A PROJECT REPORT

ON

"SURFACE TOPOGRAPHICAL ANALYSIS IN HIGH SPEED MACHINING OF TITANIUM ALLOY (Ti-6Al-4V) USING REFRIGERATED AIR AS A COOLANT"

Submitted by

MAHIMI FAIZAAN LIYAQAT (13ME91)

FAROOQUI ASIF ALI YAAD ALI (13ME74)

SHAIKH MEHMOOD IBRAHIM (13ME114)

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

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ANJUMAN-I-ISLAM

KALSEKAR TECHNICAL CAMPUS NEW PANVEL

(Approved by AICTE, recg. By Maharashtra Govt. DTE,

Affiliated to Mumbai University)

PLOT #2&3, SECTOR 16, NEAR THANA NAKA, KHANDAGAON, NEW PANVEL,NAVI MUMBAI-410206, Tel.: +91 22 27481247/48 * Website: www.aiktc.org

CERTIFICATE

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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**
(Prof.____)	(Prof.______)	

Head of Department	**Principal**
(Prof. _____)	(Dr._______)

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APPROVAL OF DISSERTATION

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____________________ ____________________

Date: ___________

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MAHIMI FAIZAAN LIYAQAT (13ME91)
FAROOQUI ASIF ALI YAAD ALI (13ME74)
SHAIKH MEHMOOD IBRAHIM (13ME114)

ABSTRACT

High speed machining has been demonstrated to greatly improve the productivity of titanium alloys in manufacturing. There exists a concern that high speed machining of such alloys (Ti-6AL-4V) may leave surfaces detrimental to fatigue life. Hence titanium alloy magnifies the need for optimizing high performance of titanium machining. Current manufacturing trends require large usage of cutting fluid for lubrication during machining. This leads to increase the cost of production in industries and polluting the environment due to harmful additives present in the cutting fluids. With the aim to reduce cost and non-polluting coolant, refrigerated air as a coolant has been adopted by various machining application. In this work, the high speed turning of titanium alloy (Ti-6Al-4V) is carried using refrigerated air as a coolant .In order to maintain the good surface integrity and to improve the machinability of Ti-6Al-4V, experiment were conducted by varying different combination of speed & feed rate. The effect of machining parameters on surface damages, surface integrity & surface hardness were measured and analyzed.

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CHAPTER 1

INTRODUCTION

Titanium alloy is extensively used in the aerospace , biomedical and petroleum industries , because of their good strength to weight ratio , fatigue properties , fracture toughness and corrosion resistance . But , the problem arises to meet following applications, that it is difficult to machine them due to poor machinability and low thermal conductivity causes the heat remain at the tool / chip interface . The lower modulus of elasticity of titanium , leads to move away from cutting tool during machining . The lower hardness of titanium leads to galling with cutting tool ,thus changes the too geometry , this leads to too wear . In this research paper , we are analyzing surface hardness and surface topography of Ti-6Al-4V, by high speed machining on **CNC** lathe using different machining parameters such as speed and feed rate . Also finding which is the best combinations , which give satisfactory results.

Surface topography represent geometric as well as functional features of machined surface . Surface alterations such as surface damage, flaws , feed marks and cracks which leads to thermo mechanical deformation of the layer underneath the machined surface . Surface hardness is the property of material that enables it to resist plastic deformation, resistance to bending , scratching and abrasion .Owing to this reasons ,it is necessary to analyze it and improve the machining of titanium alloys.

Surface topography is qualitatively analyzed using scanning electron microscope ,which was conducted in **IIT BOMBAY SAIF DEPARTMENT** and surface hardness is quantitatively analyzed using **ROCKWELL HARDNESS TESTER** .Hence , an attempt has been made to find the optimum combinations of machining parameters to maximize surface hardness and to improve the surface texture. **TAGUCHI** approach was implemented to find the optimum machining parameters.

1.1 OBJECTIVES

- To study the effect of machining parameters such as cutting speed and feed rate on the surface topography of TI-alloys.
- To find out most influencing machining parameter in maximizing the surface hardness.
- To find out the best combination of cutting speed and feed rate which would give satisfactory result in optimizing the surface texture.
- To find the substitute for MQL and OIL coolants, this increases the cost of machining and pollution from the contaminated cutting fluid.
- To use refrigerated air as a coolant which reduces the cost of machining and it is a non-polluting coolant.

1.2 LITERATURE REVIEW

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.

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.

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.

1.3 PROBLEM DEFINITION

- Owing to environmental concerns and growing regulation over contamination and pollution, the demand for renewable and biodegradable cutting fluid is rising. In this work, and attempt is made regarding of green machining including the cutting fluid type as well as the method to apply the cutting fluid in machining process.
- The demand for high strength and low weight material in aerospace industry is found to be increasing in fabrication of structure and equipment of aircraft. Titanium alloy possesses characteristics of lightweight and high strength. The Ti-6Al-4V Series Titanium Alloy is the highest strength series for aircraft applications, But the problem faced by this material is that it is difficult to machining. This problem can be solved by finding out the best combination of machining parameters.
- A variety of surface defects and surface alterations are formed in machining of Ti-alloys.An attempt is made regarding,which machining parameters are the prominent limits which influences the occurrence and magnitude of the defects on the machined surface of Ti-alloys.

1.4 FLOW CHART

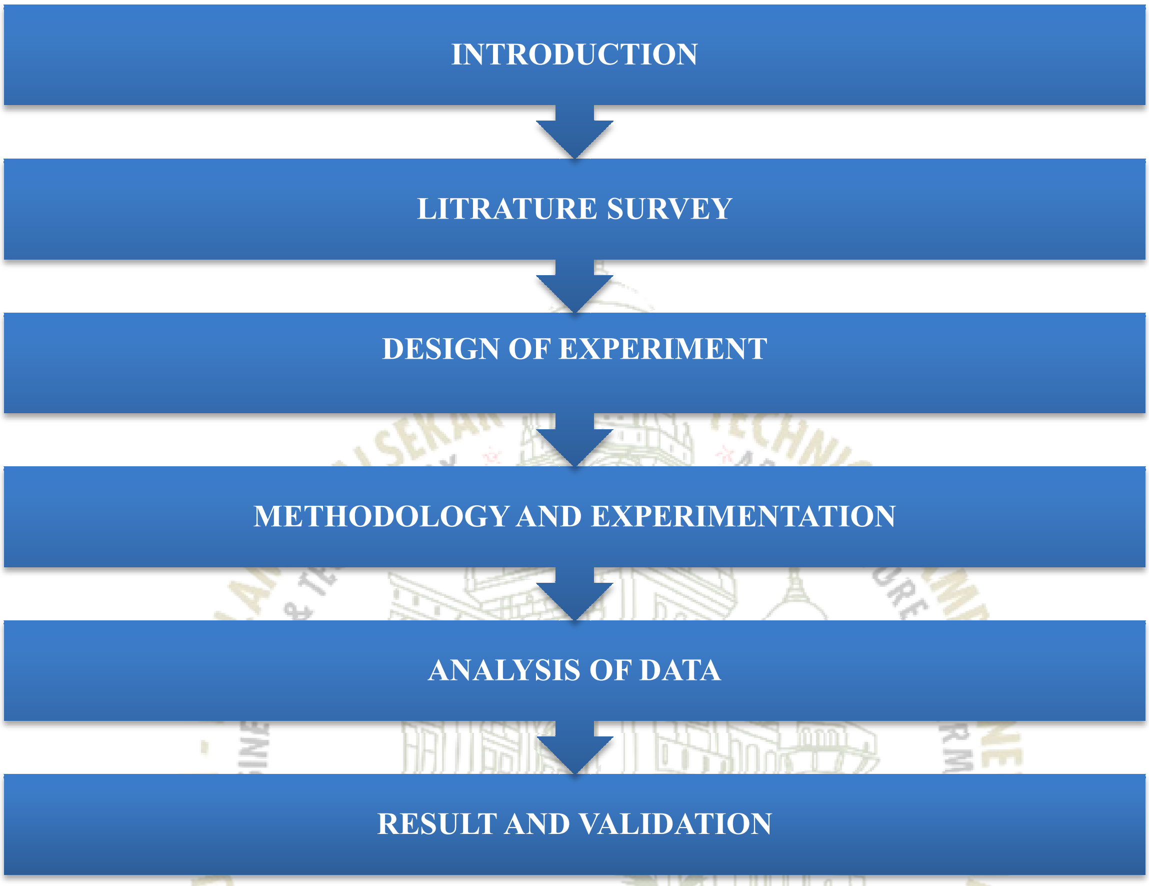


Fig no 1.1 Flow chart.

CHAPTER 2

METHODOLOGY OF PROJECT

2.1 Design of experiment (DOE)

(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.

Design of Experiments (DOE) usingthe Taguchi Approach is astandardized form of experimentaldesign technique (referred as classical DOE) introduced by R. A.Fisher in England in the early1920’s. As a researcher inJapanese Electronic ControlLaboratory, in the late 1940’s, Dr.Genichi Taguchi devoted much of his quality improvement effort onsimplifying and standardizing theapplication of the DOE technique.

Common areas of application of the technique are:

- Optimize Designs using analytical simulation studies
- Select better alternative in Development and Testing
- Optimize Manufacturing Process Designs

- Determine the best Assembly Method
- Solve manufacturing and production Problems

Design techniques, you couldimprove the performances of yourproduct and process designs in thefollowing ways:

- Improve consistency ofperformance and save cost

- Build insensitivity(Robustness) towards theuncontrollable factors

A designed experiment is a test or series of tests in which purposeful changes are made to the input variables of a process or system so that we may observe and identify the reasons for changes in the output response. For example, *Figure 5.4.3* depicts a process or system under study. The process parameters x_1, x_2, x_3, …, x_p are controllable, whereas other variables z_1, z_2, z_3, …,$z_q$are uncontrollable. The term y refers to the output variable. The objectives of the experiment are stated as:

• Determining which variables are most influential on the response, y.

• Determining where to set the influential x's so that y is almost always near the desired nominal value.

• Determining where to set the influential x's so that variability in y is small.

• Determining where to set the influential x's so that the effects of the uncontrollable z_1, z_2 …z_q are minimized.

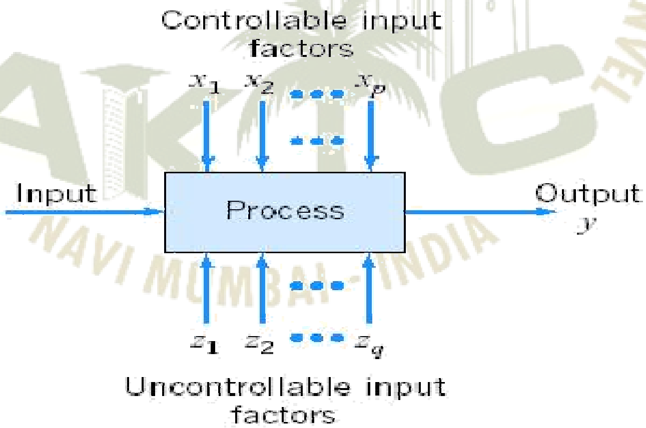


Fig no 2.1 i/p and o/p factors.

Experimental design is used as an important tool in numerous applications. For instance, it is used as a vital tool in improving the performance of a manufacturing process and in the engineering design activities. The use of the experimental design in these areas results in products those are easier to manufacture, products that have enhanced field performance and reliability, lower product cost, and short product design and development time.

Guidelines for designing experiments

- Recognition and statement of the problem.
- Choice of factors and levels.
- Selection of the response variable.
- Choice of experimental design.
- Performing the experiment.
- Data analysis.
- Conclusions and recommendations.

i. Taguchi Method

Taguchi designs are used for robust parameter design, in which the primary goal is to find factor settings that minimize response variation, while adjusting (or keeping) the process on target. Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions.

Taguchi method is based on performing evaluation or experiments to test the sensitivity of a set of response variables to a set of control parameters (or independent variables) by considering experiments in "orthogonal array" with an aim to attain the optimum setting of the control parameters. Orthogonal arrays provide a best set of well balanced (minimum) experiments. An array name indicates the number of rows and columns it has, and also the number of levels in each of the columns. For example, array L4 (23) has four rows and three "2 level" columns. Similarly, the array L18 (2137) has 18 rows; one "2 level" column; and seven "3 level" columns. Thus, there are eight columns in the array L18. The number of rowsof an orthogonal array represents the requisite number of experiments. The number of rows must be at least equal to the degrees of the freedom associated with the factors i.e. the control variables. In general, the number of degrees of freedom associated with a factor (control variable) is equal to the number of levels for that factor minus one. For example, a case study has one factor (A) with “2 levels” (A), and five factors (B, C, D, E, F) each with “3 level”. Table 5.4.2 depicts the degrees of freedom calculated for this case. The number of columns of an array represents the maximum number of factors that can be studied using that array.

Taguchi's techniques have been used widely in engineering design (Ross 1996 & Phadke 1989). TheTaguchi method contains system design, parameter design, and tolerance design procedures toachieve a robust process and result for the best product quality (Taguchi 1987 & 1993). The main trustof Taguchi's techniques is the use of parameter design (Ealey Lance A.1994), which is an engineeringmethod for product or process design that focuses on determining the parameter (factor) settingsproducing the best levels of a quality characteristic (performance measure) with minimum variation. Taguchi designs provide a powerful and efficient method for designing processes that operateconsistently and optimally over a variety of conditions. To determine the best design, it requires theuse of a strategically designed experiment, which exposes the process to various levels of designparameters.

Experimental design methods were developed in the early years of 20th century and have beenextensively studied by statisticians since then, but they were not easy to use by practitioners (Phadke1989). Taguchi's approach to design of experiments is easy to be adopted and applied for users withlimited knowledge of statistics; hence it has gained a wide popularity in the engineering andscientific community. Taguchi specified three situations:

- Larger the better (for example, agricultural yield);
- Smaller the better (for example, carbon dioxide emissions); and
- On-target, minimum-variation (for example, a mating part in an assembly).

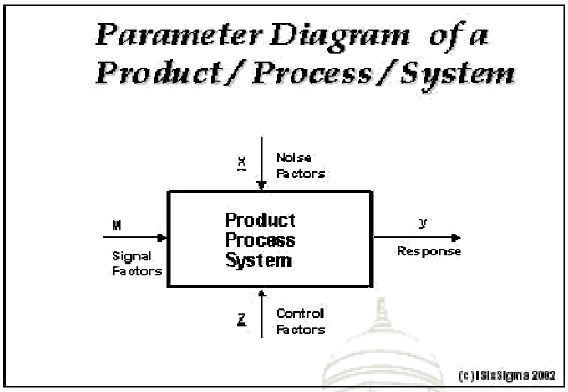


Fig no 2.2 Parameter diagram of process chart .

Eight-Steps in Taguchi Methodology:

Step-1: Identify the main function, side effects, and failure mode

Step-2: Identify the noise factors, testing conditions, and quality characteristics

Step-3: Identify the objective function to be optimized

Step-4: Identify the control factors and their levels

Step-5: Select the orthogonal array matrix experiment

Step-6: Conduct the matrix experiment

Step-7: Analyse the data, predict the optimum levels and performance

Step-8: Perform the verification experiment and plan the future action

Methodology Used: Taguchi Techniques

Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions is based on "ORTHOGONALARRAY" experiments which gives much reduced "variance" for the experiment with “optimumsettings “of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays"(OA) provide a set of well balanced (minimum)experiments & desired output, serve as objectivefunctions for optimization, help in data analysis and prediction of optimum results.

Mathematical modelling:

“ORTHOGONAL ARRAYS “(OAs) experimentsUsing OAs significantly reduces the number of experimental configurations to be studiedMontgomery, (1991). The effect of many different parameters on the performance characteristic in aprocess can be examined by using the orthogonal array experimental design proposed by Taguchi .Once the parameters affecting a process that can be controlled have been determined, the levels at which these parametersshould be varied must be determined. Determining what levels of a variableto test requires an in-depth understanding of the process, including the minimum, maximum, and current value of the parameter. If the difference between the minimum and maximum value of aparameter is large, the values being tested can be further apart or more values can be tested. If therange of a parameter is small, then less value can be tested or the values tested can be closer together.

Design of Experiment (DOE's) Requires Planning

1. Design and Communicate the Objective:
2. Define the Process:
3. Select a Response and Measurement System:
4. Ensure that the Measurement System is Adequate:
5. Select Factors to be studied:
6. Select the Experimental Design:
7. Set Factor Levels:
8. Final Design Considerations:

ii. Signal to Noise (S/N) Ratio

There are three forms of signal to noise (S/N) ratio that are of common interest for optimization of static problems.

[1]Smaller-the-better

This is expressed as

n=-10Log10[mean of sum of squares of measured data]

This is usually the chosen S/N ratio for all the undesirable characteristics like "defects" forwhich the ideal value is zero. When an ideal value is finite and its maximum or minimumvalue is defined (like the maximum purity is 100% or the maximum temperature is 92 K orthe minimum time for making a telephone connection is 1 sec) then the difference betweenthe measured data and the ideal value is expected to be as small as possible. Thus, the genericform of S/N ratio becomes,

n=-10Log10 [mean of sum of squares of {measured-ideal}]

[2]Larger-the-better

n=-10Log10 [datameasuredof reciprocalofsquaresofsumofmean]

This is often converted to smaller-the-better by taking the reciprocal of the measured data and next, taking the S/N ratio as in the smaller-the-better case.

[3] Nominal-the-best

This is expressed as

n=-10Log10 [square of mean/variance]

This case arises when a specified value is the most desired, meaning that neither a smaller nor a larger value is desired.

iii. Orthogonal Array

Orthogonal Arrays (often referred to Taguchi Methods) are often employedin industrial experiments to study the effect of several control factors. Popularized by G. Taguchi. Other Taguchi contributions include:

- Model of the Engineering Design Process
- Robust Design Principle
- Efforts to push quality upstream into the engineering design process

An orthogonal array is a type of experiment where the columns for theindependent variables are "orthogonal" to one another.

Benefits:

1. Conclusions valid over the entire region spanned by the control factors and their settings
2. Large saving in the experimental effort
3. Analysis is easy

1. Number of factors to be studied
2. Levels for each factor
3. The specific 2-factor interactions to be estimated
4. The special difficulties that would be encountered in running theexperiment

We know that with two-level full factorial experiments, we can estimatevariable interactions. When two-level fractional factorial designs are used,we begin to confound our interactions, and often lose the ability to obtain confused estimates of main and interaction effects.. The information they provide is a function of two things

- The nature of confounding.
- Assumptions about the physical system.
- Selection of proper Orthogonal array depends on the computation of total degree of freedom. The number of comparison made between the levels to know which is better is called Degree of Freedom. For example, a three level process parameters can be compared with two other levels, hence the degree of freedom is two.

EXPERIMENT NO	**SPEED**	**FEED**	**DEPTH OF CUT**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	1
5	2	2	2
6	2	3	3
7	3	1	1
8	3	2	2
9	3	3	3

Table no 2.1 EXPERIMENTAL FORMATION .

iv. Analysis of Variance (ANNOVA)

ANOVA is a statistical method that stands for analysis of variance. ANOVA was developed by Ronald Fisher in 1918 and is the extension of the t and the z test. Before the use of ANOVA, the t-test and z-test were commonly used. But the problem with the T-test is that it cannot be applied for more than two groups. In 1918, Ronald Fisher developed a test called the analysis of variance. This test is also called the Fisher analysis of variance, which is used to do the analysis of variance between and within the groups whenever the groups are more than two. If you set the Type one error to be .05, and you had several groups, each time you tested a mean against another there would be a .05 probability of having a type one error rate. This would mean that with six T-tests you would have a 0.30 (.05×6) probability of having a type one-error rate. This is much higher than the desired .05.

ANOVA creates a way to test several null hypotheses at the same time.

The logic behind this procedure has to do with how much variance there is in the population. It is likely he researcher will not know the actual variance in the population but they can estimate this by sampling and calculating the variance in the sample. You compare the differences in the samples to see if they are the same or statistically different while still accounting for sampling error.

General Purpose of ANOVA:

These days, researchers are using ANOVA in many ways. The use of ANOVA depends on the research design. Commonly, researchers are using ANOVA in three ways: one-way ANOVA, two-way ANOVA, and N-way Multivariate ANOVA.

One-Way: When we compare more than two groups, based on one factor (independent variable), this is called one-way ANOVA. For example, it is used if a manufacturing company wants to compare the productivity of three or more employees based on working hours. This is called one-way ANOVA.

Two-Way:When a company wants to compare the employee productivity based on two factors (2 independent variables), then it said to be two way (Factorial) ANOVA. For example, based on the working hours and working conditions, if a company wants to compare employee productivity, it can do that through two-way ANOVA. Two-way ANOVA's can be used to see the effect of one of the factors after controlling for the other, or it can be used to see the interaction between the two factors. This is a great way to control for extraneous variables, as you are able to add them to the design of the study.

Factorial ANOVA can be balanced or unbalanced. This is to say, you can have the same number of subjects in each group (balanced) or not (unbalanced). This can come about, depending on the study, as just a reflection of the population, or an unwanted event such as participants not returning to the study. Not having equal sizes groups can make it appear that there is an effect when this may not be the case. There are several procedures a researcher can do in order to solve this problem:

Discard cases (undesirable): Conduct a special kind of ANOVA, which can deal with the unbalanced design

There are three types of ANOVA's that can candle an unbalanced design. These are the Classical Experimental design (Type 2 analysis), the Hierarchical Approach (Type 1 analysis), and the Full regression approach (Type 3 analysis). Which approach to use depends on whether the unbalanced data occurred on purpose.

-If the data is unbalanced because this is a reflection of the population and it was intended, use the Full Regression approach (Type 3).

-If the data was not intended to be unbalanced but you can argue some type of hierarchy between the factors, use the Hierarchical approach (Type 1).

-If the data was not intended to be unbalanced and you cannot find any hierarchy, use the classical experimental approach (Type 2).

N-Way:When the factor comparison is taken, then it said to be n-way ANOVA. For example, in productivity measurement if a company takes all the factors for productivity measurement, then it is said to be n-way ANOVA.

ANOVA is used very commonly in business, medicine or in psychology research. In business, ANOVA can be used to compare the sales of different designs based on different factors. A psychology researcher can use ANOVA to compare the different attitude or behaviour in people and whether or not they are the same depending on certain factors. In medical research, ANOVA is used to test the effectiveness of a drug.

The logic behind this procedure has to do with how much variance there is in the population. It is likely he researcher will not know the actual variance in the population but they can estimate this by sampling and calculating the variance in the sample. You compare the differences in the samples to see if they are the same or statistically different while still accounting for sampling error.

Formation of Levels

Parameters	**Level 1**	**Level 2**	**Level 3**
Cutting Speed (m/min)	60	120	180
Feed Rate (mm/rev)	0.08	0.16	0.32
Depth of Cut (mm)	0.2	0.2	0.2

Table no 2.2 FORMATIONS OF LEVELS.

Orthogonal Array formed

Selection of Orthogonal Array: To select an appropriate orthogonal array for experiments, the total degrees of freedom need to be computed. In thistudy each three level parameter has 2 degree of freedom(DOF = Number of level–1), the total DOF required forthree parameters each at three levels is 8. Once thedegrees of freedom required are known, the next step is toselect an appropriate orthogonal array to fit the specifictask. The degrees of freedom for the orthogonalarray should be greater than or at least equal to those forthe process parameters. In this study, an L9 Orthogonalarray (a standard 3-level OA) having 8 degree of freedomwas selected from the Taguchi's special set of predefinedarrays.

SR No.	Cutting Speed	Feed Rate	Depth of cut
1	60	0.08	0.2
2	60	0.16	0.2
3	60	0.32	0.2
4	120	0.08	0.2
5	120	0.16	0.2
6	120	0.32	0.2
7	180	0.08	0.2
8	180	0.16	0.2
9	180	0.32	0.2

Table no 2.3 EXPERIMENTAL COMBINATIONS .

CHAPTER 3

EXPERIMENTAL PROCEDURE

3.1 WORKPIES MATERIAL

Alloys of Titanium (Ti-6Al-4V) material of 13mm diameter and 60mm length were used for all the experiments. In this present work the experiment were conducted on CNC lathe. The different sets of dry turning experiment were performed using refrigerated air as a coolant during machining.

Fig no 3.1 SPECIMENS .

3.2 CUTTING TOOL

In the context of machining, a **cutting tool** or **cutter** is any tool that is used to remove material from the workpiece by means of shear deformation. Cutting may be accomplished by single-point or multipoint tools. Single-point tools are used in turning, shaping, 31lanning and similar operations, and remove material by means of one cutting edge

We have used carbide cutting inserts for our experimental work.

- **CNMG120408ML**

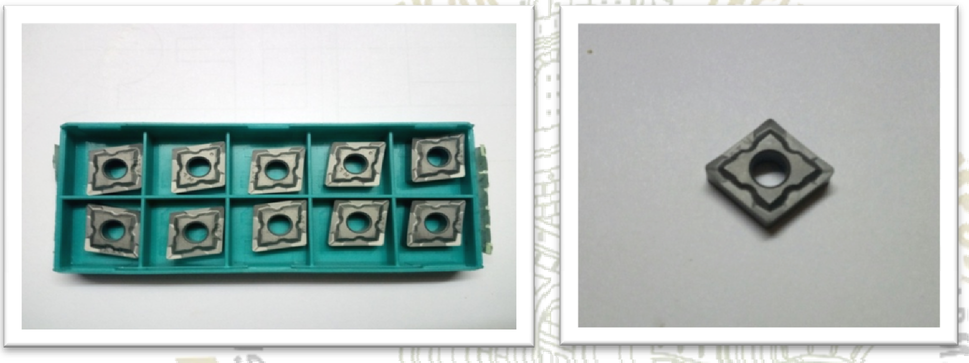


Fig no 3.2 CUTTING TOOL.

Properties of carbide cutting iserts.

Stable. Moderately expensive. The most common material used in the industry today. It is offered in several "grades" containing different proportions of tungsten carbide and binder (usually cobalt). High resistance to abrasion. High solubility in iron requires the additions of tantalum carbide and niobium carbide for steel usage. Its main use is in turning tool bits although it is very common in milling cutters and saw blades. Hardness up to about HRA 93. Sharp edges generally not recommended.

3.3 VORTEX TUBE

We have used vortex tube in our experimental work to supply a coolant at the cutting area.

Fig no 3.3 VORTEX TUBE .

The **vortex tube**, also known as the **Ranque-Hilsch vortex tube**, is a mechanical device that separates a compressed gas into hot and cold streams. The air emerging from the "hot" end can reach temperatures of 200 °C (392 °F), and the air emerging from the "cold end" can reach −50 °C (−58 °F) It has no moving parts.

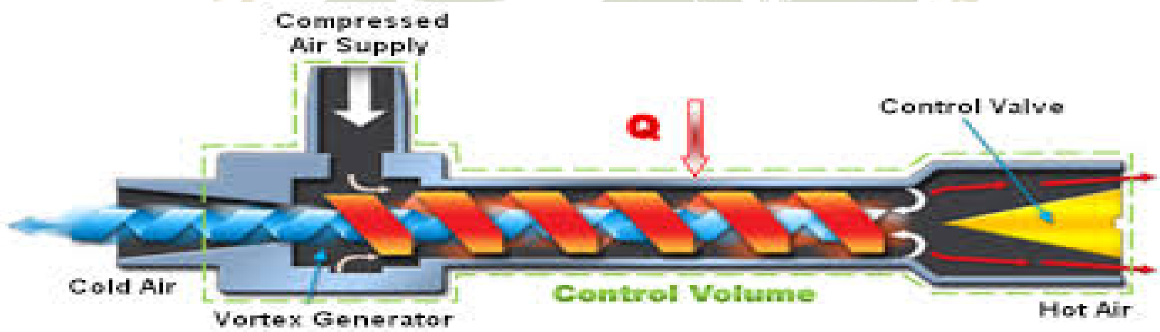


Fig no 3.4 WORKING OF VORTEX TUBE .

Pressurised gas is injected tangentially into a *swirl chamber* and accelerated to a high rate of rotation. Due to the conicalnozzle at the end of the tube, only the outer shell of the compressed gas is allowed to escape at that end. The remainder of the gas is forced to return in an inner vortex of reduced diameter within the outer vortex.

3.4 COOLANT SETUP

Coolant setup is used to hold the vortex tube and to adjust the direction of coolant flow towards the cutting zone. It helps in providing a proper flow of coolant in cutting zone. It can also help in adjusting the height of vortex tube according to the height of machine.

Fig no 3.5 COOLANT SETUP.

3.5 CNC LATHE MACHINE

- The lathe machine used in our project for high speed turning process was available at industry **ATUL ENGINEERING WORKS , THANE.**

Fig no 3.6 CNC LATHE MACHINE.

3.6 COMPRESSOR

- The supply to vortex tube is compressed air which is provided by the compressor .
- The compressor of 3 HP available at **ATUL ENGINEERING WORKS, THANE** .

Fig no 3.7 COMPRESSOR .

3.7 ROCKWELL HARDNESS TEST

WHAT IS HARDNESS ?

- Hardness is simply the resistance to plastic deformation of the material.
- The term hardness may also refer to resistance to bending, scratching , abrasion, and cutting.
- Hardness is dependent on ductility , elasticity , plasticity , strain and strength of the material.

PURPOSE OF HARDNESS TESTING

- The principle of hardness test is to determine the suitability of a material for given application.

- The ease with which the hardness test is performed has made in the most common method of inspection for metals and alloys.

WHICH TYPE OF HARDNESS TESTING SELECTED ?

- Macro hardness :

  Refer to testing with applied loads on the intender of 150 kg and material being tested are the machined specimen of titanium alloys.

HARDNESS MEASURING MECHANISM

- Static indentation test :

Indentation test measures the resistance of a specimen deformation due to constant compression load.

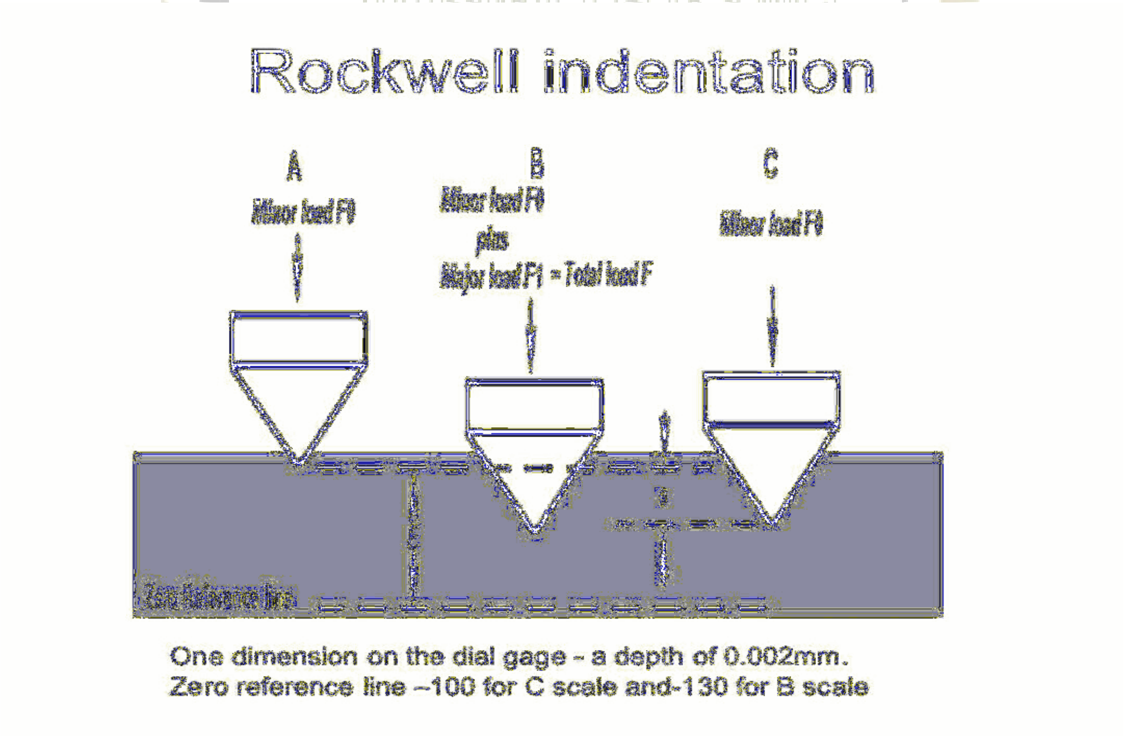


Fig no 3.8 ROCKWELL INDENTATION.

SELECTION OF HARDNESS SCALE

- Scale C: The scale C was used in conjunction with diamond cone of 120 degree angle and 150 kg of major load which is preferable for titanium alloys.

DIAL GAUGE

- One revolution of the large pointer equals to 1 mm.
- There are 100 division to a revolution.
- Therefore , 1 division equal to 0.01 mm.
- Dial gauge is connected to a plunger system in the head of the tester.
- By means of the index lever having 5: 1.

ROCKWELL HARDNESS TEST PROCEDURE

- This experiment was conducted in **KALSEKAR TECHNICAL CAMPUS, PANVEL** in **SOM** lab
- The Rockwell Hardness test uses a machine to apply a specific load and then measure the depth of resulting impression.
- Hardness number is indicated on dial .
- Specimen was place on table of the instrument.
- Diamond Intender is brought into contact with surface of the specimen under a minor load in longitudinal direction of the specimen.
- Scale is then adjusted to zero.
- Major load of 150 kg is applied and hardness index is read from the scale.

Fig no 3.9 ROCKWELL HARDNESS TESTER SETUP.

3.8 REFRIGERATED AIR COOLANT

In our experimental work we have used refrigerated air as a coolant. In this application pressurized liquid CO_2 is allowed to expand and this is accompanied by a drop in temperature, enough to cause a change of phase into a solid. These solid crystals are redirected into the cut zone by either external nozzles or through-the-spindle delivery, to provide temperature controlled cooling of the cutting tool and work piece.

Ambient air, of course, was the original machining coolant. Compressed air, supplied through pipes and hoses from an air compressor and discharged from a nozzle aimed at the tool, is sometimes a useful coolant. The force of the decompressing air stream blows chips away, and the decompression itself has a slight degree of cooling action. The net result is that the heat of the machining cut is carried away a bit better than by ambient air alone.

3.9 software used for analysis

Minitab Inc. is one of the world's leading developers of statistical and process improvement software. Minitab Statistical Software has been used in virtually every major Six Sigma initiative around the world, and is used to teach statistics in over 4,000 colleges and universities. Quality Companion is used worldwide to plan and execute Six Sigma projects. Minitab products are backed by outstanding services, including training, e-learning opportunities, and free technical support.

Minitab is distributed by Minitab Inc, a privately owned company headquartered in StateCollege, Pennsylvania. Minitab Inc. also produces Quality Trainer and Quality Companion, which can be used in conjunction with Minitabthe first being an eLearning package that teaches statistical tools and concepts in the context of quality improvement, while the second is a tool for managing Six Sigma and Lean Manufacturing.

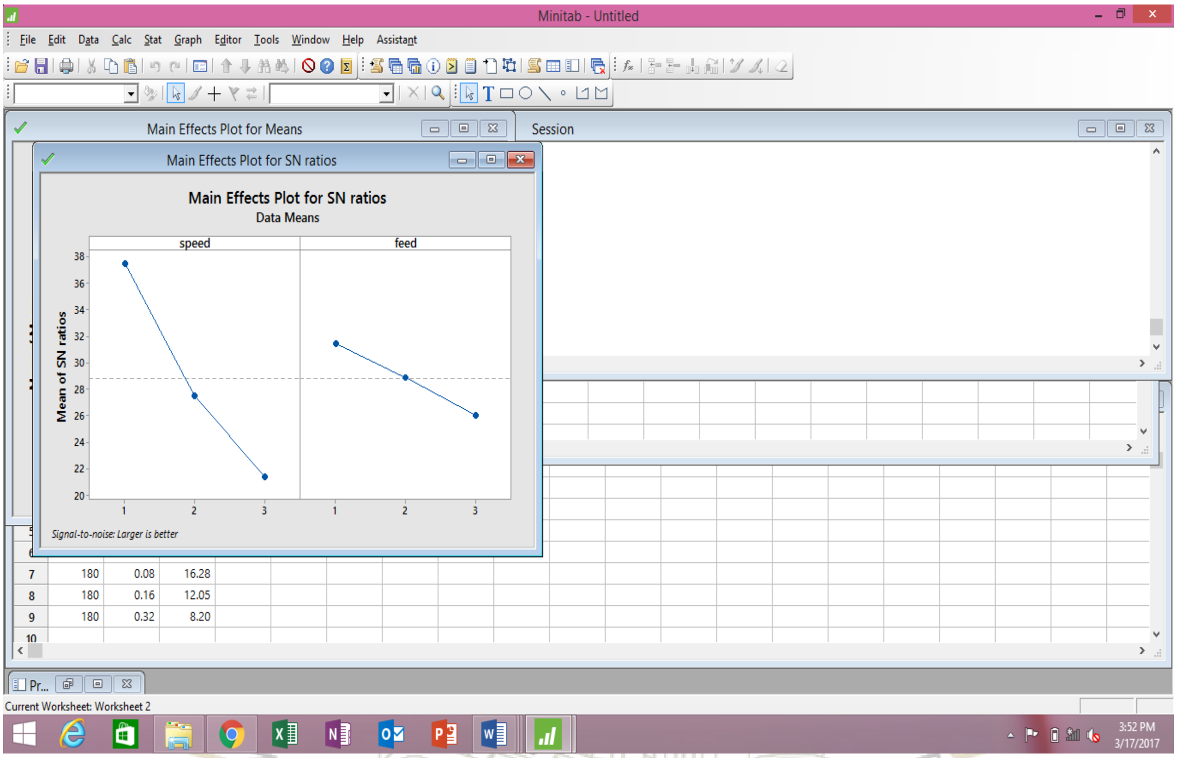


Fig no 3.10 MINITAB 17 SOFTWARE.

CHAPTER 4

ANALYSIS AND CALCULATIONS

4.1 QUANTITATIVE ANALYSIS

4.1.1ANALYSIS OF SURFACE HARDNESS:

On the basis of experiment surface hardness is measured by rockwell hardness tester having a diamond intender and a load 150kg in longitudinal direction. Experimental combination was formed by applying design of experiment by taguchi approach,the factor cutting speed and feed rate are consider an there different level.we used L9 aaray by MINITAB-17.Table 1 shows the hardness values of the nine machined workpiece with respect to experimental combinations.

Table4.1**:** surface hardness values at different machining conditions.

EX PT NO	SPEED (m/min)	FEED RATE (mm/rev)	SURFACE HARDNESS (HRC)
1	60	0.08	34.5
2	60	0.16	34.2
3	60	0.32	34
4	120	0.08	35
5	120	0.16	35
6	120	0.32	34.8
7	180	0.08	36
8	180	0.16	35.8
9	180	0.32	35.5

4.1.2TAGUCHI METHOD

Experimental results and their corresponding S/N ratios.

Table 4.2 : Calculation of S/N ratio values.

EXP T NO	SURFACE HARDNESS (HRC)	S/N RATIO
1	34.5	30.76
2	34.2	30.68
3	34	30.63
4	35	30.88
5	35	30.88
6	34.8	30.83
7	36	31.13
8	35.8	31.08
9	35.5	31

4.1.3 ANOM AND ANOVA

In the present work , the objective is to maximize the surface hardness . Hence , larger the better category for surface hardness has been selected . The analysis of mean based on S/N was carried out to determine the optimum level of control factors. The results ofANOM for surface hardness is shown in fig

.

Table 4.3 : Response table for S/N ratio (larger the better).

LEVEL	SPEED	FEED
1	29.74	29.81
2	29.79	29.79
3	29.85	29.78
DELTA	0.11	0.03
RANK	1	2

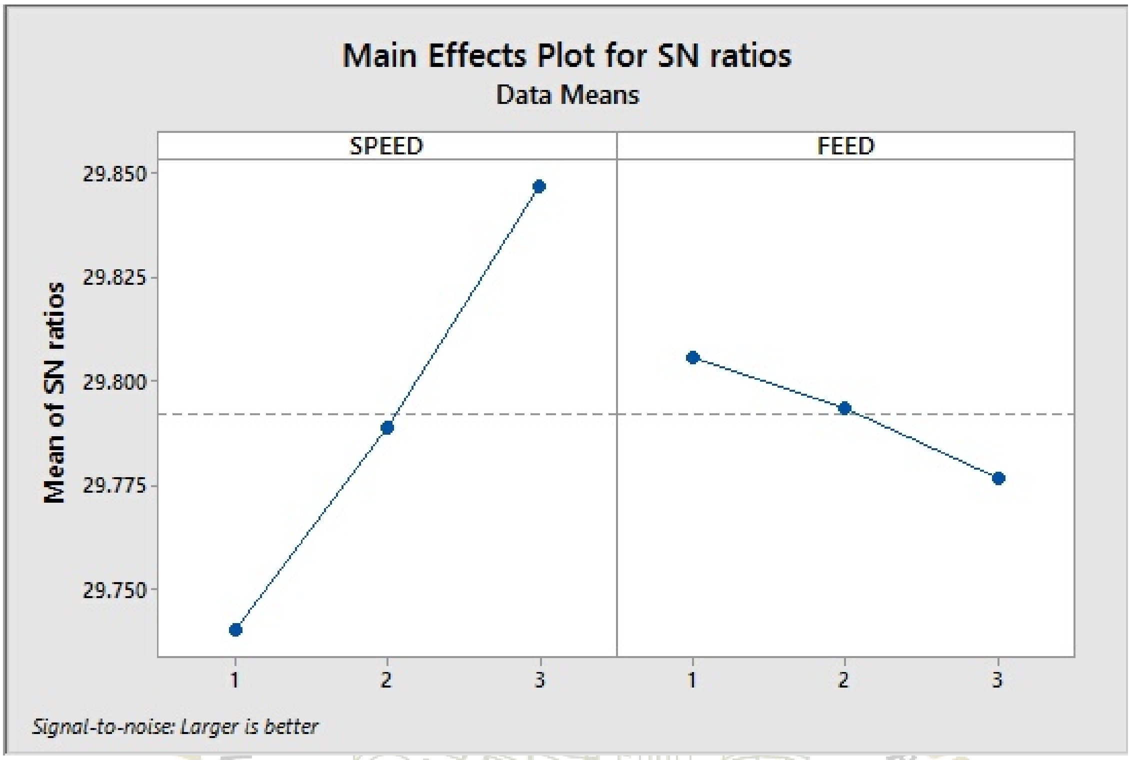


Fig 4.1 : Main effect plot for S/N ratio.

Fig shows the main on surface hardness which is primarily due to cutting speed and feed . The greater the S/N ratio , larger is the variance of the surface hardness around the desired value . Optimal result would be found out from the main effect plot selecting the highest levels of S/N ratio values . Therefore based on S/N ratio analysis , the optimal process parameter for the surface hardness are cutting speed at level 3 (180 m/min) and feed rate at level 1 (0.08 mm/rev). i.e speed 3 - feed1.

To examine the effects of control factors quantitatively , the ANOVA based on surface hardness has been performed . The summary ANOVA results for surface hardness are shown in table 3 and table 4 .

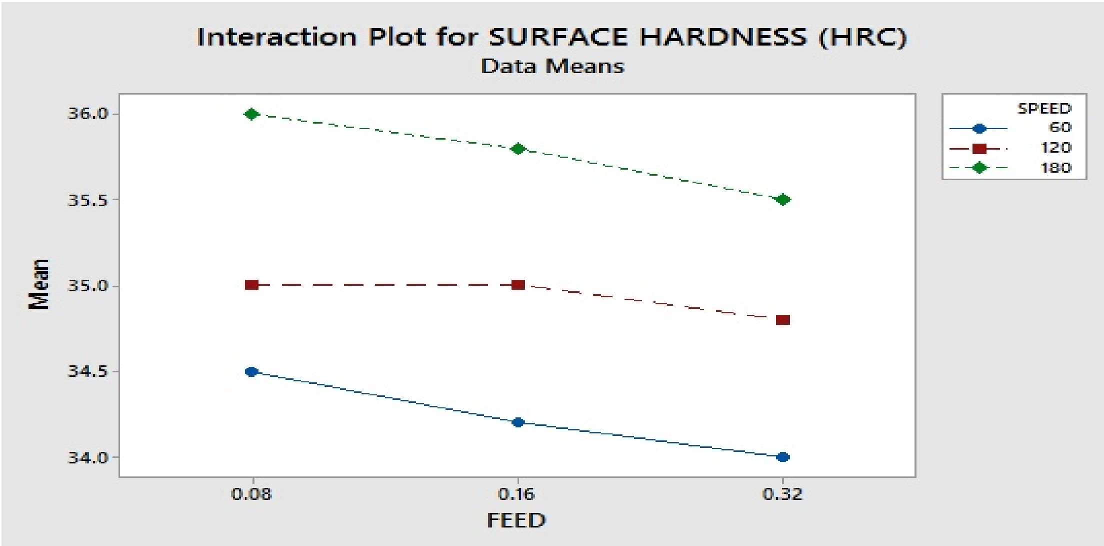
Table 4.4 : % contribution of different factors.

SOURCE	DF	ADJ SS	ADJ MS	F-VALUE	P-VALUE	% CONTRIBUTION
SPEED	1	3.52667	3.52667	433.52	0.000	92.43%
FEED	1	0.24008	0.24008	29.51	0.01	6.28%
ERROR	6	0.04881	0.00813			1.28%
TOTAL	8	3.381556				100%

Table 4.5 : Model summary .

S	R- SQ	R- SQ (ADJ)	R- SQ(PRED)
0.0333616	99.93%	99.86%	99.65%

Table present the ANOVA result of machining parameters as main effect on surface hardness using refrigerated air as a coolant . It indicates that , the spindle speed is highly significant with 92.43% contribution and feed rate with 6.29% contribution.



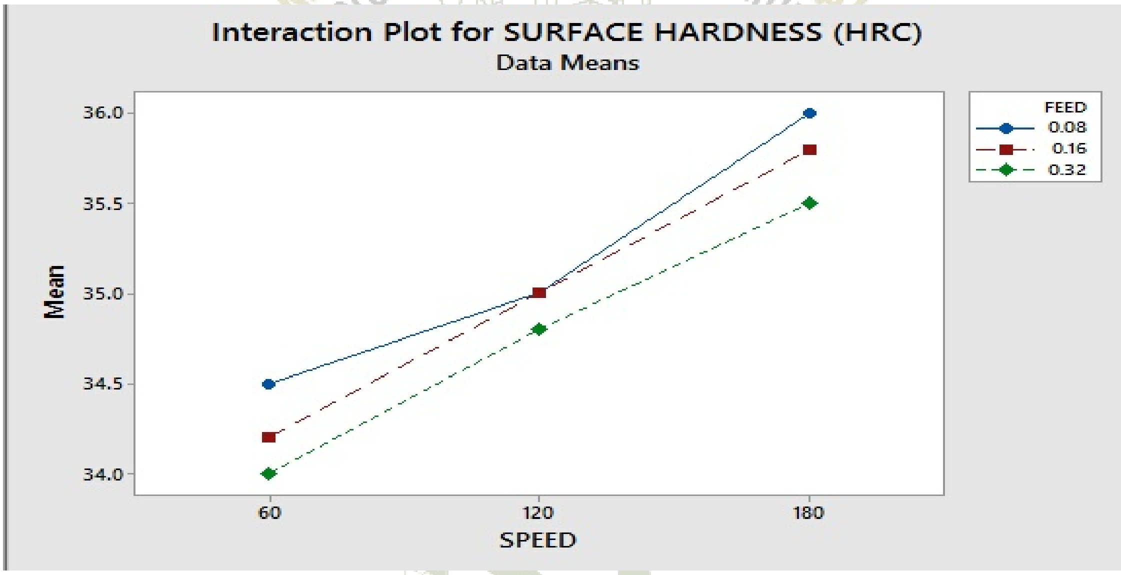


Fig 4.2 : Interaction plot for surface hardness.

From fig 4.2 , it is proved that various speed are closely interact with each other unlike feed rate in which they are not interact with each other. So, speed is the major contributor in maximizing the surface hardness.

4.1.4REGRESSIONANALYSIS

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

The result obtained from ANOVA was rectified by regression analysis.

Regression equation:

SURFACE HARDNESS= **33.7500 +0.012778 (SPEED) - 1.637 (FEED).**

Table 4.6: To calculate surface hardness error using regression equation.

EXPT NO	SPEED (m/min)	FEED RATE (mm/rev)	SURFACE HARDNESS (HRC)	SURFACE HARDNESS (REGRESSION EQUATION)	ERROR
1	60	0.08	34.5	34.4	-0.1
2	60	0.16	34.2	34.3	0.1
3	60	0.32	34	34	0
4	120	0.08	35	35.11	0.11
5	120	0.16	35	35	0
6	120	0.32	34.8	34.8	0
7	180	0.08	36	36	0
8	180	0.16	35.8	35.8	0
9	180	0.32	35.5	35.5	0

Percentage of error by regression analysis = 1.22%.

Percentage of error by ANOVA= 1.28%.

So , from the above mentioned investigation we can commit that , the error obtained for surface hardness by ANOVA and regression analysis is almost equal . Hence, the results obtained from ANOVA is rectify by regression analysis.

4.1.5 EFFECTS OF CUTTING SPEED :

From ANOVA analysis, it can be seen that cutting speed has 92.43% of major contribution in maximizing the surface hardness. From the fig 3, it is seen that surface hardness of the machined components increase with the increase in cutting speed . This is due to the fact that high spindle speed is associated with the higher cutting temperature and increasing the softening of work piece and then reduce the cutting forces . Hence, leading to better surface texture . Increase in speed leads to thermal softening of chip, so there is no chip/ tool interface. Due to this, there is no crack propagation on the workpiece , less formation layer and feed marks . Thus, increases the hardness of the machined surface.

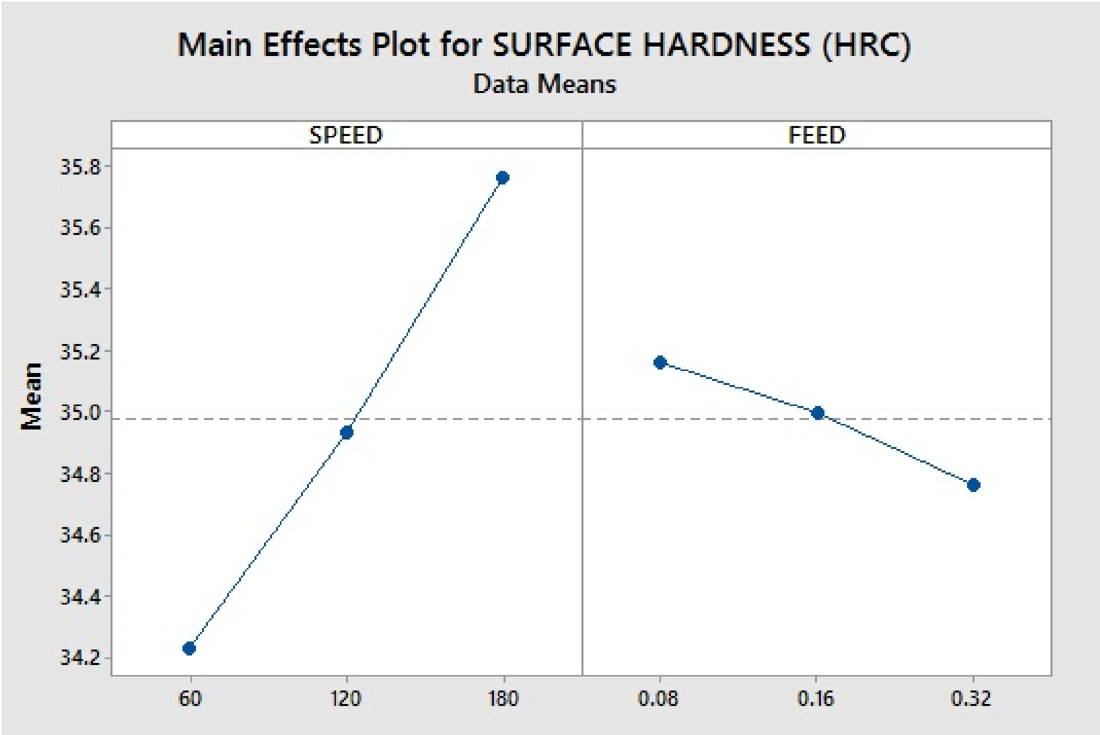


Fig 4.4 : Main effect plot for surface hardness (HRC).

4.1.6 EFFECTS OF FEED RATE:

From ANOVA analysis, table 4.4 it can be seen that feed rate contributes 6.29% in maximizing the surface hardness of the machined component. From fig 3, it can be seen that surface hardness decreases with increase in feed rate. Surface hardness is maximum at low feed rate and minimum at high feed rate. Increase in feed rate leaves surface defect such as crack scratch mark , chip formation later and adhered material particle. This due to following fact that, less time available to carry out the heat from cutting zone, high amount material removal rate and accumulation of chip between the tool /workpiece zone.

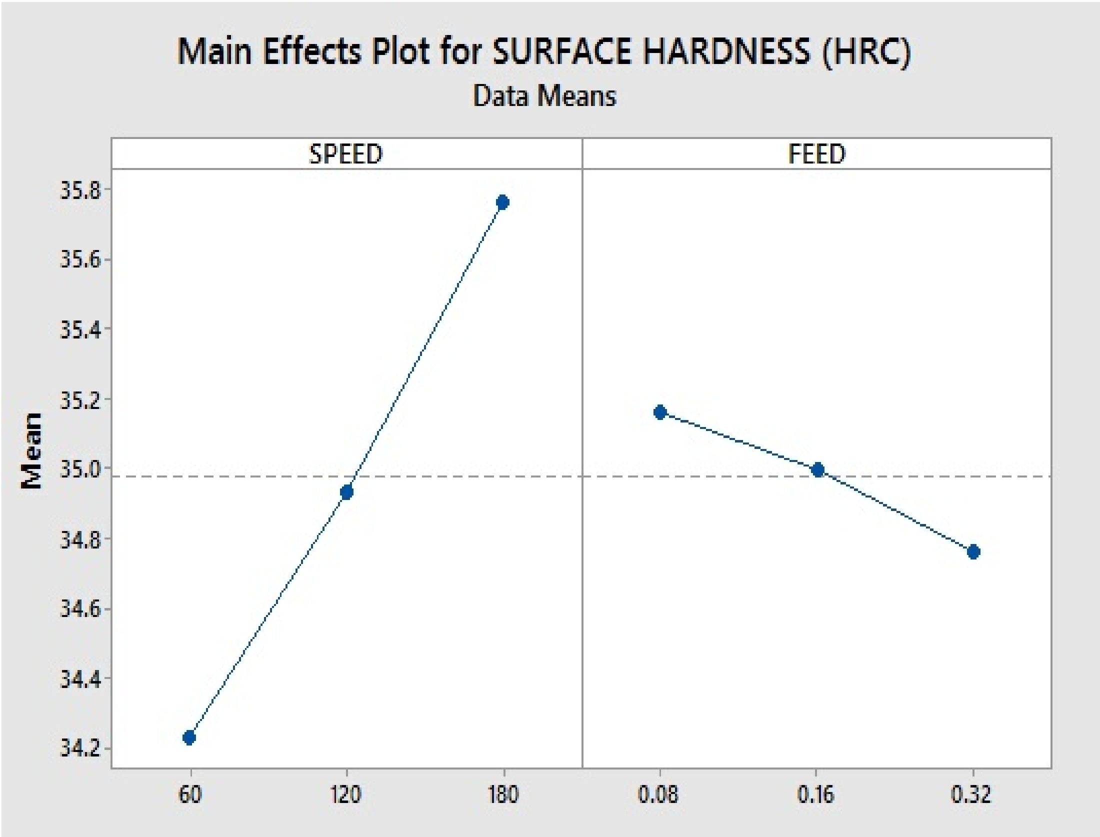


Fig no 4.5 main effect plot for surface hardness.

4.1.7 SURFACE HARDNESS ANALYSIS USING CONTOUR PLOT:

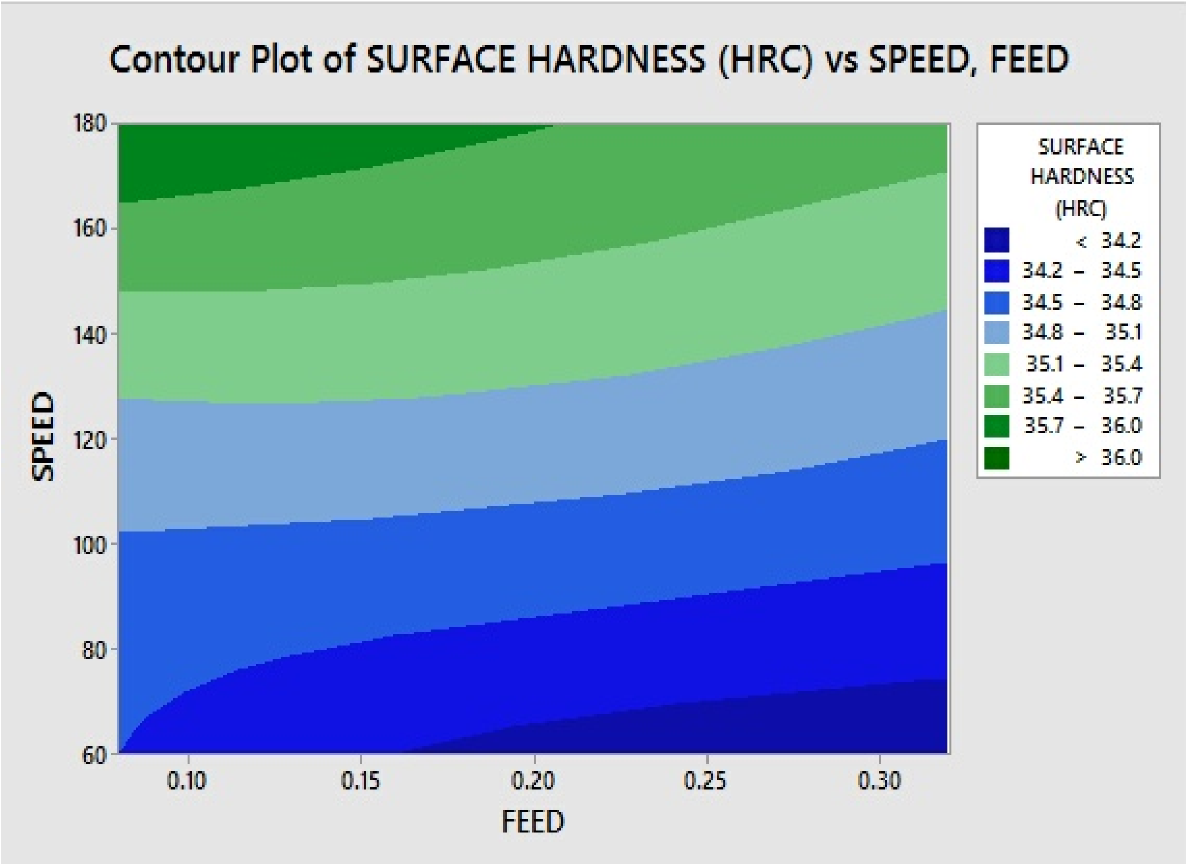


Fig 4.6 : Contour plot for surface hardness.

From fig 4.6: it is clear that surface hardness is maximum at high spindle speed and decreases with the increase in feed rate. plot shows the region of different shades with respect to the surface hardness value.

4.1.8 SURFACE HARDNESS ANALYSIS USING SCATTER PLOT:

SURFACE HARDNESS VS SPEED :

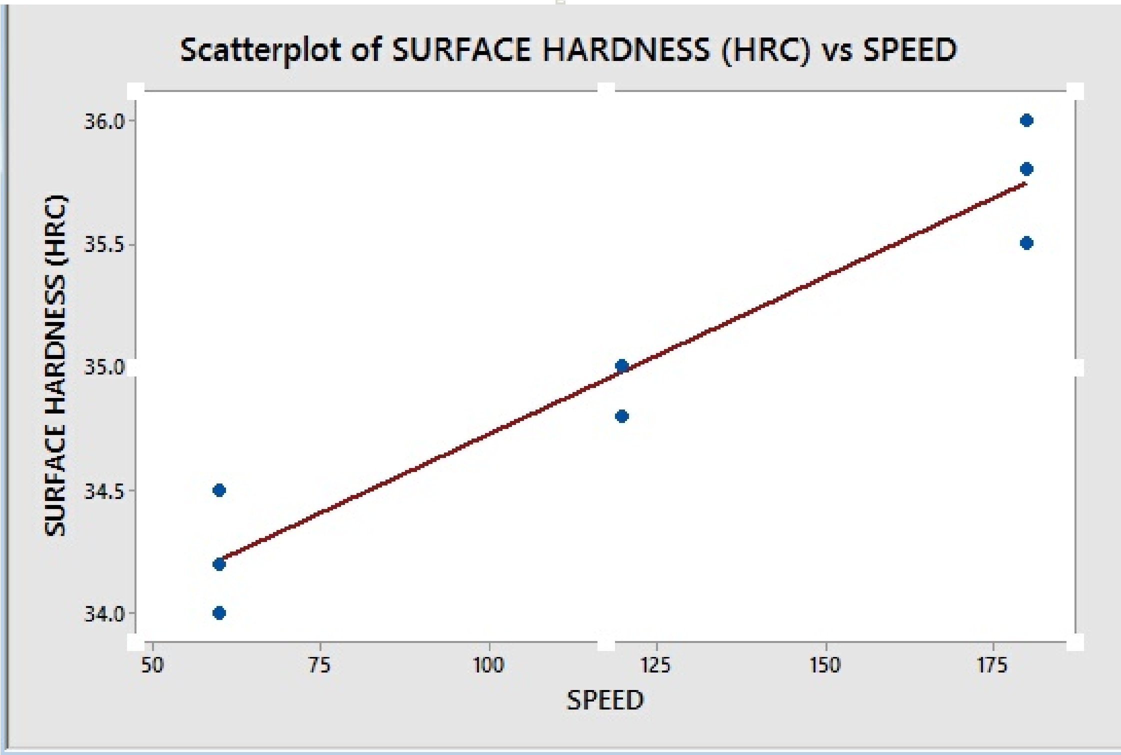


Fig 4.7: scatter plot of surface hardness VS speed.

From fig 4.7: it is clear that, the scatter point at each speed range are closely to each other and increases with increase in spindle speed. From this plot, we can conclude that speed is the major contribution in maximizing the surface hardness.

SURFACE HARDNESS VS FEED RATE :

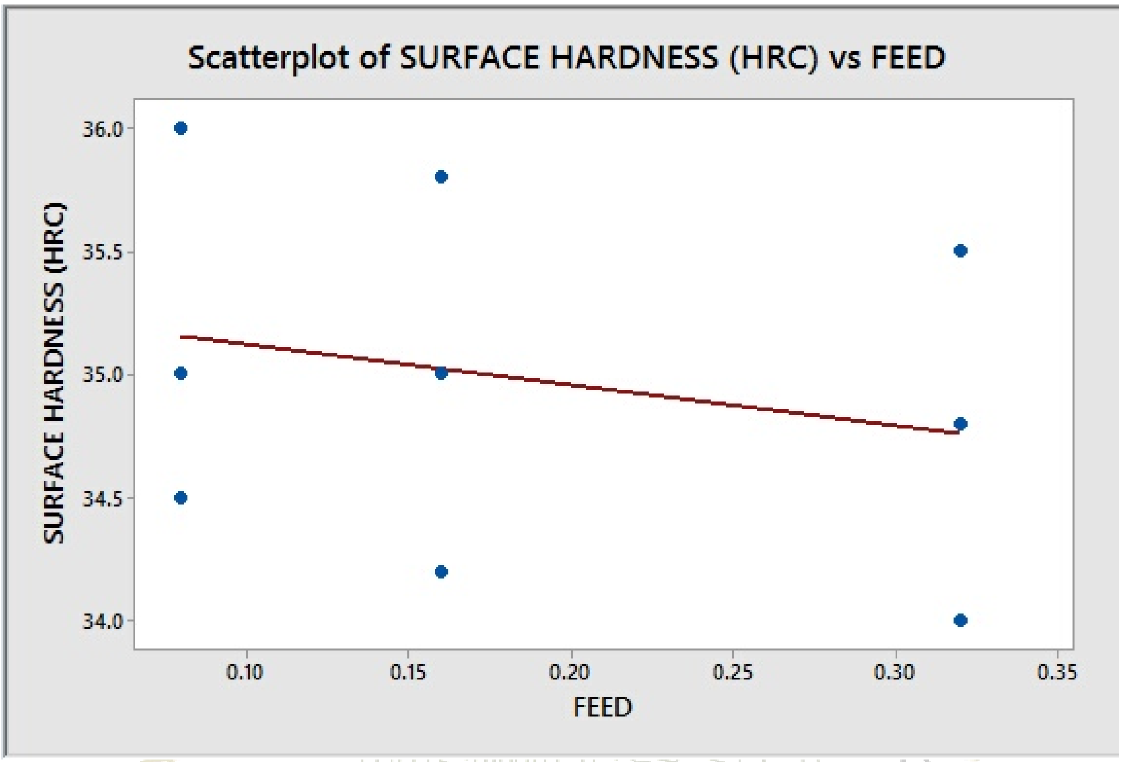


Fig 4.8: Scatter plot of Surface Hardness VS Feed Rate.

From fig 4.8: it is clear that scatter point at each feed rate range are widely spaced to each other as compared to speed and the points range decreases with the increase in feed rate . From this we can conclude, that feed rate has less contribution in maximizing the surface hardness.

4.2 QUALITATIVE ANALYSIS

SCANNING ELECTRON MICROSCOPE

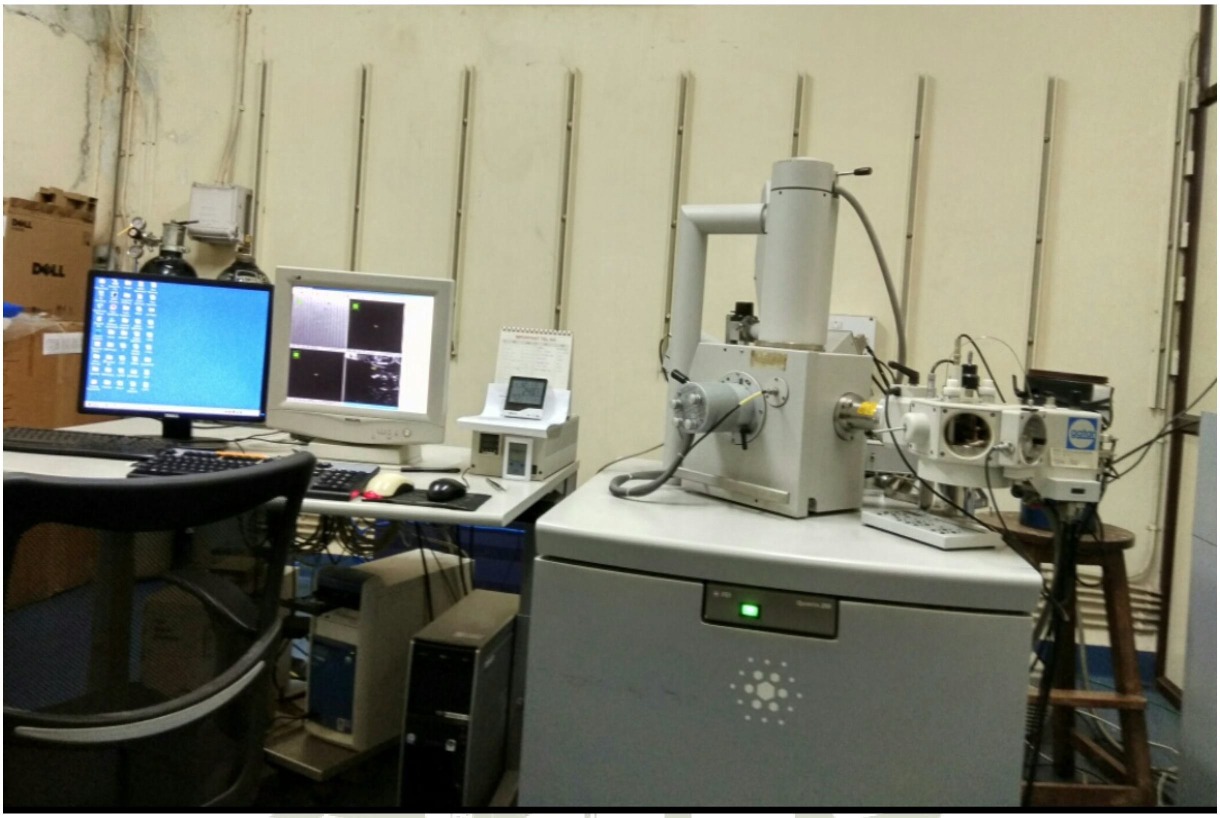


Fig 4,9 SEM setup (IIT BOMBAY)

4.2.1WHAT IS SEM AND HOW DOES IT WORKS ?

Scanning Electron Microscopes (SEM) began to appear commercially in the mid nineteen sixties. The SEM’s primary limitations, as a general imaging and analytical technique, were the restrictions it imposed on samples by requiring a high vacuum sample environ-ment. The samples had to be clean, dry and electrically conductive. Nonconductive specimen had to be coated with a conductive film to avoid specimen charging.

The ESEM was developed in the mi eighties. Its primary advantages lie in permitting the microscopic to vary the sample environment through a range of pressures, temperatures and gas compositions. The Environmental SEM retains all of the performance advantages of a conventional SEM, but removes the high vacuum constraint on the sample environment. Wet, oily, dirty, non-conductive samples may be examined in their natural state without modification or preparation.

All SEM's consist of an electron column, that creates a beam of electrons; a sample chamber, where the electron beam interacts with the sample; detectors, that monitor a variety of signals resulting from the beam-sample interaction; and a viewing system, that constructs an image from the signal.

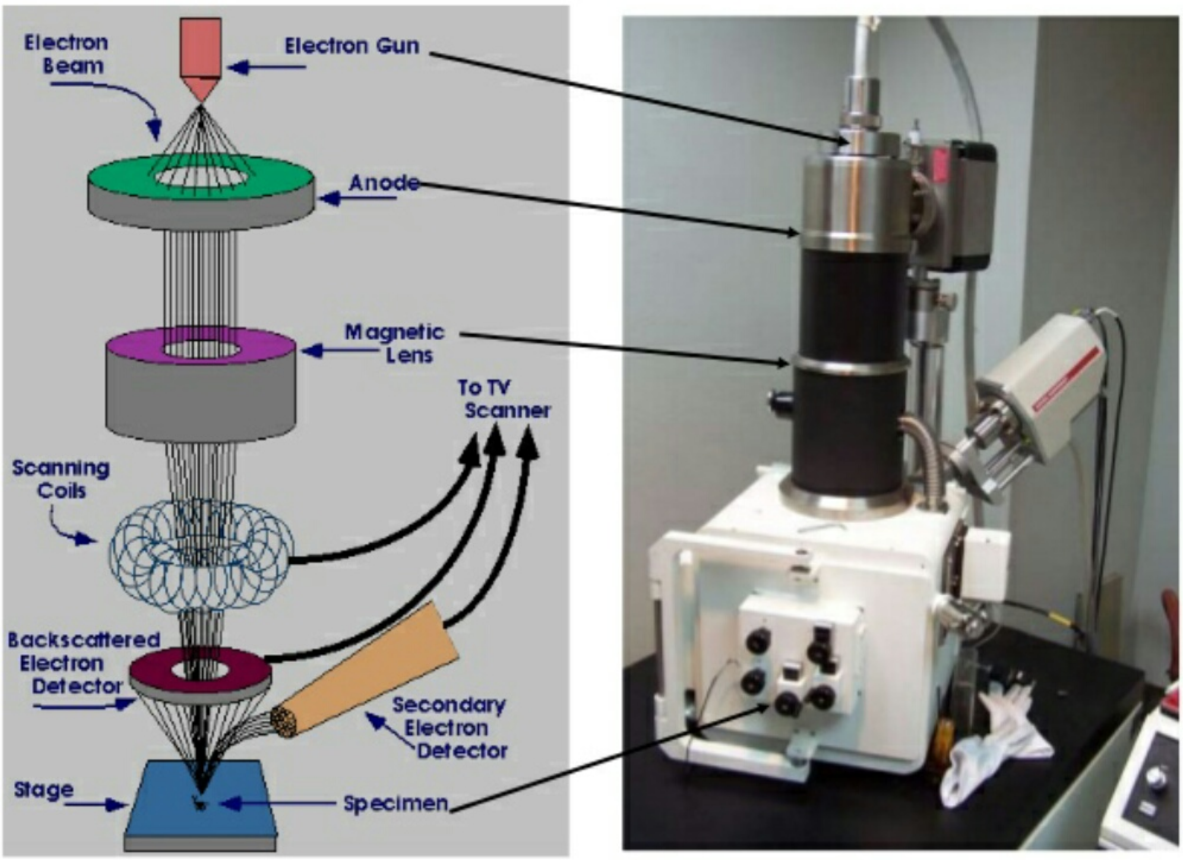


Fig No 4.10 :A schematic representation of a SEM.

The electron column accelerates and focuses a beam of electrons onto the sample surface. Interactions between the sample and the beam electrons cause a variety of signal emissions. The signals are detected and reconstructed into a virtual image displayed on a CRT.

An electron gun at the top of the column generates the electron beam. In the gun, an electrostatic field directs electrons, emitted from a very small region on the surface of an electrode, through a small spot called the crossover. The gun then accelerates the electrons down the column toward the sample with energies typically ranging from a few hundred to tens of thousands of electron volts.

The electrons emerge from the gun as a divergent beam. A series of magnetic lenses and apertures in the column reconverges and focuses the beam into a demagnified image of the crossover. Near the bottom of the column a set of scan coils deflects the beam in a scanning pattern over the sample surface. The final lens focuses the beam into the smallest possible spot on the sample surface.

The beam exits from the column into the sample chamber. The chamber incorporates a stage for manipulating the sample, a door for inserting and removing the sample and access ports for mounting various signal detectors and other accessories. As the beam electrons penetrate the sample, they give up energy, which is emitted from the sample in a variety of ways. There are two major ways of emission:

Secondary Electrons(SE) are sample atom electrons that have been ejected by interactions with the primary electrons of the beam. They generally have very low energy (by convention less than fifty electron volts). Because of their low energy they can escape only from a very shallow region at the sample surface. As a result they offer the best imaging resolution. Contrast in a secondary electron image comes primarily from sample topography. More of the volume of interaction is close to the sample surface, and there-fore more secondary electrons can escape, for a point at the top of a peak than for a point at the bottom of a valley. Peaks are bright. Valleys are dark. This makes the interpretation of secondary images very intuitive. They look just like the corresponding visual image would look.

Backscattered Electrons (BSE*)* are primarily beam electrons that have been scattered backout of the sample by elastic collisions with the nuclei of sample atoms. They have high energy, ranging (by convention) from fifty electron volts up to the accelerating voltage of the beam. Their higher energy results in a larger specific volume of interaction and de-grades the resolution of backscattered electron images. Contrast in backscattered images comes primarily from point to point differences in the average atomic number of the sample. High atomic number nuclei backscatter more electrons and create bright areas in the image. Backscattered images are not as easy to interpret, but properly interpreted, can provide important information about sample composition.

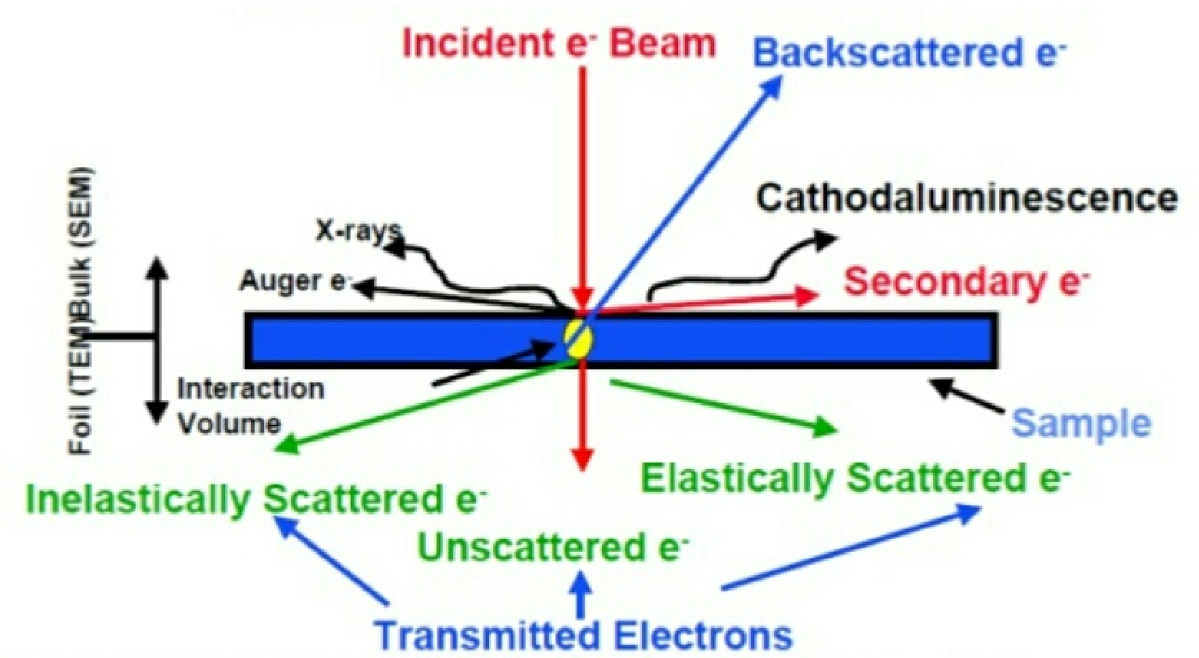


Fig 4.11 beam interaction

The interactions of beam electrons and sample atoms generate a variety of signals. The most commonly used signals are secondary electrons, backscattered electrons and characteristic X-rays.

4.2.2 HOW DOES SEM WORKS AND SAMPLE PREPARATION

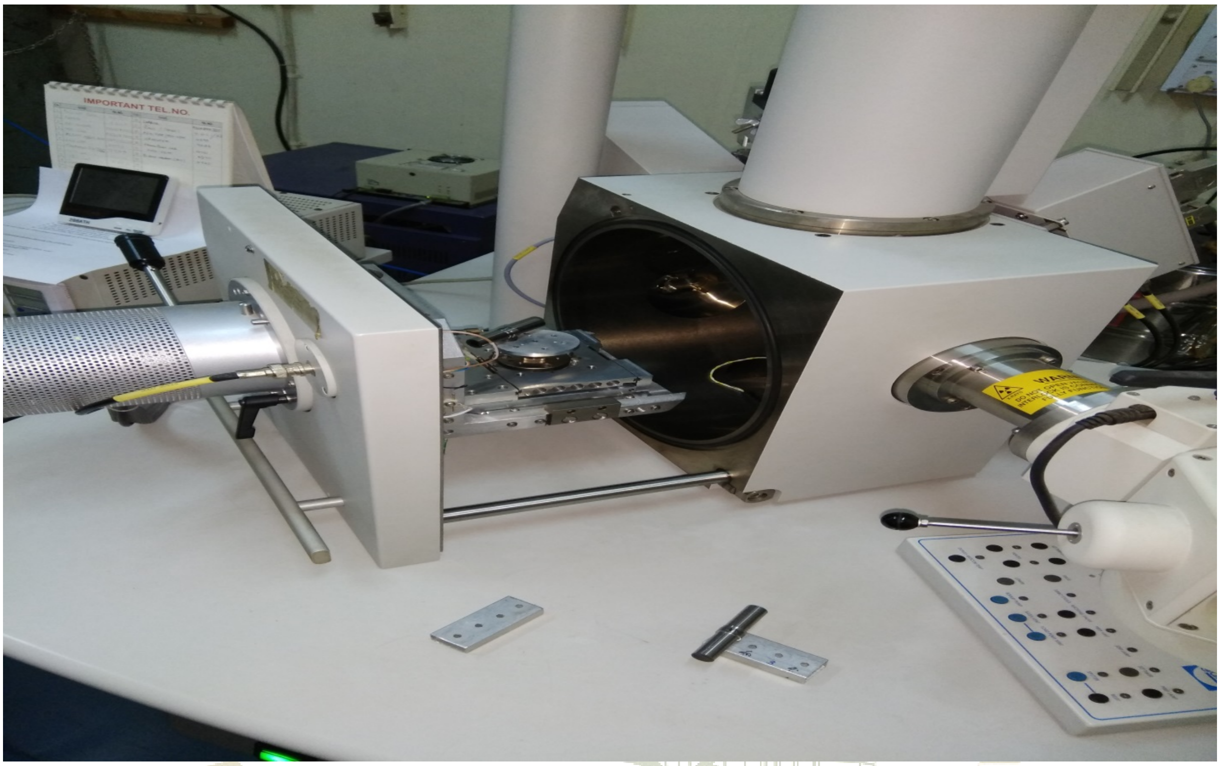


Fig 4.12 sample preparations

- **Heating filament**

  If you put your name on the schedule the day before or if anyone used the ESEM before you, the ESEM is normally already turned on and the filament is heated. If not, go to the 'gun' menu and click 'heat filament' (1.86 A). It can take up to several minutes to heated it up.

- **Placing the sample on the stage**

  Before you can put your sample in, you will have to vent the chamber. To do so, go to the 'vacuum' menu and hit 'vent chamber'. After the chamber is vented you can open the door and put your sample into the sample holder. When you put your sample in, close the door and hit 'wet' in the 'vacuum' menu. If the 'wet' button is not accessible, press the 'override' button. Make sure the door is closed by pressing it softly against the chamber. Remember to 'wet' the chamber when you finished all your tests.

- **Adjust pressure**

  Use the knob on the left board to adjust the pressure to 2.0 Torr. Wait till pressure in chamber has reached the adjusted value. (Actual pressure shown at the bottom of the image screen.

- **Adjust position of sample**

  Adjust the position of the sample by using the X-Y position stick on the control panel and adjust Z-position until the distance between the sample and the beam header is about 5-10 mm.

- **Adjust condenser**

  Adjust the condenser value to about 50. (On the static section of the screen)
- **Adjust beam**

  Adjust the beam value to about 25 keV. (On the static section of the screen)
- **Adjust scan rate**

  A lower scan rate produces sharper images. Use high scan rates for searching a sam-ple or when moving the stage with higher speed. Different scan rates can be chosen within the range of 8.6 fr/sec to 26 sec/fr.
- **Adjust brightness and contrast**

  Use contrast and brightness know to adjust for the best figure. The three knobs on the top of the electron column can be used to adjust the best position of the electron beam on the specimen.
- **Locate die**

  Begin with lowest magnification to locate the position of the die you would like to examine.

4.2.3 ANALYSIS OF SURFACE TOPOGRAPHY USING SEM

After machining, the plate formed sample was produced for analysis. The micro structure of each machined sample was obtained in order to perform a detail study of the machined surface.

Fig shows specimen no 1 has no surface defects and scratch.

Fig 4.13specimen no 1 (speed=60 m/min, feed=0.08 mm/rev)

Fig shows that specimen no 2 has adheres material particles.

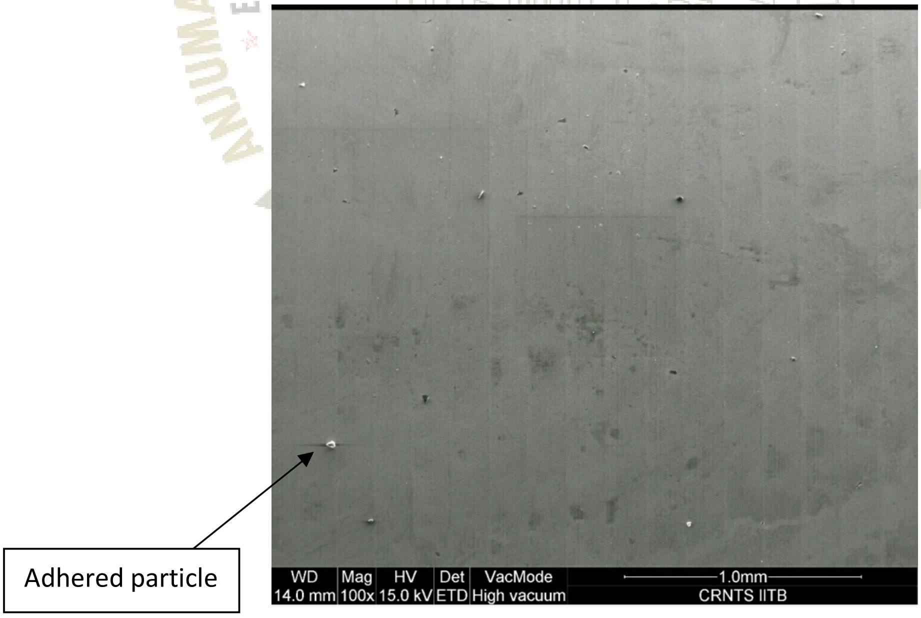


Fig 4.14 specimen no 2 (speed=60 m/min, feed=0.16 mm/rev)

Fig shows that specimen no 3 gives high value of surface roughness due to low speed and low thermal softening of the specimen.

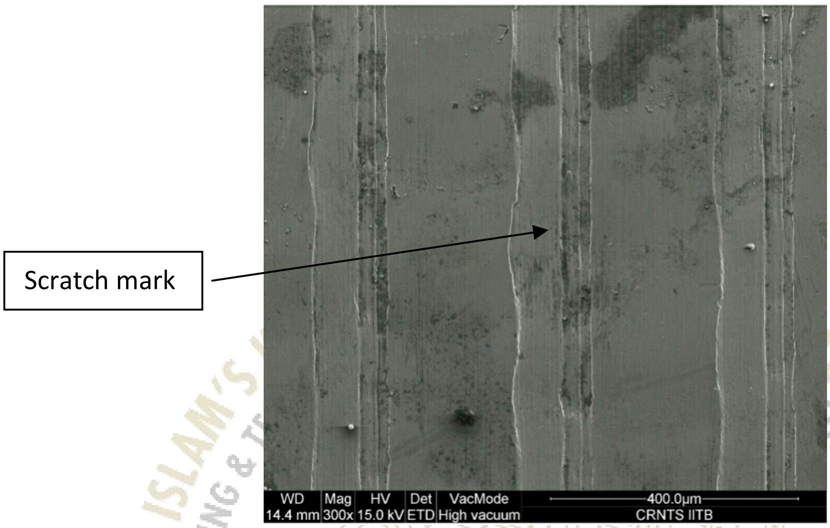


Fig 4.15 specimen no 3 (speed=60 m/min, feed=0.32 mm/rev)

Fig shows that specimen no 4has formation of notches on the surface.

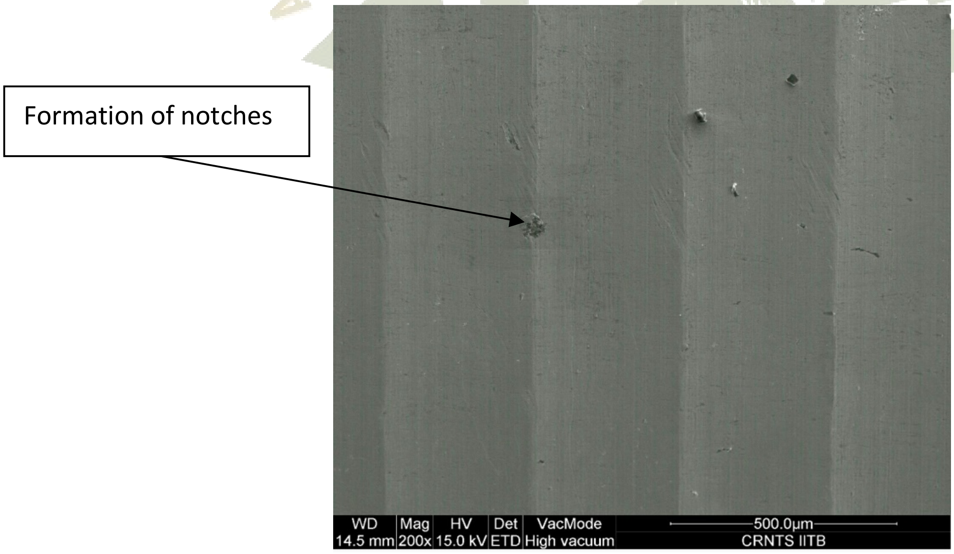


Fig 4.16specimen no 4 (speed=120 m/min, feed=0.08 mm/rev)

Fig shows that specimen no 5 has micro cracking on it,

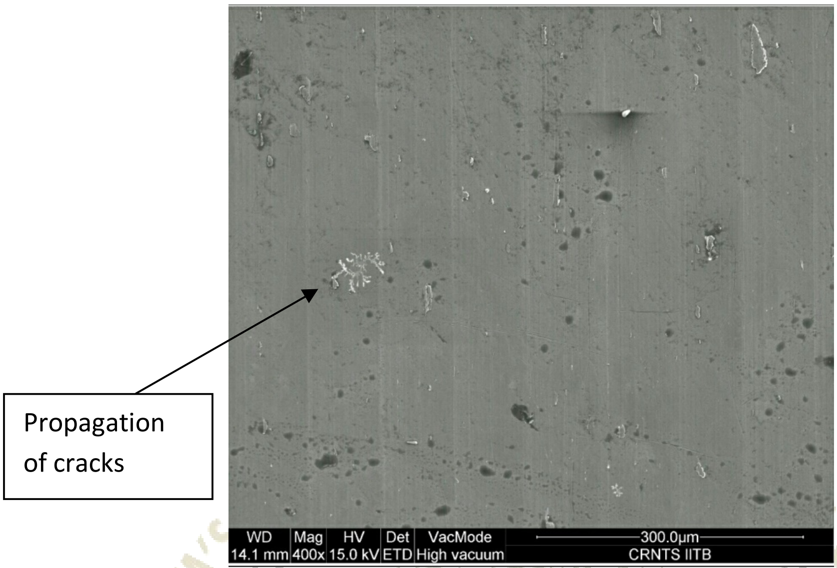


Fig 4.17 specimen no 5 (speed=120 m/min, feed=0.16 mm/rev)

Fig shows that specimen no 6 has no scratch marks as compare to specimen 9

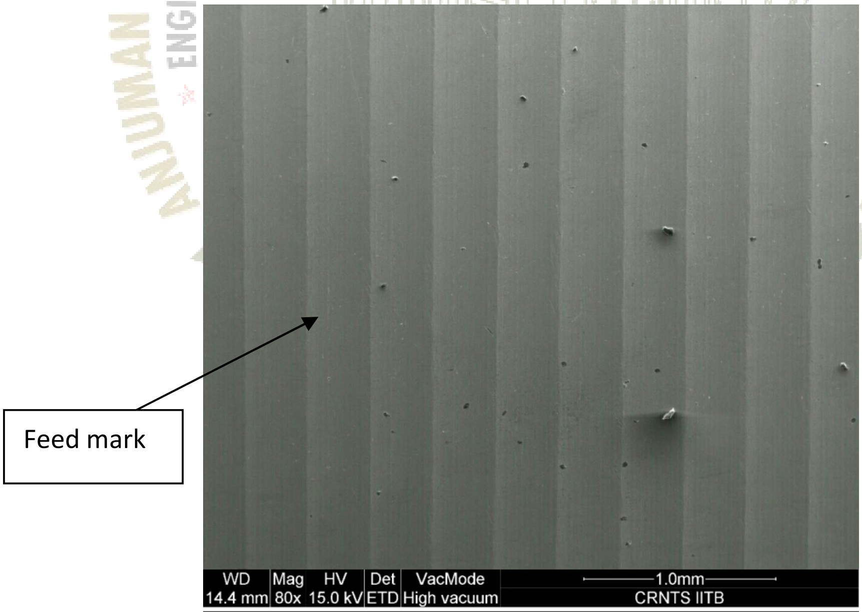


Fig 4.18specimen no 6 (speed=120 m/min, feed=0.32 mm/rev)

Fig shows that specimen no 7 has better surface texture as compare to all other specimens

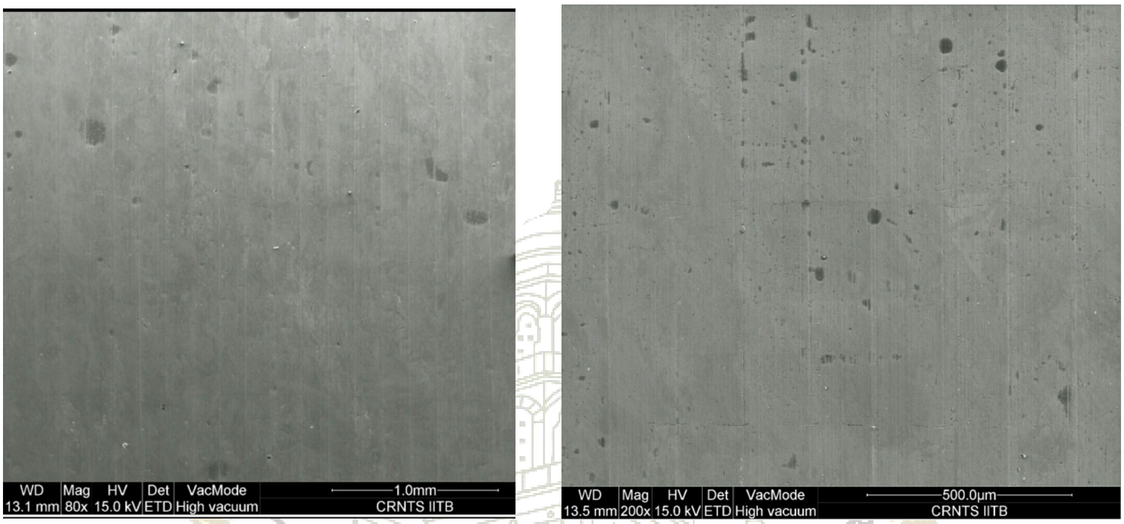


Fig 4.19specimen no 7 (speed=180 m/min, feed=0.08 mm/rev)

Fig shows that specimen no 8 gives better surface finish with less feed marks and adhered particles

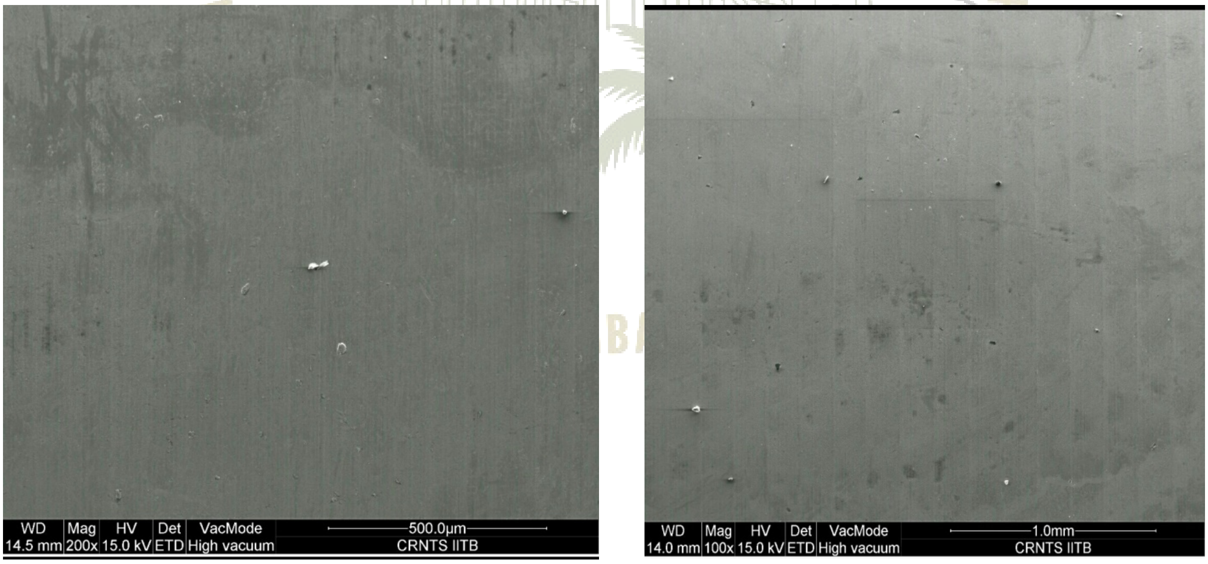


Fig 4.20specimen no 8 (speed=180 m/min, feed=0.16 mm/rev)

Fig shows that specimen no 9 has high scratch marks on the specimen

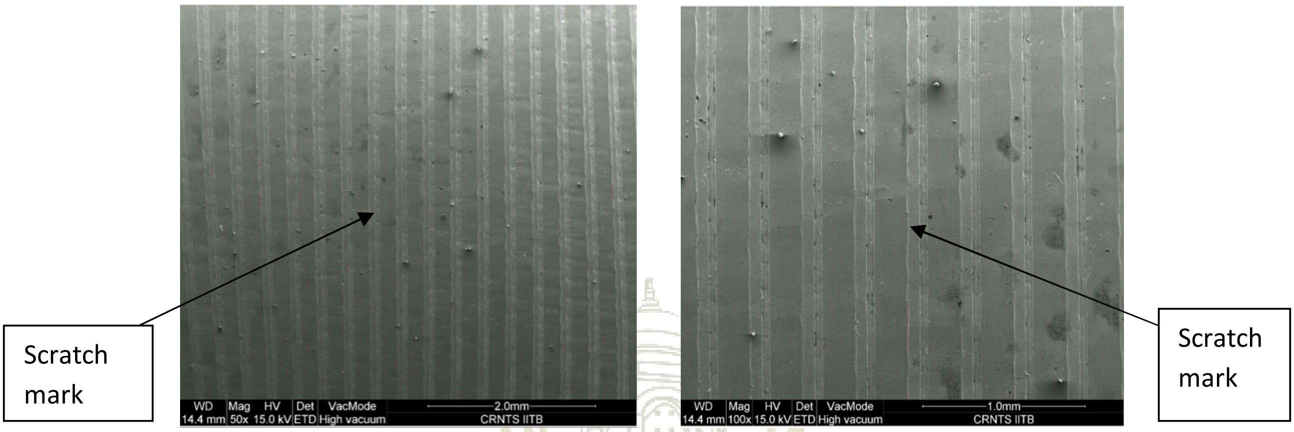


Fig4.21 specimen no 9 (speed=180 m/min, feed=0.32 mm/rev)

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

- The cutting parameters and the cooling medium used while machining process effects the surface topography of Ti-6Al-4V alloys.
- The most influencing parameter on surface hardness is cutting speed, which is followed by the feed rate. Cutting speed contributes 92.43% and while feed rate contributes 6.28%
- The optimal combinations to maximize surface hardness is (cutting speed = 180 m/min and feed rate = 0.08 mm/rev) were obtained through this study and the confirmation experiments produce high value of surface hardness.
- Cutting speed has linear relationship with surface hardness. The surface hardness is maximum at high cutting speed. Hence higher cutting speed gives maximum surface hardness.
- Interaction plot of cutting speed shows significant effect on surface hardness, as they are closely intersect with each unlike the feed rate.
- As feed rate decreases, the value of surface hardness increases. Hence, low feed rate gives maximum surface hardness.
- Carbide inserts was successfully used as a cutting tool material for machining of Titanium alloys.
- Work hardening of deformed layer beneath the machined surface up to 100 microns, caused higher hardness than the average hardness of the base material.
- A variety of surface defect are formed in machining of Titanium alloys, which has been successfully studied by using scanning electron microscope.
- Machined specimen having better surface finish and surface texture can be identify by using scanning electron microscope.

5.2 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.

CHAPTER 6

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