Analysis Effect of Surface Roughness, Material Removal Rate and Tool Life in Turning of Mild Steel Material

By

Mulukem Tesfaye

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School of Mechanical and Industrial Engineering

Addis Ababa Institute of Technology

Addis Ababa University

Advisor: Daniel Tilahun (PhD)

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DECLARATION

I, the undersigned, declare that this MSc thesis is my original work, has not been presented for fulfillment of a degree in this or any other university, and all sources and materials used for the thesis have been acknowledged.

Name: Muluken Tesfaye Gebiso

Signature: ________________________

Date: ____________________________

This MSc. thesis has been submitted for examination with my approval as an advisor.

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Daniel Tilahun (PhD)

Addis Ababa University

School of Graduate Studies

Certificate of Examination

This is to certify that the thesis prepared by Muluken Tesfaye entitled: *Analysis Effect of Surface Roughness, Material Removal Rate and Tool Life in Turning of Mild Steel***,** submitted in fulfillment of the requirements for the degree of Masters of Science (In Mechanical Design), which compiles with the regulations of the university and meets the accepted standards with respect to originality and quality.

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ABSTRACT

This Experimental work presents a technique to determine the better productive quality by Analysis of Effect Surface Roughness, Material Removal Rate and Tool Life in Turning of Mild Steel by controlling cutting experiment. Turning Experiments on Laze Machine were conducted with Spindle Speeds: 530, 700, 860 rev/min, Feeds: 0.5, 0.6, 0.7 mm/rev and Depth of cuts: 0.5, 1.0, 1.5 mm. Thus the three input process parameters such as Spindle Speed, Depth of Cut and Feed Rate have been selected to minimize the Surface Roughness, maximize Material Removal Rate and Tool life simultaneously The present work focused by using L_9 Orthogonal Array (OA) on the processing steps to get the optimal values with the help of Minitab software using main effects graph, and Analysis of variance (ANOVA) was employed to investigate the characteristics and experimental results are provided the effectiveness of this approach. This technology has met the current needs of Industry owing to its shorter design cycles and improved the design of quality using Taguchi Method. The results revealed that the feed rate (68.7%) is only significant to minimize surface roughness and optimum values are (530rpm, 0.5mm/rev, 0.5mm) secondly spindle speed (48.7%) the major significant parameter for Maximize Material Removal Rate and the Optimum values are (860rpm, 0.7mm/rev, 1.5mm) lastly spindle speed (75.3%) is Highly significant parameter for maximize Tool life and the optimum values are (530rpm, 1mm/rev, 0.5mm), Finally, the relationship between cutting parameters and the performance measures (Surface Roughness, Material Removal Rate and Tool life) were developed by using multiple regression analysis.

Keywords: Taguchi orthogonal array; S/N ratio; Surface Roughness; Material Removal Rate; Tool life, Regression Analysis

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Nomenclatures

V	:	The cutting speed in turning
D	:	The initial diameter of the work piece
N	:	The spindle speed
Fm	:	The feed
d_{cut}	:	Depth of cut
MRR	:	The material removal rate
L	:	Length of machined
Mo	:	Mass before turning
M_f	:	Mass after turning
ρ	:	Density of material
t	:	Cutting time
d	:	Diameter of work piece after machine
Ra	:	Arithmetic Roughness
RT	:	Total Roughness
OA	:	Orthogonal array
DOE	:	Design of experiment
M.S.D	:	Mean square deviation
ANOVA	:	Analysis of Variance
S/N	:	Signal to noise ratio
MSD	:	Mean square deviation

CHAPTER ONE

1. INTRODUCTION

1.1Turing Operation

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

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

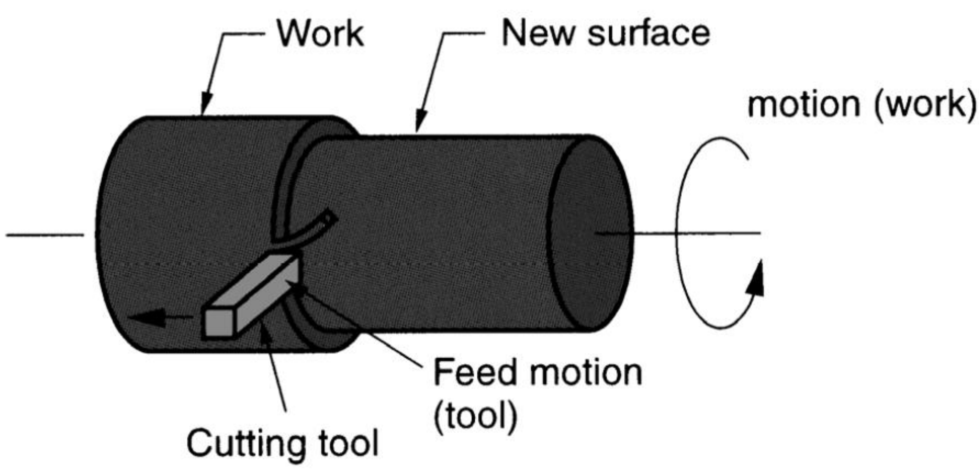

Fig 1.1: Adjustable parameters in turning

1.1.1Adjustable Cutting Factor

The three primary factors in any basic turning operation are Speed, Feed, and Depth of cut. Other factors such as kind of material and type of tool have a large influence; of course these three are the ones the operator can change by adjusting the controls, right at the machine.

1. Speed:

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

$$v = \frac{\pi DN}{1000} m \min^{-1} \quad \text{………………………………………………………….. (1)}$$

Here, *v* is the cutting speed in turning, *D* is the initial diameter of the work piece in mm, and *N* is the spindle speed in rpm

2. Feed:

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

$$F_m = f.N\, mm.\min^{-1} \quad \text{…………………………………………………………… (2)}$$

Here, F*m is* the feed in mm per minute, *f* is the feed in mm/rev and *N* is the spindle speed in RPM.

3. Depth of Cut

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

$$d_{cut} = \frac{D-d}{2} mm \qquad \text{.......... (3)}$$

Here, *D and d* represent initial and final diameter (in mm) of the job respectivel

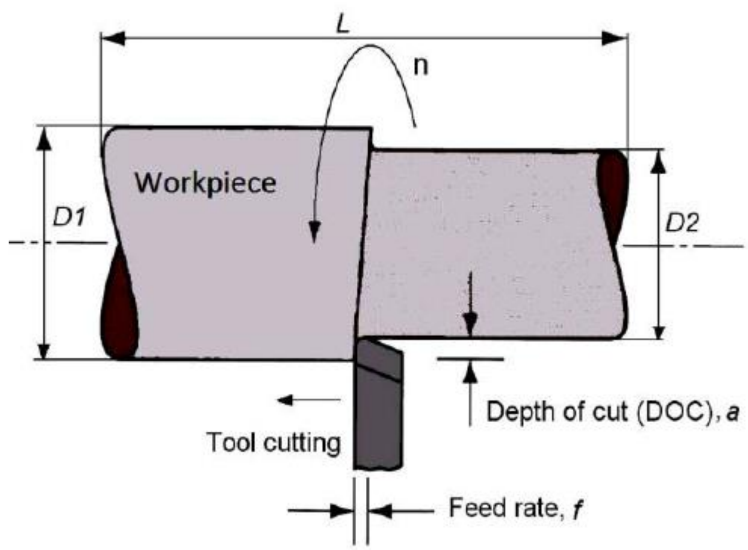

Fig 1.2: Schematic Diagram of the Orthogonal Metal cutting configuration

1.1.2 Cutting Tool Material

The classes of cutting tool materials currently in use for machining operation are high speed tool steel, cobalt-base alloys, cemented carbides, ceramic, polycrystalline cubic boron nitride and polycrystalline diamond. Different Machining applications require different Cutting Tool Materials. The Ideal cutting Tool Material should have all of the following characteristics:

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

Some cutting tool materials are: carbon steel, high speed steel (HSS), cast cobalt alloys, carbides, coatings, cermets, silicon nitride, cubic boron nitride and etc.

1.1.3 Material Removal Rates (MRR)

The Material Removal Rate (MRR) in turning operations is the volume of material/metal that is removed per unit time in mm³/min. For each revolution of the work piece, a ring shaped layer of material is removed. We can calculate MRR by using the following formula.

$$MRR = \frac{\text{volume removed}}{\text{Cutting time}} \qquad MRR = \frac{\frac{\Pi L (D_1^2 - D_2^2)}{4L}}{fn}$$

If D_1 and D_2 is diameter work piece before and after machining, L is length of machined work piece finally deduce to

$MRR = (v. f .a \times 1000)$ *in* mm^3 / min ……………………………………………………….(4)

Where: V is cutting speed, f is feed rate and a is cutting depth

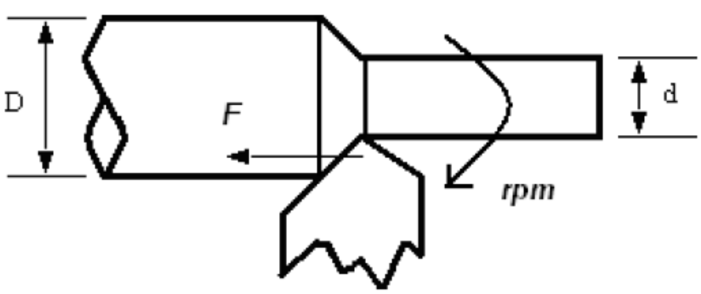

Fig.1.3: MRR in turning

The other option is to calculate material removal rate

$$MRR = \frac{Mo - Mf}{\rho t} \qquad \text{--} \; (5)$$

Where: Mo is mass before turning in (g), Mf is mass after turning in (g), ρ is density of material in (g/mm^3) and t cutting time.

1.1.4 Tool wear and Tool Life

Tool wear

Tool wear in machining is defined as the amount of volume loss of tool material on the contact surface due to the interactions between the tool and work piece. Specifically, Tool Wear is described by wear rate (volume loss per unit area per unit time) and is strongly determined by temperature, stresses, and relative sliding velocity generated at the contact interface.

Metal cutting tools are subjected to extremely arduous conditions, high surface loads, and high surface temperatures arise because the chip slides at high speed along the tool rake face while exerting very high normal pressures (and friction force) on this face. The forces may be fluctuating due to the presence of hard particles in the component microstructure, or more extremely, when interrupted cutting is being carried out. Hence cutting tools need:

- Strength at elevated temperatures
- High toughness
- High wear resistance
- High hardness

Accordingly, three main types of tool wear can be distinguished,

1. Crater wear
2. Flank wear
3. Corner wear

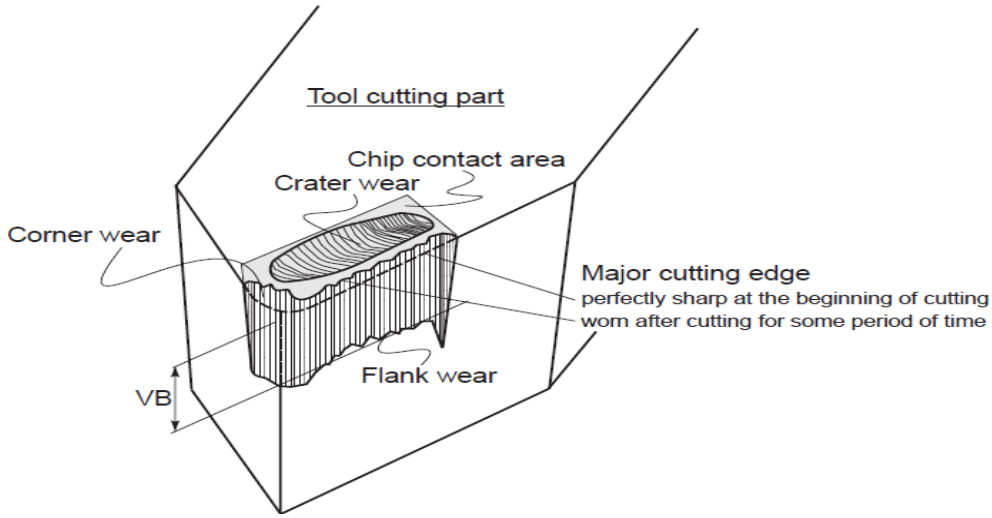

Fig.1.4: Types of Tool Wear

1. **Crater wear**: consists of a concave section on the tool face formed by the action of the chip sliding on the surface. Crater wear affects the mechanics of the process increasing the actual rake angle of the cutting tool and consequently, making cutting easier. At the same time, the crater wear weakens the tool wedge and increases the possibility for tool breakage. In general, crater wear is of a relatively small concern.
2. **Flank wear**: occurs on the tool flank as a result of friction between the machined surface of the work piece and the tool flank. Flank wear appears in the form of so-called wear land and is measured by the width of this wear land, VB, Flank wear affects to the great extend the mechanics of cutting. Cutting forces increase significantly with flank wear. If the amount of flank wear exceeds some critical value (VB > 0.5~0.6 mm), the excessive cutting force may cause tool failure.

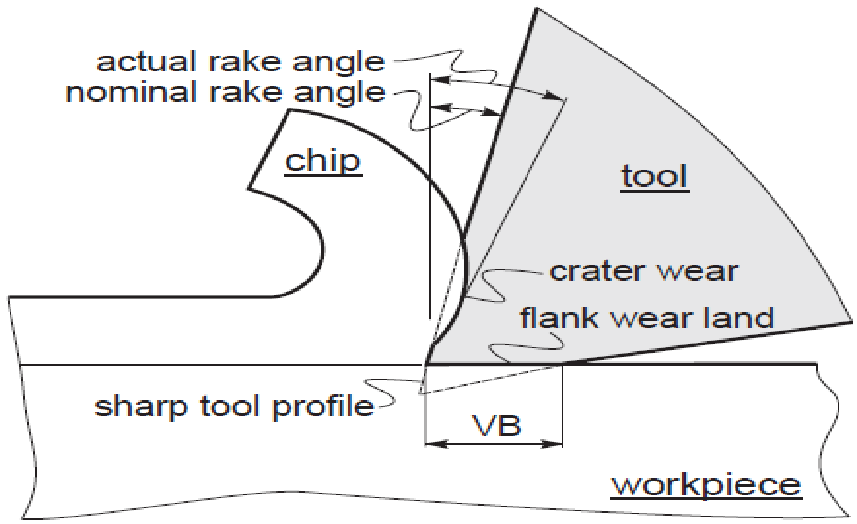

Fig: 1.5a Flank and Corner wears

3. **Corner wear**: occurs on the tool corner. Can be considered as a part of the wear land and respectively flank wear since there is no distinguished boundary between the corner wear and flank wear land. We consider corner wear as a separate wear type because of its importance for the precision of machining. Corner wear actually shortens the cutting tool thus increasing gradually the dimension of machined surface and introducing a significant dimensional error in machining, which can reach values of about 0.03~0.05 mm.

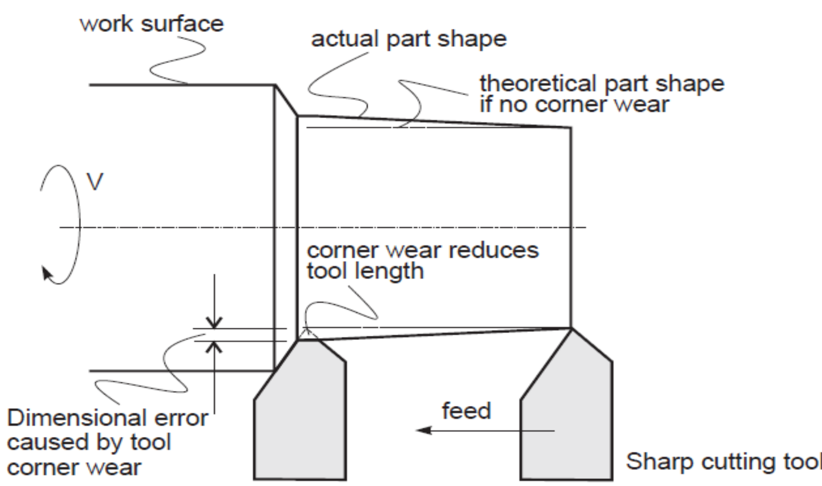

Fig: 1.5b Top view showing the effect of tool corner wear on the dimensional precision in turning

Consequences of tool wear:

1. Increase the cutting force;
2. Increase the surface roughness;
3. Decrease the dimensional accuracy;
4. Increase the temperature;
5. Vibration;
6. Lower the production efficiency, component quality;
7. Increase the cost

Tool Life

Tool life is important in machining since considerable time is lost whenever a tool is replaced and reset. Tool life is the time a tool will cut satisfactorily and is expressed as the minutes between changes of the cutting tool. The process of wear and failures of cutting tools increases the surface roughness, and the accuracy of work pieces deteriorates. The general relationship of VB versus cutting time is shown in the figure (so-called *wear curve*). Although the wear curve shown is for flank wear, a similar relationship occurs for other wear types. The figure shows also how to define the Tool Life T for a given wear criterion VB_k.

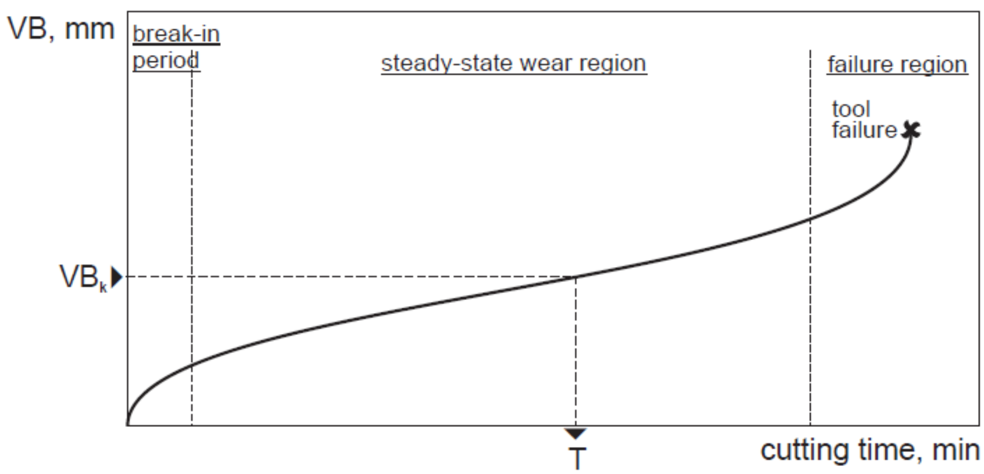

Fig.1.5c. Flank wears as a function of cutting time. Tool life T is defined as the cutting time required for flank wear to reach the value of VB_k.

Taylor's Tool Life Formula

Tool wear is almost always used as a lifetime criterion because it is easy to determine quantitatively. The flank wear land VBB is often used as the criterion because of its influence on work piece Surface Roughness and accuracy. Figure 1,5c shows the wear curves (VBB versus cutting time) for several cutting velocities (1, 2 and 3) and the construction of the life curve (cutting velocity versus tool life). Present the following formula

$$V_c T^n = C \qquad \text{(6)}$$

Where Vc is the cutting speed (m/min), T is the tool life (min) taken to develop a certain flank wear (VBB), n is an exponent that depends on the cutting parameters and C is a constant.

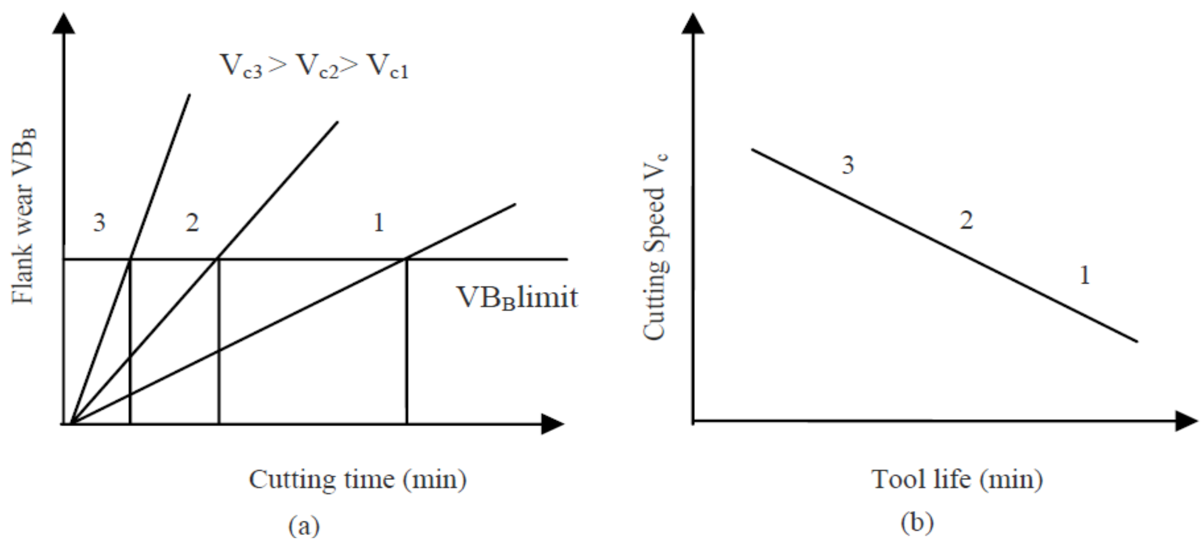

Fig: 1.5d: The wear curves (VBB versus cutting time) for several cutting velocities

According to the original Taylor tool life formula, the cutting speed is the only parameter that affects tool life. This is because this formula was obtained using high-carbon and high-speed steels as tool materials. With the further development of carbides and other tool materials, it was found that the cutting feed and the depth of cut are also significant. As a result, the Taylor's tool life formula was modified to accommodate these changes as:

$$V_c T^n f^a d^b = C \qquad \text{………………………………………………………….. (7)}$$

Where d is the depth of cut (mm) and f is the feed (mm/rev). The exponents n, a and b are to be determined experimentally for each combination of the cutting conditions.

1.1.5 Surface Roughness

Surface Roughness is an important measure of product quality since it greatly influences the performance of mechanical parts as well as production cost. Surface roughness has an impact on the mechanical properties like fatigue behavior, corrosion resistance, creep life, etc. It also affects other functional attributes of parts like friction, wear, light reflection, heat transmission. The resultant roughness produced by a machining process can be thought of as the combination of two independent quantities:

a. Ideal roughness, and

b. Natural roughness.

Whenever two machined surfaces come in contact with one another the quality of the mating parts plays an important role in the performance and wear of the mating parts. The height, shape, arrangement and direction of these surface irregularities on the work piece depend upon a number of factors such as:

a) Cutting speed

b) Feed, and

c) Depth of cut.

The roughness parameters are calculated using a formula for describing the surface. There are many different roughness parameters in use, but Out of all the surface condition criteria, Ra and Rt (expressed in μm) are often used to characterize the roughness of *machined surfaces. Rt* is total roughness (maximum depth or amplitude of the roughness), and *Ra* is arithmetic roughness (mean arithmetic deviation from the mean line of the roughness).

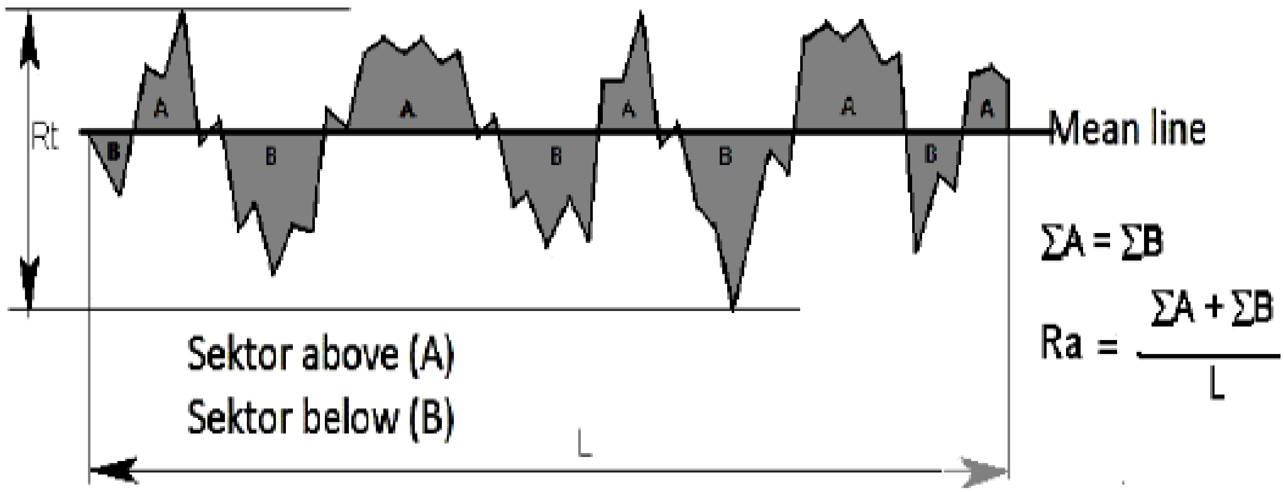

Fig 1.6: Schematic of parameter definition used to compute the Mean Arithmetic deviation (Ra) and Total Roughness (Rt).

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1.2 Statement of the Problem

In the present technical era of high productive quality of the machined parts (in terms of work piece dimensional accuracy, good Surface finish, less Tool wear/ high Tool Life on the cutting tools, high Material Removal Rate and economy of machining in terms of time per component, cost per component and the performance of the product) is one of the prime challenges of metal cutting industry. The quality of design can be improved by improving the quality and productivity in companywide activities.

Those activities concerned with quality include quality of product planning, product design and process design. Usually Surface finish, Material removal rate and Tool life are the most desirable tests for quality measurement of machining process. Especially Surface finish plays an important role on the product quality and it is a parameter of great importance in the evaluation of machining accuracy.

Then Quality and productivity play significant role in today's manufacturing market. From customer's viewpoint quality is very important because the extent of quality of an 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 the quality of the product. Especially Failures of mechanical parts due to surface roughness, sometimes leads to high cost damages, as in case of machine tool parts like spindles, shafts, bearing and automobile products etc.

Mild steel that I used for my thesis is basic important to form machine components especially automotive components are manufactured using a conventional machining process, such as turning process. This study investigated Effect of the Roughness, Material Removal Rate and Tool Life in turning of Mild Steel material working on Laze machine, the value of the research work lied in using laboratory measurement test and the results by other researches.

1.3 Objective of the Study

1.3.1 Major objective

The major objective of This Research is Analysis Effect of Surface Roughness, Material Removal Rate and Tool Life in Turning of Mild Steel on Lath Machine.

1.3.2 Specific objectives

- Determine Factor Influence (Main Effect)
- Identification which parameter significantly affected quality characteristics /ANOVA/.
- Identification of the best process condition or parametric combination for manufacturing process
- Developed Multiple Regression Model for each performance Measurements

1.4 Research Methodology

The Methods Employed to achieve the above objective are:-

a) Literature survey

Literature survey of relevant Material on different types of analysis effect of Surface Roughness, Material Removal Rate and Tool Life has been done. The literatures available are from electronic media, journals, and books. In addition secondary data are referred from previous related research studies, existing parametric data, etc.

b) Data collect from Experimental Investigation

The Mild Steel bar Material, worked turning operation on lath machine on different condition and take data of Surface Roughness, Material Removal Rate and Tool Life by using different measurement instruments and relevant equation. The experiments design was based on L_9 orthogonal array based on Taguchi Method using various operating parameters like Cutting Speed, Feed Rate, Depth of Cut and surrounding environment.

c) **Experimental Data Analysis and Discussion**

The data collected from the Experiments analysis using Signal to Noise (S/N), ANOVA and develop Multiple Regression Model by the help of Minitab 15 software.

1.5 LIMITION

Among the many, major obstacles while conducting this work were the followings;

- Financial matter.
- Experimental setups unavailability specially for tool wear

1.6 Organization of the Thesis

This Thesis is organized in to five chapters. In the First Chapter, Introduction, Statement of problem and justification of this thesis work and the objectives to be achieved are discussed. In Chapter Two, Review of literature relevant to this research work, which has been investigated in this study. In Chapter Three, Materials, Methods and Conditions that applied for result analysis and interpretations of the study are presented. In Chapter Four Results of the Analysis and Discussion. Chapter Five gives Conclusion achieved from this Thesis work, Recommendation and propose future work in this field of study.

CHAPTER TWO

2. LITERATURE REVIEW

This is one of the portions of the paper that reviews the previous related works which are basic guide for the introduction of the current work. Some of them may have a direct relation with this work whereas the others may have indirect relations. Literature depicts that a considerable amount of work has been carried out by previous investigators for modeling, simulation and parametric analysis of surface properties of the product in turning operation. Issues related Roughness, Material Removal Rat and Tool life/tool material wear have been addressed to. Apart from optimizing a single response (process output), multi objective optimization problems have also been solved using Taguchi method.

Surface quality is great importance for functional behavior of mechanical parts. surface roughness in addition to tolerance impose one of most critical constraint for cutting parameter selection in manufacturing process planning, [5] used response surface methodology (RSM) in order to develop empirical model for the prediction of surface roughness by deciding the optimum cutting condition in turning. The authors showed that the feed rate influenced surface roughness remarkably. With increase in feed rate surface roughness was found to be increased. With increase in cutting speed the surface roughness decreased. The analysis of variance was applied which showed that the influence of feed and speed were more in surface roughness than depth of cut.[12] the machining parameters affecting the roughness of surfaces produced in hard turning process for three different materials like EN8 steel, Aluminum alloy and Copper alloy under dry conditions. Three parameters were selected for study: cutting speed, feed and material hardness. For the three materials like Aluminum alloy, copper alloy and EN8 steel impact of increase in feeds versus decrease in cutting speeds with constant depth of cut adopted to analyze the influence of these parameters on the generated surface roughness.

[23] focused on hard turning of 20 MnCr5 Steel. The purpose of this paper is to analyze optimum cutting conditions to get lowest surface roughness in turning of 20 MnCr5 Steel. Taguchi methods have been used for this. An orthogonal array, the signal to noise ratio and analysis of variance (ANOVA) are employed to investigate the cutting characteristics. The results indicate that feed rate has significant role to play in producing lower surface roughness followed by cutting speed. The cutting insert used is ceramic based TNGA 160404. [17] Examined the correlation between surface roughness and cutting tool vibration for turning operation. The process parameters were cutting speed, depth of cut, feed rate and tool overhanging. The experiments were carried out on lathe using dry turning (no cutting fluid) operation of medium carbon steel with different level of aforesaid process parameters. Dry turning was helpful for good correlation between surface roughness and cutting tool vibration because of clean environment. The authors developed good correlation between the cutting tool vibration and surface roughness for controlling the surface finish of the work pieces during mass production. The study concluded that the surface roughness of work piece was observed to be affected more by cutting tool acceleration; acceleration increased with overhang of cutting tool. Surface roughness was found to be increased with increase in feed rate.

[6] This research reports the significance of influence of speed, feed and depth of cut on cutting force and surface roughness while working with tool made of ceramic with an Al_2O_3+TiC matrix (KY1615)and the work material of AISI 1050 steel (hardness of 484 HV). Experiments were conducted using Johnford TC35 Industrial type of CNC lathe. Taguchi method (L27 design with 3 levels and 3 factors) was used for the experiments. Analysis of variance with adjusted approach has been adopted. The results have indicated that it is feed rate which has significant influence both on cutting force as well as surface roughness. Depth of cut has a significant influence on cutting force, but has an insignificant influence on surface roughness [1]. Different kind of statistical optimization techniques are available for optimizing the different parameters of a CNC end milling process. In this paper a comparison is done between five different techniques such as

principal components analysis, utility theory, Grey relational analysis, technique of order preference by similarity to ideal solution and their hybrid variants. The Taguchi optimization principle is common to all the methods which are presented in the paper. The experiments were carried out and the different response features such as surface roughness (Ra, Rz and Rq) and material removal rate (MRR) were measured and the different optimization techniques were applied. Three different surface roughness values are used for the analysis and they act as indices of surface quality whereas MRR acts as index of productivity. Hence the optimization is carried out such that the resulting optimized parameters will lead to a compromise between the productivity and the surface quality.

The increasing importance of turning operations is gaining new dimensions in the present industrial age, in which the growing competition calls for all the efforts to be directed towards the economical manufacture of machined parts as well as surface finish is one of the most critical quality measure in mechanical products. [15] Empirical models for estimating the surface roughness of machined components under various cutting speed have been developed using regression analysis software. The center lathe was used to turn the components (stainless steel, mild steel and aluminum cast) at different cutting speed ranging between 76 rev/min to 600 rev/min at a constant depth of cut of 1 mm/pass and feed rate of 0.5 mm/rev.

In [22] an attempt has been made to investigate the influence of cutting parameters on surface roughness of a cast iron specimen undergoing turning operation. Experiments have been performed sing Taguchi’s orthogonal array. HSS tool is used for cutting operation. Most influencing parameters cutting speed, feed rate and depth of cut are considered for the purpose. Optimization of the cutting parameters has been achieved by analysis of the system through a regression model. A combination of parameters is arrived at for optimum surface roughness. Experimental results also indicate that cutting speed have the largest effect on surface roughness followed by feed rate and depth of cut. [14] The study has been aimed to search an appropriate process environment for simultaneous optimization of quality-productivity favorably. Various surface roughness parameters (of the machined product) have been considered as product quality characteristics whereas material removal rate (MRR) has been treated as productivity measure for the said machining process and design , three controllable process parameters, cutting speed, feed, and depth of cut, have been considered for optimizing material removal rate (MRR) of the process and multiple surface roughness features for the machined product, based on L9 orthogonal array experimental design. To avoid assumptions, limitation, uncertainty and imprecision in application of existing multi-response optimization techniques documented in literature, a fuzzy inference system (FIS) has been proposed to convert such a multi-objective optimization problem into an equivalent single objective optimization situation by adapting FIS.

[18] work on highlights application of utility theory combined with Principal Component Analysis (PCA) and Taguchi's robust design for simultaneous optimization of correlated multiple surface quality characteristics of mild steel machined product prepared by straight turning operation. The study aims at evaluating the most favorable process environment followed by an optimal parametric combination for achieving high surface quality, the study demonstrates detailed methodology and concludes robustness and flexibility of the proposed optimization technique and validates its effectiveness through a case study in which correlated multiple response characteristics of turning operation have been optimized. The [13] study investigated the multi-optimization of the turning process on AISI1045 steel material with CNMG cutting tool for an optimal parametric combination to yield the minimum surfaces roughness with the maximum MRR using a combination of a Grey relational analysis (GRA) and the Taguchi method. In view of the fact, that traditional Taguchi method can't solve a multi-objective optimization problem.

[24] Purpose was to demonstrate tool wear by hard turning of martensitic stainless steel and this material is pronounced as difficult to machine material. The evaluation was done using CBN cutting tool on SS 440 C stainless steel with hardness between 45 to 55 HRC; design turning parameters like cutting speed, feed rate and depth of cut was used. The turning was carried out dry process and finding the flank wear was caused by abrasive

action between cutting tool and work piece. The heat generated between work piece and tool tip help to form built up edge. The generated heat was conducted easily due to low thermal conductivity of the work piece material.

[4] Developed a model for the prediction of tool flank wear followed by an optimization model for the determination of optimal cutting conditions in 45 machining 17-4PH stainless steel. The back-propagation neural network (BPN) was used to construct the predictive model. The genetic algorithm (GA) was used for model optimization.

[25] in this paper experimental investigation was to analyze the effect of controlled cutting parameters namely cutting speed, feed rate, depth of cut, cutting fluid concentration and two cutting fluids with different base oils on surface roughness (Ra) of EN8 or AISI 1040 steel during turning operation by applying design of experiments, custom design method, analysis of variance, leverage plots and desirability profiling using JMP software to optimize surface roughness during wet CNC turning operation. The analysis reveals that feed rate has the most significant effect on surface roughness (Ra) and value of surface roughness does not significantly differ for two different cutting fluids used. The effects of cutting parameters on tool wear and surface roughness during hard turning of Inconel 718 material. By taking into account the Analysis of Variance (ANOVA) in accordance to Central Composite Design (CCD); the mathematical model of the flank wear and surface roughness are developed with transformation of the natural logarithm. The experimental results have revealed that the cutting speed is the most significant effect to the flank wear; whereas the surface roughness is strongly influenced by the feed rate and slight related to the tool wear mechanisms. Due to the high pressure at elevated temperature, a micro-welding and built-up-edge are formed even at relatively low cutting speeds of 30-45m/min; it is a disadvantage for the machined surface quality [7]. [21] focused on aspects such as tool life and wear, surface finish, cutting forces, material removal rate, power consumption, cutting temperature decide the productivity, product quality, overall economy in manufacturing by machining and quality of machining.

[21] presented an experimental study to investigate the effect of cutting parameters (cutting speed, depth of cut and feed) on tool wear, surface roughness and material removal rate (MRR) during dry turning of AISI 52100 steel. Turning experiments were conducted with cutting speeds: 250, 300, 350 m/min, feeds: 0.15, 0.2, 0.25 mm/rev and depth oh cuts: 0.5, 1.0, 1.5 mm. The experimental layout was designed based on the Taguchi's L9 (34) Orthogonal array technique and analysis of variance (ANOVA) was performed to identify the effect of the cutting parameters on the response variables. The results revealed that cutting speed is only the significant parameter on tool wear. On the other hand, cutting speed was found to be the dominant parameter among controllable parameters on surface roughness followed by feed. However, depth of cut only showed significant parameters for material removal rate (MRR).

[10] Study attempts to investigate tool wear (flank wear) and surface roughness during finish hard turning of AISI D3 steel (58HRC) with coated carbide (TiSiN-TiAlN coated) cutting tool. Taguchi L9 (3)3 orthogonal array has been applied for experimental design. S/N ratio and ANOVA analyses were performed to identify significant parameters influencing tool wear and surface roughness. The cutting speed and feed were the most significant factors influencing tool wear (flank wear), and feed is the most significant factor influencing surface roughness (Ra). Mathematical models for both response parameters i.e. tool wear and surface roughness was obtained through regression analysis.[2] the process and machining parameters for the performance characteristics of turning operation on CNC using different grades of Tungsten Carbide and with varying properties & surface roughness testing of work piece material to be carried out after machining. After testing optimization and compare the Effect of cutting parameters on surface roughness of different selected geometry on EN-24 alloy steel by using empirical approach i.e. Taguchi Analysis using Statistical Software.

[11] Focused on Basic terms and visualizations of the major components of the cutting tool geometry in orthogonal turning process. The parameters like rake angle, depth of cut, feed rate, temperature and cutting speed are taken in to account so as to predict their effects on tool life. Their influences on cutting forces and tool geometry have also been referred. [19] This study discussed the rotary ultrasonic machining (RUM) parameters and tool geometry parameters of optimized hole wall quality, and obtained better and uniformly distributed surface roughness of deep hole walls. The experimental configuration of this study was planned using Taguchi orthogonal array, where the hole diameter, spindle speed, feed rate and power were taken as the experimental factors. [9] This study aims to investigate the effect of the cutting speed, feed rate and depth of cut on material removal rate (MRR), surface roughness, and tool life in conventional turning of ductile cast iron FCD700 grade using TiN coated cutting tool in dry condition. The machining condition parameters were the cutting speed of 220, 300 and 360 m/min, feed rate of 0.2, 0.3 and 0.5 mm/rev, while the depth of cut (DOC) was kept constant at 2 mm. The effect of cutting condition (cutting speed and feed rate) on MRR, surface roughness, and tool life were studied and analyzed.

In [20] an attempt has been made to investigate the effect of process parameters cutting speed, feed rate and depth of cut on tool wear and surface roughness in micro turning titanium alloy using cermets insert. The experiment is carried out based on response surface methodology and sequential approach. Mathematical model is developed and used to evaluate minimum tool wear and surface roughness under optimum micro turning condition. Analytical and graphical optimization techniques have been carried out to find the optimum performance parameter. The literature review also shows that there is no much of work under taken with Mild Steel Material for measure performance parameters using for said combination parameters.

Hence, the main objective of this Research is to study Effect of Roughness, Material Removal Rate and Tool Life in Turning of Mild Steel Material the work also makes an attempt to optimize the cutting parameters.

CHAPTER THREE

3. MATERIALS, CONDITION and METHOD

3.1 Work Piece Material

The work piece material used in this experimental is the commercial Mild Steel in the form of round bar with 30mm diameter and the length 100 mm. And these material typical applications are in manufacturing of machine tool parts like spindles, shafts, shank and automobile products. Nine experiments done accordingly Taguchi's L_9 Orthogonal array. The chemical composition of work piece material is given in Table 3.1.

Material	C	Mn	Cu	Si	Fe
Mild steel	0.16 % to 0.29%	1.65 %	0.6 %	0.6 %	96.86 % to 96.99 %

Table 3.1: Chemical composition of mild steel

Fig 3.1: View of work piece before and after machined

Cutting Tool used

The cutting tool I used for experimental test is High Speed Steles Steal/ HSS/ and the specification found below table.

Insert thickness	0.1875 inches.
Nose radius	0.0157 inches
ISO number	------------
No. of edges	4

Table 3.2: Specifications of the Cutting Tool insert

3.1.1 Equipment used

A. power band saw

Fig 3.2: view of band saw machine during cutting operation

B. Center Lath Machine

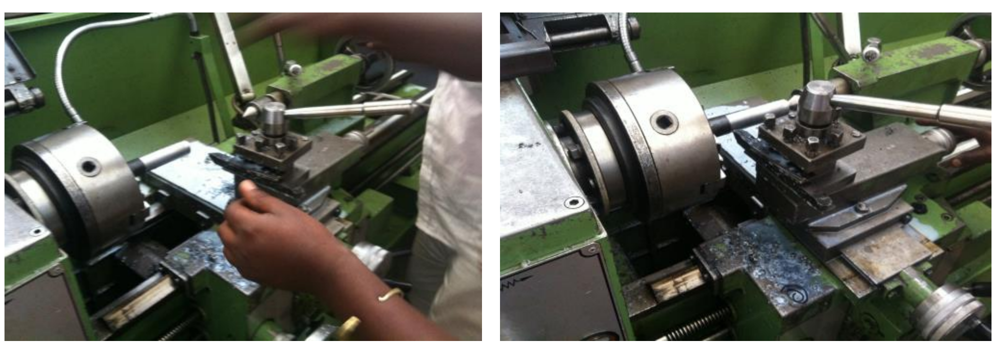

Fig 3.3: view of laze machine during turning operation

The specification of the laze machine that experimental test performed found below table.

Model	S-90 /180
Power	345Kw
controller	------
Max. Spindle speed	2000rpm
Chuck size	-------
Spindle size	-------
Tool holder	--------
Environment	Wet (flood cooling)

Table 3.3: lathe specifications and cooling environment

C. Surface Roughness Measurement

Fig 3.4: Photographic view Bell Stone during surface roughness measurement

This instrument is compatible with four standards of ISO, DIN, ANSI and JIS and is widely used in production to measure the surface roughness of several parts processed by machine, calculating corresponding parameters according to selected measuring conditions and clearly show all Measurement parameters. When measuring the roughness of a surface, the sensor is placed in the uniformly surface and then slides along the surface by driving the mechanism within meter. The sensor gets the surface roughness by incorporating fine probe.

This roughness because the displacement of the probe which causes a change in current generated in the coil induction to generate the analog signal which is proportional to the surface roughness at the outlet of phase sensitive rectifier. The exclusive DSP processes and calculates incorporating then show measurement results on LCD. Which is multi-parameter measurement: - Ra, Rz, Rq and Rt.

Specifications

- Display 4 digits, 10 mm LCD, blue backlight
- Parameters: Ra, Rz, Rq, Rt
- Measuring ranges**:**
    - ✓ Ra, Rq: 0.005-16.00µm/0.020-62.99µinch
    - ✓ Rz, Rt: 0.020-160.0µm/0.078-629.9µinch
- Accuracy: ± 10%
- Reproducibility: 6%
- Sensor:
    - ✓ Measuring Principle: Inductance type
    - ✓ Radio probe pin: 5 uM
    - ✓ Material of Probe Pin: Diamond
    - ✓ Torque Measuring Probe: 4mN (0.4gf)
    - ✓ Probe Angle: 90 °
    - ✓ Vertical Radio Guide Head: 48mm
    - ✓ Maximum driving distance: 17.5mm/0.7inch
    - ✓ Limit length (l): 0.25mm / 0.8mm / 2.5mm optional

- Drive speed:
  - ✓ for sampling length = 0.25mm, Vt = 0.135mm / s
  - ✓ for sampling length = 0.8mm, Vt = 0.5mm / s
  - ✓ for sampling length = 2.5mm , Vt = 1mm / s
- ○ for return, Vt = 1mm / s

Computer: - it is used for displaying the data measured by surface roughness tester and the Optional RS232C 8.1 software must be installed on it first**.**

D. Material Removal Rate Measurement

Material Removal Rate (MRR) has been calculated from the difference of weight of work piece before and after experiment. From Eq.5

$$MRR = \frac{W_i - W_f}{\rho_s t} mm^3 / \text{min}$$

(Model: explorer pro single pan DIGITAL reading electrically operated analytical balance made by Dhona Instruments), which can measure up to the accuracy of 10^{-4} g and thus eliminates the possibility of large error while calculating Material Removal Rate (MRR) in straight turning operation.

Fig 3.5: Photo Graphic view of Digital measurement

3.2 Experimental Condition

3.2.1 Matching parameter and their level

In this experimental study, spindle speed (x_1), depth of cut (x_2), feed rate (x_3) were considered as machining parameters. The ranges of machining conditions were based on the real industry practice for machining of mild steel. Cutting fluid flow kept constant throughout the experimentation. The considered process parameters and their levels are listed in Table 3.4.

3.2.2 Experimental procedure

In order to achieve the objective of the present study has been done through the following plan of experiment.

- Checking and preparing the Centre Lathe ready for performing the machining operation.
- Cutting MS bars by power saw and performing initial turning operation in Lathe to get desired dimension of the work pieces.
- Calculating weight of each specimen by the high precision digital balance meter before Machining.
- Performing straight turning operation on specimens in various cutting environments involving various combinations of process control parameters like: spindle speed, feed and depth of cut.
- Calculating weight of each machined specimen
- Measuring surface roughness and surface profile with the help of a portable Bell Ston Roughness Measurement.
- Calculating cutting tool life by using expanded Taylor equations (7)

$$V_c T^n f^a d^b = C$$

3.3 Taguchi Method

The quality engineering method proposed by Taguchi is commonly known as the Taguchi Method or Taguchi approach. His approach provides a new experimental strategy in which a modified and standardized form of design of experiment (DOE) is used. In other words, the Taguchi approach is a form of DOE with special application principles. The concept of the Taguchi method is that the parameter design is performed to reduce the sources of variation on the quality characteristics of product, and reach a target of process robustness Taguchi designs experiments using specially constructed tables known as "orthogonal array" (OA).

The Taguchi experimental design method is a well-known, unique and powerful technique for product or process quality improvement [16]. It is widely used for analysis of experiment and product or process optimization.Taguchi has developed a methodology for the application of factorial design experiments that has taken the design of experiments from the exclusive world of the statistician and brought it more fully into the world of manufacturing. His contributions have also made the practitioner's work simpler by advocating the use of fewer experimental designs, and providing a clearer understanding of the nature of variation and the economic consequences of quality engineering in the world of manufacturing.

It utilizes the orthogonal arrays from experimental design theory to study a large number of variables with a small number of experiments. This technique helps to study effect of many factors (variables) on the desired quality characteristic most economically. By studying the effect of individual factors on the results, the best factor combination can be determined. The standardized Taguchi-based experimental design used in this study is an L_9 (3^3) orthogonal array (3).

Taguchi recommends a stage process to achieve desirable product quality by design system Design, parameter design. While system design helps to identify working levels of the design parameters, parameter design seeks to determine parameter levels that provide the best performance of the product or process under study [28].

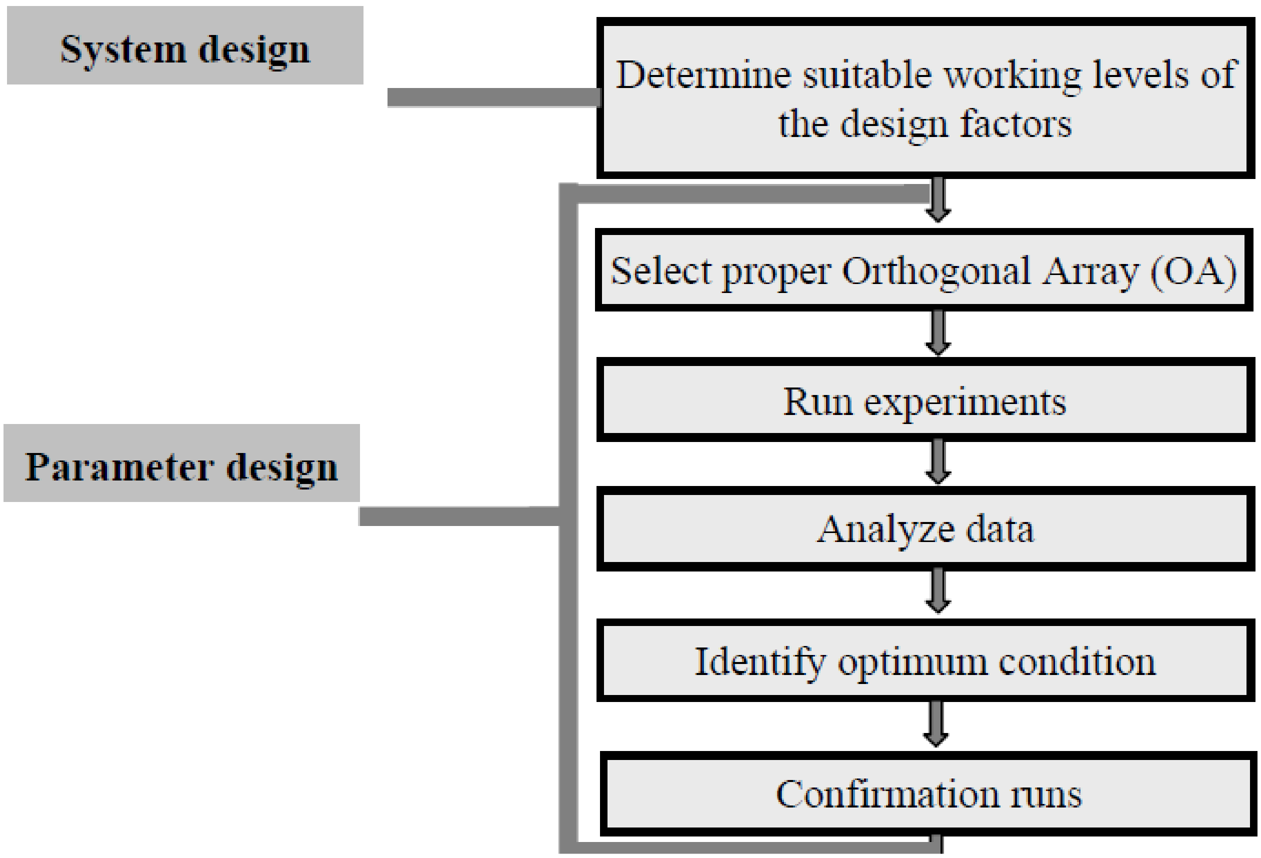

Fig 3.6: Taguchi Design Procedure

3.3.1Analysis of S/N ratio

In the Taguchi Method, the term "signal" represents the desirable value (mean) for the output characteristic and the term "noise" represents the Undesirable value (S.D) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the S.D. S/N ratio is used to measure the quality characteristic deviating from the desired value. The S/N ratio η is defined as

$$S/N = -10log(M.S.D) \quad \text{...(8)}$$

Where M.S.D is the mean square deviation for the output characteristic. To obtain optimal cutting performance, the–lower–the–better quality characteristic for Surface Roughness and the–higher–the–better for material removal rate and tool life must be taken [8].

The M.S.D. for the–lower– the – better quality (minimize): characteristic can be expressed as:

$$S/N_S = -10 \cdot \log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right),$$

The M.S.D for the–higher–the–better (maximize): ----------------- (9)

$$S/N_L = -10 \cdot \log\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right).$$

Where yi is the value of the observed data for the i-th test and n is the number of measurements in a trial/row (here n=1)

3.3.2 **ANALYSIS OF VARIANCE (ANOVA)**

In analysis of variance many quantities as:

(a) Degree of freedom

(b) Sums of squares

(c) Variance used to identify significant factors

(d) F-ratio

(e) Pure sum

(f) Percentage contribution

[26] ANOVA can be computed and organized in a standard tabular format. Utilize this step to review a number of examples analyses to build the confidence in interpreting the experimental results. The purpose of the analysis of variance (ANOVA) was to investigate which parameters significantly affected the quality characteristics.

(a) Degree of freedom: Total degree of freedom is equal to the degree of freedom is associated with number of levels plus degree of freedom is associated with error. Therefore, the total degree of freedom is equal to N-1. It can be calculated by this formula:

$$V_T = V_A + V_E \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (10)$$

Where,

V_T = Total degree of freedom.

V_A = Degree of freedom for a controlled factor or Number of levels.

V_E = Degree of freedom for error.

Therefore, $V_T = N-1$ ………………………………….…….... (11)

V_A = Number of levels -1

$V_E = V_T – V_A$

(b) Sums of squares: The sum of squares is a measure of the deviation of the experimental data from the mean value of the data. Summing each squared deviation emphasizes the total deviation. The sum of squares $(SS)_A$ analysis for the factors and total variation is:

$$(SS)_A = \frac{A_1^2}{n_{A1}} + \frac{A_2^2}{n_{A2}} + \frac{A_3^2}{n_{A3}} - \frac{T^2}{N} \quad \ldots\ldots\ldots\ldots\ldots\ldots \; (12)$$

This is the value for the percentage (%) participation of factor one, X variations can be observed in terms of sum of squares. Also the participation of Particle size, Y can be calculated by:

$$(SS)_B = \frac{B_1^2}{n_{B1}} + \frac{B_2^2}{n_{B2}} + \frac{B_3^2}{n_{B3}} - \frac{T^2}{N} \quad \ldots\ldots\ldots\ldots\ldots\ldots \; (13)$$

(c) Variance: Variance measures the distribution of the mean of data. Since the data is representative of only a part of all possible data, DOF rather than the number of observations is used in the calculation.

$$\text{Variance} = \frac{\text{Sum of Squares}}{\text{Degrees of freedom}}$$

Or, $$V_A = \frac{(SS)_A}{f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (14)$$

Similarly, $$V_B = \frac{(SS)_B}{f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (15)$$

(d) F- Ratio or Variance ratio is used to measure the significance of the factor under investigation with respect to the variance of all the factors included in the error term. When the computed F value is less than the value determined from the F tables at the selected level of significance, the factor does not contribute to the sum of the squares within the confidence level. The F values are calculated by:

$$F_{RA} = \frac{\text{mean variance}}{\text{Error variance}} = \frac{V_m}{V_E} = \frac{(SS)_A/f}{V_E}$$

$$\text{Also,} \quad F_{RB} = \frac{(SS)_B/f}{V_E} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (16)$$

(e) Pure sum of squares are determined by using relation:

$$\text{Pure sum of squares, } (S')_A = (SS)_A - DOF \times V_E$$

$$\text{Also, } (S')_B = (SS)_B - DOF \times V_E \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (17)$$

(f) The percentage contribution for any factor is obtained by dividing the pure sum of squares for that factor by ST and multiplying the result by 100. The percentage contribution is denoted by P and can be calculated using the following equations.

$$P_A = (S')_A \times \frac{100}{S_T}$$

$$\text{Also, } P_B = (S')_B \times \frac{100}{S_T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (18)$$

3.4 Design of Experiment

An experimental design methodology that allows me to choose a product or process that performs more consistently in the operating environment. Three machining parameters were selected as control factors, each parameters have three levels, denoted by 1, 2, and 3. The experimental design was based on L_9 orthogonal array based on Taguchi method. Taguchi designs use orthogonal arrays, which estimate the effects of factors on the response mean and variation.

An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be evaluated independently of all the other factors, so that effect of one factor does not influence the estimation of another factor. In robust parameter design, we first choose control factors and their levels and choose an orthogonal array appropriate for these orthogonal arrays.

The control parameters and the levels used in experiment, experimental set up and conditions are given in the Table 3.4 and Table 3.5 respectively. The ranges of machining conditions were based on the real industry practice for machining mild steel.
A design step of experimental parameters is given in Fig 3.7.

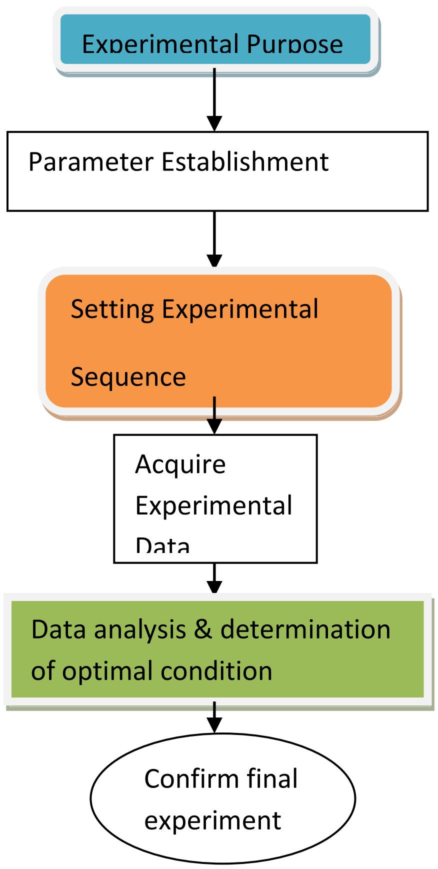

Fig. 3.7: Design steps of experimental parameters

level	Spindle speed (rpm)	Depth of cut In mm	Feed (mm/ rev)
1	530	0.5	0.5
2	700	1	0.6
3	860	1.5	0.7

Table 3.4 Machining parameters and their levels

E.N	Factorial combination		
	Spindle speed (rpm)	Depth of cut (mm)	Feed (mm/rev)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 3.5 Experimental design matrix based on Taguchi L_9 orthogonal array

Experimental Data Collection

Data collection plays a significant role in statistical analysis of any field, as it decides the progression of the analysis to the best or worst. A proper and suitable data collection leads to better results from analysis. In such focus it is very much essential to choose a well suitable data collection technique for the analysis.

In this research MS bars (of diameter 30 mm and length 100 mm) required for conducting the experiment have been prepared first and nine numbers of samples of same material and same dimensions have been made. After that, the weight of each samples have been measured accurately with the help of a high precision digital balance meter. Then, using different levels of the process parameters nine specimens have been turned in lathe accordingly. Machining time for each sample has been calculated accordingly. After machining, weight of each machined parts have been again measured precisely with the help of the digital balance meter. Then

1. Data collection for Roughness is done using a portable Roughness measurements, in the transverse direction, on the work pieces have been repeated four times and average of four measurements of surface roughness parameter values are recorded. The measured profile have been digitized and processed through the dedicated advanced surface finish analysis software and the value displayed on monitor. Surface roughness readings were recorded at four locations on the work piece and the average value was used for analysis.

2. Data collection method for material removal rate is done using eq.5 the formula found below

$$MRR = \frac{W_i - W_f}{\rho_s t} mm^3 / \min$$

Where, W_i is the initial weight of work piece in kg; W_f is the final weight of work piece in kg; t is the machining time in minutes; ρs is the density of mild steel (7.8 x 10^{-3}g/mm^3). The weight of the work piece has been measured in a high precision digital balance meter.

1. Data collection method for tool life is done using Taylor equation equ.(7), the expanded the Taylor's tool life formula

$$V_c T^n f^a d^b = C$$

Where the exponents a and b are to be determined experimentally for each combination of the cutting conditions. In practice, typical values for HSS tools are n = 0.17, a = 0.77 and b = 0.37 [27] and according to [28] the value of c for carbide tool is C=80. According to this information, the order of importance of the parameters is: cutting speed, then feed, then depth of cut. Using these parameters, the above Equation for the expanded Taylor tool life formula model can be rewritten as

$$\left.\begin{array}{l} T = C^{\frac{1}{n}} V_c^{\frac{-1}{n}} f^{\frac{-a}{n}} d^{\frac{-b}{n}} \\ \quad \text{Or} \\ T = C^{5.88} V^{-5.88} f^{-4.53} d^{-2.18} \end{array}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (19)$$

- ❖ The results of the Experiments test have been shown in Table 3.6 (a) to (d)
  - ✓ The Experimental test results for Material Removal Rate found below

Exp. NO.	Initial Mass(g)	Final Mass (g)	Matching Time (min)	MRR (mm^3/min)
1	**1067.4**	**1063.3**	**2.1322**	**240.5**
2	**1039.6**	**1025.5**	**2.0661**	**868.7**
3	**1022.0**	**995.8**	**1.3774**	**2420.0**
4	**1041.9**	**1030.1**	**1.7153**	**869.9**
5	**1063.8**	**1051.9**	**0.8576**	**1793.8**
6	**1074.1**	**1067.1**	**0.5718**	**2242.3**
7	**1017.5**	**993.4**	**1.0571**	**2425.6**
8	**1089.9**	**1079.7**	**0.5285**	**2425.6**
9	**1071.7**	**1057.6**	**0.3781**	**4746.5**

Table 3.6 (a) Experimental Data for Material Removal Rate / MRR/

❖ The result of Surface Roughness for each trial found in appendix but the mean value found below the table.

Exp.No	1	2	3	4	5	6	7	8	9
Roughness Mean value(**µm**)	9.93	13.725	36.517	27.714	39.923	30.226	10.36	27.664	38.08

Table 3.6 (b) Experimental Data for Average Surface Roughness

❖ Then the value of Tool Life that calculated according to experimental parameters and eq. (19) found below table.

Exp.No	1	2	3	4	5	6	7	8	9
Tool life (**min**)	161.2	161	33	72	13	20	9	7	5

Table 3.6 (c) Data for Tool Life

☞ The Overall Experimental and Analytical compiled Results found below

EXP. NO.	CONTROL PARAMETER						Surface Roughness (µm)	Material removal rate (mm^3/min)	TOL Life (min)
	Combination parameter of control			Actual Value					
				Spindle Speed (rpm)	Feed rate (mm/rev)	Depth of Cut (mm)			
1	1	1	1	530	0.5	0.5	9.93	240.5	161.2
2	1	2	2	530	0.6	1	13.725	868.7	161
3	1	3	3	530	0.7	1.5	36.517	2420.0	33
4	2	1	2	700	0.5	1	27.714	869.9	72
5	2	2	3	700	0.6	1.5	39,923	1793.8	13
6	2	3	1	700	0.7	0.5	30.226	2242.3	20
7	3	1	3	860	0.5	1.5	10.36	2425.6	9
8	3	2	1	860	0.6	0.5	27.664	2425.6	7
9	3	3	2	860	0.7	1	38.08	4746.5	5

Table 3.6 (d) Orthogonal Array L_9 of Taguchi Experiment Design and Experimental Results

Using the nine of machining trials was as tabulated in Table 3.6 (d) Analysis has been made based on those experimental data in the following chapter. Minitab 15(30-Days Trial Version) Software was used for Analysis Effect of Surface Roughness, Material Removal Rate and Tool life of the cutting tool has been made by Taguchi method, and then followed by analysis the results using S/N ratio and Analysis of Variance (ANOVA) to find the maximum MRR, minimum surface roughness, and maximum tool life.

CHAPTER FOUR

4. DATA ANALYSIS AND DISCUSSION

The Results of the Machining Experiment for Material Removal Rate (MRR), Surface Roughness and Tool life were as tabulated in Table 3.6(d). The commercial software package MINITAB15 was explored to analyze the mean effect of Signal-to-Noise (S/N) ratio and ANOVA and form regression equation to achieve the multi-objective features and carried out the Analysis Effect for Surface Roughness, Material Removal Rate /MRR/ and Tool Life were plotted and tabulated based on the experiment measurement.

4.1 Result Analysis and discussion for surface Roughness

4.1.1 Effect of input parameters on Roughness

In order to see the effect of input parameters on the surface roughness experiments were conducted using L9 OA (Table 3.5). The experimental data is given in Tables 4.1 then Figures 4.1 show that the Surface Roughness first increase after then decrease with the increase of spindle speed and decreases with increase in depth of cut and increase of feed in turning operation.

Ex. No.	Spindle Speed (rpm)	Feed rate (mm/rev)	Depth of Cut (mm)	Surface Roughness (μm)	S/N ratio
1	530	0.5	0.5	9.93	**-19.9389**
2	530	0.6	1	13.725	**-22.7502**
3	530	0.7	1.5	36.517	**-31.2499**
4	700	0.5	1	27.714	**-28.8539**
5	700	0.6	1.5	39.923	**-32.0244**
6	860	0.7	0.5	30.226	**-29.6076**

7	860	0.5	1.5	10.36	**-20.3071**
8	860	0.6	0.5	27.664	**-28.8382**
9	860	0.7	1	38.08	**-31.6139**

Table 4.1 Experimental result and S/N ratio for surface roughness in turning operation.

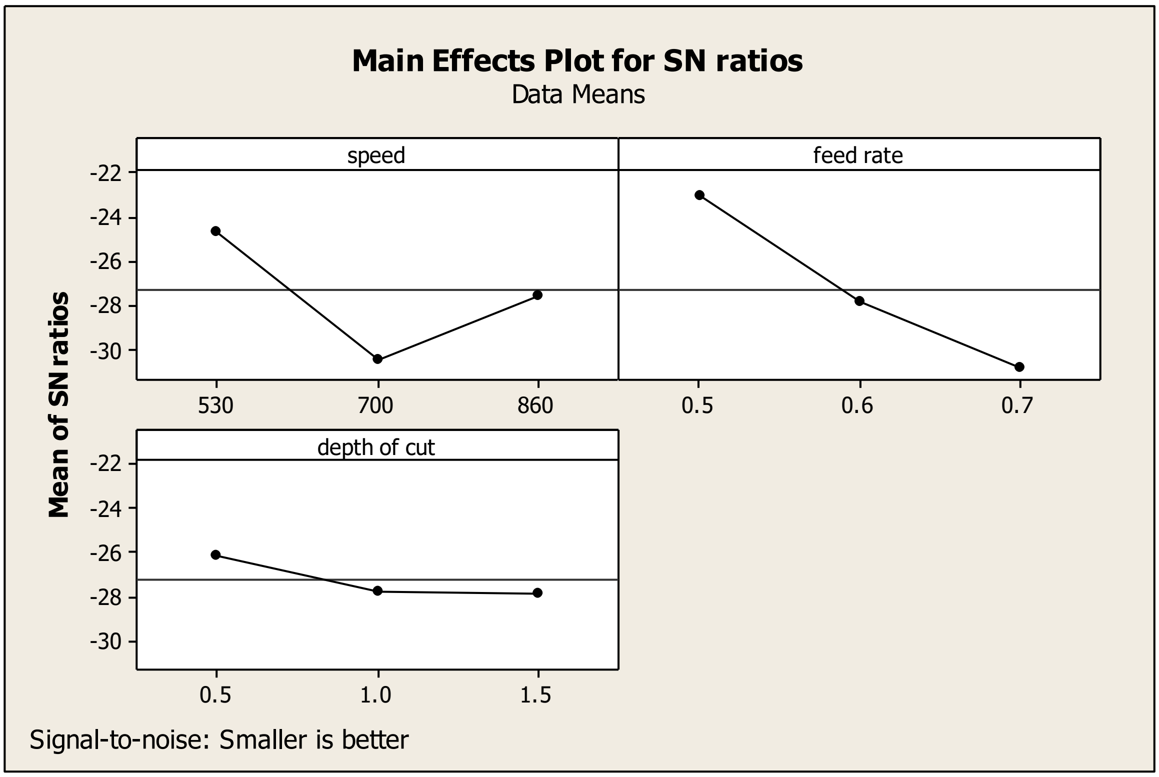

Figure 4.1: Effect of input parameters on Surface Roughness

4.1.2 ANALYSIS OF VARIANCE (ANOVA) FOR SURFCE ROUGHNESS

The Experimental results were analyzed with analysis of variance (ANOVA) using Minitab, which used for identifying the factors significantly affecting the performance measures. The results of the ANOVA for Surface Roughness shown in Tables 4.2. This analysis was carried out for significance level of α=0.05 i.e. for a confidence level of 95%. The sources with a P-value less than 0.05 are considered to have a statistically significant contribution to the performance measures. The last column of the tables shows the percent contribution of significant source of the total variation and indicating the degree of influence on the result.

SOURCE	**DOF**	**SS**	**MS**	**F**	**P**	**C (%)**
v	**2**	41.145	37.233	4.25	0.190	21.7
f	**2**	130.991	65.236	7.45	0.118	68.7
d	**2**	0.755	0.378	0.04	0.959	0.4
Error	**2**	17.503	8.751			9.2
Total	**8**	190.395				100

S = 2.95829 R-Sq = 90.81% R-Sq(adj) = 63.23%

DOF= Degree of freedom**, SS=** Sum of squares, **MS=** Mean squares**, C=**Contribution

Table 4.2 ANOVA analysis for surface roughness

From the analysis of the Table 4.2 shows that the largest significant parameter for Surface Roughness is feed rate which contributes 68.7% of the total variation. The next largest contribution comes from the spindle speed (21.7%) then depth of cut (0.4%), which is not statistically significant and the error contribution is 9.2%.

4.1.3 Selection of Optimal Levels and Regression equation

The optimum condition of turning process is concerning with minimizing surface roughness. The response table 4.3 shows the average of each response characteristic for each level of each factor. The Tables include ranks based on delta statistics, which compare the relative magnitude of effects. The delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on delta values; rank 1 to the highest delta value, rank 2 to the second highest, and so on. The ranks indicate the relative importance of each factor to the response. The ranks and the delta values for various parameters show that the feed rate has greatest effect on Surface Roughness and is followed by spindle speed and feed in that order. As Surface Roughness is the "**lower the**

better” type quality characteristic, from Figure 4.1 it can be seen that the first level of spindle speed(**530rpm**), first level of depth of cut(**0.5 mm**) and first level of feed rate (**0.5mm)** result in minimum value of surface roughness.

Level	**Spindle speed (rpm)**	**Feed (mm/rev)**	**Depth of cut (mm)**
1	-24.65	-23.03	-26.13
2	-30.44	-27.87	-27.74
3	-27.59	--30.82	27.86
Delta	5.79	7.79	1.73
Rank	*2*	*1*	*3*

Table 4.3: Response Table for Signal to Noise Ratios for surface roughness Smaller is better.

Regression equation for surface roughness

The relationship between the factors (Spindle Speed, Depth of Cut and Feed) and the performance measures (Surface Roughness) was modeled by multiple linear regressions using Minitab the following equation is formed. The final regression models in terms of coded parameters:

Ra= surface roughness, V= spindle speed, F= feed rate, DC= depth of cut

$$\boxed{\mathbf{Ra = -45.3 + 0.0134V + 91.1F + 7.04DC}}$$

4.2 Result Analysis and Discussion for Material Removal Rate

4.2.1 Effect of input parameters on Material Removal Rate

In order to see the effect of input parameters on Material removal rate experiments were conducted using L9 OA (Table 3.5). The experimental data is given in Tables 4.4 then the experimental result in Figures 4.2 show that material removal rate increase with the increase of spindle speed, with increase in depth of cut and with increase of feed in turning operation. When MRR increase showed, this is mainly due to more volume of chips generated during machining.

Ex. No.	Spindle Speed (rpm)	Feed rate (mm/rev)	Depth of Cut (mm)	Material removal rate (mm^3/min)	S/N ratio
1	530	0.5	0.5	240.5	**47.6223**
2	530	0.6	1	868.7	**58.7774**
3	530	0.7	1.5	2420.0	**67.6763**
4	700	0.5	1	869.9	**58.7894**
5	700	0.6	1.5	1793.8	**65.0755**
6	700	0.7	0.5	2242.3	**67.0139**
7	860	0.5	1.5	2425.6	**67.6964**
8	860	0.6	0.5	2425.6	**67.6964**
9	860	0.7	1	4746.5	**73.5275**

Table 4.4: Experimental result and S/N ratio for material removal rate in turning operation.

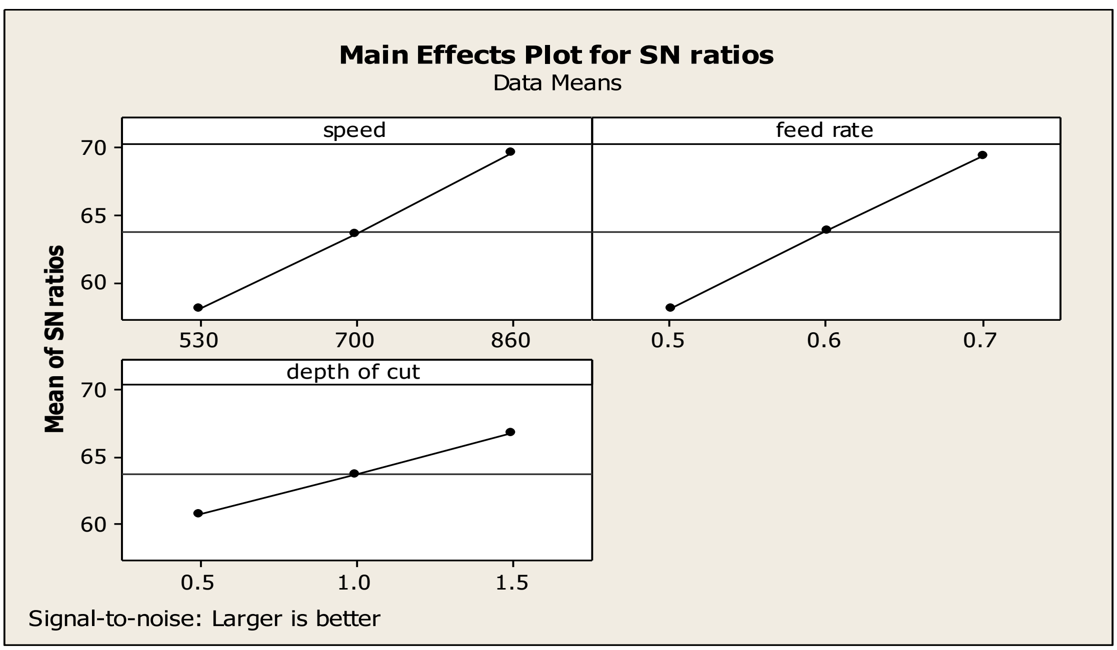

Figure 4.2: Effect of input parameters on material removal rate

4.2.2 ANALYSIS OF VARIANCE (ANOVA) FOR MATERIAL REMOVAL RATE/ MMR/

The experimental results analyzed with analysis of variance (ANOVA), which used for identifying the factors significantly affecting the performance measures. The results of the ANOVA for Material Removal Rate are shown in Tables 4.5. This analysis was carried out for significance level of α=0.05 i.e. for a confidence level of 95%. The sources with a P-value less than 0.05 are considered to have a statistically significant contribution to the performance measures. The last column of the tables shows the percent contribution of significant source of the total variation and indicating the degree of influence on the result.

SOURCE	**DOF**	**SS**	**MS**	**F**	**P**	**C (%)**
v	**2**	6748258	3374129	22.37	0.043	48.77
F	**2**	6174138	3087069	20.47	0.047	44.63
d	**2**	611795	305897.5	2.03	0.330	4.42
Error	**2**	301656	150828			2.18
Total	**8**	13835846				100

S = 388.366 R-Sq = 97.82% R-Sq(adj) = 91.28%

DOF= Degree of freedom**, SS=** Sum of squares, **MS=** Mean squares**, C=**Contribution

Table 4.5: ANOVA analysis for MMR

From the analysis of the Table 4.5 shows that the largest significant parameter for material removal rate is the speed depth of cut which contributes 48.77% of the total variation. The next largest contribution comes from depth of cut (44.63%) then feed (4.42%), which is not statistically significant and the error contribution is 2.18%.

4.2.3 Selection of Optimal Levels and Regression equation for Material Removal Rate

Optimum condition of the turning process is concerned with maximizing MRR. Response table 4.6 shows the average of each response characteristic for each level of each factor. The Tables include ranks based on delta statistics, which compare the relative magnitude of effects. The delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on delta values; rank 1 to the highest delta value, rank 2 to the second highest, and so on. The ranks indicate the relative importance of each factor to the response. The ranks and the delta values for various parameters show that spindle speed has greatest effect on material removal rate and is followed by feed and the depth of cut in that order. As material removal rate is the " **the higher the better**" type quality characteristic, from Figure 4.2 it can be seen that the third level of spindle speed (**860rpm**), third level of depth of cut(**1.5 mm**) and third level of feed (**0.7 mm/rev**) result in maximum value of material removal rate. The high value of cutting speed, depth of cut and feed give high value of material removal rate i.e. high production rate

Level	Spindle speed (rpm)	Feed (mm/rev)	Depth of cut(mm)
1	58.03	58.04	60.78
2	63.63	63.85	63.7
3	69.64	69.41	66.82
Delta	11.61	11.37	6.04
Rank	1	2	3

Table 4.6: Response Table for Signal to Noise Ratios for Material Removal Rate higher is better.

Regression Equation for Material Removal Rate

The relationship between the factors (cutting speed, depth of cut and feed) and the performance measure (Material Removal Rate) was modeled by multiple linear regressions. Using Minitab The following equation is formed.

The final regression models in terms of coded parameters:

MMR= material removal rate, V= spindle speed, F= feed rate, DC= depth of cut

$$\boxed{\textbf{MRR} = -8692 + 6.09V + 9788F + 577DC}$$

4.3 Result Analysis and Discussion for Tool Life

4.3.1 Effect of input parameters on Tool Life

In order to see the effect of input parameters on Tool Life experiments were conducted using L9 OA (Table 3.5). The experimental data is given in Tables 4.7 then Figures 4.3 show that the tool life decrease with the increase of spindle speed and increases feed rate but first increase then decrease with increase of depth of cut in turning operation.

Ex. No.	Spindle Speed (rpm)	Feed rate (mm/rev)	Depth of Cut (mm)	Tool Life (min)	S/N ratio
1	530	0.5	0.5	161.2	**44.15**
2	530	0.6	1	161	**44.14**
3	530	0.7	1.5	33	**30.47**
4	700	0.5	1	72	**37.15**
5	700	0.6	1.5	13	**22.14**
6	700	0.7	0.5	20	**26.02**
7	860	0.5	1.5	9	**19.08**
8	860	0.6	0.5	7	**16.9**
9	860	0.7	1	5	**13.26**

Table 4.7: Experimental Results and S/N ratio for Tool Life in turning operation.

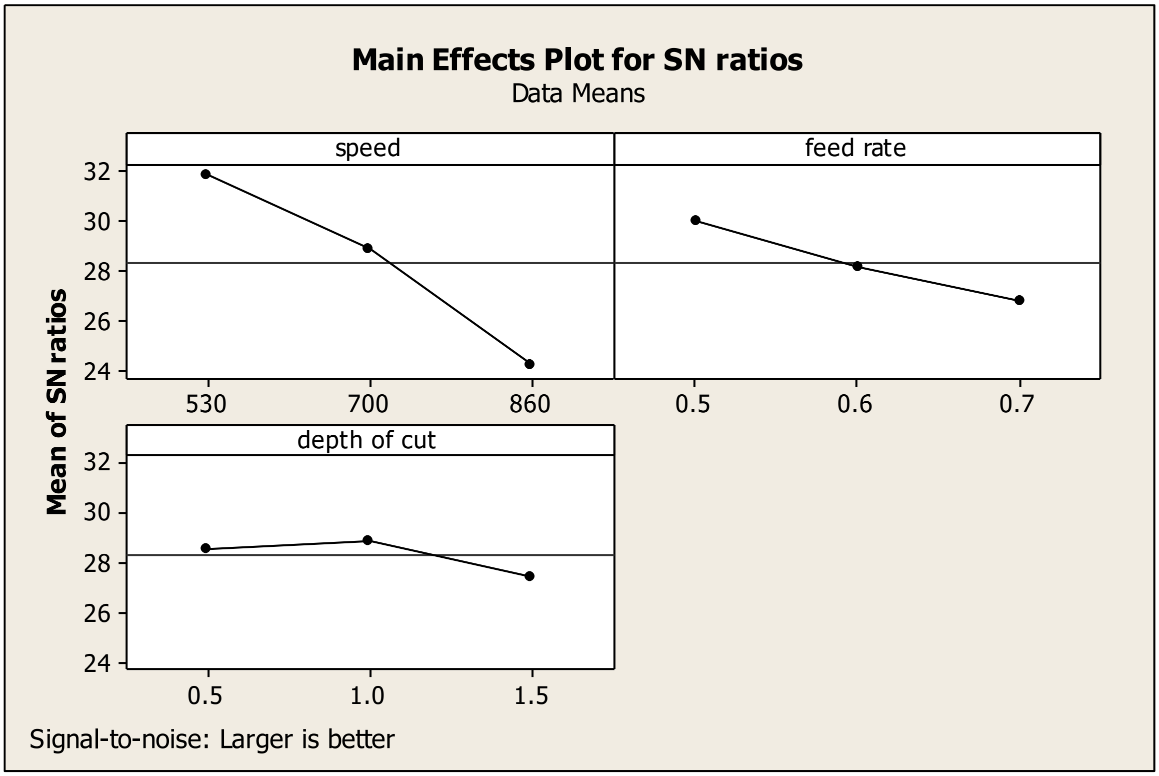

Figure 4.3: Effect of input parameters on Tool Life

4.3.2 ANALYSIS OF VARIANCE (ANOVA) FOR TOOL LIFE

The experimental results analyzed with analysis of variance (ANOVA), which used for identifying the factors significantly affecting the performance measures. The results of the ANOVA for Tool Life are shown in Tables 4.8. This analysis was carried out for significance level of α=0.05 i.e. for a confidence level of 95%. The sources with a P-value less than 0.05 are considered to have a statistically significant contribution to the performance measures. The last column of the tables shows the percent contribution of significant source of the total variation and indicating the degree of influence on the result.

SOURCE	DOF	SS	MS	F	P	C (%)
v	**2**	805.89	402.94	51.49	0.019	75.3
f	**2**	157.16	78.58	10.04	0.091	14.7
d	**2**	90.56	45.28	5.79	0.147	8.5
Error	**2**	15.65	7.83			1.5
Total	**8**	1069.26				100

S = 2.79757   R-Sq = 98.54%   R-Sq(adj) = 94.14%

DOF= Degree of freedom**, SS=** Sum of squares, **MS=** Mean squares**, C=**Contribution

Table 4.8: ANOVA analysis for tool life

From the analysis of the Table 4.8 shows that the largest significant parameter for Tool life is the spindle speed which highly contributes 75.3% of the total variation. The next largest contribution comes from feed (14.7%) then depth of cut (8.5%), which is not statistically significant and the error contribution is also minor 1.5 %.

4.3.3 Selection of Optimal Levels and Regression equation for Tool Life

Optimum condition of the turning process is concerned with maximizing tool life. Response table 4.9 shows the average of each response characteristic for each level of each factor. The Tables include ranks based on delta statistics, which compare the relative magnitude of effects. The delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on delta values; rank 1 to the highest delta value, rank 2 to the second highest, and so on. The ranks indicate the relative importance of each factor to the response. The ranks and the delta values for various parameters show that spindle speed has greatest effect on tool life and is followed by feed and the depth of cut in that order.

As Tool life is the " **the higher the better**" type quality characteristic, from Figure 4.3 it can be seen that the first level of spindle speed **(530rpm**), second level of depth of cut(**1 mm)** and first level of feed (**0.5 mm/rev**) result in maximum value of tool life.

Level	Spindle speed	Feed (mm/rev)	Depth of cut (mm)
1	39.55	33.46	29.02
2	28.48	27.77	31.75
3	16.66	23.46	23.91
Delta	22.90	10.00	7.84
Rank	1	2	3

Table 4.9: Response Table for Signal to Noise Ratios for Tool Life the higher is better

Regression Equation for Tool Life

The relationship between the factors (cutting speed, depth of cut and feed) and the performance measure (tool life) was modeled by multiple linear regressions using Minitab The following equation is formed.The final regression models in terms of coded parameters:

TL= tool life, V= spindle speed, F= feed rate, DC= depth of cut

TL= 518 – 0.339V - 307F-44.4DC

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

In the present investigation, Analysis Effect of Surface Roughness, Material Removal Rate and Tool Life when turning of Mild Steel on Laze Machine have been successfully studied by Taguchi method. Therefore from the Experimental and the Analytical Results, the following conclusions were drawn.

1. The study shows Optimum condition of the turning process is concerned with Minimizing the Surface Roughness, while Maximizing the MRR and Tool Life, cannot be achieved simultaneously with a particular combination of control parameter settings
2. The significant factors for the Surface Roughness were spindle speed and feed with contribution of 21.7% and 68.7% respectively. Although not statistically significant, the depth of cut has a physical influence explaining 0.4% of the total variation so the optimal combination of cutting parameters for minimum Surface Roughness is obtained by Spindle Speed and Feed Rate should be set as low as possible.
3. Spindle speed (48.77%) was found the significant parameters followed by Feed Rate (44.63%) and depth of cut (4.42%) on Material Removal Rate (MRR). Moreover, MRR is apparently to have an increasing trend with increase cutting speed, depth of cut and feed. So the optimal combination of cutting parameters for Maximum Material Removal Rate is obtained by Spindle Speed and Feed Rate should be set as high as possible.
4. The Tool Life is highly influenced by the cutting speed (75.3%) in a smaller degree, by feed (14.7%) and smallest influencing by depth of cut (8.5%). In order to maximize tool life is obtained by Spindle Speed and Feed Rate should be set as low as possible, However Depth of cut that much no Effect on performance measurements.

5. The Relationship between the cutting parameters and performance measures are expressed by Multiple Regression Equation, which can be used to estimate the expressed values of the performance level for any parameters levels.

5.2 Recommendation

This study succeeded in achieving the optimal response utilizing minimum resources and time. Also important to know the quality of design can be improved by improving the quality and productivity in companywide activities. Those activities concerned with quality like wear test/tool life/, Material Removal Rate and Surface finish are the most desirable tests for quality measurement of machining process. Especially surface finish plays an important role on the product quality and it is a parameter of great importance in the evaluation of machining accuracy.

Also The Taguchi Method is especially suitable for Industrial use, but it can also be used for scientific research purposes and it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specified limits, thus improving the product quality. Using Main Effects and analysis of Variance/ANOVA/ important to get the Effect of performances Measurement also important to get the best optimum combinations of parameters within the experimental results.

5.3 Future Work

In this Thesis work Analysis Effect of performance parameters such as Surface Roughness, Material Removal Rate and Tool Life in turning of Mild Steel on Laze machine using analytical and Experimental Method, it can be further studied by performing Experiments for a better result in addition to that other influencing factor is not studied in this paper. So this work is restricted to the specified cases. However, this paper can be extended to other situation listed below. So the following research areas are recommended for future studies.

- How to optimize and determine the Effect of cutting parameters on tool Wear especially flank tool wear.
- To get more reliable result Analysis compare with the Experimental result conducting machining simulation using FEM software.
- Influence of cutting parameters on cutting force in turning operation
- Determine Effect of Machining Parameters on Dimensional Accuracy in turning operation

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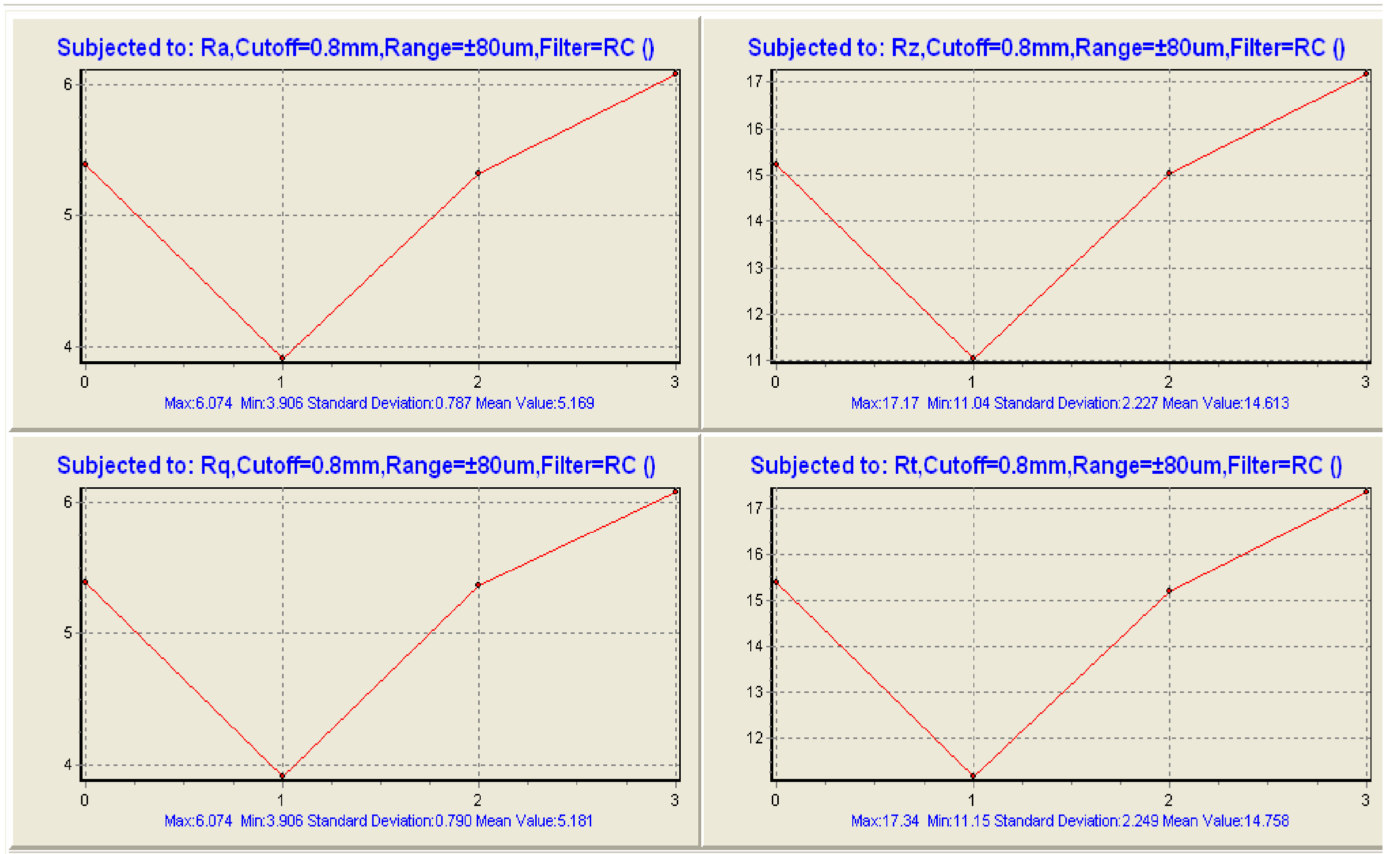
APPENDIX

Appendix A: Surface roughness and waviness profile curve

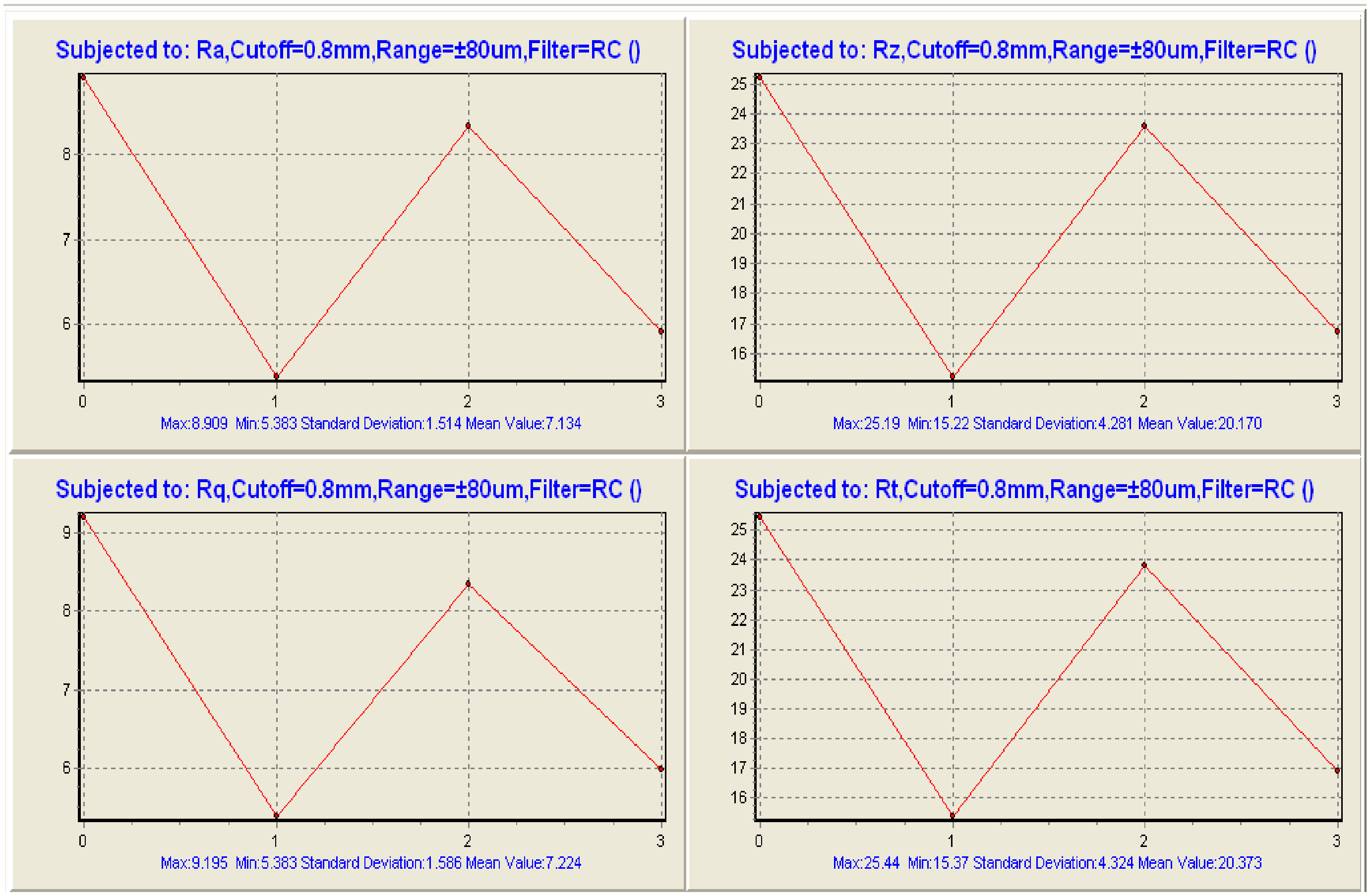


(**Sample 1**) Surface roughness and waviness profile curve at factor setting:

Spindle speed 530 rpm, feed rate 0.5 mm/rev and depth of cut 0.5 mm

Cut off length = 0.8mm, Maximum value = 17.34um ,Minimum value = 3.906 um

Standard deviation = 5.043um, Mean value = 9.93um

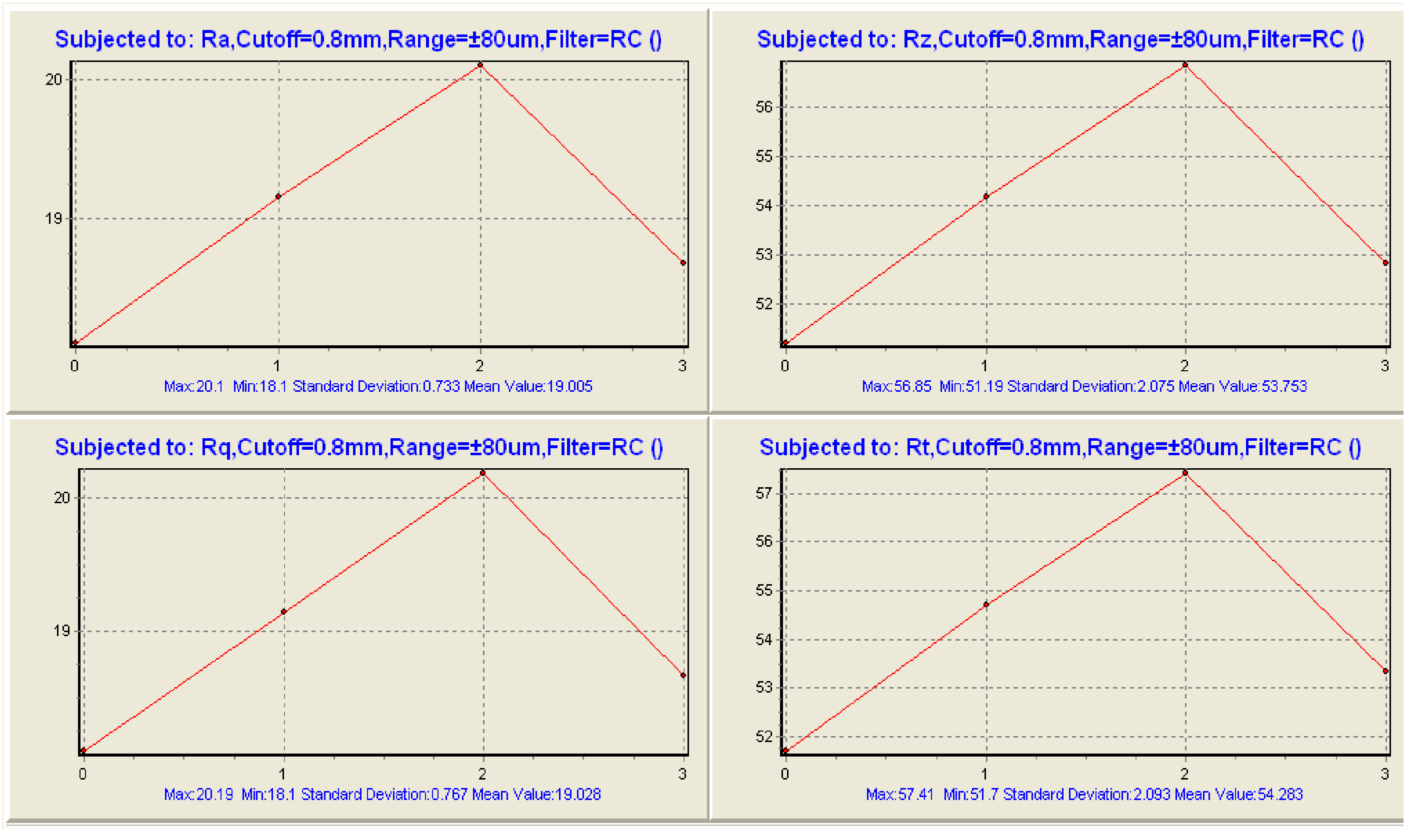


(**Sample 2**) Surface roughness and waviness profile curve at factor setting:

Spindle speed 530rpm, feed rate 0.6 mm/rev and depth of cut 1 mm

Cut off length = 0.8mm, Maximum value = 25.44 um, Minimum value = 5.385 um,

Standard deviation = 7.302 um, Mean value =13.725

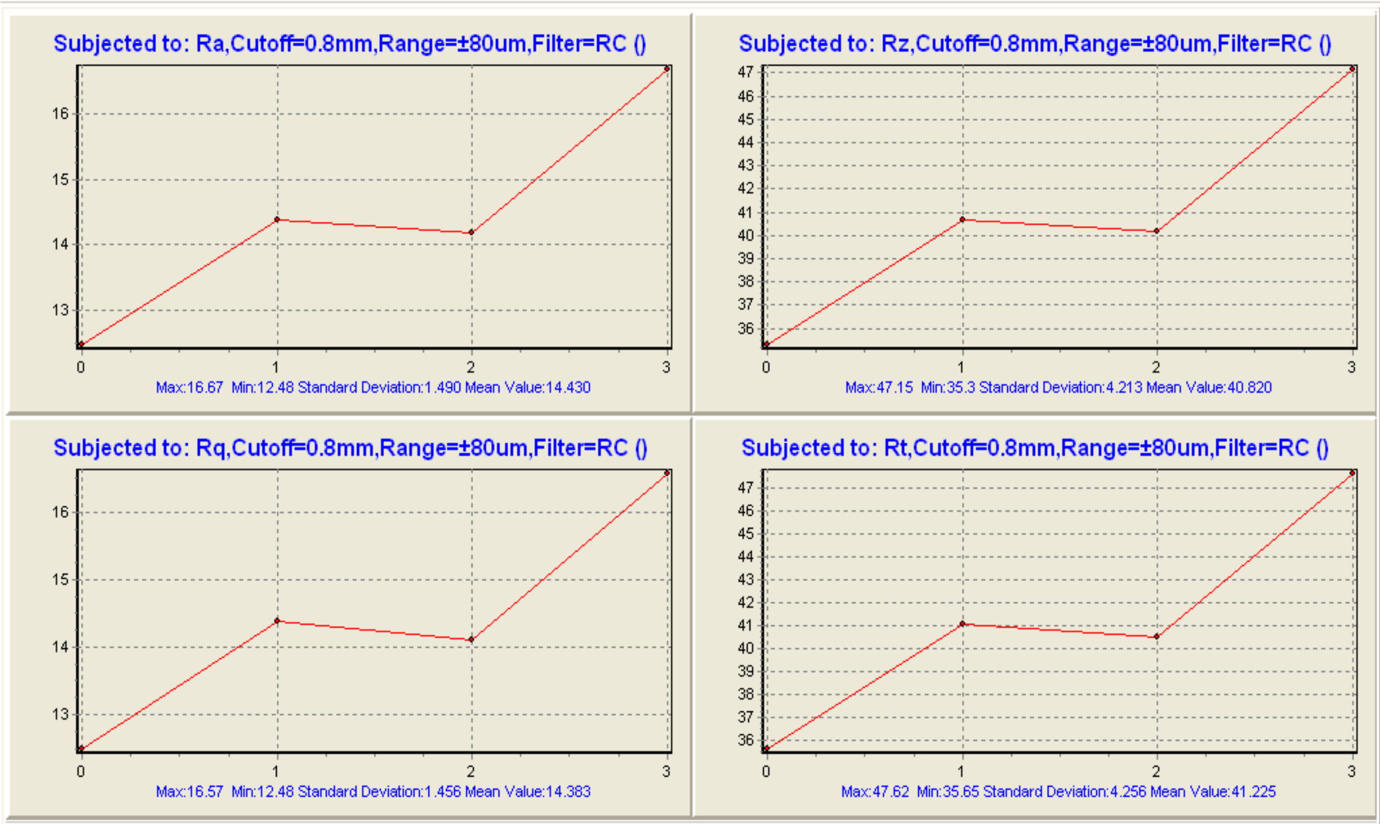


(**Sample 3**) Surface roughness and waviness profile curve at factor setting:

Spindle speed 530 rpm, feed rate 0.7 mm/rev and depth of cut 1.5 mm

Cut off length = 0.8mm, Maximum value = 57.41um, Minimum value = 18.1um

Standard deviation = 17.572um, Mean value =36.517

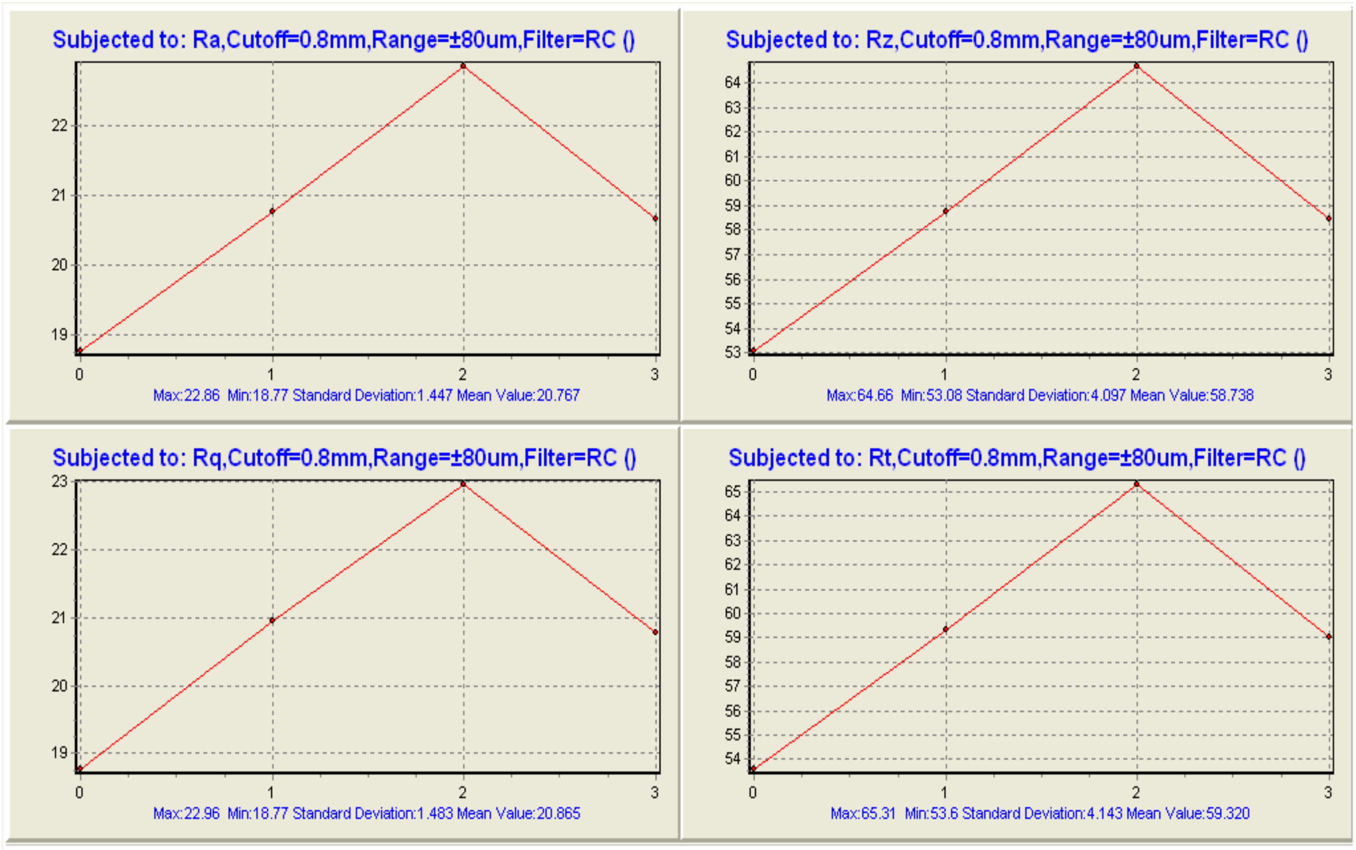


(**Sample 4**) Surface roughness and waviness profile curve at factor setting:

Spindle speed 700 rpm, feed rate 0.5 mm/rev and depth of cut 1 mm

Cut off length = 0.8mm, Maximum value = 47.62 um, Minimum value = 12.48 um

Standard deviation = 13.681um, Mean value = 27.714

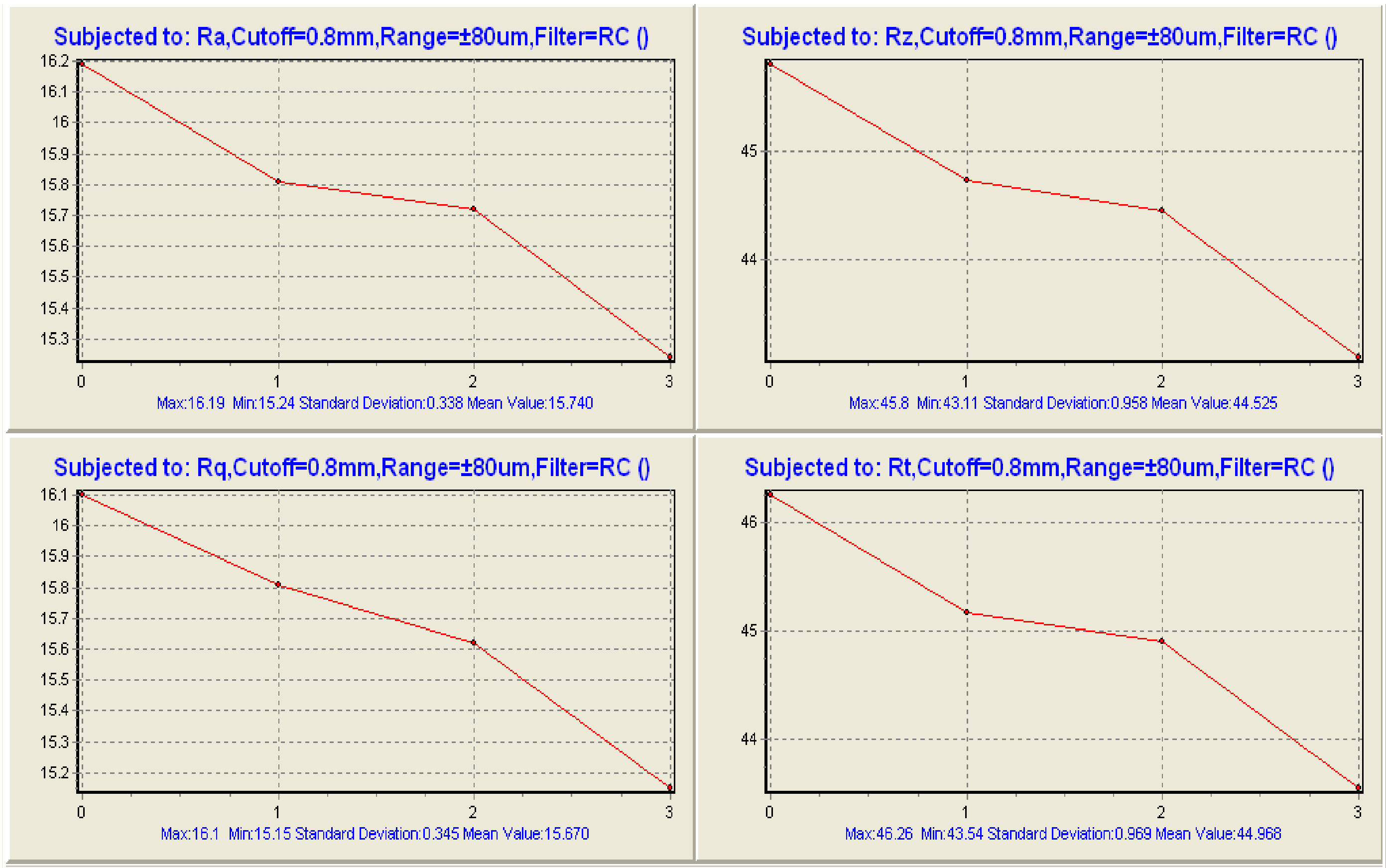


(**Sample 5**) Surface roughness and waviness profile curve at factor setting:

Spindle speed 700 rpm, feed rate 0.6 mm/rev and depth of cut 1.5 mm

Cut off length = 0.8mm, Maximum value = 65.31um, Minimum value = 18.37 um

Standard deviation = 19.356um, Mean value = 39.923

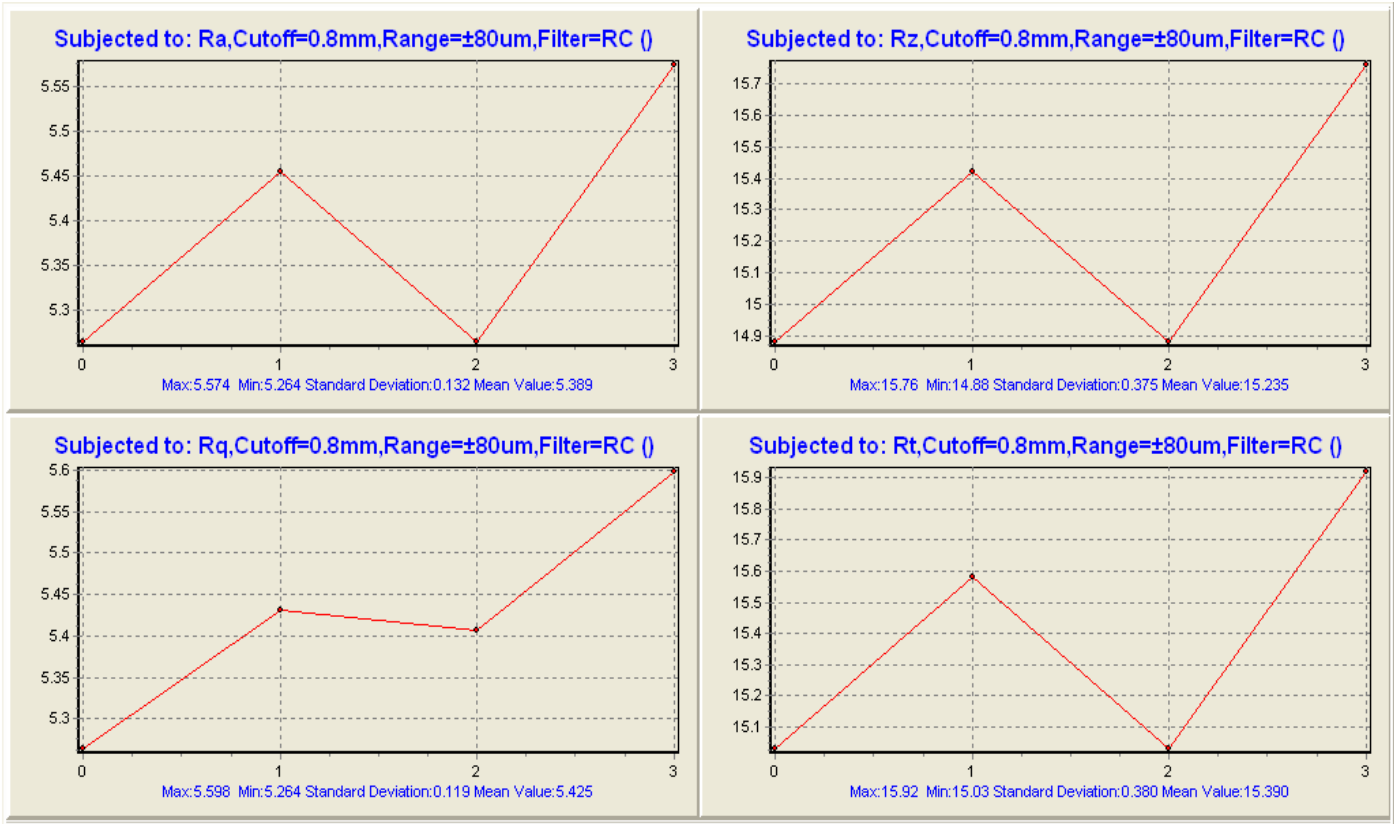


(**Sample 6**) Surface roughness and waviness profile curve at factor setting:

Spindle speed 700 rpm, feed rate 0.7 mm/rev and depth of cut 0.5 mm

Cut off length = 0.8mm, Maximum value = 46.26um, Minimum value = 15.15um

Standard deviation = 14.539um, Mean value =30.226

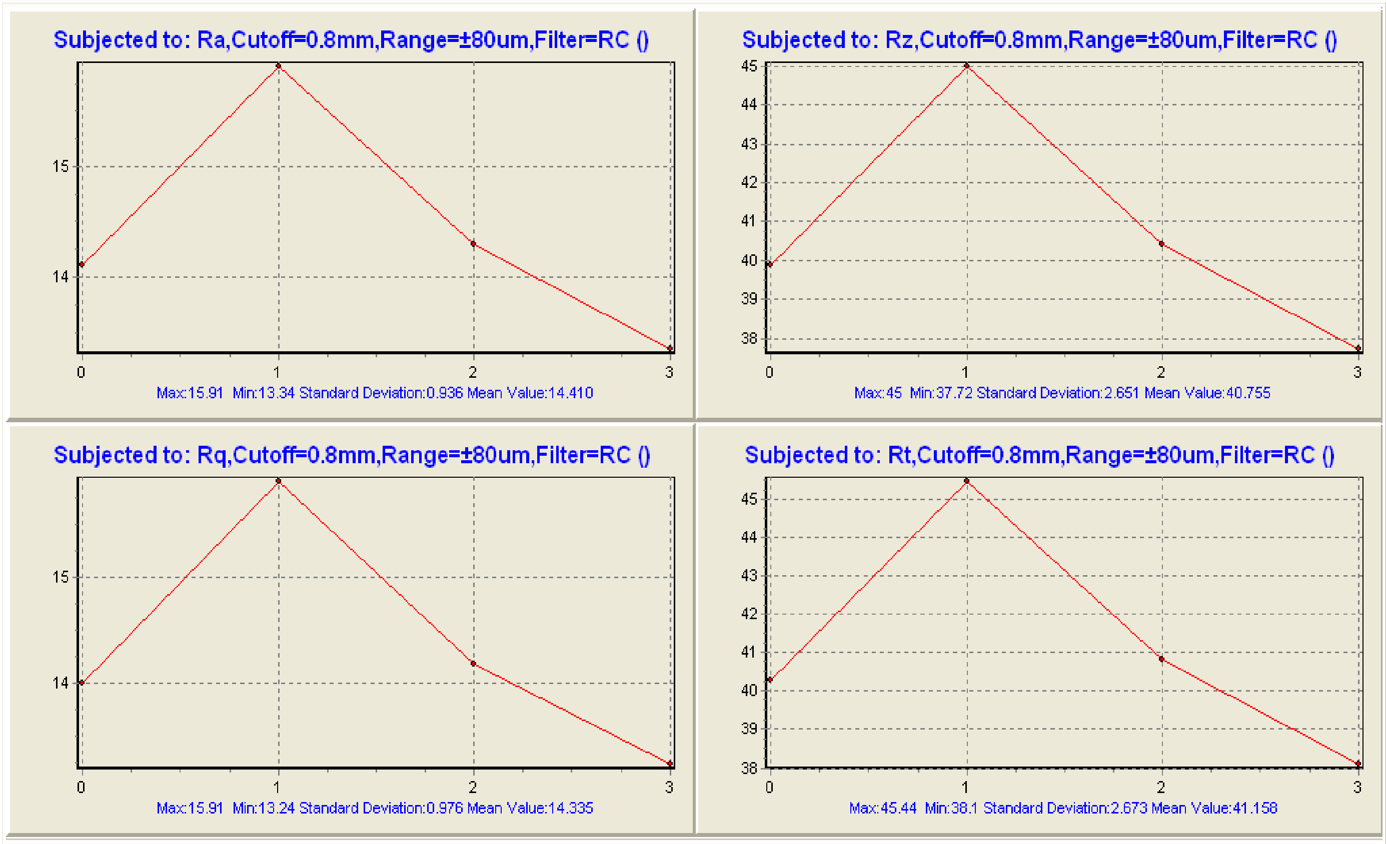


(**Sample 7**) Surface roughness and waviness profile curve at factor setting:

Spindle speed 860 rpm, feed rate 0.5 mm/rev and depth of cut 1.5 mm

Cut off length = 0.8mm, Maximum value = 15.92um, Minimum value = 5.264um

Standard deviation = 4.961um, Mean value =10.36

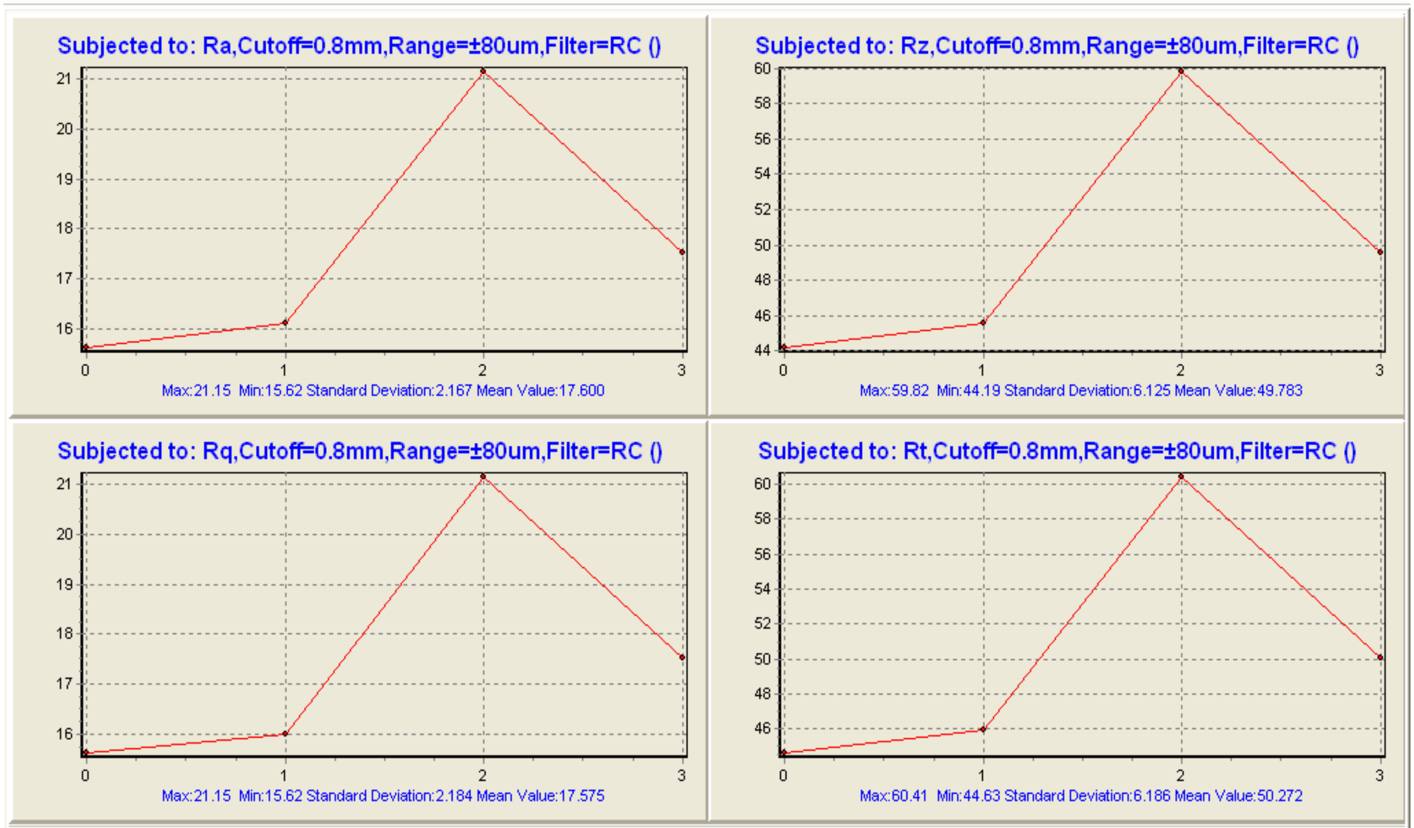


(**Sample 8**) Surface roughness and waviness profile curve at factor setting:

Spindle speed 860 rpm, feed rate 0.6 mm/rev and depth of cut 0.5 mm

Cut off length = 0.8mm, Maximum value = 45.44um, Minimum value = 13.24um

Standard deviation = 13.442um, Mean value =27.664um



(**Sample 9**) Surface roughness and waviness profile curve at factor setting:

Spindle speed 860 rpm, feed rate 0.7 mm/rev and depth of cut 1 mm

Cut off length = 0.8mm, Maximum value = 60.41um, Minimum value = 15.62um

Standard deviation = 16.865um, Mean value =33.808

Appendix B: Surface roughness value for each trial

For experiment sample 1

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	2015-10-14 10:46:43 AM	Real time measurement	0	um
True	1	2015-10-14 10:46:43 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	5.383	
True	2	2015-10-14 10:46:43 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	15.22	
True	3	2015-10-14 10:46:43 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	5.383	
True	4	2015-10-14 10:46:44 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	15.37	
True	0			0	
True	0	2015-10-14 10:47:13 AM	Real time measurement	0	um
True	5	2015-10-14 10:47:13 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	3.906	
True	6	2015-10-14 10:47:14 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	11.04	
True	7	2015-10-14 10:47:14 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	3.906	
True	8	2015-10-14 10:47:14 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	11.15	
True	0			0	
True	0	2015-10-14 10:47:45 AM	Real time measurement	0	um
True	9	2015-10-14 10:47:45 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	5.312	
True	10	2015-10-14 10:47:45 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	15.02	
True	11	2015-10-14 10:47:45 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	5.359	
True	12	2015-10-14 10:47:46 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	15.17	
True	0			0	
True	0	2015-10-14 10:48:13 AM	Real time measurement	0	um
True	13	2015-10-14 10:48:13 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	6.074	
True	14	2015-10-14 10:48:13 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	17.17	
True	15	2015-10-14 10:48:14 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	6.074	
True	16	2015-10-14 10:48:14 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	17.34	

For experiment sample 2

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	2015-10-14 10:55:22 AM	Real time measurement	0	um
True	1	2015-10-14 10:55:23 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	8.909	
True	2	2015-10-14 10:55:23 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	25.19	
True	3	2015-10-14 10:55:23 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	9.195	
True	4	2015-10-14 10:55:23 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	25.44	
True	0			0	
True	0			0	um
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0	2015-10-14 10:58:03 AM	Real time measurement	0	um
True	5	2015-10-14 10:58:03 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	5.383	
True	6	2015-10-14 10:58:03 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	15.22	
True	7	2015-10-14 10:58:04 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	5.383	
True	8	2015-10-14 10:58:04 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	15.37	
True	0			0	
True	0	2015-10-14 10:58:28 AM	Real time measurement	0	um
True	9	2015-10-14 10:58:29 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	8.338	
True	10	2015-10-14 10:58:29 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	23.57	
True	11	2015-10-14 10:58:29 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	8.338	
True	12	2015-10-14 10:58:29 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	23.81	
True	0			0	
True	0			0	um
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0	2015-10-14 11:00:07 AM	Real time measurement	0	um
True	13	2015-10-14 11:00:07 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	5.907	
True	14	2015-10-14 11:00:08	Subjected to:	16.7	

		AM	Rz,Cutoff=0.8mm,Range=±80um,Filter=RC		
True	15	2015-10-14 11:00:08 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	5.979	
True	16	2015-10-14 11:00:08 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	16.87	

For experiment sample 3

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	2015-10-14 11:02:23 AM	Real time measurement	0	um
True	1	2015-10-14 11:02:23 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	18.1	
True	2	2015-10-14 11:02:23 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	51.19	
True	3	2015-10-14 11:02:23 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	18.1	
True	4	2015-10-14 11:02:24 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	51.7	
True	0			0	
True	0	2015-10-14 11:02:51 AM	Real time measurement	0	um
True	5	2015-10-14 11:02:51 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	19.15	
True	6	2015-10-14 11:02:51 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	54.16	
True	7	2015-10-14 11:02:51 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	19.15	
True	8	2015-10-14 11:02:52 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	54.69	
True	0			0	
True	0	2015-10-14 11:04:03 AM	Real time measurement	0	um
True	9	2015-10-14 11:04:03 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	20.1	
True	10	2015-10-14 11:04:04 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	56.85	
True	11	2015-10-14 11:04:04 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	20.19	
True	12	2015-10-14 11:04:04 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	57.41	
True	0			0	
True	0	2015-10-14 11:04:36 AM	Real time measurement	0	um
True	13	2015-10-14 11:04:36 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	18.67	
True	14	2015-10-14 11:04:36 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	52.81	
True	15	2015-10-14 11:04:36 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	18.67	
True	16	2015-10-14 11:04:37 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	53.33	

For experiment sample 4

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	2015-10-14 11:06:34 AM	Real time measurement	0	um
True	1	2015-10-14 11:06:34 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	12.48	
True	2	2015-10-14 11:06:34 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	35.3	
True	3	2015-10-14 11:06:34 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	12.48	
True	4	2015-10-14 11:06:35 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	35.65	
True	0			0	
True	0	2015-10-14 11:07:02 AM	Real time measurement	0	um
True	5	2015-10-14 11:07:02 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	14.38	
True	6	2015-10-14 11:07:02 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	40.68	
True	7	2015-10-14 11:07:02 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	14.38	
True	8	2015-10-14 11:07:03 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	41.09	
True	0			0	
True	0	2015-10-14 11:07:29 AM	Real time measurement	0	um
True	9	2015-10-14 11:07:29 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	14.19	
True	10	2015-10-14 11:07:29 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	40.15	
True	11	2015-10-14 11:07:29 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	14.1	
True	12	2015-10-14 11:07:30 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	40.54	
True	0			0	
True	0	2015-10-14 11:07:57 AM	Real time measurement	0	um
True	13	2015-10-14 11:07:57 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	16.67	
True	14	2015-10-14 11:07:58 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	47.15	
True	15	2015-10-14 11:07:58 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	16.57	
True	16	2015-10-14 11:07:58 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	47.62	

For experiment sample 5

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	2015-10-14 11:10:13 AM	Real time measurement	0	um
True	1	2015-10-14 11:10:14 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	18.77	
True	2	2015-10-14 11:10:14 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	53.08	
True	3	2015-10-14 11:10:14 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	18.77	
True	4	2015-10-14 11:10:14 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	53.6	
True	0			0	
True	0	2015-10-14 11:10:47 AM	Real time measurement	0	um
True	5	2015-10-14 11:10:47 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	20.77	
True	6	2015-10-14 11:10:48 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	58.74	
True	7	2015-10-14 11:10:48 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	20.96	
True	8	2015-10-14 11:10:48 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	59.32	
True	0			0	
True	0	2015-10-14 11:11:18 AM	Real time measurement	0	um
True	9	2015-10-14 11:11:19 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	22.86	
True	10	2015-10-14 11:11:19 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	64.66	
True	11	2015-10-14 11:11:19 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	22.96	
True	12	2015-10-14 11:11:19 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	65.31	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0			0	
True	0	2015-10-14 11:14:50 AM	Real time measurement	0	um
True	13	2015-10-14 11:14:50 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	20.67	
True	14	2015-10-14 11:14:50 AM	Subjected to:	58.47	

			Rz,Cutoff=0.8mm,Range=±80um,Filter=RC		
True	15	2015-10-14 11:14:51 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	20.77	
True	16	2015-10-14 11:14:51 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	59.05	

For experiment sample 6

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	2015-10-14 11:17:23 AM	Real time measurement	0	um
True	1	2015-10-14 11:17:24 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	16.19	
True	2	2015-10-14 11:17:24 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	45.8	
True	3	2015-10-14 11:17:24 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	16.1	
True	4	2015-10-14 11:17:24 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	46.26	
True	0			0	
True	0	2015-10-14 11:17:48 AM	Real time measurement	0	um
True	5	2015-10-14 11:17:49 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	15.81	
True	6	2015-10-14 11:17:49 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	44.73	
True	7	2015-10-14 11:17:49 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	15.81	
True	8	2015-10-14 11:17:49 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	45.17	
True	0			0	
True	0	2015-10-14 11:18:17 AM	Real time measurement	0	um
True	9	2015-10-14 11:18:17 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	15.72	
True	10	2015-10-14 11:18:17 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	44.46	
True	11	2015-10-14 11:18:17 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	15.62	
True	12	2015-10-14 11:18:18 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	44.9	
True	0			0	
True	0	2015-10-14 11:18:44 AM	Real time measurement	0	um
True	13	2015-10-14 11:18:44 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	15.24	
True	14	2015-10-14 11:18:44 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	43.11	
True	15	2015-10-14 11:18:45 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	15.15	
True	16	2015-10-14 11:18:45 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	43.54	

For experiment sample 7

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	2015-10-14 11:21:18 AM	Real time measurement	0	um
True	1	2015-10-14 11:21:18 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	5.264	
True	2	2015-10-14 11:21:18 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	14.88	
True	3	2015-10-14 11:21:18 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	5.264	
True	4	2015-10-14 11:21:18 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	15.03	
True	0			0	
True	0	2015-10-14 11:21:43 AM	Real time measurement	0	um
True	5	2015-10-14 11:21:43 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	5.455	
True	6	2015-10-14 11:21:43 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	15.42	
True	7	2015-10-14 11:21:44 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	5.431	
True	8	2015-10-14 11:21:44 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	15.58	
True	0			0	
True	0	2015-10-14 11:22:20 AM	Real time measurement	0	um
True	9	2015-10-14 11:22:20 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	5.264	
True	10	2015-10-14 11:22:20 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	14.88	
True	11	2015-10-14 11:22:20 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	5.407	
True	12	2015-10-14 11:22:21 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	15.03	
True	0			0	
True	0	2015-10-14 11:22:46 AM	Real time measurement	0	um
True	13	2015-10-14 11:22:46 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	5.574	
True	14	2015-10-14 11:22:46 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	15.76	
True	15	2015-10-14 11:22:47 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	5.598	
True	16	2015-10-14 11:22:47 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	15.92	

For experiment sample 8

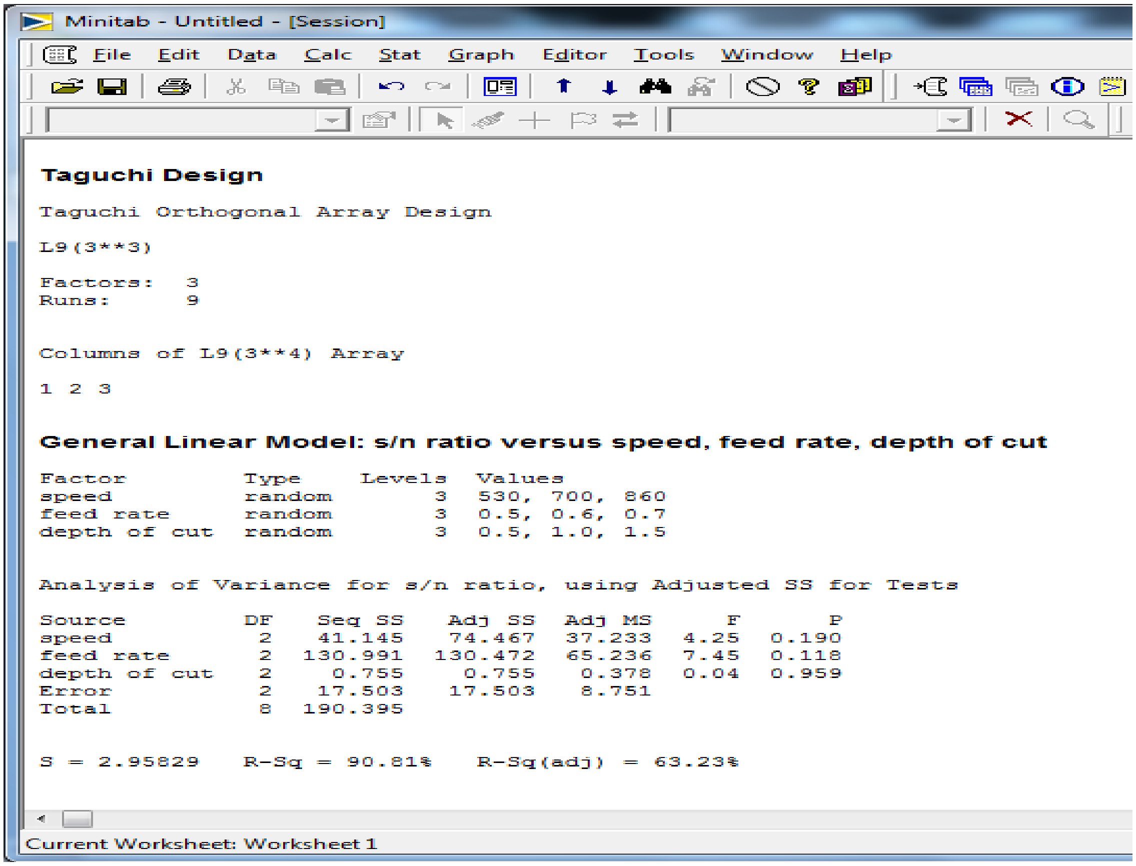
Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	2015-10-14 11:24:52 AM	Real time measurement	0	um
True	1	2015-10-14 11:24:52 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	14.1	
True	2	2015-10-14 11:24:52 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	39.88	
True	3	2015-10-14 11:24:53 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	14	
True	4	2015-10-14 11:24:53 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	40.27	
True	0			0	
True	0	2015-10-14 11:25:16 AM	Real time measurement	0	um
True	5	2015-10-14 11:25:16 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	15.91	
True	6	2015-10-14 11:25:16 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	45	
True	7	2015-10-14 11:25:17 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	15.91	
True	8	2015-10-14 11:25:17 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	45.44	
True	0			0	
True	0	2015-10-14 11:25:43 AM	Real time measurement	0	um
True	9	2015-10-14 11:25:44 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	14.29	
True	10	2015-10-14 11:25:44 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	40.42	
True	11	2015-10-14 11:25:44 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	14.19	
True	12	2015-10-14 11:25:44 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	40.82	
True	0			0	
True	0	2015-10-14 11:26:13 AM	Real time measurement	0	um
True	13	2015-10-14 11:26:13 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	13.34	
True	14	2015-10-14 11:26:14 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	37.72	
True	15	2015-10-14 11:26:14 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	13.24	
True	16	2015-10-14 11:26:14 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	38.1	

For experiment sample 9

Status	No.	Date & Time	Project Name	Value	Unit
True	0			0	
True	0	2015-10-14 11:28:07 AM	Real time measurement	0	um
True	1	2015-10-14 11:28:07 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	15.62	
True	2	2015-10-14 11:28:07 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	44.19	
True	3	2015-10-14 11:28:07 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	15.62	
True	4	2015-10-14 11:28:08 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	44.63	
True	0			0	
True	0	2015-10-14 11:28:31 AM	Real time measurement	0	um
True	5	2015-10-14 11:28:32 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	16.1	
True	6	2015-10-14 11:28:32 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	45.54	
True	7	2015-10-14 11:28:32 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	16	
True	8	2015-10-14 11:28:32 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	45.98	
True	0			0	
True	0	2015-10-14 11:28:56 AM	Real time measurement	0	um
True	9	2015-10-14 11:28:56 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	21.15	
True	10	2015-10-14 11:28:57 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	59.82	
True	11	2015-10-14 11:28:57 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	21.15	
True	12	2015-10-14 11:28:57 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	60.41	
True	0			0	
True	0	2015-10-14 11:29:24 AM	Real time measurement	0	um
True	13	2015-10-14 11:29:24 AM	Subjected to: Ra,Cutoff=0.8mm,Range=±80um,Filter=RC	17.53	
True	14	2015-10-14 11:29:24 AM	Subjected to: Rz,Cutoff=0.8mm,Range=±80um,Filter=RC	49.58	
True	15	2015-10-14 11:29:24 AM	Subjected to: Rq,Cutoff=0.8mm,Range=±80um,Filter=RC	17.53	
True	16	2015-10-14 11:29:25 AM	Subjected to: Rt,Cutoff=0.8mm,Range=±80um,Filter=RC	50.07	

Appendix C: ANNOVA result from Minitab software

1. ANNOVA result for surface roughness



Taguchi Design

```
Taguchi Orthogonal Array Design

L9(3**3)

Factors:  3
Runs:     9


Columns of L9(3**4) Array

1 2 3
```

General Linear Model: s/n ratio versus speed, feed rate, depth of cut

```
Factor        Type    Levels  Values
speed         random       3  530, 700, 860
feed rate     random       3  0.5, 0.6, 0.7
depth of cut  random       3  0.5, 1.0, 1.5


Analysis of Variance for s/n ratio, using Adjusted SS for Tests

Source        DF   Seq SS   Adj SS  Adj MS     F      P
speed          2   41.145   74.467  37.233  4.25  0.190
feed rate      2  130.991  130.472  65.236  7.45  0.118
depth of cut   2    0.755    0.755   0.378  0.04  0.959
Error          2   17.503   17.503   8.751
Total          8  190.395


S = 2.95829   R-Sq = 90.81%   R-Sq(adj) = 63.23%
```

2 . ANNOVA result for material removal rate

Minitab - ANOVA FOR MMR.MPJ - [Session]

File Edit Data Calc Stat Graph Editor Tools Window Help

```
Taguchi Design

Taguchi Orthogonal Array Design

L9(3**3)

Factors:  3
Runs:     9


Columns of L9(3**4) Array

1 2 3


General Linear Model: material rem versus spindle spee, feed rate, ...

Factor         Type   Levels  Values
spindle speed  fixed       3  530, 700, 860
feed rate      fixed       3  0.5, 0.6, 0.7
debth of cut   fixed       3  0.5, 1.0, 1.5


Analysis of Variance for material removal rate, using Adjusted SS for Tests

Source         DF    Seq SS   Adj SS   Adj MS      F      P
spindle speed   2   6748258  6748258  3374129  22.37  0.043
feed rate       2   6174138  6174138  3087069  20.47  0.047
debth of cut    2    611795   611795   305897   2.03  0.330
Error           2    301656   301656   150828
Total           8  13835846


S = 388.366   R-Sq = 97.82%   R-Sq(adj) = 91.28%
```

3. ANNOVA result for Tool Life

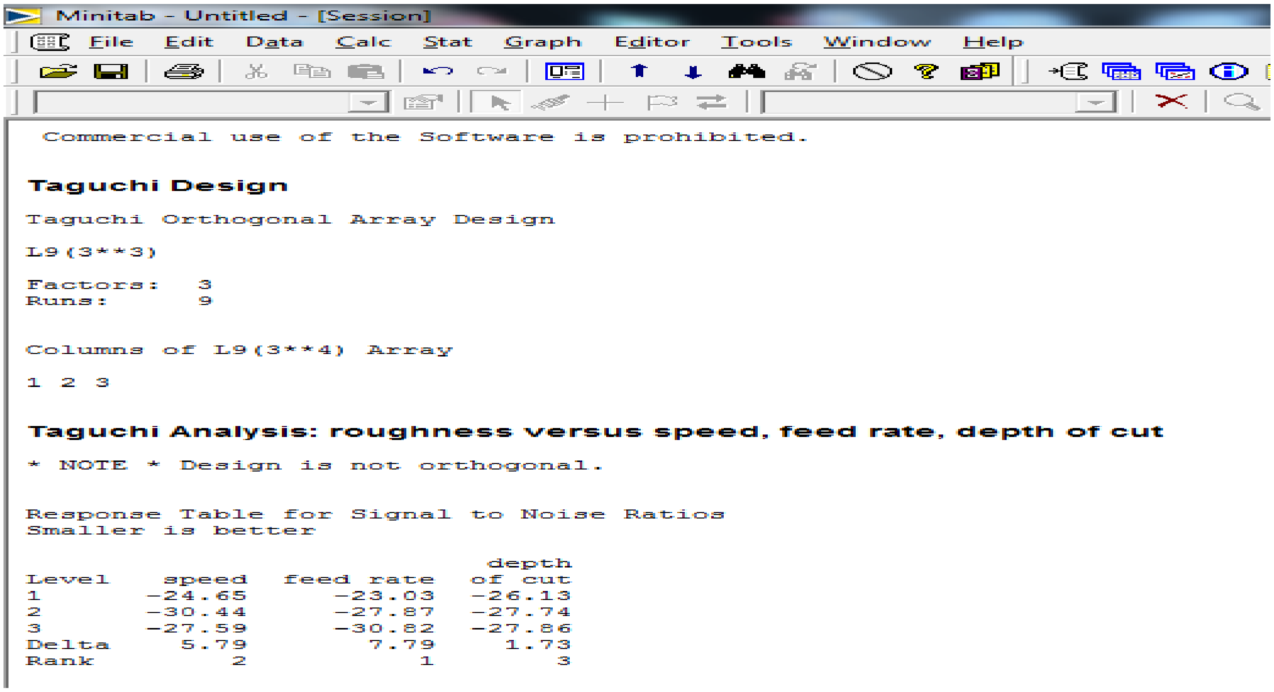
Minitab - Untitled - [Session]

File Edit Data Calc Stat Graph Editor Tools Window Help

```
Taguchi Design

Taguchi Orthogonal Array Design

L9(3**3)

Factors:  3
Runs:     9


Columns of L9(3**4) Array

1 2 3


General Linear Model: S/N Ratio versus speed, feed rate, depth of cut

Factor         Type   Levels  Values
speed          fixed       3  530, 700, 860
feed rate      fixed       3  0.5, 0.6, 0.7
depth of cut   fixed       3  0.5, 1.0, 1.5

Analysis of Variance for S/N Ratio, using Adjusted SS for Tests

Source         DF   Seq SS   Adj SS   Adj MS      F      P
speed           2   805.89   805.89   402.94  51.49  0.019
feed rate       2   157.16   157.16    78.58  10.04  0.091
depth of cut    2    90.56    90.56    45.28   5.79  0.147
Error           2    15.65    15.65     7.83
Total           8  1069.26

S = 2.79757   R-Sq = 98.54%   R-Sq(adj) = 94.14%
```

Appendix D: delta result from Minitab software

For surface roughness




```
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Taguchi Design

Taguchi Orthogonal Array Design

L9(3**3)

Factors:  3
Runs:     9

Columns of L9(3**4) Array

1 2 3

Taguchi Analysis: roughness versus speed, feed rate, depth of cut

* NOTE * Design is not orthogonal.

Response Table for Signal to Noise Ratios
Smaller is better

                                depth
Level    speed   feed rate     of cut
1       -24.65      -23.03     -26.13
2       -30.44      -27.87     -27.74
3       -27.59      -30.82     -27.86
Delta     5.79        7.79       1.73
Rank         2           1          3
```
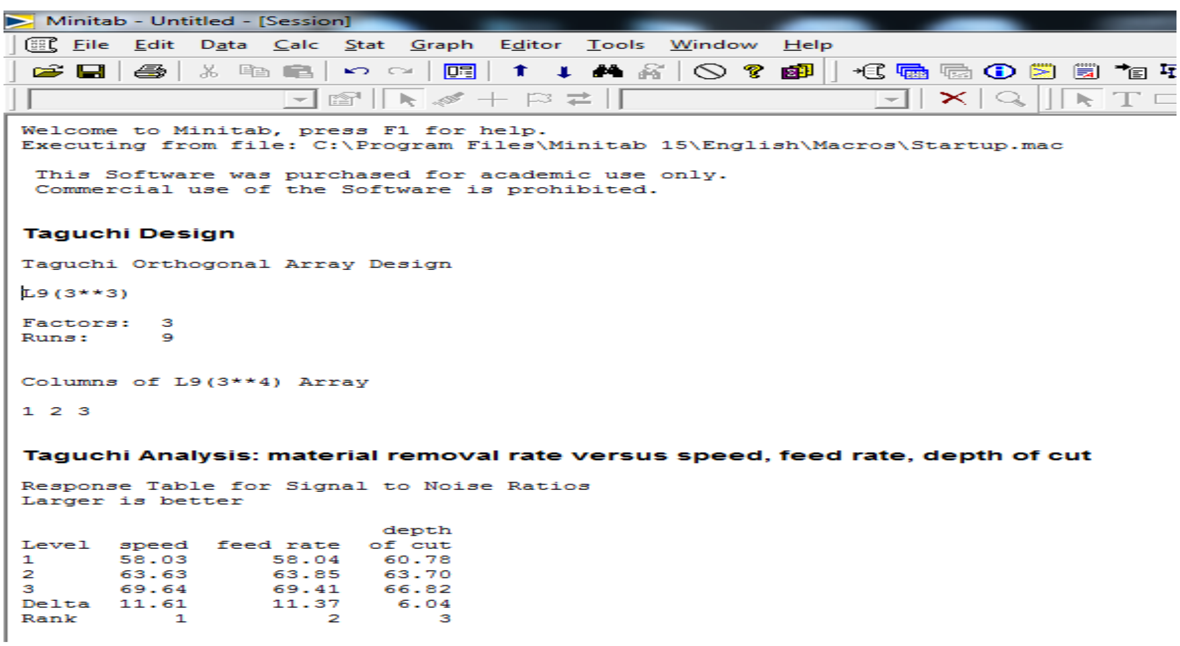

For material removal rate




```
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Taguchi Design

Taguchi Orthogonal Array Design

L9(3**3)

Factors:  3
Runs:     9

Columns of L9(3**4) Array

1 2 3

Taguchi Analysis: material removal rate versus speed, feed rate, depth of cut

Response Table for Signal to Noise Ratios
Larger is better

                              depth
Level   speed  feed rate     of cut
1       58.03      58.04      60.78
2       63.63      63.85      63.70
3       69.64      69.41      66.82
Delta   11.61      11.37       6.04
Rank        1          2          3
```

For tool life

```
8/12/2015 12:24:39 PM

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Taguchi Design

Taguchi Orthogonal Array Design

L9(3**3)

Factors:  3
Runs:     9


Columns of L9(3**4) Array

1 2 3

Taguchi Analysis: Tool life versus speed, feed rate, depth of cut

Response Table for Signal to Noise Ratios
Larger is better

                                 depth
Level   speed   feed rate   of cut
1       39.55       33.46    29.02
2       28.48       27.77    31.75
3       16.66       23.46    23.91
Delta   22.90       10.00     7.84
Rank        1           2        3
```

Appendix E: regression Analysis

For surface roughness

```
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Taguchi Design

Taguchi Orthogonal Array Design

L9(3**3)

Factors:  3
Runs:     9


Columns of L9(3**4) Array

1 2 3

Regression Analysis: Rouhhness versus speed, feed rate, depth of cut

The regression equation is
Rouhhness = - 45.3 + 0.0134 speed + 91.1 feed rate + 7.04 depth of cut


Predictor       Coef   SE Coef      T      P
Constant      -45.27     29.66  -1.53  0.187
speed        0.01339   0.02359   0.57  0.595

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```

For material removal rate

```
—————————— 9/12/2015 12:17:57 PM ————————————————————————————

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Taguchi Design

Taguchi Orthogonal Array Design

L9(3**3)

Factors:  3
Runs:     9

Columns of L9(3**4) Array

1 2 3

Regression Analysis: MMR versus speed, feed rate, depth of cut

The regression equation is
MMR = - 8692 + 6.09 speed + 9788 feed rate + 577 depth of cut


Predictor      Coef  SE Coef      T      P
Constant      -8692     1721  -5.05  0.004
speed         6.094    1.364   4.47  0.007
feed rate      9788     2251   4.35  0.007

Current Worksheet: Worksheet 1
```

For Tool Life

```
—————————— 9/12/2015 12:11:39 PM ————————————————————————————

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Taguchi Design

Taguchi Orthogonal Array Design

L9(3**3)

Factors:  3
Runs:     9

Columns of L9(3**4) Array

1 2 3

Regression Analysis: Tool Life versus speed, feed rate, depth of cut

The regression equation is
Tool Life = 518 - 0.339 speed - 307 feed rate - 44.4 depth of cut


Predictor          Coef  SE Coef      T      P
Constant          518.4    106.0   4.89  0.005
speed          -0.33917  0.08401  -4.04  0.010
feed rate        -307.0    138.6  -2.21  0.078
```