OPTIMIZATION OF CUTTING PARAMETERS FOR TITANIUM ALLOY ON TURNMILL UNDER DRY CONDITIONS

A Project Report Submitted In Partial Fulfilment Of Requirement For The Report Of Degree Of

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

M.VARUN APESH (318126520096)

B. KARTHEEK (319126520L21)

CH. PARDHA SARADHI (318126520074)

A. SUBHAM RAO (318126520060)

A. RAGHAV (318126520110)

Under the esteemed guidance of

Mr. R.D.V PRASAD M.Tech,(Ph.D)

ASSISTANT PROFESSOR

DEPARTMENT OF MECHANICAL ENGINEERING

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES

(Permanently Affiliated to Andhra University, AICTE, Accredited by NBA NAAC)

SANGIVALSA, VISAKHAPATNAM (District)- A.P, INDIA 531162

2018-2022

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES

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Sangivalasa, Bheemunipatnam Mandal Visakhapatnam (District) – A.P, INDIA 531162

PRAGNANAM BRAHMA
ANITS

CERTIFICATE

This is to certify that the Project Report entitled "**OPTIMIZATION OF CUTTING PARAMETERS FOR TITANIUM ALLOY ON TURNMILL UNDER DRY CONDITIONS**" being submitted by **M. VARUN APESH (318126520096), B. KARTHEEK (319126520L21), CH. PARDHA SARADHI (318126520074), A. SUBHAM RAO (318126520060), A. RAGHAV (318126520110)**. In partially fulfilment for the award of Degree of Bachelor of Technology in Mechanical Engineering. It is the work of bonafide, carried out under the guidance and supervision of **Mr. R.D.V PRASAD** Assistant Professor Department of Mechanical Engineering during the academic year 2018 to 2022.

PROJECT GUIDE	HEAD OF THE DEPARTMENT
(Mr. R.D.V.PRASAD)	(Dr. B. NAGA RAJU)
Assistant Professor	Head of the Department
Mechanical Department	Mechanical Department
ANITS, Visakhapatnam	ANITS, Visakhapatnam

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa 531 162 VISAKHAPATNAM Dist A P

THIS PROJECT WORK IS APPROVED BY THE FOLLOWING BOARDOF EXAMINERS

INTERNAL EXAMINER:

27.5.22

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa-531 162 VISAKHAPATNAM Dist A.P

EXTERNAL EXAMINER:

27/5/22

ACKNOWLEDGMENT

We express our gratitude to our guide **Mr. R. D. V PRASAD**, Assistant Professor, Mechanical Engineering Department, Anil Neerukonda Institute of Technology and Sciences, for his inspiration, guidance and plentiful support in bringing out this project. In spite of his busy schedule, he shared his valuable time for fruitful discussion and guidance.

We respectfully acknowledge our gratitude to **Prof. T.V. Hanumantha Rao** (PRINCIPAL), **Dr. B. Nagaraju** (Head of the Department) Anil Neerukonda Institute of Technology and Sciences for his dynamic counselling, encouragement, perennial approachability and for extending his help for completion of the project.

We sincerely thank **Dr. K. Arun Vikram,** G.I.T, GITAM for his guidance and plentiful support in bringing out this project.

Finally, we sincerely thank all the staff members of the department for giving us their heart full support in all stages of this project.

Last but not least, we like to convey our thanks to all who have contributed either directly or indirectly for the completion of this project work.

M.VARUN APESH (318126520096)

B. KARTHEEK (319126520L21)

CH. PARDHA SARADHI (318126520074)

A. SUBHAM RAO (318126520060)

A. RAGHAV (318126520110)

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ABSTRACT

Sustainable machining necessitates energy-efficient processes, longer tool lifespan, and greater surface integrity of the products in modern manufacturing. All these factors can be controlled by using the optimum cutting parameters. Cutting tool plays a very important role in the machining process of a part in production. It not only performs the cutting action but helps in getting the required surface finish and accuracy of the part. In order to perform these tasks, the tool hast to be strong enough to withstand wear resistance and serve for long period of time to produce a greater number of components with same accuracy. However, when considering Ti6Al4V alloy, these objectives turn out to be difficult to achieve as titanium alloys pose serious machinability challenges, especially at elevated temperatures.

In this research, we investigate the optimal machining parameters required for turning of Ti6Al4V alloy. Turning experiments were performed to optimize three response parameters, tool temperature, work piece temperature, with coated carbide inserts in the dry cutting environment. Response surface optimization was used to optimize the developed multi-objective function and determine the optimal cutting condition. As per the ANOVA, the interaction of depth of cut was found to be the most significant factor influencing tool temperature, the interaction of speed, depth of cut was found to be the most significant factor influencing workpiece temperature, the interaction of feed was found to be the most significant factor influencing surface roughness. The optimized machining conditions will increase the tool life and reduce workpiece temperature and improve surface roughness.

CHAPTER 1

CHAPTER 1

INTRODUCTION

1.1 TURNING OPERATION

Turning is the removal of metal from the outer diameter of a rotating cylindrical work piece. Turning is used to reduce the diameter of the work piece, usually to a specified dimension, and to produce a smooth finish on the metal. Often the work piece will be turned so that adjacent sections have different diameters. Turning is the machining operation that produces cylindrical parts. In its basic form, it can be defined as the machining of an external surface:

- With the work piece rotating.
- With a single-point cutting tool and
- With the cutting tool feeding parallel to the axis of the work piece. and at a distance that will remove the outer surface of the work.

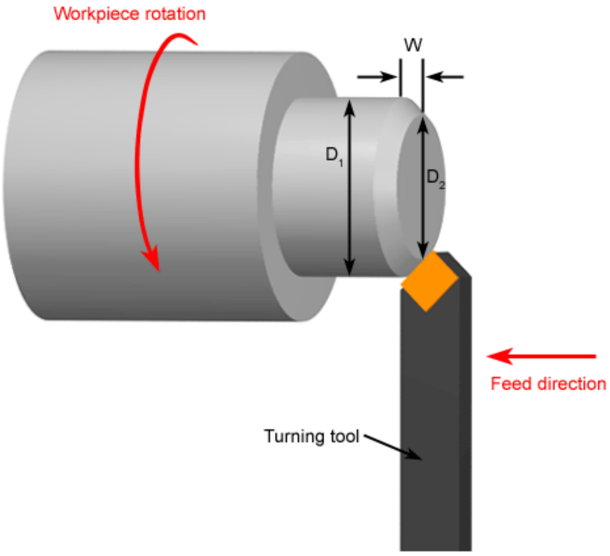


Figure 1.1: Adjustable Parameters In Turning Operation

Taper turning is practically the same, except that the cutter path is at an angle to the work axis. Similarly, in contour turning, the distance of the cutter from the work axis is varied to produce the desired shape. Even though a single-point tool is specified, this does not exclude multiple-tool setup as a single-point which is often employed in turning. In such setups, each tool will operate independently as a single cutting tool.

1.2 ADJUSTABLE CUTTING PARAMETERS IN TURNING

The three primary factors in any basic turning operation are speed, feed, and depth of cut. Other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right on the machine.

1.2.1 SPEED

Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it defines the speed of rotation. But, the important feature for a particular turning operation is the surface speed, or the speed at which the work piece. material is moving past the cutting tool. It is simply, the product of the rotating speed times the circumference of the work piece before the cut is started. It is expressed in meter per minute (m/min), and it refers only to the work piece. Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same

$$v=\pi DN/1000.$$

Here, v is the cutting speed in turning in m/min,

D is the initial diameter of the work piece in mm,

N is the spindle speed in r.p.m.

1.2.2 FEED

Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle), or mm/rev.

$$F_m = f \times N \text{ (mm/min)}$$

Here,

F_m is the feed in mm per minute,
f-Feed in mm/rev and
N-Spindle speed in r.p.m.

1.2.3 DEPTH OF CUT

Depth of cut is practically self-explanatory. It is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm. It is important to note, though, that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work

$$D_{cut} = (D-d)/\ 2$$

D_{cut} - Depth of cut in mm
D- Initial diameter of the work piece
d- Final diameter of the work piece

1.3 CUTTING TOOL MATERIALS

The classes of cutting tool materials currently in use for machining operation are high-speed cutting tool steel, cobalt-based alloys, cemented carbides, ceramics and polycrystalline cubic boron nitride and polycrystalline diamond. Different machining applications require different cutting tool materials. The ideal cutting tool material should have all of the following characteristics:

- Harder than the work it is cutting
- High temperature stability
- Resists wear and thermal shock
- Impact resistant
- Chemically inert to the work material and cutting fluid

To effectively select tools for machining, a machinist or engineer must have specific information about:

- The starting and finished part shape
- The work piece hardness
- The material's tensile strength
- The material's abrasiveness
- The type of chip generated
- The work holding setup
- The power and speed capacity of the machine tool

Some common cutting tool materials are described below:

1.3.1 CARBON STEELS

Carbon steels have been used since the 1880s for cutting tools. However, carbon steels start to soften at a temperature of about 180°C. This limitation means that such tools are rarely used for metal cutting operations. Plain carbon steel tools, containing about 0.9% carbon and about 1% manganese, hardened to about 62 Rc, are widely used for Woodworking and they can be used in a router to machine aluminium sheet up to about 3mm thick.

FIG 1.2 Carbon Steels

1.3.2 HIGH SPEED STEELS (HSS) HSS tools are so named because they were developed to cut at higher speeds. Developed around 1900 HSS are the most highly alloyed tool steels. The tungsten (T series) was developed first and typically contains 12-18% tungsten, plus about 4% chromium and 15% vanadium. Most grades contain about 0.5% molybdenum and most grades contain 412% cobalt. It was soon discovered that molybdenum (smaller proportions) could be substituted for most of the tungsten resulting in a more economical formulation which had better abrasion resistance than the T series and undergoes less distortion during heat treatment. Consequently about 95% of all HSS tools are made from M series grades, these contain 5-10% molybdenum, 1.5 - 10% tungsten. I 4% vanadium, 4% Chromium and many grades contain 5- 10% cobalt. HSS tools are tough and suitable for interrupted cutting and are used to manufacture tools of complex shape such as drills, reamers, taps, dies and gear cutters. Tools may also be coated to Improve wear resistance. HSS accounts for the largest tonnage of tool materials currently used. Typical cutting speeds: 10-60 m/min.

Fig 1.3 High Speed Steel (HSS) Tool

1.3.3 CAST COBALT ALLOYS

Introduced in early 1900s these alloys have compositions of about 40-55% cobalt, 30% chromium and 10-20% tungsten and are not heat treatable. Maximum hardness values of 55-64 Re. They have good wear resistance but are not as tough as HSS but can be used at somewhat higher speeds than HSS. Now only in limited use.

FIG 1.4 Cast Cobalt Alloys

1.3.4 CARBIDES

Also known as cemented carbides or sintered carbides were introduced in the 1930s and have high hardness over a wide range of temperatures, high thermal conductivity, high Young's modulus making them effective tool and die materials for a range of applications. The two groups used for machining are tungsten carbide and titanium carbide; both types may be coated or uncoated. Tungsten carbide particles (1 to 5 micrometres) are bonded together in a cobalt matrix using powder metallurgy. The powder is pressed and sintered to the required insert shape. Titanium and niobium carbides may also be included to impart special properties. A wide range of grades are available for different applications. Sintered carbide tips are the dominant type of material used in metal cutting. The proportion of cobalt (the usual matrix material) present has a significant effect on the properties of carbide tools. 3-6% matrix of cobalt gives greater hardness while 6 - 15% matrix of cobalt gives a greater toughness while decreasing the hardness, wear resistance and strength. Tungsten carbide tools are commonly used for machining steels, cast irons and abrasive non-ferrous materials. Titanium carbide has a higher wear resistance than tungsten but is not as tough. With a nickel-molybdenum alloy as the matrix, TIC is suitable for machining at higher speeds than those which can be used for tungsten carbide. Typical cutting speeds are: 30 150 m/min or 100 - 250 when coated

FIG 1.5 Carbides

1.3.5 HIGH CARBIDE STEELS (HCS)

Generally, the high carbon steels contain from 0.60 to 1.00% C with manganese contents ranging from 0.30 to 0.90%. The pearlite has a very fine structure, which makes the steel very hard. Unfortunately, this also makes the steel quite brittle and much less ductile than mild steel.

Medium and high carbon steels are widely used in many common applications. Increasing carbon as the primary alloy for the higher strength and hardness of steels is usually the most economical approach to improved performance. However, some of the effects of elevated carbon levels include reduced weldability, ductility and impact toughness. When these reduced properties can be tolerated, the increased strength and hardness of the higher carbon materials can be used to a significant advantage. Common applications of higher carbon steels include forging grades, rail steels, spring steels (both flat rolled and round), pre-stressed concrete, wire rope, tire reinforcement, wear resistant steels (plates and forgings), and high strength bar.

Fig 1.6 High Carbide Steels (Hcs)

1.4 TURNING MACHINES

The turning machines are, of course, every kind of lathes. Lathes used in manufacturing can be classified as engine, turret, automatics, and numerical control etc. They are heavy duty machine tools and have power drive for all tool movements. They commonly range in size from 12 to 24 inches swing and from 24 to 48 inches centre distance, but swings up to 50 inches and centre distances up to 12 feet are not uncommon.

1.4.1 TURRET LATHES

In a turret lathe, a longitudinally feed able. hexagon turret replaces the tailstock. The turret, on which six tools can be mounted, can be rotated about a vertical axis to bring cache tool into operating position, and the entire unit can be moved longitudinally, either annually or by power, to provide feed for the tools. When the turret assembly is backed away from the spindle by means of a capstan wheel, the turret indexes automatically at the end of its movement, thus, bring each of the six tools into operating position. The square turret on the cross slide can be rotated manually about a vertical axis to bring each of the four tools into operating position. On most machines, the turret can be moved transversely, either manually or by power, by means of the cross slide, and longitudinally through power or manual operation of the carriage. In most cased, a fixed tool holder also is added to the back end of the cross slide, this often carries a parting tool. Through these basic features of a turret lathe, a number of tools can be set on the machine and then quickly be brought successively into working position so that a complete part can be machined without the necessity for further adjusting, changing tools, or making measurements.

FIG 1.7 Turret Lathes

1.4.2 SINGLE-SPINDLE AUTOMATIC SCREW MACHINES

There are two common types of single-spindle screw machines, One, an American development and commonly called the turret type (Brown & Sharp), is shown in the following figure 1.5. The other is of Swiss origin and is referred to as the Swiss type. The Brown & Sharp screw machine is essentially a small automatic turret lathe, designed for bar stock, with the main turret mounted on the cross slide. All motions of the turret, cross slide, spindle, chuck, and stock-feed mechanism are controlled by cams. The turret cam is essentially a program that defines the movement of the turret during a cycle. These machines usually are equipped with an automatic rod feeding magazine that feeds a new length of bar stock into the collect as soon as one rod is completely used.

This speckle image can be related to surface characteristics. The degree of correlation of two speckle patterns produced from the same surface by two different illumination beams can be used as a roughness parameter. Monochromatic plane wave with an angle of incidence w.r.t the normal to the surface; multi-scattering and shadowing effects are neglected. The photo-sensor of a CCD camera placed in the focal plane of a Fourier lens is used for recording speckle patterns. Assuming Cartesian coordinates x,y,z a rough surface can be represented by its ordinates Z(x,y) w.r.t an arbitrary datum plane having transverse coordinates (x,y,z). Then the RMS value of surface roughness can be defined and calculated roughness values.

a. Inductance method: An inductance pickup is used to measure the distance between the surface and pickup. This measurement gives a parametric value that may be used to give a comparative roughness. However, this method is limited to measuring magnetic materials.

b. Ultrasound: A spherically focused ultrasonic sensor is positioned with a non-normal incidence angle above the surface. The sensor sends out an ultrasonic pulse to the personal computer for analysis and calculation of roughness parameters

.

FIG 1.8 Single-Spindle Automatic Screw Machines (Brown And Sharp)

1.5 TEMPERATURE GUN MEASUREMENT

Temperature guns have electro sonic sensors that enable them to collect the amount of heat energy coming from given object whose temperature would otherwise be difficult to measure. These guns often use infrared beams and you only have to aim at the object whose temperature you are interested in measuring without having to touch it. The sensors have the capability to collect the accurate temperature provided the gadget is functional.

These are however some basics that you must know in order to use these temperature guns correctly.

First, the temperature gun used beams to collect information on the heat energy that is coming from a given object. Thus, the gun does not state whether the heat is coming from the intended object or the surroundings. This means that in order to collect the right temperature measurement, you will have to ensure that you point the gun directly at the object whose temperature you intend to measure. You need to be as close as possible to avoid reading other heat waves that may interfere with your reading’s accuracy. The gun will only read the heat energy on the area where it is pointing, and for accuracy, you must aim directly at the object whose temperature you intend to measure.

Fig 1.9 Temperature Gun Measurement

1.6 INTRODUCTION TO MINITAB

Minitab is a statistic package. It was developed at the Pennsylvania State University by researchers Barbara F. Ryan, Jr., and Brain L. Joiner in 1972. Minitab began as a light version of OMNITAB, a statistical analysis program by NSIT. It can be used for learning about statistics as well as statistical as well as statistical research. Statistical analysis computer applications have the advantage of being accurate, reliable, and generally faster than computing statistics and drawing graphs by hand. Minitab is relatively easy to use once you know a few fundamentals.

Minitab is distributed by Minitab Inc, a privately owned company headquartered in State College, Pennsylvania, with subsidiaries in Coventry, England (Minitab Ltd.), Paris, France (Minitab SARL) and Sydney, Australia (Minitab Pty.).

Today, Minitab is often used in conjunction with the implementation of six Sigma, CMMI and other statistics-based process improvement methods. Minitab21, the latest version of software, is available in 7 languages; English, French, German, Japanese, Korean, Simplified Chinese, & Spanish.

Minitab is statistical analysis software. It can be used for learning about statistics as well as statistical research. Statistical analysis computer applications have the advantage of being accurate, reliable, and generally faster than computing statistics and drawing graphs by hand. Minitab is relatively easy to use once you know a few fundamentals.

Minitab Inc, produces two other products that complement Minitab 16; Quality Trainer, an eLearning package that teaches statistical tools and concepts in the context of quality improvement that integrates with Minitab 16 to simultaneously develop the user’s statistical knowledge and ability to use the Minitab software and Quality Companion 3, an integrated tool for managing Six Sigma and Lean Manufacturing projects that allows Minitab data to be combined with management and governance tools and documents.

Minitab has two main types is files, projects and worksheets. Worksheets are files that are made up of data; think of a spreadsheet containing variables of data. Projects are made up of the commands, graphs and worksheets. Every time you save a Minitab project you will be saving graphs, worksheets and commands. However, each one of the elements can be saved individually for use in other commands or Minitab projects. Likewise, you can print projects and elements.

1.6.1 MINITAB PROJECT AND WORKSHEETS

Minitab has two main types of files; projects and worksheets. Worksheets are files that are made up of data; think of a spreadsheet containing variables of data. Projects are made up of the commands, graphs, and worksheets. Every time you save a Minitab project you will be saving graphs, worksheets and commands. However, each one of the elements can be saved individually for use in other documents or Minitab projects. Likewise, you can print projects and its elements.

The menu bar: You can open menus and choose commands. Here you can find the built-in routines.

The Toolbar: Shortcuts to some Minitab commands.

1.6.2 TWO WINDOWS IN MINITAB

1.Session Window: The area that display the statistical results of your data analysis and can also be used to enter commands.

2.Worksheet Window: A grid of rows and columns used to enter and manipulate the data. Note: This area looks like a spreadsheet but will not automatically update the columns when entries are changed.

Other windows include

. **Graph Window:** When you generate graphs, each graph is opened in its own window.

. **Report Window:** Version 13 has a report manager that helps you organize your results in a report.

. **Other Windows:** History and Project Manager are other windows. See Minitab help for more information on these if needed. Mini tab version used-**MINITAB VERSION 2021**

FIG 1.10 Minitab Workspace

CHAPTER-2

CHAPTER-2

LITERATURE SURVEY

K. Arun Vikram et al. (2021) [1] have studied on Tool Wear and Temperatures Analysis While Machining Ti-6Al4V in MQCL-MIST Environment and concluded that Sustainable machining of titanium alloys have deficiency of studies on the built-up edges over the cutting tools and temperature correlation in minimum quantity cooling lubrication (MQCL) environment. Researchers focused on experimentation in dry, wet, and MQL (minimum quantity lubrication) conditions to analyze surface finish, cutting forces, and metal removal rates. This work focuses on the study of cutting parameters effects on temperatures and tool wear analysis by consideration of individual response and their optimality basing on signal-to-noise ratios. Efficacy of process parameters on wear of tool and temperatures requires a comprehensive understanding. An elaborated tool wear analysis is carried based on the microscopic flank wear investigations. Machining of Ti-6Al-4V alloy is carried in the environment of MQCL in form of mist using semi-synthetic fluid. Correlation study of tool wear with regard to temperatures is analyzed and regression models generated on tool wear and cutting temperatures individually showed 83% of goodness-of-fit and correlation regression is 85%.

Hongbing Wu et al. (2014) [2] studied on series of milling experiments and simulation under up-milling and down-milling were performed to investigate cutting mechanisms of Ti6Al4Valloy. The influences of cutting conditions on milling forces were investigated in detail. In view of the above results, milling forces increase significantly with the increase of feed per tooth and cutting depth. In order to optimize a milling process, feed per tooth and cutting depth should be considered firstly. In addition, the cutting speed has an important effect on milling forces, and there exists a given value of speed at which the forces reach their maximum, and beyond that value, the milling forces are decreased. Finally, the orthogonal cutting finite element model has been established to simulate the up-milling and downmilling processes of Ti6Al4V. The affected zone of temperature and stress on tool tip and workpiece under down-milling is larger than that under up-milling.

K. Arun Vikram et al.(2017)[3] have studied on evaluation of process parameters using GRA while machining low machinability material in dry and wet conditions and concluded that The chips generated in dry conditions were as birds nest with stringy nature and were difficult to remove due to high temperatures and so recommended a tool with chip breaker, while in wet conditions the bird's nested chip broke at some point of time due to cutting fluid, thus results in adopting wet machining in case of hard to machine materials.

E. F. Smart et al. (2010) [4] have studied on Temperature distribution in tools used for cutting iron, titanium and nickel and concluded that the temperature distribution and the influence of speed and feed must be dependent on factors such as rake and clearance angles and nose radius. The methods of temperature measurement used here offer a means of exploring these relationships as well as the influence of coolants. Direct evidence can be obtained only for steel tools, which limits the range of cutting conditions that can be used. It will be necessary to explore the extent to which it is justifiable to extrapolate the tool temperature, speed, feed rate relationships established on steel tools, to estimate the temperatures when using other tool materials such as cemented carbides and ceramics.

Turnad Lenggo Ginta et al. (2009) [5] have studied on Improved Tool Life in End Milling Ti-6Al-4V Through Workpiece Preheating and concluded that Preheating helps in substantially increasing tool life during end milling Ti-6Al-4V using polycrystalline diamond inserts. Experiment with preheating at 650ºC gives benefit in increasing tool life by 2.7 times compared to the experiment at room temperature. High frequency induction heating was proved as a suitable technique for preheated machining. Preheating helps in appreciable lowering down the cutting force values during cutting and reducing acceleration amplitude of vibration. Experiment with preheating at 650ºC can significantly reduce the magnitude of cutting force and acceleration amplitude of vibration in 21.6 % and 66.7%, respectively. Built up edge is a big problem in cutting Titanium Alloy Ti-6Al-4V. Evidence of built up edge was found in both room temperature and preheating experiments. This is related to the high chemical reactivity between workpiece material and the cutting tools.

M. Nouari et al. (2013) [6] have studied on Experimental investigation on the effect of the material microstructure on tool wear when machining hard titanium alloys: Ti–6Al–4V and

Ti-555 and concluded that several analyses (SEM, EDS, AES, infrared camera and profilometer analysis) confirmed that the differences in machinability and microstructure of tested titanium alloys have an important impact on tool wear. The low machinability of titanium alloys due to the low thermal conductivity and high microhardness of these materials leads to severe and premature tool wear in dry machining process.

Muhammad Ali Khan et.al. (2019) [7] have studied on multi-objective optimization of turning titanium-based alloy Ti-6Al-4V under dry, wet, and cryogenic conditions using gray relational analysis (GRA) and concluded that the effects of machining parameters (feed, cutting speed, depth of cut, and cutting condition including dry, wet, and cryogenic) were analyzed. Since sustainable production demands a balance between production quality and energy consumption, therefore, response parameters including specific cutting energy, tool wear, surface roughness, and material removal rate were considered. Taguchi-gray integrated approach was adopted in this study. Multi-objective function was developed using gray relational methodology, and its regression analysis was conducted. Response surface optimization was carried out to optimize the formulated multi-objective function and derive the optimum machining parameters. Concurrent responses were optimized with best-suited values of input parameters to make the most out of the machining process. Analysis of variance results showed that feed is the most effective parameter followed by cutting condition in terms of overall contribution in multi-objective function. The proposed optimum parameters resulted in improvement of tool wear and surface roughness by 30% and 22%, respectively, whereas specific cutting energy was reduced by 4%.

F. J. Sun et al. (2014) [8] have studied on Effects of cutting parameters on dry machining Ti-6Al-4V alloy with ultra-hard tools and concluded that d that the main failure mechanisms of the PCBN tool were chipping, notch, adhesion, and crater. And, the main failure mechanisms of the PCD tool were adhesion, crater, and dissolution-diffusion. The strong diffusivity of PCD material made the performance of the PCD tool better than that of the PCBN tool. When cutting speed increased in machining with the PCD tool, decreasing cutting temperature caused by the reduction of adhered workpiece material on the tool surface resulted in a lower tool wear rate at the cutting speed of 80 m/min, and workpiece surface roughness initially increased and then decreased. The surface roughness initially increased, and after the feed rate of 0.10 mm/r, the surface roughness basically kept a constant value with feed rate increasing. High cutting speed and high feed rate increased and decreased the hardening rate of machined workpiece surface layer in machining with PCD tool, respectively.

Mehmet Emre Kara et al. (2014) [9] have studied on Optimization of Turn-milling Processes and concluded that Turn-milling is a relatively new machining process technology offering important advantages such as increased productivity, reduced tool wear and better surface finish. Because two conventional cutting processes turning and milling are combined in turn-milling, there are many parameters that affect the process making their optimal selection challenging. Optimization studies performed on turn-milling processes are very limited and consider one objective at a time. In this work, orthogonal turn-milling is considered where spindle and work rotational speeds, tool-work eccentricity, depth of cut and feed per revolution are selected as process parameters. The effects of each parameter on tool wear, surface roughness, circularity, material removal rate (MRR) and cutting forces were investigated through process model-based simulations and experiments carried out on a multi-tasking CNC machine tool. The results are used to select process parameters through multi-objective optimization.

D. K. Suker et al. (2016) [10] have studied on Studying the Effect of Cutting Conditions in Turning Process on Surface Roughness for Different Materials and concluded that the cutting speed is by far the most dominant factor for surface roughness then the feed rate, while the working materials has less effect. The effect of cutting condition on the quality has been established with the help of mathematical models, the optimal conditions to minimize the surface roughness has been determined.

Manikandakumar Shunmugavela et al. (2015) [11] have studied on Microstructure and mechanical properties of wrought and Additive manufactured Ti-6Al-4V cylindrical bars and concluded that Titanium alloys are widely used in various engineering design application due to its superior material properties. The traditional manufacturing of titanium products is always difficult, time consuming, high material wastage and manufacturing costs. Selective laser melting (SLM), an additive manufacturing technology has widely gained attention due to its capability to produce near net shape components with less production time. In this technical paper, microstructure, chemical composition, tensile properties and hardness are studied for the wrought and additive manufactured SLM cylindrical bar. Microstructure, mechanical properties and hardness were studied in both the longitudinal and transverse directions of the bar to study the effect of orientation. It was found that additive manufactured bar has higher yield strength, ultimate tensile strength and hardness than the wrought bar. For both conventional and SLM test samples, the yield strength, ultimate tensile strength and hardness was found to be high in the transverse direction. The difference in the properties can be attributed to the difference in microstructure as a result of processing conditions. The tensile fracture area was quantified by careful examination of the fracture surfaces in the scanning electron microscope.

Anna Dziubińska et al (20170 [12] have studied on the effect of forging temperature on the microstructure of grade 5 titanium. The paper reports the experimental results of an investigation of the effect of forging temperature on the microstructure and hardness of Grade 5 titanium ELI. A growing interest in the use of titanium alloys in implantology results from their unique properties. Grade 5 titanium ELI is widely used in medicine for producing a variety of implants and medical tools such as hip, knee and shoulder joints; bone plates; pacemaker casing and its components; screws; nails; dental materials and tools. In the first part of the paper the properties of Grade 5 titanium ELI are described and examples of medical applications of this alloy are given. In a subsequent section of the paper, forging tests performed on this biomaterial in a temperature range from 750°C to 1100°C are described. Following the forging process, the results of the titanium alloy's microstructure and hardness are reported. The experimental results are used to determine the most suitable forging temperature range for Grade 5 titanium ELI with respect to its microstructure.

Neeraj Saraswat et al (2013) [13] focused on Optimization of Cutting Parameters in Turning Operation of Mild Steel. He had adopted the Taguchi method for the design of experiments and results have been by minimizing S/N ratio. Optimization of the surface roughness was done using Taguchi method and Predictive equation was obtained. A confirmation test was then performed which depicted that the selected parameters and predictive equation were accurate to within the limits of the measurement instrument.

Rahul Davis et al (2015) [14] Optimization of Process Parameters of Turning Operation of EN 24 Steel using Taguchi. He has observed that the parameter designs yielded the optimum condition of the controlled parameters, as well as a predictive equation was used. A confirmation tests was then performed which indicated that the selected parameters and predictive equation were accurate to within the limits of the measurement instrument. Therefore, the above results can be recommended to get the lowest surface roughness for further studies. The experimentation can also be done for other materials having more hardness to see the effect of parameters on Surface Roughness.

Rahman et al (2017) [15] conducted experimental study varying speed 78,112,156mm/min feed rates at 0.12,0.14 &0.16 mm/rev at a constant depth-of-cut in dry and pressure applied lubricant delivery environment. The cutting temperatures were reported to be decreased by more than 50% when machined under pressured jets in comparison to dry environment. The surface quality was also enhanced at high speeds and feeds in pressure jets condition but didn’t exhibit the same trend at lesser speeds. They employed two jets one on rake face and another on flank face for better cooling properties.

Aslant et al (2018) [16] recommends that Titanium (Ti-6Al-4V) to be machined in micro condition if required to have high cutting velocities, various speeds and feeds to have higher surface finish and less cutting forces. But (Narendra, Yogesh, & Vivek, 2018) reported that micro machining includes the requirement of electromechanical systems which leads to more cost involvement. In addition, the work-piece cannot be treated as homogenous and isotropic in nature. Furthermore, micro machining acts a plough mechanisms rather than chip removal process which is required essentially in alloy grain structures. Hence this work concentrated on macro machining with usage of reduced coolant in form of mist.

Muthukrishnan et al (2011) [17] presented application of coolant on the ceramic insert tool wear study while machining Ti-6Al-4V at average speeds (45-135mm/min) using a ceramic insert. The cutting environment chosen was water soluble coolant and compared the results with dry cutting and reported that diffusion combined attrition is main type of wear mechanism observed followed by attrition wear. In theirstudy (Mustafa, Rahman & Debashish, 2017) reviewed application of nanofluid MQL in metal machining and they reported use of coolant while cutting aidsto slow tool wear process, augments better surface finish, eradicate heat oriented effects and reduce sticking of the work-piece particles on the tool while machining process. So it is immense required to use the cutting fluids for reducing cutting forces, tool wear and temperatures which are not desired in metal machining due to coolant pollution. So the usage of cutting fluids makes the titanium metal machining to be of non-eco-friendly. Apart from it, the cutting fluids influence reduction in temperature fire flames and cutting force generation due to cooling and lubrication effect between tool and rotary work-piece.

Hegab, Kishawy et al (2018) [18] used Nano multi walled nano-carbon tubes (MWNCT) additives in vegetable oil in MQL environment to enhance the heat capacity during conduction and convective heat transfer modes. They reported that at 120mm/min the surface quality was best. All experiments were carried at constant doc. The chips were segmented and no serrations observed. Only surface roughness and chip morphology were studied and reported.

Bolzonia, RuizNavas et al (1986) [19] focused study of cutting Ti–6Al– 7Nb alloy and Ti-6Al-4V respectively using powder metallurgy. But the limitation of having less fatigue performance using titanium can be further treated with laser surface modification or blending with powder metallurgy can be substituted with hot pressing fallowed by machining, suggested by (Alan, Santos et.al, 2019)

Bermingham et al (2012) [20] conducted experiments in high pressure water-based emulsion and cryogenic cooling environment and concluded that the former environment is better in giving tool life than cryogenic-cooling during turning of Ti-6Al-4V. They emphasized position of nozzle through which coolant evicts as most prime parameter of concern. On the other hand (Niancong, Xiang, Zheng, Huang & Wang, 2019) utilized MQL and MQCL environment while machining AISI304 steel and reports that as the speed accelerates, the built-up edge (BUE) close to the cutting edge of the tool disappears due to diffusion wear mechanism. (Xu, Liu, An & Chen, 2012) conducted experimental study while machining alloy titanium under dry and MQL environment with nano coated TiAlN and concluded that coated tools have better tool life than uncoated tool. (Lin, Wang, Yuan, Chen, Wang & Xiong, 2015) applied water cooling and cryogenic cooling while turning of Ti-6Al-4V alloy at very low depth of cut and compared surface roughness, tool wear. (Pervaiz, Rashid, Deiab & Nicolescu, 2016) had compared machinability at dry, flood, MQCL environment using vegetable oil while machining of Titanium alloy using an uncoated carbide insert at constant depth of cut 0.8mm. (Najiha, Rahman & Yusoff, 2016) & (Groover, 2002) summarized the advantages and disadvantages of different fluids used in metal cutting process. They straight oils as reported by their studies are excellent as lubricators but very poor coolants and also likely to cause fire, generate smoke at high speeds. Hence their use is limited to low speeds. Whereas on the other extreme the water-soluble oils i.e., semi synthetics offer excellent performance as coolants and good corrosion resistance but may cause foaming problem when in flood condition. (Brian, 2020) in his work reiterated that any attempt to improve the process performance depends on variables effect, models and concepts in addition a reliable measuring system in place ensures the objective of waste minimization. Hence selection of factors effecting system, and measuring system accuracy and reliability are also important for system to improve.

Mr. Yash R. Bhoyar et al (2013) [21] has studied on creating a finite element analysis simulation model in order to obtain solutions of the cutting forces, specific cutting energy and adequate temperatures occurring at different points through the chip/tool contact region and the coating/substrate boundary for a range of cutting tool materials and defined cutting conditions. Interfacial temperature in machining plays a major role in tool wear and can also result in modifications to the properties of the work piece and tool materials. As there is a general move towards dry machining, for environmental reasons, it is increasingly important to understand how machining temperature are affected by the process variables involved (cutting speed, feed rate, tool geometry, etc.) and by other factors such as tool wear.

S. Ramesh et al (2008) [22] had conducted the experiment on Surface Roughness Analysis in Machining of Titanium Alloy. He had concluded that the surface roughness increases with increasing feed but decreased with increasing cutting speed. The variance analysis for the twofactor interaction model shows that the depth of cut is the least significant parameter. The predicted and the measured values are satisfactorily close to each other which indicates that the developed surface roughness prediction model can be effectively used for predicting the surface roughness during the machining of titanium alloy with 95% confident level.

Upendra Kumar et al (2019) [23] had studied on A comparative machinability study on titanium alloy Ti-6Al-4V during dry turning by cryogenic treated and untreated condition of uncoated WC inserts. He had concluded that during turning of titanium alloys, thrust force most dominates over feed force and cutting force for all cutting condition. Depth of cut demonstrates a significant influence on all three components of cutting force. Cutting speed has the least effect on all element of force.

S. Ramesh et al (2011) [24] has studied on Measurement and analysis of surface roughness in turning of aerospace titanium alloy and concluded that the effect of cutting parameters on the surface roughness in turning of titanium alloy has been investigated using response surface methodology. The experimental studies were conducted under varying cutting speeds, feed and depths of cut. The chip formation and SEM analysis are discussed to enhance the supportive surface quality achieved in turning. The work material used for the present investigation is commercial aerospace titanium alloy (gr5) and the tool used is RCMT 10T300 – MT TT3500 round insert. The equation developed using response surface methodology is used for predicting the surface roughness in machining of titanium alloy. The results revealed that the feed was the most influential factor which affect the surface roughness.

Nexhat Qehaja et al. (2015) [25] Studied on various cutting parameters affecting the surface roughness in dry turning of coated tungsten carbide inserts. The investigations of this study indicate that the cutting parameters like feed rate, nose radius and cutting time are the primary influencing factors, which affect surface roughness. Statistical models' deduction defined the degree of influence of each cutting regime element on surface roughness criteria.

CHAPTER -3

CHAPTER -3

DESIGN OF EXPERIMENTS

3.1 DESIGN OF EXPERIMENTS (DOE) OVERVIEW

In industry, designed experiments can be used to systematically investigate the process or product variables that influence product quality. After identifying the process conditions and product components that influence product quality, direct improvement efforts enhance a product's manufacturability, reliability, quality, and field performance. As the resources are limited, it is very important to get the most information from each experiment performed. Well-designed experiments can produce significantly more information and often require fewer runs than haphazard or unplanned experiments. A well-designed experiment identifies the effects that are important. If there is an interaction between two input variables

They should be included in design rather than doing a "one factor at a time" experiment. An interaction occurs when the effect of one input variable is influenced by the level of another input variable.

Designed experiments are often carried out in four phases: planning, screening (also called process characterization), optimization, and verification.

3.1.1 PLANNING

Careful planning help in avoiding the problems that can occur during the execution of the experimental plan. For example, personnel, equipment availability, funding, and the mechanical aspects of system may affect the ability to complete the experiment. The preparation required before beginning experimentation depends on the problem. Here are some steps need to go through:

•**Define the problem.** Developing a good problem statement helps in studying the right variables.

•**Define the objective**. A well-defined objective will ensure that the experiment answers the right questions and yields practical, usable information. At this step, define the goals of the experiment.

• **Develop an experimental plan that will provide meaningful information.** Review relevant background information, such as theoretical principles, and knowledge gained through observation or previous experimentation.

•**Make sure the process and measurement systems are in control.** Ideally, both the process and the measurements should be in statistical control as measured by a functioning statistical process control (SPC) system Minitab provides numerous tools to evaluate process control and analyze your measurement system

3.1.2 SCREENING

In many process development and manufacturing applications, potentially influential variables are numerous. Screening reduces the number of variables by identifying the key variables that affect product quality. This reduction allows focusing process improvement efforts on the really important variables. Screening suggests the "best" optimal settings for these factors

The following methods are often used for screening

- Two-level fall and fractional factional designs are used extensively in industry
- Placken-Burman designs have low resolution, but they are useful in some screening experimentation and robustness testing
- General full factorial designs (designs with more than two-levels) may also be useful for small screening experiments

3.1.3 OPTIMIZATION

After identifying the vital variables by scroening, there is need to determine the "best" or optimal values for these experimental factors Optimal factor values depend on the process objective

The optimization methods available in Minitab include general full factorial designs (designs with more than two-levels), response surface designs, mixture designs, and Taguchi designs.

- Factorial Designs Overview describes methods for designing and analyzing general full factorial designs
- Response Surface Designs Overview describes methods for designing and analyzing central composite and Box-Behnken designs.
- Mixture Designs Overview describes methods for designing and analyzing simplex centroid, simplex lattice, and extreme vertices designs. Mixture designs are a special class of response surface designs where the proportions of the components (factors), rather than their magnitude, are important.
- Response Optimization describes methods for optimizing multiple responses Minitals provides numerical optimization, an interactive graph, and an overlaid contour plot to help to determine the "best" settings to simultaneously optimize multiple responses.
- Taguchi Designs Overview describes methods for analyzing Taguchi designs. Taguchi designs may also be called orthogonal array designs, robust designs, or inner-cuter array designs. These designs are used for creating products that are robust to conditions in their expected operating environment.

3.1.4 VERIFICATION

Verification involves performing a follow-up experiment at the predicted "best" processing conditions to confirm the optimization results

3.2 MERITS AND DEMERITS OF DOE

DOE became a more widely used modelling technique superseding its predecessor one factor-at-time (OFAT) technique One of the main advantages of DOE is that it shows the relationship between parameters and responses. In other words, DO shows the interaction between variables which in turn allows us to focus on controlling important parameters to obtain the best responses DOE also can provide us with the most optimal setting of parametric values to find the best possible output characteristics. Besides from that, the mathematical model generated can be used as a prediction model which can predict the possible output response based on the input values. Another main reason DOE is used because it saves time and cost in terms of experimentation. DOE function in such manner that the number of experiments or the number of runs is determined before the actual experimentation is done. This way, time and cost can be saved as we do not have to repeat unnecessary experiment runs: Most usually, experiments will have error occurring Some of them might be predictable while some errors are just out of control, DOE allows us to handle these errors while still continuing with the analysis. DOE is excellent when it comes to prediction linear behavior. However, when it comes to nonlinear behavior, DOE does not always give the best results.

3.3 INTRODUCTION

In 1982 Deng established Grey System theory, which focused on decision making with partial information known and partial unknown. The information between known and unknown information is called as grey information. Grey System theory is applied for complex problem subjected to complex data. Grey relation analysis is quantitative and systematic approach, subsystem of grey system theory and most widely used in solving complex system. GRA can be used in financial, logistic and also to optimize process. GRA method can effectively be used for problems with multiple criteria's and their exists complicated relationship between criteria's. It can also be used effectively to determine optimum process parameter influencing two or more response variables. Multi criteria problems can effectively handled using Grey Relation analysis.

3.3.1. GREY RELATION ANALYSIS STEPS

Steps in Grey Relation Analysis includes

- Defining problems and response variables or quality characteristics.
- Data collection.
- Normalizing data for smaller the better or larger the better quality characteristics.
- Find grey relation coefficient for normalized data.
- Calculate grey relation grade.
- Select optimum level based on grade value.

For larger the better quality characteristic, normalized value (Xi) is given by

$$X_i = \left(\frac{x_i - x_{min}}{x_{max} - x_{min}}\right)$$

For smaller the better quality characteristic, normalized value (Xi) is given by

$$X_i = \left(\frac{x_{max} - x_i}{x_{max} - x_{min}}\right)$$

Where(xi)max and (xi)min are the maximum and minimum values of the original sequence Xi

Grey Coefficient, γi is given by.

$$\gamma_i = \left\{\frac{(\delta_i)max + (\delta_i)min}{(\delta_i)max + (\delta_i)}\right\}$$

Where, Delta value, γi .is given by

$$\delta_i = (X_i)_{max} - X_i$$

CHAPTER-4

CHAPTER-4

EXPERIMENTAL SETUP

4.1 INTRODUCTION

For this experiment we selected titanium alloy (Ti-6Al-4V) as our work piece and Physical vapour deposition (PVD) Ti-Al-N coating inserts as our cutting tool. The experiment was performed on CNC Turn Mill Centre Model TMC-XL-200.

4.2 PROBLEM DEFINITION

In present world everyone is looking for the metal that is strong as well as lighter in weight. Aluminium was one of the metals that is strong as well as lighter in weight, but Titanium is stronger than aluminium and lighter than it. While both materials have excellent corrosion resistance, manufacturers figured that titanium is more corrosion resistant than aluminium. Titanium is more inert and has more biocompatibility with good application in many industries. Aluminium forms a layer of oxide to make more non-reactive materials. Because of all these advantages titanium is having over aluminium present world is running around titanium.

As titanium is very strong machining titanium is also very hard. Titanium one of the strongest metals ever discovered is well known for its applications and its unique properties. Manufacturing of titanium components is always challenging due to their high chemical reactivity and high tensile strength. Cutting of titanium also requires special kind to cutting tools which must be hard enough to withstand the cutting forces as titanium is very hard. Ti-6Al-4V is grade 5, alpha-beta alloy of titanium which is even harder than the parent metals and requires optimum cutting conditions.

Therefore, selection of optimum machining parameters, speed, feed ,depth of cut, tool temperature, workpiece temperature, surface roughness etc. is an important and complicated task for the manufacturing industries in providing best quality at less cost to the customers.

4.3 SELECTION OF WORKPIECE

Titanium one of the strongest metals ever discovered and is well known for its applications and its unique properties such as its thin oxide layer around it which prevents it from getting corroded making it corrosion resistant metal, because of its resistance towards sea water, it is used in offshore rigs, ships' propellers and rigging, and desalination plants. Titanium is as strong as steel but it is 50% lighter than steel so it is used in almost every aerospace application. Even biologically human body won't reject titanium so it can be used as joint replacements, tooth implants. Because of all these wide range of applications titanium is otherwise called as – the metal of future.

While aluminum and aluminum alloys were previously the preferred materials of the aerospace industry, newer aircraft designs are increasingly making use of titanium and titanium alloys. These materials are also used in the biomedical industry. The reasons for their popularity include light weight, high strength, excellent fatigue performance and high resistance to aggressive environments, remaining free of rust and degeneration. Titanium parts last longer and provide better performance and results than other metals and materials.

Even though titanium metal has wide range of applications and very unique properties many industries think second time before using it because the very properties of titanium that make it so unique and beneficial make it difficult to use as it is very hard to machine. Titanium (Ti-6AI-4V) because of its low young's modulus 113Gpa spring back effect is more which in turn results in poor surface finish of final product. Automation of titanium is nearly impossible because titanium when machined produces very long continuous chips, this chips entangle around the tool and is very hard to estimate it.

Since the discovery of titanium in 1825 Jöns Jakob Berzelius, machining titanium was very difficult even now. Some of the titanium grades such as Ti-6Al-4V, Ti-17 are still difficult to machine. Today there are even more hard, grade of titanium and Many manufacturers were cutting blind and making parts through trial and error which results in drastic reduction of tool life and more expenditure. The machining of titanium also results in producing high temperatures, to over come this we may use high viscosity lubricants and coolants but they result in escalation of cost of production, unsafe conditions for the workmen.

Titanium alloys are widely used in aerospace, automobile, biomedical and chemical industries because of their superior properties like corrosion resistance and high strength to weight ratio(Leyens and Peters, 2003, Lütjering and Williams, 2007). Despite of their applications, manufacturing of titanium components is always challenging due to their high chemical reactivity and poor thermal conductivity. Casting, forging and machining are being traditionally used to manufacture titanium products and they have their own disadvantages like high material wastage and low production rate(Mitchell, 1998)

Grade 5 Titanium is one of the most popular alloys in the titanium industry and makes up almost half of the titanium used in the world. Commonly referred to as Ti-6AL-4V (or Ti 6-4), this designation refers to its chemical composition of almost 90% titanium, 6% aluminium, 4% vanadium, 0.25% (max) iron and 0.2% (max) oxygen. It has excellent strength, low modulus of elasticity, high corrosion resistance, good weldability and it is heat treatable. The addition of aluminium and vanadium increases the hardness of the material in the alloy matrix, improving its physical and mechanical properties.

- High tensile strength—Ti 6Al-4V's strength nears that of stainless steel, requiring high cutting forces.
- Low thermal conductivity—Heat does not readily transfer into the chip but rather flows into the
  cutting tool, which makes the cutting edge very hot during the machining process.
- High modulus of elasticity—Titanium is very "springy." For a given force, it will deflect more than
  steel, which results in a higher likelihood of vibration, chatter, and poor chip formation.
- Shear mechanism—Titanium requires a sharp cutting edge to cut the material and avoid tearing and smearing, which will quickly lead to tool failure
- Titanium Ti6Al4V is the workhorse alloy of the titanium industry, also known as Grade 5, TA6V or Ti64. This α-β titanium-based alloy is the most commonly used of all titanium alloys and accounts for 50% of total titanium usage in the world.

Phase stabilizers are Aluminium and Vanadium. Al reduces density, stabilizes and strengthens α while vanadium provides a greater amount of the more ductile β phase for hot-working.

FIG4.1 Work piece material (Ti-6Al-4V)

Properties of Grade 5 titanium alloy

Titanium 6al-4v has a density of 4.43 g/cc.

Thermal Properties:

Melting Point	1604 – 1660 °C
Solidus	1604 °C
Liquidus	1660 °C

Mechanical Properties:

Tensile Strength, Ultimate	1170 Mpa
Tensile Strength, Yield	1100 Mpa
Elongation at Break	10%
Modulus of Elasticity	114 Gpa

4.4 SELECTION OF TOOL

The new thin Physical vapour deposition (PVD) Ti-Al-N coating with excellent adhesion, also on sharp edges, guarantees toughness, even flank wear and outstanding performance in heat resistant super alloys. The physical vapor deposition (PVD) Ti-Al-N coated carbide inserts inserts are used. Standard Kennametal inserts (ADET 090308 SR 42) for Turn mill operation which are mounted on to tool holder (PCLNL 2020 K12 WDAS).

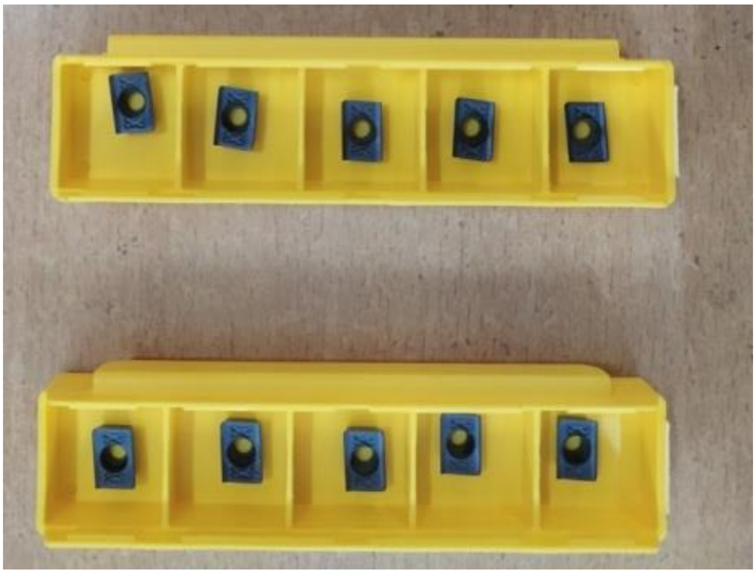


FIG4.2 Cutting Tool Inserts (ADET 090308 SR 42)

FIG4.3 Cutting Tool

4.5 TAGUCHI DESIGN FOR EXPERIMENTATION

Table 4.1 Levels of Machining Parameters

Parameters	**Levels**			
	1	**2**	**3**	**4**
Speed	510	764	1019	1273
Feed	0.05	0.10	0.15	0.20
DOC	0.25	0.50	0.75	1.00

Table 4.2 Taguchi Design For Experimentation

Machining Parameters				**Actual Parameters**		
Sl.No.	**A**	**B**	**C**	**Speed (RPM)**	**Feed (mm/rev)**	**DOC (mm)**
1	1	1	1	510	0.05	0.25
2	1	2	2	510	0.1	0.5
3	1	3	3	510	0.15	0.75
4	1	4	4	510	0.2	1
5	2	1	2	764	0.05	0.5
6	2	2	1	764	0.1	0.25
7	2	3	4	764	0.15	1
8	2	4	3	764	0.2	0.75
9	3	1	3	1019	0.05	0.75
10	3	2	4	1019	0.1	1
11	3	3	1	1019	0.15	0.25
12	3	4	2	1019	0.2	0.5
13	4	1	4	1273	0.05	1
14	4	2	3	1273	0.1	0.75
15	4	3	2	1273	0.15	0.5
16	4	4	1	1273	0.2	0.25

Turn mill parameters

P1: speed (4 levels) = 510,764,1019,1273

P2: feed (4 levels) = 0.05,0.1,0.15,0.2

P3: depth of cut (4 levels) = 0.25, 0.50 0.750 1.00

1) Number of experiments = (levels) parameter = 4*4*4 = 64
2) Possibility of experiments using Taguchi 4=1 or 4*1=4 or 4*4=16 or 4*4*4= 64
3) Minimum no. of experiments

   M=1+(XL-1)=1+[(n-1) +(n-1) +(n-1)]=10 experiments
4) Taguchi is orthogonality the repeated sequence doesn’t exist.

Taguchi DOE basing on concept of orthogonal array (OA) adopted for designing experiments, considering three process parameters (like Spindle speed (N), feed (f) and depth of cut (doc) with four levels each which generated 16 (L16) experimental combinations as shown in Table.

CHAPTER-5

CHAPTER-5

RESULTS

5.1 EXPERIMENTAL VALUES

The below table 5.1, shows the experimental values that were obtained from the experiment that was performed on CNC turn-mill. According to Taguchi model 4 levels were set and 16 readings were taken.

Table 5.1. Experiment values

Sl.No.	Speed (RPM)	Feed (mm/rev)	DOC (mm)	Tool Temperature (°C)	Workpiece Temperature (°C)	Surface Roughness (R_a)
1	510	0.05	0.25	36	35	0.66
2	510	0.1	0.5	39	37	0.82
3	510	0.15	0.75	41	41	1.45
4	510	0.2	1	45	43	1.92
5	764	0.05	0.5	37	35	0.6
6	764	0.1	0.25	36	36	0.89
7	764	0.15	1	43	43	0.99
8	764	0.2	0.75	40	41	1.27
9	1019	0.05	0.75	42	43	0.44
10	1019	0.1	1	44	46	0.89
11	1019	0.15	0.25	37	38	0.97
12	1019	0.2	0.5	37	43	1.39
13	1273	0.05	1	44	43	0.45
14	1273	0.1	0.75	42	45	0.58
15	1273	0.15	0.5	39	42	0.94
16	1273	0.2	0.25	38	40	1.16

5.2 Grey relational analysis

5.2.1 Output parameters

Table 5.2 output parameters

Sl.No	Tool Temperature (°C)	Workpiece Temperature (°C)	Surface Roughness (R_a)
1	36	35	0.66
2	39	37	0.82
3	41	41	1.45
4	45	43	1.92
5	37	35	0.6
6	36	36	0.89
7	43	43	0.99
8	40	41	1.27
9	42	43	0.44
10	44	46	0.89
11	37	38	0.97
12	37	43	1.39
13	44	43	0.45
14	42	45	0.58
15	39	42	0.94
16	38	40	1.16

5.2.2 NORMALIZED VALUES

Normalized Value Of Tool Temperature:

$$\frac{\text{(Maximum Tool Temperature – Tool Temperature)}}{\text{(Maximum Tool Temperature – Minimum Tool Temperature)}}$$

Maximum Tool Temperature: 45

Minimum Tool Temperature: 36

Tool Temperature: 36

Normalised value of tool temperature: (45-36)/(45-36) = 1

Normalized Value Of Workpiece Temperature:

$$\frac{\text{(Maximum Workpiece Temperature – Workpiece Temperature)}}{\text{(Maximum Workpiece Temperature – Minimum Workpiece Temperature)}}$$

Maximum Workpiece Temperature: 46

Minimum Workpiece Temperature: 35

Workpiece Temperature: 35

Normalised value of Workpiece temperature: (46-35)/(46-35) = 1

Normalized Value Of Surface Roughness:

$$\frac{\text{(Maximum Surface Roughness – Surface Roughness)}}{\text{(Maximum Surface Roughness – Minimum Surface Roughness)}}$$

Maximum Surface Roughness: 1.92

Minimum Surface Roughness: 0.44

Surface Roughness: 0.66

Normalised value of Surface Roughness: (1.92-0.66)/(1.92-0.44) = 0.851351351

Table 5.3 Normalized Values

Sl.No	Tool Temperature (°C)	Workpiece Temperature (°C)	Surface Roughness (R_a)
1	1	1	0.85
2	0.66	0.81	0.74
3	0.44	0.45	0.31
4	0	0.27	0
5	0.88	1	0.89
6	1	0.90	0.69
7	0.22	0.27	0.62
8	0.55	0.45	0.43
9	0.33	0.27	1
10	0.11	0	0.696
11	0.88	0.72	0.64
12	0.88	0.27	0.35
13	0.11	0.27	0.99
14	0.33	0.09	0.90
15	0.66	0.36	0.66
16	0.77	0.54	0.51

5.2.3 DEVIATION SEQUENCES

Deviation Sequences Of Tool Temperature:

Maximum Normalized Value Of Tool Temperature – Normalized Value Of Tool Temperature

Maximum Normalized Value Of Tool Temperature: 1

Normalized Value Of Tool Temperature:1

Deviation Value Of Tool Temperature: 1-1 = 0

Deviation Sequences Of Workpiece Temperature:

Maximum Normalized Value Of Workpiece Temperature – Normalized Value Of Workpiece Temperature

Maximum Normalized Value Of WorkpieceTemperature:1

Normalized Value Of WorkpieceTemperature:1

Deviation Value Of Workpiece Temperature: 1-1 = 0

Deviation Sequences Of Surface Roughness:

Maximum Normalized Value Of Surface Roughness – Normalized Value Of Surface Roughness

Maximum Normalized Value Of Surface Roughness:1

Normalized Value Of Surface Roughness: 0.851351351

Deviation Value Of Surface Roughness: 1 - 0.851351351= 0.148648649

Table 5.4 Deviation Sequences

Sl.No	Tool Temperature (ºC)	Workpiece Temperature (ºC)	Surface Roughness (R_a)
1	0	0	0.14
2	0.33	0.18	0.25
3	0.55	0.54	0.68
4	1	0.72	1
5	0.11	0	0.10
6	0	0.09	0.30
7	0.77	0.72	0.37
8	0.44	0.54	0.56
9	0.66	0.72	0
10	0.88	1	0.30
11	0.11	0.27	0.35
12	0.11	0.72	0.64
13	0.88	0.72	0.006
14	0.66	0.90	0.094
15	0.33	0.63	0.33
16	0.22	0.45	0.48

5.2.4 Grey Relational Coefficient

Grey Relational Coefficient Of Tool Temperature:

$$\frac{\text{(Minimum Deviation Sequence Of Tool Temperature +(0.5*Maximum Deviation Sequence Of Tool Temperature))}}{\text{(Deviation Sequence Value + (0.5*Maximum Deviation Sequence Of Tool Temperature))}}$$

Minimum Deviation Sequence Of Tool Temperature:0

Maximum Deviation Sequence Of Tool Temperature:1

Deviation Sequence Value:0

Grey Relational Coefficient Of Tool Temperature:(0+(0.5*1))/(0+(0.5*1))= 1

Grey Relational Coefficient Of Workpiece Temperature:

$$\frac{\text{(Minimum Deviation Sequence Of Workpiece Temperature +(0.5*Maximum Deviation Sequence Of Workpiece Temperature))}}{\text{(Deviation Sequence Value + (0.5*Maximum Deviation Sequence Of Workpiece Temperature))}}$$

Minimum Deviation Sequence Of Workpiece Temperature:0

Maximum Deviation Sequence Of Workpiece Temperature:1

Deviation Sequence Value:0

Grey Relational Coefficient Of Workpiece Temperature:
(0+(0.5*1))/(0+(0.5*1)) = 1

Grey Relational Coefficient Of Surface Roughness:

$$\frac{\text{(Minimum Deviation Sequence Of Surface Roughness +(0.5*Maximum Deviation Sequence Of Surface Roughness))}}{\text{(Deviation Sequence Value + (0.5*Maximum Deviation Sequence Of Surface Roughness))}}$$

Minimum Deviation Sequence Of Surface Roughness:0

Maximum Deviation Sequence Of Surface Roughness:1

Deviation Sequence Value: 0.148648649

Grey Relational Coefficient Of Surface Roughness:

(0+(0.5*1))/(0.148648649+(0.5*1))= 0.770833333

Table 5.5 Grey Relational Coefficient

Sl.No	Tool Temperature (^oC)	Workpiece Temperature (^oC)	Surface Roughness (R_a)
1	1	1	0.77
2	0.6	0.73	0.66
3	0.47	0.47	0.42
4	0.33	0.40	0.33
5	0.81	1	0.82
6	1	0.84	0.62
7	0.39	0.40	0.57
8	0.52	0.47	0.47
9	0.42	0.40	1
10	0.36	0.33	0.62
11	0.81	0.64	0.58
12	0.81	0.40	0.43
13	0.36	0.40	0.98
14	0.42	0.35	0.84
15	0.6	0.44	0.59
16	0.69	0.52	0.50

5.2.5 Grey Relation Grade:

1/3*(Grey Relation Coefficient Of Tool Temperature+ Grey Relational Coefficient Of Workpiece Temperature+ Grey Relational Coefficient Of Surface Roughness)

Grey Relational Grade: 1/3*(1+1+ 0.770833333) = 0.923611111

GREY RELATIONAL ANALYSIS TABLE

Table 5.6 Grey Relational Analysis Calculation

Sl.No	Normalized Values			Deviation Sequence			Grey Relational Coefficient			GRG	Rank
	T.T(°C)	**W.T(°C)**	**Ra**	**T.T(°C)**	**W.T(°C)**	**Ra**	**T.T (°C)**	**W.T (°C)**	**Ra**		
1	1.00	1.00	0.85	0.00	0.00	0.15	1.00	1.00	0.77	0.92	1.00
2	0.67	0.82	0.74	0.33	0.18	0.26	0.60	0.73	0.66	0.66	5.00
3	0.44	0.45	0.32	0.56	0.55	0.68	0.47	0.48	0.42	0.46	13.00
4	0.00	0.27	0.00	1.00	0.73	1.00	0.33	0.41	0.33	0.36	16.00
5	0.89	1.00	0.89	0.11	0.00	0.11	0.82	1.00	0.82	0.88	2.00
6	1.00	0.91	0.70	0.00	0.09	0.30	1.00	0.85	0.62	0.82	3.00
7	0.22	0.27	0.63	0.78	0.73	0.37	0.39	0.41	0.57	0.46	14.00
8	0.56	0.45	0.44	0.44	0.55	0.56	0.53	0.48	0.47	0.49	12.00
9	0.33	0.27	1.00	0.67	0.73	0.00	0.43	0.41	1.00	0.61	6.00
10	0.11	0.00	0.70	0.89	1.00	0.30	0.36	0.33	0.62	0.44	15.00
11	0.89	0.73	0.64	0.11	0.27	0.36	0.82	0.65	0.58	0.68	4.00
12	0.89	0.27	0.36	0.11	0.73	0.64	0.82	0.41	0.44	0.55	9.00
13	0.11	0.27	0.99	0.89	0.73	0.01	0.36	0.41	0.99	0.58	7.00
14	0.33	0.09	0.91	0.67	0.91	0.09	0.43	0.35	0.84	0.54	11.00
15	0.67	0.36	0.66	0.33	0.64	0.34	0.60	0.44	0.60	0.55	10.00
16	0.78	0.55	0.51	0.22	0.45	0.49	0.69	0.52	0.51	0.57	8.00

***T.T- Tool Temperature; W.T-Work Piece Temperature; Ra-Surface Roughness**

The below table 5.6, shows the grey relation grade calculated values that were obtained from the experiment that was performed on CNC turn-mill.

5.3ANNOVA REGRESSION ANALYSIS

Analysis of Variance: Tool Temperature (°C) versus Speed, Feed, DoC.

Table 5.7 Analysis of Variance: Tool Temperature (°C) versus Speed, Feed, DoC.

Analysis of Variance: Tool Temperature (°C) versus Speed, Feed, DoC.						
Source	DF	Adj SS	Adj MS	F-Value	P-Value	% contribution
Speed	3	6.5	2.1667	2.89	0.124	4.80
Feed	3	0.5	0.1667	0.22	0.878	0.37
DoC.	3	128.5	42.8333	57.11	0.000	94.83
Error	6	4.5	0.75			
Total	15	140	45.1667			

From the above Table 5.7., we can see that P-value for the model is 0.000 which is lesser than the significance value of 0.05. Hence the model is significant. Depth of cut is found be the most influential parameter affecting the tool temperature with the lowest value (0.000, significant) among all three parameters followed by speed with the p-value (0.124, significant).

Analysis of Variance: Workpiece Temperature (°C) versus Speed, Feed, DoC.

Table 5.8 Analysis of Variance: Workpiece Temperature (°C) versus Speed, Feed, DoC.

Analysis of Variance: Workpiece Temperature (°C) versus Speed, Feed, DoC.						
Source	DF	Adj SS	Adj MS	F-Value	P-Value	% contribution
Speed	3	52.687	17.562	13.38	0.005	30.01
Feed	3	16.688	5.563	4.24	0.063	9.51
DoC.	3	106.188	35.396	26.97	0.001	60.48
Error	6	7.875	1.313			
Total	15	183.438	58.521			

From the above Table 5.8., we can see that P-value for the model is 0.001 which is lesser than the significance value of 0.05. Hence the model is significant. Depth of cut is found be the most influential parameter affecting the tool temperature with the lowest value (0.001, significant) among all three parameters followed by speed with the p-value (0.005, significant).

Analysis of Variance: Surface Roughness (Ra) versus Speed, Feed, doc

Table 5.9 Analysis of Variance: Surface Roughness (Ra) versus Speed, Feed, DoC.

Analysis of Variance:Surface Roughness (Ra) versus Speed, Feed, doc						
Source	DF	Adj SS	Adj MS	F-Value	P-Value	% contribution
Speed	3	0.38847	0.12949	4.41	0.058	17.41
Feed	3	1.79023	0.59674	20.3	0.002	80.23
DoC.	3	0.05273	0.01758	0.6	0.639	2.36
Error	6	0.17635	0.02939			
Total	15	2.40778	0.74381			

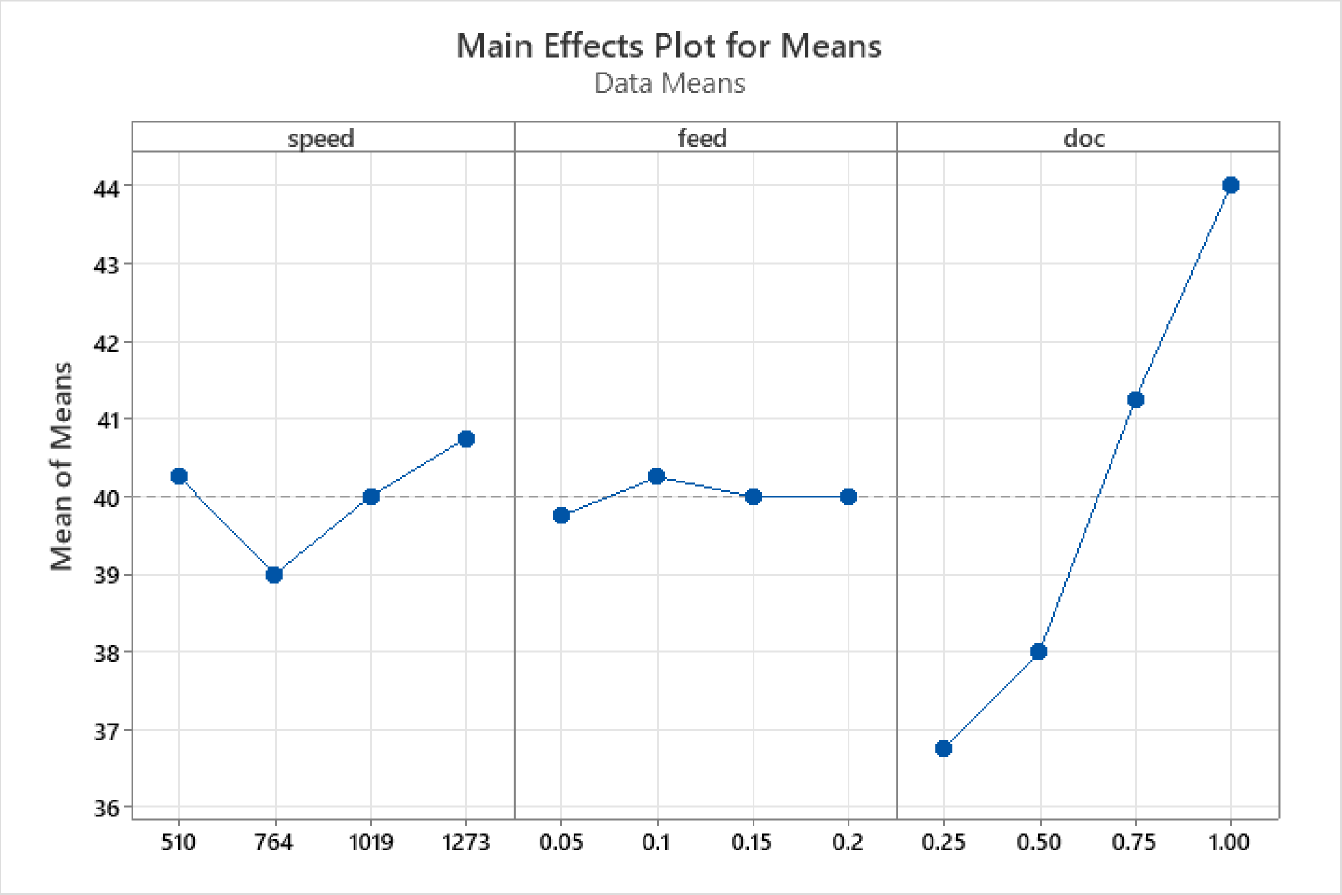
From the above Table 5.9., we can see that P-value for the model is 0.002 which is lesser than the significance value of 0.05. Hence the model is significant. Feed is found be the most influential parameter affecting the Surface Rouhness (Ra) with the lowest value (0.002, significant) among all three parameters followed by speed with the p-value (0.058, significant).

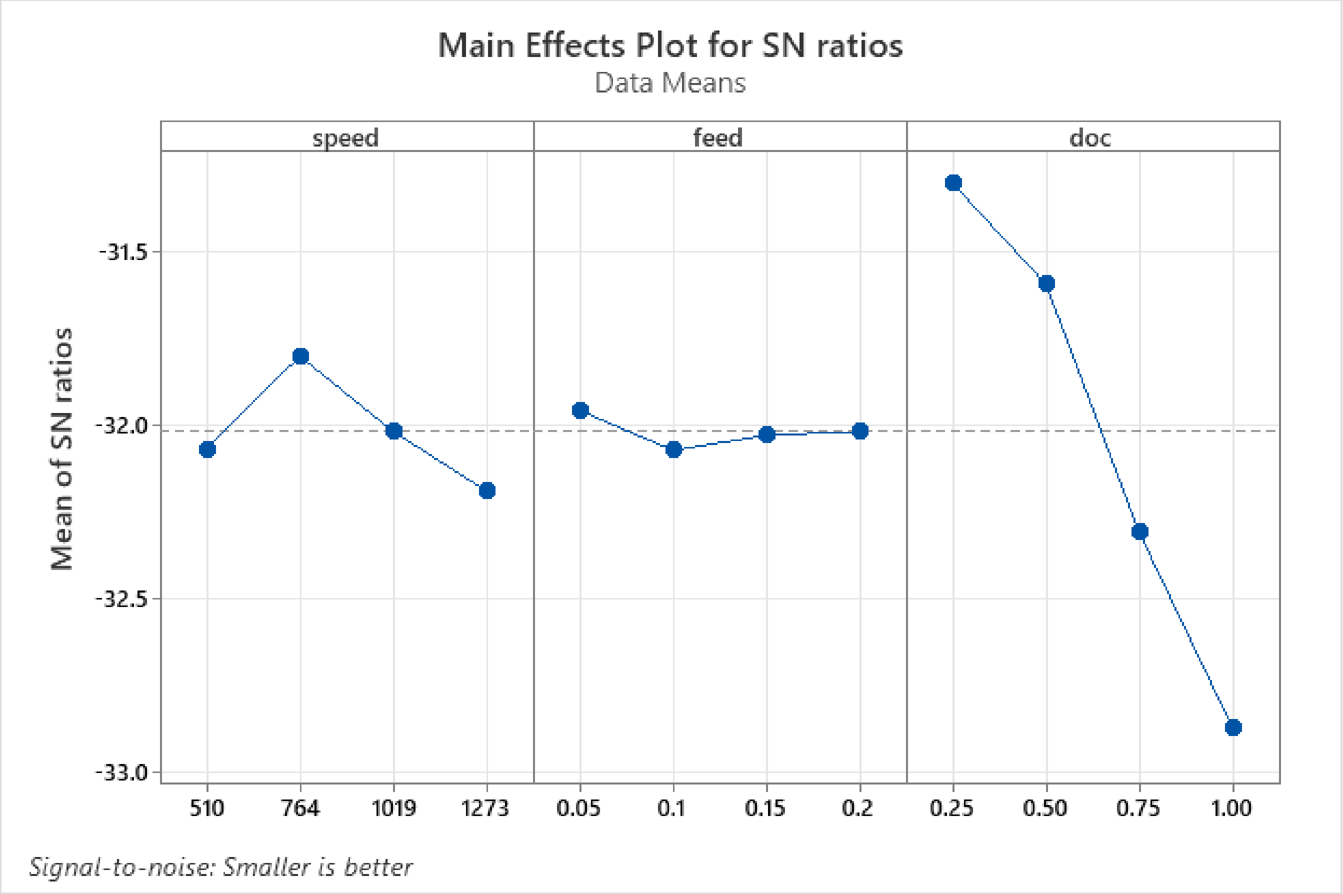
5.4 TAGUCHI ANALYSIS: TOOL TEMPERATURE (OC) VERSUS SPEED, FEED, DOC

Response Table for Signal to Noise Ratios

Smaller is better

Level	Speed	Feed	DoC
1	-32.07	**-31.96**	**-31.30**
2	**-31.80**	-32.07	-31.59
3	-32.02	-32.03	-32.31
4	-32.19	-32.02	-32.87
Delta	0.39	0.11	1.56
Rank	2	3	1


Main Effects Plot for Means
Data Means
speed
feed
doc
Mean of Means
44
43
42
41
40
39
38
37
36
510
764
1019
1273
0.05
0.1
0.15
0.2
0.25
0.50
0.75
1.00

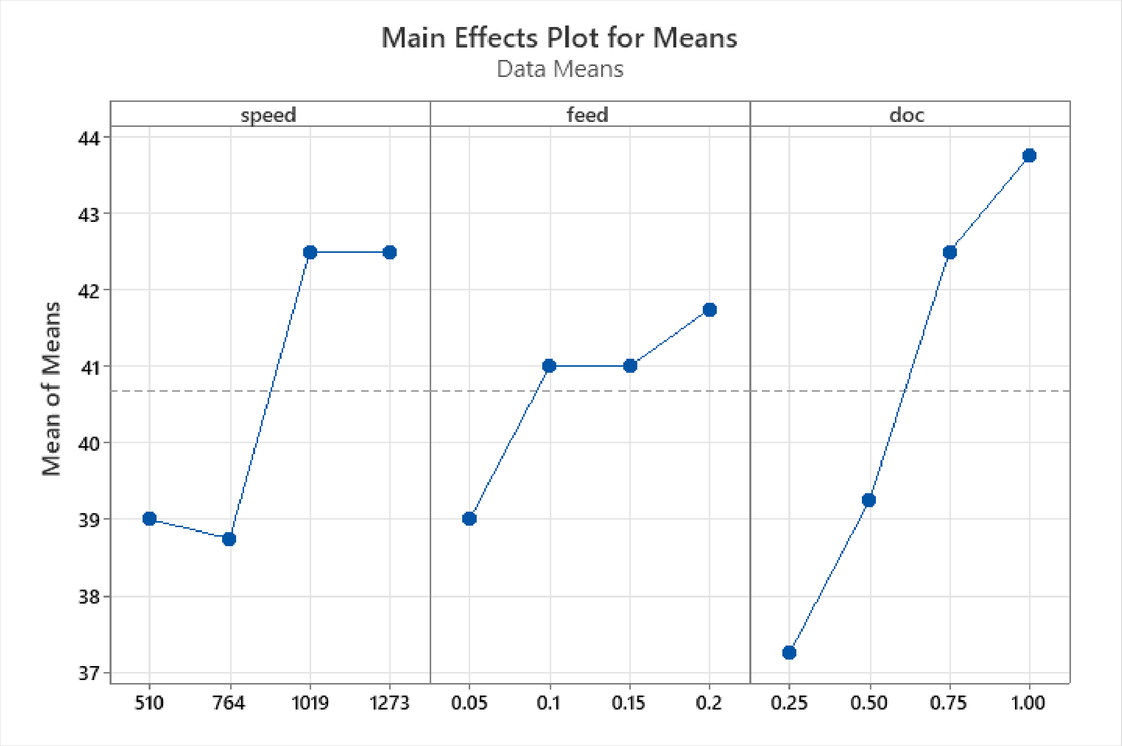

Main Effects Plot for SN ratios
Data Means
speed
feed
doc
Mean of SN ratios
-31.5
-32.0
-32.5
-33.0
510
764
1019
1273
0.05
0.1
0.15
0.2
0.25
0.50
0.75
1.00
Signal-to-noise: Smaller is better

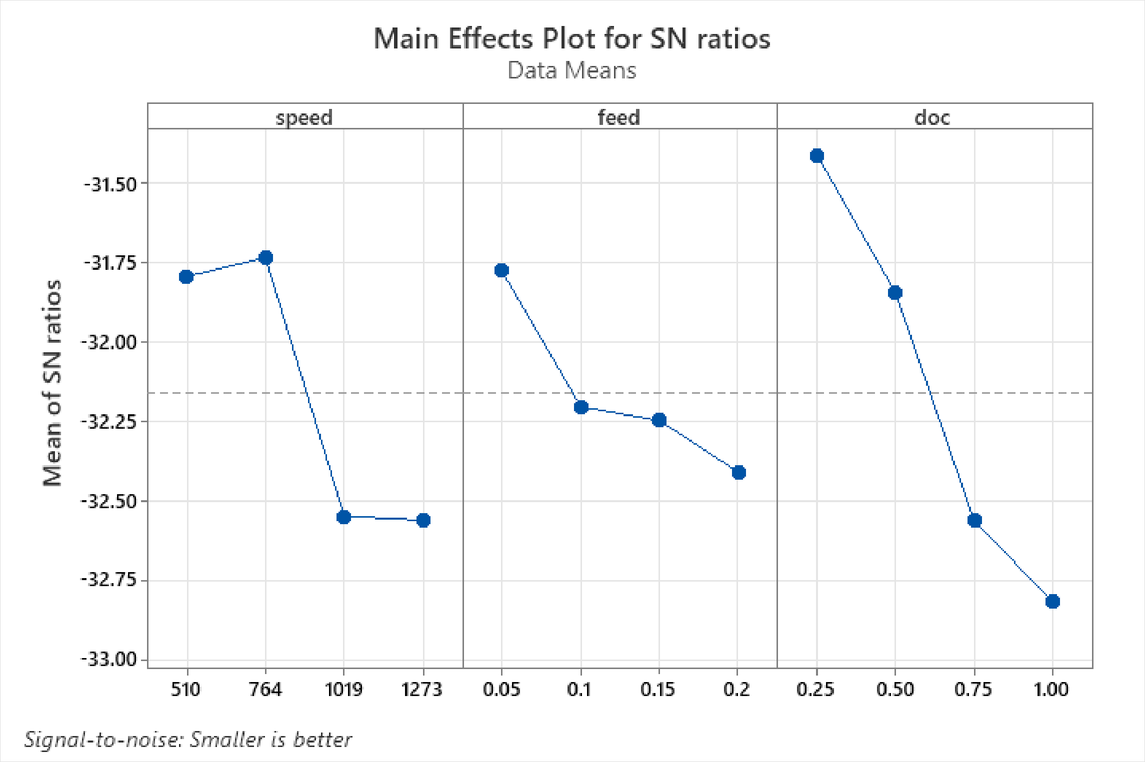
Taguchi Analysis: Workpiece Temperature (oC) versus speed, feed, doc

Response Table for Signal to Noise Ratios

Smaller is better

Level	Speed	Feed	DoC
1	-31.79	**-31.78**	**-31.41**
2	**-31.73**	-32.20	-31.84
3	-32.55	-32.25	-32.56
4	-32.56	-32.41	-32.82
Delta	0.83	0.63	1.40
Rank	2	3	1





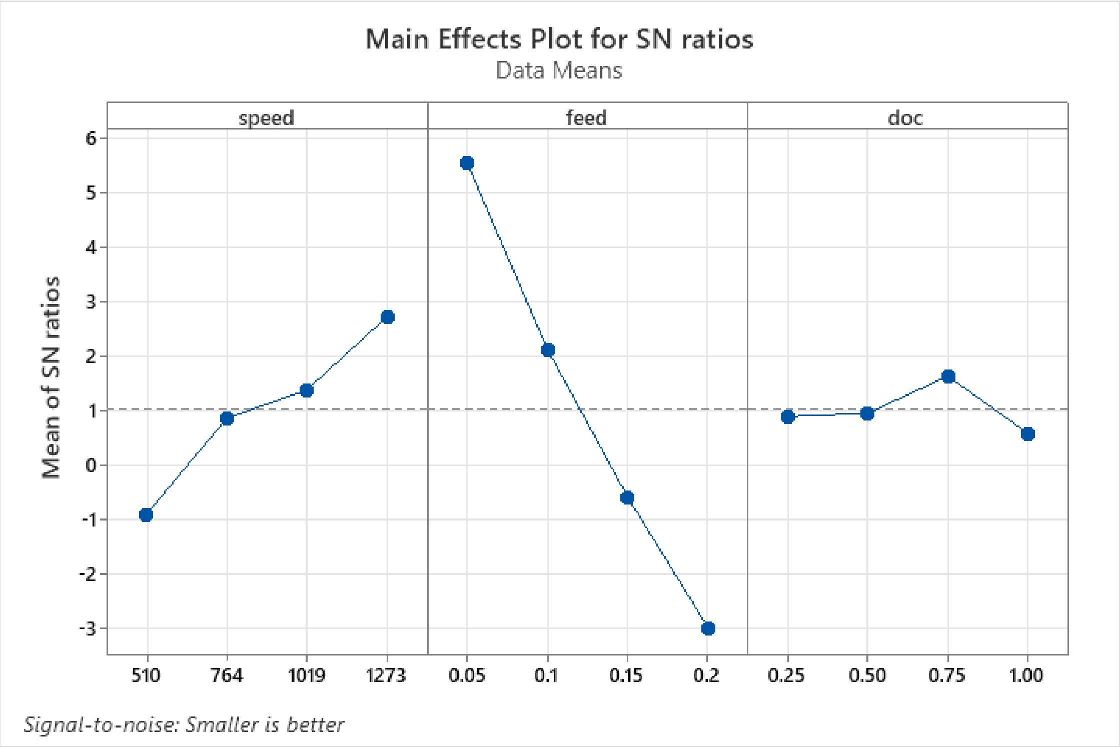
Taguchi Analysis: Surface Roughness (Ra) versus speed, feed, doc

Response Table for Signal to Noise Ratios

Smaller is better

Level	Speed	Feed	DoC
1	-0.8901	**5.5282**	0.8992
2	0.8651	2.1199	0.9595
3	1.3869	-0.5845	**1.6397**
4	**2.7289**	-2.9729	0.5923
Delta	3.6190	8.5011	1.0474
Rank	2	1	3


Main Effects Plot for Means
Data Means
speed
feed
doc
Mean of Means
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
510
764
1019
1273
0.05
0.1
0.15
0.2
0.25
0.50
0.75
1.00


Main Effects Plot for SN ratios
Data Means
speed
feed
doc
Mean of SN ratios
6
5
4
3
2
1
0
-1
-2
-3
510
764
1019
1273
0.05
0.1
0.15
0.2
0.25
0.50
0.75
1.00
Signal-to-noise: Smaller is better

5.5 INDIVIDUAL OPTIMIZATION

Optimization is a method of obtaining the best result under the given circumstances. It plays a vital role in mechanical engineering because the mechanical components, are to be designed in an optimal manner. While designing machine elements, optimization helps in a number of ways to reduce material cost, to ensure better service of components, to increase production rate, and many such other parameters. Thus, optimization techniques can effectively be used to ensure optimal production rate. There are several methods available in the literature of optimization. Some of them are direct search methods and others are gradient methods.

Experimental values of Dry Turn-mill

Experiments	**Actual Parameters**			**Reponses**			**S/N Ratio**		
	Speed (RPM)	**Feed (mm/rev)**	**DOC (mm)**	**Tool Temperature (ºC)**	**Workpiece Temperature (ºC)**	**Surface Roughness (R_a)**	**SN Ratio of T_T**	**SN Ratio of W_T**	**SN Ratio of Ra**
1	510	0.05	0.25	36	35	0.66	-31.13	-30.88	3.61
2	510	0.1	0.5	39	37	0.82	-31.82	-31.36	1.72
3	510	0.15	0.75	41	41	1.45	-32.26	-32.26	-3.23
4	510	0.2	1	45	43	1.92	-33.06	-32.67	-5.67
5	764	0.05	0.5	37	35	0.6	-31.36	-30.88	4.44
6	764	0.1	0.25	36	36	0.89	-31.13	-31.13	1.01
7	764	0.15	1	43	43	0.99	-32.67	-32.67	0.09
8	764	0.2	0.75	40	41	1.27	-32.04	-32.26	-2.08
9	1019	0.05	0.75	42	43	0.44	-32.46	-32.67	7.13
10	1019	0.1	1	44	46	0.89	-32.87	-33.26	1.01
11	1019	0.15	0.25	37	38	0.97	-31.36	-31.60	0.26
12	1019	0.2	0.5	37	43	1.39	-31.36	-32.67	-2.86
13	1273	0.05	1	44	43	0.45	-32.87	-32.67	6.94
14	1273	0.1	0.75	42	45	0.58	-32.46	-33.06	4.73
15	1273	0.15	0.5	39	42	0.94	-31.82	-32.46	0.54
16	1273	0.2	0.25	38	40	1.16	-31.60	-32.04	-1.29
						Average	**-32.02**	**-32.16**	**1.02**
						Ideal speed	**-31.8**	**-31.73**	**2.72**
						Ideal feed	**-31.96**	**-31.78**	**5.52**
						Ideal DOC	**-31.3**	**-31.41**	**1.63**
						Optimum SN Ratio	**-31.02**	**-30.60**	**7.85**
						Optimum Value	**35.58**	**33.89**	**0.405**

5.6. RESPONSE OPTIMIZATION

Many designed experiments involve determining optimal conditions that will produce the "best" value for the response.

5.6.1. RESPONSE OPTIMIZER

- Response Optimizer - combinations and an optimization plot. The optimization plot is interactive; we can adjust variable input variable settings on the plot to search for more desirable solutions. Optimizer Provides with an optimal solution for the input.
- Use response optimization to help and identify the combination of input variable settings that jointly optimize a single response or a set of responses. Joint optimization must satisfy the all the responses in the set, which is measured by the composite desirability. Minitab calculates an optimal solution and draws a plot. The optimal solution serves as the starting point for the plot. This optimization plot allows to interactively changing the input variable settings to perform sensitivity analyses and possibly improve the initial solution.

5.6.2 RESPONSE OPTIMIZATION: SURFACE ROUHNESS (RA), WORKPIECE TEMPERATURE (OC), TOOL TEMPERATURE (OC)

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
Surface Rouhness (Ra)	Minimum		0.44	1.92	1	1
Workpiec Temperature (oC)	Minimum		35.00	46.00	1	1
Tool Temperature (oC)	Minimum		36.00	45.00	1	1

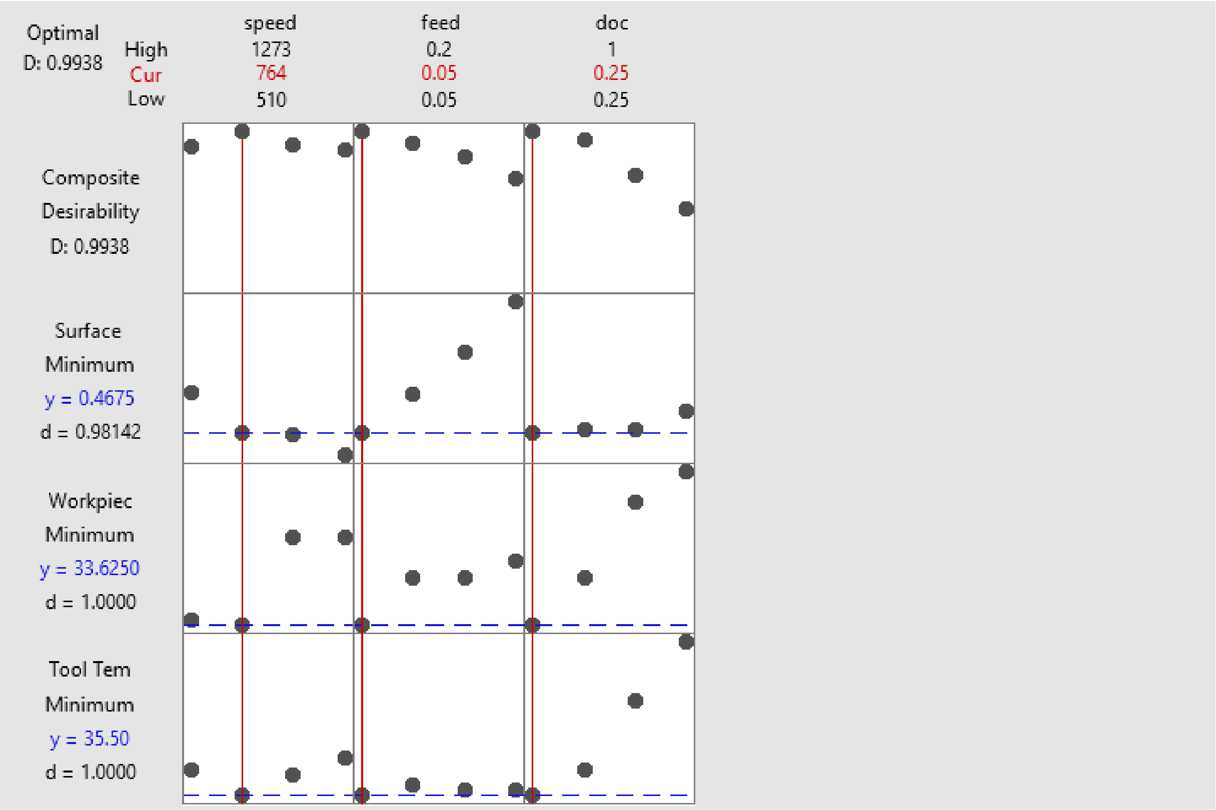
Solution

Solution	speed	feed	doc	Surface Rouhness (Ra) Fit	Workpiec Temperature (oC) Fit	Tool Temperature (oC) Fit	Composite Desirability
1	764	0.05	0.25	0.4675	33.625	35.5	0.993768

Multiple Response Prediction

Variable	Setting
speed	764
feed	0.05
doc	0.25

Response	Fit	SE Fit	95% CI	95% PI
Surface Rouhness (Ra)	0.467	0.136	(0.136, 0.799)	(-0.067, 1.002)
Workpiec Temperature (oC)	33.625	0.906	(31.409, 35.841)	(30.051, 37.199)
Tool Temperature (oC)	35.500	0.685	(33.825, 37.175)	(32.799, 38.201)



The optimization plot as shown signifies the effect of each factor (columns) on the responses or composite desirability (rows). The vertical red lines on the graph represent the current factor settings. The numbers displayed at the top of a column show the current factor level. The horizontal blue lines and numbers represent the responses for the current factor level. Minitab calculates minimum surface roughness and maximum material removal rate.

CHAPTER-6

CHAPTER-6

DISCUSSIONS

	SPEED	**FEED**	**DEPTH OF CUT**
TOOL TEMPERATURE	-	-	Highly Influencing with 94.6%
WORK PIECE TEMPERATURE	Influencing with 30.01%	-	Highly Influencing with 60.48%
SURFACE ROUGHNESS	-	Highly Influencing with 80.23%	-

As per the ANOVA, the interaction of depth of cut was found to be the most significant factor influencing tool temperature, the interaction of speed, depth of cut was found to be the most significant factor influencing workpiece temperature, the interaction of feed was found to be the most significant factor influencing surface roughness. The optimized machining conditions will increase the tool life and reduce workpiece temperature and improve surface roughness.

CONCLUSIONS

From the experiment conducted that is optimisation of cutting parameters for Titanium alloy on turn-mill under dry conditions & the calculations that were done, it is concluded that:

- According to grey relation analysis it is found out the first set of values that is at 510 RPM speed, 0.05 mm per revolution feed and 0.25 mm depth of cut, 36-degree Celsius tool temperature, 35 degrees work piece temperature 0.66 Ra surface roughness is optimum.
- Further from Annova regression it is deduced that

  i) depth of cut effected tool temperature more than the other factors

  ii) depth of cut and speed combinedly effected work is temperature more than the other factors

  iii) speed has affected surface roughness more than the other factors

- Using Taguchi method that was performed individual optimization and found out we can achieve the optimum conditions at 764 RPM speed, 0.05 mm per revolution feed and 0.25 mm depth of cut.

CHAPTER-7

CHAPTER-7

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