower chip curl contributes to higher dimensional accuracy in machining, because it decreases the scratching effect of the chip on the machined surfaces as well as chip side-flow.

It is also observed that the surface quality decreases when the chip curl diameter increases and decrease in feed rate with corresponding increase in cutting speed led to decrease in chip curl diameter.

Continuous chips were obtained at all conditions this indicates good surface finish; it facilitates low power consumption. Provide longer lifespan of tool due to less wear and tear. Due to minimize friction between chip and tool face, it requires less heat generation.

Formation of snarled chips are observed during turning operation using TiN coated tools and TiAlN coated tools which are mainly formed due to dry turning.

4.1.4 Scanning Electron Microscopy

SEM Analysis of cutting inserts have been done in order to find out the major failures of tools that occur during machining process. Wear and tear of tools can lead to inaccurate processes or poor productivity.

By analysing used tools, we can achieve maximum tool life and predict tool usage; thereby maintaining part accuracies and reducing equipment deterioration. By understanding the various mechanisms that contribute to insert failure, you can take appropriate course of action to ensure optimal cutting performance at all time.

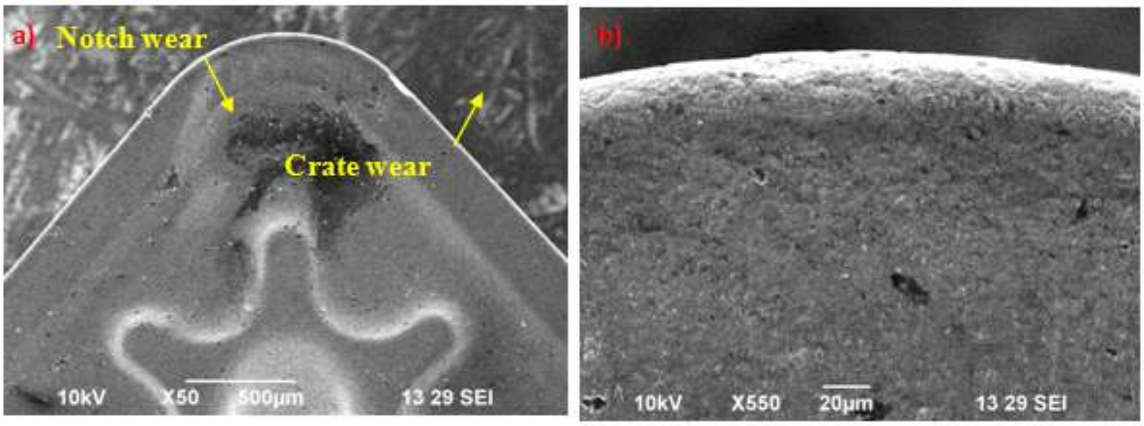


Fig 4SEM images for Cryo treated TiAlN coated tool (Flood 80 m/min) a) 50x zoom b) 550x zoom

Fig 4 shows SEM images for Cryo treated TiAlN coated tool (flood 80 m/min) which gives better machinability results under every condition of input parameters. While observing the images we can observe nearly no or very minute wear or failure.

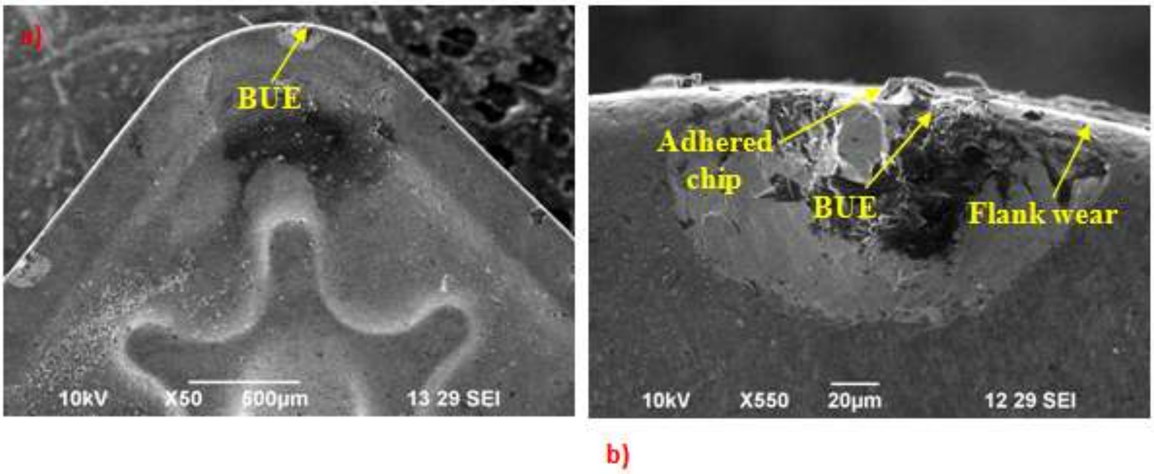


Fig 5shows SEM images for Cryo treated TiAlN coated tool (Dry 80 m/min) while analysing the images we can observe Built up edge formation and flank wear. Adhesion of particles can also be observed.

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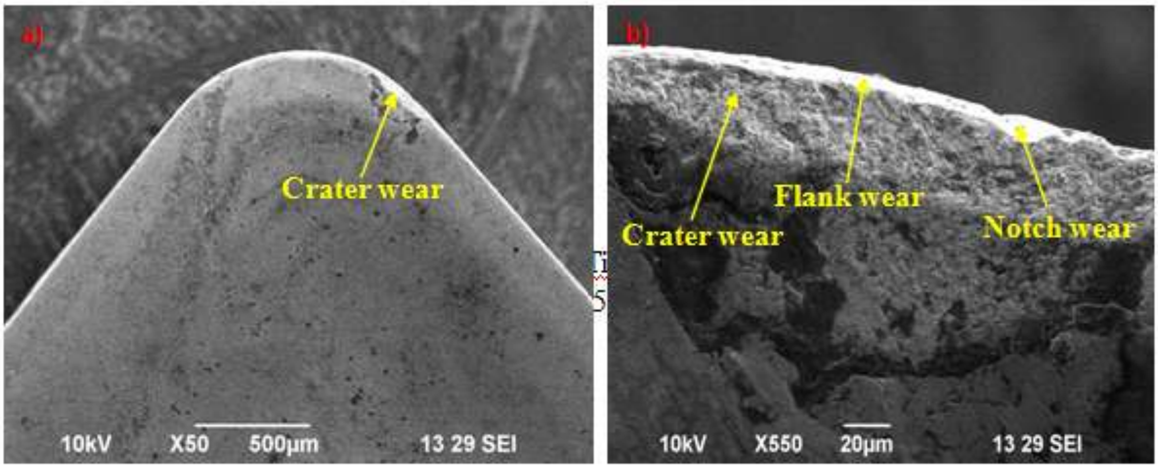

Fig 7SEM images for Cryo treated Un-coated tool (Dry 80 m/min) a) 50x zoom b) 550x zoom

Fig 7SEM images for Cryo treated Un-coated tool (Dry 80 m/min) as from the experiments done un-coated tools give comparatively poor results than TiAlN coated and TiN coated tools. While analysing the SEM images we can observe that there is an occurrences of crater wear on the rake surface as well as notch wear and flank wear.

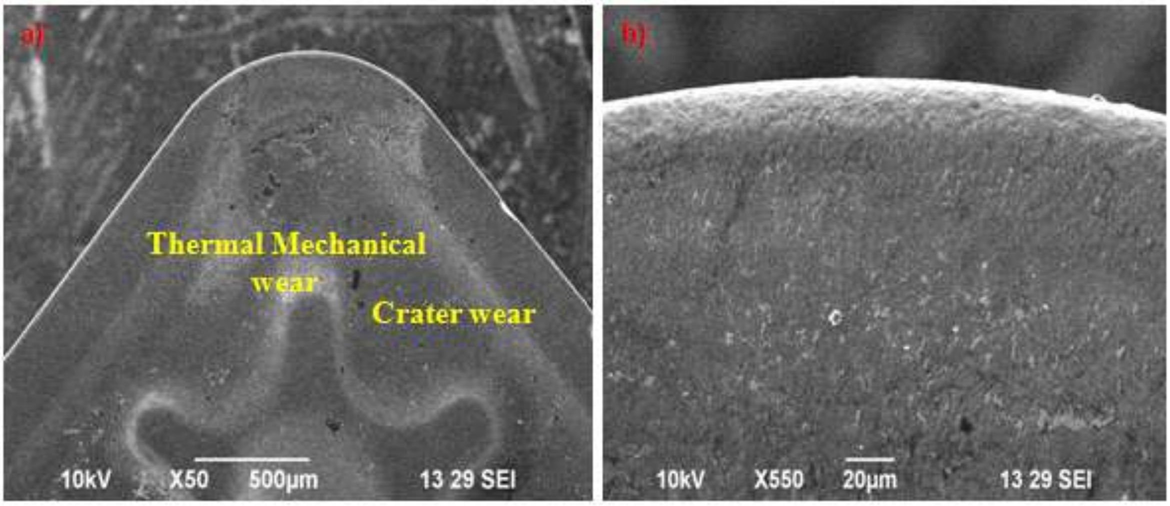

Fig 8SEM images for Cold treated TiAlN coated tool (Dry 80 m/min) a) 50x zoom b) 550x zoom

Fig 8 is the SEM images for Cold treated TiAlN coated tool (Dry 80 m/min) as from the experiments done cryo treated tools have better results than cold treated tools but while analysing the SEM images we can observe nearly less failures or wears for this tool. We can observe a narrow zone of thermal mechanical wear on the rake surface.

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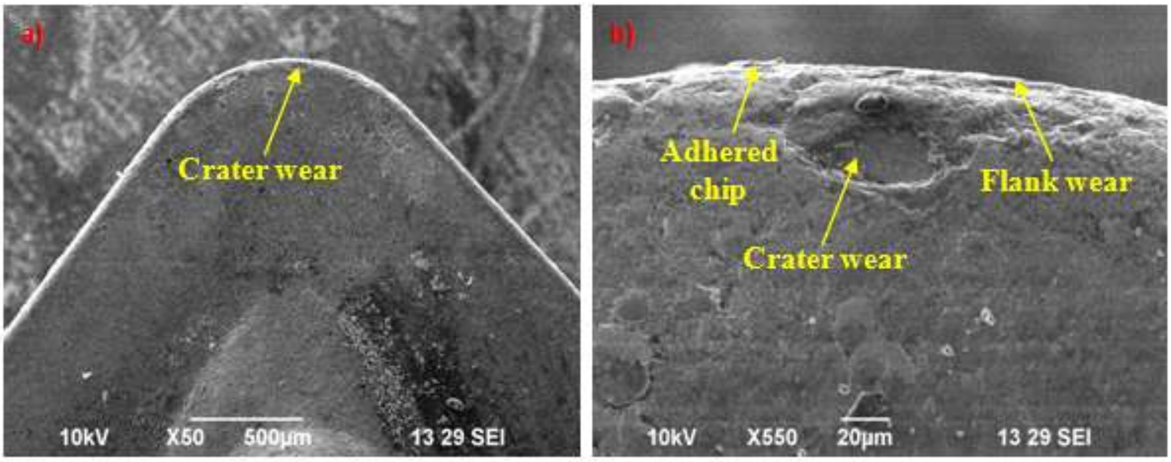

Fig 9SEM images for Cold treated TiN coated tool (Dry 80 m/min) a) 50x zoom b) 550x zoom

Fig 9 is the SEM images for Cold treated TiN coated tool (Dry 80 m/min). while observing the images we can see a large zone of cratering as well as flank wear. Chip adhesion can also be observed

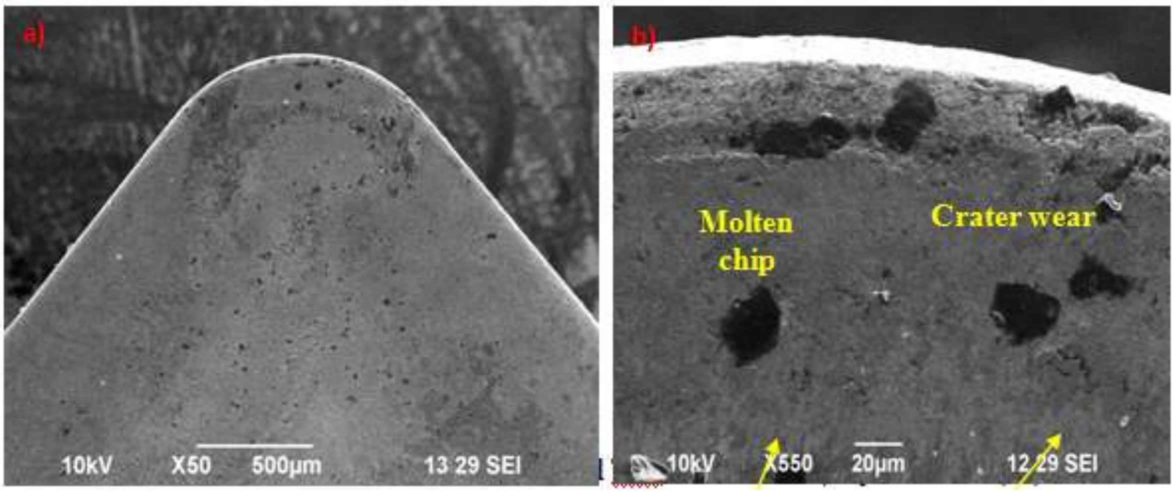

Fig 10 shows the SEM images for Cold treated Un-coated tool (Dry 80 m/min). while observing the images we can see crater wear as well large amount of molten chip adhered to the surface of tool

4.1.5 Energy dispersive X-ray spectroscopy (EDX)

Energy dispersive X-ray spectroscopy is done in order to find out the to identify the elemental composition of materials. The standard EDX analysers can detect elements with an atomic number from 11 (sodium) upward.

The abscissa of the EDX spectrum indicates the ionization energy and ordinate indicates the counts. Higher the counts of a particular element, higher will be its presence at that point or area of interest. You can display the amount of each element in number of counts or in weight percentage. For thoroughly performed EDS analysis (quantification with standards, no light elements) Wt. % IS concentration. Wt. % gives the concentration of the element in terms of the mass fraction of that element in the sample.

The accuracy of EDX can be quite high for certain element combinations (fraction of a percent), but e.g., for carbon it is not better than several percent, i.e., one or two orders of magnitude difference.

By analysing the EDX spectrum of selected tools we can identify the amount and composition of workpiece material and coating material present in the tool surface and hence evaluate.

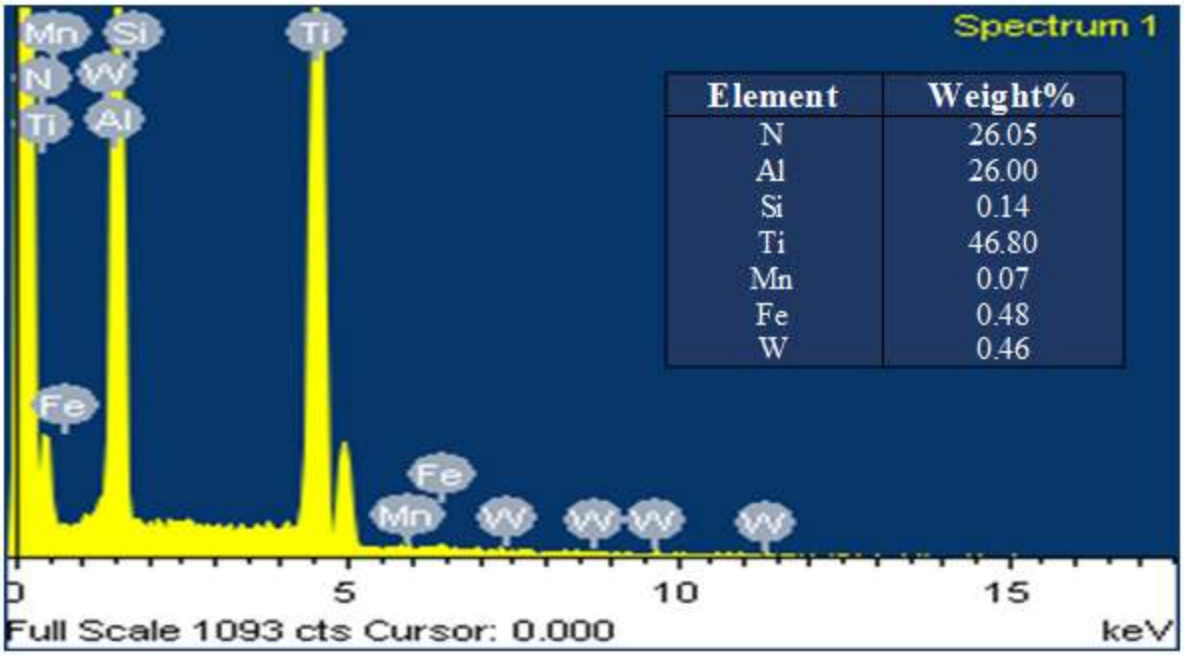

Fig 13 shows the EDX spectrum of Cryo treated TiAlN coated tool (Flood 80 m/min). While observing the spectrum we can see that the major Wt.% is of Ti, Al, N which indicates the presence of coating material TiAlN. The Wt.% are 46.80% 26.00% and 26.05% respectively, and 0.46 Wt.% of W therefore there is no much loss or defect happened to the coating material. Also, there are presence of Mn and Fe at Wt.% 0.07% and 0.48% this indicates that there is only a minute adhesion of workpiece material to the tool surface.

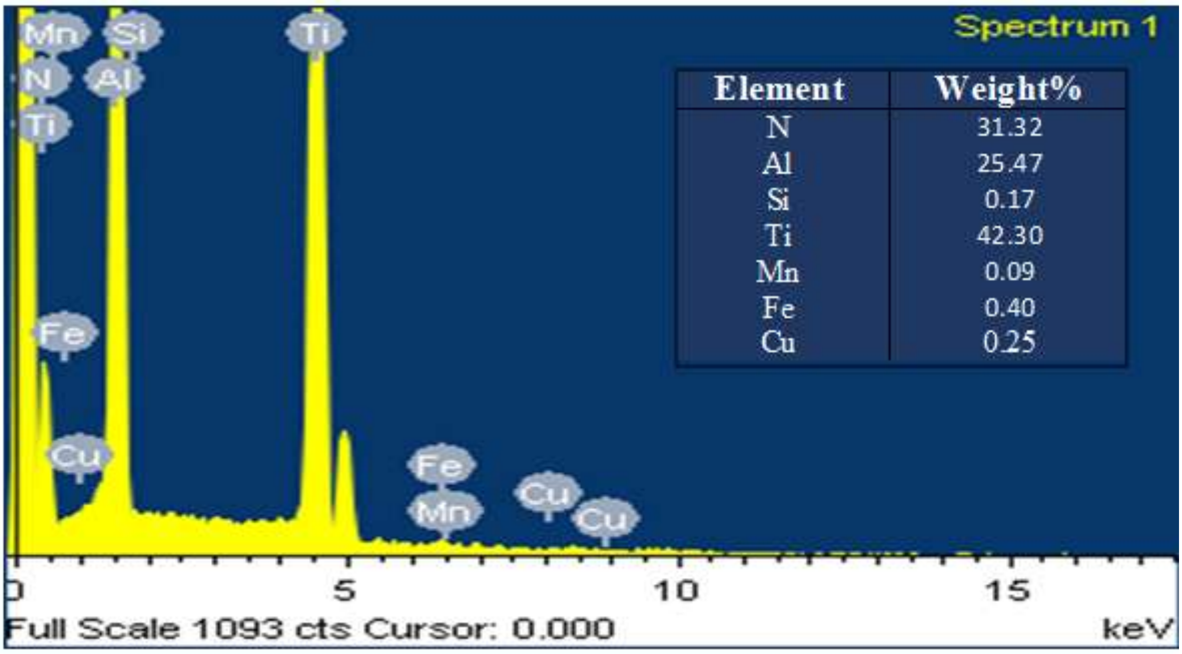

Fig 14 shows the EDX spectrum for Cryo treated TiAlN coated tool (Dry 80 m/min). While observing the spectrum we can see that the major Wt.% is of Ti, Al, N which indicates the presence of coating material TiAlN.

The Wt.% are 42.30% 25.47% and 31.32% respectively, therefore there is no much loss or defect happened to the coating material.

Also, there are presence of Cu, Mn and Fe at Wt.% 0.25%, 0.09% and 0.40% this indicates

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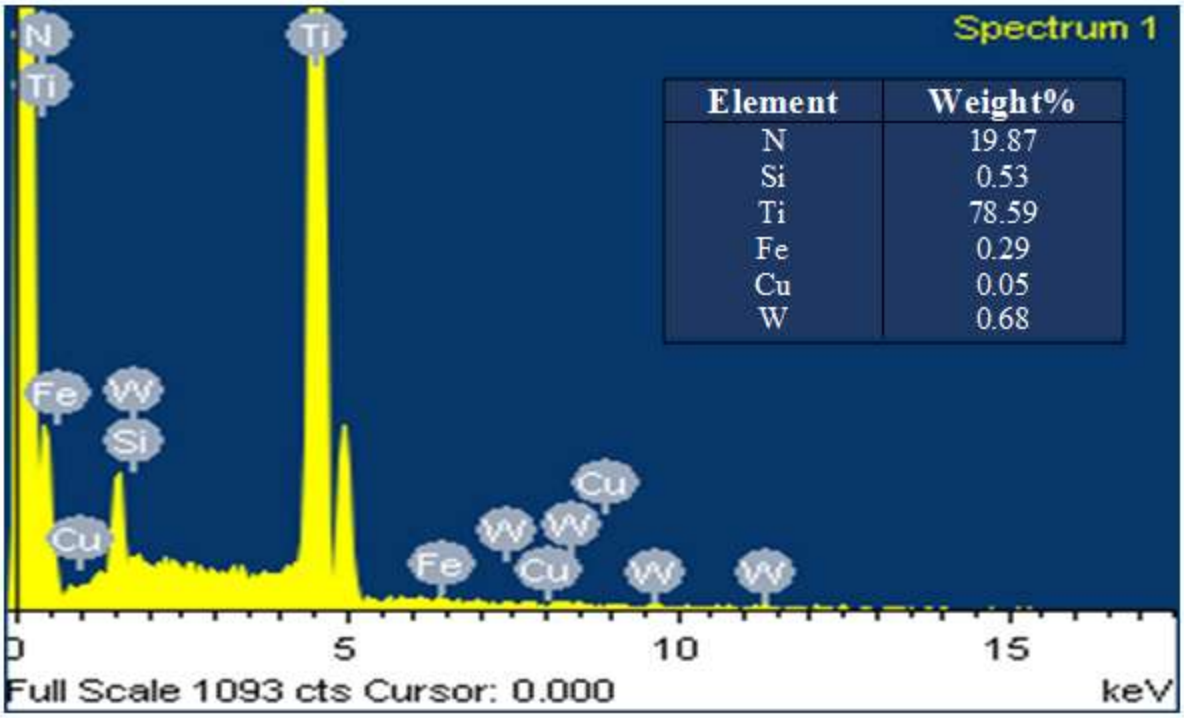
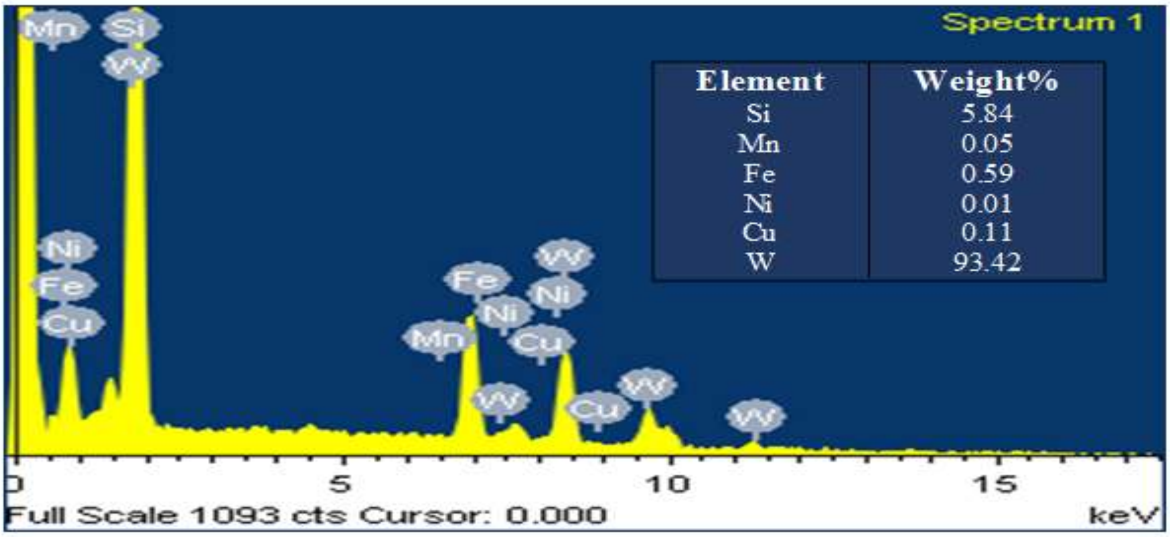
that there is only a minute adhesion of workpiece material to the tool surface.



Element	Weight%
N	19.87
Si	0.53
Ti	78.59
Fe	0.29
Cu	0.05
W	0.68

Fig 15 shows the EDX spectrum for Cryo treated TiN coated tool (Dry 80 m/min) while observing the spectrum we can see that the major Wt.% is of Ti, N which indicates the presence of coating material TiN.

The Wt.% are 78.59% and 19.87% respectively, therefore there is no much loss or defect happened to the coating material. A 0.68 Wt.% of W is also observed which is the presence of tool material but it can be ignored hence it's a minute value. Also, there are presence of Cu and Fe at Wt.% 0.05%, 0.29% which indicate the presence of workpiece material this means that there is only a minute adhesion of workpiece material to the tool.



Element	Weight%
Si	5.84
Mn	0.05
Fe	0.59
Ni	0.01
Cu	0.11
W	93.42

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Fig 16 shows the EDX spectrum of Cryo treated Un-coated tool (Dry 80 m/min). While observing the spectrum we can see that the major Wt.% is of W that is of 93.42% which indicate the presence of tool material. We can also observe Wt.% of Si 5.84% Mn 0.05%, Cu 0.11% and Ni 0.01% which indicate the presence of workpiece material therefore the adhesion of workpiece material to tool is high for Un-coated tool compared to coated tool. Which can lead to abrasion and tool wear.

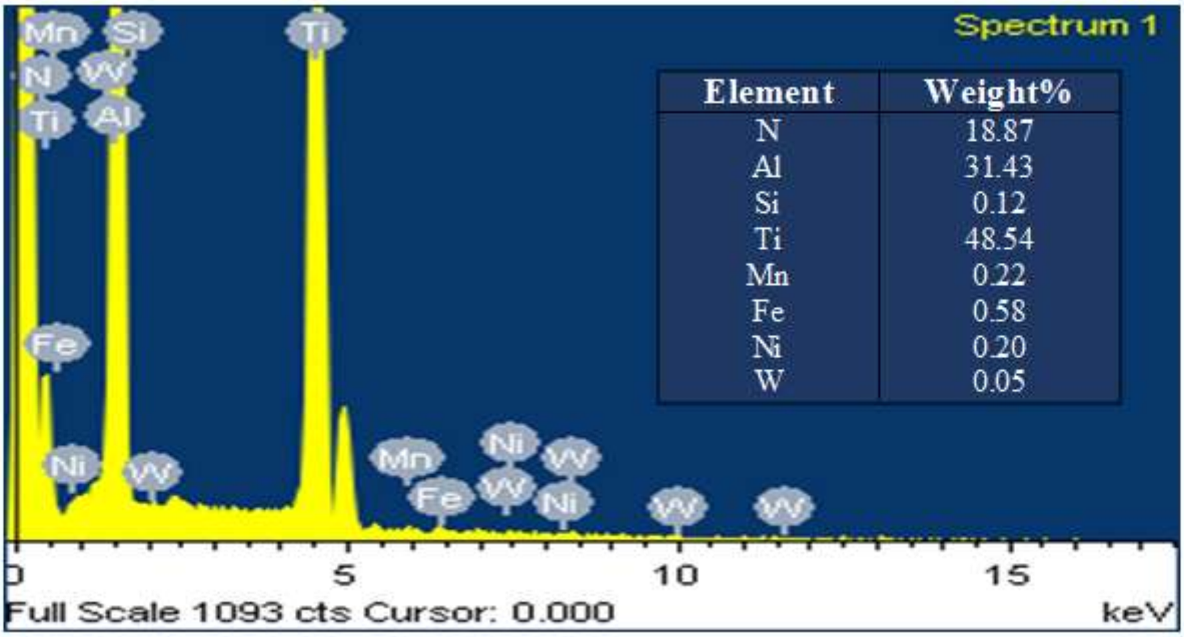

Fig 17 shows the EDX spectrum of Cold treated TiAlN coated tool (Dry 80 m/min). While observing the spectrum we can see that the major Wt.% is of Ti 48.54%, Al 31.43% and N 18.87% which indicates the presence of coating material TiAlN and hence it is present in large quantity there is no much defect or lose of coating material.

A 0.05 Wt.% of W is observed which indicate the presence of tool material where the coating is lose at a minute amount

We can also observe presence of Ni 0.20 Wt.%, Fe 0.58 Wt.%, Mn 0.22 Wt.%. and Si 0.12 Wt.% which indicate presence of workpiece material which means adhesion of workpiece material occurs at a low amount which may due to wear occurred.

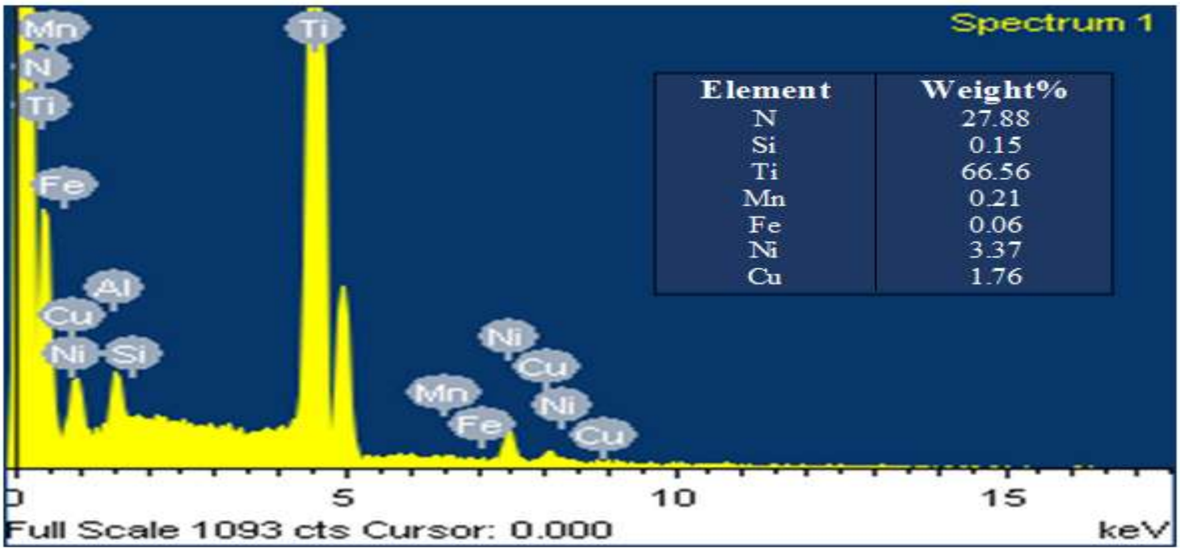

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Fig 18 shows the EDX spectrum of Cold treated TiN coated tool (Dry 80 m/min). While observing the spectrum we can see that the major Wt.% is of Ti 66.56% and N 27.88% which indicates the presence of coating material TiAlN and hence it is present in large quantity there is no much defect or lose of coating material.

We can also observe presence of Ni 3.37 Wt.%, Cu 1.76 Wt.%, Mn 0.21 Wt.%., Fe 0.06 Wt.% and Si 0.15 Wt.% which indicate presence of workpiece material, which means adhesion of workpiece material to tool surface.

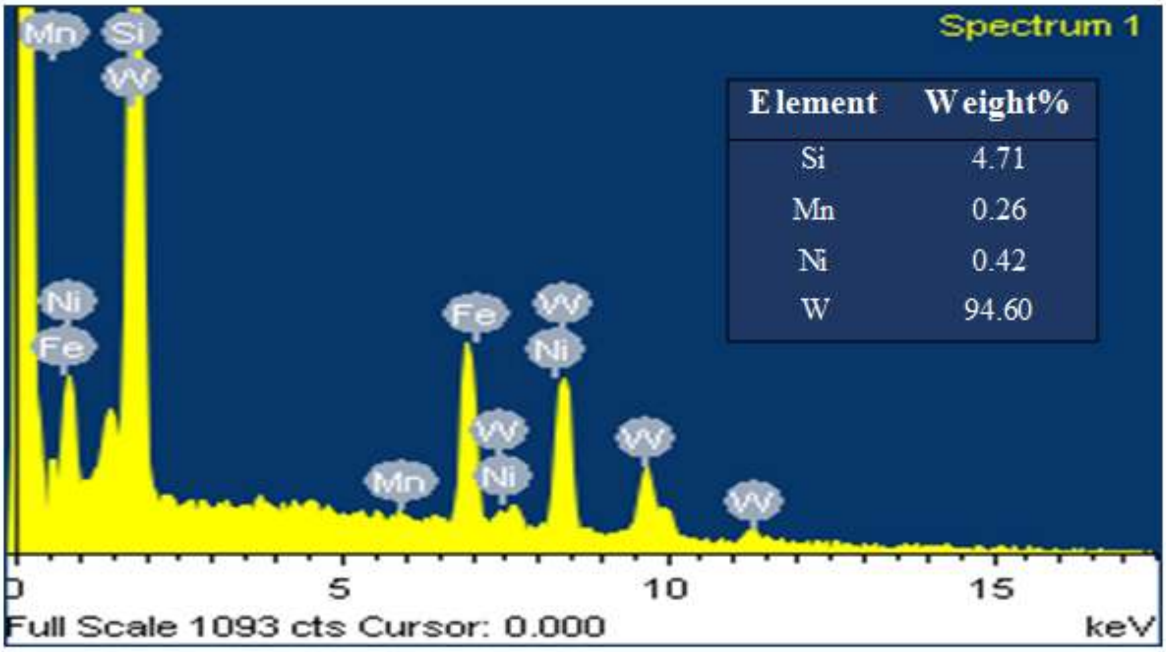

Fig 20 shows the EDX spectrum of Cold treated Un-coated tool (Dry 80 m/min). While observing the spectrum we can see that the major Wt.% is of W that is of 94.60% which indicate the presence of tool material. We can also observe Wt.% of Si 4.71% Mn 0.26%and Ni 0.42% which indicate the presence of workpiece material therefore the adhesion of workpiece material to tool is high for Un-coated tool compared to coated tool. Which can lead to abrasion and tool wear

V. CONCLUSIONS

In the present study, comparison of machinability in terms of cutting speed, Lubrication, Treatment, Material removal rate, surface finish, chip-curl diameter of turning of the nickel base alloy Monel-400 were discussed. The same has done for TiN coated, TiAlN coated and Uncoated Tungsten Carbide tools. The following conclusion may be drawn from present work.

- Material Removal is high for cryo treated tools compared to cold treated tools.
- MRR increases with increase in cutting speed.
- TiAlN coated tool have higher MRR compared to compared to TiN coated and Uncoated tools.
- Surface Roughness is less for cryo treated tools compared to cold treated tools.
- Surface Roughness is reduced with implementation of lubricant.
- TiAlN coated tool gives more surface finish compared to compared to TiN coated and Uncoated tools.
- Surface roughness is reduced with increase in cutting speed.
- Chip curl diameter is less for cryo treated tools compared to cold treated tools.
- TiAlN coated tool gives lesser chip curls compared to compared to TiN coated and Uncoated tools.
- Lubricant has no much effect on MRR and chip curl
- From SEM results we can observe that TiAlN tool have less defects or failure compared to TiN coated and Un-Coated tool.
- Tool coating have a great effect from protecting the tool from wear and tear.
- From SEM images we can observe that molten chips are adhered to tool surface of un-coated tool, which means that uncoated tools are more vulnerable to heat and thermal stress.

- Therefore, we can conclude that coating can protect tool from thermal stress.
- Major wear that is observed in tools are crater wear and flank wear.
- Adhesion of chips and workpiece material is high in Un-coated tools compared to TiAlN coated and TiN coated tools.
- Finally, we can conclude that best result is obtained for TiAlN cutting tool at 80 m/min at flood lubrication condition.

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