A PROJECT REPORT

ON

"CHIP FORMATION ANALYSIS OF TITANIUM ALLOY IN HIGH SPEED MACHINING BY USING REFRIGERATED AIR AS A COOLANT"

Submitted by

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In partial fulfillment for the award of the Degree

Of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

UNDER THE GUIDANCE

Of

Prof. AFAQAHMED JAMADAR

DEPARTMENT OF MECHANICAL ENGINEERING

ANJUMAN-I-ISLAM

KALSEKAR TECHNICAL CAMPUS NEW PANVEL,

NAVI MUMBAI – 410206

UNIVERSITY OF MUMBAI

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ANJUMAN-I-ISLAM

KALSEKAR TECHNICAL CAMPUS NEW PANVEL

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CERTIFICATE

This is to certify that the project entitled

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To the Kalsekar Technical Campus, New Panvel is a record of bonafide work carried out by him under our supervision and guidance, for partial fulfillment of the requirements for the award of the Degree of Bachelor of Engineering in Mechanical Engineering as prescribed by **University Of Mumbai**, is approved.

Project co-guide **Internal Examinar** **External Examiner**

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APPROVAL OF DISSERTATION

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Prof. AfaqAhmed Jamadar

Date: __________

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Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Abstract

Cutting fluids are used to improve the machining performance during cutting processes. However, the use of cutting fluids in machining process has caused some problems like high cost, pollution, and hazards to operator's health. All the problems related to the use of cutting fluids have made researchers to search for some alternatives to minimize or even avoid the use of cutting fluids in machining operations. Cooling gas cutting is one of these alternatives. Therefore, in this work refrigerated air is used as a cutting medium for machining of ti alloy. Finally, the effects of cutting speed and cutting feed rate on the chip thickness ratio is investigated.

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1.1 Introduction

The formation of serrated chips (or shear-localized chips) is an typical characteristic of the machining of titanium alloys. These kinds of chips are favoured for machined components as continuous chip get tangled and are not appropriate for automated processes. However, segmentation is also believed to be a critical aspect due to periodic variations in the cutting forces that increase tool wear rates and degradation of the machined surface finish. The causes and effects of chip segmentation in titanium alloys have received important attention in the aim of selecting the optimal cutting conditions to improve the production and increase both the tool life and surface quality.

Titanium alloys have received considerable interest recently due to their wide range of applications in the aerospace, automotive, chemical, and medical industries.The most common titanium alloy is Ti6Al4V, which belongs to the alpha + beta alloy group and accounts for more than 50% of the titanium alloy production[3]. Boyer and Briggs (2004) analyzed the properties and different applications of the new beta titanium alloys, which are being used by aerospace companies because they provide an exceptional combination of fracture toughness, high strength, simpler processing, and deep hardenability.

The machining of metals has traditionally involved the use of large quantities of water and oils for dissipating the cutting tool temperature, improving the surface finish of parts and increasing tool life. Invariably, the cutting fluid has become contaminated with use, has required being environmentally disposed and has accounted for approximately 17% of the total production cost of parts. Traditional cooling techniques are often ineffective in machining difficult to cut materials. Also,the use of cutting fluids is often associated with the health hazards to the operator. Its adverse effect is the disease of nausea.

1.2 Drawbacks of flood coolants

Most cutting fluids are not biodegradable and contain various components, which can cause environmental and health hazards. Dangerous bacteria can grow and mix with the shop floor environment allowing dangerous biocides to be present. Moreover, the frequently used mineral oil is carcinogenic and can cause skin cancer. Chlorinated and sulphurized additives are also present in the shop-floor. The vaporized particles of such cutting fluids when inhaled by workers can cause severe damage and their smell can make the work conditions uncomfortable.

Toyota found that coolant contributed 31.8% of energy usage in their machining centre system [1].Huge amounts of cutting fluids consumption have been recorded in many countries, e.g. 100 million gallons a year in the U.S. and 75491 tons in Germany. In Japan very high consumption and disposal costs were recorded. An estimate suggests that almost 16% of the total manufacturing costs are comprised of cutting fluid costs and when it comes to the machining of hard to machine materials, they reach up to 20-30 percent.[2]

Applying cutting fluids in metal cutting is an important approach to enhance machining performance.However,the use of cutting fluids has caused some problems such as high cost, pollution, and hazards to operator's health. All the problems related to the use of cutting fluids have urged researchers to search for some alternatives to minimize or even avoid the use of

cutting fluids in machining operations. So far various alternatives have been offered. Some of these alternatives are minimal quantity lubrication (MQL) and cooling gas cutting.

The cooling air has a lot of advantages such as

- Ecofreindly
- Greener and cleaner machining approach
- Low cost
- High quality products

1.3 Vortex tube for cool air

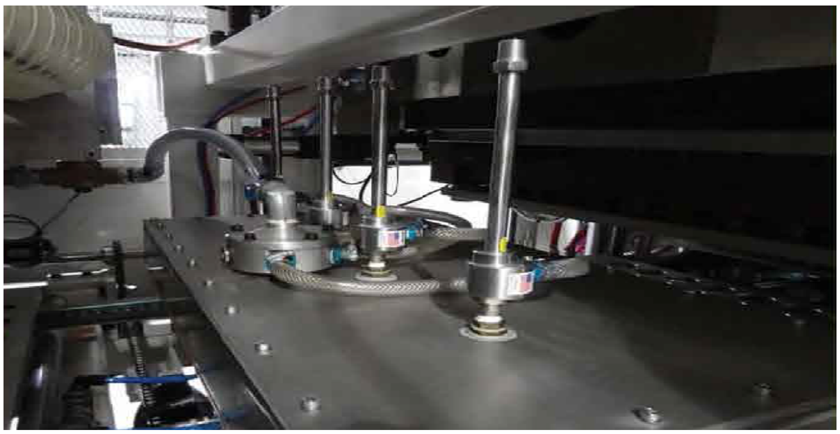


Fig 1: Vortex tubes in industries

Vortex Tubes are an effective, low cost solution to a wide variety of industrial spot and process cooling needs. With no moving parts, a vortex tube spins compressed air to separate the air into cold and hot air streams.

Vortex Tubes have a wide range of applications for spot cooling on machines, assembly lines, and processes.

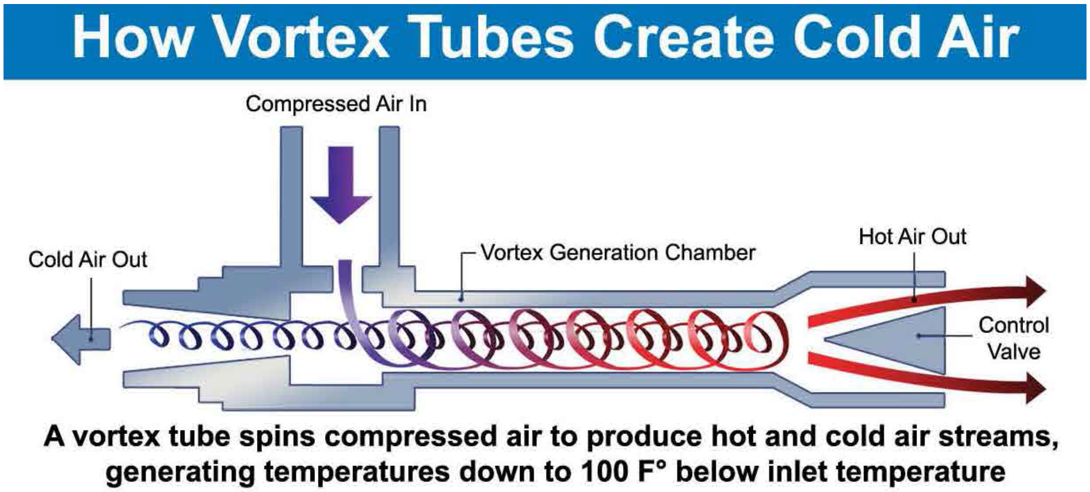


Fig 2: How does vortex tube creates cool air

Fluid (air) that rotates around an axis (like a tornado) is called a vortex. A Vortex Tube creates cold air by forcing compressed air through a generation chamber, which spins the air at a high speed rate (1,000,000 RPM) into a vortex. The high speed air heats up as it spins along the inner walls of the tube towards the control valve. A percentage of hot , high speed air is permitted to exit at this valve. The remainder of the (now slower) air stream is forced to counter flow up through the center of the high speed air stream in a second cortex. The slower moving air gives up energy in the form of heat and becomes cooled as it apins up the tube. The chilled air passes through the center of the generation chamber finally exiting through the opposite end as extremely cold air. Vortex tube generates temperature down to 100 F^0 below inlet air temperatures. The control valve located in the hot exhaust end can be used to adjust the temperature drop and rise for all Vortex Tubes.

Fig 3: Vortex tube Fig4: Diff. Types of vortex tubes

The Advantages of Vortex Tube are :

- Cools without refrigerants, as low as -40^0 F (-40^0 C)
- Drops compressed air inlet temperature by upto 100^0 F (56 C^0)
- Lowest cost per unit of refrigeration of any cooling technique.
- Cools instantaneously.
- Environmentally friendly, with no refrigerants or chemicals needed.
- Fits to provide cooling in the most confined areas.
- Cycle repeatedly within +/- 1 deg F.
- Available heating, using the same tube, upto 250^0 F (121^0 C).
- Available in both aluminium and stainless steel models.
- Fully adjustable for varying cooling needs.
- Maintenance free with no moving parts.

1.4 CNC machining of Titanium alloys

High speed Machining of Ti alloys is done on CNC machining. Different pieces of Ti alloys will be machined at different values of cutting parameters like speed & feed and keeping depth of cut constant. The table below shows the values to be taken during experimentation:

Fig5: CNC Machine

Carbide material is used as a tool in this operation due to its superior hardness at high temperature, low chemical affinity to work piece gives better finish and machining accuracy, high wear resistance and ensures longer tool life.

1.5 Compressor

Compressors are used for providing compressed air to the vortex tube. The air is passed from a compressor through a long pipe. The exit of the vortex tube is connected with a flexible pipe and a nozzle of adequate exit diameter is provided to obtain a convenient pressurized flow of cool air for machining.

Fig6: Compressor

2. Problem Definition

1. To find the best combination of feed rate and speed which would give the desirable chip thickness ratio.

2. To get the contribution percentage of speed and feed rate in machining process.

3. To investigate which type of chips are desirable for machining of Ti6Al4V

3. Literature Review

3.1Ti Alloys

P.-J. Arrazolaa, A. Garay a, L.-M. Iriarte , M. Armendia, 5 JUNE, 2008

Analysis of variables such as cutting forces, chip geometry and tool wear shows that: (I) greater difficulty is encountered when machining Ti555.3 alloycompared with Ti6Al4V alloy which can be machined at higher speeds up to 90mmin−1; (II)there was a correlation between the mechanical properties of work material, tool wear, and component forces; (III) the occurrence of the diffusion process leads to the formation of a layer of adhered material composed of Ti and TiC on the tool’s rake face for both Ti alloys.

X.Y. Gu , C.Y. Dong , J.L. Li , Z.Y. Liu , J.Y. Xu 28 MAY, 2015

The evolution of the temperature and cutting force are studied, and the effects of cutting speed and cutting feed rate on the chip morphology and cutting force are also investigated. It was the first time to simulate the serrated and discontinuous chips with the MPM and obtain relatively satisfactory results. The transition from serrated to discontinuous chips has been well captured in this paper.

Y. Ayeda, G. Germaina, A. Ammar a, B. Furet b 9 JUNE, 2015

The optimum water jet pressure has been determined, leading to an increase in tool life of approximately 9 times. Compared to conventional lubrication, an increase of about 30% in productivity can be obtained.

B.E. Tegnera, L. Zhua, b, C. Siemersc, K. Saksld, G.J. Acklanda, 5 SEPT, 2015

Titanium alloys are ideally suited for use as lightweight structural materials, but their use at high temperature is severely restricted by oxidation.

The Ti–Nb surface has three-layer structure: the oxide itself, an additional Nb-depleted zone below the oxide and a deeper sublayer of enhanced Nb. Microfocussed X-ray diffraction also demonstrates recrystallization in the Nb-depleted zone. We interpret this using a dynamical model: slow Nb-diffusion leads to the build up of a Nb-rich sublayer, which in turn blocks oxygen diffusion. Nb effects contrast with vanadium, where faster diffusion prevents the build up of equivalent structures.

3.2 Refrigerated air as a coolant

Y. Kaynak , S.W. Robertson, H.E. Karaca , I.S. Jawahir 17 FEB, 2012

Experimental findings reveal that cryogenic machining substantially improves theperformance of cutting tools by reducing the progressive tool-wear in machining of the room-temperature austenitic *NiTi* alloys. Therefore, cryogenic machining could result in improved productivity and reduced manufacturing costs compared to dry and MQL machining. Experimental evidence suggests that cold working did not alter the progressive tool-wear substantially; however, the presence of carbide inclusions increased the progressive tool-wear in machining *NiTi*. Surface quality of machined samples under cryogenic machining presents promising improvement upon short-duration machining compared to dry and MQL machining, but all three techniques resulted in comparable quality after 4 min of machining.

Jamadar Afaqahmed Mushtaqahmed ,Prof. Shinde Vilas B. 18 MAY, 2012

Many authors have investigated the machinability with coolant in machining with flood coolant, MQL and cryogenic cooling and it is observed that surface finish, cutting forces, chip formation and tool wear are all affected with the type of coolant, cutting speed, feed rate and depth of cut. Very little investigation in water vapor as coolant is available in the literature hence the water vapor as a coolant has been selected to explore the machinability of titanium alloy with the introduction of this environmental friendly coolant.

M. Bicek , F. Dumont b, C. Courbonb, F. Pusavec , J. Rechb, J. Kopac 19 JULY, 2015

The current drive for achieving the implementation of sustainability concepts in manufacturing calls for sustainable machining practices to be adopted. A key area of research is the search for environmentally benign cooling strategies. Vegetable oils have often been proposed as sustainable alternatives to the conventional synthetic emulsion coolants.Techniques like dry and cryogenic machining, minimum quantity lubrication(MQL) and minimum quantity cooled lubrication (MQCL) current study investigates the effect of six different strategies on the flank tool wear, surface roughness and energy consumption during turning of titanium Ti-6Al-4V using uncoated carbide tool at certain speed and feed. The use of rapeseed vegetable oil in MQL and MQCL configuration turns out to be an overall sustainable alternative. Thus confirming the promise predicted in the use of vegetable oil as a lubricant for machining

Shoujin, Milan Brandt, Suresh Palanisamy, Matthew S. Dargusch 15 JULY, 2014

It is found that the application of cryogenic compressed air dramatically increased tool life compared with dry machining, and the increase in tool life was more significant at higher cutting speed as the plastic deformation of cutting edge that occurred during dry machining was suppressed during machining with cryogenic compressed air cooling.

The improvement of tool life with application of cryogenic compressed air cooling during machining is attributed to the low temperature and high pressure of cryogenic air jet, which leads to the reduction in cutting temperature due to the enhanced cooling and reduction in tool-chip contact length. Low cutting temperature results in reducing wear rate, size of chip built-up edge and maintaining the strength of the cutting edge in order to resist plastic deformation.

3.3 Cutting Parameters

Dong Yang, Zhanqiang Liu' 15 JULY, 2004

The experimental results have shown that the main forms of surface defect in peripheral milling of Ti–6Al–4V are feed marks, scratch marks, adhered material particles, etc. The high quality of the machined surface can be obtained in the combined conditions with high cutting speed, low feed and small radial depth of cut. Auto-correlation analysis is used to describe the spatial relation dependence of the surface topography, the direction and periodicity of the surface texture. Increasing cutting speed is helpful to reduce the random components in the auto-correlation spectra of the machined surfaces. However, increasing feed rate has the opposite effect. Radial depth of cut has no significant influence on auto-correlation spectra in finish milling.

G. Sutter , G. List 29 AUGUST, 2008

A transition, from serrated more or less regular with localized shearing and possible presence of cracking, to discontinuous at very high speed is observed. The cutting speed appears as the most important factor when compared with the uncut chip thickness, in determining the formation of chips by affecting the frequency of segmentation, the shear angles and the crack length.

L.-J. Xiea, J. Schmidta, C. Schmidta, F. Biesingerb 2011

In this paper, modeling techniques on continuous chip formation by using the commercial FEM code ABAQUS are discussed. A combination of three chip formation analysis steps including initial chip formation, chip growth and steady-state chip formation, is used to simulate the continuous chip formation process. Steady chip shape, cutting force, and heat flux at tool/chip and tool/work interface are obtained. Further, after introducing a heat transfer analysis, temperature distribution in the cutting insert at steady state is obtained. In this way, cutting process variables e.g. contact pressure (normal stress) at tool/chip and tool/work interface, relative sliding velocity and cutting temperature distribution at steady state are predicted.

4. Objective

Owing to environmental concerns and growing regulations over contamination and pollution, the demand for renewable and biodegradable cutting fluids is rising. In this work, an attempt is made regarding of green machining including the cutting fluid type as well as the methods to apply the cutting fluids in machining process.

The effect of cutting fluid (refrigerated air in this case) on the product quality in terms of chip thickness ratio, surface topography and surface roughness is investigated. Our area of consult is chip thickness ratio as it is the factor that decides the surface topography and surface roughness.

In this work we analysed the values of chip thickness ratio, obtained from experimental results . After analysing, we got the best combination of speed and feed rate that would give optimum chip thickness ratio that would in turn give good surface finish.

5. Methodology

5.1 Experimental work

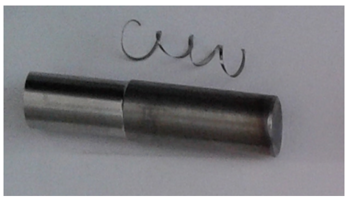
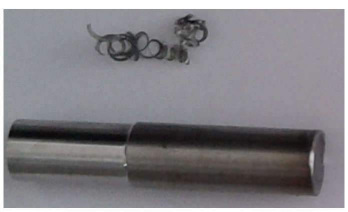
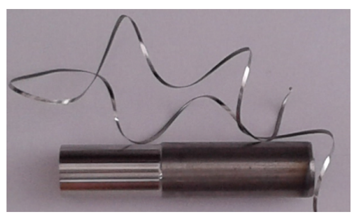
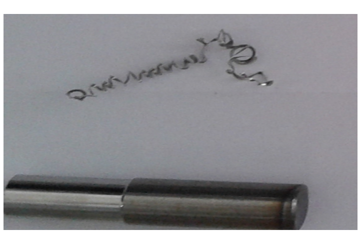
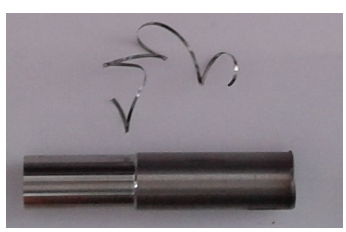
1)Speed – 60 , Feed rate – 0.08 	2)Speed – 60, Feed rate – 0.16 	3)Speed – 60, Feed rate – 0.32 
4)Speed – 120, Feed rate – 0.08 	5)Speed – 120 , Feed rate – 0.16 	6)Speed – 120 , Feed rate -0.32 
7)Speed – 180, Feed rate – 0.08 	8)Speed – 180, Feed rate – 0.16 	9)Speed – 180, Feed rate – 0.32 

Fig7: **Nine pieces of Ti Alloys at different speed and feed rate**

Sample no.1 Sr.no.	**Chip thickness** mm	**Chip width** mm	**Chip cross section area** mm^2	**Chip thickness ratio**
01	0.13	0.92	0.119	1.538
02	0.21	1.01	0.121	0.952
03	0.33	1.13	0.372	0.606
04	0.12	0.94	0.112	1.667
05	0.30	0.99	0.297	0.667
06	0.33	1.06	0.349	0.606
07	0.11	0.95	0.104	1.818
08	0.18	1.02	0.183	1.111
09	0.32	1.10	0.352	0.625

Sample no.02 Sr.no**.**	**Chip thickness**	**Chip width**	**Chip cross section area**	**Chip thickness ratio**
01	0.10	0.97	0.097	2.000
02	0.25	0.99	0.247	0.800
03	0.32	1.04	0.332	0.625
04	0.40	1.09	0.436	0.500
05	0.21	0.96	0.201	0.952
06	0.33	1.08	0.356	0.606
07	0.12	0.89	0.106	1.667
08	0.24	1.02	0.244	0.834
09	0.37	1.07	0.395	0.540

5.2 DOE (Design Of Experiments)

Design of experiments (DOE) is a systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output.

In its simplest form, an experiment aims at predicting the outcome by introducing a change of the preconditions, which is reflected in a variable called the predictor. The change in the predictor is generally hypothesized to result in a change in the second variable, hence called the outcome variable. Experimental design involves not only the selection of suitable predictors and outcomes, but planning the delivery of the experiment under statistically optimal conditions given the constraints of available resources.

Main concerns in experimental design include the establishment of validity, reliability, and replicability. For example, these concerns can be partially addressed by carefully choosing the predictor, reducing the risk of measurement error, and ensuring that the documentation of the method is sufficiently detailed. Related concerns include achieving appropriate levels of statistical power and sensitivity.

5.3 Taguchi based Design of experiments

Taguchi design can be use as the most powerful DOE methods for analyzing experiment. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulates the way of conducting the minimal number of experiments which could give the full information of all the factors that affect the performance parameter. It is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipments and facilities. A simple, efficient and systematic method to optimize product/process to improve the performance or reduce the cost. Therefore the Taguchi method has great potential in area of low cost experimentation . Thus it becomes an attractive and widely accepted tool to engineers and scientists [23].

Taguchi method based design of experiments involves following steps :

a)Definition of the problem.

b)Identification of noise factors.

c)Selection of response variables.

d)Selection of control parameter and their levels.

e)Selection of orthogonal array.

f)Identification of control factor interaction.

g)Conducting the matrix experiments.

h)Analysis of the data and prediction of optimum level.

a)Definition of problem.

Maximizing chip thickness ratio of Ti-alloy [Ti6Al4V] in high speed turning process using refrigerated air as coolant.

b)Identification of noise factors.

The environment in which experiments are performed is the main external source of performance of turning processes . Some examples of the environmental noise factors are temperature , vibrations and human errors in operating the process.

c)Selection of response variables .

The most important measures of surface quality during the machining process is the chip thickness ratio, hence chosen as response variable.

d)Selection of control parameter and their levels.

The chip thickness ratio is mostly affected by many machining parameters such as true rake angle and side cutting edge angle , cutting speed ,feed rate ,depth of cut ,nose radius ,machining time etc. Among above parameter selection cutting speed , feed rate as control parameter for experimentation. And these control parameter will be operated on **three** levels**.**

e) Selection of orthogonal array

Minimum number of experiments = L^K

Where ,

L= Number of levels.

K=Control parameters

Here 3^2=9 experiments i.e. L9 array , hence required minimum number of experiments to be conducted (9) , the nearest orthogonal Array fulfilling this condition is L9 .

Sr. No.	Cutting Speed (m/min)	Feed Rate (mm/rev)
1	60	0.08
2	60	0.16
3	60	0.32
4	120	0.08
5	120	0.16
6	120	0.32
7	180	0.08
8	180	0.16
9	180	0.32

f) Identification of control factor interaction .

1)Test specimen :

Ti-alloy rod (dia. 14 mm , length 60 mm)

COMPONENTS	Al	Fe	O	Ti	V
Wt. %	6	0.25 max	0.2 max	90	4

Hardness , Rockwell C = 36 (Metric)

Brinell = 334 (Metric)

2) Cutting tool :

The recently developed tool materials like coated carbides have improved the productivity levels of difficult to machine materials. Thus coated carbide tool reduces wear and tear between tool insert and work piece . Thus coated carbide tool is selected for turning of Ti-alloy .

g) Conducting the matrix experiments.

The above mentioned experiment can be carried out on CNC turning machine with precision and observations are carried out by using profile projector and digital vernier calliper .

h) Analysis of the data and prediction of optimum level.

For analysis above experiment minitab software can be use as it provides an effortless method to create , edit and update graphs. Also it provides a dynamic link between graphs and its worksheet that helps in updating the graph automatically whenever the data is changed . Its apperance and easy to use enhancements further add to its advantages.

Data analysis can be carried out as follows :

1) Computation of (Signal to Noise ration) S/N ratio of experimental data.

2) ANOVA is carried out to find out the contribution of each parameter on turning process.

3)The predicted optimal setting has been evaluated from mean response.

The salient features of the Taguchi method are as follows:

a. A simple, efficient and systematic method to optimize product/process to improve the performance or reduce the cost.
b. Help arrive at the best parameters for the optimal conditions with the least number of analytical investigations.
c. It is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipments and facilities.
d. Can include the noise factor and make the design robust.
e. Therefore, the Taguchi method has great potential in the area of low cost experimentation. Thus it becomes an attractive and widely accepted tool to engineers and scientists.

Taguchi defines three quality characteristics in terms of signal to noise (S/N) ratio which can be formulated for different categories which are as follows:

a. Nominal and small are best characteristics
Data sequence for surface finish and tool wear, which are lower-the-better performance characteristics, are pre processed as per equations.

S/N = -10 log (ŷ/s2y)………………….1,
S/N = -10 log ((l/n) (Σy2))…………..….2

b. Larger is best characteristics

Data sequence for chip thickness ratio, which is higher-the-better performance characteristics, is preprocessed as per equation 3.

S/N = -10 log ((1/n) (Σ (1/y2))……..…3,

Where, y is value of response variables and
n is the number of observations in the experiments.

6. Analysis

Analysis of the obtained results is done by two way approach

1. Taguchi Analysis

2. Regression Analysis

The Taguchi Analysis is done for sample no. 1 and because for regression we require more than one samples to do analysis, we do regression analysis for two samples, sample no. 1 and sample no. 2. The results obtained from both the analysis tools are compared with each other for the purpose of accuracy.

6.1 Taguchi

Taguchi Orthogonal Array Design

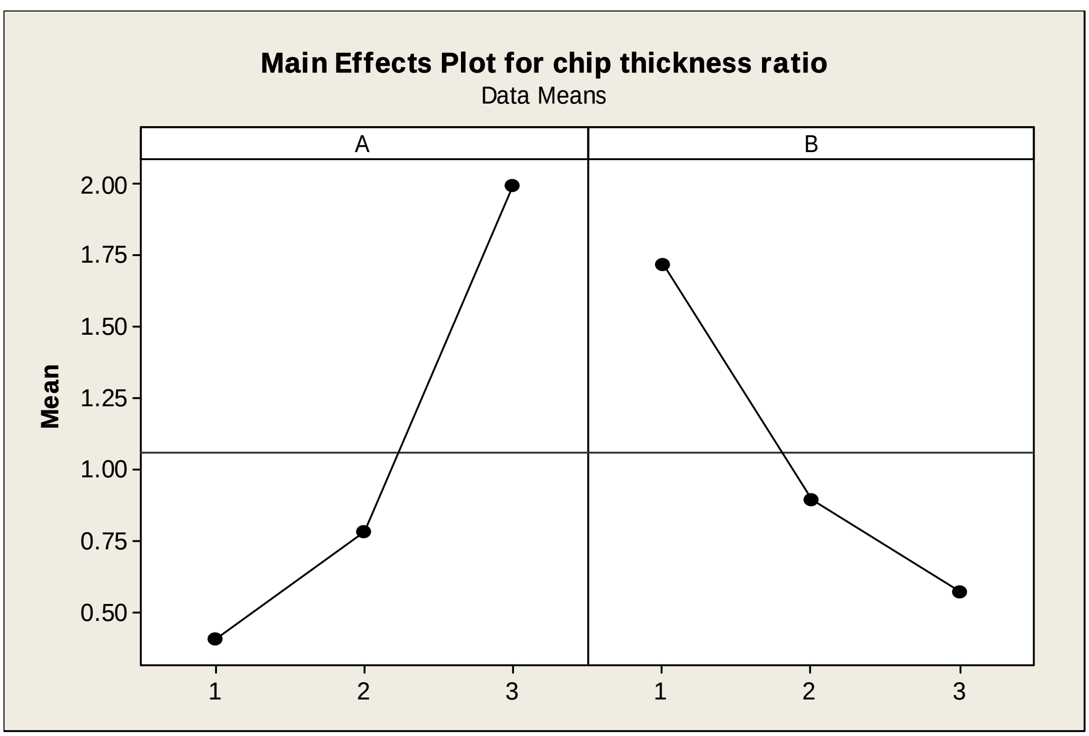
L9(3**2)

Factors: 2

Runs: 9

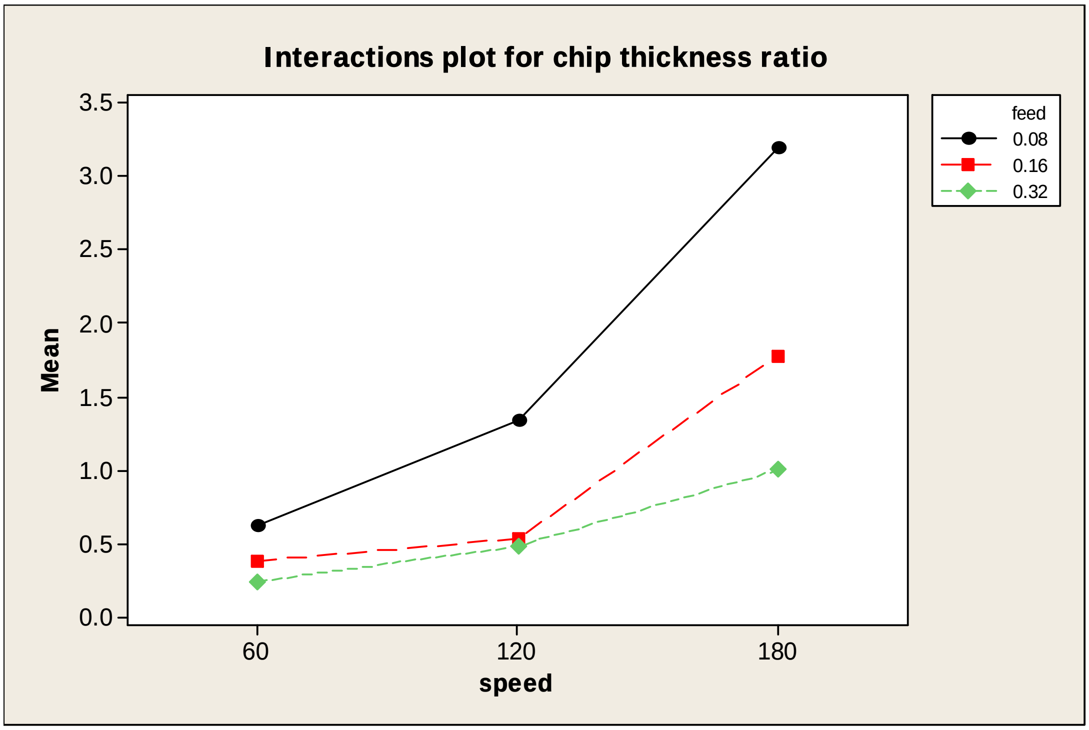
Columns of L9(3**4) Array

1 2



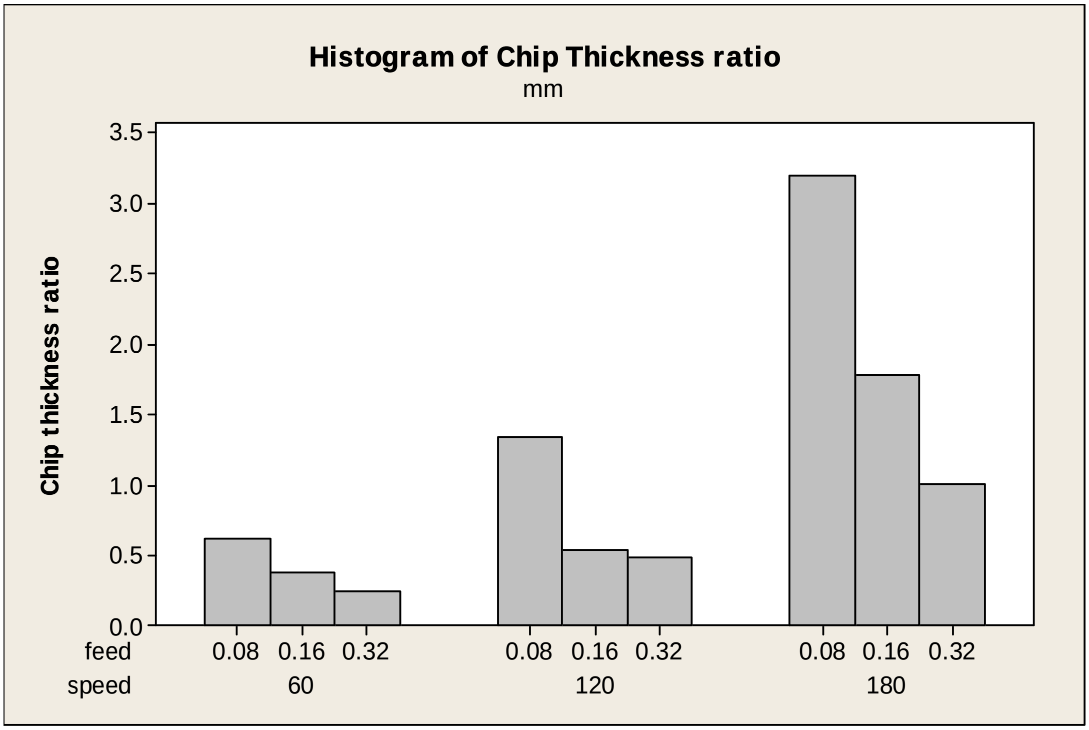
The graph shows the variation in chip thickness ratio with A (SPEED) and B (FEED RATE). The graph shows the chip thickness ratio varies linearly with cutting speed . The change in chip thickness ratio is very low between speeds 60 m/s and 120 m/s. Further increase in cutting speed increases the chip thickness ratio drastically.

The relation of chip thickness ratio with feed rate is also linear. Chip thickness ratio linearly decreases with increase in feed rate. With increase in feed rate from 0.08 mm/rev to 0.16 mm/rev the chip thickness ratio decreases with a great amount. Further increase in feed rate to 0.32 mm/rev gives a small change in chip thickness ratio.



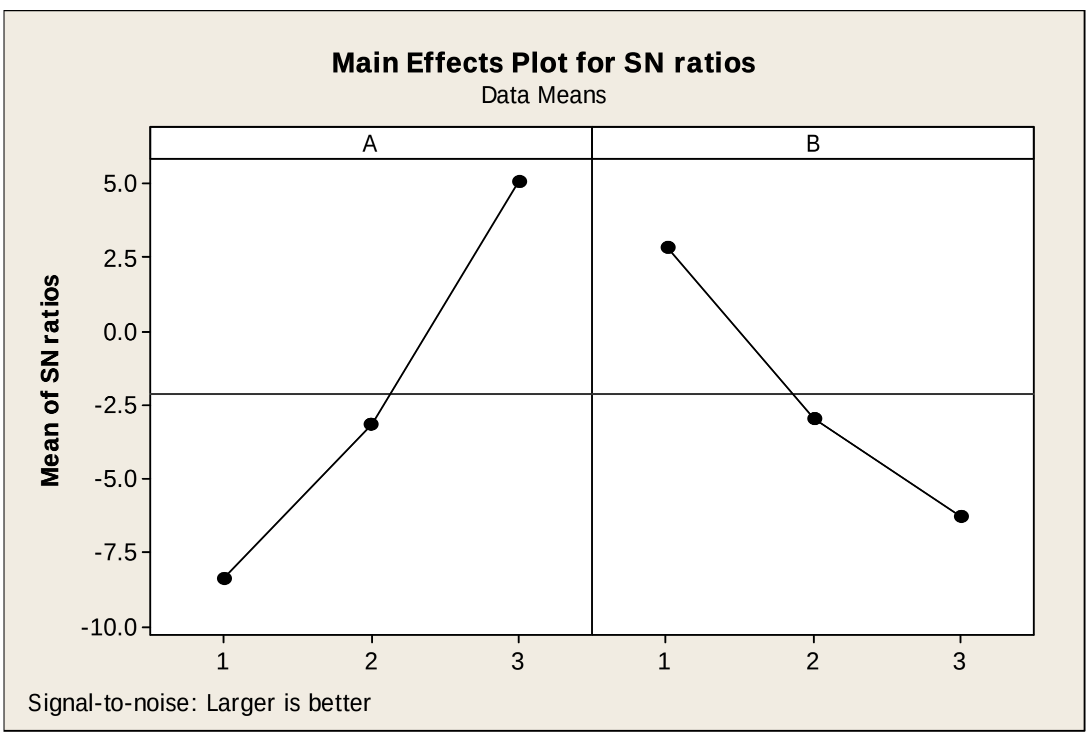
The graph shows the interaction of chip thickness ratio with cutting speed and feed rate . Its evident from the graph that the chip thickness ratio has a linear dependency with cutting speed and feed rate. There is a very little increase in chip thickness ratio at the speed 60 m/s at feed rate varying from 0.08 to 0.32 mm/rev. The chip thickness ratio increases greatly by increasing feed rate from 0.08 to 0.32 mm/rev by keeping speed constant at 180 m/s and reaches to maximum value at feed rate 0.08 mm/rev.

Also, it is seen from the graph that at the speed 120 m/s feed rates 0.16 and 0.32 interact closely.



The graph shows that at a particular speed by increasing the feed rate, the chip thickness ratio goes on decreasing. Chipthickness ratio is highest at speed and feed rate 180 m/s and 0.08 mm/rev respectively.

Taguchi Analysis: chip versus A, B

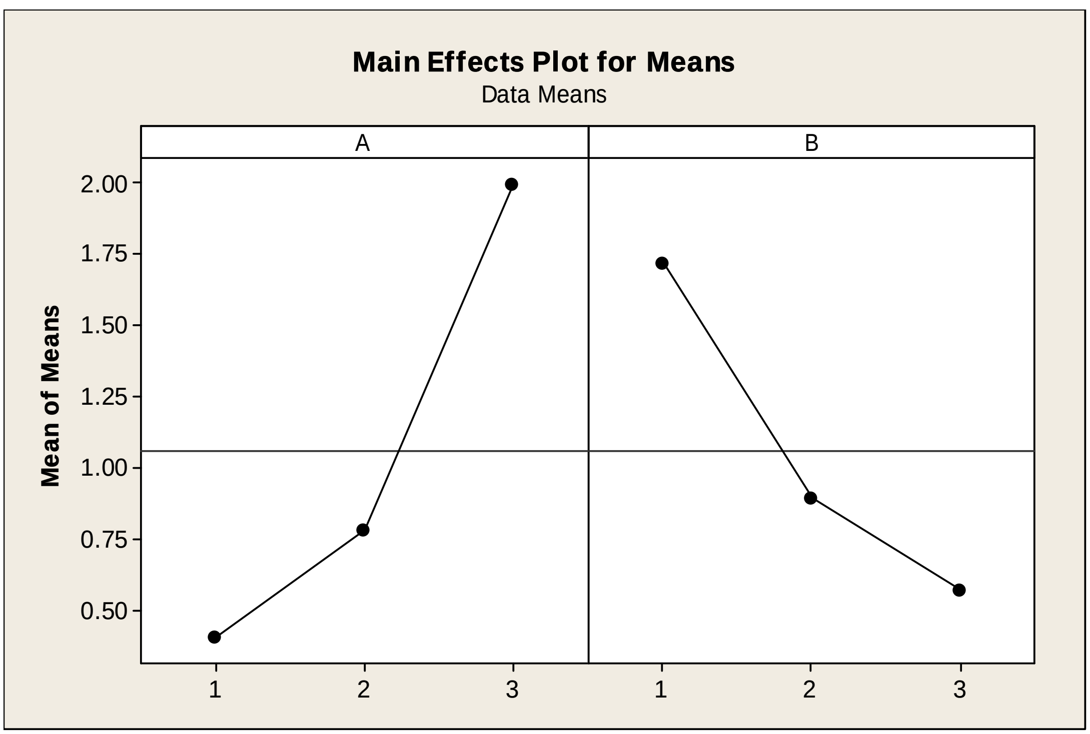


Response Table for Signal to Noise Ratios

Larger is better.

Level	A	B
1	-8.314	2.808
2	-3.116	-2.970
3	5.037	-6.257
Delta	13.378	9.065
Rank	1	2

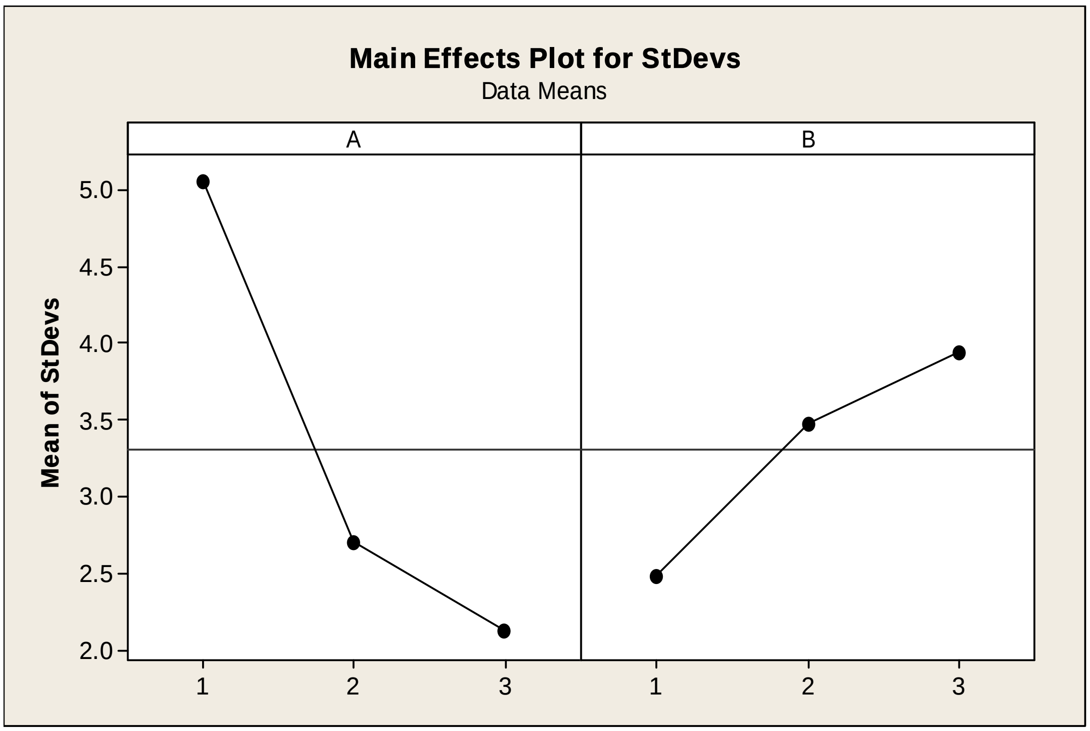
The response table for S/N ratio shows a Rank 1 in the parameter A i.e., speed. Hence, this resembles the significant effect of speed in machining process as compared to feed rate.



Response Table for Means

Level	**A**	B
1	0.4117	1.7183
2	0.7833	0.8967
3	1.9933	0.5733
Delta	1.5817	1.1450
Rank	1	2

5.2.Taguchi Analysis: chip thickness ratio, SNRA1, MEAN1 versus A, B



Response Table for Standard Deviations

Level	A	B
1	5.053	2.491
2	2.714	3.475
3	2.142	3.943
Delta	2.911	1.453
Rank	1	2

6.2 ANOVA

Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences among group means and their associated procedures (such as "variation" among and between groups), developed by statistician and evolutionary biologist Ronald Fisher. In the ANOVA setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are equal, and therefore generalizes the t-test to more than two groups. ANOVAs are useful for comparing (testing) three or more means (groups or variables) for statistical significance. It is conceptually similar to multiple two-sample t-tests, but is less conservative (results in less type I error) and is therefore suited to a wide range of practical problems.

5.3.Two-way ANOVA: chip thickness ratio versus A, B

A	B	Chip thickness ratio	S/N RA	MEAN1	STDE1
1	1	0.615	-4.2225	0.615	2.79293
1	2	0.380	-8.4043	0.380	5.07163
1	3	0.240	-12.3958	0.240	7.29527
2	1	1.340	2.5421	1.340	0.69403
2	2	0.530	-5.5145	0.530	3.48978
2	3	0.480	-6.3752	0.480	3.95784
3	1	3.200	10.1030	3.200	3.98545
3	2	1.780	5.0084	1.780	1.86392
3	3	1.000	0.0000	1.000	0.57735

Source	DF	SS	MS	F	P
A	2	4.10391	2.05195	8.77	0.034
B	2	2.09071	1.04535	4.47	0.096
Error	4	0.93544	0.23386		
Total	8	7.13006			
R-Sq	86.88%				

S = 0.4836 R-Sq = 86.88% R-Sq(adj) = 73.76%

The p value is an indication of the significance of a particular parameter in a process or product. A p-value below 0.05 shows that we can reject the null hypothesis. A p-value above 0.05 shows that we cannot reject the null hypothesis. The p-value in the par A p-value below 0.05 shows that we can reject the null hypothesis. The p-value in the parameter B is 0.096 which is above the value 0.05, hence we cannot reject the null hypothesis.

6.3 Regression analysis

In statistical modeling, **regression analysis** is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables (or 'predictors'). More specifically, regression analysis helps one understand how the typical value of the dependent variable (or 'criterion variable') changes when any one of the independent variables is varied, while the other independent variables are held fixed. Most commonly, regression analysis estimates the conditional expectation of the dependent variable given the independent variables – that is, the average value of the dependent variable when the independent variables are fixed. Less commonly, the focus is on a quantile, or other location parameter of the conditional distribution of the dependent variable given the independent variables. In all cases, the estimation target is a function of the independent variables called the **regression function**. In regression analysis, it is also of interest to characterize the variation of the dependent variable around the regression function which can be described by a probability distribution.

Regression analysis is widely used for prediction and forecasting, where its use has substantial overlap with the field of machine learning. Regression analysis is also used to understand which among the independent variables are related to the dependent variable, and to explore the forms of these relationships

Many techniques for carrying out regression analysis have been developed. Familiar methods such as linear regression and ordinary least squares regression are parametric, in that the regression function is defined in terms of a finite number of unknown parameters that are estimated from the data. Nonparametric regression refers to techniques that allow the regression function to lie in a specified set of functions, which may be infinite-dimensional.

Linear regression calculates an equation that minimizes the distance between the fitted line and all of the data points.

Sample 1:

The regression equation is

chip = 2.71 - 0.0180 speed + 5.95 feed

Predictor	Coef	SE Coef	T	P
Constant	2.7083	0.4967	5.45	0.002
speed	-0.017969	0.003129	-5.74	0.001
feed	5.952	1.536	3.87	0.008
R-Sq	88.9%			

S = 0.459850   R-Sq = 88.9%   R-Sq(adj) = 85.2%

A p-value below 0.05 shows that we can reject the null hypothesis. A p-value above 0.05 shows that we cannot reject the null hypothesis. The p-value in the parameter A is 0.001 which is below the value 0.05, hence we can reject the null hypothesis. The p-value in the parameter B is 0.008 which is also below the value 0.05, hence we can reject the null hypothesis.

R-squared is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination

The definition of R-squared is fairly straight-forward; it is the percentage of the response variable variation that is explained by a linear model. Or:

R-squared = Explained variation / Total variation

R-squared is always between 0 and 100%:

- 0% indicates that the model explains none of the variability of the response data around its mean.
- 100% indicates that the model explains all the variability of the response data around its mean.

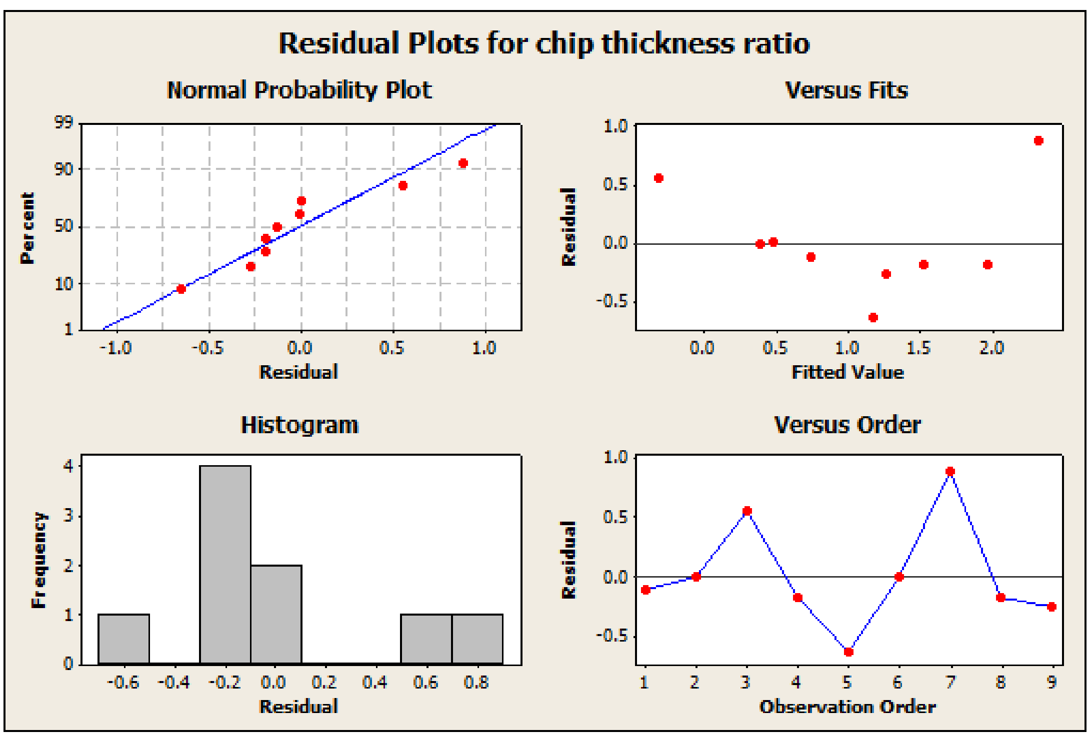
In general, the higher the R-squared, the better the model fits your data.

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	10.1489	5.0744	24.00	0.001
Residual Err	6	1.2688	0.2115		
Total	8	11.4177			

The contribution of speed is 90.09 %

Source	DF	Seq SS
speed	1	6.9742
feed	1	3.1747



Sample 2:

The regression equation is

chip thickness ratio = 0.259 + 0.00973 speed - 2.95 feed

Predictor	Coef	SE Coef	T	P
Constant	0.2592	0.5763	0.45	0.669
speed	0.009733	0.003631	2.68	0.036
feed	-2.950	1.783	-1.65	-1.65

S = 0.533573 R-Sq = 62.3% R-Sq(adj) = 49.8%

The p-value in the parameter A is 0.036 which is below the value 0.05, hence we can reject the null hypothesis. The p-value in the parameter B is 0.149 which is also below the value 0.05, hence we can reject the null hypothesis.

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	2.8259	1.4130	4.96	0.053
Residual Err	6	1.7082	0.2847		
Total	8	4.5341			

The contribution of speed is 62.3 %

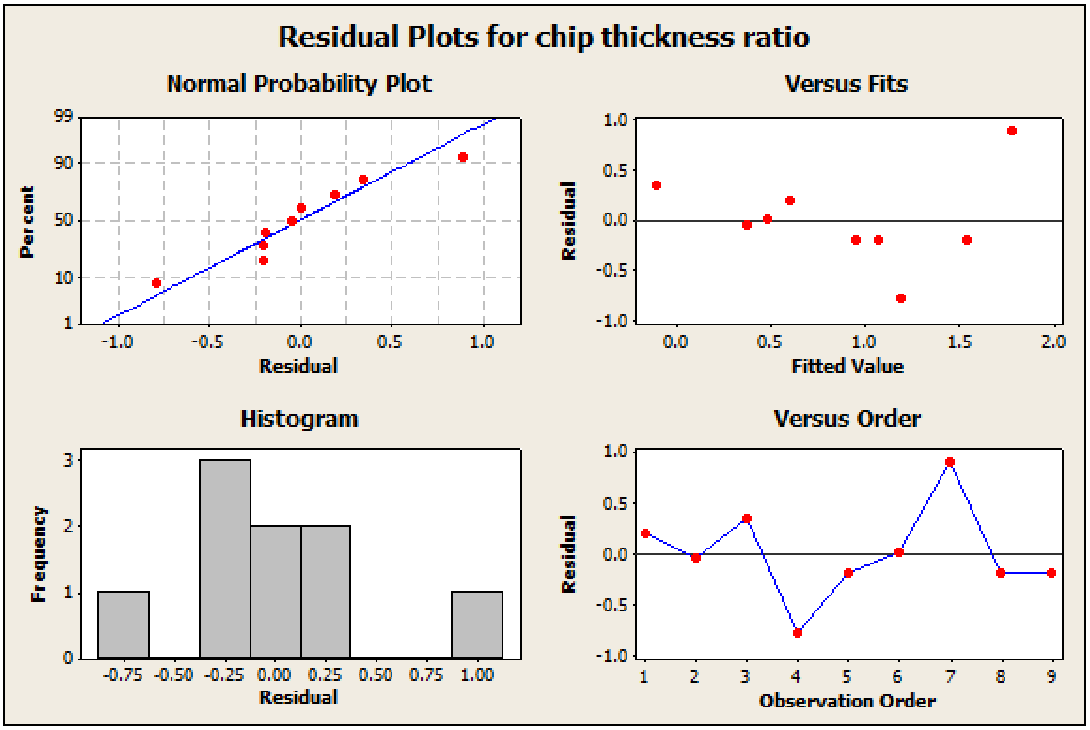
Source	DF	Seq SS
speed	1	2.0463
feed	1	0.7796

Unusual Observations

Obs	Speed	Chip Thickness Ratio	Fit	SE Fit	Residual	St Residual
7	180	2.670	1.775	0.339	0.895	2.17R

R denotes an observation with a large standardized residual.

Unusual observations (also called influential observations) are observations that have a disproportionate impact on a regression or ANOVA model. Unusual observations are important to identify because they can produce misleading results. For example, an unusual observation can cause a significant coefficient to seem insignificant.



7. Conclusion

We have successfully studied and carried out the experimental work in the chip formation mechanism in machining of Ti-6Al-4V alloy and its influence on the quality of chip formed and its surface finish

Based on the analysis of chip formation,we have observed and investigated the following conclusions**:**

- ✓ The cutting parameters and the cooling medium used while machining process effects the mechanism of chip formation of Ti-6Al-4V alloy.
- ✓ Interaction of cutting speed with feed rate shows significant effect on the formation of chips.
- ✓ At lower and medium cutting speed of 60m/min and 120 m/min respectively, the chip thickness ratio is less. And while at higher cutting speed of 180m/min, it is higher.
- ✓ Feed rate has almost linear relationship with chip thickness ratio. Thus the chip thickness ratio increases with increase in the feed rate during machining.
- ✓ Higher chip width and chip thickness ratio is produced when feed rate(0.32 mm/rev) and cutting speed (180 m/min)are higher. However lower value of chip thickness ratio is obtained when the feed rate was at lowest level(0.08 mm/rev) and the cutting speed at the highest level(180m/min).

8. Future scope

Environmental and health friendly technologies with economic justification have nowadays an increasing importance in global industrial trends. Idea of global sustainable development issue is now to change the way mechanical components are being machined and move to alternative technologies that could moreover increase the machining performance. Cryogenic machining is one possibility to reach this goal. It consists of a system for cutting (turning, milling, etc.) assisted by liquid nitrogen, which enables a clean process with possible lower production costs and higher productivity.

There are large no of environmental and energy saving benefits associated with the replacement of traditional cooling method, with Minimum Quantities of Liquid (MQL) combined with cold compressed air. These are :

- The refrigerated air can also be used with vegetable oil blend for increasing the performance.
- Cutting forces can be reduced
- Multi holed nozzle can be used.

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