OPTIMIZATION OF CNC TURNING PROCESS PARAMETERS ON INCONEL 625 USING RESPONSE SURFACE METHODOLOGY

Dissertation- II

Submitted in partial fulfillment of the requirement for the award of the degree

Of

Master of Technology

IN

MECHANICAL ENGINEERING

By

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CERTIFICATE

I hereby certify that the work being presented in the thesis entitled **"Optimization of CNC Turning process parameters on Inconel 625 using response surface methodology"** in partial fulfillment of the requirement of the award of the Degree of master of technology (Spl. in Manufacturing Technology) and submitted to the Department of Mechanical Engineering of Lovely Professional University, Phagwara, is an authentic record of my own work carried out under the supervision of **(Ramandeep Singh, Assistant professor)** Department of Mechanical Engineering, Lovely Professional University. The matter embodied in this Thesis has not been submitted in part or full of any other University or Institute for the award of any degree.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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APPROVAL PAGE

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Qualitative Assessment of Proposed Topic by PAC		
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2	Project Feasibility: Project can be timely carried out in-house with low-cost and available resources in the University by the students.	7.25
3	Project Academic Inputs: Project topic is relevant and makes extensive use of academic inputs in UG program and serves as a culminating effort for core study area of the degree program.	7.00
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ABSTRACT

This paper examines the effect of cutting parameters and machining conditions on workpiece surface when turning Inconel 625 solid round bar by using PVD coated (TiAlN/TiN) carbide tool. CNC Turning was conducted under two cutting conditions, namely dry and Wet. CNC turning process parameters determined by using Taguchi L9 orthogonal arrays and effect of turning process parameters, i.e. cutting speed (m/min), feed rate (mm/min) and depth of cut (mm) are examined for two output aims, i.e. Surface Roughness and MRR. In this study, it is originated that the cutting condition, feed followed by the depth of cut, and cutting speed plays more significant task on the selected response parameters.

Keywords*:* Inconel 625, CNC turning, Surface Roughness, MRR, Taguchi Method, Cutting conditions.

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LIST OF ABBREVIATIONS

Vc	Cutting speed
f	Feed rate
d	Depth of Cut
Ra	Average Surface Roughness
Rt	Distance from the highest peak to the deepest valley
Rz	The average Rt over a given length
Rc	Mean height of profile Irregularities
MRR	Material removal rate

Chapter 1

Introduction

Manufacture of materials is the most important task in industries. The innovation in manufacturing technologies in the modern past has carried out about new transmute in the world industrial performing area. The developing technologies have created the possibility for innovative products. Fast varying technologies on the product front cautioned the need for evenly fast reaction from the production industries. Therefore, to overcome this challenge, the manufacturing industries have to choose proper strategies, manufactured materials, designs, production processes, work piece, and tool material, machine accessories, and apparatus and so on.

The Demanding task of any contemporary machining industries focuses upon the attainment of enhancing the surface quality of the product work piece, their dimensions precision, surface finish, large manufacturing quantity, diminish the effect of tool wear throughout the machining, reasonable in machining cost and magnifies the execution of the product, diminished the atmospheric influences. The Surface finishes of the goods acting as a significant responsibility in several regions and is an aspect of a large significance in the evaluation of high precision machining. The most common traditional lathes are still used for machining in the production industries for manufacturing distinct round parts, except this time CNC machines are most extensively employed for outstanding essential characteristics, high production rate with high accuracy. Now a day's industries, followed the automated and flexible manufacturing, it is generally common to be all industries and this process are more efficient of high performing rate with attaining high accuracy.

The numerical control (NC) started when the automation of machine tools first associated idea of conceptual logic, and it maintains recently with the continuing development of computer numerical control (CNC) technology. In the 1940s and 1950s, the first NC machines were introduced based on present tools that were adapted with motors that indented the controls to track the points fed in to on punched tape. These near the beginning servo mechanisms were quickly exaggerated along with analog and digital computers, originating the recent CNC machine tools that have revolutionized the process of machining.

1.1 CNC Machine

In recent, the manufacturing processes are widely carried out by the CNC machine. The CNC machine is utilized, through board computer which recollect several programs of different parts as per the requirement.

Because of a high accuracy rate, it is speedily replacing the production lathe. The enhancement of design structure for the purpose of achieving optimum performance the use of new carbide tooling. The preparation of part design and the tool parts programmed by using CAD & CAM techniques and by manually operated by the program maker. After that the issuing data file uploaded to the machine, and formerly locates and marked, and then the machine will keep on to arrive out the parts in the chance of inspection direction of a performer.

Figure 1 CNC turning Centre

The CNC machine is operated automatically assisted by the computer menu mode; the program improved and expressed on the machine, with an imitative analysis of the progression. The machinist requires a talent to execute the process. CNC machines are frequently placed and performed by the operator, instead of the skilled performer will able to conduct the maximum machines. The most significant utilization of several CNC machines is fully automatic, high precise and well-suited motion command. A program is required to start any CNC machines. This command is reasonable instruction a number of processes can be carried out by using CNC but turning is the most suitable process to cut the metal. However, the turning procedure affected feature of surface, the geometry of the tool.

1.2 Turning operation

Turning is the metal removal as well as machining procedures in which cutting tool cut the metal from the surface of a rotating work piece using single or multi point cutting tool. By the turning we can easily introduce the accurate shape with high surface finish. By the turning process introduce a cylindrical part as shown in fig. 1.2. It's essential appearance; it can be explained as the machining of the outside surface.

a. The work piece revolution by rotating spindle.

b. Single cutting point tool using for turning.

c. The feeding of cutting tool equivalent to the axis of the work piece. It will cut the metal and remove from the external surface.

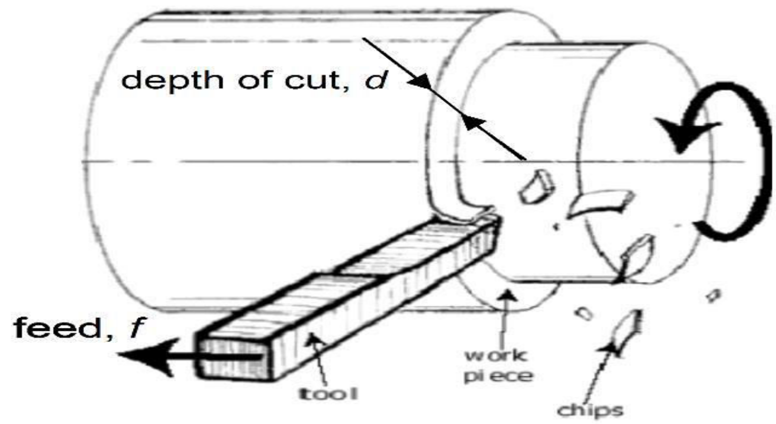


Figure 2 Cutting parameters

There are three major aspects in turning actions are speed, feed and depth of cut. Other aspects such that nature of material characteristics and the distinct types of tool has shown more effectiveness, but the performer can alter by arranging the controls, of machines.

1.3.1 Speed

Speed is consisting that the rotary motion of the spindle and work piece. It represents unit is revolutions per minute (RPM) it shows their speed of revolving. However, the significant properties used for a considerable turning process are the speed which the workpiece material is affecting the surface of cutting tool. Speed is formulated in meter per minute (m/min) and it has consigned just to the work piece.

1.3.2 Feed

Feed rate forever concerns that the cutting tool and the rate of the tool travels along with cutting pathway. The feed rate is directly associated with the spindle speed is articulated in mm per revolution.

1.3.3 Depth of cut

Depth of cut is processed, the removal of specific thickness of the work piece. The formulation of depth of cut is the distance from the uncut surface to the cut surface. The dimension measured in mm.

Chapter 2

2.1Review of Literature

Dr. C. J. Rao (2013) has studied about that the effect of speed, feed and depth of cut on the surface roughness & cutting force acted by ceramic tool with an Al2O3+TiC matrix and the workpiece material of AISI 1050 steel. They have concluded that the interface of feed and depth of cut and the all the three cutting parameters have an important effect on cutting force [1].

Surendra Kumar Saini (2014) has studied about CNC turning action is using L_{27} Taguchi orthogonal arrays applied in Aluminum alloy 8011 with the using of carbide insert. The process parameters, i.e. feed rate, Cutting Speed, and Depth of Cut are calculating the MRR and surface roughness. They have concluded that COM is used as output and the effect on elected Independent parameters are considered on fuzzy crisp output by the Taguchi SNR analysis [2].

P. Jayaraman (2014) has studied Multi-response optimization of parameters on turning on AA6063 T6 aluminium alloy performs based on orthogonal arrays by using gray relational analysis. The turning parameters such as cutting speed, depth of cut and feed rate are optimized allowing For the several responses i.e., Ra, roundness (Ø) and material MRR. They have concluded that several performance uniqueness were carried out with uncoated carbide tools when the turning of

aluminium alloy at a feed rate of 0.05 mm/rev, lower cutting speed of 119.22 m/min, medium depth of cut of 0.15 mm considered by several performance characteristics (GRG) of 0.8084.The value of GRG is 0.7717 which overcome by the experiment [3].

Ramo n QuizaSardinas (2006) has analyzed multi-objective optimization technique, based on genetic algorithms, by turning process to achieve the cutting parameters, i.e. cutting, depth of cut, feed and speed. There are two main objectives, tool life & operation time. They have concluded that by the Pareto frontier graphics, numerous distinct situations measured, to make simple the selection of exact parameters for various states [4].

Aman Aggarwal (2008) has studied about optimization of several qualities, uniqueness the tooll ife, surface roughness, cutting force and power consumption in CNC turning. The tool material is AISI P-20. The liquid nitrogen coolant is used for operation. The main four convenient terms of the turning process have investigated. For single and multiple response optimizations the using of desirability function. They have concluded that the Plots revealed low cutting speed, feed and depth of cut was favored for receiving elevated value of desirability [5].

Anil Gupta (2011) has studied about the function of Taguchi technique by logical fuzzy reasoning to achieve the turning process at a maximum speed of CNC. The work piece standard grade AISI P-20 steel using and the tool material were Tin coated tungsten carbide coatings to achieve the maximum results. The machining parameters, i.e. nose radius, cutting speed, feed rate, depth of cut, nose radius and the cutting environment. They have completed and result found out the cutting speed 160 m/min, nose radius 0.8 mm, feed rate 0.1 mm/rev, and depth of cut 0.2 mm. The most positive state carried out the greatest appropriate cutting environments was cryogenic. [6].

E. Daniel Kirby (2006) has studied about the Taguchi parameter design system to achieving the turning process in terms of surface finish. The main control parameters were used for this procedure, i.e. tool radius, spindle speed, feed rate, and depth of cut. Including noise factor, changing room temperature and the use of insert more than one of as similar requirement, which familiarized the variability of tool dimension. They have concluded that the chosen factor values from this method developed the roughness on the surface that was extremely low comparatively another combination [7].

N. Satheesh Kumar (2012) has investigated that the consequences of process parameters to perform turning of carbon alloy steels by CNC. Spindle speed and feed rate were wide-ranging to analysis their impact the roughness on the surface. They have used five types carbon alloy steels i.e. SAE8620, EN8, EN19, EN24 and EN47. They have concluded that the less be the feed rate, more will be the surface finish [8].

M. Nalbant (2007) has studied the turning operations of the work piece of AISI 1030. For this purpose he used Tin coated tools. The optimization of insert radius, feed rate and depth of cut has been calculated. They have concluded that the confirmation experiments were performed to verify the best possible cutting parameters [9].

Salman Nisar (2015) has studied about the use of machining parameters by several cutting tools. This is essential to diminish the force of cutting and temperature during machining AISI 1045 steel. They have concluded that the possible p value for depth of cut is zero and cutting forces has been considered as one of the most important cutting factor. [10].

SupriyaSahu (2015) has studied about the multi-layer performance of Tin coated tool in the machining of AISI 4340 steel, which has also been compared with that of uncoated tool. The effect of cutting parameters (speed, feed, and depth of cut) on roughness of surface has been analyzed using the Taguchi methodology. [11].

IlhanAsilturk (2011) has studied about the optimizing the turning parameters by using Taguchi method to diminish roughness of surface. The cutting speed, feed rate and depth of cut have been examined by signal to noise ratio and ANOVA. L9 orthogonal array is used in the CNC turning machine. [12].

CarmitaCamposeco-Negrete (2013) has studied about that the optimum cutting parameters by using AISI 6061 T6 to obtain minimum energy consumption. The feed rate, cutting speed and depth of cut has been analyzed by using ANOVA. [13].

LaxmanAbhang (2015) has studied about the optimization of numerous characteristics(Surface roughness and tool wear) in turning of EN-31 steel by using tungsten carbide inserts. Five factors were analyzed, i.e. cutting velocity, feed rate, depth of cut, tool nose radius and different concentrations of solid-liquid lubricants. They concluded that the Response surfacemethod found successful technique to execute the tendency investigation of the tool wear rate and surface roughness with respect to a variety of combinations of design variables This analysis shows that tool wear is primarily affected by cutting speed, feed rate, tool nose radius and concentration of lubricants, where as depth of cut have inappropriate result. The substantial improvement of 0.304899 on the whole desirability of the multi-response characteristics [14].

M.Z.A.Yazid (2012) has studied about the cutting parameters on Inconel 718. The work wasc arried out in three different cutting conditions (dry, MQL 50ml/h and MQL 100ml/h) by using turning with the PVD coated carbide tool. The microstructure analysis was conducted by using SEM. [15].

OguzColak (2014) has studied the consequences of High pressure jet assisted coolant on the integrity of surface in the machining of Inconel 718 aerospace super alloys. Designed experiments were performed under conventional (0.6 MPa) and High pressure jet assisted cooling (15 MPa and 30 MPa) conditions by (TiAl) N+TiN coated carbide cutting tool. L9 (3^4)Taguchi experimental techniques were used, in analyzing the machined surface and subsurface. Surface roughness measuring appliance (X-ray diffraction (XRD)) method was used to resolve residual stresses [16].

Henrik Jager (2016) has studied about the residues on the face of the insert and residual stress on the work piece surface produced by regular and modified cutting inserts. The residual elemental examination was directed on usual as well as improved inserts in group's coolant the application of forced coolant on both rake and flank face by using energy dispersive X-rays spectrometer and EDS. They concluded that calcium rich zone just below the flank wear zone one very one inserts. The surface roughness for the Gen II insert was minor compared to the reference insert at higher cutting conditions. Residual stress study exhibited difficulties measuring with X-ray diffraction due to the microstructure and grain size of the machined Alloy718 material [17].

Nageswaran Tamil Alagan (2016) has used Inconel 718 for analyzing cutting inserts with the forced coolant application. For this purpose Using he used Nusselt-Channel insert which enhances tool life [18].

C. Courbon (2009) has used Inconel 718 for analyzing the influence of high pressure jet assistance. For this purpose he used tool material pair. They concluded that HPJA can alternatively provide removal of better chip formation. [19].

A. Devillez (2011) has used Inconel 718 for the analyzing the influence of the integrity of the surface. For this purpose he used dry and wet conditions at different cutting speed by using coated carbide tool. They have concluded that the cutting force levels were quite similar in wet and dry conditions. With the increase in cutting speed the peak tensile stress reduces [20].

E.O. Ezugwu (2004) has used the triple PVD coated (TiCN/Al2O3/TiN) carbide tool for speeding up the various coolant pressure. For this purpose he recorded surface roughness, tool lie and tool wears. He concluded that with increase coolant pressure tool life improves [21].

Y. Kamata (2007) has applied minimal quantity lubrication for turning finish. For this purpose he used three different types of Inconel 718.cutting speeds were located at comparatively elevated values [22].

Toshiyuki Obikawa (2014) has used Inconel 718 in the reinforced alumina tool he concluded that when we use Inconel 718 then the life of tool extended compared to any ordinary machine [23].

FranciPusavec (2014) has studied about Inconel 718 for high performance machines. For this purpose he used response surface methodology. They concluded that Cryo lubrication produces the lowest cutting force and it improves sustainability [24].

P. Marimuthu (2014) has used Inconel 625 for turning to minimize the roughness of the surface. For this purpose, we used a TiAlN coated cutting tool and they concluded that feed and cutting speed as valuable cutting parameters and it affects the MRR and TW [25].

K. Venkatesan (2014) has used Inconel 625 for analyzing the effect of cutting parameters. Fort his purpose turning experiments were carried out for measuring cutting speed, feed rate and depth of cut. He concluded that these parameters play a vital role on the surface of the workpiece. Each parameter paid maximum contribution to better machining performance. [26].

2.2 Research gap

The Literature survey revealed the machining of nickel base alloys and different Inconel Grades the machining already has done. But we found that there are still plenty of work left on Inconel 625. Given this, we selected the machining on Inconel 625 to attain a high surface finish and MRR. We will optimize the process parameters and their effects.

2.3 Rationale and scope of the Study

According to the literature survey, it has been observed that the most of machining work has been done in different steel grades and Inconel 718, But the very less work done on Inconel 625. Inconel 625 is complicated to perform machining because of its high strength. Machining of super alloys is challenging deed. Researchers aim to investigate machining characteristics of Inconel 625.

Following is the scope of proposed work which mentioned below.

- High surface finish enhances the quality of the products. Every industry seeks to high productivity in order to minimize the According machining time.
- Widely used of Inconel 625 in Pollution control equipments, jet engine parts, heat exchangers, pressure valves, and steam piping lines.
- It may also be useful to produce corrosion resistive equipments.

2.4 Objective of the study

The under mentioned objective of the study.

1. The selection of the most excellent combination between the tool and work piece at the distinct substitute of tool and work piece designed for turning procedure. The selecting tool material is comparatively harder than the work piece material.

2. To evaluate the association the value of surface Roughness and MRR.

3. To study the effect of the three process parameters in a turning operation, namely spindle speed, feed rate and depth of cut and investigate the response variables like surface finish and MRR.

4. To study the different cutting conditions, i.e. (dry and wet) to evaluate their consequences on surface finish and MRR.

Chapter 3

Materials and Research methodology

3.1Equipments

The Turning Trials were conducted on a computer numerically controlled (CNC) machine Emco PC Turn 345 II employs a spindle with maximum speed of 6300 rev/min. The surface roughness was measured by the RT-10 (code 1.101) surface roughness Tester.

3.2Materials

3.2.1Work piece material

The work piece material was used for the investigation is Inconel 625. The Turning operation was conducted using 23 mm diameter × 100 mm long solid round bar which is shown in figure no.The Chemical composition of the work piece is shown Table no.1

Ni	Cr	Mo	Nb	Fe	Si	Al	Ti	Mn	C
60.522	22.890	9.275	3.326	2.774	0.225	0.143	0.227	0.126	0.015

Table 1 Chemical composition of Inconel 625

Figure 3 Inconel 625 Solid round bar

3.2.2Tool material

The selection of the cutting tool on the basis of their properties and its attributes. It plays a very significant role to perform the operation. Inconel 625 has hardest material properties so not easy to perform machining. Given this problem, turning operation performed by (CNMG- 120408) PVD coated TiAlN carbide cutting tools. It has high hardness, wear resistance, anti seizure with excellent mechanical, chemical, and thermal properties. Tool geometry and several important specifications are shown in figure no. 4and tableno. respectively.

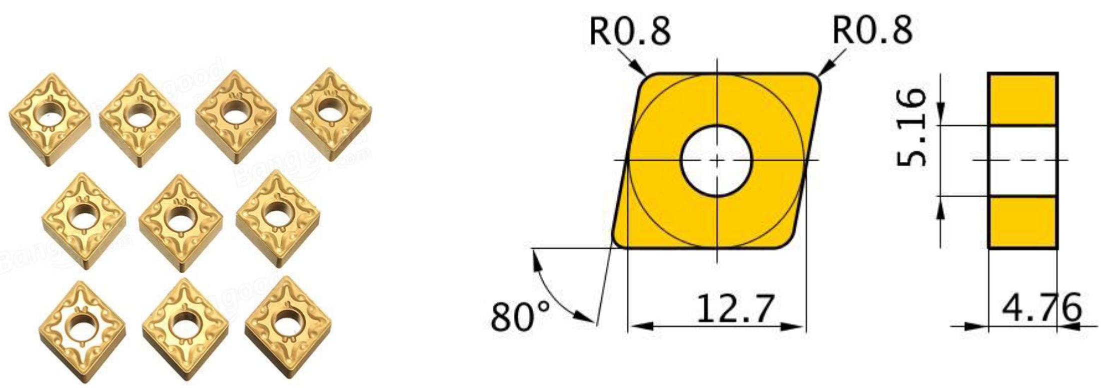
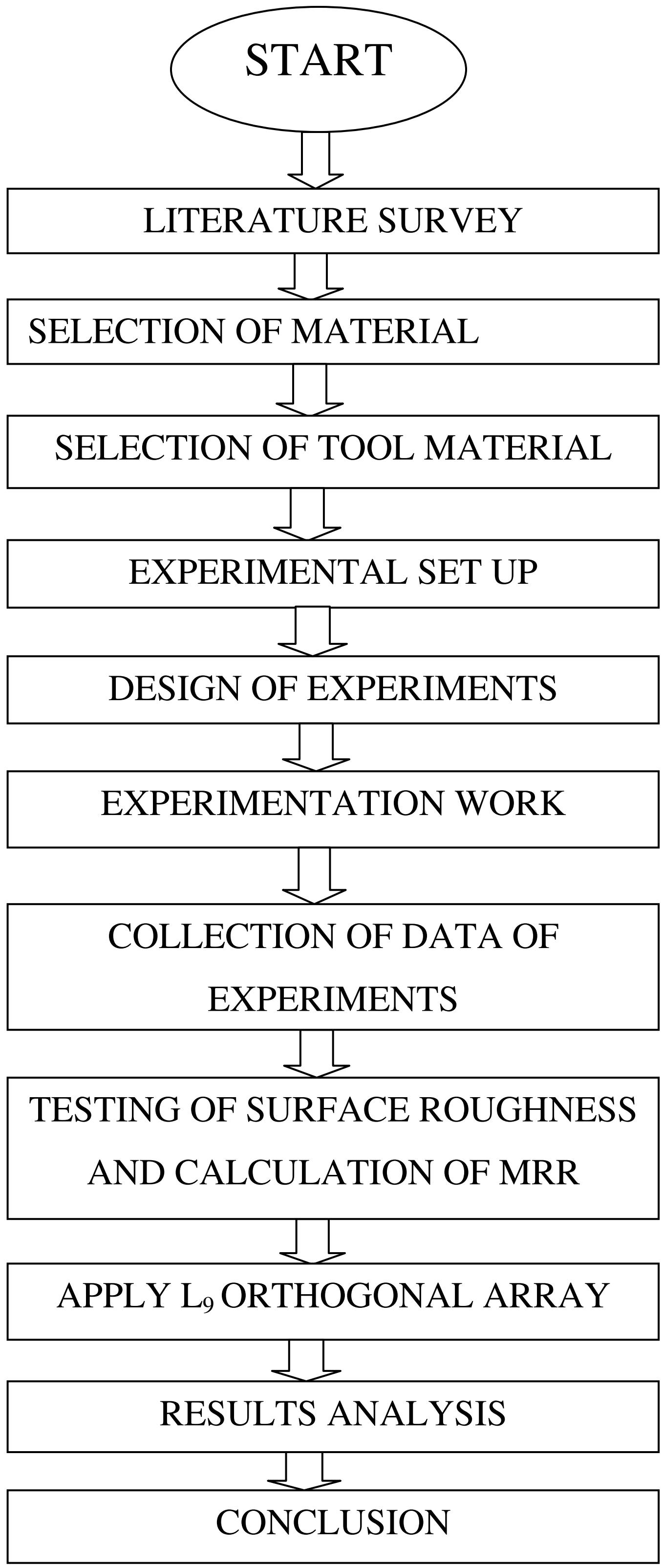


Figure 4 Tool geometry

Tool specifications	
Inscribed Circle	12.7 mm
Cutting edge length	12.9 mm
Shape	80◦ Rhombic
Insert size	120408
ISO category grade	M N S
Rake	Negative
Thickness	4.76
Material	Carbide
ISO designation	CNMG 120408 QM
Insert style	CNMG
Finish / Coating	TiAlN/TiN
Material application	Alloy, Nonferrous metal, Steel
Clearance angle	0◦
Corner radius	0.8
Cutting direction	Neutral

Table 2 Specification of tool material

3.3 Research methodology



- **Literature survey**

  Literature survey is most essential part of our report; it provides the suggestion of the field of research. It assisted the set the intention for the analysis of the problem statements.

- **Selection of material**

  The selection of materials depends upon the basis of their performance, quality and life of the final products. Therefore, Inconel 625 has been selected for the present work. The material for the present work has the dimensions (23*100) mm.

- **Selection of tool**

  The tool material selected on the basis of their mechanical properties and thermal stability. Seeing this problem, decided to select the PVD coated TiAlN carbide cutting tools. It has high hardness, wear resistance, and sustain high temperatures without deformation.

- **Experimental setup**

  The experimental work has been performed on a Computer numeric control machine. We selected the optimum cutting parameters. The three major cutting parameters is preferred for the current examine is the cutting speed, feed and depth of cut. L_9orthogonal array is employed for the find out the exact value. It is most appropriate for this experiment. The whole experimental work is carried out with three different conditions, i.e. dry and wet. Surface Roughness is measured by with the help of surface roughness tester.

- **Design of experiments based on Taguchi Design**

  Design of experiments comprises to clarify to the input factors their levels, response variables, selection of the wok pieces, tools, the overall experimental setup and methodology are used to examine the experimental data. The process parameters have been evaluated by the design of experiments. The L9 orthogonal array is employed to find out the parameter space to minimize the number of experiments. The level of parameter is elected in order to cover a suitable ample range of achievable conditions. The Wet and Dry cutting conditions have been employed for each trial to optimize the optimum value in terms of surface Roughness and MRR. Orthogonal array provides the minimum number of experiments which are different at each level. The three controlled factors cutting speed, feed rate, Depth of cut, which are varied for three levels each to effectively cover up the whole range accessible by machine tool, has been calculated. Table no. 3 represents the steps in the Taguchi optimization process parameters.

Parameter, Symbol	**Units**	**Levels**		
		1	**2**	**3**
Cutting speed	m/min	40	60	80
Feed rate	mm/rev	0.1	0.1	0.2
Depth of cut	Mm	0.2	0.2	0.3

Table 3 Taguchi Optimization process parameters

- **Experimentation work**

  The aim of this study is carried out the consequence of several cutting conditions on surface finish and MRR. All the Inconel 625 bar turning test is performed on CNC with PVD coated TiAlN carbide cutting tool.Cutting conditions is varying at different stages, and then we optimized the effective parameters which have been optimizedall the turnings steps. We will estimate the optimum outcomes and consider them as the best result.

- **Collection of data of experiments**

  The effect of surface finish and MRR are calculated by arranging all the samples and estimated their output values. All the output value arranges and applies the L_9 orthogonal array to find out the optimum result. The Best suited condition is carried out which provided the optimum solution in order to achieve a high surface finish and MRR. Table no. 4 shown the experimental design is based on Taguchi L_9 orthogonal array.

Trials No.	Process parameters and its Level			
	Vc (m/min)	f (mm/rev)	d (mm)	Cutting conditions
1	80	0.1	0.2	Wet
2	60	0.1	0.2	Wet
3	40	0.1	0.2	Wet
4	80	0.1	0.2	Dry
5	60	0.1	0.2	Dry
6	40	0.1	0.2	Dry
7	80	0.2	0.3	Wet
8	60	0.2	0.3	Dry
9	40	0.2	0.3	Wet

Table 4 Design of Experiments

- **L_9 Orthogonal Array**

  The several standard orthogonal arrays, existing, each one of the arrays is intended for a specific number of independent design variables and levels. If one needs to perform an experiment to recognize the effect of four distinct, independent variables with each variable having three set values (level values), then an L_9 orthogonal array is exact option. The L_9 orthogonal array is intended for considerate the effect of four independent factors, each having three factor level values.

L_9 Orthogonal array					
Trials No.	**Independent variables**				**Performance parameters value**
	Variable 1	**Variable 2**	**Variable 3**	**Variable 4**	
1	1	1	1	1	R1
2	1	2	2	2	R2
3	1	3	3	3	R3
4	2	1	2	3	R4
5	2	2	3	1	R5
6	2	3	1	2	R6
7	3	1	3	2	R7
8	3	2	1	3	R8
9	3	3	2	1	R9

Table 5 L_9 Orthogonal array

The table no. 5 is Showing an L_9 orthogonal array. The total nine experiments to be conducted and every trial is based on the combination of level values as revealed in the table. For example, the third experiment is performed by observance the independent design variable 1 at level 1, variable 2 at level 3, variable 3 at level 3, and variable 4 at level 3.

Chapter 4

Results and Discussion

4.1 Experimental Setup

The Wet and Dry Turning was carried out at medium speed of spindle speed. The experiment conducted based on the orthogonal array experimental design and take the suitable parameters at each level of Trials. The experiment performed with coolant (WET) and without coolant (DRY). The surface roughness was measured by the RT-10 (code 1.101) surface roughness Tester. The ability to measure the specimen is range up to ±200µm. The surface roughness value was recorded on the work piece surface. Ra value was used for the analysis. The experimental set-up for turning and surface tester is shown in figure 5& 56respectively.

Figure 5Emco PC Turn II CNC

Figure 6 Surface roughness measurement setup

4.2 Material removal rate (MRR)

The volume of the material removed per unit time in mm3/Sec in turning operation.

MRR = (1000×v×f×d) /60

Where, v is the cutting speed (m/min), f is the feed rate (mm/min), and d is the depth of cut (mm)

The experimental work was organized based on the L9 Orthogonal array design. Taguchi method provided an influential methodology for the design optimization of turning parameters. Orthogonal array experimental design is applied to formulating the parameters.The results instated from the experimental runs executed, according to the orthogonal array design shown in Table 6. The influence of the turning parameters and its consequence on the surface roughness (Ra, Rt, Rz and Rc) and MRR on the Dry and wet machining has been analyzed. The results have been discussed in table no. 6 also. The surface roughness value recorded during the experimental work at Dry and wet condition. From the result, the lowest average surface roughness value was recorded 0.55 μm at 40m/min cutting speed with a lower feed rate and depth of cut. The cutting condition and independent variables play a major role to obtain the surface quality. Wet condition provided better results compared to dry. The surface roughness graphs of different samples at different cutting conditions are shown in following figures.

Trials No.	Process parameters and its level				Experimental results				
	Vc (m/min)	f (mm/rev)	d (mm)	Cutting conditions	Ra (µm)	Rt (µm)	Rz (µm)	Rc (µm)	MRR (mm^3/min)
1	80	0.1	0.2	Wet	0.75	5.98	5.02	2.41	2032
2	60	0.1	0.2	Wet	0.75	11.23	5.56	2.08	1152
3	40	0.1	0.2	Wet	0.55	4.35	3.2	1.38	512
4	80	0.1	0.2	Dry	1.47	6.57	6.09	4.87	2032
5	60	0.1	0.2	Dry	1.73	7.5	7.21	6.25	1152
6	40	0.1	0.2	Dry	1.59	9.86	7.99	5.02	512
7	80	0.2	0.3	Wet	3.32	15.7	13.34	10.7	6120
8	60	0.2	0.3	Dry	1.45	8.83	7.73	4.31	3438
9	40	0.2	0.3	Wet	1.78	9.63	7.71	5.89	1524

Table 6 Experimental results for Taguchi L_9 Orthogonal array

- Ra, Rt, Rz ,and Rc corresponds to sample 1 at Vc =80 m/min, f= 0.1 and d= 0.2 mm in wet condition are shown in figure 7a, 7b, 7c, 7d respectively.

Figure 7 Ra, Rt, Rz and Rc

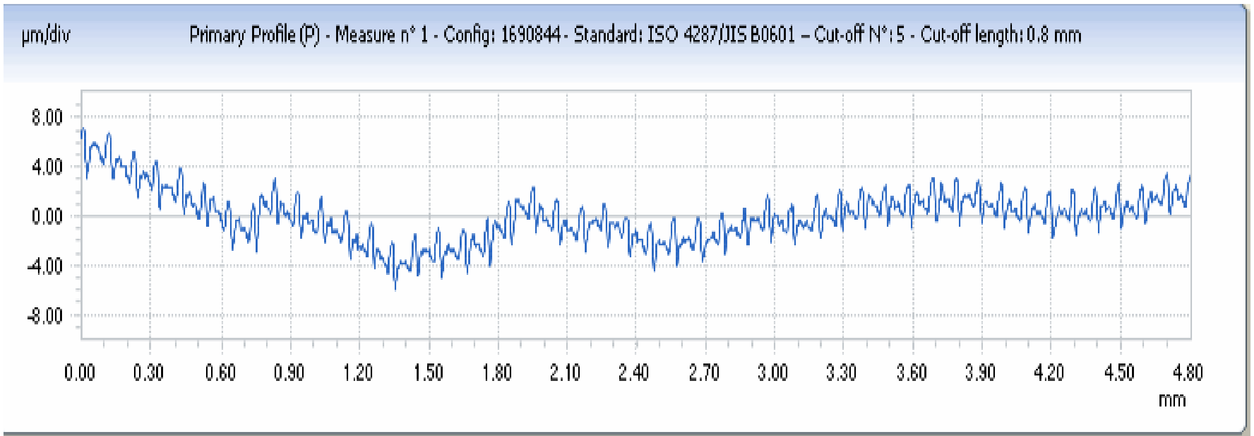


Fig.7a

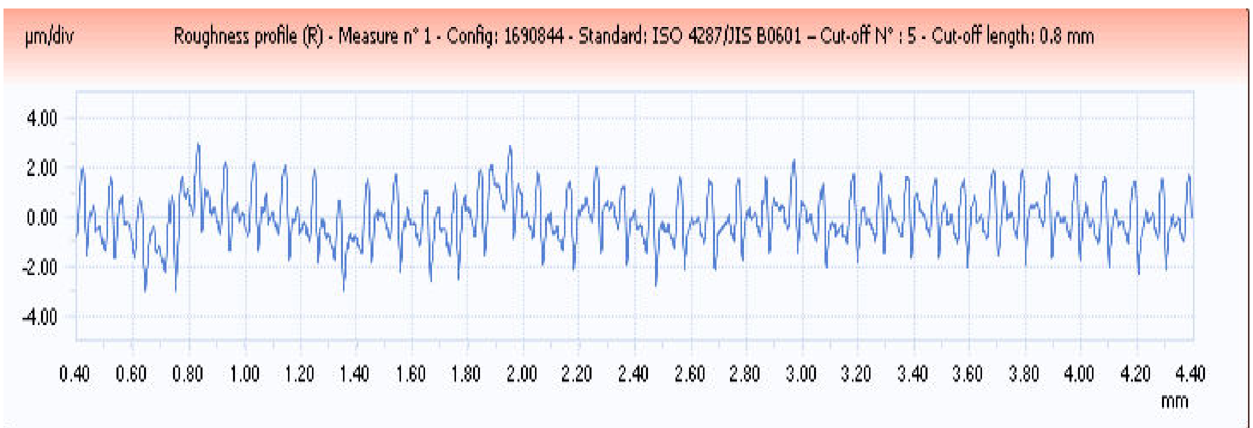


Fig.7b

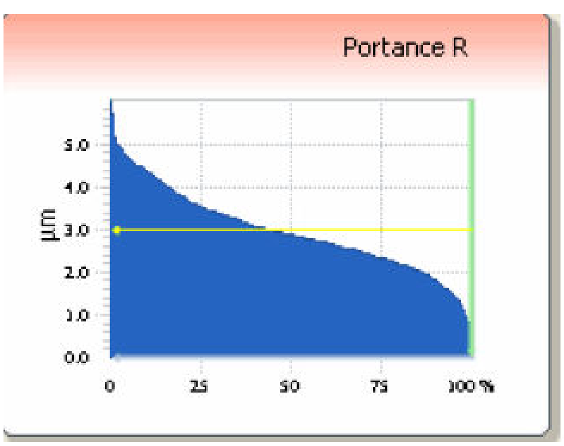


Fig. 7c

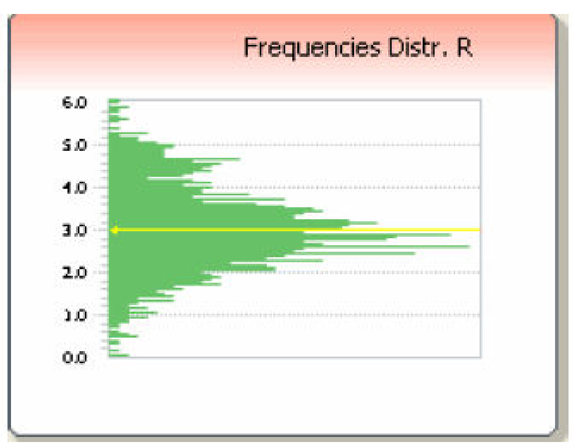


fig 7d.

- Ra, Rt, Rz ,and Rc corresponds to sample 2 at Vc =60 m/min, f= 0.1 and d= 0.2 mm in wet condition are shown in figure 8a, 8b, 8c, 8d respectively.

Figure 8 Ra, Rt, Rz and Rc

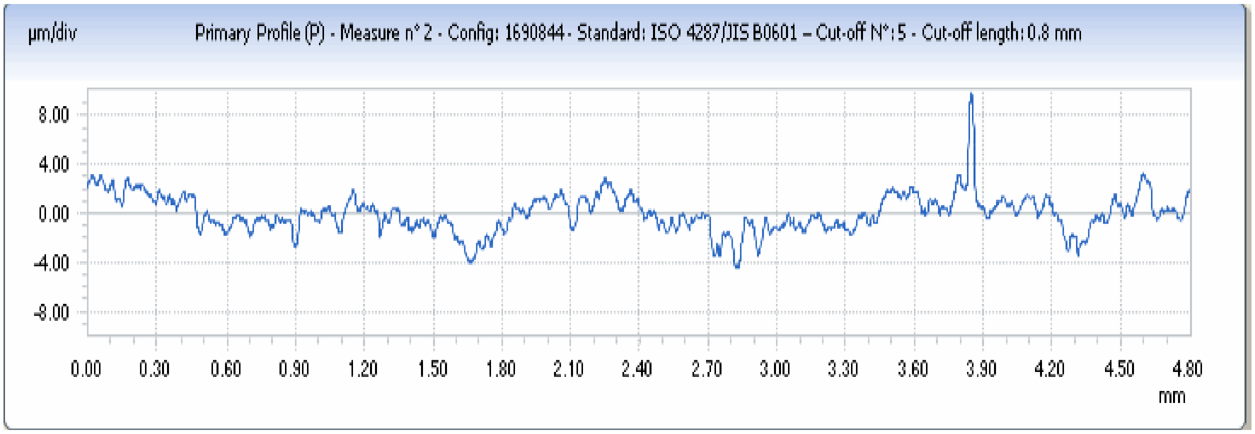


Fig. 8a

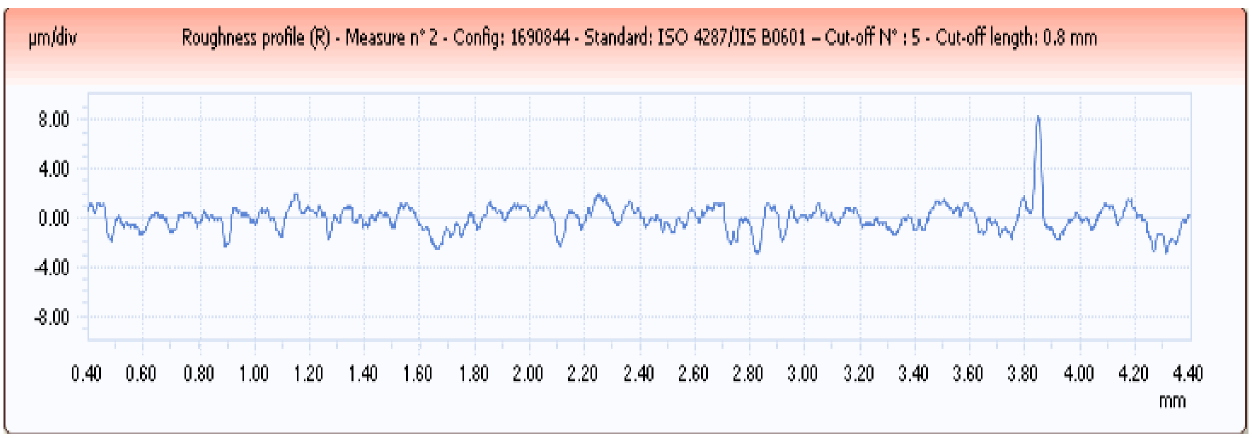


Fig. 8b

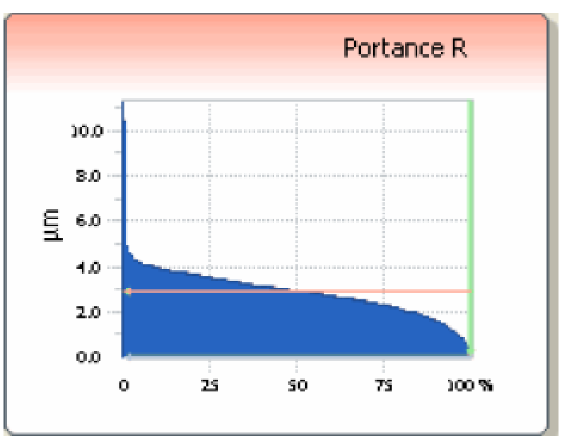


Fig. 8c

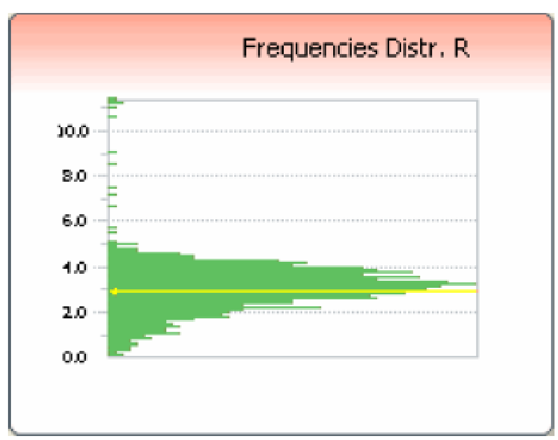


Fig. 8d

- Ra, Rt, Rz ,and Rc corresponds to sample 3 at Vc =40 m/min, f= 0.1 and d= 0.2 mm in wet condition are shown in figure 9a, 9b, 9c, 9d respectively.

Figure 9 Ra, Rt, Rz and Rc

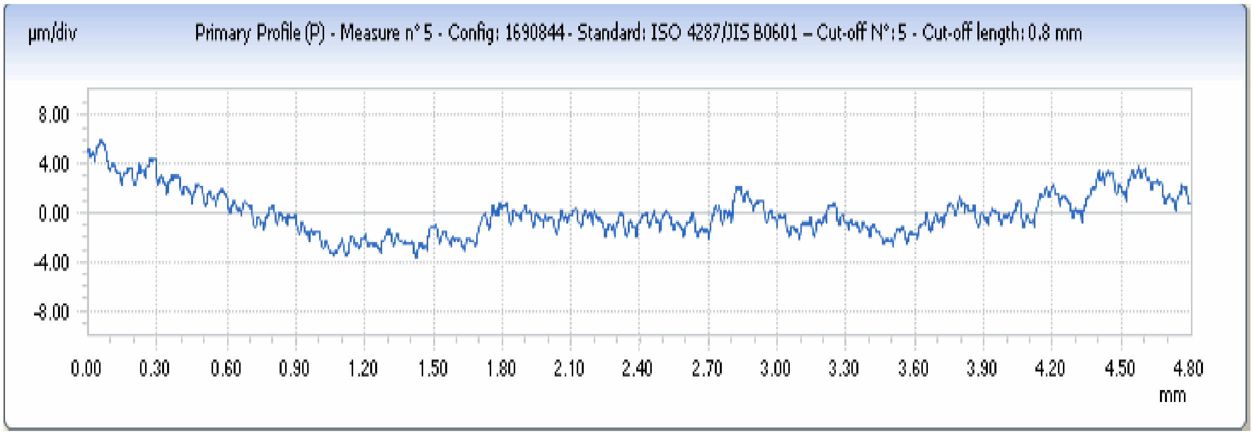


Fig. 9a

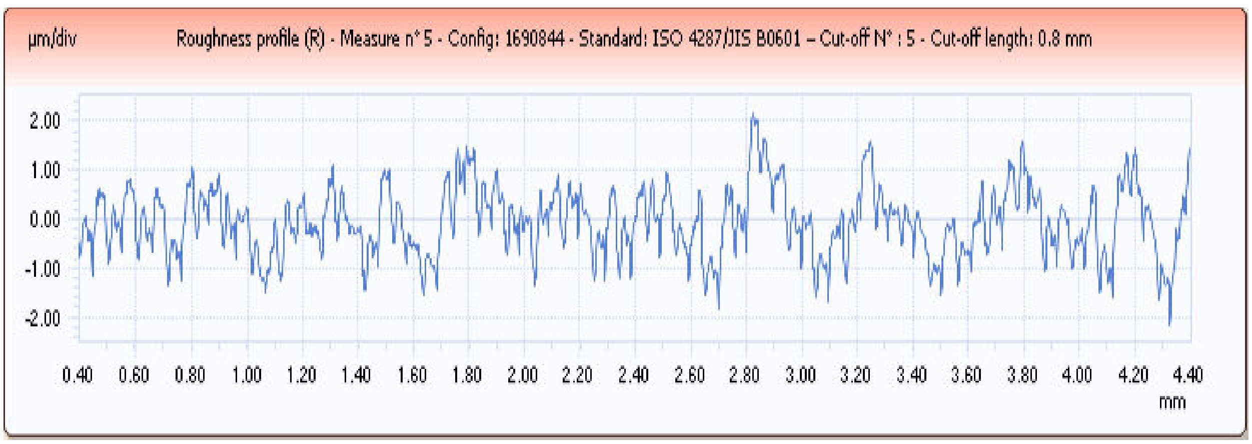


Fig. 9b

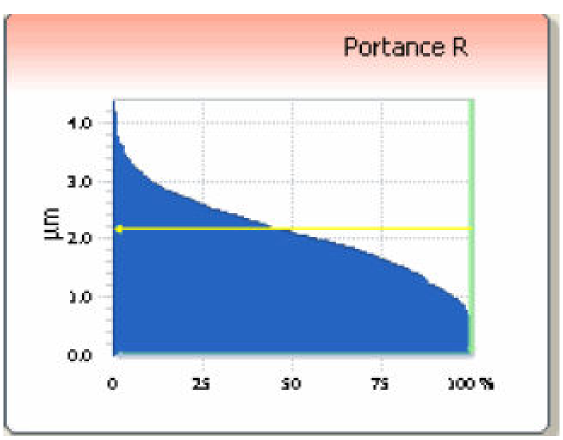


Fig. 9c

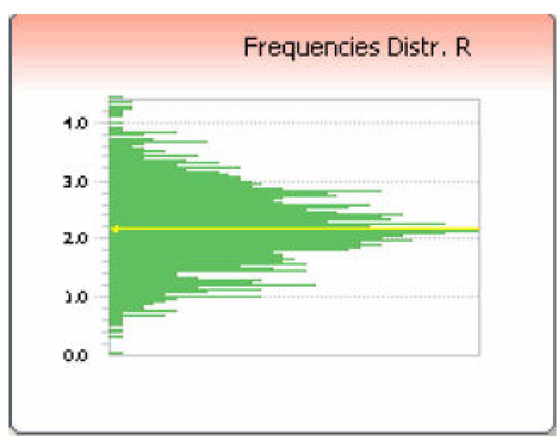


Fig. 9d

- Ra, Rt, Rz ,and Rc corresponds to sample 4 at Vc =80 m/min, f= 0.1 and d= 0.2 mm in Dry condition are shown in figure 10a, 10b, 10c, 10d respectively.

Figure 10 Ra, Rt, Rz and Rc

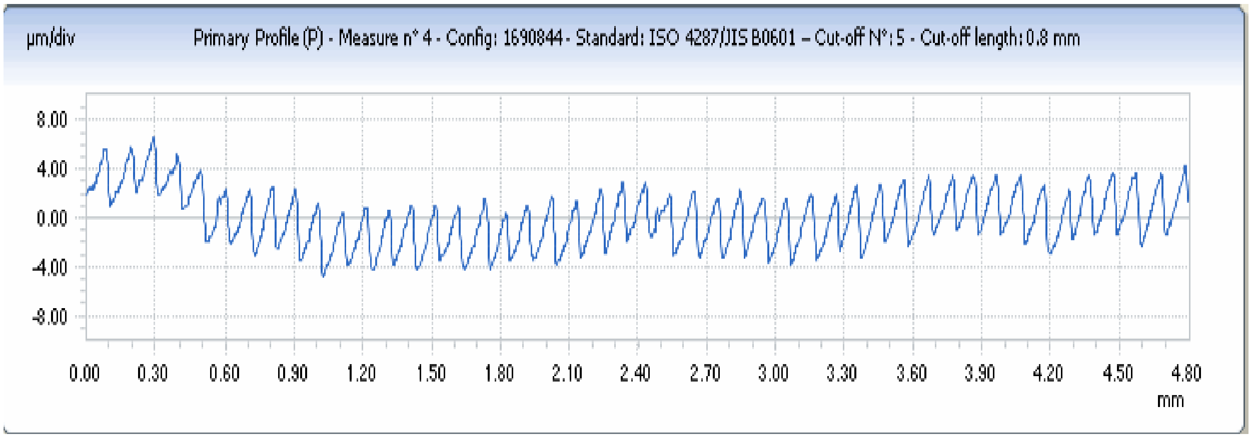


Fig. 10a

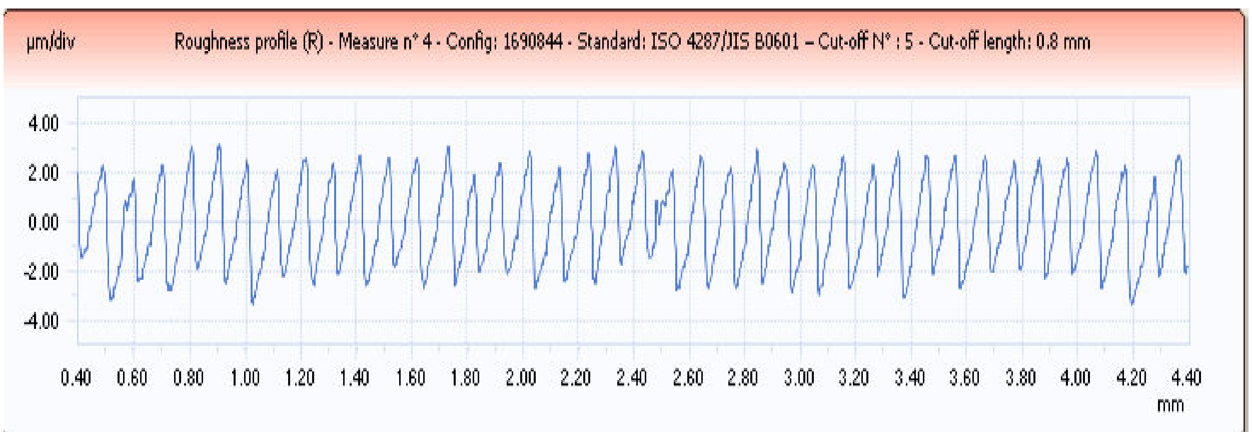


Fig. 10b

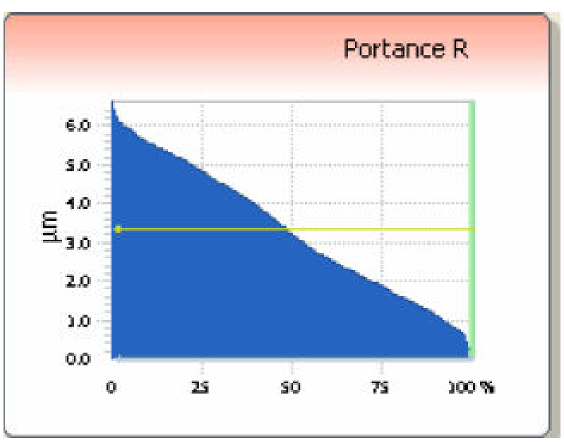


Fig. 10c

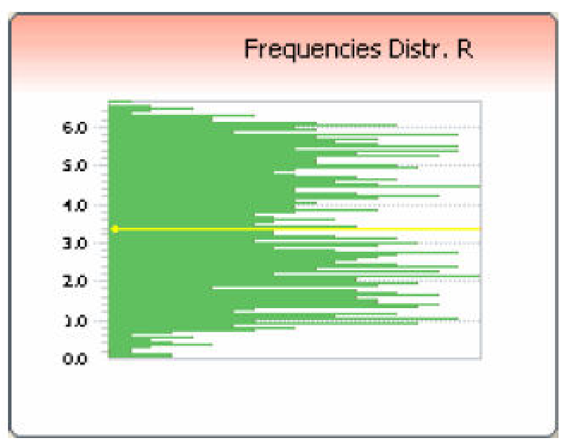


Fig. 10d

- Ra, Rt, Rz ,and Rc corresponds to sample 5 at Vc =60 m/min, f= 0.1 and d= 0.2 mm in Dry condition are shown in figure 11a, 11b, 11c, 11d respectively.

Figure 11 Ra, Rt, Rz and Rc

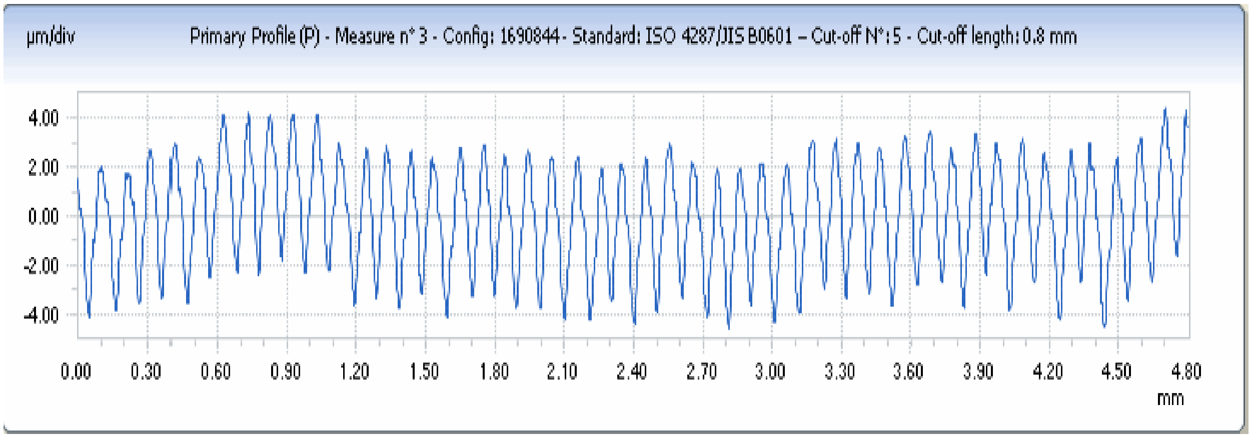


Fig. 11a

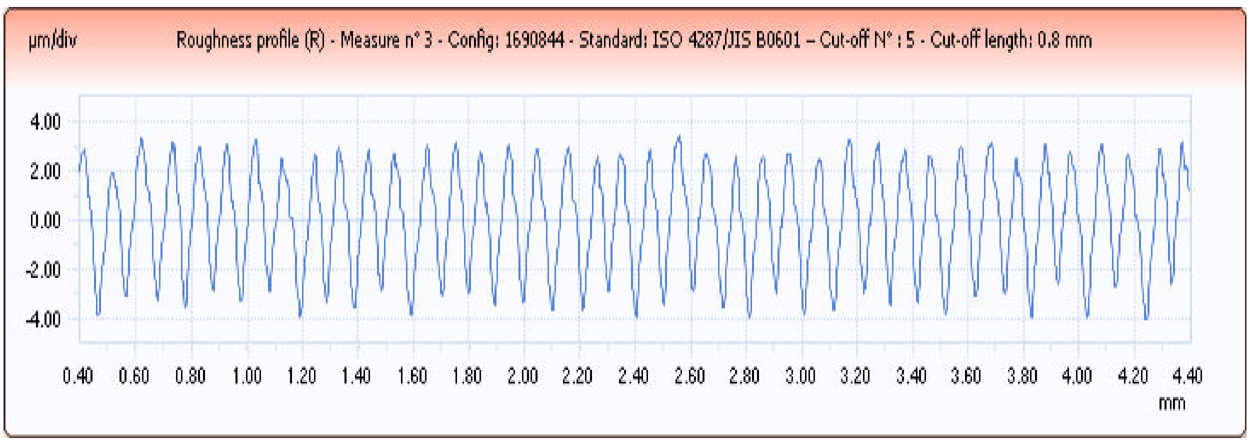


Fig. 11b

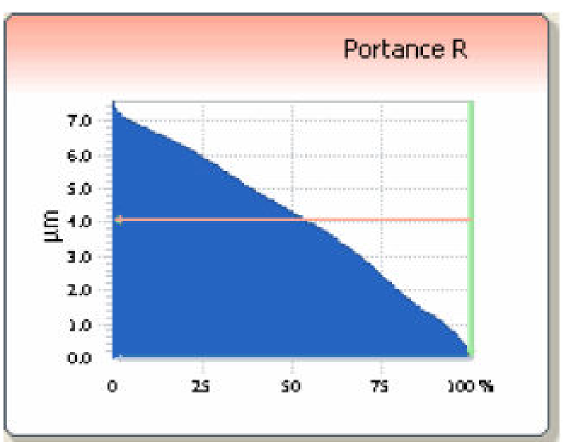


Fig. 11c

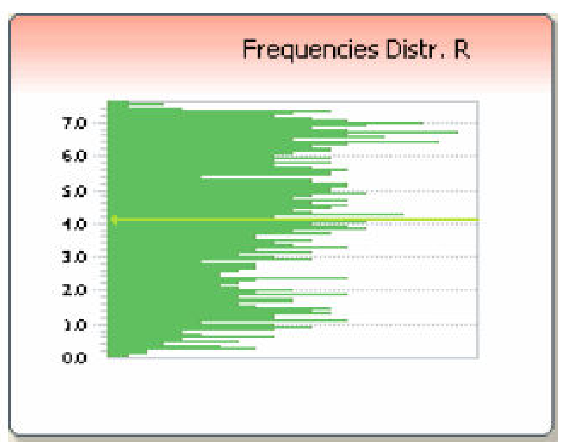


Fig. 11

- Ra, Rt, Rz ,andRc corresponds to sample 6 at Vc =40 m/min, f= 0.1 and d= 0.2 mm in Dry condition are shown in figure 12a, 12b, 12c, 12d respectively.

Figure 12 Ra, Rt, Rz and Rc

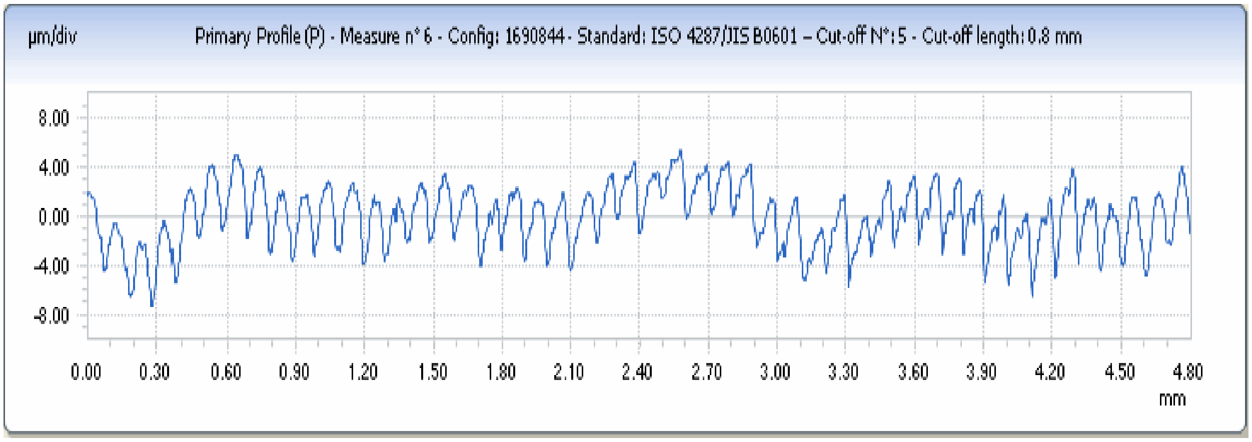


Fig. 12a

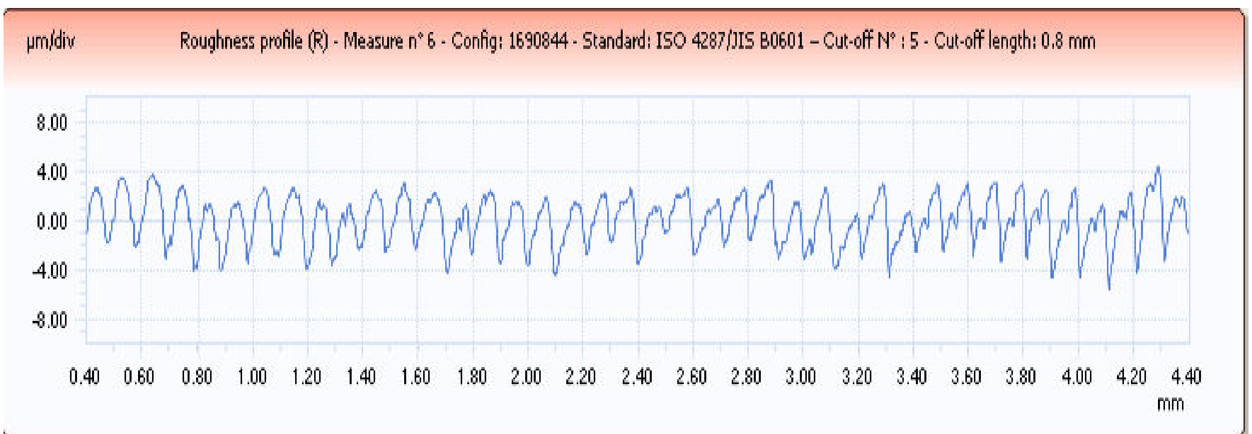


Fig. 12b

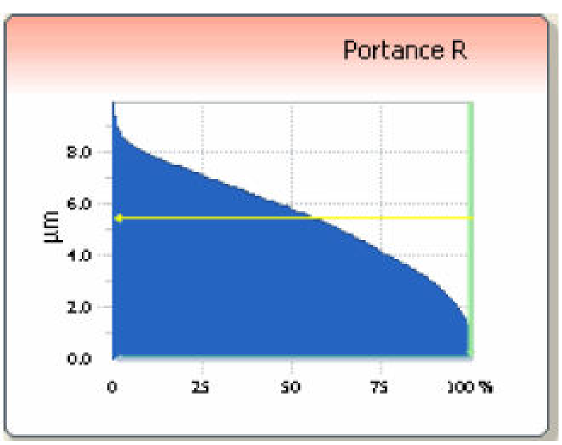


Fig. 12c

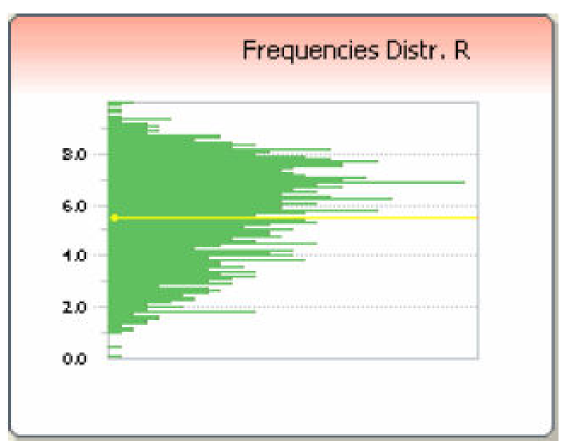


Fig. 12d

- Ra, Rt, Rz ,andRc corresponds to sample 7 at Vc =80 m/min, f= 0.2 and d= 0.23mm in wet condition are shown in figure 13a, 13b, 13c, 13d respectively.

Figure 13 Ra, Rt, Rz and Rc

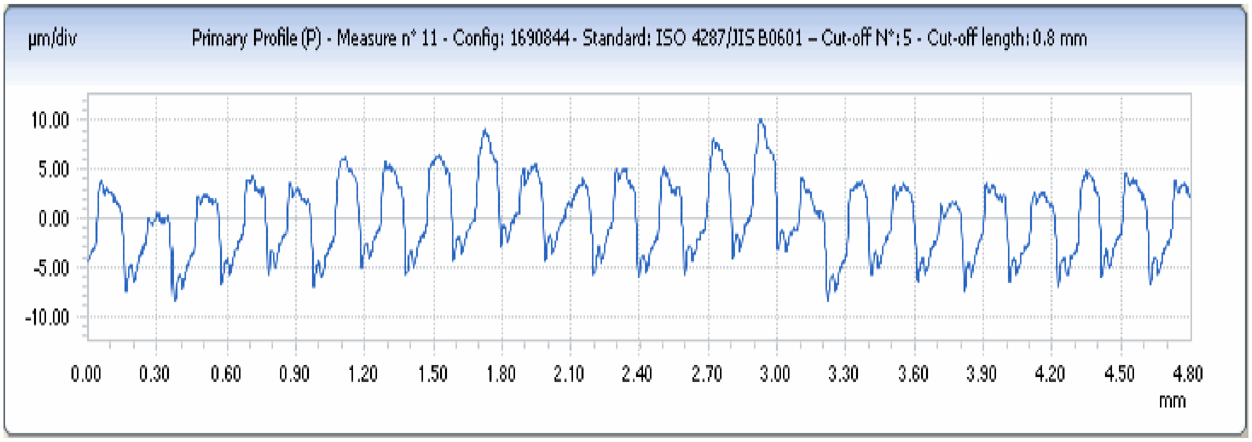


Fig. 13a

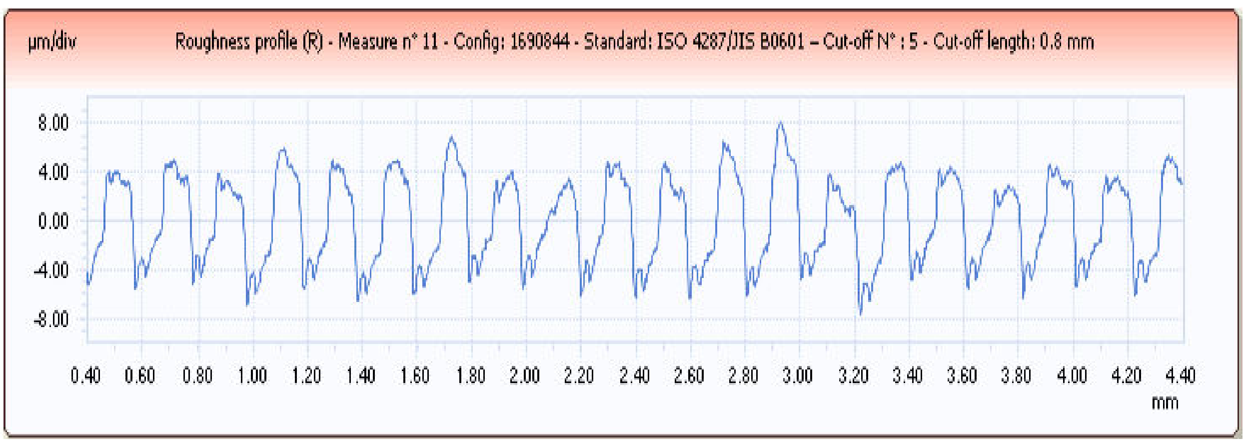


Fig. 13b

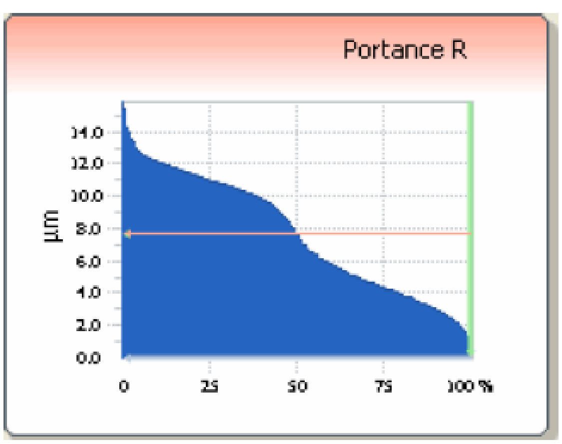


Fig. 13c

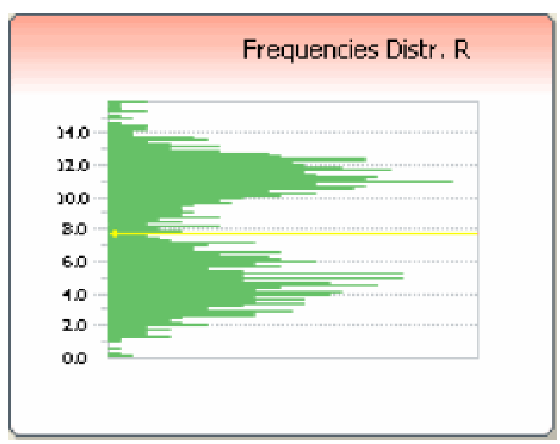


Fig. 13d

- Ra, Rt, Rz ,and Rc corresponds to sample 8 at Vc =60 m/min, f= 0.2 and d= 0.23mm in Dry condition are shown in figure 14a, 14b, 14c, 14d respectively.

Figure 14 Ra, RT, Rz and Rc

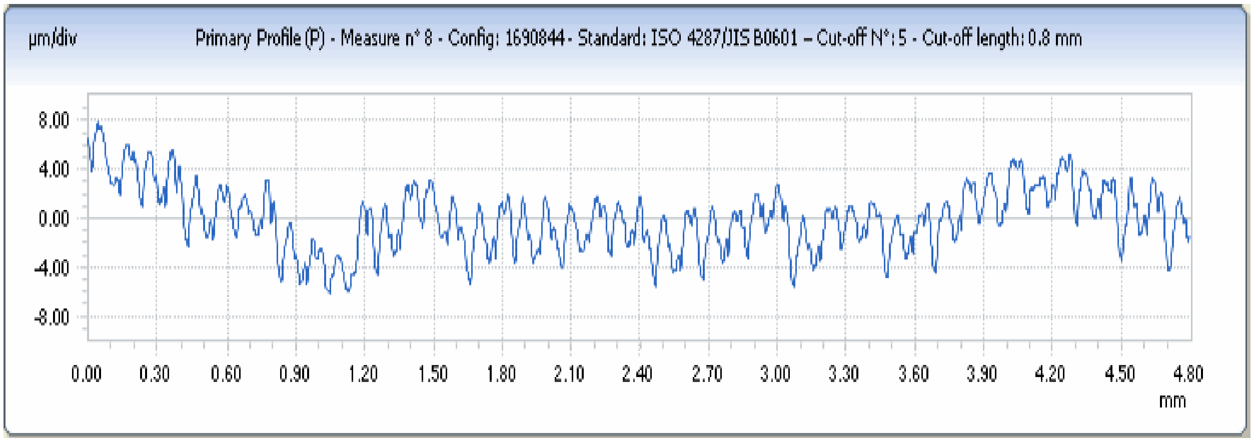


Fig. 14a

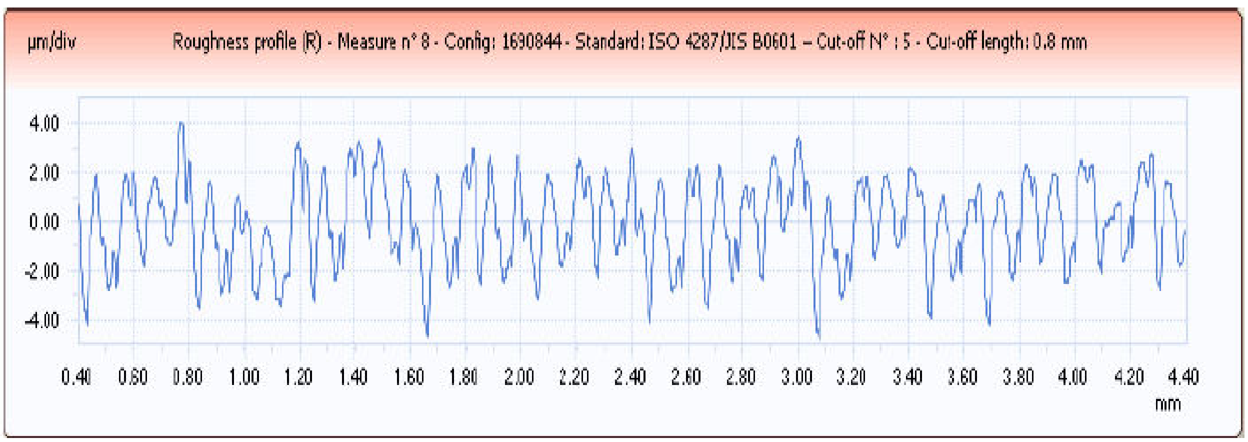


Fig. 14b

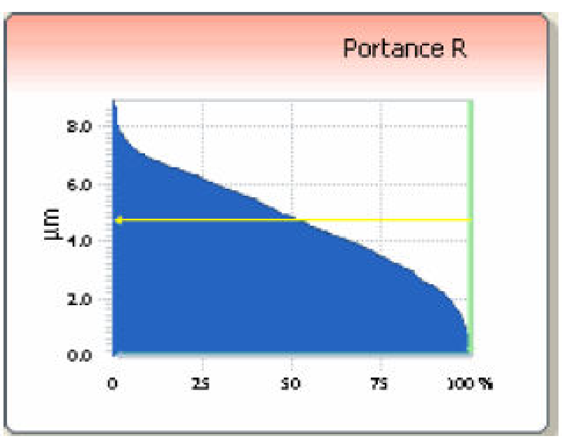


Fig. 14c

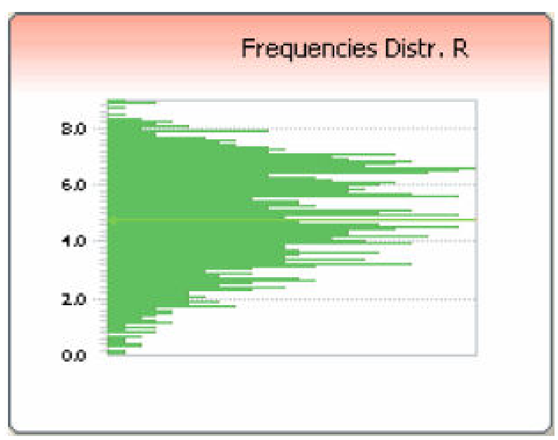


Fig. 14d

- Ra, Rt, Rz ,and Rc corresponds to sample 9 at Vc =40 m/min, f= 0.2 and d= 0.23mm in Wet condition are shown in figure 15a, 15b, 15c, 15d respectively.

Figure 15 Ra, Rt, Rz and Rc

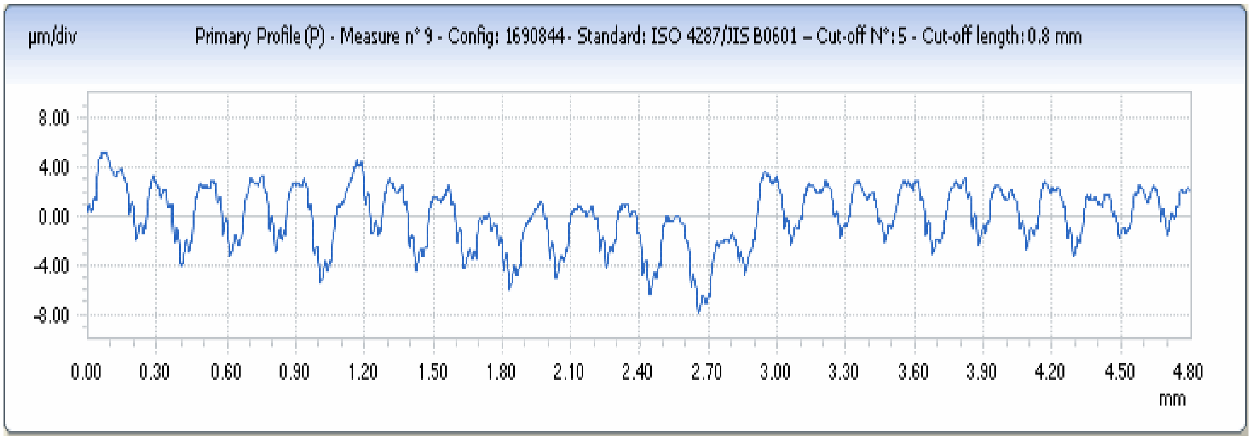


Fig. 15a

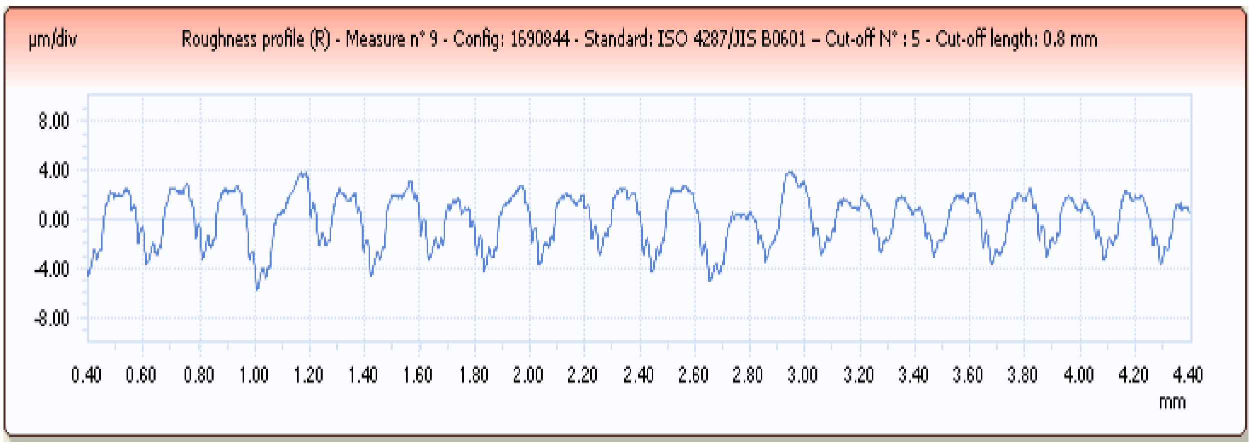


Fig.15b

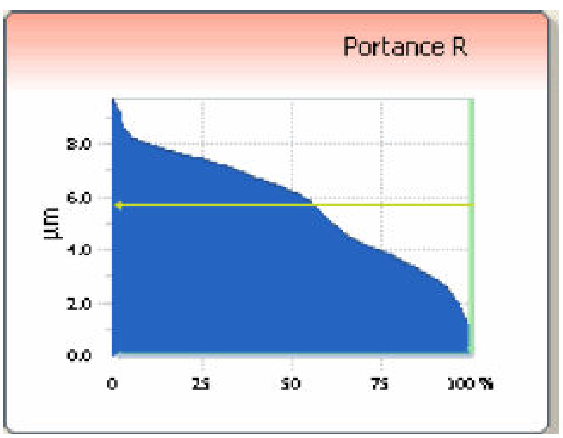


Fig. 15c

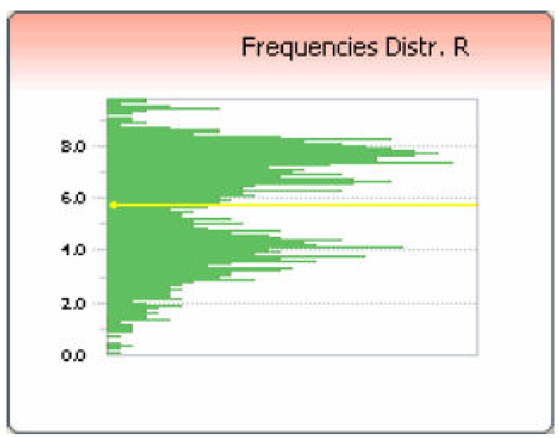


Fig. 15d

Chapter 5

Conclusion

The Taguchi L9 orthogonal array has been employed to evaluate the best possible combination of cutting speed, feed rate, depth of cut for instantaneous minimization of surface roughness and maximization of MRR. The final conclusion is mentioned below.

- The influence of cutting condition like Dry and Wet on finish turning Inconel 625 using PVD coated TiAlN
- Carbide tool display that Wet generates superior surface roughness compare with Dry condition. Better Surface roughness obtained at 40 m/min lower cutting speed compared to high cutting speed.
- Maximum MRR produces at high cutting speed (80 m/min), medium feed rate (0.2 mm/rev) and depth of cut (0.3 mm).[Refer to appendix]

Chapter 6

Future Scope

The subsequent recommendations can consider for further study.

1. In further study, dissimilar kinds tool materials and process parameters can be taken in the examination of the surface roughness and results can be analyzed by comparing different cutting conditions.

2. Additional types of tool inserts with different tool geometry can be inspected under similar process parameters.

3. A different type of work piece material and tool insert combinations can be investigated under similar process parameters.

4. Other type's optimization like; genetic algorithm, techniques can be applied for the estimation of the results.

5. More response variables like Tool life, tool wear, machining time, signal to noise ratio can be analyzed.

References

1. C. J. Raoa , Nageswara Rao, P. Sriharic, "Influence of cutting parameters on cutting force and surface finish in turning operation", *Procedia Engineering*, vol. 64, page 1405-1415, 2013.

2. Surendra Kumar Sainia, Sharad Kumar Pradhan, "Optimization of Multi-Objective Response during CNC Turning using Taguchi-Fuzzy Application", *Procedia Engineering*, vol. 97, page 141-149, 2014.

3. P. Jayaramana, L. Mahesh kumar, "Multi-response Optimization of Machining Parameters of Turning AA6063 T6 Aluminium Alloy using Grey Relational Analysis in Taguchi Method", *Procedia Engineering* , vol. 97, page 197-204, 2014.

4. Ramo n QuizaSardin , Marcelino Rivas Santana, Eleno Alfonso Brindis, "Genetic algorithm-based multi-objective optimization of cutting parameters in turning processes", *Artificial Intelligence*, vol. 31, page 127-133, 2006.

5. AmanAggarwala, Hari Singh, Pradeep Kumar, Manmohan Singh, "Optimization of multiple quality characteristics for CNC turning under cryogenic cutting environment using desirability function", *journal of materials processing technology*, Vol. 205, page 42-50, 2008.

6. Anil Gupta, Hari Singh, AmanAggarwala, Taguchi-fuzzy multi output optimization (MOO) in high speed CNC turning of AISI P-20 tool steel", *Expert Systems with Applications*, vol. 38, page 6822-6828, 2011.

7. E. Daniel Kirby, Zhe Zhang, Joseph C. Chen. Jacob Chen,"Optimizing surface finish in a turning operation using the Taguchi parameter design method", *Int J AdvManufTechnol*, vol.30, page 1021-1029, 2006.

8. N. Satheesh Kumara, Ajay Shetty, Ashay Shetty, Ananth K., Harsha Shetty, "Effect of spindle speed and feed rate on surface roughness of Carbon Steels in CNC turning", International Conference on Modeling, Optimization and Computing, *Procedia Engineering*, vol. 38, 691-697, 2012.

9. M. Nalbant, H. Gokkaya, G. Sur, "Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning", *Material and Design*, vol. 28, 1379-1385, 2007.

10. ArsalanQasim, Salman Nisar, Aqueel Shah, Muhammad Saeed Khalid, Mohammed A. Sheikh, “Optimization of process parameters for machining of AISI-1045 steel using Taguchi design and ANOVA”, *Simulation Modeling Practice and Theory*, vol. 59, page 36-51, 2015.
11. SupriyaSahu, B. B. Choudhury, “Optimization of Surface Roughness using Taguchi Methodology & Prediction of Tool Wear in Hard Turning Tools”, *Materials Today*, vol. 2, page 2615-2623, 2015.
12. IlhanAsilturk, Harun Akkus, “Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method”, *Measurement*, vol. 44, page 1697-1704, 2011.
13. CarmitaCamposeco-Negrete, “Optimization of cutting parameters for minimizing energy consumption in turning of AISI 6061 T6 using Taguchi methodology and ANOVA”, *Journal of Cleaner Production*, page 1-9, 2013.
14. LaxmanAbhang, M Hameedullah, “Simultaneous Optimization of Multiple Quality Characteristics In Turning EN-31Steel,*’’Materials today proceedings*, vol.2, page 2640-2647, 2015.
15. M.Z.A.Yazid, G.A. Ibrahim, A.Y.M. Said, C.H. CheHaron, J.A. Ghani, “ Surface integrity of Inconel 718 when finish turning with the PVD coated carbide tool under MQL”. *Procedia Engineering,* vol. 19, page 396 – 401, 2011.
16. LokmanYunlu, OguzColak, CahitKurbanoglu, “Taguchi DOE Analysis of Surface Integrity for High Pressure Jet Assisted Machining of Inconel 718”. *Procedia CIRP,* vol.13, page 333 – 338, 2014.
17. Henrik Jager, Nageswaran Tamil Alagan, Jonas Holmberg, Tomas Beno, Anders Wretland, “EDS Analysis of Flank Wear and Surface Integrity in Machining of Alloy 718 with Forced Coolant Application”, *Procedia CIRP,* vol. 45, page 271-274, 2016.
18. Nageswaran Tamil Alagan, Tomas Beno, Anders Wretland, “Investigation of modified cutting insert with forced coolant application in machining of Alloy 718”, *Procedia CIRP,* vol. 42, page 481–486, 2016.
19. C. Courbon, D.Kramar, P.Krajni, F.Pusavec, J.Rech, J.Kopac, “Investigation of machining performance in high-pressure jet assisted turning of Inconel 718: An experimental study”,*Machine tools &manufacture,vol*. 49, page 1114–1125, 2009. 20

20. A. Devillez, G. Le Coz, S. Dominiak, D. Dudzinski, “Dry machining of Inconel 718, workpiece surface integrity”, *Materials processing technology,* vol. 211, page 1590–1598, 2011.
21. E.O. Ezugwu, J. Bonney, “Effect of high-pressure coolant supply when machining nickel-base, Inconel 718, alloy with coated carbide tools”, *Materials processing technology,* vol. 153-154, page 1045-1050, 2004.
22. Y. Kamata, T. Obikawa, “High speed MQL finish-turning of Inconel 718with different coated tools”, *Materials processing technology,* vol. 192-193, page 281-286, 2007.
23. Toshiyuki Obikawa, Masashi Yamaguchi,“Suppression of notch wear of a whisker reinforced ceramic tool in air-jet-assisted high-speed machining of Inconel 718”, *Precision Engineering,* 2014.
24. FranciPusavec, Ashish Deshpande, Shu Yang, RachidM'Saoubi, JanezKopac, Oscar W. Dillon Jr., I.S. Jawahir, “Sustainable machining of high temperature Nickel alloy e Inconel 718:part 1 e predictive performance models”, *Cleaner production,* page 1-15, 2014.
25. P.Marimuthu, R.Baskaran, K.Chandrasekaran, and J.Bensamraj, “Effect of cutting parameters on super alloy in turning operation under dry condition*”, International Journal of Engineering and Technolog,* vol. 6, page 2573-2578, 2014.
26. K. Venkatesan, R. Ramanujam, VimalSaxena, NilendukarChawdhury and VikashChoudhary, “Influence of cutting parameters on dry machining of Inconel 625 alloy with coated carbide insert – A Statistical approach.”*ARPN Journal of Engineering and Applied Sciences,* vol.9, page 250-258, 2014.

APPENDIX

1. List of tables

The results are shown in tabular form.

1.1 Sample 1

Par.	Value	Tol +	Tol -
Ra	0.75 µm	129,990	0,000
Rt	5.98 µm	129,990	0,000
Rz	5.02 µm	129,990	0,000
Rc	2.41 µm	129,990	0,000

1.2 Sample 2

Par.	Value	Tol +	Tol -
Ra	0.75 µm	129,990	0,000
Rt	11.23 µm	129,990	0,000
Rz	5.56 µm	129,990	0,000
Rc	2.08 µm	129,990	0,000

1.3 Sample 3

Par.	Value	Tol +	Tol -
Ra	0.55 µm	129,990	0,000
Rt	4.35 µm	129,990	0,000
Rz	3.2 µm	129,990	0,000
Rc	1.38 µm	129,990	0,000

1.4 Sample 4

Par.	Value	Tol +	Tol -
Ra	1.47 µm	129,990	0,000
Rt	6.57 µm	129,990	0,000
Rz	6.09 µm	129,990	0,000
Rc	4.87 µm	129,990	0,000

1.5 Sample 5

Par.	Value	Tol +	Tol -
Ra	1.73 µm	129,990	0,000
Rt	7.5 µm	129,990	0,000
Rz	7.21 µm	129,990	0,000
Rc	6.25 µm	129,990	0,000

1.6 Sample 6

Par.	Value	Tol +	Tol -
Ra	1.59 µm	129,990	0,000
Rt	9.86 µm	129,990	0,000
Rz	7.99 µm	129,990	0,000
Rc	5.02 µm	129,990	0,000

1.7 Sample 7

Par.	Value	Tol +	Tol -
Ra	3.32 µm	129,990	0,000
Rt	15.7 µm	129,990	0,000
Rz	13.34 µm	129,990	0,000
Rc	10.7 µm	129,990	0,000

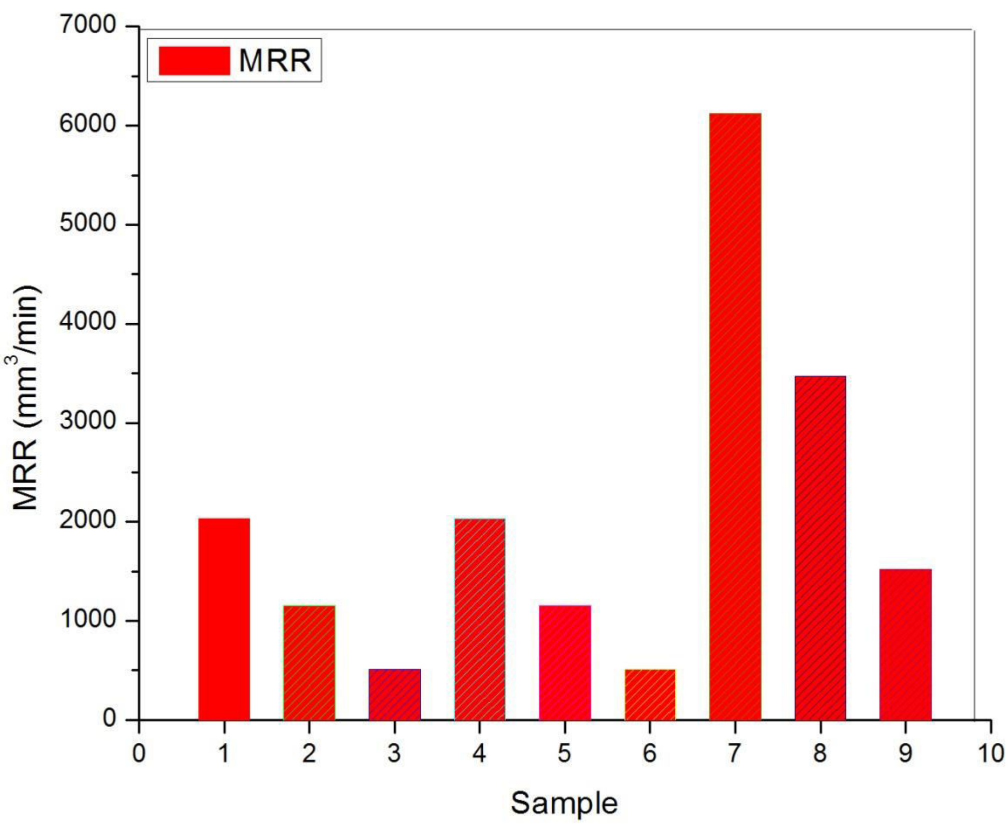
1.8 Sample 8

Par.	Value	Tol +	Tol -
Ra	1.45 µm	129,990	0,000
Rt	8.83 µm	129,990	0,000
Rz	7.73 µm	129,990	0,000
Rc	4.31 µm	129,990	0,000

1.9 Sample 9

Par.	Value	Tol +	Tol -
Ra	1.78 µm	129,990	0,000
Rt	9.63 µm	129,990	0,000
Rz	7.71 µm	129,990	0,000
Rc	5.89 µm	129,990	0,000

2. The MRR of different samples are shown through following bar diagram.



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