SURFACE ROUGHNESS ANALYSIS WHILE MACHINING AISI 1040 STEPPED STEEL BAR USING TAGUCHI DESIGN OF EXPERIMENTS

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

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CERTIFICATE

This is to certify that the Project Report entitled "**SURFACE ROUGHNESS ANALYSIS WHILE MACHINING AISI1040 STEPPED STEEL BAR USING TAGUCHI DESIGN OF EXPERIMENTS**" being submitted by TILLAPUDI SAIKUMAR (318126520L10), KOLLIVALASA SAI KRISHNA (318126520L12), SUFI MOHAMMAD NAZEEMUDDIN (317126520052), DURGA VENKATA KARTHIK CHIPPALA (317126520017), BOYIDAPU RAHUL (316126520125) in partial fulfillments for the award of degree of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING, ANITS**. It is the work of bona-fide, carried out under the guidance and supervision of **MR.B.V. RAVI TEJA**, Assistant Professor, Department Of Mechanical Engineering, ANITS during the academic year of 2017-2021.

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ABSTRACT

This work focuses on the study of surface roughness and Temperatures while machining AISI 1040 stepped steel bar for various combinations of machining parameters like feed, depth of cut and speed based on **Taguchi philosophy** using TiN-Al_2O_3-TiCN-TiN Carbide inserts using dry conditions.
The **Surface Roughness tester** and **Thermocouple** are used to measure the surface roughness and temperatures respectively and are used to analyze the effect on variation in machining parameters on the surface roughness in turning operation.

Taguchi Design method carried out for experimental design **(DOE using Orthogonal Arrays)** and the analysis of contribution of process parameters based experimental results analyzed using Regression Analysis using **MINITAB** software.

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1.INTRODUCTION TO LATHE AND ITS OPERATIONS

1.1 INTRODUCTION

Quality and productivity play significant role in today's manufacturing market. From customers point of view quality is very important because the extent of quality of the procured item (or product) influences the degree of satisfaction of the consumers during usage of the procured goods. Therefore, every manufacturing or production unit should concern about quality of the product. Apart from quality, there exists another criterion, called productivity which is directly related to the profit level and also goodwill of the organization.

Every manufacturing industry aims at producing a large number of products within relatively lesser time. But it is felt that reduction in manufacturing time may cause severe quality loss. In order to embrace these two conflicting criteria is necessary to check quality level of the item either online or offline. The purpose is to check whether the quality lies within the desired tolerance levels which can be accepted by the customers. Quality of a product can be described by various quality attributes. The attributes may be quantitative or qualitative. In online quality control controller and related equipments are provided with the job under operation ad continuously the quality is being monitored.

If quality falls down the expected level the controller supplies a feedback in order to reset the process environment. In offline quality control the method is either to check the quality of few products from a batch or lot (acceptance sampling) or to evaluate the best process environment which could simultaneously satisfy requirements of both quality and as well as productivity with special emphasis on reduction of cutting tool flank wear, because reduction in flank wear ensures increase in tool life.

This study focused in optimum cutting speed, feed and depth of cut that will produced the best surface finish for different materials. Lathe machine was used to conduct the experiment. Selecting the wrong parameter may lead to several negative parameters. For example: high maintenance cost of the lathe machine, poor surface finish of the work pieces, short tool life, low production rate, material waste and increase production cost. In machining operation, the quality of surface finish was an important requirement for many turned work pieces. Thus the choice of optimized cutting parameters was very important for controlling the required surface quality. The focus of this study was to find a correlation between surface roughness and cutting speed, feed and depth of cut based on **Taguchi's** philosophy.

1.2 INTRODUCTION TO LATHE AND ITS OPERATIONS

A lathe is a tool that rotates the workpiece against a tool whose position it controls; the spindle is the part of the lathe that rotates. Various work holding attachments such as jaw chucks, collets, and centers can be held in the spindle. The spindle is driven by and electric motor through a system is driven by an electric motor through a system of belt drives and gear trains. Spindle rotational speed is controlled by varying the drive train. .

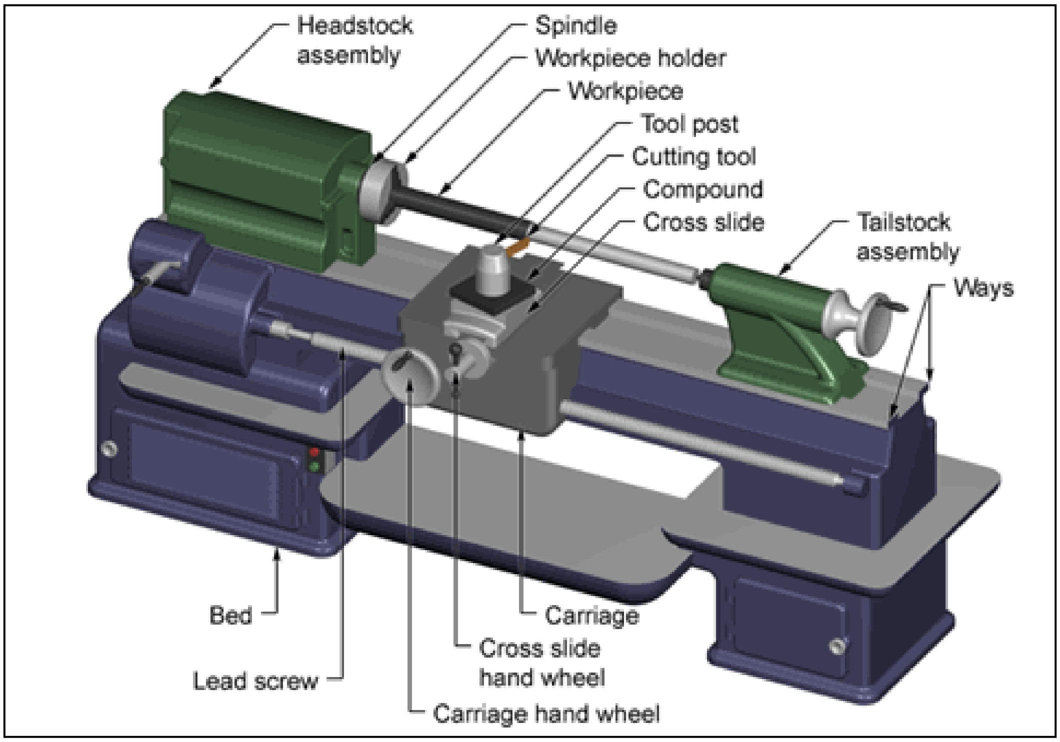

Figure 1.1: Important Parts of a Lathe Machine

The tailstock can be used to the support the end of the center, or to hold tools for drilling, reaming, threading or cutting tapers. It can be adjusted in position along the ways to accommodate different length work pieces. The tailstock barrel can be fed along the axis of rotation with the tail stock hand wheel.

The carriage controls and supports the cutting tool. It consists of:

- A **saddle** that slides along the ways;
- An **apron** that controls the feed mechanisms;
- A **cross slide** that controls the feed mechanisms;
- A **tool** compound that adjusts to permit angular tool movement

Engine Lathes

Engine lathe is the basic, simplest and most versatile lathe. This machine tool is manually operated that is why it requires skilled operators. This is suitable for low and medium production, and for repair work. On an engine lathe the tool is clamped onto a cross slide that is power driven on straight paths parallel or perpendicular to the work axis.

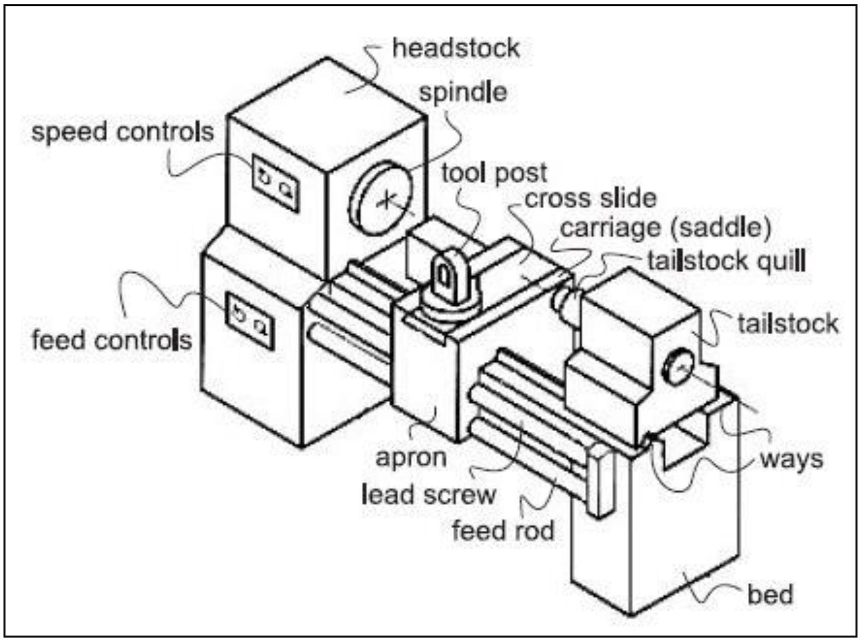

Figure 1.2: Principal Components of Lathe

Turning Process

Turning is a machining process to produce parts round in shape by a single point tool on lathes. The tool is fed either linear in the direction parallel or perpendicular to the axis of rotation of the workpiece, or along a specified path to produce complex rotational shapes. The primary motion of cutting in turning is the rotation of the workpiece, and the secondary motion of cutting is the fed motion.

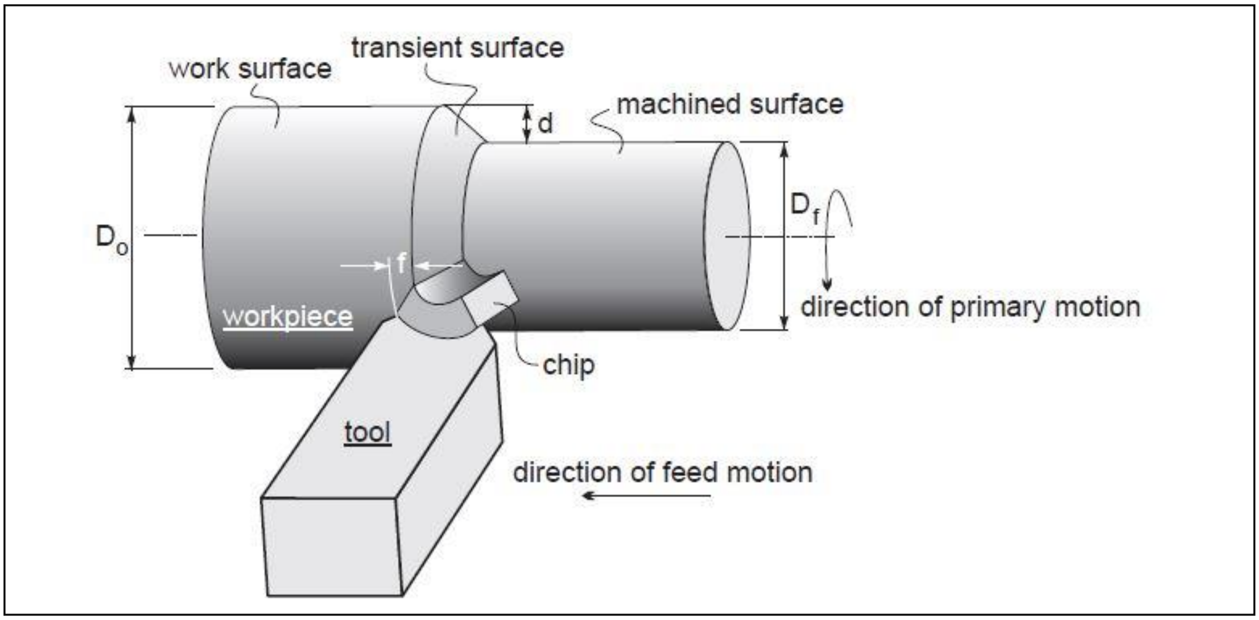

Figure 1.3: Turning Operation

1.3 TURNING SPEED AND FEEDS

The RPM depends on the cutting speed and the diameter of the part. The RPM setting will change with the diameter of the part. As the diameter of the part gets smaller, the RPM must increase to maintain the recommend surface footage. Again, take the case of the wheel. Think of the part as a wheel and the cutting speed as a distance. A larger wheel (part) will need to turn fewer revolutions per minutes to cover the same distance in the same amount of time than a smaller wheel (part). Therefore, to maintain the recommended cutting speed, larger diameters parts must be run at slower speeds than a smaller diameter part. The lathe must be set so that the part will be operating at the proper surface speed.

Spindle speed settings on the lathe are done in RPMs. To calculate the proper RPM for the tool and the workpiece we must use the following formula.

RPM = (Cutting Speed) / (π x Diameter of workpiece)

If two pieces of different sizes are turning at the same revolutions per minute the larger piece has a greater surface speed. Surface speed is measured in surface feet per minute (SFPM). All cutting speeds work on surface footage principle. Again, cutting speeds depend upon the primarily on the kind of material you are cutting and the kind of cutting tool you are using. The hardness of the work material has a great deal to do with the recommended cutting speed. Harder the work material, slower the cutting speeds. Softer the work material, faster the recommended cutting speeds.

Summary of Turning parameters and formulae:

Cutting feed: The distance that the cutting tool or workpiece advances during one revolution of the spindle, measured in inches per revolution. In some operations the tool feeds into the workpiece and in others the workpiece feeds into the tool. For a multi point tool, the cutting feed is also equal to the feed per tooth, measured in inches per tooth, multiplied by the number of teeth on the cutting tool.

Cutting speed: The speed of the workpiece surface relative to the edge of the edge of the cutting tool during a cut, measured in surface feet per minute.

Spindle speed: The rotational speed of the spindle and the work piece in revolutions per minute (RPM). The spindle speed is equal to the cutting speed divided by the circumference of the workpiece where the cut is being made. In order to maintain a constant cutting speed, the spindle speed must vary based on the diameter of the cut. If the spindle speed is held constant, then the cutting speed will vary.

Feed rate: The speed of the cutting tool's movement relative to the workpiece as the tool makes a cut. The feed rate is measured in inches per minute and is the product of the cutting feed (IPR) and the spindle speed (RPM).

Axial depth of cut: The depth of the tool along the axis of the workpiece as it makes a cut, as in a facing operation. A large axial depth of cut will require a low feed rate, or else it will result in a high load on the tool and reduce the tool life. Therefore, a feature is typically machined in several passes as the tool moves to the specifies axial depth of cut for each pass.

1.4 CUTTING TOOL AND GEOMETRY

Cutting tools for metal cutting have many shapes, each of which are described by their angles or geometries. Every one of these tools shapes has a specific purpose in metal cutting. The primary machining goal is to achieve the most efficient separation of chips from the workpiece. For this reason, the selection of the right cutting tool geometry is critical. Other chip formation influences include:

- The workpiece material
- The cutting tool material
- The power and speed of the machine
- Various process conditions, such as heat and vibration

Turning and Single point cutting Tools

Nearly all turning process use single point cutting tools, this is, tool that cut with only a single edge in contact with the work. Most turning is done with coated index able carbide inserts, but the tool material may also be high speed steel, brazed carbide, ceramic, cubic boron nitride or polycrystalline diamond. 75% of turning operations use just a few basic tool geometries. When turning with inserts, much of the geometry is built into to the tool holder itself rather that actual insert. However, let's first focus on the inserts. The geometry of an insert includes:

- The insert's basic shape
- It's relief or clearance angle
- The insert shape
- The insert's inscribed circle or "IC' size
- The insert's nose radius
- The insert's chip breaker design

In turning, insert shape selection is based on the trade-off between strength and versatility. For example, larger point angles are stronger, such as round inserts for contouring and square inserts for roughing and finishing.

The smaller angles (35° and 55°) are the most versatile for intricate work. Turning inserts may be molded or ground to their working shape. The molded types are more economical and have wide application. Ground inserts are needed for maximum accuracy and to produce well defined or sharp contours. Several angles are important when introducing the cutting tool's edge into a rotating workpiece. These angles include:

- The angle of inclination
- Rake angle
- Effective rake angle
- Lead or entry angle
- Tool Nose Radius

The **angle of inclination** is angle viewed from the side or front when tool is in the insert seat or pocket in the tool holder. This inclination can be positive, negative or neutral.

The cutting tool's **rake angle** is the angle between the cutting edge and the cut itself. It may also be positive, negative or neutral.

The effective rake angle is the combination of the tool holder's angle of inclination and the rake built into the insert.

The lead or entry angle is the angle formed by the point of the cutting tool feed and the cutting edge.

The tool nose radius is the angles formed by the point of the tool. This radius may be large for strength, or sharp for fine radius turning.

Since a sharp edge is weak and fractures easily, an insert's cutting edge is prepared with particular shapes to strengthen it. These shapes include a honed radius, a chamfer, a land, or a combination of the three.

Insert size is designated by the largest circle which can be inscribed within the perimeter of the insert, called the inscribed circle. Insert size is directly connected to the tool holder size. Insert type tool holder's for turning consist of a shank, head; insert pocket, and clamping hardware. Tool holders are either right or left handed or neutral. The size and type of the tool holder are determined by:

- The turning operation
- The feed direction
- The size of cuts
- Machine tool design
- The need for accessibility
- The shape of the workpiece

In turning, chip breaking is critical to efficient work processing and good finishing qualities. Proper chip breaking results from balancing the depth of cut and the geometry of the tool. The first type, shaped like numerals "6" or "9", represents the ideal chips. The other types indicate the need for speed and feed adjustments, or selection of a different chip breaker design.

Lathe Machine

Experiments are conducted on PSG – 124 lathe at constant conditions. This machine has both auto feed and variable spindle capabilities. The following image depicts the experimental setup on lathe machine.

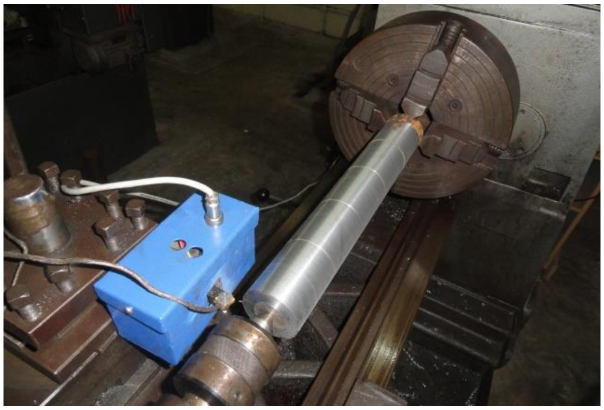

Figure 1.4: Turning Process on Lathe Machine

Specifications:

Make:	PSG, India
Type of Bed:	Straight, Single V
Length of Bed:	2.1 m
Swing over the Bed:	21 cm
Swing over the carriage:	14 cm
Length between the Centers:	96 cm
Variable spindle Speed:	63-1250 RPM
Motor Capacity:	10 H.P
Tool Post:	Square Headed
Chuck Type:	Four Jaw

1.5 USAGE OF LATHE

Basically Lathe machine is a tool use to shape elements. In lathe machine, the material is rotated in the cylindrical motion and then touches a cutting tool to it which cuts the material. The metal sheet is fixed on the chuck of the lathe machine and then the chuck rotates in the vertical direction as well as right and left direction and touching byte’s tip to the material to cut the metal. The original lathe machine when invented used to complete tasks like cutting cylindrical metal sheets and then it was further developed to produce screw threads, tapered works, drilled holes, knurled surfaces and crank shafts. Modern lathe machines available now days, offer the rotating speeds as well as adjusting manually and automatically the cutting tool in the lathe machine. There are different types of lathe machines available like light duty lathe machines, medium duty lathe machines, heavy duty lathe machines, extra heavy duty lathe machines, all geared lathe machine, imported lathe machine, CNC lathe machine, roll turning lathe machines and many more, No matter what type of lathe machine it is, you need to follow the below given basic instructions while using it.

- You need to ensure that the lathe machine about not be started cold. First of all warm up the lathe machine for 10 minutes, setting up its speed up to 1000 rpm. The lathe machine should also be well lubricated and you need to check all tools and ensure that they are tight.
- Now tool holder should be located and tool block should be inserted in it. The spot is supposed to be located in the tool block where you can insert a cutter. Also for safety reason, you need to tight the tool black as tighter as you can. The cutters allow the users to cut from left to right, which is also known as cutting on a Z axis.
- The tail stock is to be located where drill chuck can be inserted. The tail stock is very useful as it helps in drilling holes in the metal. The crank at the end of the measuring devices helps in performing precision depths to the cuts.

- The next step would be set your zero and stop the turning spindle. You need to get a tool holder and put in the tool at least 0.5 inch block between the tip of your tool and the metal sheet. Slide the tool holder in and out on an X axis to tighten it. The micrometer wheel should be set to zero.
- Also you need to set your X zero point by pulling the Z axis tool towards the spindle and slide 0.5 inch block between the tool and the work piece. You also need to set the X axis micrometer to zero and turn the wheel 0.58 inch away.
- So, now if you want to cut 0.5 inches from the metal sheet keep X axis and Z axis both 0.25 inches away from the metal sheet and then start the spindle.

1.6 SAFETY PRECAUTIONS

In machining operations always keep safety in mind, no matter how important the job is or how well the machine you know the machine you are operating.

Listed here are some safety precautions that you must follow.

i. Before starting any lathe operation, always prepare yourself by rolling up your shirt sleeves and removing your watch, finger rings and any other jewelry that might become caught while you operate the machine.
ii. Wear shades or an approved face shield at all times whenever you operate a lathe or when you are near a lathe that is being operated.
iii. Be sure the work area is clear of obstruction that you might fall or trip over.
iv. Keep the deck area around your machine clear of oil or grease to prevent the possibility of slipping or falling into the machine.
v. Always use assistance when handling large work pieces or large chucks

1.7 CHIP FORMATION

The following figure shows a schematic diagram of material deformation during cutting, and subsequently removal if the deformed material from the workpiece by a single point cutting tool.

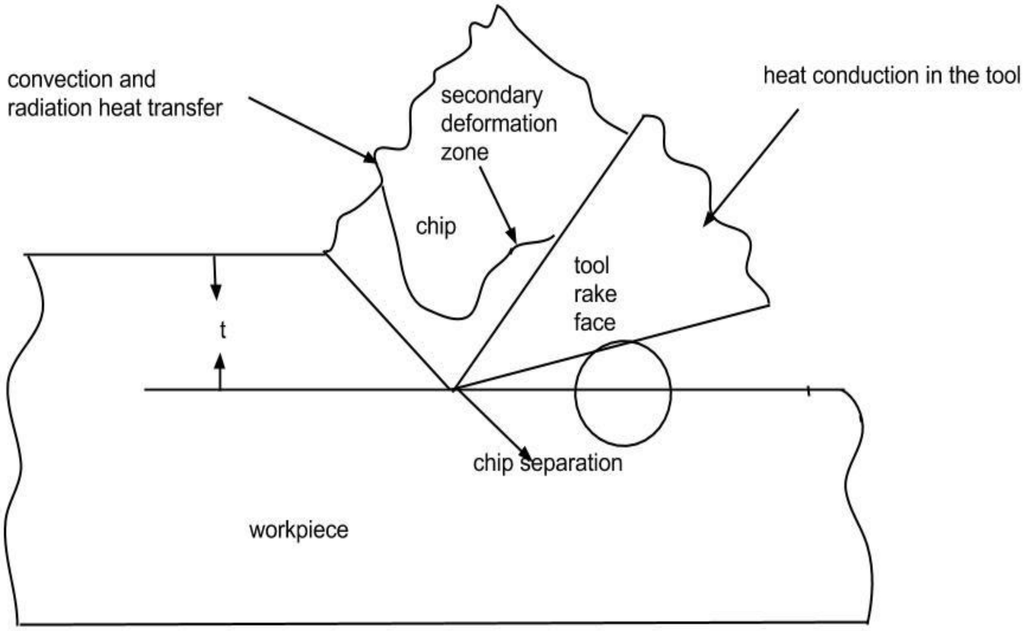

Figure 1.5: Chip Formation

Because of the relative motion between the tool and the workpiece, material ahead of the tool face (rake face) is compressed (elastically and then plastically). Further, movement of the tool into the workpiece deforms the work material plastically and finally separates the deformed material from the workpiece. This separated material flows on the rake face of the tool called as chip. The chip near end of the rake face is lifted away from the tool, and the resultant curvature of the chip is called chip curl.

The study of mechanism of chip formation involves deformation process of the chip ahead of the cutting tool. Theoretical study of the material deformation in metal cutting is difficult and therefore experimental techniques have been resorted for analyzing the process of deformation in chips. The methods commonly employed for this purposes are:

i. Use of movie camera for taking pictures of chip
ii. Observing grid deformation during cutting
iii. Examination of frozen chip samples obtained by the use of quick stop device

Experimental study if chip deformation process has relieved that:

a) During machining of ductile materials, a plastic deformation zone is formed in front of the cutting edge
b) The distinctive zone of separation between the chip and workpiece where deformation gradually increases toward the cutting edge is called the primary deformation/shear zone. In shear zone extensive deformation occurs. The width of shear zone is very small.
c) The plastic deformation involved in the formation of chips affects the hardness of material (strain hardening). Strain hardening increases when a layer undergoes deformation in the shear zone.

2. LITERATURE REVIEW

In LATHE machining processes like turning, a proper selection of cutting conditions generates high surface finish and less dimensional error parts subject to fatigue loads, precision fits and aesthetic requirements. Hence many researchers focuses on the literature on the measurement of surface roughness using (lathe) and multi-point (milling) cutting tool using different machining parameters like feed, speeds, depth of cut and tool geometry are well documented. Totally the researches in this field can be divided in four groups:

1. Trends based on machining theories
2. Trends based on experimental tests
3. Trends based on designed tests (TAGUCHI based)
4. Trends based on intelligent neutral networks

Smair Khraiset. Al [1] focused on evaluating surface roughness and developed a multiple regression model for surface roughness as a function of cutting parameters during the machining of flame hardened medium carbon steel with TiN-Al_2O_3-TiCN coated inserts. Taguchi methodology was adapted for experimental plan of work and signal-to-noise ratio (S/N) were used to relate influence of turning parameters to the workpiece surface finish and the effects of turning parameters were studied by using the ANOVA.

Ali MotorcuRiza [2], studied the surface roughness in the turning of AISI 8660 hardened alloy steels by ceramic based cutting tools with cutting parameters such as cutting speed, depth of cut, feed rate in addition tool's nose radius, using a statistical approach An orthogonal design, signal-to-noise ratio and analysis of variance were employed to find out the effective cutting parameters and nose radius on the surface roughness.

W.H. Yang and Y.S. Tarng, studied the Taguchi method, as a powerful tool to design optimization for quality and used to find the optimal cutting parameters for turning operations based on orthogonal array, signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) to investigate the cutting characteristics of S54C steel bars using tungsten carbide cutting tools. Through this study, they found not only the optimal cutting parameters for cutting operations can be obtained, but also the main cutting parameters that affect the cutting performance in turning operations. Experimental results are provided to confirm the effectiveness of this approach.

A.E. Dinizet. Al [4] focused to find cutting conditions more suitable for dry cutting, i.e., conditions in which make tool life in dry cutting, closer to that obtained with cutting with fluid, without damaging the surface roughness of the workpiece and without increase cutting power consumed by the process. To reach these goals several finish turning experiments were carried out. varying cutting speed, feed and tool nose radius, with and without the use of cutting fluid. The main conclusion of this work was that to remove the fluid from a finish turning process, without harming tool life and cutting time and improving surface roughness and power consumed, it is necessary increase feed and tool nose radius and decrease cutting speed.

Dilbag Singh et. Al [5] investigated the effects of cutting conditions and tool geometry on surface roughness in the finish hard turning of the bearing steel (AISI 52100) with mixed ceramic inserts made up of aluminum oxide and titanium carbon nitride. This study showed that feed is dominant factor determining the surface finish followed by cutting velocity and the tool rake angle and a mathematical model for the surface roughness were developed by using the response surface methodology.

T. Tamizharasanet. Al [6] analyzed the process of hard turning and its potential benefits compared to the conventional grinding operation. Additionally, tool wear, tool life, quality of surface turned and amount of material removed are also predicted.

Turnad L. Gintaet. Al [7] focused on developing an effective methodology to determine the performance of uncoated WC-CO inserts in predicting minimum surface roughness in en milling of titanium alloys Ti-6AL-4V under dry conditions. Response surface methodology was employed to create an efficient analytical model for surface roughness in terms of cutting parameters and surface roughness values were measured using a surface roughness measuring instrument-Mitutoyo Surftest model SV-500.

R.A. Mahdavinejadet. Al [8] highlighted the methods of predicted the surface roughness, like based on the trends of machining theories, based on the designed tests, based on Artificial intelligence such as Neutral networks, GA, Fuzzy etc and based on lab research such as statistics and regression model analysis. The combination of adaptive neutral fuzzy system is used to predict the roughness of dried surface machined in turning process.

Julie Z. Zhang et. Al [9] developed an in process surface roughness adaptive control (ISRAC) system in turning operations using Artificial neutral network (ANN) employing two subsystem: the neutral network base, in-process surface roughness prediction (INNSRP) sub system and the neutral network based, in-process adaptive parameter control (INNAPC) subsystem and predicted surface roughness during the finish cutting process with an accuracy of 92.42%. Development of regression models based on experimental test of turning operations are widely in exercise for predicting the behavior and effects of machining parameters given a required surface roughness.

C**.X. (Jack) Feng et. Al [10]** developed an empirical model for the prediction of surface roughness in finish turning basing on workpiece hardness (material), cutting parameters, tool geometry and cutting time by mean of non linear regression with logarithmic data transformation and their applications in determining the optimum machining conditions.

Not only material machining, but also recent trend focuses on composites matrix machining [10-13]. **Rajesh Kumar Bhushanet. Al [11]** attempted to investigate the influence of cutting speed, depth of cut and feed rate basing on surface roughness during machining of 7075 alloy and 10% wt. SiC particulate metal matrix composites using tungsten carbide and polycrystalline diamond (PCD) inserts on a CNC turning machine and found machining with tungsten carbide tool, lower in the feed range of 0.1 to 0.3 mm/rev and depth of cut (DOC) range of 0.5 to 1.5mm as compared to surface roughness at other process parameters to be considered and above cutting speed of 220 m/min surface roughness of other values of cutting speed considered.

V. Ananda Krishnan et. Al [12] investigated on the maintainability parameters such as cutting speed, feed rate and depth of cut on flank wear, cutting force and surface roughness were analyzed during turning operations of a in situ Al-6061-TiB_2metal matrix composite (MMC) prepared by flux-assisted synthesis being on the composites characterization using scanning microscopy, X-ray diffraction and micro-hardness analysis.

Li Zhou et. Al [13] investigated a two-dimensional orthogonal cutting experiments and simulation analysis on the machining of SiCp/Al composites with a polycrystalline diamond tool. Using two kinds of finite element models, the cutting force and Von-Mises equivalent stress at different cutting conditions were studied in detail.

A Manna. B. Bhattacharyya [14] investigated influence of cutting conditions on surface finish during turning of Al/Sic-MMC with a fixed rhombic tooling system using Taguchi method for optimizing the cutting parameters for effective turning. Taking significant cutting parameters into consideration and using multiple linear regression mathematical models relating to surface roughness height Ra and Rt were established.

Several researchers applied Taguchi method not only for lathe machining but also for wire-cut electrical discharge machining (WEDM) of various materials like Aluminuim-24345, DC 53 die steel etc [15-17] basing on Taguchi’s orthogonal array under different conditions of parameters.

Researchers like **B. Srinivasa Prasad et. Al [18]** developed a methodology for extracting the relevant information regarding the cutting process, tool wear monitoring, vibrations and effect on the machined surface topography for online tool condition monitoring. Vibrational data acquisition and signal processing were grabbed using acoustic optic emission sensor (i.e., Laser Doppler Vibrometer) and the surface topography analysis of machined surfaces during progression of the tool wear was done with vision based surface textural analysis.

Faith Bascifctiet. Al [19] generated online prediction of tool wears using artificial neural networks and fuzzy logic, considering cutting parameters as combination of different cutting speed and feed with constant depth of cut.

Researchers focused more on combination of various cutting parameters using single point cutting tool in turning operations and the regression model generation of surface roughness and cutting forces. However, the effect of cutting parameters combination of cutting force, while turning operation using Taguchi philosophy are less concentrated. Hence this paper focuses on study of turning operation taking into account on surface roughness prediction, model generation and cutting forces based on machining parameters like feed, speed and depth of cut.

3. INTRODUCTION TO TAGUCHI DESIGN OF EXPERIMENTS

3.1 DESIGN OF EXPERIMENTS

In general usage, design of experiments (DOE) or experimental design is the design of any information gathering exercises where variation is present, whether under the full control of the experimenter or not. However, in statistics these terms are usually used for controlled experiments. Former planned experimentation is often used in evaluating physical objects, chemical formulations, structures, components and materials. Other types of study and their design are discussed in the articles on opinion polls and statistics surveys (which are types of observational study), natural experimentation and quasi-experiments (for example, quasi-experimental design), see experiment for the distinction between these types of experiments or studies.

In the design experiments, the experimenter is often inserted in the effect of some process or intervention (the treatment) on some objects(the experimental units) which may be people, parts of people, groups of people, plants, animals etc. Design of experiments is thus a discipline that has very broad application across all the natural and social sciences and engineering.

Designed experiments are also powerful tools to achieve manufacturing cost savings by minimizing process variation and reducing network, scrap and the need for inspection. A strategically planned and executed experiment may provide a great deal of information about the effect on a response variable due to one or more factors. Many experiments involve holding certain factors constant and holding the altering levels of another variable. Thos One-Factor-at-a-Time (OFAT) approach to process knowledge is however inefficient when compared with changing factor levels simultaneously.

Many of the current statistical approaches to designed experiments originate from the work of **R.A. Fisher** in the early part of the 20th century. Fisher demonstrated how taking the time to seriously consider the design and execution of an experiment before trying it helped to avoid frequently encountered problems in analysis. Key concepts in creating a designed experiment include blocking, randomization and replication.

A well performed experiment may provide answers to questions such as:

- What are the key factors in the process?
- At what settings would the process deliver acceptable performance?
- At what settings would the process deliver acceptable performance?
- What are the key main and interaction effects in the process?
- What settings would bring about less variation in the output?

A repetitive approach to gain knowledge is encouraged typically involving the following consecutive steps:

1) A screening design which narrows the field of variables under assessment
2) A "full factorial" design which studies the response of every combination of factors and factor levels and an attempt to zone in on a region of values where the process is close to optimization
3) A response surface design to model the response

The major design of experiments terms generally include:

- **Blocking:** When randomizing a factor it is impossible or too costly, blocking lets you restrict randomization by carrying out all of the trials with one setting of the factor and then all the trials with the other setting.
- **Randomization:** Refers to the order in which the trials of an experiment are performed. A randomized sequence helps to eliminated effects of unknown or uncontrolled variables.

- **Replication:** This is the process of repetition of a complete experimental treatment including the setup.
- **Reflection:** A reflection is a new set of combinations that are run at the opposite levels of the original set.

3.2 HISTORY OF TAGUCHI

Who is Dr. Taguchi??

- Born is 1924 in Tokomachi, Japan
- Studied Textile Engineering and earned his doctorate from the Kyushu University in 1962
- Developed much of his thinking in isolation from the school of Ronald Fisher (Factorial DOE) and he pioneered his method with Dr. Yuin Wu in 1966 while consulting Bell Labs

Taguchi Method:

One method presented in this study is an experimental design process called the Taguchi design method. Taguchi design, developed by Dr. Genichi Taguchi, is a set of methodologies by which the inherent variability of materials and manufacturing processes has been taken into account at the design stage.

Three steps procedure for experimental design:

1. Find the total degree of freedom (TOF)
2. Select a standard orthogonal array using the following two rules:
    - The number of runs in the orthogonal design≥ Total DOF
    - The selected orthogonal array should be able to accommodate the factor level combinations in the experiment.
3. Assign factors to appropriate columns

Therefore, not only controlled factors can be considered but also noise factors too. Although similar to design of experiments (DOE), the Taguchi design onlyconducts the balanced (orthogonal) experimental combinations, which makes the Taguchi design even more effective than a factorial design. By using the Taguchi techniques, industries are able to greatly reduce product development cycle timefor both design and production, therefore reducing costs and increasing profit.

The complete procedure in Taguchi design method can be divided into three stages; system design, parameter design and tolerance design. Of the three design stages, the second stage i.e., the paramater design is the most important stage.

Taguchi's Orthogonal Array (OA) provides a set of well balanced experiments (with less number of experimental run), and Taguchi's signal-to-noise ratios (S/N), which are logarithimic functions of desired output; serve as objective function in the optimization process. Taguchi method uses a statistical measure of performance called signal-to-noise ratio. The S/N ratio take moth variability and the mean into the account. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The ratio depends upon the quality characteristics of product/process to be optimized. The standard S/N ratios generally used are as follows:

i. Nominal-is-Best (NB)
ii. Lower-the-Better (LB)
iii. Higher-the-Better (HB)

The optimal setting is the parameter combination, which has the highest S/N ratio. Because, of the irrespective quality criteria may be (NB, LB, HB) S/N ratio should always be maximized. Once experimental data is normalized using NB/LB/HB criteria; normalized value lies in between 0 & 1. Zero represents worst quality to be rejected and one represents most satisfactory quality. Since S/N ratio is expressed as mean to the noise; maximizing S/N ratio ensures minimum deviation and hence it its (S/N ratio) to be maximized.

Taguchi’s Approach to Parameter Design

Taguchi’s approach to parameter design provides the design engineer with a systematic and efficient method for determining near optimum design parameters for performance and cost (Kackar, 1985; Phadke, 1989; Taguchi 1986). The objective is to select the best combination of control parameters so that the product or process is most robust with respect to noise factors, The Taguchi method utilizes orthogonal arrays from design of experiments theory to study a large number of variables with a small number of experiments. Using orthogonal arrays significantly reduces the number of experimental configurations to be studied. Furthermore, the conclusion drawn from small scale experiments are valid over the entire experimental region spanned by the control factors and their settings (Phadke, 1989). Orthogonal arrays are not unique to Taguchi. They were discovered considerably earlier (Bendell, 1988). However, Taguchi has simplified their use by providing tabulated sets of standard orthogonal arrays and corresponding linear graphs to fit specific projects (ASI, 1989; Taguchi and Konisho, 1987). A typical tabulation is shown in Figure.

Experiment no	Factor A	Factor B	Factor C	Factor D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 3. 1: Orthogonal Arrays

In this array the columns are mutually orthogonal. For any pair of columns, all combinations of factor levels occur; and they occur an equal number of times.

Here there are four parameters A, B, C, D each at three levels. This is called an "L9" design, with the 9 indicating the nine rows, configurations or prototypes to be tested. Specific test characteristics for each experimental evaluation are identifies in the associated row of the table. Thus, L9 means that nine experiments are to be carried out to study four variables at three levels. The number of columns of an array represents the maximum number of parameters that can be studied using that array. Note that this design reduces number of parameters that van be studied using that array. Note that this design reduces 91 (34) configurations to 9 experimental evaluations. There are greater savings in testing for the larger arrays. For example, using an L27 array, 13 parameters can be studies at 3 levels by running only 27 experiments instead of 15,94,323 (313). The Taguchi method can reduce research and development costs by improving the efficiency of generating information needed top design systems that are intensive to usage conditions, manufacturing variation and deterioration of parts. As a result, development time can be shortened significantly; and important design parameters affecting operation, performance and cost can be identified. Furthermore, the optimum choice of parameter can result in wider tolerances so that low cost components and production processes can be used. Thus, manufacturing and operations costs can also be greatly reduced.

3.3 FULL AND FACTORIAL DESIGN

In statistics, a full factorial experiment is an experiment whose design consists of two or more factors, each with discrete possible "levels" and whose experimental units take on all possible combinations of these levels across all such factors. A full factorial design may also be called a fully crossed design. Such an experiment allows studying the effect of each factor on the response variables, as well as the effects of interaction between factors on the response variable.

For the vast majority of factorial experiments, each factor has only two levels. For example, with two factors each taking two levels, a factorial experiment would have four treatment combinations in total, and is usually called a 2x2 factorial design. If there are n factors at 2 levels, a full factorial design has 2^n runs.

Number of Factors	**Number of Runs**
2	4
3	8
4	16
5	32
6	64

Table 3.2: Table for number of Runs and number of Factors

In statistics, fractional designs are experimental designs consisting of a carefully chose subject (fraction) of the experimental runs of a full factorial design. The subset is chose so as to exploit the sparsity-of-effects- principle to expose information about the most important features of the problem studied, while using a fraction of the effort of a full factorial design in terms of experimental runs and resources.

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4.EXPERIMENTATION METHADOLOGY

4.1 INTRODUCTION

In modern manufacturing, there has been strong renewed internet in high-efficiency machining, while use of advance materials has increased due to their special mechanical and physical properties. This is mainly affected selection of suitable machining parameters like cutting speed, feed rate and depth of cut according to cutting tool and work piece material. The selection of optimum machining parameters will result in longer tool life, better surface finish and higher material removal rate,

In this chapter, we will study in brief and the various understandings available from the metal cutting research work to comprehend fully the nitty-gritty of machining and machining process parameters. During the course we intend to appreciate the weight of various parameters as speed feed, depth of cut, cutting temperatures, cutting forces etc., which not only influence the quality of the machined product but also the tool life of the tool. The task of confirming the above parameters such as cutting forces and cutting temperatures to the optimum permissible limits is very vital to the machining process.

4.2 PROCESS OF MACHINING

Workpiece of length 300mm was divided into four equal parts (i.e. 4 x 75m) and then using Taguchi Design of Experiments test conditions were generated by taking feed, Cutting Speed and Depth of cut as parameters

As the surface is cylindrical, surface roughness was measured on the four diametrical end points and average of them was considered as the surface roughness of the test material

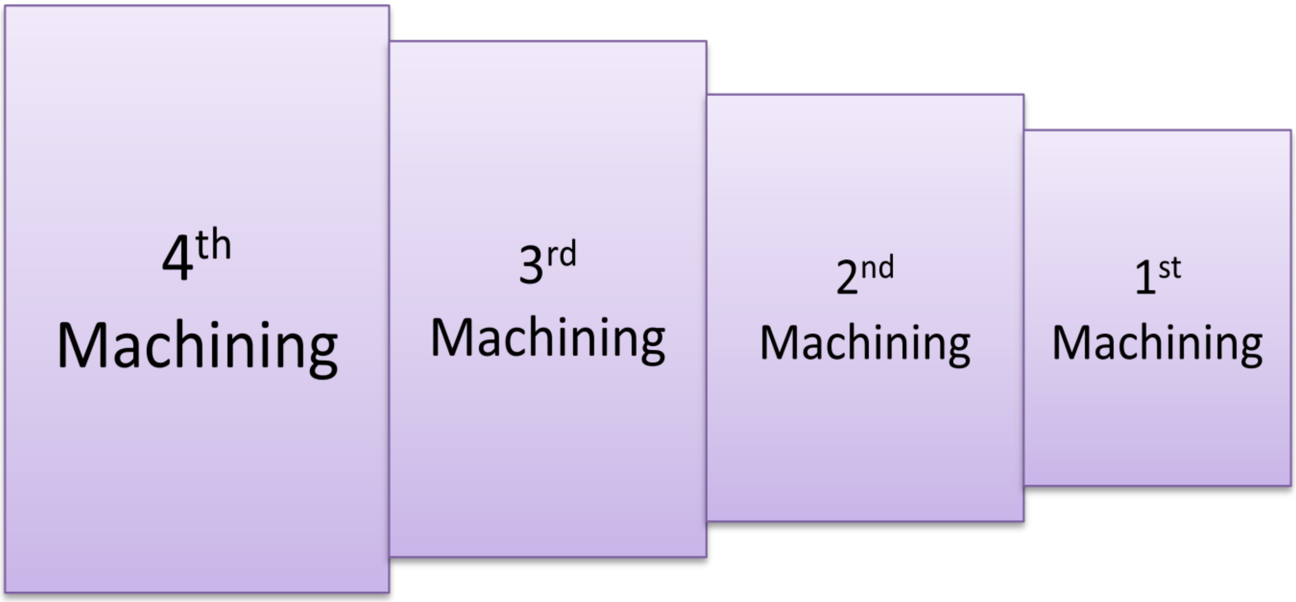


Figure 4.1: Stepped Bar

In this project, sixteen cutting experiments were done and the surface roughness readings were measured using surface roughness tester.The surface roughness was use to find the parametric regression equation basing on the regression analysis with the help of commercially available data mining technique software packages like MINITAB software.

4.3 PROCESS PARAMETERS

The characteristic parameters of a turning operation are (example: straight turning of a cylinder with a diameter d (in mm))

Cutting Parameters:

- The depth of cut α_p (mm)
- The feed per rotation f(mm)

The cutting speed v_c(m min^{-1}) which gives the rotational speed N (rev min^{-1})

$$n = \frac{1000 \cdot v_c}{\pi \cdot D}$$

The cutting parameters are at the root of the following performance parameters:

N = Rotational speed of the workpiece, RPM

f = Feed, mm/rev or in/rev

V = Surface speed of workpiece, m/min or ft/min = π x Do xN(for max speed)

l = Length of cut, mm or in.

D_o= Original diameter of workpiece, mm or in.

D_f= Final diameter of workpiece, mm or in.

D_{avg} = Average diameter of workpiece, (mm or in) = (Do + Df) /2

d = Depth of cut (mm or in) = (Do - Df) /2

t = Cutting time, s or min =$l/f\ N$

4.4 WORKPIECE MATERIAL AND CUTTING TOOL

EN8 STEEL

EN8 is also known as 080M40 and is an unalloyed medium carbon steel. EN8 is a medium strength steel, good tensile strength. This type of steel is generally suitable for shafts, stressed pins, studs, keys etc. EN8 steel is supplied or available as round/turned, round hot rolled, hexagon, flats and plates.

Mechanical Properties of EN8 Steel:

Heat Treatment	Condition Tos/ SQ. Inch	Tensile Strength	Yield Stress RE MPA	RE 0,2 MPA	A min on 5,65 √So	Impact Izod KCV FT.Lb Joules	Hardness HB	Limited Ruling Section mm
Normalize	35	550	-	16	15	16	152/207	150
	33	510	-	17	-	-	146/197	250
Q	40/50	625/775	355	16	25	28	179/229	63
R	45/55	700/850	450	16	25	28	201/255	19

EN8 - 080M40 Black (As rolled or forged)
40 Ton Tensile Black Axle Steel (Carbon Steel)

Equivalents:
BS970 Part 1 1983, 080M40
BS970 of 1955 EN8
German W. Stoff No. 1.1186 | American AISI 1038

Chemical:
Composition %
Carbon = 0.36 - 0.44
Silicon = 0.10 - 0.40
Manganese = 0.60 - 1.00
Sulphur = 0.050 max
Phosphorus = 0.050 max

Cutting Tool

TiCN-Al_2O_3-TiN coating on a substrate features excellent resistance to both mechanical and thermal shock. This gives excellent adhesion with high wear resistance to crater wear and plastic deformation at high temperatures. Also reduces friction and hence the formation of built up edges.

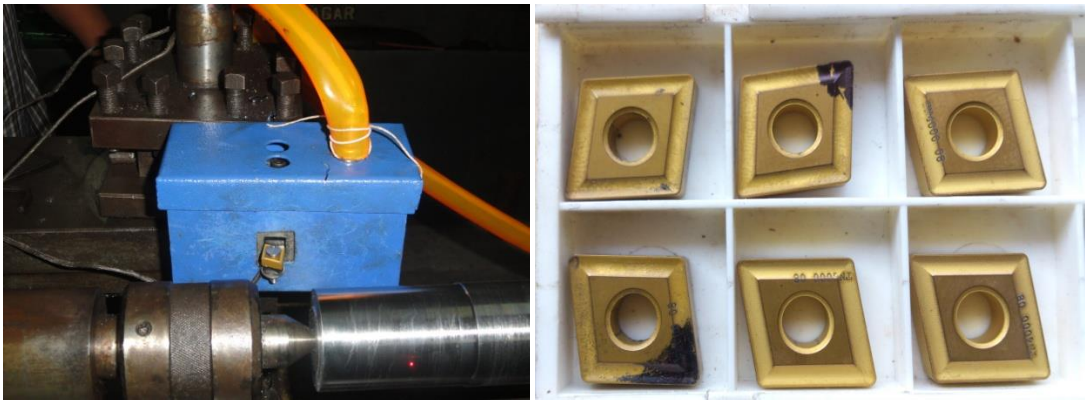


Figure 4.4: Cutting Tool (CARBIDE INSERT)

Measurement of Cutting Temperatures

Cutting Temperatures indicate the amount of heat generated during machining. To assay the effectiveness of the cutting fluid as coolant, cutting temperatures are measured. Embedded thermocouple is used to measure the temperature if the cutting tool insert at a nodal point. Digital temperature indicator is used for recoding and displaying the temperature of the hot junction of thermocouple.

Specification of Temperature Indicator:

Range:	0-1200^{0}C
Supply Voltage:	230V, AC 50Hz
Input:	Cr-Al (K-type)

Specification of Thermocouple:

Designation:	K type, Shielded Thermocouple
Element outside Diameter:	2 mm
Element Length:	120 mm
Element Type:	Duplex
Sheath Material:	Recrystallized Alumina
Temperature Range:	-250^{0}C to 1260^{0}C

Figure 4.5: Thermocouple

Machining tests are carried out under constant cutting conditions to assess the performance of fluids in machining. Tool temperature is measured at a nodal point. Heat transfer coefficients are calculated for the fluids with different fluids of varying nano - particle concentration.

4.5 SURFACE ROUGHNESS AND ITS IMPORTANCE

Surface roughness, often shortened to roughness, is a measure of the texture of a surface. It is quantifies by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be high frequency, short wavelength component of a measured surface. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface.

Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surface. Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. On the other hand, roughness may promote adhesion.

Although roughness is often undesirable, it is difficult and expensive to control in manufacturing. Decreasing the roughness of a surface will usually increase exponentially its manufacturing costs. This often results in a tradeoff between the manufacturing cost of a component and its performance in application.

Roughness is typically measured in 'RMS" micro inches and is often only measure by manual comparison against a "surface roughness comparator"", a sample of known surface roughness.

A roughness value can either be calculated on profile (line) or on a surface (area). The profile roughness parameter (Ra, Rq,...) are more common. The area roughness parameters (Sa, Sq...) give more significant values.

The surface tester used in the experiment is SJ 301. The surf test SJ 301 is a stylus type surface roughness measuring instrument developed for shop floor use. The measurement results are displayed on the touch panel, and output to the built - in printer.

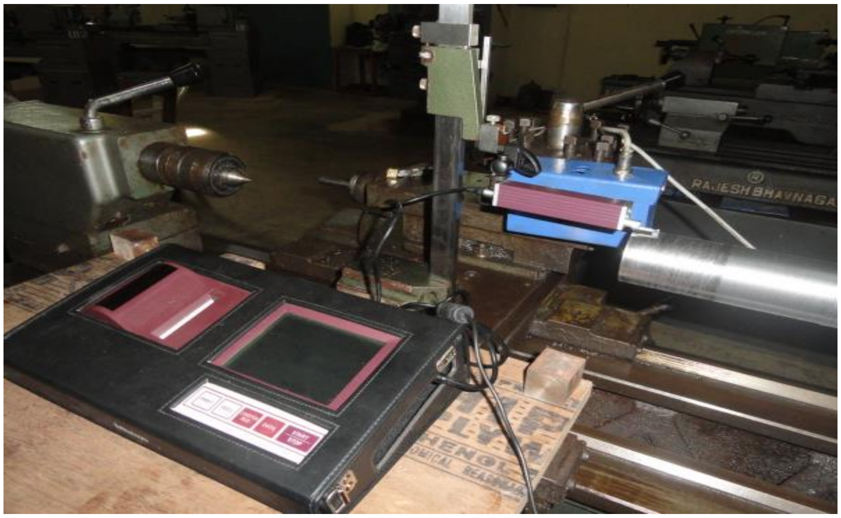


Figure 4. 1: Surface Roughness Testing Apparatus

The Surface Roughness Tester used in the experiment is SJ-301. The Surf test SJ-301 is a stylus type surface roughness measuring instrument developed for the shop floor use. The measurement results are displayed digitally on the touch panel, and the output to the built-in printer.

Specifications of Detector:

Detection Method:	Differential Inductance Method
Measuring range:	350 gm (-200 to +150 pm)
Stylus Material:	Diamond
Tip Radius:	5 pm
Measuring Force:	4 mN
Radius of the Skid Curvature:	40 mm

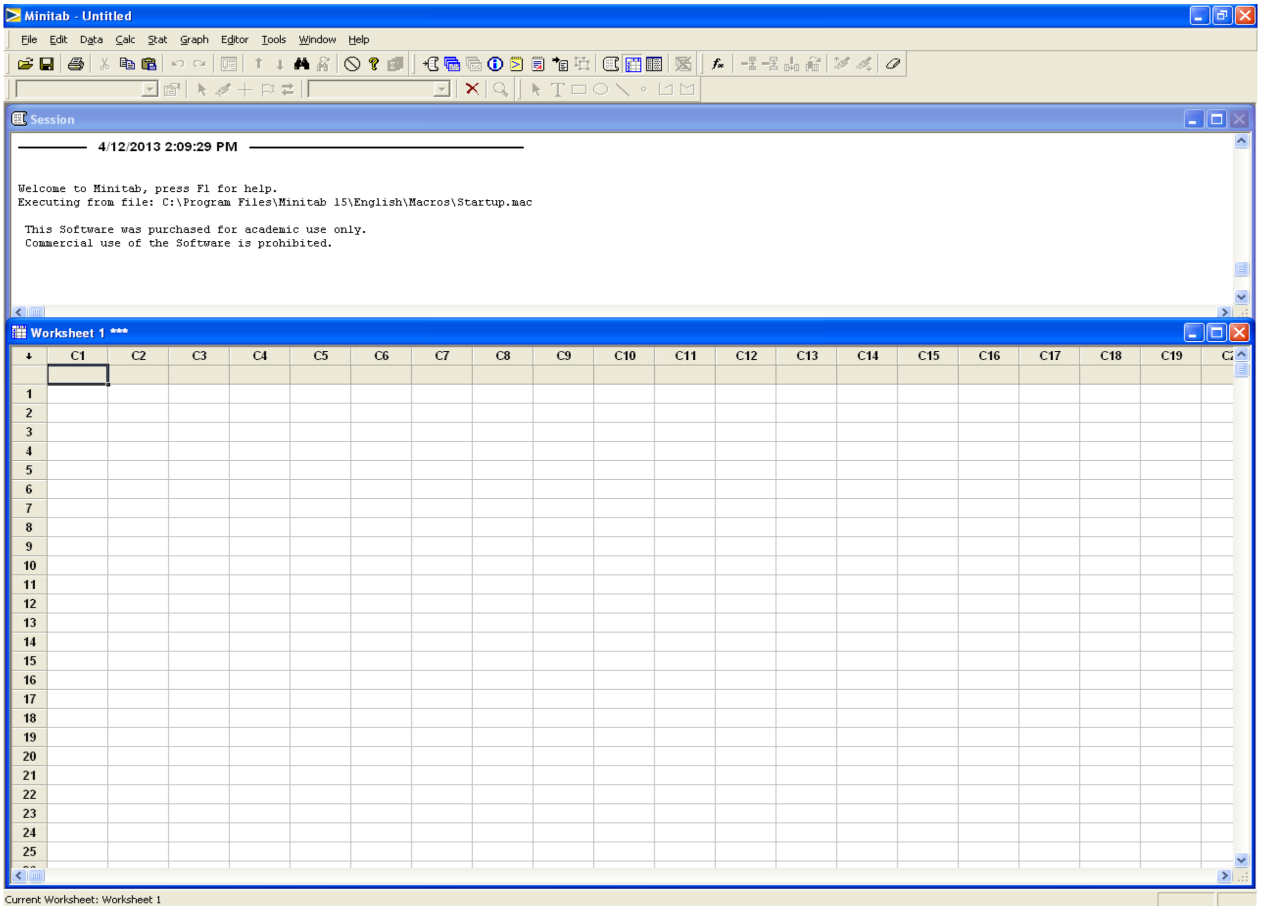
Procedure:

1. Insert a new Carbide tool insert
2. Start machining of the workpiece with the test conditions that were obtained from Taguchi Design of experiments
3. During the process of machining the Temperatures through thermocouple were captured.
4. Once the machining for each test condition is completed surface roughness was tested with MITUTOYO tester.
5. Analysis was done for Surface roughness , Temperatures.

5. APPLICATION OF MINITAB SOFTWARE

5.1 INTRODUCTION

MINITAB provides a wide range of basic and advanced statistics, including exploratory data analysis, basic statistics, regression, analysis of variance (ANOVA), multivariate analysis, time series, cross-tabulations, simulations and distributions. It also has facilities to produce a comprehensive array of graphs.



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4/12/2013 2:09:29 PM


Welcome to Minitab, press F1 for help.
Executing from file: C:\Program Files\Minitab 15\English\Macros\Startup.mac

 This Software was purchased for academic use only.
 Commercial use of the Software is prohibited.
```

Figure 5. 1: MINITAB Work Sheet

Below the MINITAB menu bar are two sub-windows, session and worksheet1. The session window is where any non-graphical output is displayed. Not that you can also type in commands in this window, but for this tutorial you will use pull-down menus. The worksheet1 window is a spreadsheet, where you can type in and view your data.

Worksheet Window

Data in Minitab is stored in a worksheet of columns and rows. Typically, each column contains the data for 1 variable, with 1 observation in each row. Columns are numbered C1. C2, C3....., while rows are numbered as 1,2,3,.... You can change the column names by checking the field below the column number, typing the name and hitting return. You can also change the name using commands.

Column Data can easily be edited without any obligations. Data in the column can also be inserted by copying from excel sheets or data in .txt format can also be inserted.

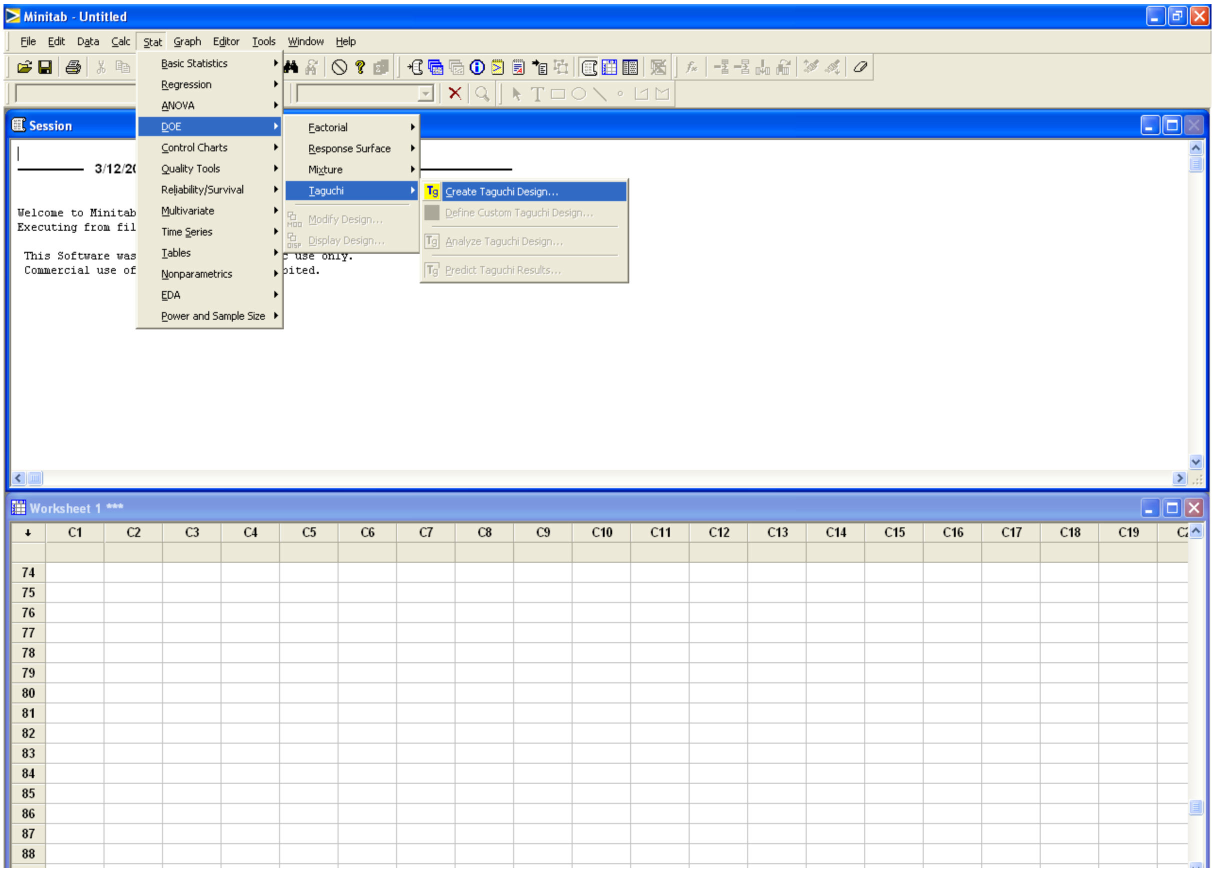
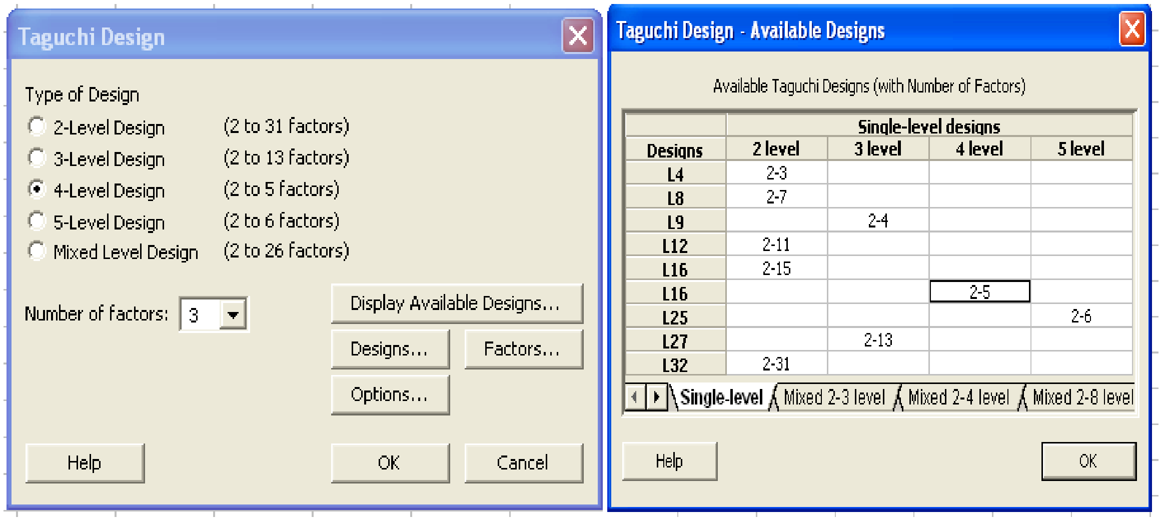


Figure 5. 2: MINITAB for DOE using Taguchi Design



Type of Design

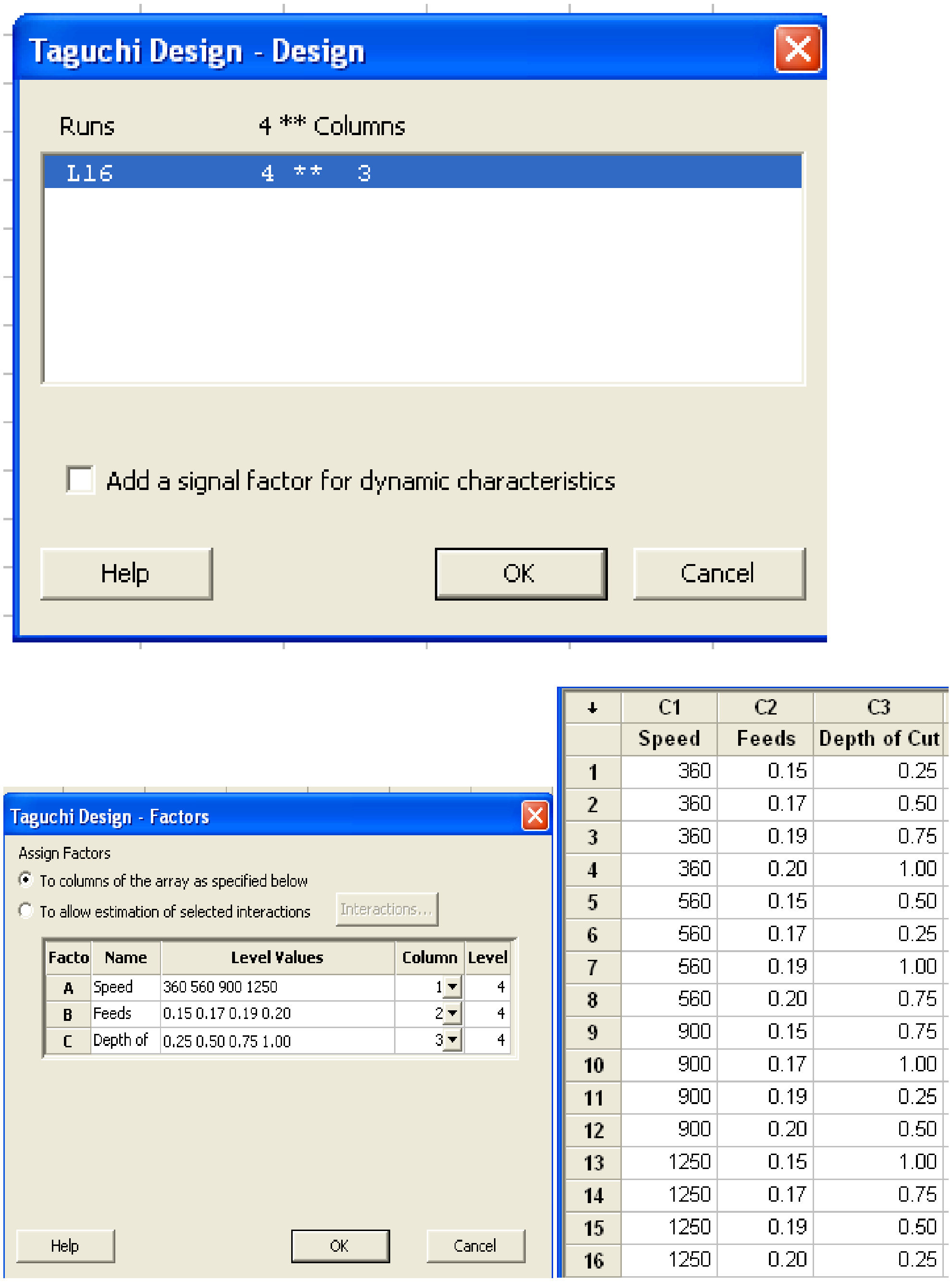
○ 2-Level Design (2 to 31 factors)
○ 3-Level Design (2 to 13 factors)
● 4-Level Design (2 to 5 factors)
○ 5-Level Design (2 to 6 factors)
○ Mixed Level Design (2 to 26 factors)

Number of factors: 3

Available Taguchi Designs (with Number of Factors)

	Single-level designs			
Designs	2 level	3 level	4 level	5 level
L4	2-3			
L8	2-7			
L9		2-4		
L12	2-11			
L16	2-15			
L16			2-5	
L25				2-6
L27		2-13		
L32	2-31			

Figure 5. 3: Taguchi 4 Level Design



Runs	4 ** Columns
L16	4 ** 3

☐ Add a signal factor for dynamic characteristics

Assign Factors

● To columns of the array as specified below

○ To allow estimation of selected interactions

Facto	Name	Level Values	Column	Level
A	Speed	360 560 900 1250	1	4
B	Feeds	0.15 0.17 0.19 0.20	2	4
C	Depth of	0.25 0.50 0.75 1.00	3	4

↓	C1	C2	C3
	Speed	Feeds	Depth of Cut
1	360	0.15	0.25
2	360	0.17	0.50
3	360	0.19	0.75
4	360	0.20	1.00
5	560	0.15	0.50
6	560	0.17	0.25
7	560	0.19	1.00
8	560	0.20	0.75
9	900	0.15	0.75
10	900	0.17	1.00
11	900	0.19	0.25
12	900	0.20	0.50
13	1250	0.15	1.00
14	1250	0.17	0.75
15	1250	0.19	0.50
16	1250	0.20	0.25

Figure 5. 4: Taguchi Design Factors

The three design factor levels feed, speed, depth of cut are selected and given in the above table.

5.2 REGRESSION ANALYSIS

In statistics, regression analysis is statistical technique 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. More specifically, regression analysis helps one understand how the typical value of the dependent variable changes when any one of the independent variables are 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 quantile or other location parameter of the conditional distribution of the dependent variables given the independent variables. In all cases, the estimation target is the function of the independent variables called the regression function. In regression analysis, it is also of interest to characterize the variation of dependent variable around the regression function, which can be described by a probability distribution.

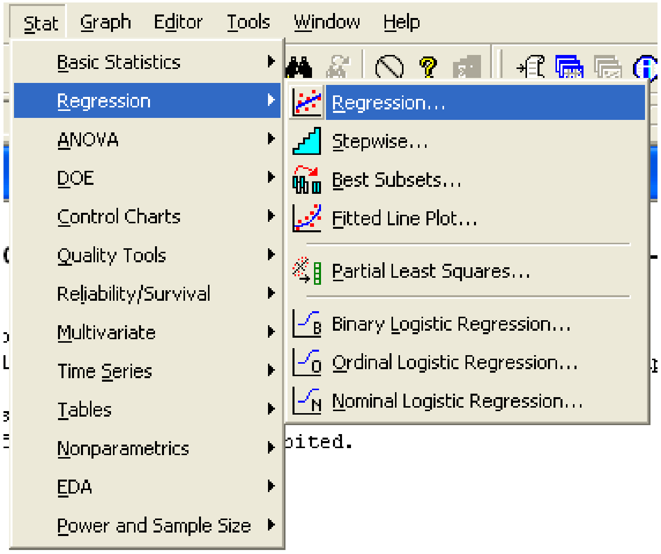
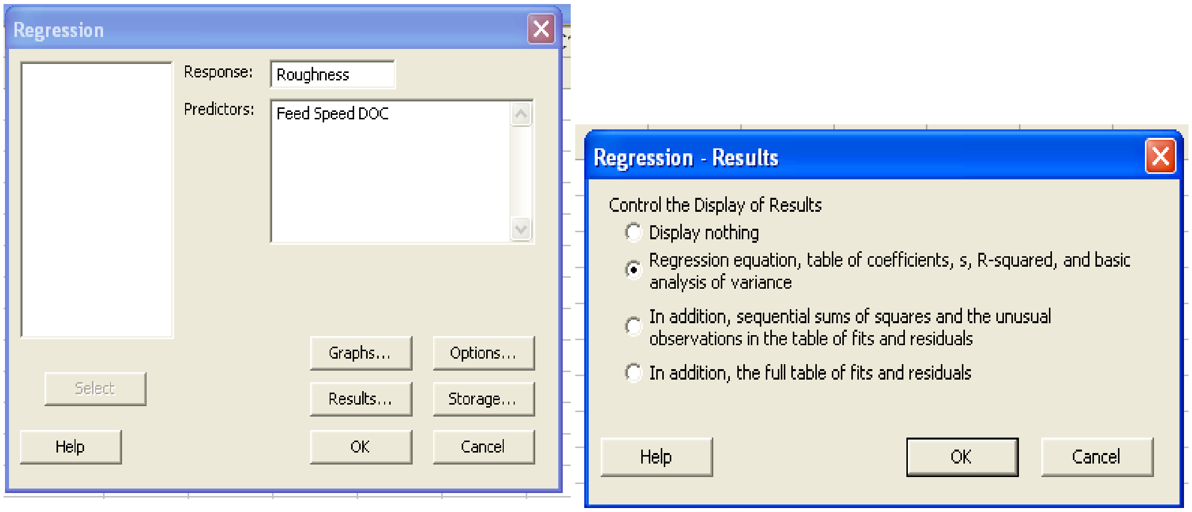


Figure 5. 5: Regression Analysis using MINITAB



Response: Roughness

Predictors: Feed Speed DOC

Control the Display of Results

○ Display nothing

● Regression equation, table of coefficients, s, R-squared, and basic analysis of variance

○ In addition, sequential sums of squares and the unusual observations in the table of fits and residuals

○ In addition, the full table of fits and residuals

Figure 5. 6: Regression Equation Parameters

5.3 ANOVA

Analysis of Variance (ANOVA) is a collection of statistical models used to analyze the differences between group means and their associated procedures (such as “variation” among and between groups), in which the observed variance in a particular variable is partitioned into components and attributable to different sources of variation. In its simplest for, ANOVA provides statistical test of whether or not the means of several groups are all equal, and therefore generalizes t-test to more than two groups. Doing multiple twosample t-tests would result in an increased chance of committing a type I error. For this reason ANOVA’s are useful in comparing (testing) three or more means (groups or variables) for statistical significances.

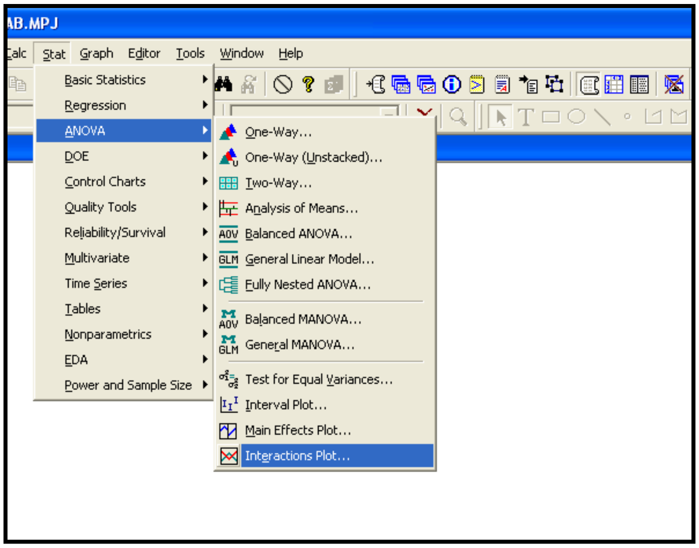
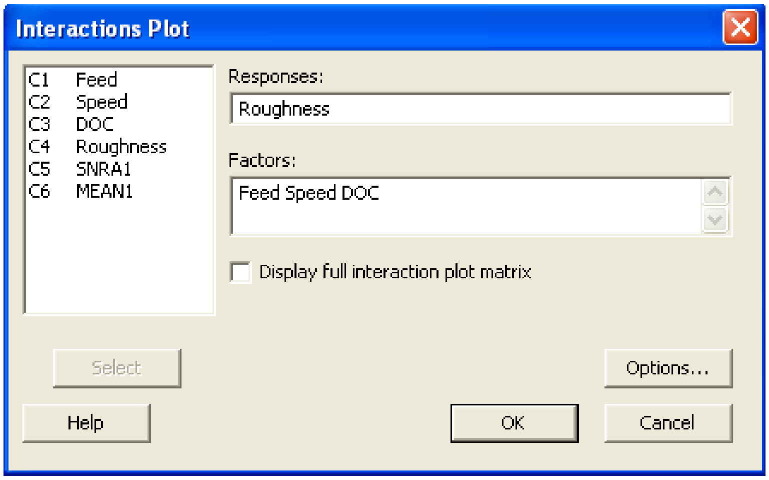


Figure 5. 7: ANOVA Interactions



C1	Feed
C2	Speed
C3	DOC
C4	Roughness
C5	SNRA1
C6	MEAN1

Responses: Roughness

Factors: Feed Speed DOC

☐ Display full interaction plot matrix

Figure 5. 8: Interaction Responses and Factors

6. EXPERIMENTAL RECORDINGS AND ANALYSIS

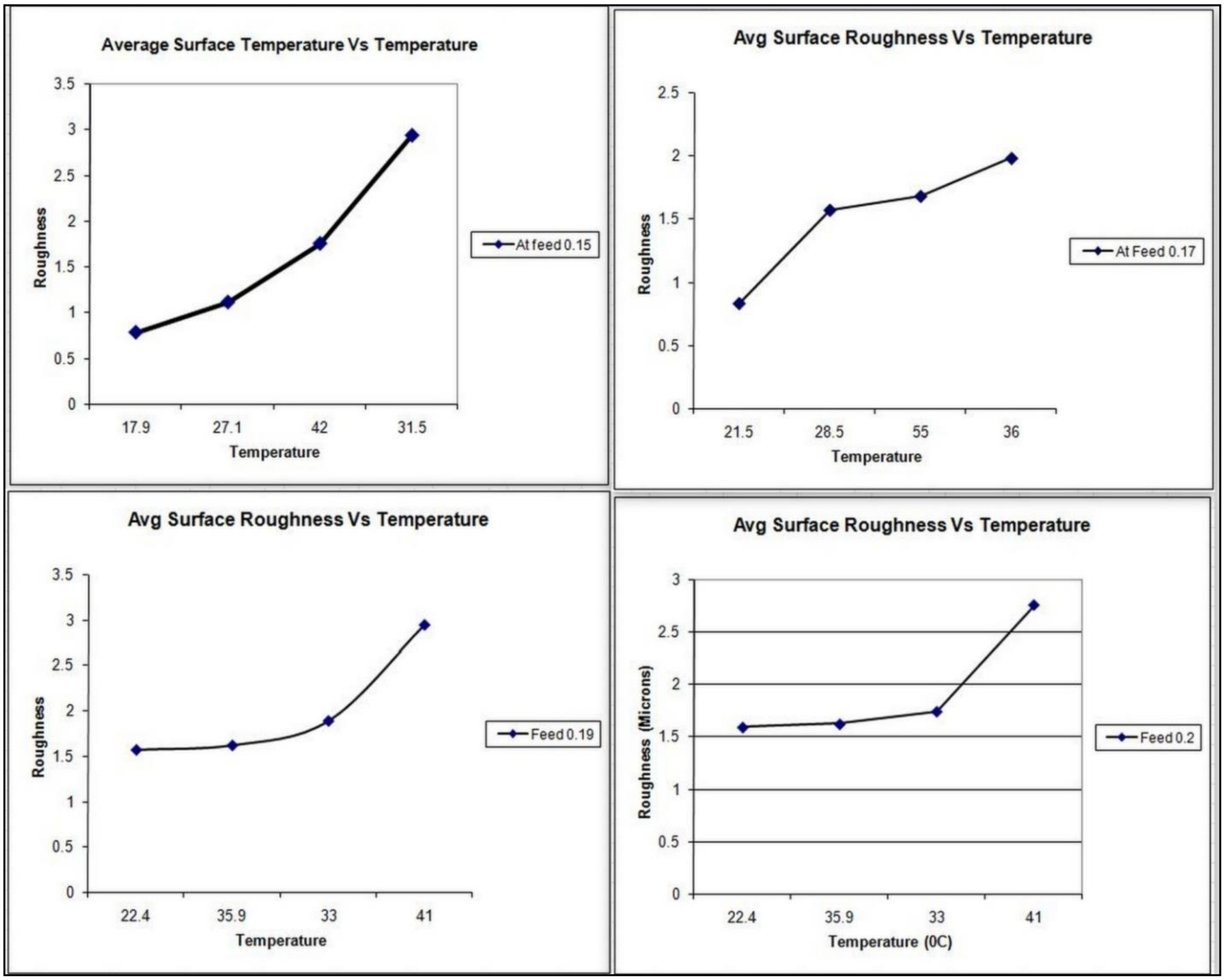
6.1 RECORDING OF SURFACE ROUGHNESS AND TEMPERATURES

Workpiece	Average Surface Roughness (microns)	Feed (mm/ rev)	Diameter of workpiece	Spindle Speed (RPM)	Depth of cut (mm)	Tool Tip Temperature (^{0}C)
Run 1- 1	2.93	0.15	58	360	0.25	31.5
Run 1- 2	1.77		56	560	0.5	42
Run 1- 3	1.12		54	900	0.75	27.1
Run 1- 4	0.94		52	1250	1.0	17.9
Run 2- 1	1.97	0.17	58	360	0.5	36
Run 2- 2	1.7		56	560	0.25	55
Run 2- 3	1.64		54	900	1.0	28.5
Run 2- 4	1.57		52	1250	0.75	21.5
Run 3- 1	2.97	0.19	58	360	0.75	41
Run 3- 2	1.9		56	560	1.0	33
Run 3- 3	1.62		54	900	0.25	35.9
Run 3- 4	1.57		52	1250	0.5	22.4
Run 4- 1	2.79	0.2	58	360	1.0	45
Run 4- 2	1.96		56	560	0.75	39
Run 4- 3	1.85		54	900	0.5	35.3
Run 4- 4	1.8		52	1250	0.25	24.7

7. RESULTS AND CONCLUSIONS

7.1 GRAPHICAL ANALYSIS

Average Surface Roughness Vs Temperature

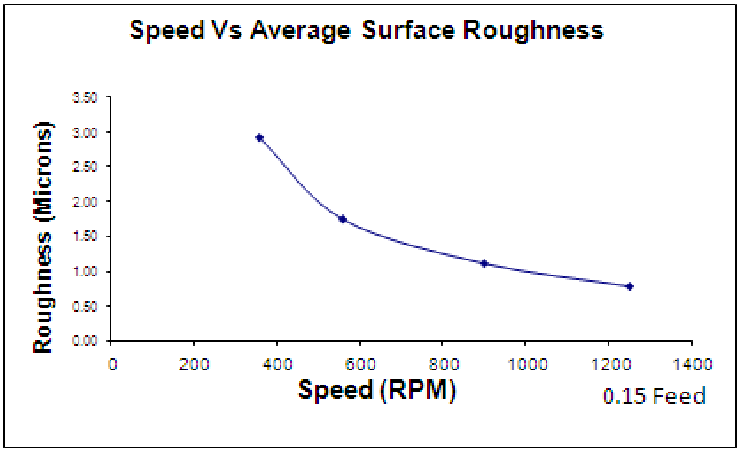


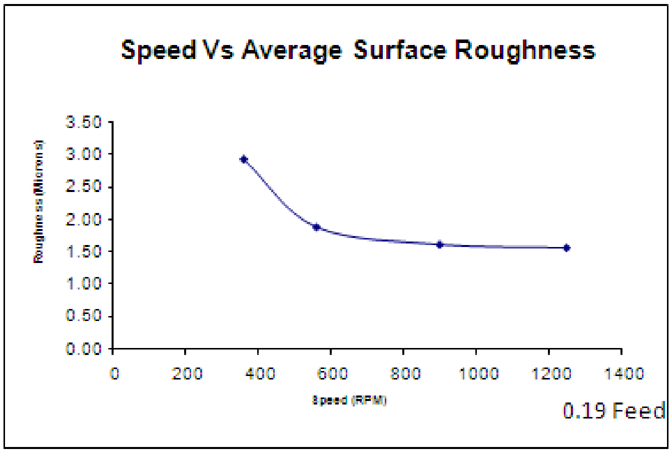
From the graph,

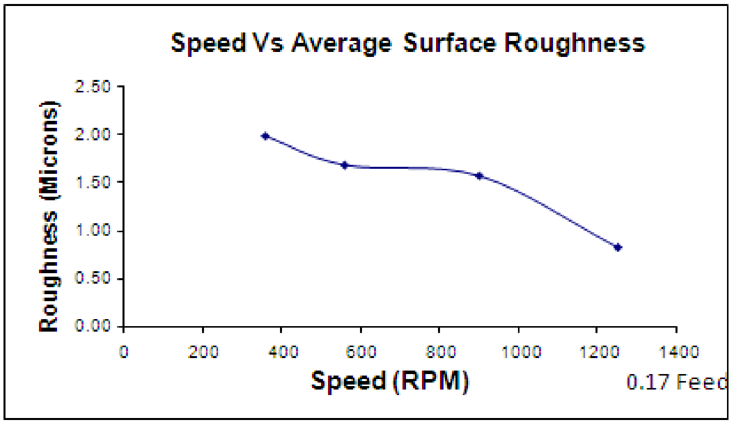
- At feed 0.15 as the temperature increases the surface roughness is increasing rapidly.
- At feed 0.17 as the temperature increases the surface roughness is gradually increasing.

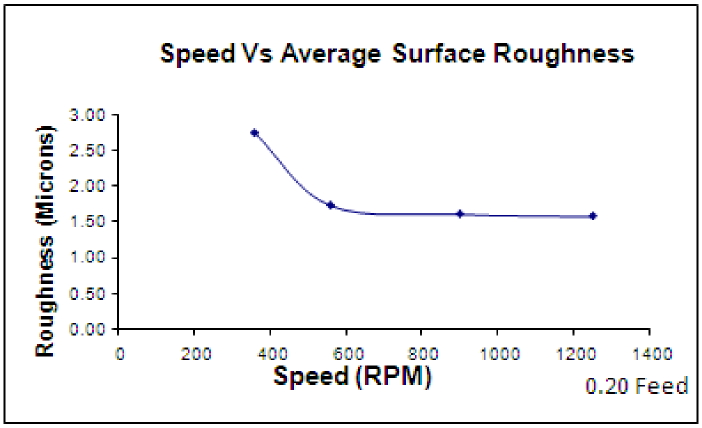
- At feed 019 as the temperature increases the surface roughness did not show any variation till third point and then increased suddenly.
- Finally, at feed 0.20 as the temperature increases the surface roughness increases gradually till the third point and then increases suddenly.

Speed Vs Average Surface Roughness







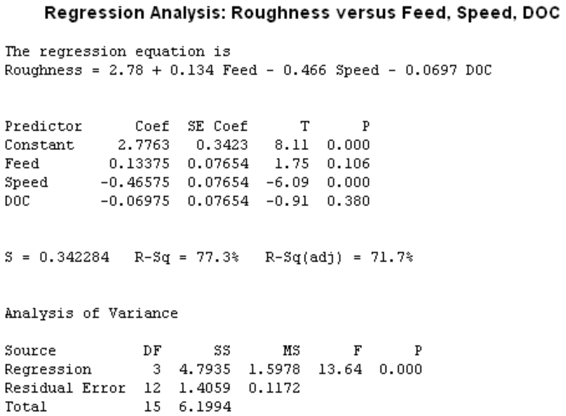


- At 0.15 feed, as the speed increases the average surface roughness of the workpiece decreases rapidly in all the runs.

- At 0.17 feed, as the speed increases the average surface roughness of the workpiece decreases gradually in all the four runs.
- At 0.19 feed, as the speed increases the average surface roughness of the workpiece decreases rapidly between third and fourth run.
- At 0.20 feed, as the speed increases the average surface roughness of the workpiece increases rapidly between first and second run. The roughness remains constant during second, third and fourth runs.

7.2 REGRESSION AND ANOVA RESULTS

- **Regression Results**



Regression Analysis: Roughness versus Feed, Speed, DOC

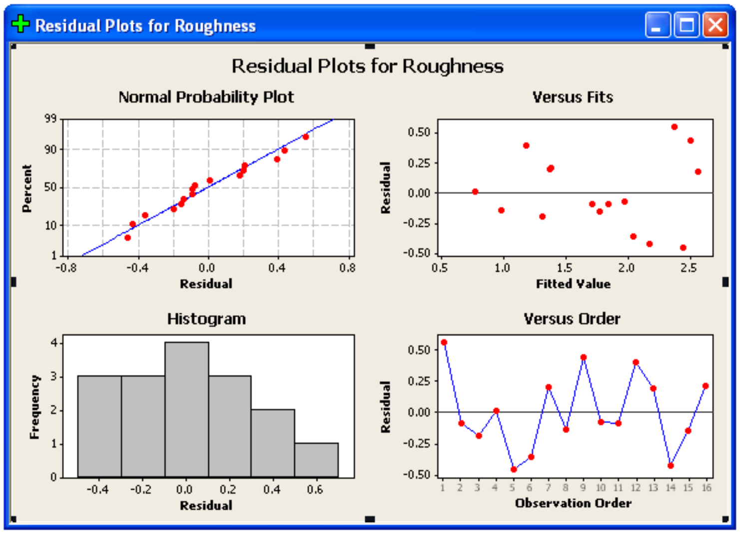
```
The regression equation is
Roughness = 2.78 + 0.134 Feed - 0.466 Speed - 0.0697 DOC


Predictor       Coef  SE Coef      T      P
Constant      2.7763   0.3423   8.11  0.000
Feed         0.13375  0.07654   1.75  0.106
Speed       -0.46575  0.07654  -6.09  0.000
DOC         -0.06975  0.07654  -0.91  0.380


S = 0.342284   R-Sq = 77.3%   R-Sq(adj) = 71.7%


Analysis of Variance

Source          DF      SS      MS      F      P
Regression       3  4.7935  1.5978  13.64  0.000
Residual Error  12  1.4059  0.1172
Total           15  6.1994
```



- **Figure 5. 9: Plots for Roughness**

- **Regression Analysis: Roughness versus Feed, Speed, DOC**
- The Regression equation is:
- Roughness = 2.78 + (0.34 * Feed) - (0.466 * Speed) - (030697 * DOC)

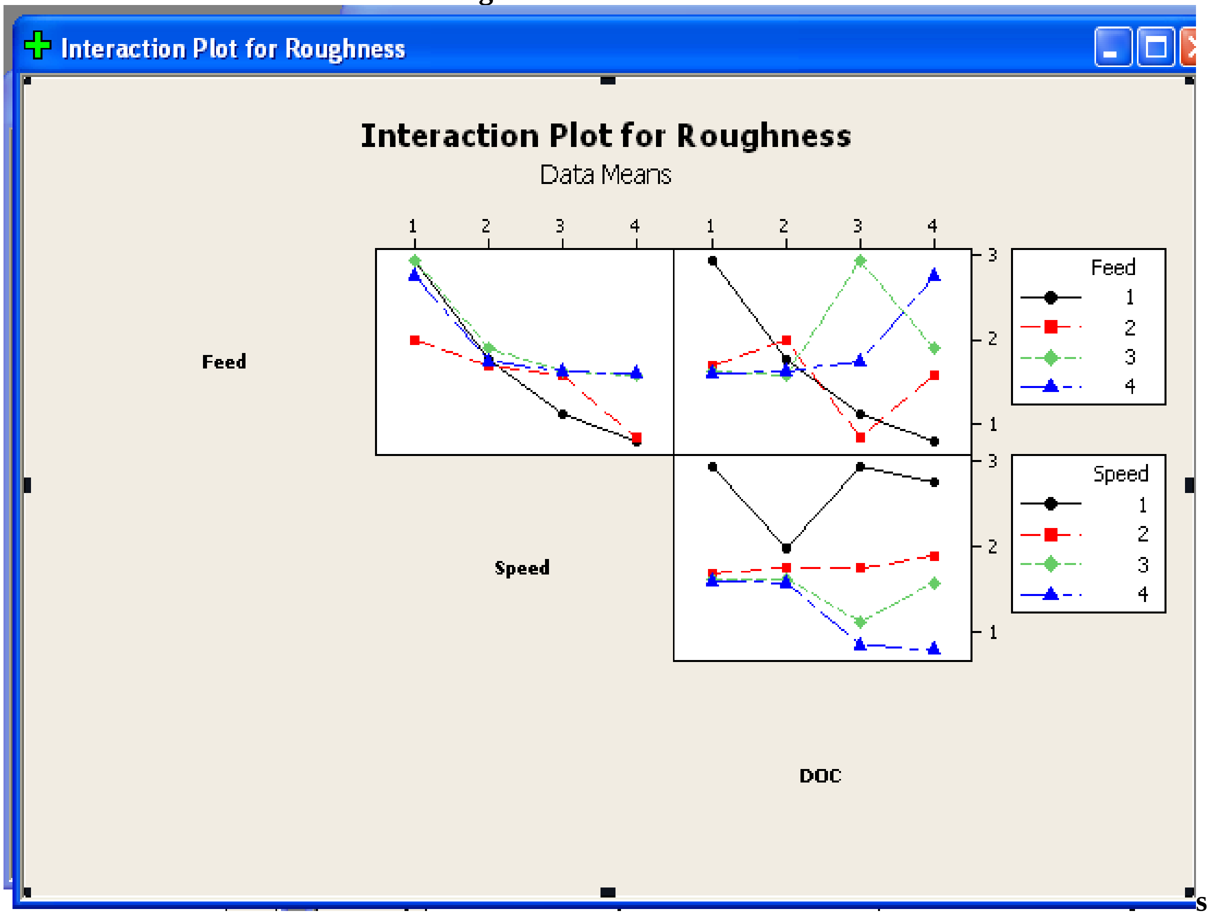
Predictor	Coef	SE	T	P

Constant	2.7763	0.3423	8.11	0
Feed	0.13375	0.07654	1.75	0.106
Speed	-0.4658	0.07654	-6.09	0
DOC	-0.0698	0.07654	-0.91	0.38

-
- S = 0.342284   R-Sq = 77.3%   R-Sq(adj) = 71.7%

7.3 ANOVA Plots

Figure 5. 10: Interaction



Plots for Roughness

Source	**DF**	**Seq SS**	**Adj MS**	**F**	**P**	**$F_{critical}$**	**Remark**
Regression	3	4.7935	1.5798	13.64	0	3.49	Significant
Residual Error	12	1.4059	0.1172				
Total	15	6.1994					

8. CONCLUSION

In the present work an attempt to optimize multiple roughness criteria using regression analysis has been made. The process parameters considered are depth of cut , feed rate and cutting speed . By the graphical analysis we to have analyze the plots of average surface roughness vs temperature and speed vs average surface roughness. At feed 0.2 as temperature increases the surface roughness gradually increases till the third period and then increases also. At 2.0 feed the roughness remains constant during 2-4 points at speed vs average surface roughness. Feed rate is the most significant factor affecting the surface roughness parameter followed by cutting environment and lastly by depth of cut . This has been proven in the confirmation test which indicates that the application of regression analysis has caused a significant effect of surface roughness parameters considered.

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