ANALYSIS OF CUTTING PARAMETERS ON SURFACE ROUGHNESS IN TURNING OF MILD STEEL

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SUBMITTED BY

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CANDIDATE'S DECLARATION

I, YASHWANT KOLI, hereby certify that the work which is being presented in this thesis entitled "**ANALYSIS OF CUTTING PARAMETERS ON SURFACE ROUGHNESS IN TURNING OF MILD STEEL**" being submitted by me is an authentic record of my own work carried out under the supervision of **Dr. VIPIN, Professor, Department of Mechanical Engineering, Delhi Technological University, Delhi.**

The matter presented in this thesis has not been submitted in any other University/Institute for the award of M.Tech Degree.

YASHWANT KOLI
(2K15/PIE/21)

CERTIFICATE

I, YASHWANT KOLI, hereby certify that the work which is being presented in this thesis entitled "**ANALYSIS OF CUTTING PARAMETERS ON SURFACE ROUGHNESS IN TURNING OF MILD STEEL**" in the partial fulfillment of requirement for the award of degree of **Masters of Technology** submitted in the **Department of Mechanical Engineering** at **Delhi College Of Engineering**, **Delhi University**, is an authentic record of my own work carried out during a period from July 2016 to June 2017, under the supervision of **Dr. VIPIN, Professor, Department of Mechanical Engineering, Delhi College of Engineering, Delhi.**

The matter presented in this thesis has not been submitted in any other University/Institute for the award of M.Tech Degree.

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ABSTRACT

In metal cutting and manufacturing industries, surface finish of a product is very crucial in determining the quality. Good surface finish not only assures quality, but also reduces manufacturing cost. Surface finish is important in terms of tolerances, it reduces assembly time and avoids the need for secondary operation, thus reduces operation time and leads to overall cost reduction. Besides, good-quality turned surface is significant in improving fatigue strength, corrosion resistance, and creep life.

This study focuses on optimizing cutting parameters based on the Taguchi method, a powerful tool to design optimization for quality, is used to minimize surface roughness. A full factorial 27 experiments, the signal-to-noise (S:N) ratio, analysis of variance (ANOVA) and regression analysis are employed to investigate the cutting characteristics of mild steel bars using carbide cutting tools. The main objective is to study the effect of cutting speed, feed and depth of cut on surface roughness of mild steel in turning operation using carbide tool. Different cutting parameters have different influential on the surface finish. The cutting speed, feed and depth of cut were decide using the suitable range recommended; which were 71.628m/min, 95.504m/min and 119.380m/min for cutting speed, 0.04mm/rev, 0.14mm/rev and 0.24mm/rev for feed and lastly 0.2mm, 0.4mm and 0.6mm for depth of cut. The specimen was turned under different level of parameters and was measured the surface roughness using a Taylor Hobson's Surtronic 3+. From the result, it is concluded that higher cutting speed and lower feed produce better surface finish. The optimum cutting parameters were 119.380m/min, 0.04mm/rev and 0.6mm, which produced minimum surface roughness of 1.33µm. According to the ANOVA analysis, feed is the dominant factor by 85.82%.

Keywords: Surface roughness, Taguchi, ANOVA, Regression analysis and Taylor Hobson's Surtronic 3+.

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Nomenclature

Parameter	Description
Ra	Parameter of roughness
SR	Surface Roughness
ANOVA	Analysis of Variance
CNC	Computer Numerical Controlled
DOE	Design of Experiment

The motif (R) parameters

R	Mean depth of roughness motifs
Rx	Maximum depth of roughness motifs
Ar	Mean spacing of roughness motifs
Rsm	Mean width of profile
Pt	Maximum peak to valley height

CHAPTER 1

1.1 INTRODUCTION

Lathe machine is the oldest machine tool that is still the most familiar used machine in the manufacturing industry to produce cylindrical parts. Lathes are machines that cut work pieces while they are rotated. CNC lathes are capable to produce fast, precision cuts, usually by indexable tools and drills in comparison to lathe. They are predominantly effective for complex programs intended to make parts that would be infeasible to make on normal lathes.

CNC lathes have alike control specifications to CNC mills and can frequently interpret G-code as well as the manufacturer's exclusive programming language. CNC lathes usually have two axes (X and Z), but fresher models have more axes, letting for more innovative jobs to be machined. CNC's are extremely versatile and allow you to cut an array of different types of product and materials. The exact capacities of a machine will vary with size, inflexibility and power. Naturally most CNC routers are able to cut soft and hard wood, plastics, other composites and non-ferrous metals. CNC machines offer many advantages in manufacturing like higher flexibility, increased productivity, improved quality, reduced scrap rate, reliable and safe operation. It is broadly used in variety of manufacturing industries including aerospace, electronics, automotive sectors, firearm manufacturing, where quality of surface plays an extremely vital role in the operation of turning as suitable quality turned surface is important in enhancing fatigue strength, corrosion resistance and creep life. SR also affects numerous functional qualities of parts, such as wearing, heat transmission, facility of holding a lubricant, coating and resisting fatigue. Nowadays, SR plays a major role in controlling and assessing the surface quality of a product as it influences the functional attribute.

A widely known model to establish the SR is $R_a = f^2/32r$, where f is the feed rate and r is the nose radius. Undoubtedly, feed rate and nose radius affect SR the most [1][2]. The product value depends extremely on surface roughness. Decrease of SR quality also leads to decrease of product value. In field of production, particularly in engineering, the surface finish quality can be a significant importance that can affects the working of a component, and possibly its cost. SR has been obtaining responsiveness for numerous years in the machining industries. It is a vital design characteristic in many situations, such as parts subject to fatigue loads, precision fits, and fastener holes and so on.

In terms of tolerances, SR executes one of the greatest vital constraints for the machines and cutting parameters selection in process planning. Manufacturing industries are very much anxious about the quality of their products. They are concentrated on producing high quality products in time at minimum cost. Surface finish is one of the vital performance parameters that have to be constrained within appropriate limits for a specific process. Therefore, forecast or observing of the SR of machined components has been a significant area of research. SR is harder to accomplish and track than physical dimensions are, because comparatively many factors affect SR. Some of these aspects can be regulated and some cannot. Manageable process parameters include feed, cutting speed, tool geometry, and tool setup. Other factors, such as tool, work piece and machine vibration, tool wear and degradation, and work piece and tool material inconsistency cannot be controlled as easily. SR also affects numerous functional characteristics of parts, such as contact causing surface friction, wearing, light reflection, heat transmission, ability of dispensing and holding a lubricant, coating or opposing fatigue. Therefore the preferred finish surface is usually specified and the appropriate are selected to reach the requisite quality. Several works have been reported in the broad field of tool condition monitoring. Researchers are trying to acquire a robust and exact model that can find a relationship between the cutting parameters and the SR of the machined products.

1.2 Types of Roughness

The subsequent roughness produced by a machining method can be thought of as the combination of two autonomous effects: Ideal roughness and Natural roughness.

1.2.1 Ideal Roughness

Ideal SR is a function of only feed and geometry. It signifies the finest possible finish which can be acquired for a given tool shape and feed. It can be attained only if the built-up-edge, chatter and inaccuracies in the machine tool movements are eliminated completely. For a sharp tool without nose radius, the maximum height of unevenness is given by:

$$\mathbf{R_{max} = f / (\cot \varphi + \cot \beta)}$$

The SR value is given by:

$$R_a = R_{max} / 4$$

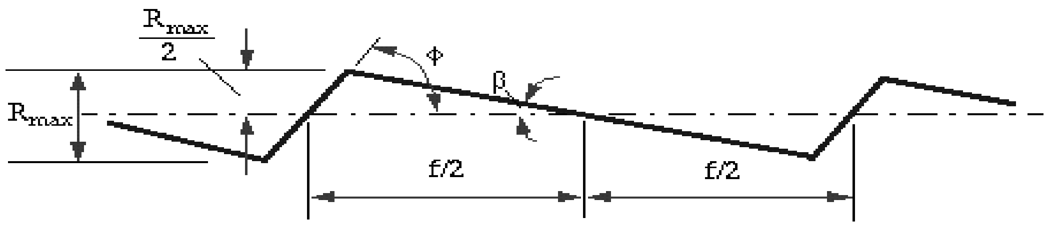


Figure: 1 Surface profile

f → Feed

Φ → Major cutting edge angle

B → working minor cutting edge angle

1.2.2 Natural Roughness

One of the key aspects contributing to natural SR is the existence of a built-up edge. Thus, greater the built up edge, the rougher would be the surface produced, and aspects tending to reduce chip-tool friction and to eradicate the built-up edge would give enhanced surface finish.

1.3 Cutting Parameters

It is significant task to select cutting parameters for achieving high cutting performance. However, this does not confirm that the selected cutting parameters have best or near best cutting performance for a specific machine and environment [3]. The important cutting parameters discussed here are cutting speed, feed and depth of cut.

1.3.1 Cutting Speed

All materials have an optimal cutting speed and it is expressed as the speed at which a point on the surface of the work passes the cutting edge or point of the tool and is normally given in meters/min. To calculate the cutting speed required,

$$V_c = \pi DN/1000$$

Where: V_C = Cutting Speed of Metal (m/min), D = Diameter of Work piece, N = Spindle Speed (RPM)

1.3.2 Feed

The term ‘feed’ is used to define the distance the tool moves per revolution of the work piece and varies largely on the surface finish needed. For rough turning of soft material a feed of up to 0.25 mm/rev may be used and for tougher materials this should be decreased to a maximum of 0.10 mm/rev. For good finishing finer feed is recommended.

1.3.3 Depth of cut

It is the advancement of tool in the job in a direction perpendicular to the surface being machined. Depth of cut depends upon cutting speed, rigidity of machine tool and tool material etc. Depth of cut normally varies between 1 to 5 mm for roughing operation and 0.2 to 1 mm for finishing operation.

1.3.4 Effect of cutting parameters

It is found in most of the cases SR decreases with increase in cutting speed and decrease in feed and depth of cut.

Since these cutting parameters will choose about the type of chips which we assume at the time of machining of a single constant material thus we have to examine them for no such built-up edge chips formation. At the optimal cutting speed at which the consequence of built up edge is insignificant, (high speed, ductile material) the profile of the cutting edge of the tool is imitated on the work surface and this ideal SR is largely reliant on cutting feed. That means for a larger feed the mean roughness value is more as associated to the lesser feed.

It would be noted that the size of chips cross-sectional area has a great influence on surface finish. Surface finish is poor for large cuts which is required from significant of great tool life and power consumption. Larger feed is more detrimental to surface finish than a larger depth of cut.

For very high cutting speeds the probabilities of built up edge decreases thus SR also expected to decrease, while when cutting speed is small built-up formation of chips would increase the SR.

1.4 Carbon Steel

Carbon steels are steels with carbon content up to 2.1% by weight. Carbon steel is a metal alloy, a mixture of two elements that are iron and carbon, where other elements are present in magnitudes too small to influence the properties. The only other elements permissible in plain-carbon steel are: manganese (1.65% max), silicon (0.60% max), and copper (0.60%

max). It is by far the most frequent used steel. As carbon content increases the metal turn into harder and tougher but less ductile and more problematic to weld. Higher carbon content drops steel's melting point and its temperature resistance in general. Carbon steels may be further classified into 3 major groups: low carbon steel, medium carbon steel and high carbon steel.

1.4.1 Low Carbon Steel

Low carbon steel, also known as mild steel, contains 0.05 % to 0.26 % of carbon with up to 0.4% manganese content (e.g. AISI 1018, AISI 1020 steel). It is now the most general form of steel because its value is comparatively low while it offers material properties that are suitable for many applications. These steels are ductile and have properties similar to iron. They are cheap, but engineering applications are limited to non-critical components and general paneling and fabrication work. These steels cannot be efficiently heat treated. So, there are typically no problems related with heat affected zones (HAZ) in welding process. The surface properties can be improved by carburizing and then heat treating the carbon-rich surface. High ductility characteristic results in poor machinability.

1.4.2 Medium Carbon Steel

Medium carbon steel contains 0.29 % to 0.54 % of carbon content with 0.60 to 1.65% manganese content (e.g. AISI 1040, AISI 1045 steel). These steels are highly vulnerable to thermal treatments and work hardening. They effortlessly flame harden and can be treated and functioned to yield great tensile strengths provided that low ductility can be endured. It stabilities ductility and strength and has decent wear resistance. The corrosion resistance of these steels is similar to low carbon steel, although small additions of copper can lead to major improvements when weathering performance is important. Medium carbon steels which are still cheap and command mass market. They are general purpose but can be specified for use in stressed applications such as rails and rail products, couplings, crankshafts, axles, bolts, rods, gears, forgings, tubes, plates and constructional steels.

1.4.3 High Carbon Steel

High carbon steel contains 0.55 % to 0.95 % carbon content with 0.30 to 0.90% manganese content (e.g. AISI 1086, AISI 1090). Cold working is not achievable with any of these steels, as they fracture at very low elongation. They are extremely sensitive to thermal treatments. Machinability is good, although their hardness needs machining in the normalized condition.

Welding is not suggested and these steels must not be exposed to impact loading. They are normally used for components that require high hardness such as cutting tools, blades, springs and high-strength wires.

1.5 Taguchi Method

Taguchi's parametric design is the efficient tool for robust design it proposes a easy and organized qualitative optimal design to a relatively low cost. The Taguchi method of off-line (Engineering) quality control includes all stages of product/process development. However the significant element for attaining high quality at low cost is DOE. Taguchi's (DOE) method is used to observe the consequence of cutting parameters like cutting speed, feed, and depth of cut on SR of mild steel work material while machining with carbide tool and to obtain an optimal setting of these parameters that may result in good surface finish [4].

The idea of Taguchi is broadly applicable. He suggested that engineering optimization of a process or product should be carried out in a three-step approach, i.e., system design, parameter design, and tolerance design.

1.5.1 System Design

In system design, the engineer applies scientific and engineering knowledge to create a basic functional prototype design, this design includes the product design stage and the process design stage. In the product design stage, the choice of materials, components, uncertain product parameter values, etc., are involved. As to the process design stage, the evaluation of processing sequences, the selections of production equipment, provisional process parameter values, etc., are involved. Since system design is an initial functional design, it may be far from optimum in terms of quality and cost. This is design at the conceptual level, involving creativity and innovation.

1.5.2 Parameter Design

The purpose of the parameter design is to enhance the settings of the process parameter values for refining performance features and to identify the product parameter values under the ideal process parameter values. In addition, it is likely that the ideal process parameter values attained from the parameter design are indifferent to the variation of environmental conditions and other noise factors. Therefore, the parameter design is the significant step in the Taguchi method to attaining great quality without increasing cost. Basically, traditional parameter design, established by Fisher, is complicated and not easy to use. Especially, a great number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses an extraordinary design of orthogonal arrays to study the whole parameter space with a small number of experiments only. A loss function is then expressed to compute the abnormality between the experimental value and the desired value. Taguchi suggests the employment of the loss function to compute the performance characteristic contrary from the anticipated value. The significance of the loss function is further altered into a signal-to-noise (S/N) ratio η; usually there are three types of the performance characteristic in the assessment of the S/N ratio, that is, the lower-the-better, the higher-the-better, and the nominal- the-better. The S/N ratio for each level of process parameters is calculated based on the S/N assessment [5].

$$\text{Smaller-is-the better(minimize)}: S/N_S = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

1.5.3 Tolerance Design

With a positively accomplished parameter design, and an understanding of the consequence that the several parameters have on performance, resources can be focused on reducing and controlling deviation in the critical few dimensions.

1.6 Design of Experiments

Design of experiments is a powerful analysis tool for modeling and analyzing the influence of process variables over some specific variable which is an unknown function of these process variables [6]. The DOE is considered as one of the most widespread approach in product/process developments. It is a statistical approach that attempts to provide a predictive knowledge of a complex, multi-variable process with few trials.

1.7 Full Factorial Design

A full factorial experiment is an experiment whose design involves two or more factors, each with a distinct possible level and whose experimental units take all probable combinations of all those levels among all such factors. Such an experiment permits studying the consequence of each factor on the response variable, as well as on the effects of connections between factors on the response variable. A general experimental design is the one with all input factors set at two levels each. If there are k factors each at 2 levels; a full factorial design has 2^k runs. Thus for 3 factors at three levels it would take 27 trial runs.

Steps of Taguchi method are as follows [7][8]:

i. Identification of key function, side effects and failure mode.
ii. Identification of noise factor, testing condition and quality characteristics.
iii. Identification of the key function to be optimized.
iv. Identification of the governor factor and their levels.
v. Selection of orthogonal array and matrix experiment.
vi. Conducting the matrix experiment.
vii. Analyzing the data, forecast of the optimal level and performance.
viii. Executing the verification experiment and scheduling the future action.

1.8 ANOVA

Since there are a great number of variables monitoring the process, some mathematical models are required to signify the process. However, these models are to be established using only the important parameters influencing the process rather than including all the parameters. In order to achieve this, statistical analysis of the experimental results will have to be processed using the ANOVA which is a computational technique that permits the estimation of the comparative assistances of each of the control factors to the overall measured response.

ANOVA can be beneficial for defining impact of any given input parameter from a series of experimental results by DOE for machining process and it can be used to interpret experimental data. ANOVA is an assembly of statistical models, and their related procedures, in which the monitored variance in a particular variable is partitioned into components attributable to different sources of variation. In its easiest form, ANOVA offers a statistical test of whether or not the means of several groups are all equal, and therefore simplifies t-test to more than two groups. ANOVA is used in the study of relative experiments, those in which only the alteration in outcomes is of interest. The statistical implication of the experiment is determined by a ratio of two variances. This ratio is independent of several possible modifications to the experimental observations: Adding or multiplying a constant to all observations does not alter consequence. So ANOVA statistical consequence results are independent of constant bias and scaling errors as well as the units used in expressing observations.

1.9 MOTIF-method

The MOTIF-method is a structure for the assessment of the primary profile and established on the envelope system and is appropriate as an alternative to the mean line system. The MOTIF-method controls the upper points of the surface profile, which have an importance for the functional behavior.

SR and waviness can be evaluated directly based on the diagram of the unfiltered profile. SR and waviness measurements in industry are globally widespread accomplished by stylus instruments. To isolated SR from waviness, the mean line system uses electronic filtering. The MOTIF-method (ISO 12085) offers a substitute assessment to isolated SR and waviness by means of unfiltered profiles. The MOTIF-method is a graphical assessment with the complete explanation of roughness and waviness with merely 7 parameters and the assessment based on the upper envelope line. The MOTIF-method finds out within these limits the horizontal and vertical properties of the vital profile irregularities without removal of important profile points. It is very well matched for technical inquiries on unknown surfaces and processes, functions related to the envelope of the surfaces and profiles with very close wavelengths for roughness and waviness [9].

CHAPTER 2

LITERATURE REVIEW

A considerable number of studies have investigated the general effects of the speed, feed, and depth of cut, nose radius and others on the surface roughness. These studies have been briefly discussed for the variations observed experimentally.

- ***Davim.J et al. [1]*** worked on surface roughness prediction models using artificial neural network (ANN) are developed to investigate the effects of cutting conditions during turning of free machining steel, 9SMnPb28k(DIN). The ANN model of surface roughness parameters (Ra and Rt) is developed with the cutting conditions such as feed rate, cutting speed and depth of cut as the affecting process parameters. The experiments are planned as per L27 orthogonal array with three levels defined for each of the factors in order to develop the knowledge base for ANN training using error back-propagation training algorithm (EBPTA). 3D surface plots are generated using ANN model to study the interaction effects of cutting conditions on surface roughness parameters. The analysis reveals that cutting speed and feed rate have significant effects in reducing the surface roughness, while the depth of cut has the least effect. When the depth of cut is low, the surface roughness is highly sensitive to cutting speed; an increase in cutting speed sharply reduces the surface roughness. However, this reduction becomes smaller and smaller with the higher values of depth of cut. It is also observed that, surface roughness variation is minimal with the variations of depth of cut at higher values of cutting speed. The surface roughness has a tendency to reduce with the increase in cutting speed and also with the reduction in feed rate.

- ***I.A. Choudhury et al. [2]*** worked on the development of surface roughness prediction models for turning EN 24T steel (290 BHN) utilizing response surface methodology. A factorial design technique has been used to study the effects of the main cutting parameters such as cutting speed, feed, and depth of cut, on surface roughness. The tests have been carried out using uncoated carbide inserts without any cutting fluid. A first-order prediction model within the speed range of 36-117 m min^{-1} a second-order model covering the speed range of 28-150 m min^{-1} have been presented. The results reveal that response surface methodology combined with factorial design of experiments is a better alternative to the traditional one-variable-at-a-time approach for studying the effects of cutting variables on responses such as surface roughness and tool life. This significantly reduces the total number of experiments required. The results have revealed that the effect of feed is much more pronounced than the effects of cutting speed and depth of cut, on the surface roughness. However, a higher cutting speed improves the surface finish.

- ***W.H. Yang et al. [3]*** states that the Taguchi method, a powerful tool to design optimization for quality, is used to find the optimal cutting parameters for turning operations. An orthogonal array, the signal-to-noise (S:N) ratio, and the analysis of variance (ANOVA) are employed to investigate the cutting characteristics of S45C steel bars using tungsten carbide cutting tools. The Taguchi method provides a systematic and efficient methodology for the design optimization of the cutting parameters with far less effect than would be required for most optimization techniques. The confirmation experiments were conducted to verify the optimal cutting parameters. The improvement of tool life and surface roughness from the initial cutting parameters to the optimal cutting parameters is about 250%.

- ***M. Nalbant et al. [4]*** uses Taguchi method to find the optimal cutting parameters for surface roughness in turning. The orthogonal array, the signal-to-noise ratio, and analysis of variance are employed to study the performance characteristics in turning operations of AISI 1030 steel bars using TiN coated tools. Three cutting parameters namely, insert radius, feed rate, and depth of cut, are optimized with considerations of surface roughness. The experimental results demonstrate that the insert radius and feed rate are the main parameters among the three controllable factors (insert radius, feed rate and depth of cut) that influence the surface roughness in turning AISI 1030 carbon steel. In turning, use of greater insert radius (1.2 mm), low feed rate (0.15 mm/rev) and low depth of cut (0.5 mm) are recommended to obtain better surface roughness for the specific test range. The improvement of surface roughness form initial cutting parameters to the optimal cutting parameters is about 335%.

- ***IlhanAsilturk et al. [5]*** focuses on optimizing turning parameters based on the Taguchi method to minimize surface roughness (Ra and Rz). Experiments have been conducted using the L9 orthogonal array in a CNC turning machine. Dry turning tests are carried out on hardened AISI 4140 (51 HRC) with coated carbide cutting tools. Each experiment is repeated three times and each test uses a new cutting insert to ensure accurate readings of the surface roughness. The statistical methods of signal to noise ratio (SNR) and the analysis of variance (ANOVA) are applied to investigate effects of cutting speed, feed rate and depth of cut on surface roughness. Results of this study indicate that the feed rate has the most significant effect on Ra and Rz. Optimum cutting conditions which correspond for the smaller surface roughness in hard turning method were found to be 120 m/min for the cutting speed, 0.18 mm/rev for the feed rate and 0.4 mm for the depth of cut.

- ***Hamdi Aouici et al. [6]*** the effects of cutting speed, feed rate, workpiece hardness and depth of cut on surface roughness and cutting force components in the hard turning were experimentally investigated. AISI H11 steel was hardened to (40; 45 and 50) HRC, machined using cubic boron nitride (CBN 7020 from Sandvik Company) which is essentially made of 57% CBN and 35% TiCN. Four-factor (cutting speed, feed rate, hardness and depth of cut) and three-level fractional experiment designs completed with a statistical analysis of variance (ANOVA) were performed. Mathematical models for surface roughness and cutting force components were developed using the response surface methodology (RSM). Results show **f**eed rate and work piece hardness have major statistical influences on the surface roughness. Lower feed rate and the high cutting speed lead to best surface roughness.

- ***S. Ramesh et al. [7]*** studies the effect of cutting parameters on the surface roughness in turning of titanium alloy has been investigated using response surface methodology. The experimental studies were conducted under varying cutting speeds, feed and depths of cut. The chip formation and SEM analysis are discussed to enhance the supportive surface quality achieved in turning. The work material used for the present investigation is commercial aerospace titanium alloy (gr5) and the tool used is RCMT 10T300 –MTTT3500 round insert. Taguchi ANOVA analysis was performed. The most influencing parameter was identified as the feed. The order of importance was feed, followed by depth of cut and cutting speed.

- ***Günay.M et al. [8]***, focused on optimizing the cutting conditions for the average surface roughness (Ra) obtained in machining of high-alloy white cast iron (Ni-Hard) at two different hardness levels (50 HRC and 62 HRC). Machining experiments were performed at the CNC lathe using ceramic and cubic boron nitride (CBN) cutting tools on Ni-Hard materials. Cutting speed, feed rate and depth of cut were chosen as the cutting parameters. Taguchi L18 orthogonal array was used to design of experiment. Optimal cutting conditions was determined using the signal-to-noise (S/N) ratio which was calculated for Ra according to the ‘‘the-smaller-the-better’’ approach. The effects of the cutting parameters and tool materials on surface roughness were evaluated by the analysis of variance. The most significant variable for Ni-Hard with 62 HRC was found the feed rate while the variable that was the most significant for Ni-Hard with 50 HRC was the cutting speed.

- ***N.R. Abburi et al. [9]*** develops a knowledge-based system for the prediction of surface roughness in turning process. Neural networks and fuzzy set theory are used for this purpose. Knowledge acquired from the shop floor is used to train the neural network. The trained network provides a number of data sets, which are fed to a fuzzy-set-based rule generation module. A large number of IF–THEN rules are generated, which can be reduced to a smaller set of rules by using Boolean operations. The developed rule base may be used for predicting surface roughness for given process variables as well as for the prediction of process variables for a given surface roughness. Results shows that reducing the ranges and increasing the number of training data is expected to improve the accuracy of the surface roughness.

- ***Janez Kopac et al. [10]*** focuses on optimising the turning of raw workpieces of low-carbon steel with low cold pre-deformation to achieve acceptable surface roughness. An attempt was made to minimise the number of experimental runs and increase the reliability of experimental results. According to the presence in the additive model and according to the analysis results, the cutting speed is the most powerful control factor of the process. A higher cutting speed results in a smoother surface.

- ***P.V.S. Suresh et al. [11]***, deals with the study and development of a surface roughness prediction model for machining mild steel, using Response Surface Methodology (RSM). The experimentation was carried out with TiN-coated tungsten carbide (CNMG) cutting tools, for machining mild steel work-pieces covering a wide range of machining conditions. A second order mathematical model, in terms of machining parameters, was developed for surface roughness prediction using RSM. This model gives the factor effects of the individual process parameters. An attempt has also been made to optimize the surface roughness prediction model using Genetic Algorithms (GA) to optimize
the objective function. Surface quality can be greatly controlled using Genetic Algorithms.

- ***W.S. Lin et al. [12]***, an abductive network is adopted to construct a prediction model for surface roughness and cutting force. This network is composed of a number of functional nodes, which are self-configured to form an optimal network hierarchy by using a predicted square error (PSE) criterion. Once the process parameters (cutting speed, feed rate and depth of cut) are given, the surface roughness and cutting force can be predicted by this network. To verify the accuracy of the abductive network, regression analysis has been adopted to develop a second prediction model for surface roughness and cutting force. Comparison of the two models indicates that the prediction model developed by the abductive network is more accurate than that by regression analysis. Critical elements that affect surface roughness are the feed rate, where increasing feed rate will increase the surface roughness value, while a regression multiplier for the surface roughness demonstrates that the cutting speed does not have a significant impact on surface roughness.

- ***M.Y. Noordin et al. [13]***, The performance of a multilayer tungsten carbide tool was described using response surface methodology (RSM) when turning AISI 1045 steel. Cutting tests were performed with constant depth of cut and under dry cutting conditions. The factors investigated were cutting speed, feed and the side cutting edge angle (SCEA) of the cutting edge. The main cutting force, i.e. the tangential force and surface roughness were the response variables investigated. The experimental plan was based on the face centred, central composite design (CCD). The experimental results indicate that the proposed mathematical models suggested could adequately describe the performance indicators within the limits of the factors that are being investigated. The ANOVA revealed that feed is the most significant factor influencing the response variables investigated.

- ***D.I. Lalwani et al. [14]***, In the present study, an attempt has been made to investigate the effect of cutting parameters (cutting speed, feed rate and depth of cut) on cutting forces (feed force, thrust force and cutting force) and surface roughness in finish hard turning of MDN250 steel [equivalent to 18Ni(250) maraging steel] using coated ceramic tool. The machining experiments were conducted based on response surface methodology (RSM) and sequential approach using face centered central composite design. The results show that cutting forces and surface roughness do not vary much with experimental cutting speed in the range of 55–93 m/min. A non-linear quadratic model best describes the variation of surface roughness with major contribution of feed rate and secondary contributions of interaction effect between feed rate and depth of cut, second order (quadratic) effect of feed rate and interaction effect between speed and depth of cut. Good surface roughness can be achieved when cutting speed and depth of cut are set nearer to their high level of the experimental range (93m/min and 0.2mm) and feed rate is at low level of the experimental range (0.04mm/rev).

- ***Davim. J et al. [15]***, presents a study of the influence of cutting parameters on surface roughness in turning of glass-fibre-reinforced plastics (GFRPs). A plan of experiments was performed on controlled machining with cutting parameters prefixed in workpiece. A statistical technique, using orthogonal arrays and analysis of variance, has been employed to investigate the influence of cutting parameters on surface roughness in turning GFRPs tubes using polycrystalline diamond cutting tools. The objective was to obtain the contribution percentages of the cutting parameters (cutting velocity and feed rate) on the surface roughness in GFRPs workpiece. Results shows that with this cutting parameters (speed and feed) it was possible to obtain surfaces with 0.80-1.75mm of arithmetic average roughness (Ra) and 4.9-9.3mm of maximum peak-to-valley height (Rt/Rmax). The surface roughness (Ra and Rt/Rmax) increases with the feed rate and decreases with the cutting velocity and feed rate is the cutting parameter that has the highest physical as well statistical influence on surface roughness (Ra and Rt/Rmax) in workpiece.

- ***Dilbag Singh et al. [16],*** An experimental investigation was conducted to determine the effects of cutting conditions and tool geometry on the surface roughness in the finish hard turning of the bearing steel (AISI 52100). Mixed ceramic inserts made up of aluminium oxide and titanium carbonitride (SNGA), having different nose radius and different effective rake angles, were used as the cutting tools. Mathematical models for the surface roughness were developed by using the response surface methodology. The results also indicate that feed is the dominant factor affecting the surface roughness, followed by the nose radius, cutting velocity and effective rake angle.

- ***Ahmet Hasçalhk et al. [17],*** In this study, the effect and optimization of machining parameters on surface roughness and tool life in a turning operation was investigated by using the Taguchi method. The experimental studies were conducted under varying cutting speeds, feed rates, and depths of cut. An orthogonal array, the signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) were employed to the study the performance characteristics in the turning of commercial Ti-6Al-4V alloy using CNMG 120408-883 insert cutting tools. Results show that the feed rate parameter is the main factor that has the highest importance on the surface roughness and this factor is about 1.72 times more important than the second ranking factor (depth of cut) whereas the cutting speed does not seem to have much of an influence on the surface roughness.

- ***Vishal S. Sharma et al. [18],*** In this study, machining variables such as cutting forces and surface roughness are measured during turning at different cutting parameters such as approaching angle, speed, feed and depth of cut. The data obtained by experimentation is analyzed and used to construct model using neural networks. The model obtained is then tested with the experimental data and results are indicated. Surface roughness (Ra) is positively influenced with feed and it shows negative trend with approaching angle, speed and depth of cut. The neural network model for cutting force Ra could predict with moderate accuracy.

- ***Hardeep Singh et al. [19],*** Surface finish is one of the prime requirements of customers for machined parts. The present paper presents an experimental study to investigate the effects of cutting parameters like spindle speed, feed and depth of cut on surface finish and material removal rate on EN-8. Taguchi methodology has been applied to optimize cutting parameters. The results showed that the spindle speed (the most significant factor) contributed 63.90%, depth of cut (second most significant factor) contributed only 11.32% and feed rate contribution was least with 8.33% for Ra. The contribution for feed and RPM was 60.91% and 29.83%.whereas the depth of cut contributed only 7.82% for material removal rate. It was concluded that interesting to note that spindle speed and depth of cut an approximate decreasing trend. The feed has the variable effect on surface roughness.

- ***Thomas M. et al. [20],*** Choice of optimized cutting parameters is very important to control the required surface quality. The focus of this study is the collection and analysis of surface roughness and tool vibration data generated by lathe dry turning of mild carbon steel samples at different levels of speed, feed, depth of cut, tool nose radius, tool length and workpiece length. A full factorial experimental design (288 experiments) that allows to consider the three-level interactions between the independant variables has been conducted. The analogy of the effect of cutting parameters between tool dynamic forces and surface roughness is also investigated. The results show that second order interactions between cutting speed and tool nose radius, along with third-order interaction between feed rate, cutting speed and depth of cut are the factors with the greatest influence on surface roughness and tool dynamic forces in this type of operation and parameter levels studied. The analysis of variance revealed that the best surface roughness condition is achieved at a low feed rate (less than 0.35 mm/rev), a large tool nose radius (1.59 mm) and a high cutting speed (265 m/min and above). The results also show that the depth of cut has not a significant effect on surface roughness, except when operating within the built-up edge range. In these cases, built-up edge formation deteriorates surface roughness and increases dynamic forces acting on the tool. The effect of built-up edge formation on surface roughness can be minimized by increasing depth of cut and increasing tool vibration.

- ***Ranganath M.S. et al. [21]***, investigates the parameters affecting the roughness of surfaces produced during the turning process for the material Aluminium 6061. The surface roughness is considered as quality characteristic while the process parameters considered are speed, feed and depth of cut .Design of experiments were conducted for the analysis of the influence of the turning parameters on the surface roughness by using Taguchi design. The results of the machining experiments for Aluminium 6061were used to characterize the main factors affecting surface roughness by the Analysis of Variance (ANOVA) method. The ANOVA and F-test revealed that the feed is dominant parameter followed by depth of cut and speed for surface roughness.

  The optimal combination process parameter for minimum surface roughness is obtained at 2100 rpm, 0.1 mm/rev and 0.2mm. A regression model is developed for surface roughness which is reasonably accurate and can be used of prediction within limits. Taguchi gives systematic simple approach and efficient method for the optimum operating conditions.

CHAPTER 3

EXPERIMENT SET UP

In this chapter, we would discuss the experimental set up, machine used, its limitations, advantages, measuring instrument, tooling used on the machine.

3.1 CNC lathe

Computer numerical controlled (CNC) lathes are swiftly substituting the older production lathes due to their simplicity of setting, operation, repeatability and accuracy. They are designed to use modern carbide tooling and fully use modern processes. The part might be designed and the tool paths programmed by the CAD/CAM process or manually by the programmer, and the resulting file uploaded to the machine, and once set and trialed the machine will continue to turn out parts under the occasional supervision of an operator.

The machine is regulated electronically via a computer menu style interface; the program may be customized and displayed at the machine, along with a simulated view of the process. The CNC Lathe comprises of the machine unit with a three jaw independent chuck, a computer numerically controlled tool slide, which cud move accordingly to two axis horizontal and vertical X and Z axis. X axis represents the vertical movement which gives the depth of cut whereas Z axis represents the location of the cutting tool. Thus after deciding the machining zero at a certain point the command is given in the form of a part program. The machine is also provided with an automatic lubrication motor for its slides.

Figure: 3.1 CNC Machine

TABLE 3.1 CNC specifications

Model	Turn master-3S
Capacity	
Swing over bed	510mm
Swing over carriage	340mm
Admit between centres	420mm
Maximum Turning Length	310mm
Interference free Turning dia	265mm
Maximum Turning Diameter	320mm
Chuck size	210 (8”)mm
Spindle	
Spindle Nose	A2-6
Spindle Inside Taper	MT-7
Hole through Spindle	61mm
Maximum Bar Capacity	51mm
Spindle speed range	3500rpm
Maximum Torque in Spindle	140Nm
Turret	
Number of stations	8
Tool shank size	25x25mm
Maximum Boring bar diameter	40mm
Indexing	Bi-directional
Indexing time (per station)	0.9sec
General	

Machine size (Length x Breadth x Height)	2065x1925x1680
Weight (Approx.)	3500kg
Floor Space required	4.0m^2
Power Supply	
Voltage	AC, 415 ±10% V, 300
Frequency	50 ± 1 Hz
Power	22.2kVA
Accuracy	
Positioning of slides - X Axis	0.005mm
Positioning of slides - Z Axis	0.010mm
Repeatability : X-Axis / A Axis	± 0.002 / ±0.003mm
CNC System	Fanuc 0i- mateTD

3.2 Surface Roughness Measuring Instrument

The Surtronic 3+ is a movable, self-contained for the measurement of surface texture and is appropriate for use in both the workshop and laboratory. Parameters accessible for surface texture evaluation are: Ra, Rq, Rz (DIN), Ry and Sm.

The parameters evaluations and other functions of the instrument are microprocessor based. The measurement results are displaced on an LCD screen and can be output to a voluntary printer or another computer for further results.

The instrument is normally powered by an alkaline non-rechargeable battery. If preferred, a Ni-Cad rechargeable battery can be used [30][31].

Figure: 3.2 Surface roughness measurement apparatus

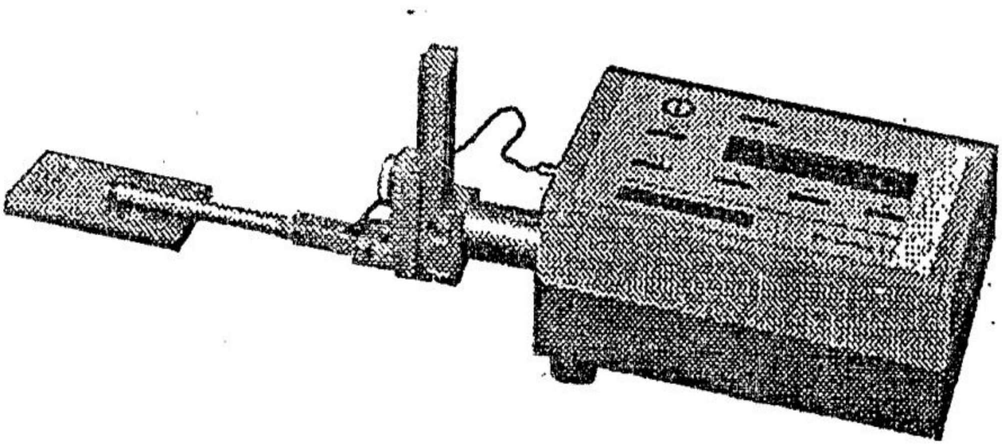


Figure: 3.3 Surface roughness measurement apparatus
(Referred from Instrument Manual)

3.2.1 Display-Transverse Unit

The top panel of the display-traverse unit carries a membrane type control panel and a liquid crystal display. The unit houses the electronics for controlling the measurement sequence, calculating the measurement data and outputting the results to the display, or to the RS232 port for use with a printer (when included) or to a computer for further analysis.

The unit also comprises a drive motor which traverses the pickup across the surface to be measured. The measuring stroke always starts from the extreme outward positions. At the conclusion of the measurement the pickup returns to this position prepared for the next measurement. The traverse length is determined from selections of cut-off (Lc) or length (Ln).

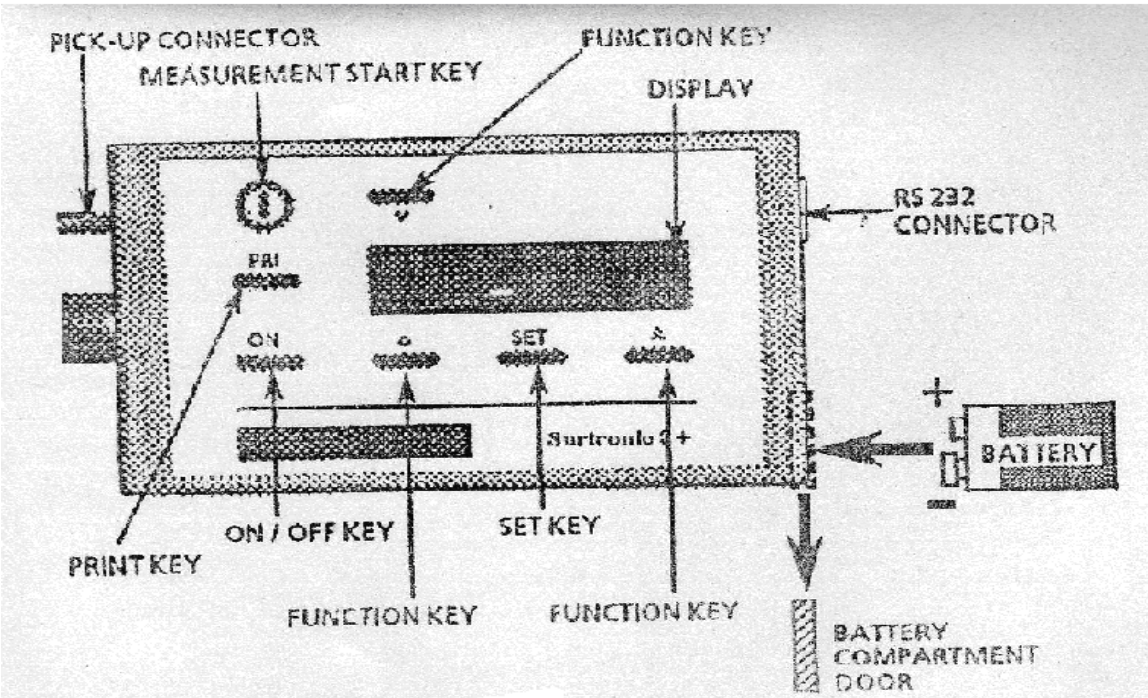


Figure: 3.4 Display Transverse Unit (Referred from Instrument Manual)

3.2.2 Pick-Up Mounting Components

The pick-up is fastened to the drive shaft by the following means.

3.2.3 Mounting Bracket

This is fastened to the drive shaft by means of a knurled knob. Although normally used upright, it can be turned to angle the pick-up or to take it off the centre line. It can also be mounted sideways on the drive shaft, when the right-angle pick-up is in use.

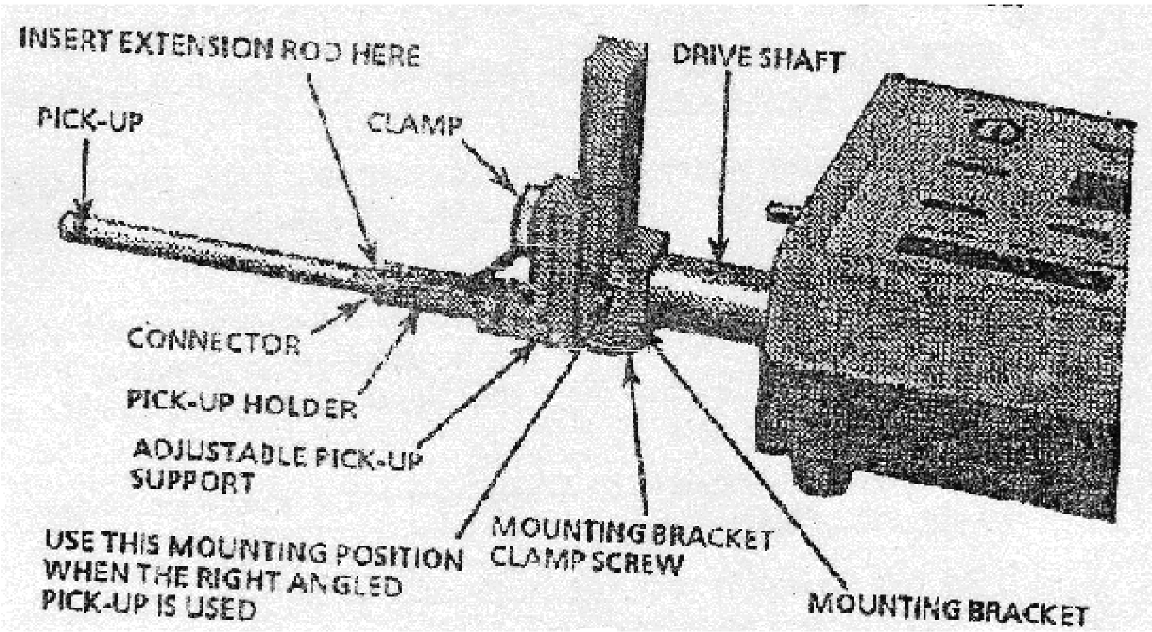


Figure: 3.5 Mounting Bracket (Referred from Instrument Manual)

3.2.4 Adjustable Support

This can be clamped at any positions on the slide of the mounting bracket to provide pick-up height adjustment.

3.2.5 Pick-up Holder

This fits into the crutch of the pick-up support and is held in place by a spring plunger.

3.2.6 Connector

The connector of the pick-up lead is screwed into the end of pick-up and is then inserted into the end of the pick-up holder, with the lead coming out through the slot in the holder. It is advisable to connect the lead to the display-traverse unit first and then to the pick-up. When the extension rod is used, the short pick-up is not required and the end of the rod itself is inserted into the holder.

3.2.7 DIP switch settings

The instrument default settings, when powering up with a new battery, are set via DIP switches housed inside the display-traverse unit. The selections can be altered by menu/pushbuttons operations. The DIP switches are accessed by unscrewing the three feet from the base of the display-traverse unit, then removing the screws which were partly covered by the feet.

3.2.8 Pick-up

The pickup is a variable reluctance type transducer which is supported on the surface to be measured by a skid, a curved support projecting from the underside of the pickup in the vicinity of the stylus. As the pickup traverses across the surface, movements of the stylus relative to the skid are detected and are converted into a proportional electrical signal. The radius of curvature of the skid is much greater than the roughness spacing. This enables it to ride across the surface almost unaffected by the roughness, and provides a datum representing the general form of the surface. Even so, where the waviness is widely spaced it will be necessary to use the pickup with shoe, in conjunction with the 2.5mm (0.1 in) cut-off.

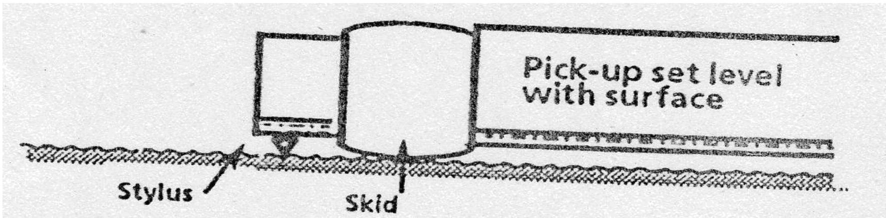


Figure: 3.6 Pick-up (Referred from Instrument Manual)

TABLE 3.2 Surtronic 3+ Specifications

Battery	Alkaline: Minimum 600 Measurements of 4mm Measurements Lengths. Ni-Cad: Minimum 200 Measurement of 4mm Length Size: 6 LR 61 (USA/Japan), Fixed Battery External Charger (Ni-Cad Only) 110/240V, 50/60 Hz
Traverse Unit	Traverse Speed: 1mm/Sec
Measurement	Metric/Inch Preset by DIP-Switch
Cut-Off Values	0.25mm, 0.8mm, and 2.50mm
Traverse Length	1, 3, 5, 10, Or 25.4 + 0.2mm At 0.8mm Cut-Off.
Display	LCD-Matrix. 2lines * 16 Characters
Keyboard	Membrane Switch Panel Tactile
Filters	Digital Gauss Filters or 2CR Filter (ISO) Selectable By DIP-Switch.
Parameters	Ra, Rq, Rz (DIN), Ry and Sm.
Calculations Time	Less Than Reversal Time Or 2 Sec Which Ever Is The Longer.

3.3 Experimental Procedure

Experiment was conducted on a CNC lathe with work piece of 38 mm diameter and 300 mm long mounted between 3-jaw chuck and tailstock. Initially rough turning is done on CNC to remove scaling that is present on the surface of mild steel. The full factorial 27 experiments were conducted according to the Taguchi DOE and surface is measured by using instrument Surtronic 3+. With the help of Minitab software, Taguchi, ANOVA and Regression analysis are applied and results are obtained.

Figure: 3.7 Machined parts

3.3.1 Work piece material

Lathe was available for centering and CNC lathe machine is used for turning the work piece. The chuck holding the work piece was self-centering type. Material was selected to ensure consistency of the alloy, which is a Mild Steel made in the form of bars with the size of diameter 38mm and 300mm length so as to fit under the chuck. To more carefully replicate typical finish turning processes and to evade unnecessary vibrations due to work piece dimensional inaccuracies and defects, each work piece was rough-cut or rough-turning is done just prior to the measured finish cut.

Figure: 3.8 Mild Steel work piece undergoing rough-turning

Taylor Hobson Surtronic 3+ instrument available has a pickup with a skid which is used to travel automatically through a drive motor. Thus such travel would at least require a distance of at least 10 mm. Thus we require appropriate surface travel distance on turned work piece. These dimensions were engaged so as to keep travel the stylus on the best surface as the cutting could improper at the starting or at the end. In this way the error in measurement could also be reduced and there are less chance of measuring the wrong side values.

TABLE 3.3 Chemical Composition of Work Piece

Element	Requirement Specification (As per IS:2062-2006 Gr. E-250 (Fe410W) B)	Weight %
C	0.22 Max	0.2012
Mn	1.5 Max	0.4936
Si	0.40 Max	0.1537
P	0.045 Max	0.0304
S	0.045 Max	0.0323
Cr.		0.1961
Mo		0.0146
Ni		0.0870
Hardness		160 BHN

3.3.2 Cutting Tool Material

Figure: 3.9 Carbide tool material (CNMG 120408-THM-F)

Figure: 3.10 Carbide tool material (CNMG 120408-THM-F)

The cutting tool which is used for the present work was a carbide tip-CNMG 120408-THM-F. The fundamental properties of carbide tools have great hardness over a wide range of temperature ; are very stiff (Young's modulus is nearly three times that of steel); exhibit no plastic flow (yield point) even on experiencing stresses of the order of 33300 kg/cm^2, have low thermal expansion compared with steel ; relatively high thermal conductivity: and a strong tendency to form pressure weld at low cutting speed, these are weak in tension than in compression. Their high hardness at elevated temperature enable them to be used at much faster cutting speed (3 to 4 m/sec with mild steel) superior hot hardness and wear resistance. These can retain cutting hardness upto 700^{o}C and have high wear resistance. The tool used was cemented carbide insert type with tip radius 0.8mm.

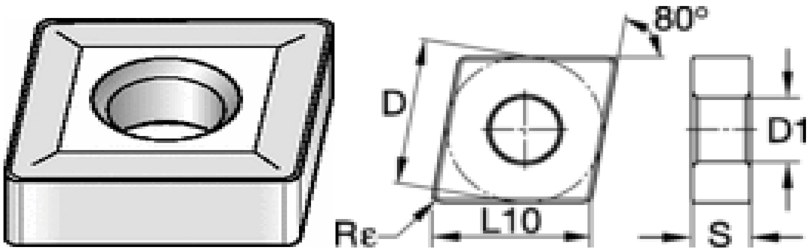


Figure: 3.11 Carbide tool specification

TABLE 3.4 Carbide Tool Specification

ISO catalog number	ANSI catalog number	Grade	D (mm)	L10 (mm)	S (mm)	Rε (mm)	D1 (mm)
CNMG 120408	CNMG432	THM-F	12,70	12,90	4,76	0,8	5,16

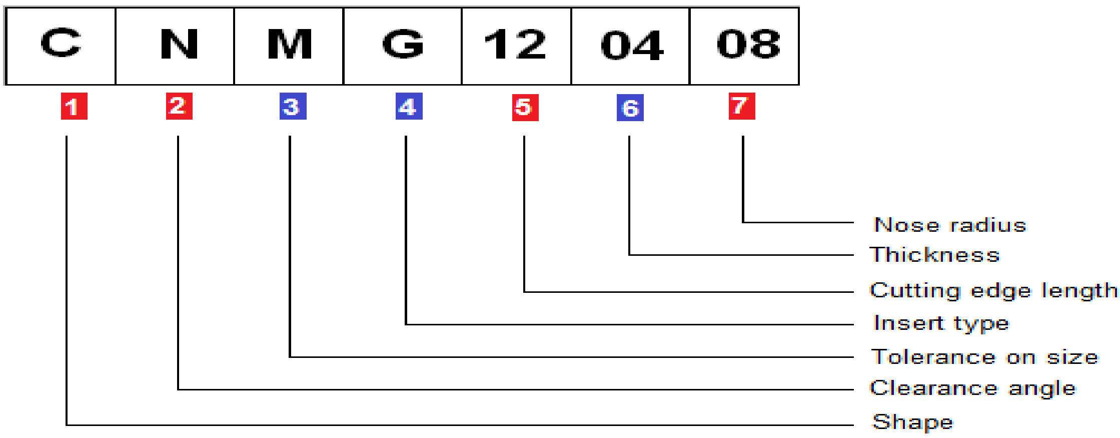


Figure: 3.12 Carbide tool insert-ISO nomenclature

3.4 Measurement of Surface Roughness

Inspection and calculation of SR of machined work pieces can be carried out by means of different measurement techniques. These methods can be ranked into the following classes:

- Direct measurement methods
- Comparison based techniques
- Non-contact methods

3.4.1 Direct Measurement Methods

Direct methods access surface finish by means of stylus type devices. Measurements are achieved using a stylus drawn along the surface to be measured. The stylus motion perpendicular to the surface is registered. This registered profile is then used to compute the roughness parameters. The parameter Ra is used here.

$$R_a = \frac{1}{L}\int_0^L |Y(x)|\,dx,$$

where

R_a = the arithmetic average deviation from the mean line

L= the sampling length

Y= the ordinate of the profile curve

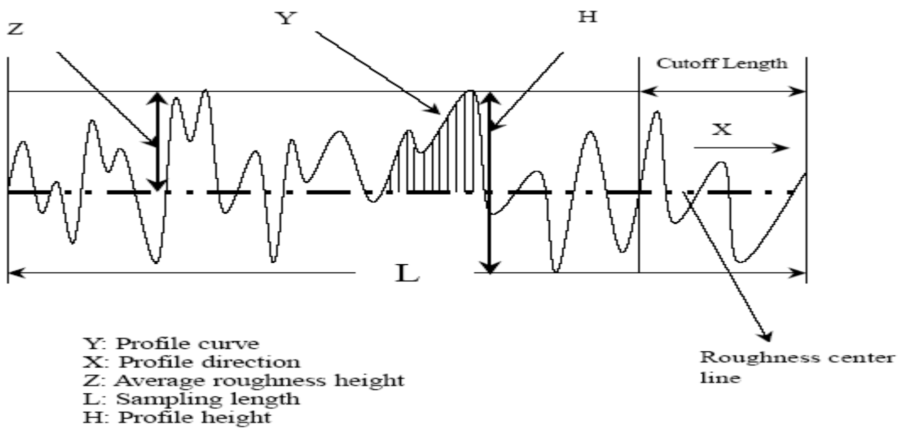


Figure 3.15 Measurement of SR by Stylus [5][32][33]

3.4.2 Comparison Based Techniques

Comparison techniques use specimens of SR produced by the same process, material and machining parameters as the surface to be compared. Visual and tactile senses are used to compare a specimen with a surface of known surface finish. This method is useful for SR Ra>1.6 micron.

3.4.3 Non-Contact Methods

In it a rough surface is brightened by a monochromatic plane wave with an angle of incidence with respect to the normal to the surface. The photo sensor of a camera placed in the focal plane of a fourier lens is used for recording speckle patterns. Then the SR can be defined and calculated. In these experiments direct measurement technique has been used i.e. stylus type SR meter was used to calculate the SR of the specimen. There were two main reasons behind choosing stylus type SR; one is its easy obtainability and other is the ease with which it can be functioned. The instrument used in these experiments is a product of precision devices.

3.5 Factors and their Levels

The factors and their levels have been selected on the basis of tool, work piece material, machine parameters and by studying different research papers and data hand books. Different cutting parameters and their level are shown in table:

TABLE 3.5 Cutting Parameters and their levels

Symbol	**Cutting Parameters**	**Units**	**Level 1**	**Level 2**	**Level 3**
A	**Speed**	m min^{-1}	71.628	95.504	119.380
B	**Feed**	mm rev^{-1}	0.04	0.14	0.24
C	**Depth of Cut**	mm	0.2	0.4	0.6

ANALYSIS OF DATA

As per the experiments done on CNC the following is the Design of Experiment used.

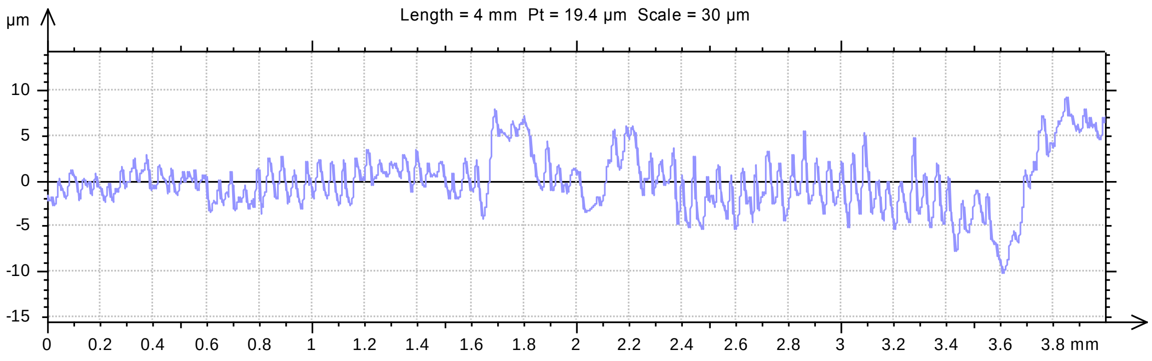
Table 4.1 Experiment conducted as per DOE:

S.No.	Diameter ‘D’ mm	Speed ‘S’ Rpm	m/min	Depth of Cut ‘d’ mm	Feed ‘f’ mm/rev
1	38	600	71.628	0.20	0.04
2	38	600	71.628	0.20	0.14
3	38	600	71.628	0.20	0.24
4	38	600	71.628	0.40	0.04
5	38	600	71.628	0.40	0.14
6	38	600	71.628	0.40	0.24
7	38	600	71.628	0.60	0.04
8	38	600	71.628	0.60	0.14
9	38	600	71.628	0.60	0.24
10	38	800	95.504	0.20	0.04
11	38	800	95.504	0.20	0.14
12	38	800	95.504	0.20	0.24
13	38	800	95.504	0.40	0.04
14	38	800	95.504	0.40	0.14
15	38	800	95.504	0.40	0.24
16	38	800	95.504	0.60	0.04
17	38	800	95.504	0.60	0.14
18	38	800	95.504	0.60	0.24
19	38	1000	119.380	0.20	0.04
20	38	1000	119.380	0.20	0.14
21	38	1000	119.380	0.20	0.24
22	38	1000	119.380	0.40	0.04
23	38	1000	119.380	0.40	0.14
24	38	1000	119.380	0.40	0.24
25	38	1000	119.380	0.60	0.04
26	38	1000	119.380	0.60	0.14
27	38	1000	119.380	0.60	0.24

4.1 Graphical analysis for variable feed at constant speed (600 rpm) and depth of cut (0.2 mm)

4.1.1 S=600 rpm, f=0.04 mm/rev, d=0.2 mm

1. **Profile Curve**

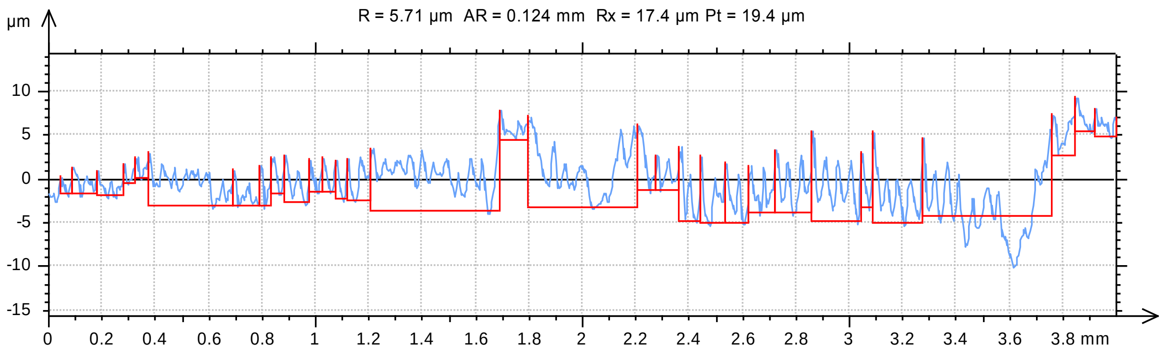


Length of profile= 4 mm

Max. peak to valley height P_t=19.4 µm

Scale of profile=30 µm

2. **Roughness and Waviness Motifs (ISO 12085)**



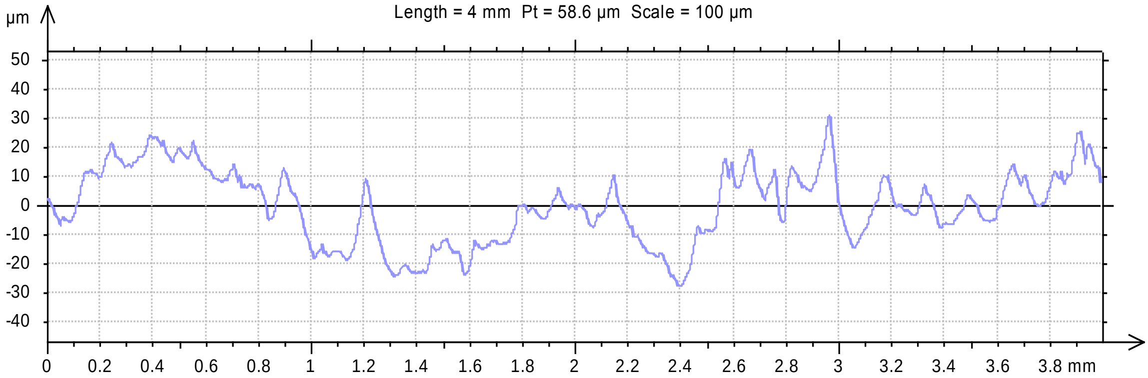
Mean depth of roughness motifs R= 5.71 µm

Mean spacing of roughness motifs AR=124 µm

Max depth of roughness motifs R_x= 17.4 µm

4.1.2 S=600rpm, f=0.14mm/rev, d=0.2mm

1. Profile Curve

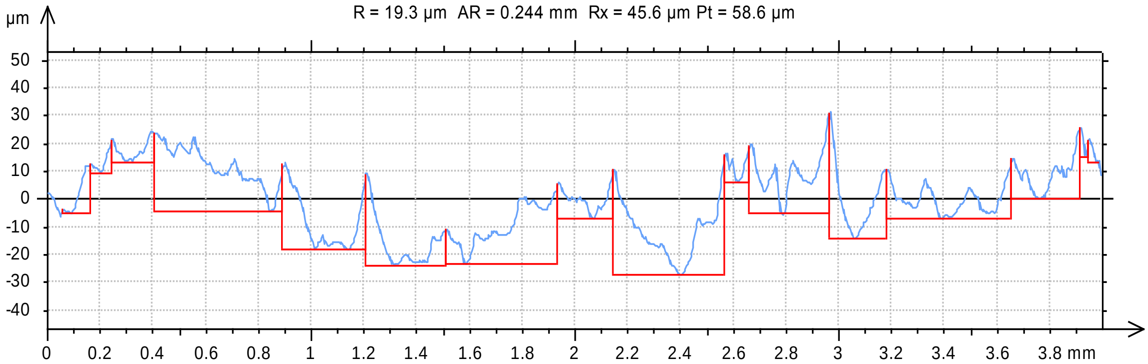


Length of profile= 4mm

Max. peak to valley height P_t=58.6 µm

Scale of profile=100 µm

2. Roughness and Waviness Motifs (ISO 12085)



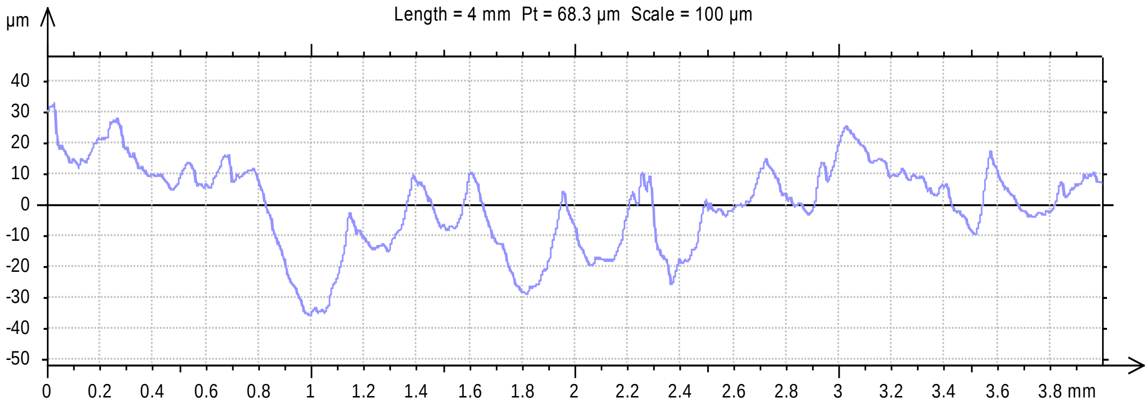
Mean depth of roughness motifs R= 19.3µm

Mean spacing of roughness motifs AR=244 µm

Max. depth of roughness motifs R_x= 45.6 µm

4.1.3 S=600rpm, f=0.24mm/rev, d=0.2mm

1. Profile Curve

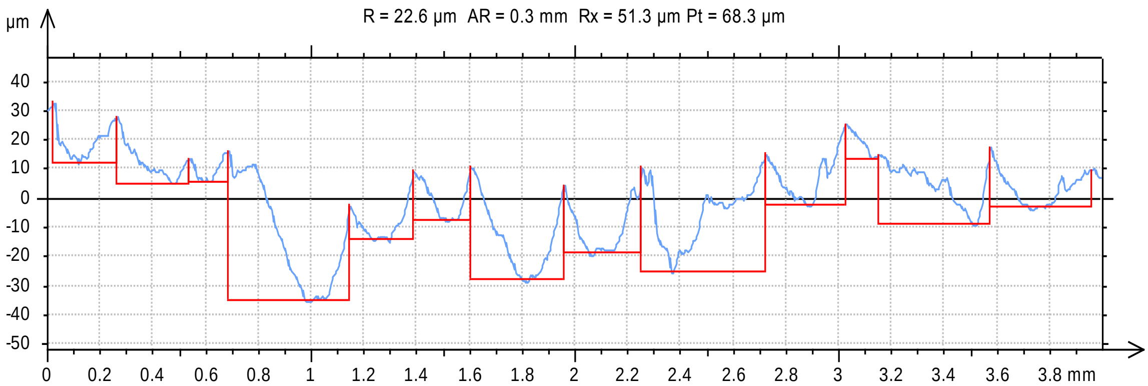


Length of profile= 4mm

Max. peak to valley height P_t=68.3 µm

Scale of profile=100 µm

2. Roughness And Waviness Motifs (ISO 12085)



Mean depth of roughness motifs R= 22.6µm

Mean spacing of roughness motifs AR=300 µm

Max. depth of roughness motifs R_x= 51.3µm

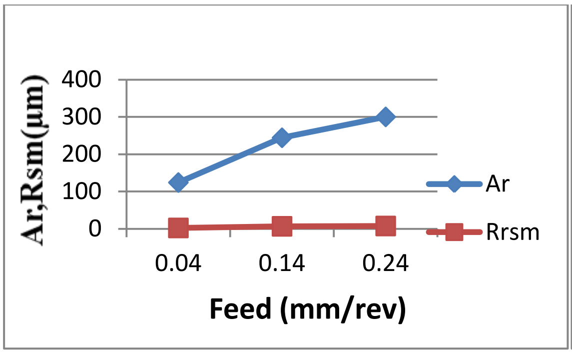


Figure 4.1.1

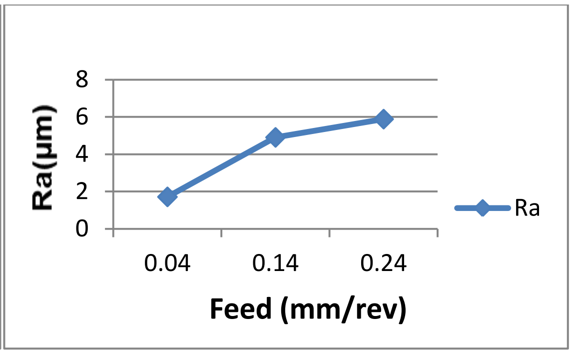


Figure 4.1.2

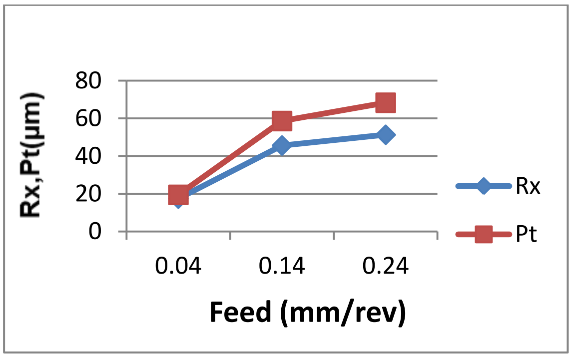


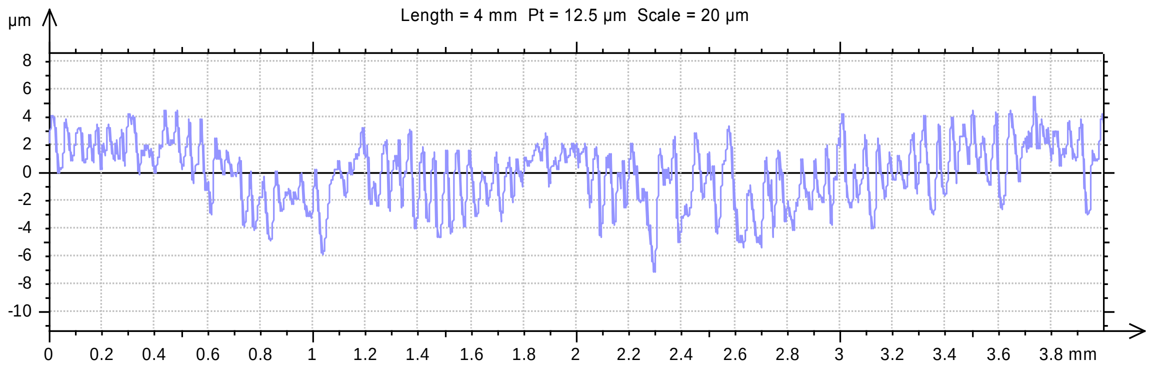
Figure 4.1.3

- From Fig. 4.1.1 it is seen that with increase in feed there is increase in Ar (Mean spacing of roughness) and Rsm (Mean width of profile).
- From fig. 4.1.2 it is seen that with increase in feed there is increase in Ra (Mean roughness parameter).
- From fig. 4.1.3 it is seen that with increase in feed there is increase in both Rx (Mean depth of profile irregularity) and Pt (Max. peak to valley height), it is also seen that incremental in Pt is more than Rx.

4.2 Graphical analysis for variable feed at constant speed (600rpm) and depth of cut (0.40mm)

4.2.1 S=600rpm, f=0.04mm/rev, d=0.40mm

1. **Profile Curve**

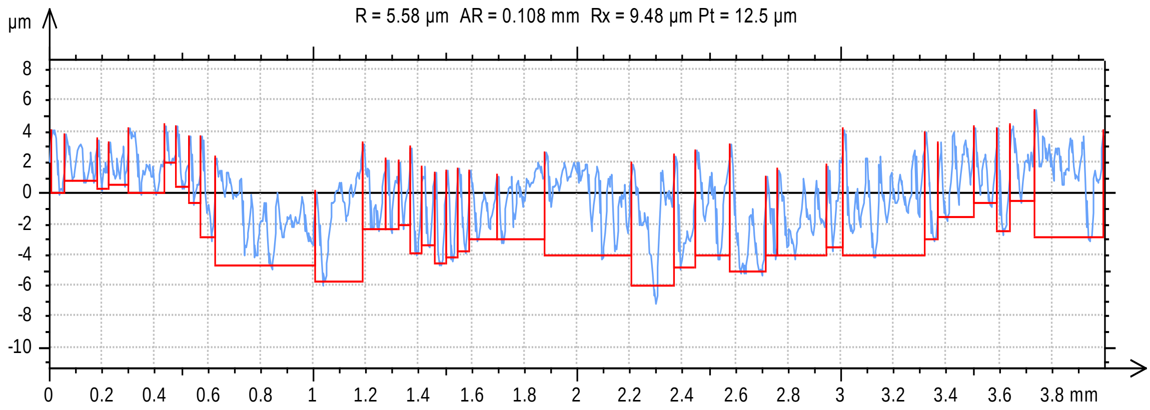


Length of profile= 4mm

Max. peak to valley height P_t=12.5µm

Scale of profile=20µm

2. **Roughness and Waviness Motifs (ISO 12085)**



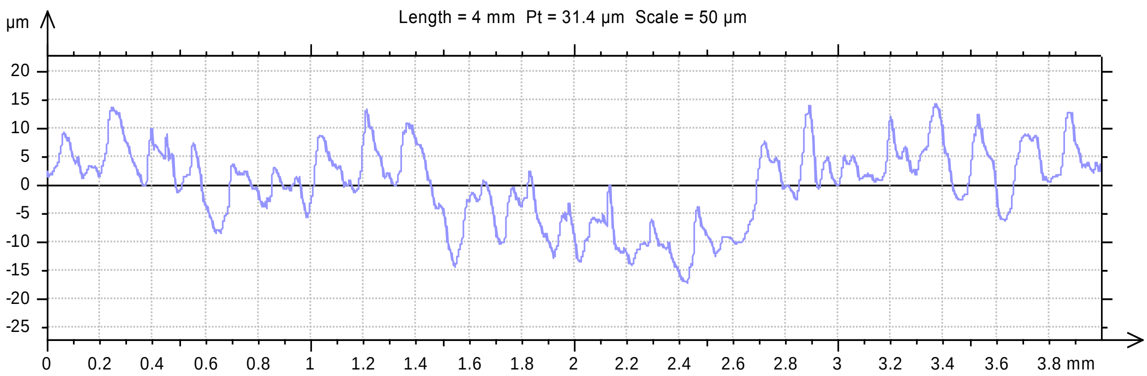
Mean depth of roughness motifs R= 5.58µm

Mean spacing of roughness motifs AR=108µm

Max. depth of roughness motifs R_x= 9.48µm

4.2.2 S=600rpm, f=0.14mm/rev, d=0.40mm

1. Profile Curve

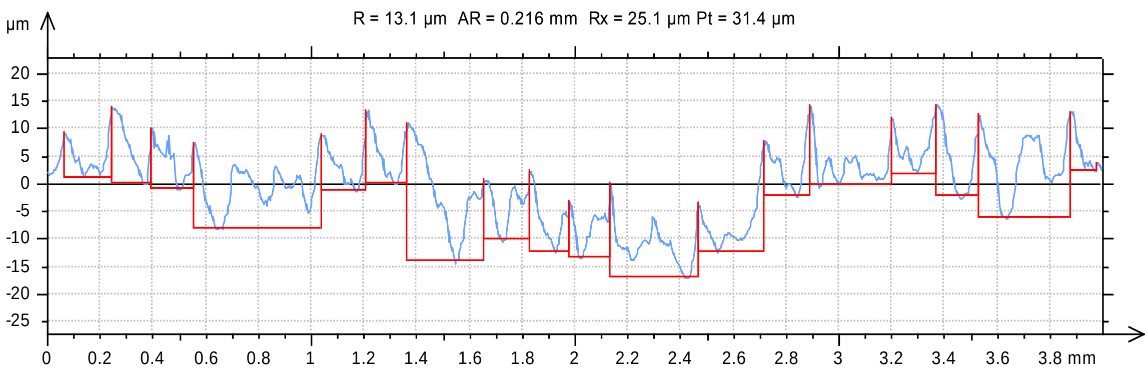


Length of profile= 4mm

Max. peak to valley height P_t=31.4µm

Scale of profile=50µm

2. Roughness and Waviness Motifs (ISO 12085)



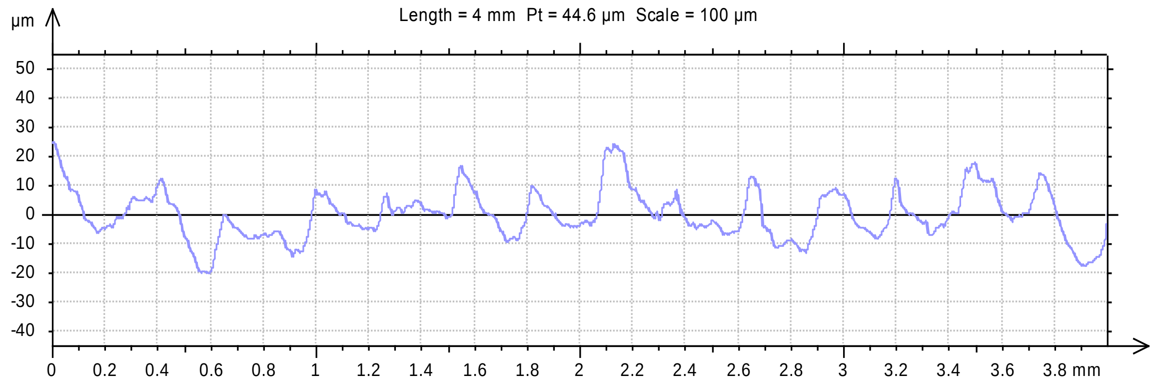
Mean depth of roughness motifs R= 13.1µm

Mean spacing of roughness motifs AR=216µm

Max. depth of roughness motifs R_x= 25.1µm

4.2.3 S=600rpm, f=0.24mm/rev, d=0.40mm

1. **Profile Curve**

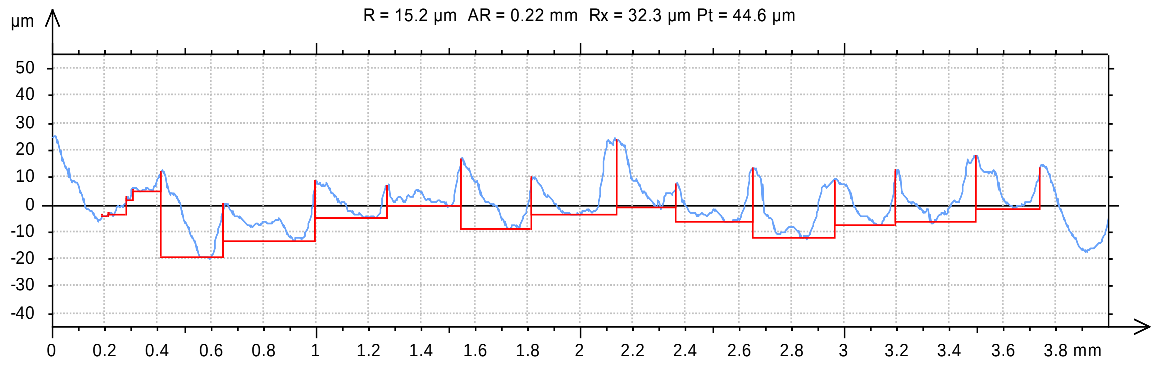


Length of profile= 4mm

Max. peak to valley height P_t=44.6µm

Scale of profile=100µm

2. **Roughness and Waviness Motifs (ISO 12085)**



Mean depth of roughness motifs R= 15.2µm

Mean spacing of roughness motifs AR=220µm

Max. depth of roughness motifs R_x= 32.3µm

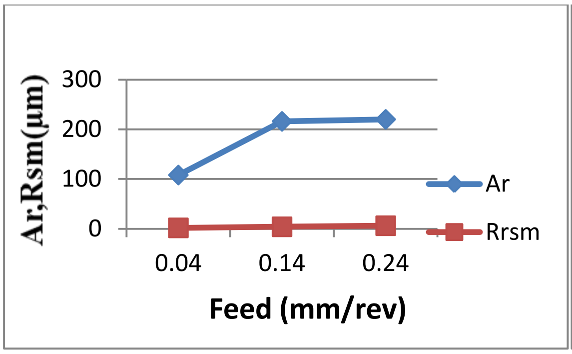


Figure 4.2.1

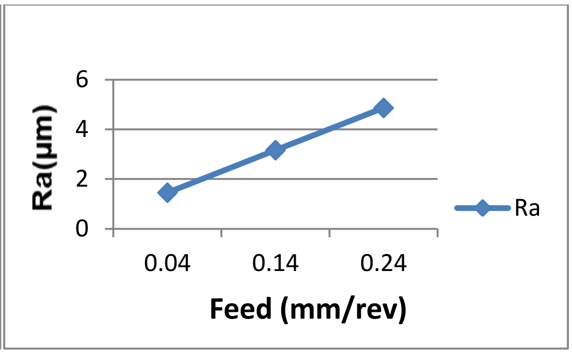


Figure 4.2.2

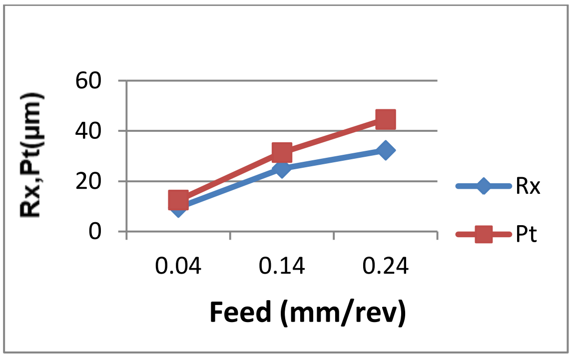


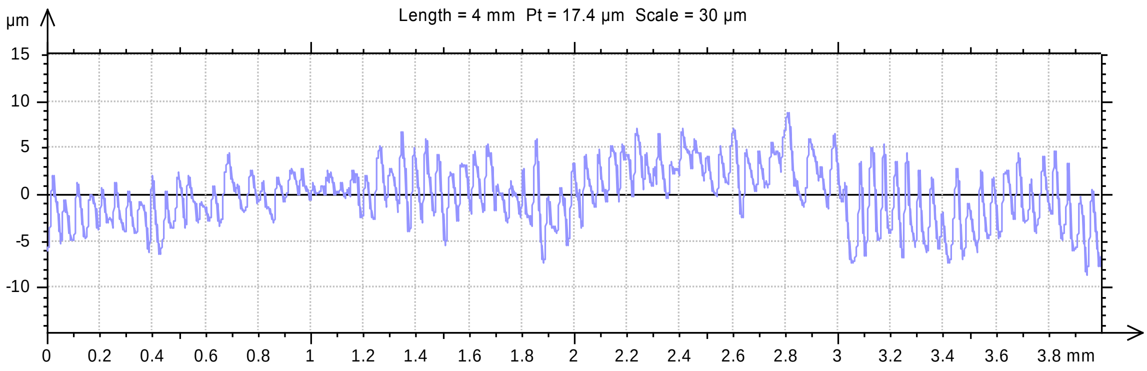
Figure 4.2.3

- From Fig. 4.2.1 it is seen that with increase in feed there is increase in both Ar (Mean spacing of roughness) and Rsm (Mean width of profile).
- From fig. 4.2.2 it is seen that with increase in feed there is increase in Ra (Mean roughness parameter).
- From fig. 4.2.3 it is seen that with increase in feed there is increase in both Rx (Mean depth of profile irregularity) and Pt (Max. peak to valley height), it is also seen that incremental in Pt is more than Rx.

4.3 Graphical analysis for variable feed at constant speed (600rpm) and depth of cut (0.6mm)

4.3.1 S=600rpm, f=0.04mm/rev, d=0.60mm

1. **Profile Curve**

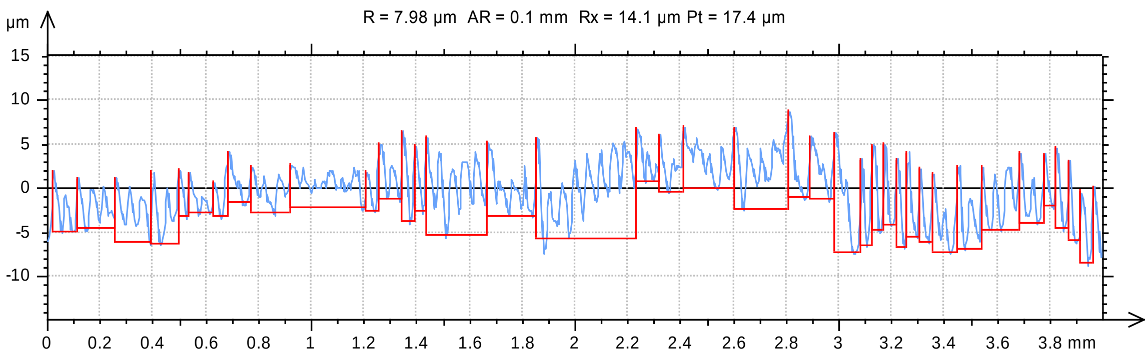


Length of profile= 4mm

Max. peak to valley height P_t=17.4µm

Scale of profile=30µm

2. **Roughness and Waviness Motifs (ISO 12085)**



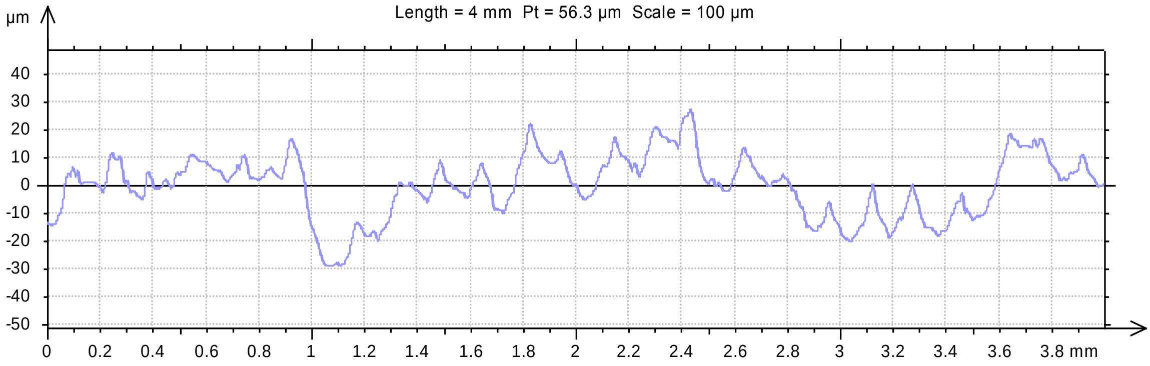
Mean depth of roughness motifs R= 7.98µm

Mean spacing of roughness motifs AR=100µm

Max. depth of roughness motifs R_x= 14.1µm

4.3.2 S=600rpm, f=0.14mm/rev, d=0.60mm

1. Profile Curve

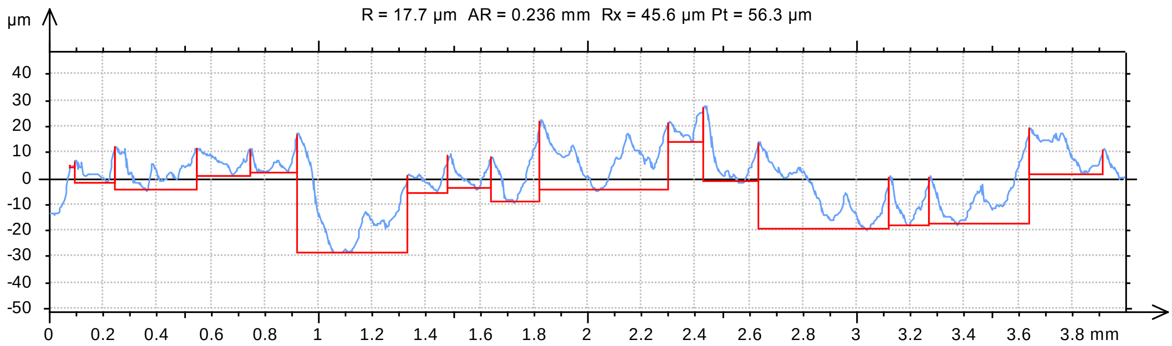


Length of profile= 4mm

Max. peak to valley height P_t=56.3µm

Scale of profile=100µm

2. Roughness and Waviness Motifs (ISO 12085)



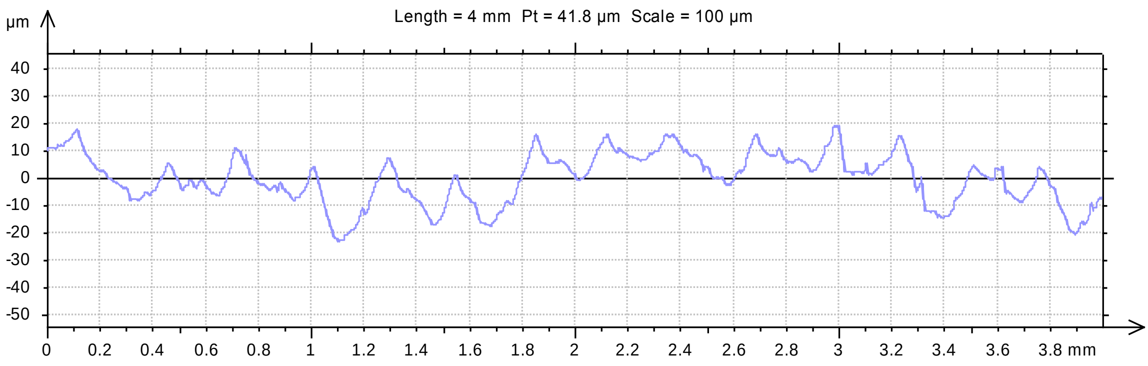
Mean depth of roughness motifs R= 17.7µm

Mean spacing of roughness motifs AR=236µm

Max. depth of roughness motifs R_x= 45.6µm

4.3.3 S=600rpm, f=0.24mm/rev, d=0.60mm

1. Profile Curve

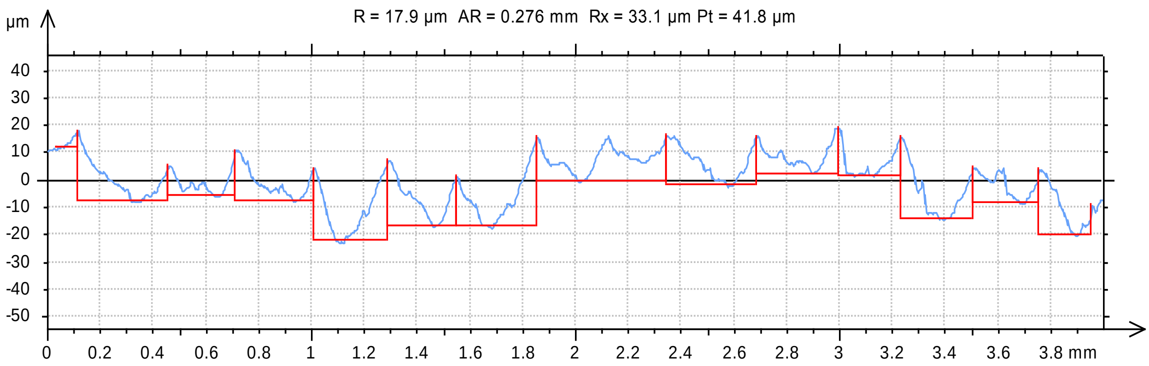


Length of profile= 4mm

Max. peak to valley height P_t=41.8µm

Scale of profile=100µm

2. Roughness and Waviness Motifs (ISO 12085)



Mean depth of roughness motifs R= 17.9µm

Mean spacing of roughness motifs AR=276µm

Max. depth of roughness motifs R_x= 33.1µm

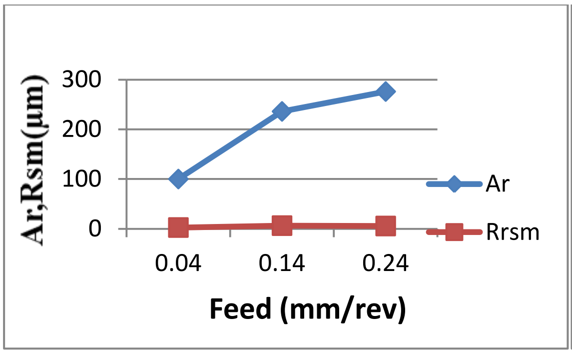


Figure 4.3.1

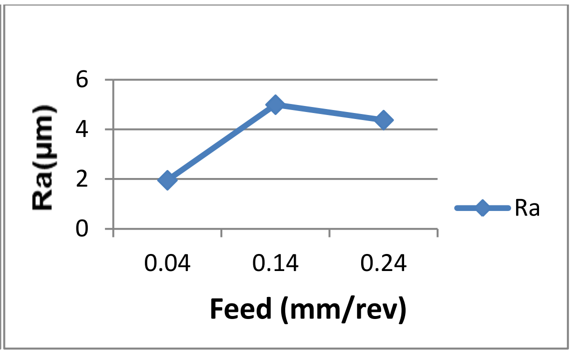


Figure 4.3.2

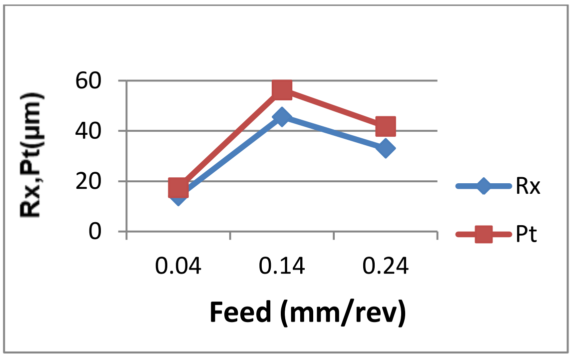


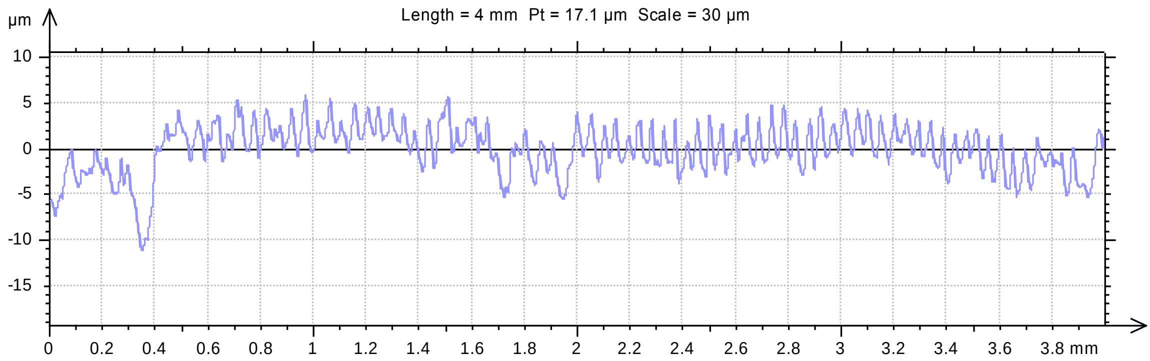
Figure 4.3.3

- From Fig. 4.3.1 it is seen that with increase in feed there is increase in both Ar (Mean spacing of roughness) and Rsm (Mean width of profile).
- From fig. 4.3.2 it is seen that with increase in feed there is increase in Ra (Mean roughness parameter) till 0.14 mm/rev and decreases till 0.24 mm/rev.
- From fig. 4.3.3 it is seen that with increase in feed there is increase in both Rx (Mean depth of profile irregularity) and Pt (Max. peak to valley height) till 0.14 mm/rev and decreases till 0.24 mm/rev, it is also seen that incremental in Pt is more than Rx.

4.4 Graphical analysis for variable feed at constant speed (800rpm) and depth of cut (0.2mm)

4.4.1 S=800rpm, f=0.04mm/rev, d=0.20mm

1. **Profile Curve**

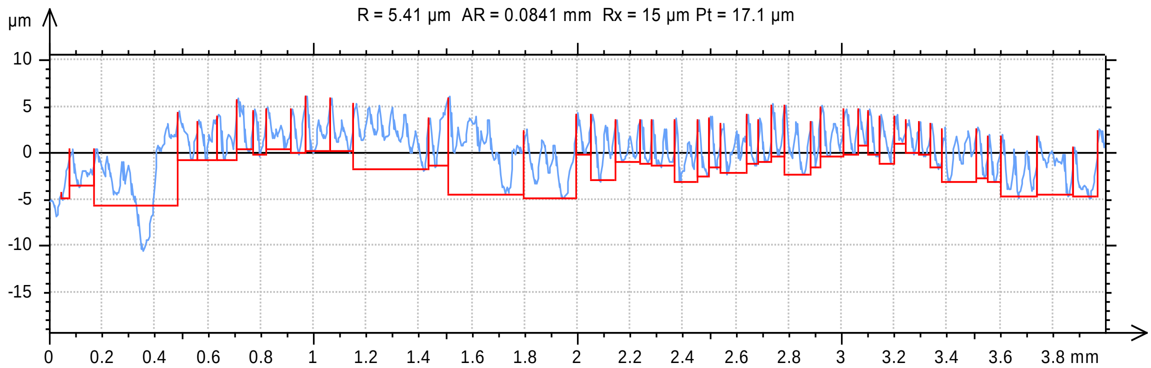


Length of profile= 4mm

Max. peak to valley height P_t=17.1µm

Scale of profile=30µm

2. **Roughness and Waviness Motifs (ISO 12085)**



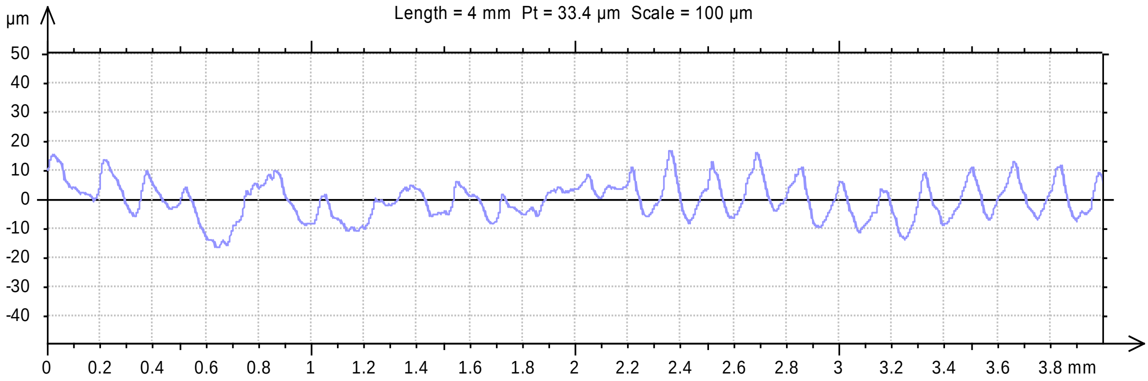
Mean depth of roughness motifs R= 5.41µm

Mean spacing of roughness motifs AR=83.1µm

Max. depth of roughness motifs R_x= 15µm

4.4.2 S=800rpm, f=0.14mm/rev, d=0.20mm

1. **Profile Curve**

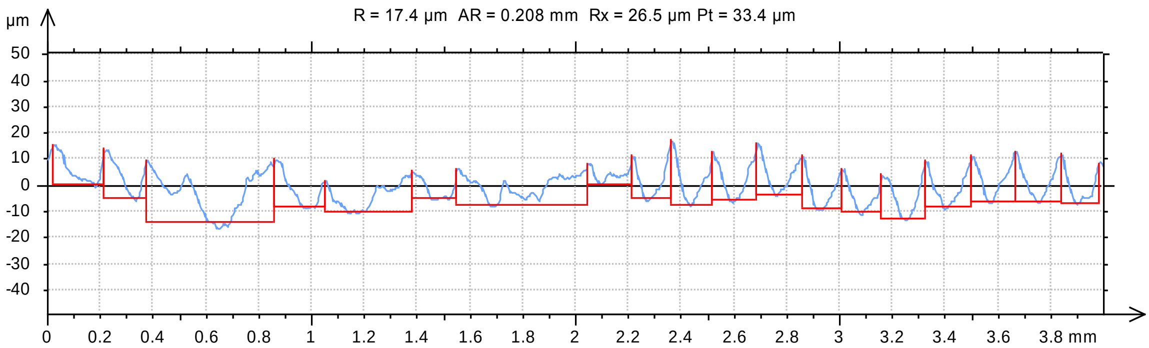


Length of profile= 4mm

Max. peak to valley height P_t=33.4µm

Scale of profile=100µm

2. **Roughness and Waviness Motifs (ISO 12085)**



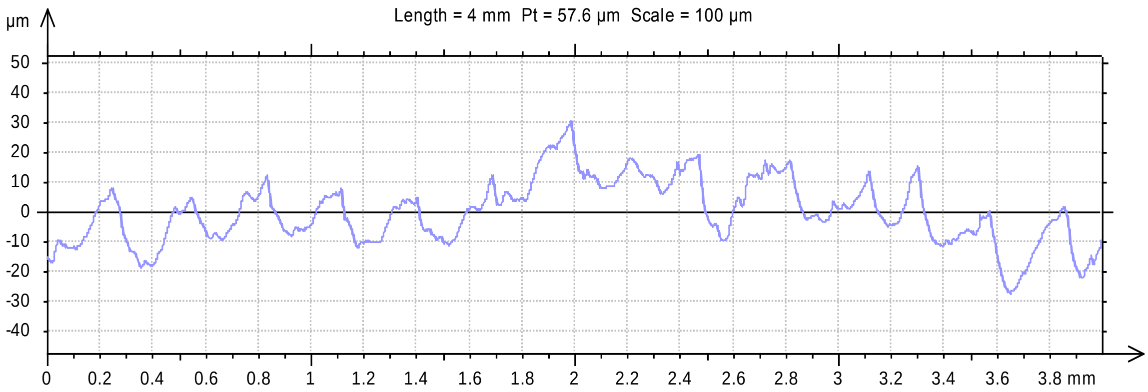
Mean depth of roughness motifs R= 17.4µm

Mean spacing of roughness motifs AR=208µm

Max. depth of roughness motifs R_x= 26.5µm

4.4.3 S=800rpm, f=0.24mm/rev, d=0.20mm

1. Profile Curve

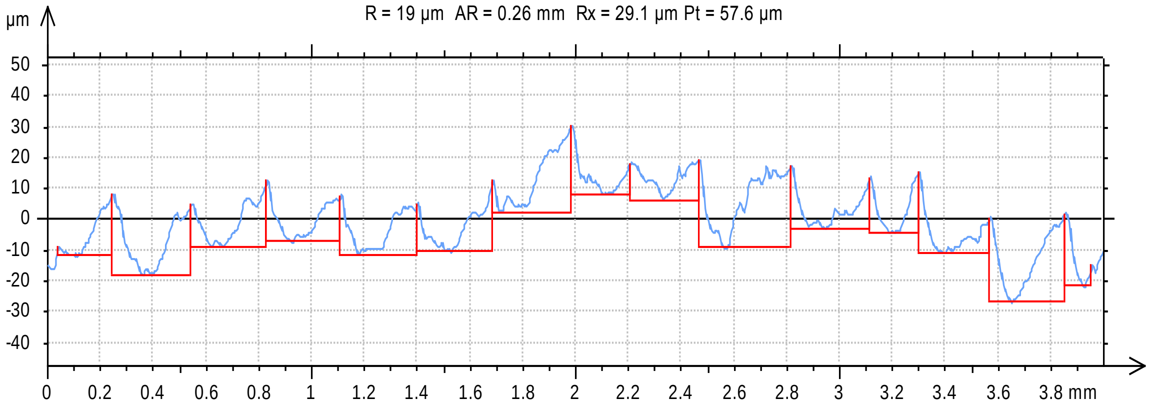


Length of profile= 4mm

Max. peak to valley height P_t=57.6µm

Scale of profile=100µm

2. Roughness and Waviness Motifs (ISO 12085)



Mean depth of roughness motifs R= 19µm

Mean spacing of roughness motifs AR=260µm

Max. depth of roughness motifs R_x= 29.1µm

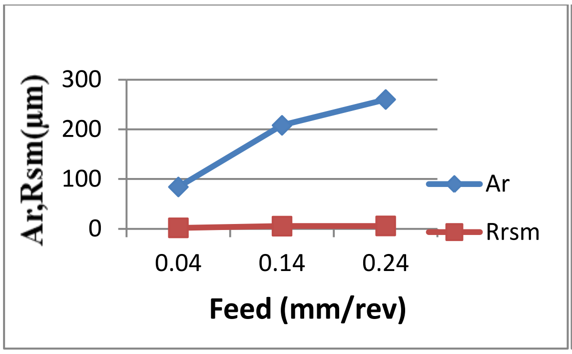


Figure 4.4.1

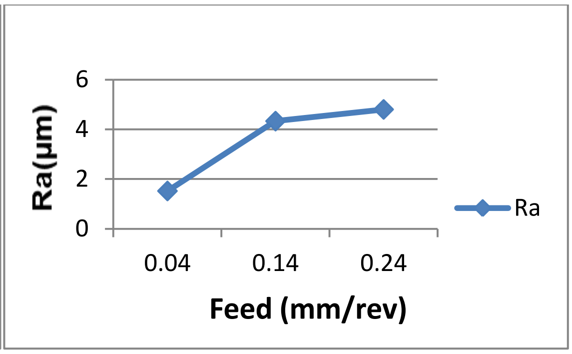


Figure 4.4.2

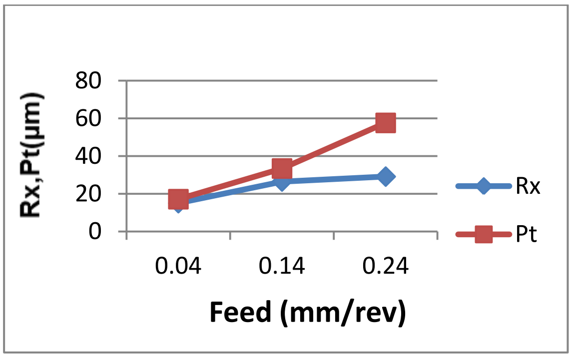


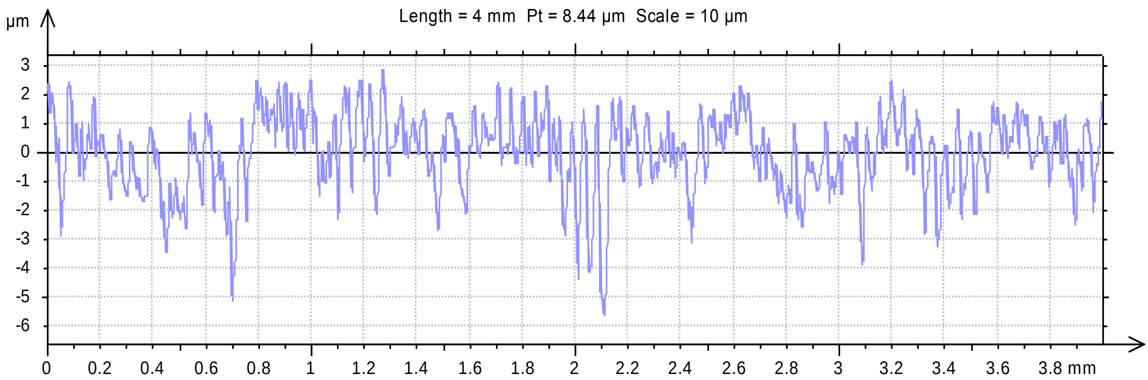
Figure 4.4.3

- From Fig. 4.4.1 it is seen that with increase in feed there is increase in both Ar (Mean spacing of roughness) and Rsm (Mean width of profile).
- From Fig. 4.4.2 it is seen that with increase in feed there is increase in Ra (Mean roughness parameter).
- From Fig. 4.4.3 it is seen that with increase in feed there is increase in both Rx (Mean depth of profile irregularity) and Pt (Max. peak to valley height), it is also seen that incremental in Pt is more than Rx.

4.5 Graphical analysis for variable feed at constant speed (800rpm) and depth of cut (0.40mm)

4.5.1 S=800rpm, f=0.04mm/rev, d=0.40mm

1. **Profile Curve**

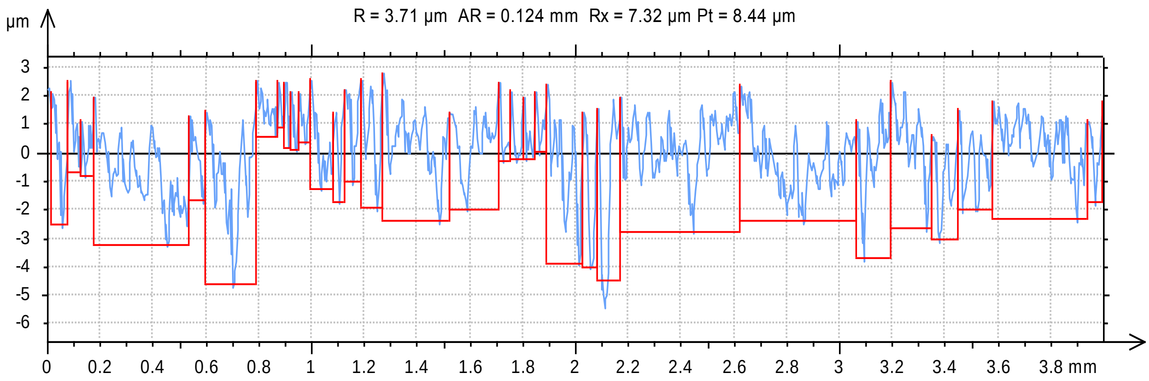


Length of profile= 4mm

Max. peak to valley height P_t=8.44µm

Scale of profile=10µm

2. **Roughness and Waviness Motifs (ISO 12085)**



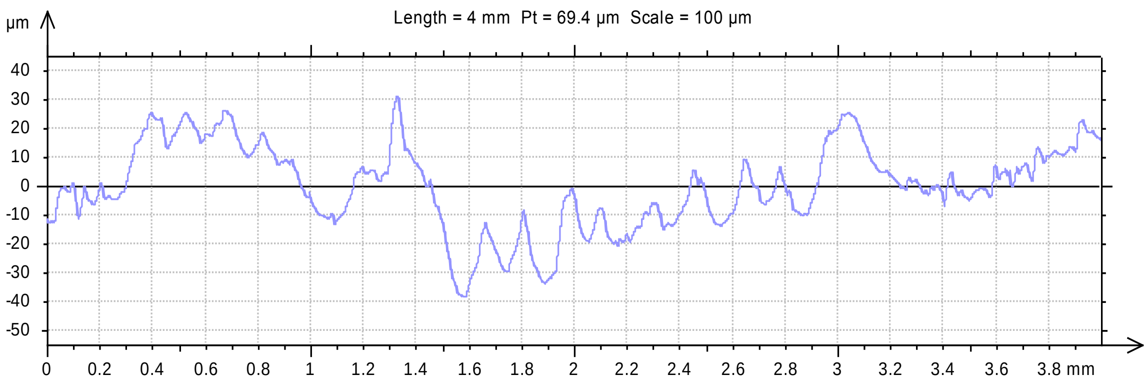
Mean depth of roughness motifs R=3.71µm

Mean spacing of roughness motifs AR=124µm

Max. depth of roughness motifs R_x= 7.32µm

4.5.2 S=800rpm, f=0.14mm/rev, d=0.40mm

1. Profile Curve

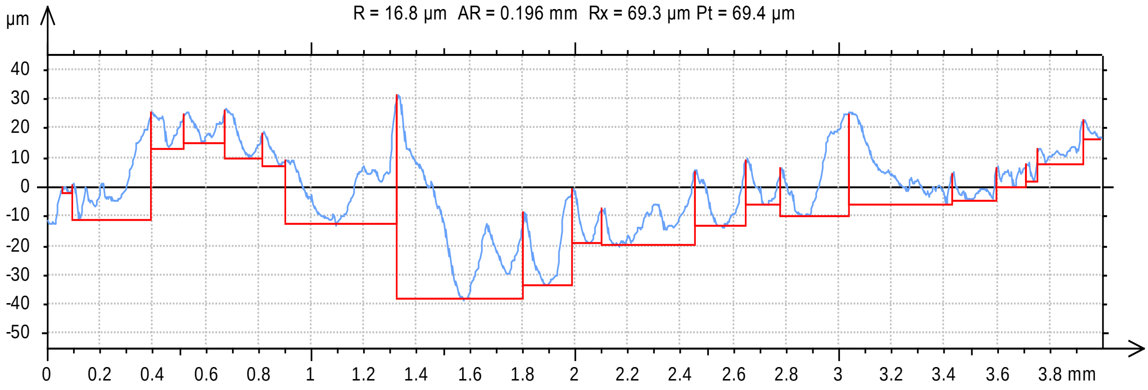


Length of profile= 4mm

Max. peak to valley height P_t=69.4µm

Scale of profile=100µm

2. Roughness and Waviness Motifs (ISO 12085)



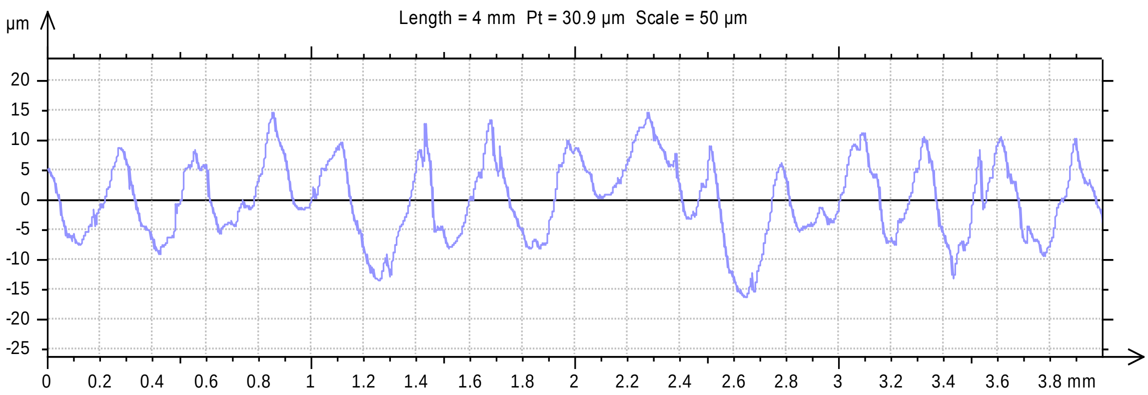
Mean depth of roughness motifs R= 16.8µm

Mean spacing of roughness motifs AR=196µm

Max. depth of roughness motifs R_x= 69.3µm

4.5.3 S=800rpm, f=0.24mm/rev, d=0.40mm

1. Profile Curve

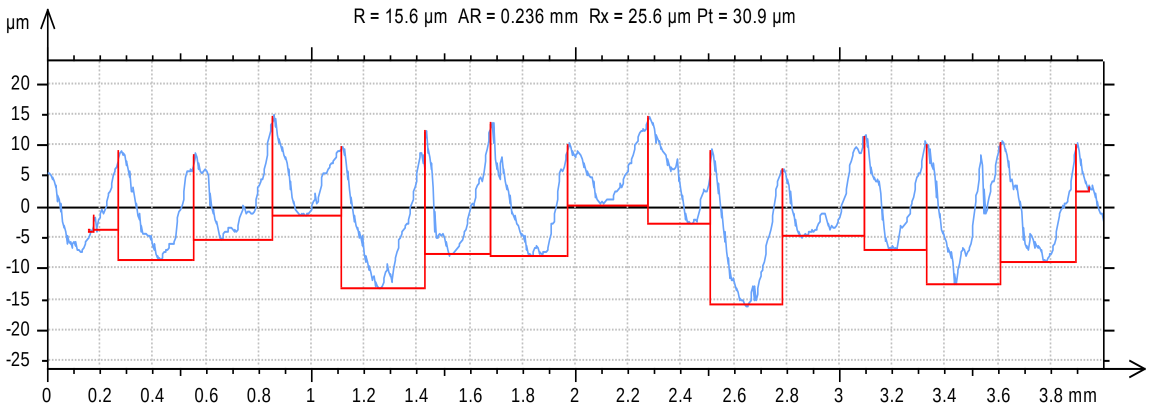


Length of profile= 4mm

Max. peak to valley height P_t=30.9µm

Scale of profile=50µm

2. Roughness and Waviness Motifs (ISO 12085)



Mean depth of roughness motifs R= 15.6µm

Mean spacing of roughness motifs AR=236µm

Max. depth of roughness motifs R_x= 25.6µm

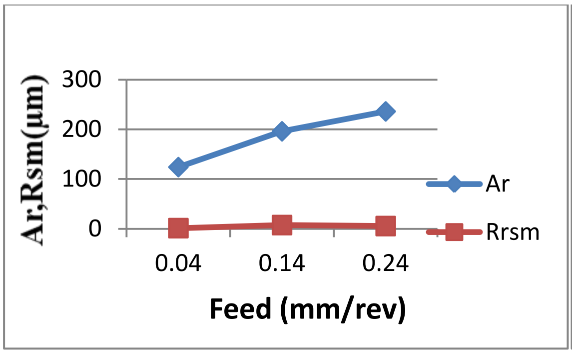


Figure 4.5.1

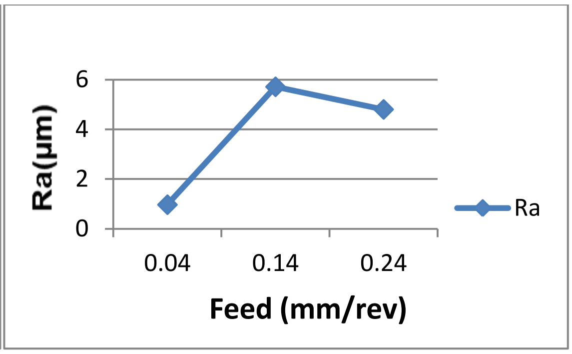


Figure 4.5.2

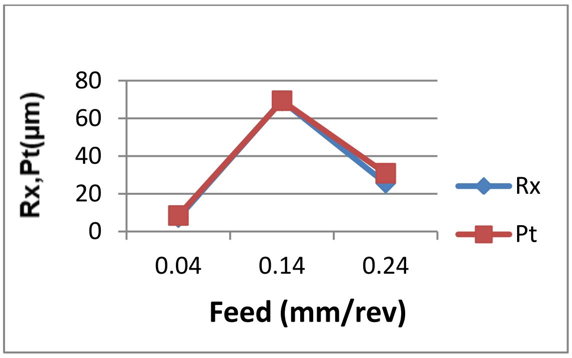


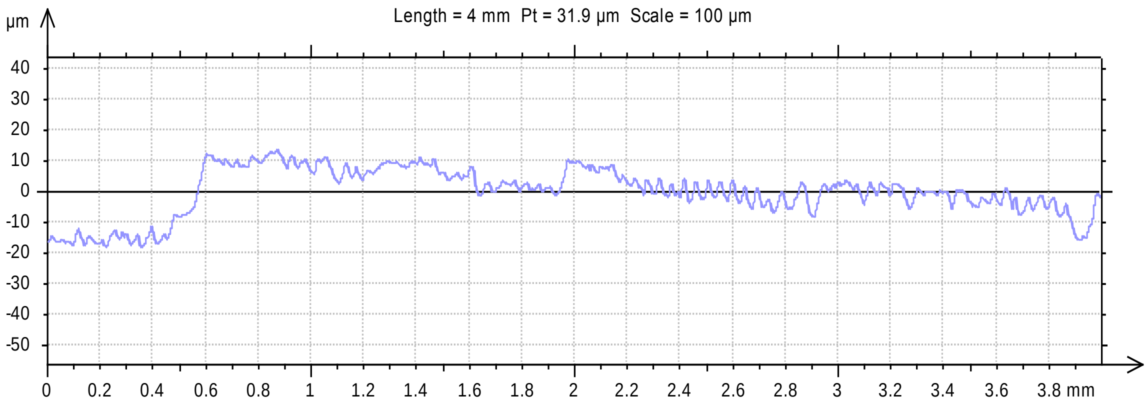
Figure 4.5.3

- From Fig. 4.5.1 it is seen that with increase in feed there is increase in both Ar (Mean spacing of roughness) and Rsm (Mean width of profile).
- From fig. 4.5.2 it is seen that with increase in feed there is increase in Ra (Mean roughness parameter) till 0.14 mm/rev and decreases till 0.24 mm/rev.
- From fig. 4.5.3 it is seen that with increase in feed there is increase in both Rx (Mean depth of profile irregularity) and Pt (Max. peak to valley height) till 0.14 mm/rev and decreases till 0.24 mm/rev, it is also seen that incremental in Pt is more than Rx.

4.6 Graphical analysis for variable feed at constant speed (800rpm) and depth of cut (0.60mm)

4.6.1 S=800rpm, f=0.04mm/rev, d=0.60mm

1. **Profile Curve**

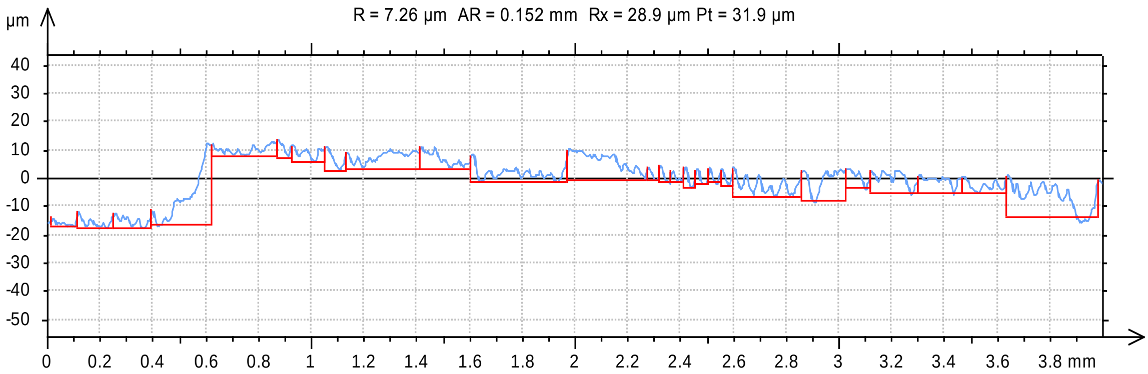


Length of profile= 4mm

Max. peak to valley height P_t=31.9µm

Scale of profile=100µm

2. **Roughness and Waviness Motifs (ISO 12085)**



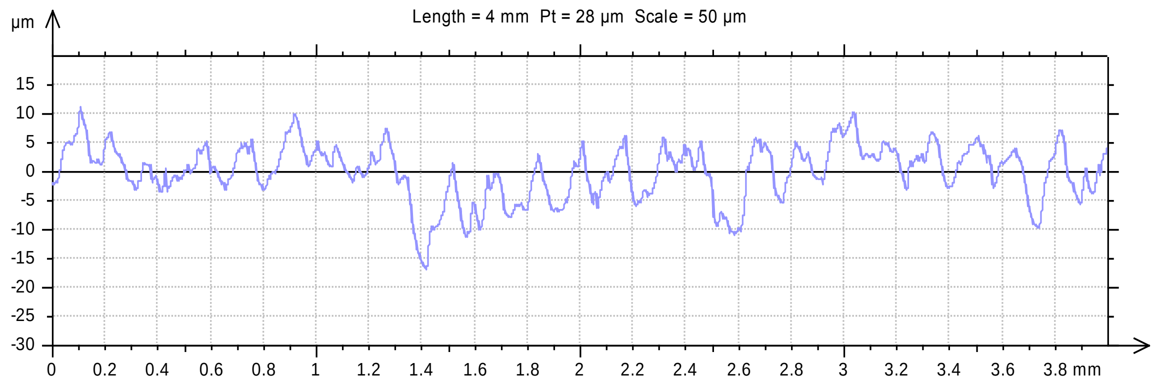
Mean depth of roughness motifs R= 7.26µm

Mean spacing of roughness motifs AR=152µm

Max. depth of roughness motifs R_x= 28.9µm

4.6.2 S=800rpm, f=0.14mm/rev, d=0.60mm

1. Profile Curve

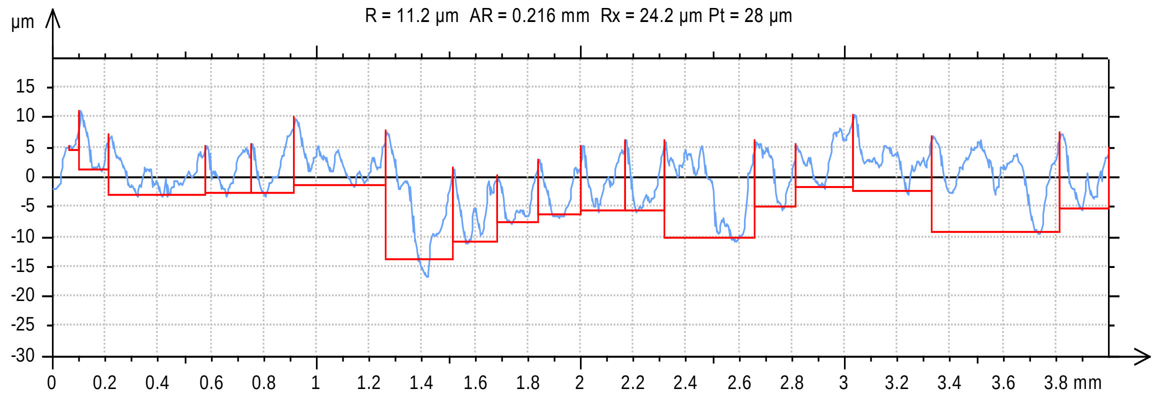


Length of profile= 4mm

Max. peak to valley height P_t=28µm

Scale of profile=50µm

2. Roughness and Waviness Motifs (ISO 12085)



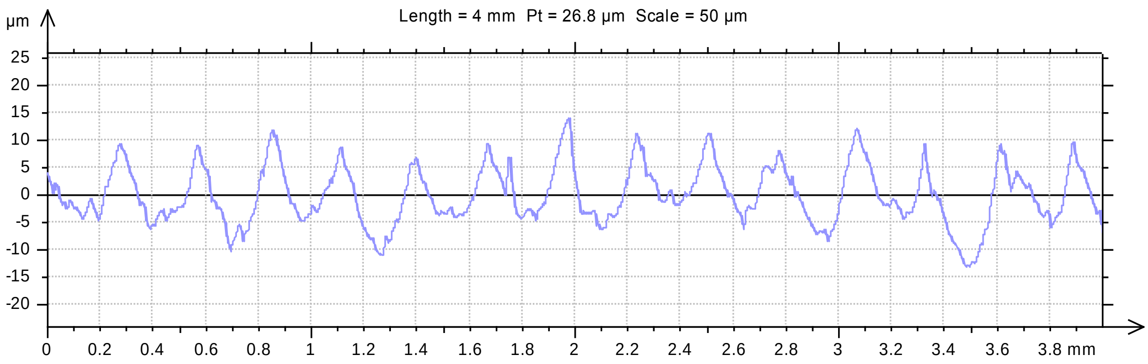
Mean depth of roughness motifs R= 11.2µm

Mean spacing of roughness motifs AR=216µm

Max. depth of roughness motifs R_x= 24.2µm

4.6.3 S=800rpm, f=0.24mm/rev, d=0.60mm

1. Profile Curve

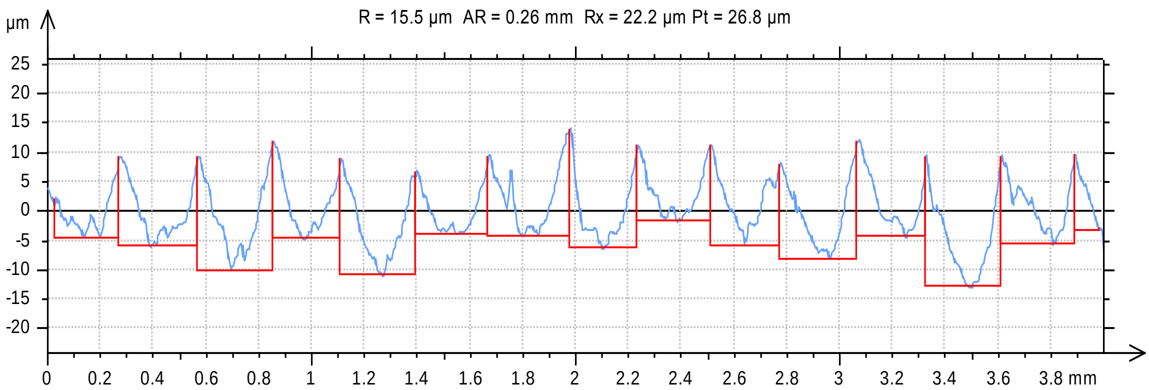


Length of profile= 4mm

Max. peak to valley height P_t=26.8µm

Scale of profile=50µm

2. Roughness and Waviness Motifs (ISO 12085)



Mean depth of roughness motifs R= 15.5µm

Mean spacing of roughness motifs AR=260µm

Max. depth of roughness motifs R_x= 22.2µm

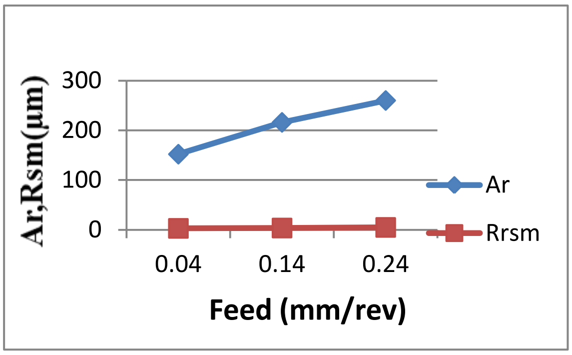


Figure 4.6.1

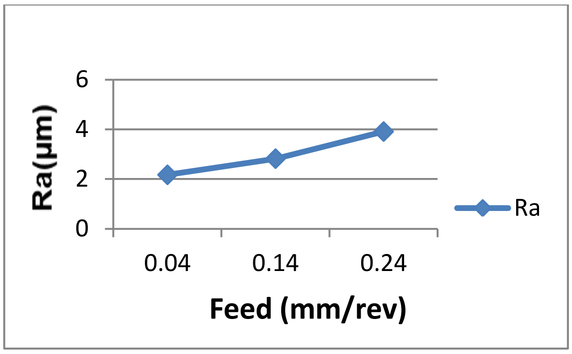


Figure 4.6.2

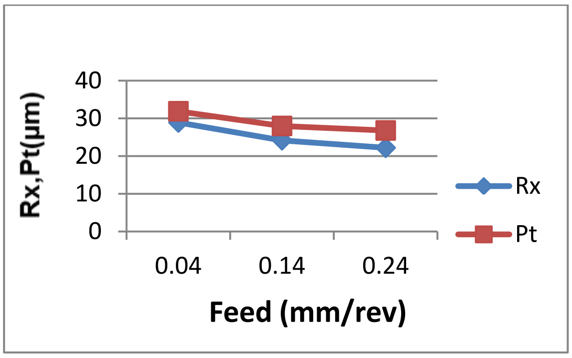


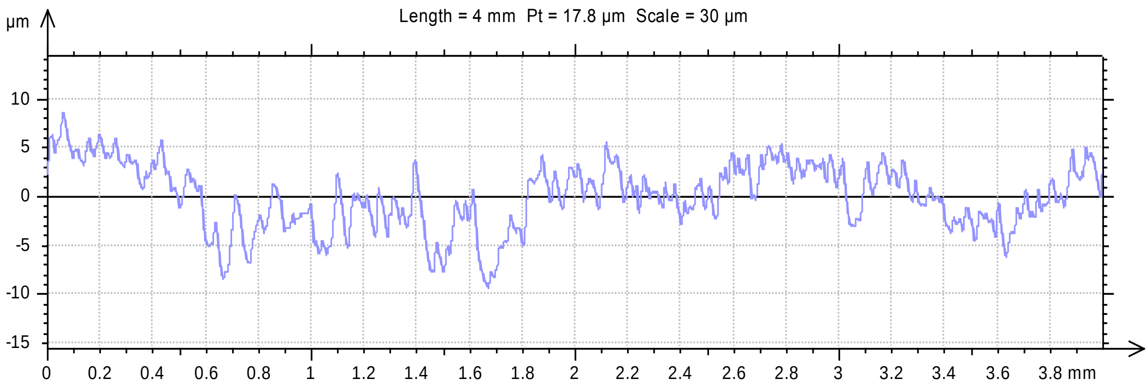
Figure 4.6.3

- From Fig. 4.6.1 it is seen that with increase in feed there is increase in both Ar (Mean spacing of roughness) and Rsm (Mean width of profile).
- From Fig. 4.6.2 it is seen that with increase in feed there is increase in Ra (Mean roughness parameter).
- From Fig. 4.6.3 it is seen that with increase in feed there is decrease in both Rx (Mean depth of profile irregularity) and Pt (Max. peak to valley height), it is also seen that incremental in Pt is more than Rx.

4.7 Graphical analysis for variable feed at constant speed (1000rpm) and depth of cut (0.2mm)

4.7.1 S=1000rpm, f=0.04mm/rev, d=0.20mm

1. **Profile Curve**

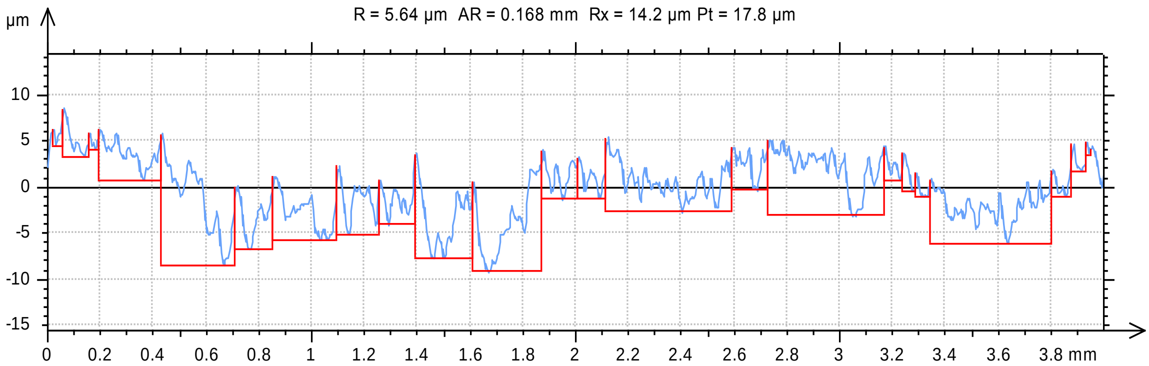


Length of profile= 4mm

Max. peak to valley height P_t=17.8µm

Scale of profile=30µm

2. **Roughness and Waviness Motifs (ISO 12085)**



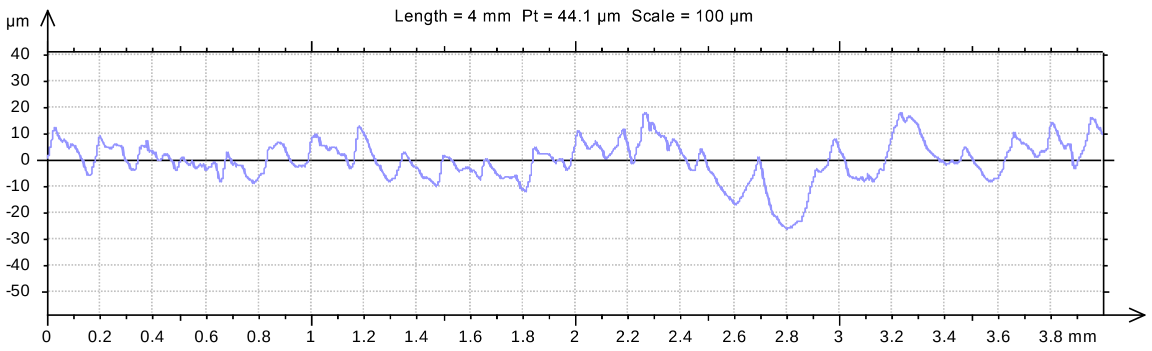
Mean depth of roughness motifs R= 5.64µm

Mean spacing of roughness motifs AR=168µm

Max. depth of roughness motifs R_x= 14.2µm

4.7.2 S=1000rpm, f=0.14mm/rev, d=0.20mm

1. **Profile Curve**

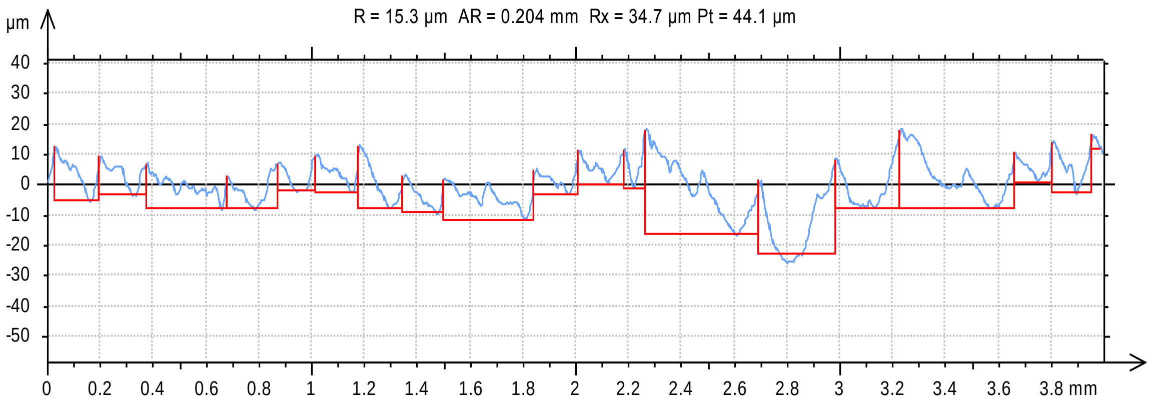


Length of profile= 4mm

Max. peak to valley height P_t=44.1µm

Scale of profile=100µm

2. **Roughness and Waviness Motifs (ISO 12085)**



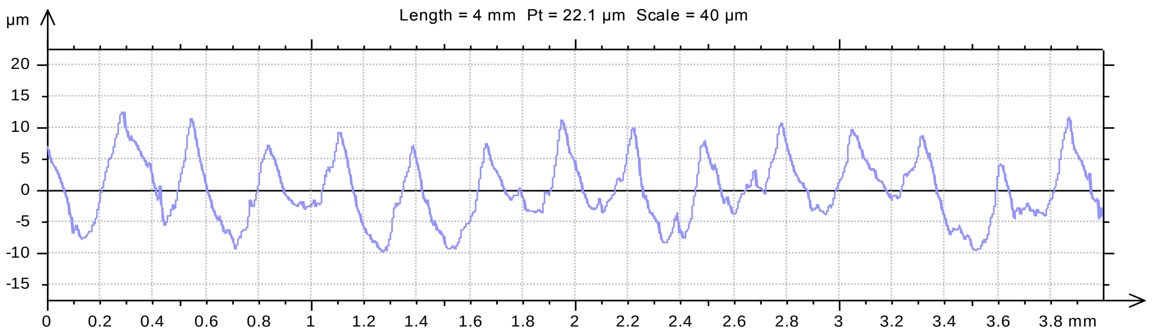
Mean depth of roughness motifs R= 15.3µm

Mean spacing of roughness motifs AR=204µm

Max. depth of roughness motifs R_x= 34.7µm

4.7.3 S=1000rpm, f=0.24mm/rev, d=0.20mm

1. **Profile Curve**

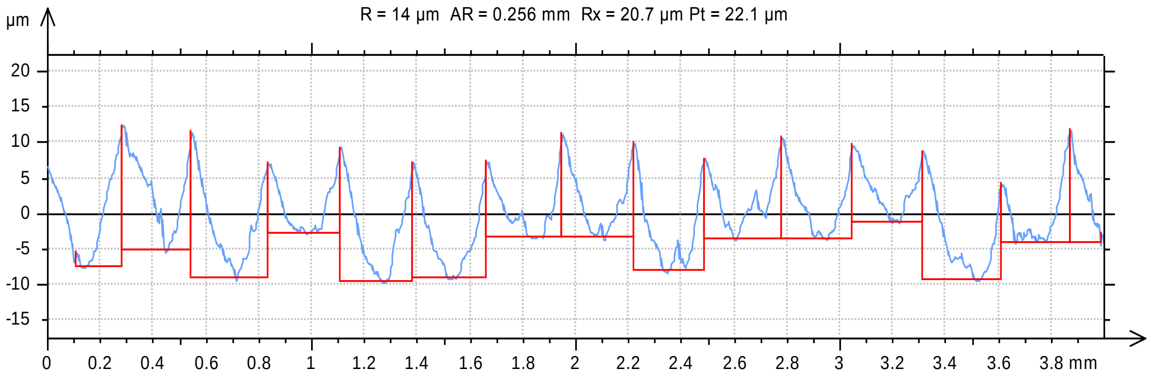


Length of profile= 4mm

Max. peak to valley height P_t=22.1µm

Scale of profile=40µm

2. **Roughness and Waviness Motifs (ISO 12085)**



Mean depth of roughness motifs R=14µm

Mean spacing of roughness motifs AR=256µm

Max. depth of roughness motifs R_x= 20.7µm

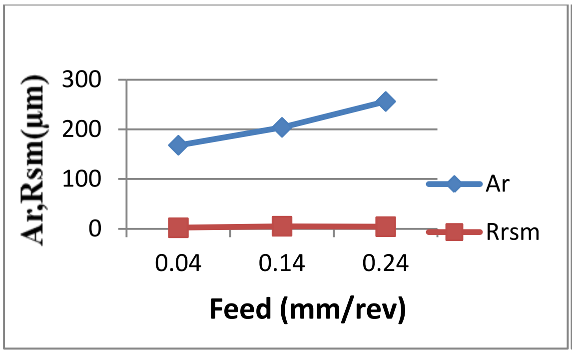


Figure 4.7.1

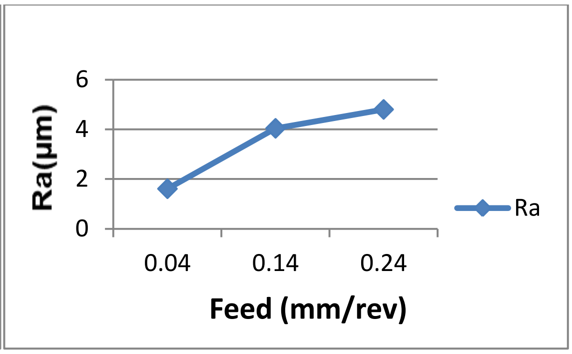


Figure 4.7.2

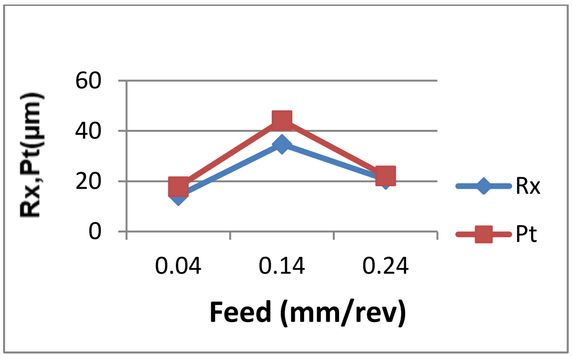


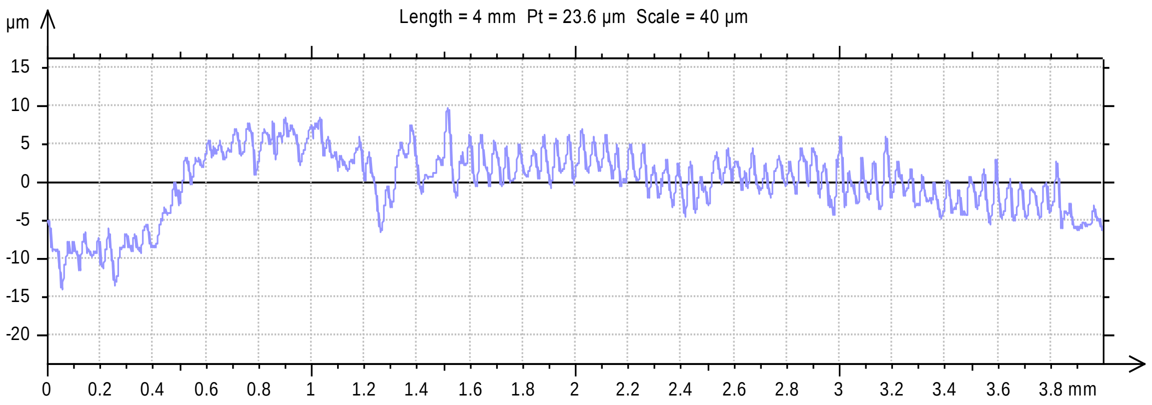
Figure 4.7.3

- From Fig. 4.7.1 it is seen that with increase in feed there is increase in both Ar (Mean spacing of roughness) and Rsm (Mean width of profile).
- From Fig. 4.7.2 it is seen that with increase in feed there is increase in Ra (Mean roughness parameter).
- From Fig. 4.7.3 it is seen that with increase in feed there is increase in both Rx (Mean depth of profile irregularity) and Pt (Max. peak to valley height) till 0.14 mm/rev and decreases till 0.24 mm/rev, it is also seen that incremental in Pt is more than Rx.

4.8 Graphical analysis for variable feed at constant speed (1000rpm) and depth of cut (0.40mm)

4.8.1 S=1000rpm, f=0.04mm/rev, d=0.40mm

1. **Profile Curve**

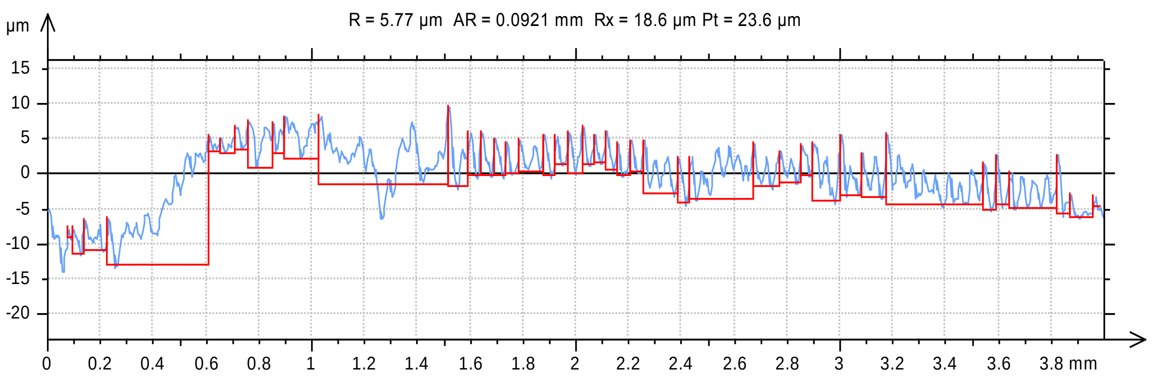


Length of profile= 4mm

Max. peak to valley height P_t=23.6µm

Scale of profile=40µm

2. **Roughness and Waviness Motifs (ISO 12085)**



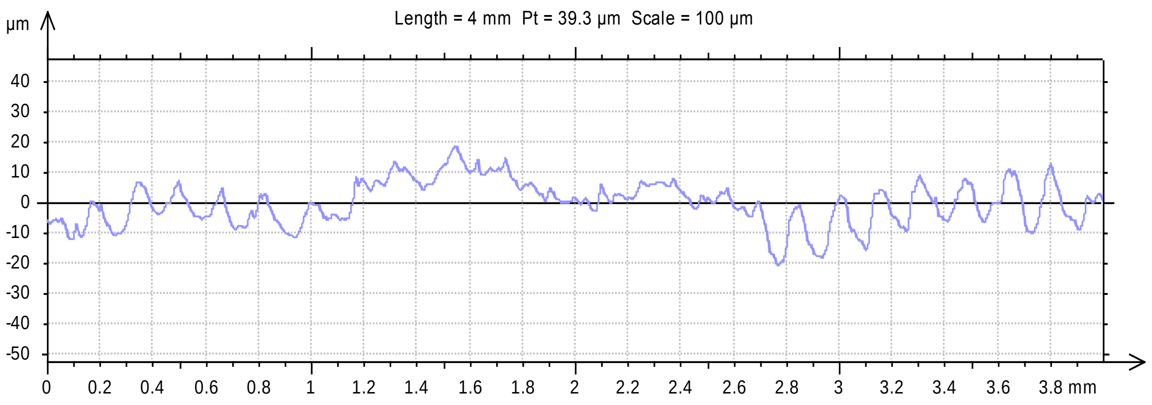
Mean depth of roughness motifs R= 5.77µm

Mean spacing of roughness motifs AR=92.1µm

Max. depth of roughness motifs R_x= 18.6µm

4.8.2 S=1000rpm, f=0.14mm/rev, d=0.40mm

1. **Profile Curve**

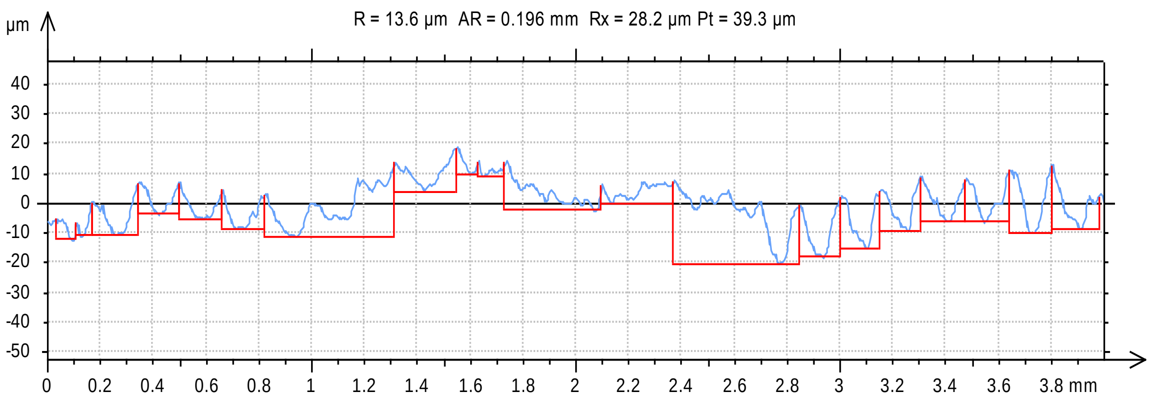


Length of profile= 4mm

Max. peak to valley height P_t=39.3µm

Scale of profile=100µm

2. **Roughness and Waviness Motifs (ISO 12085)**



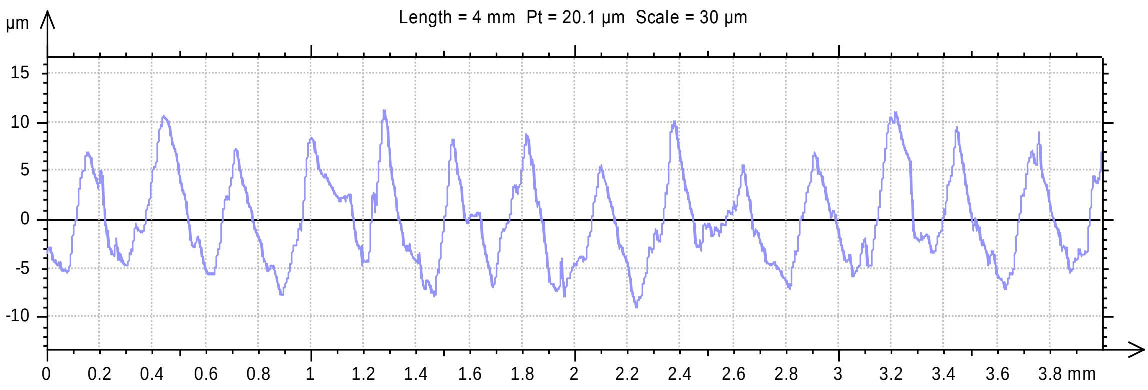
Mean depth of roughness motifs R= 13.6µm

Mean spacing of roughness motifs AR=196µm

Max. depth of roughness motifs R_x= 28.2µm

4.8.3 S=1000rpm, f=0.24mm/rev, d=0.40mm

1. Profile Curve

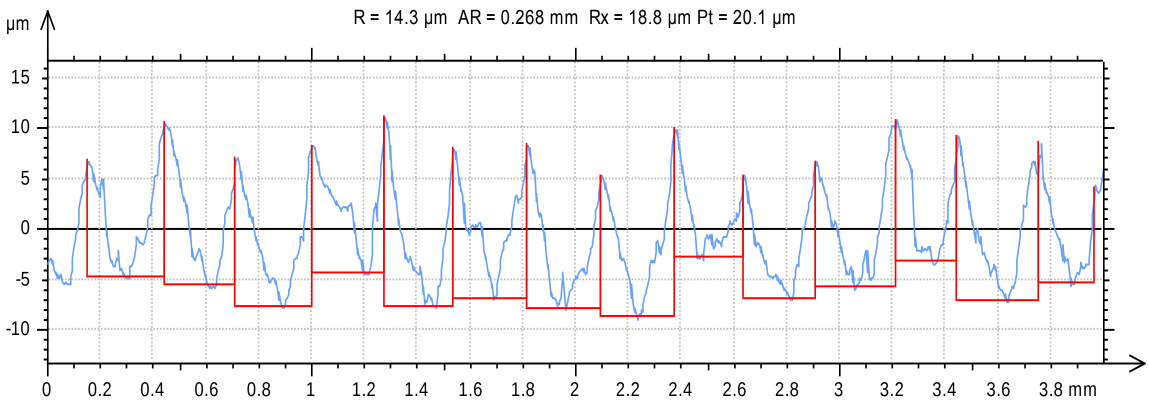


Length of profile= 4mm

Max. peak to valley height P_t=20.1µm

Scale of profile=30µm

2. Roughness and Waviness Motifs (ISO 12085)



Mean depth of roughness motifs R= 14.3µm

Mean spacing of roughness motifs AR=268µm

Max. depth of roughness motifs R_x= 18.8µm

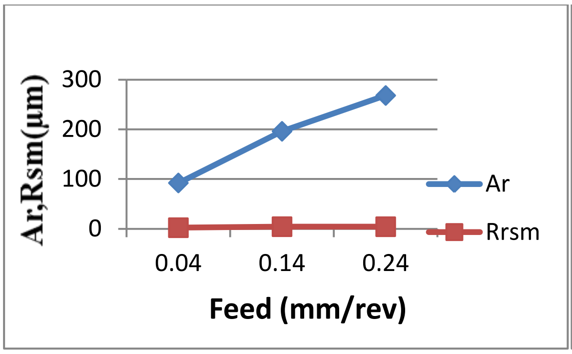


Figure 4.8.1

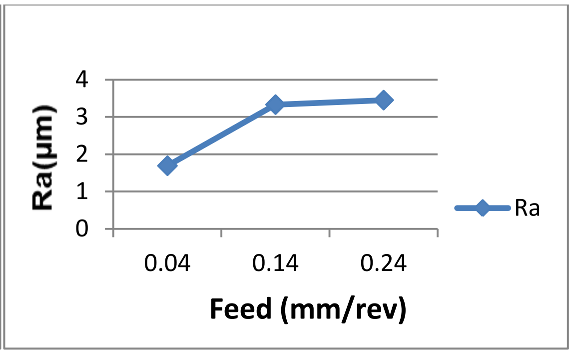


Figure 4.8.2

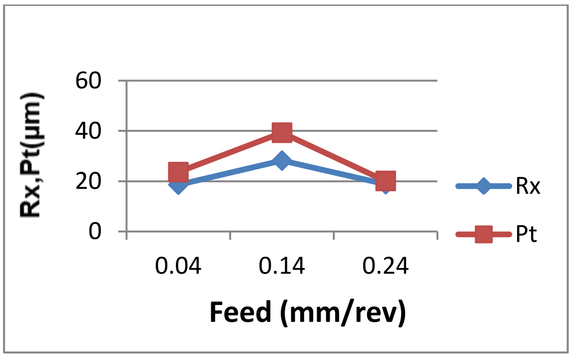


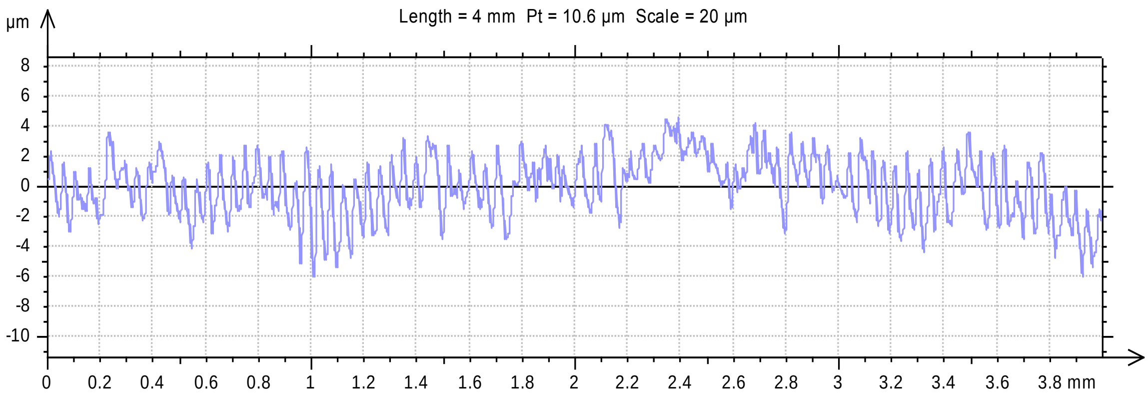
Figure 4.8.3

- From Fig. 4.8.1 it is seen that with increase in feed there is increase in both Ar (Mean spacing of roughness) and Rsm (Mean width of profile).
- From Fig. 4.8.2 it is seen that with increase in feed there is increase in Ra (Mean roughness parameter).
- From Fig. 4.8.3 it is seen that with increase in feed there is increase in both Rx (Mean depth of profile irregularity) and Pt (Max. peak to valley height) till 0.14 mm/rev and decreases till 0.24 mm/rev, it is also seen that incremental in Pt is more than Rx.

4.9 Graphical analysis for variable feed at constant speed (1000rpm) and depth of cut (0.60mm)

4.9.1 S=1000rpm, f=0.04mm/rev, d=0.60mm

1. **Profile Curve**

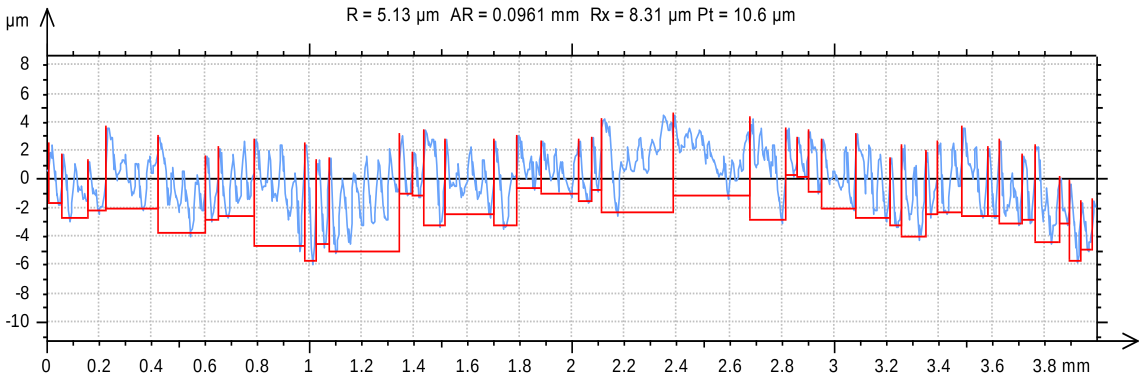


Length of profile= 4mm

Max. peak to valley height P_t=10.6µm

Scale of profile=20µm

2. **Roughness and Waviness Motifs (ISO 12085)**



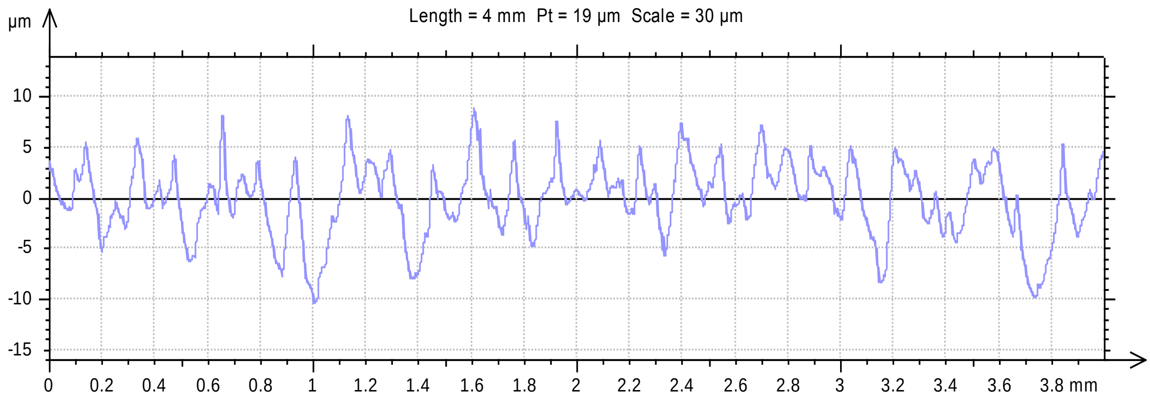
Mean depth of roughness motifs R= 5.13µm

Mean spacing of roughness motifs AR=96.1µm

Max. depth of roughness motifs R_x= 8.31µm

4.9.2 S=1000rpm, f=0.14mm/rev, d=0.60mm

1. Profile Curve

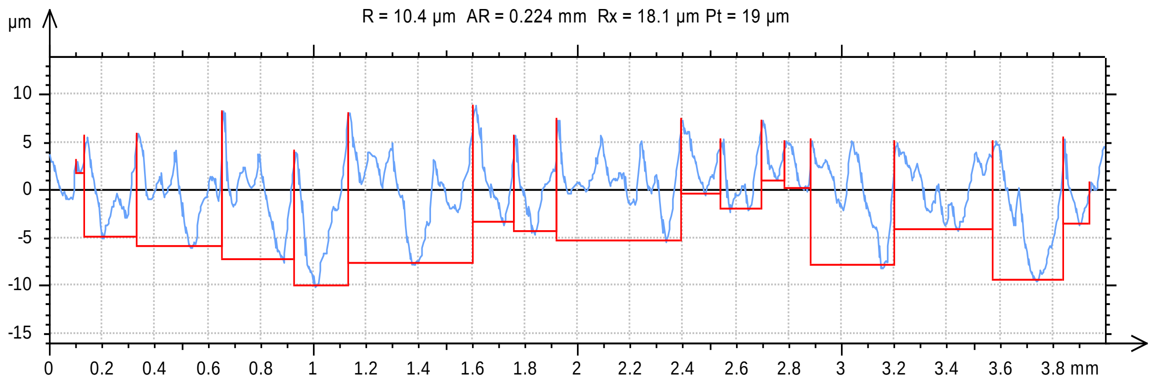


Length of profile= 4mm

Max. peak to valley height P_t=19µm

Scale of profile=30µm

2. Roughness and Waviness Motifs (ISO 12085)



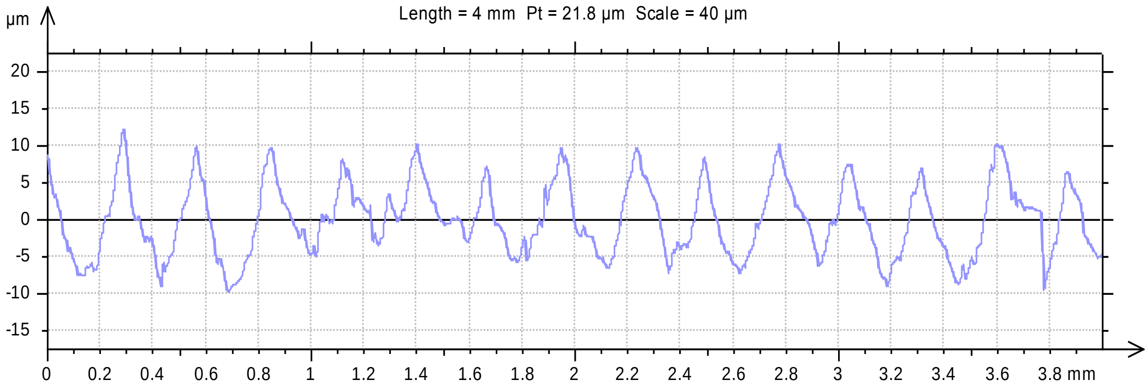
Mean depth of roughness motifs R= 10.4µm

Mean spacing of roughness motifs AR=224µm

Max. depth of roughness motifs R_x= 18.1µm

4.9.3 S=1000rpm, f=0.24mm/rev, d=0.60mm

1. **Profile Curve**

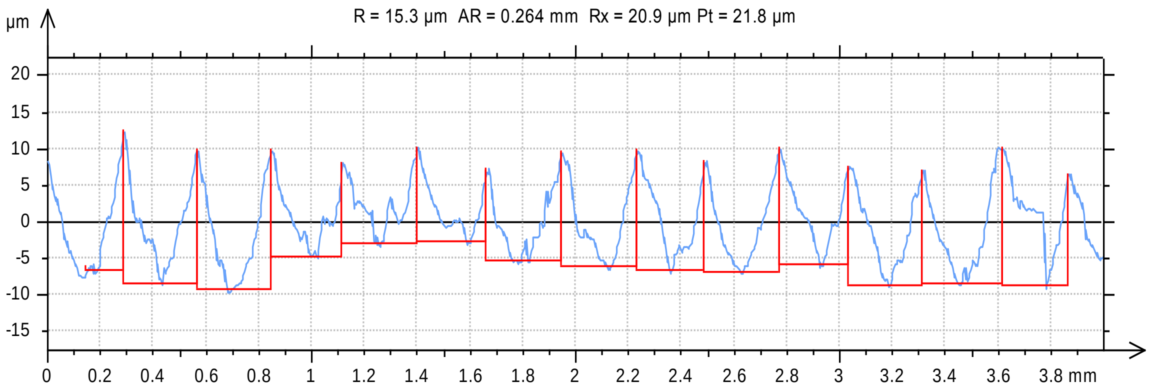


Length of profile= 4mm

Max. peak to valley height P_t=21.8µm

Scale of profile=40µm

2. **Roughness and Waviness Motifs (ISO 12085)**



Mean depth of roughness motifs R= 15.3µm

Mean spacing of roughness motifs AR=264µm

Max. depth of roughness motifs R_x= 20.9µm

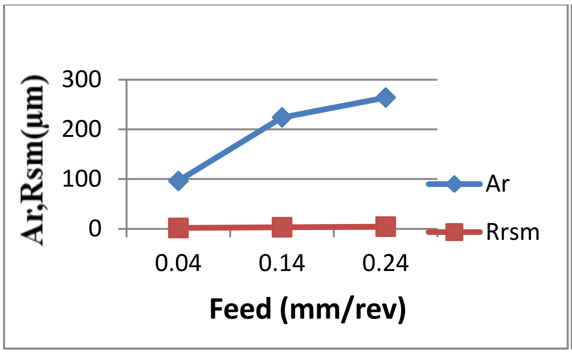


Figure 4.9.1

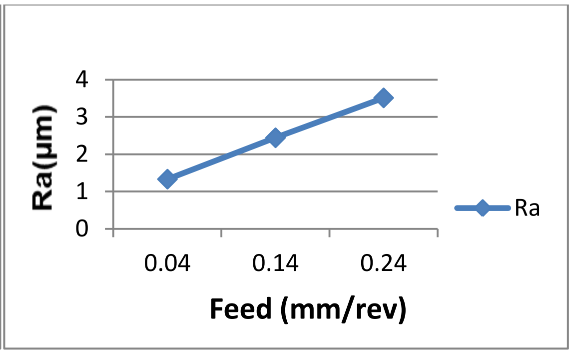


Figure 4.9.2

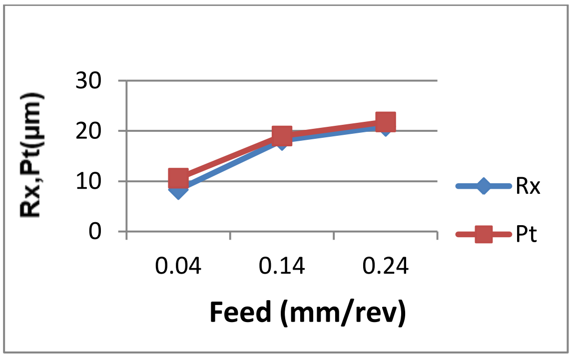
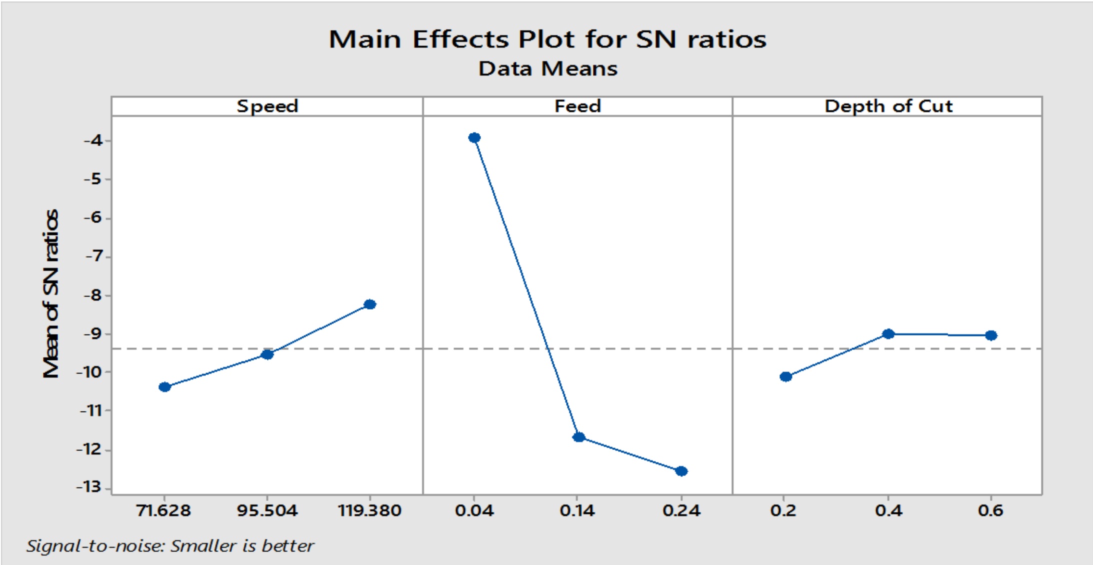


Figure 4.9.3

- From Fig. 4.9.1 it is seen that with increase in feed there is increase in both Ar (Mean spacing of roughness) and Rsm (Mean width of profile).
- From Fig. 4.9.2 it is seen that with increase in feed there is increase in Ra (Mean roughness parameter).
- From Fig. 4.9.3 it is seen that with increase in feed there is increase in both Rx (Mean depth of profile irregularity) and Pt (Max. peak to valley height), it is also seen that incremental in Pt is more than Rx.

4.10 Graphs from Taguchi

4.10.1 Signal-to-Noise: 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. Taguchi uses the S:N ratio to measure the quality characteristic deviating from the desired value. [4]



4.10.2 Mean: The main effect plots are used to determine the optimal design conditions to obtain the optimal surface finish. According to this main effect plot, the optimal conditions for minimum surface roughness is A3B1C3 which is speed at level 3 (119.380 m min^{-1}), feed rate at level 1 (0.04 mm rev^{-1}) and depth of cut at level 1 (0.6 mm).

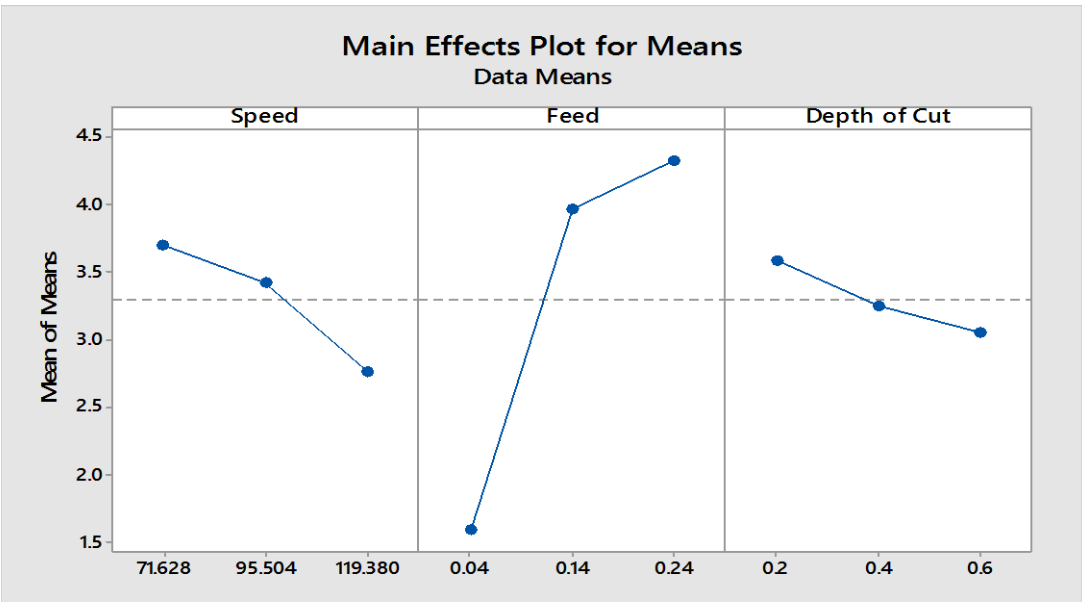


Table 4.2 Experimental results for S/N ratio by Taguchi method

S.No.	Diameter (mm)	RPM	Speed (m/min)	d (mm)	Feed 'f' (mm/rev)	Ra (μm)	S/N Ratio (dB)	Mean (μm)
1.	38	600	71.628	0.20	0.04	1.71	-4.6599	1.710
2.	38	600	71.628	0.20	0.14	4.90	-13.8039	4.900
3.	38	600	71.628	0.20	0.24	5.88	-15.3875	5.880
4.	38	600	71.628	0.40	0.04	1.45	-3.2274	1.450
5.	38	600	71.628	0.40	0.14	3.16	-9.9937	3.160
6.	38	600	71.628	0.40	0.24	4.86	-13.7327	4.860
7.	38	600	71.628	0.60	0.04	1.95	-5.8007	1.950
8.	38	600	71.628	0.60	0.14	4.99	-13.9620	4.990
9.	38	600	71.628	0.60	0.24	4.37	-12.8096	4.370
10.	38	800	95.504	0.20	0.04	1.52	-3.6369	1.520
11.	38	800	95.504	0.20	0.14	4.33	-12.7298	4.330
12.	38	800	95.504	0.20	0.24	4.80	-13.6248	4.800
13.	38	800	95.504	0.40	0.04	0.967	0.2915	0.967
14.	38	800	95.504	0.40	0.14	5.71	-15.1327	5.710
15.	38	800	95.504	0.40	0.24	4.63	-13.3116	4.630
16.	38	800	95.504	0.60	0.04	2.17	-6.7292	2.170
17.	38	800	95.504	0.60	0.14	2.82	-9.0050	2.820
18.	38	800	95.504	0.60	0.24	3.91	-11.8435	3.910
19.	38	1000	119.380	0.20	0.04	1.61	-4.1365	1.610
20.	38	1000	119.380	0.20	0.14	4.04	-12.1276	4.040
21.	38	1000	119.380	0.20	0.24	3.48	-10.8316	3.480
22.	38	1000	119.380	0.40	0.04	1.69	-4.5577	1.690
23.	38	1000	119.380	0.40	0.14	3.33	-10.4489	3.330
24.	38	1000	119.380	0.40	0.24	3.45	-10.7564	3.450
25.	38	1000	119.380	0.60	0.04	1.33	-2.4770	1.330
26.	38	1000	119.380	0.60	0.14	2.44	-7.7478	2.440
27.	38	1000	119.380	0.60	0.24	3.51	-10.9061	3.510

Table 4.3 S/N response table for surface roughness

Symbol	Cutting Parameters	Mean S/N Ratio (dB)				
		Level 1	Level 2	Level 3	Max-min	Rank
A	**Speed**	-10.375	-9.525	-8.221	2.154	2
B	**Feed**	-3.882	-11.661	-12.578	8.697	1
C	**Depth of Cut**	-10.104	-8.986	-9.031	1.119	3

Total mean S/N ratio = -9.3736

Table 4.4 Mean response table for surface roughness

Symbol	Cutting Parameters	Mean (μm)				
		Level 1	Level 2	Level 3	Max-min	Rank
A	**Speed**	3.697	3.429	2.764	0.932	2
B	**Feed**	1.600	3.969	4.321	2.721	1
C	**Depth of Cut**	3.586	3.250	3.054	0.531	3

Table 4.5 Analysis of Variance (ANOVA) for Surface Roughness

Symbol	Cutting Parameters	DF	SS	MS	F	P	Contribution (%)
A	**Speed**	2	4.1459	2.0729	3.89	0.037	9.02
B	**Feed**	2	39.4306	19.7153	36.98	0.000	85.82
C	**Depth of Cut**	2	1.2990	0.6495	1.22	0.317	2.82
Error		20	10.6626	0.5331			2.32
Total		26	55.5382				100

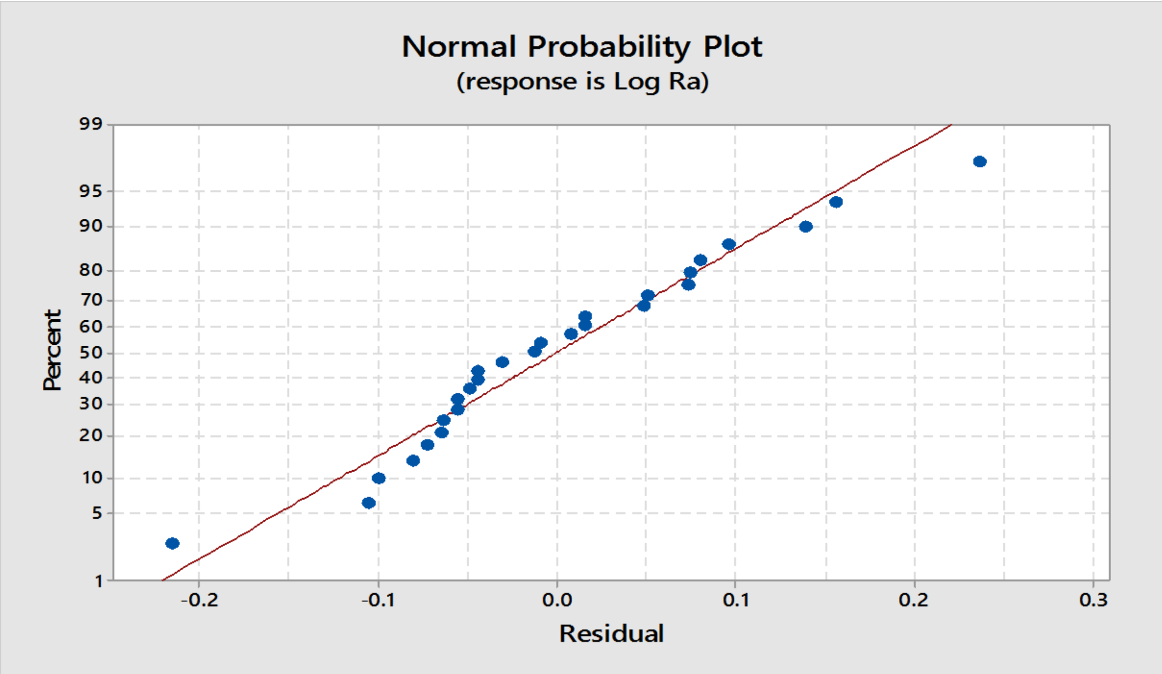
It can be seen from ANOVA table 4.5 that feed is the highest contributing factor with 85.82% and other details of DOF - Degrees of freedom, S.S - Sum of Squares, M.S - Mean of Squares, F-value, P-value and Error are mentioned.

Table 4.6 Regression Analysis for Surface Roughness

S.No.	Log S	Log d	Log f	Log Ra	Residual	Fits
1.	1.855082825	-0.698970004	-1.397940009	0.232996	-0.063812	0.296808
2.	1.855082825	-0.698970004	-0.853871964	0.690196	0.074377	0.615819
3.	1.855082825	-0.698970004	-0.619788758	0.769377	0.016305	0.753072
4.	1.855082825	-0.397940009	-1.397940009	0.161368	-0.099211	0.260579
5.	1.855082825	-0.397940009	-0.853871964	0.499687	-0.079902	0.579589
6.	1.855082825	-0.397940009	-0.619788758	0.686636	-0.030206	0.716842
7.	1.855082825	-0.22184875	-1.397940009	0.290035	0.050649	0.239386
8.	1.855082825	-0.22184875	-0.853871964	0.698101	0.139704	0.558396
9.	1.855082825	-0.22184875	-0.619788758	0.640481	-0.055168	0.695649
10.	1.980021562	-0.698970004	-1.397940009	0.181844	-0.055161	0.237005
11.	1.980021562	-0.698970004	-0.853871964	0.636488	0.080473	0.556015
12.	1.980021562	-0.698970004	-0.619788758	0.681241	-0.012027	0.693268
13.	1.980021562	-0.397940009	-1.397940009	-0.01457	-0.215348	0.200775
14.	1.980021562	-0.397940009	-0.853871964	0.756636	0.236851	0.519785
15.	1.980021562	-0.397940009	-0.619788758	0.665581	0.008543	0.657038
16.	1.980021562	-0.22184875	-1.397940009	0.33646	0.156878	0.179582
17.	1.980021562	-0.22184875	-0.853871964	0.450249	-0.048343	0.498592
18.	1.980021562	-0.22184875	-0.619788758	0.592177	-0.043669	0.635845
19.	2.076931575	-0.698970004	-1.397940009	0.206826	0.016209	0.190617
20.	2.076931575	-0.698970004	-0.853871964	0.606381	0.096754	0.509628
21.	2.076931575	-0.698970004	-0.619788758	0.541579	-0.105301	0.646881
22.	2.076931575	-0.397940009	-1.397940009	0.227887	0.073499	0.154387
23.	2.076931575	-0.397940009	-0.853871964	0.522444	0.049046	0.473398
24.	2.076931575	-0.397940009	-0.619788758	0.537819	-0.072832	0.610651
25.	2.076931575	-0.22184875	-1.397940009	0.123852	-0.009343	0.133194
26.	2.076931575	-0.22184875	-0.853871964	0.38739	-0.064815	0.452205
27.	2.076931575	-0.22184875	-0.619788758	0.545307	-0.044151	0.589458

4.11 Graphs from Regression Analysis

4.11.1 Normal probability plot of Residuals for Log Ra

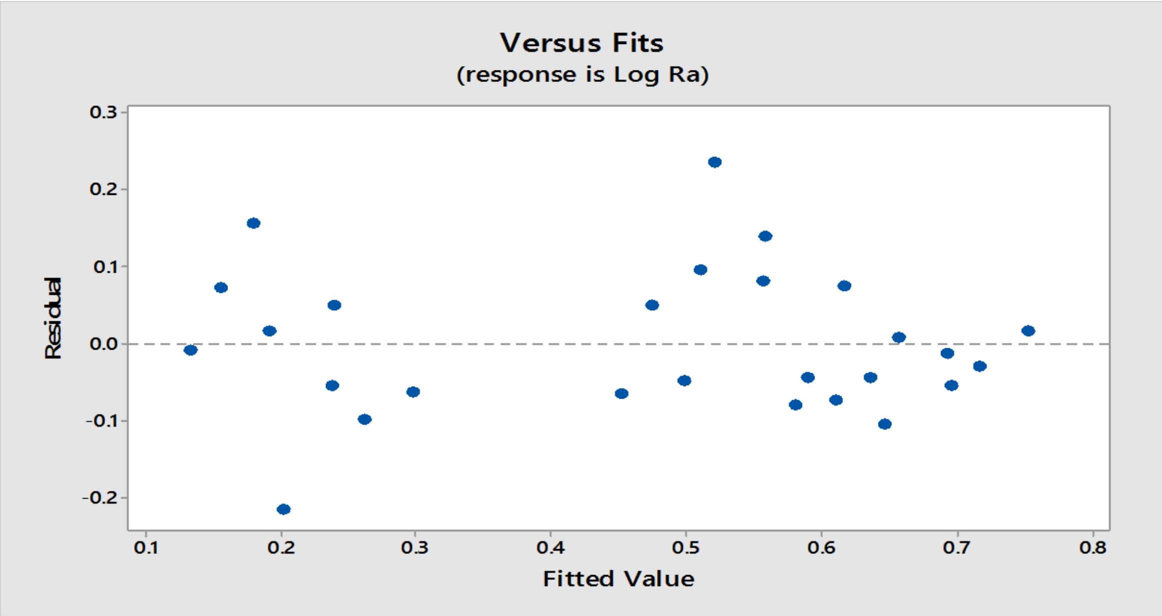


The points in this plot should generally form a straight line if the residuals are normally distributed. If the points on the plot depart from a straight line, the normality assumption may be invalid. As in this project work data have less than 50 observations, the plot may show bend in the tails even if the residuals are normally distributed. As the number of observations drops, the probability plot may show substantial difference and nonlinearity even if the residuals are normally distributed.

4.11.2 Residuals vs Fits for Log Ra

This plot should display a random pattern of residuals on both sides of 0. If a point lies distant from the majority of points, it may be an outlier. Also, there should not be any familiar patterns in the residual plot. The following may show error that is not random:

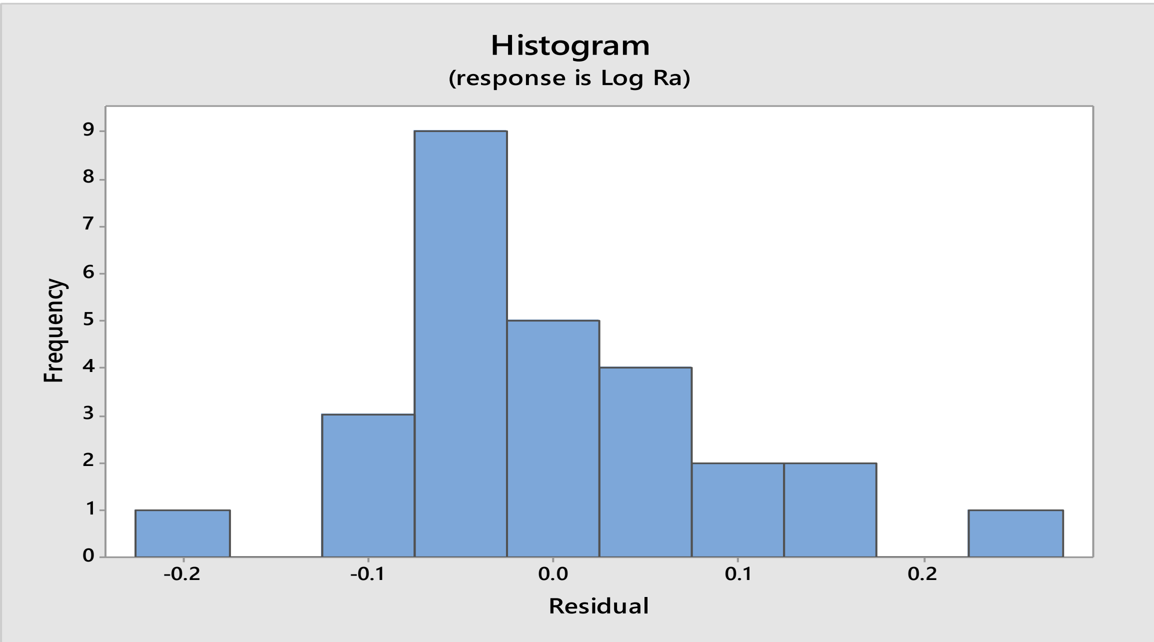
- a series of increasing or decreasing points
- a majority of positive residuals, or a majority of negative residuals
- patterns, such as increasing residuals with increasing fits



It can be concluded that all the values are within the control range, indicating that there is no obvious pattern and unusual structure.

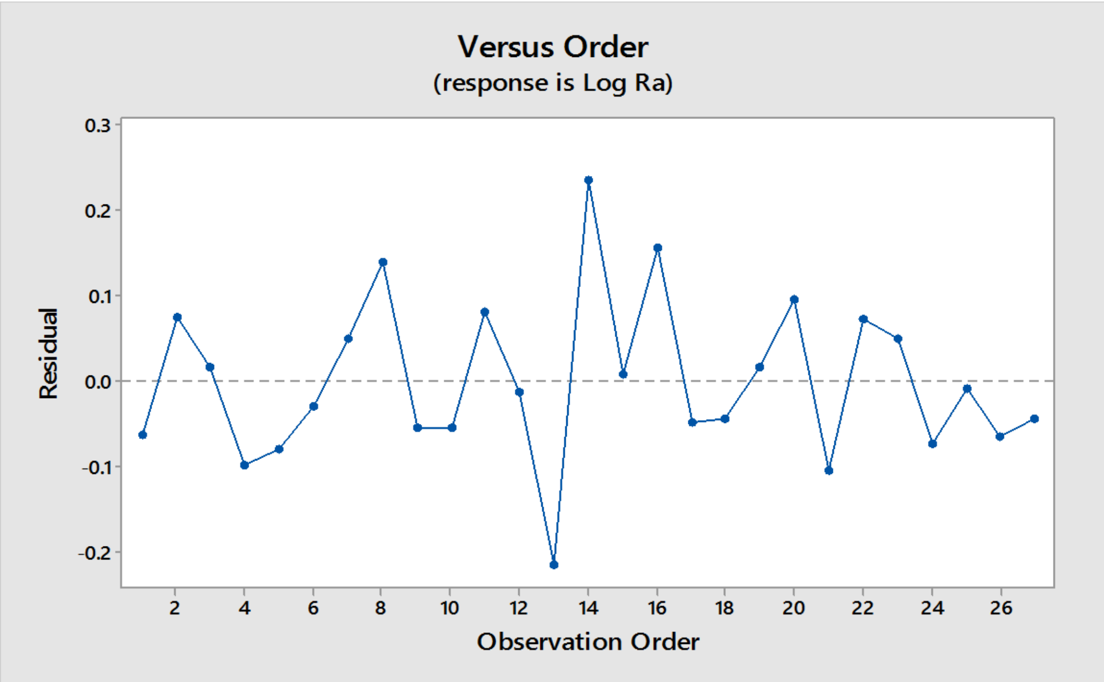
4.11.3 Residual Histogram for Log Ra

Long tails in the plot may indicate skewness in the data. If one or two bars are far from the others, those points may be outliers because the appearance of the histogram changes depending on the number of intervals used to group the data.



4.11.4 Residuals vs Order for Log Ra

This is a plot of all residuals in the order that the data was collected and can be used to find non-random error, especially of time-related effects. A positive correlation is indicated by a clustering of residuals with the same sign and a negative correlation is indicated by rapid changes in the signs of consecutive residuals.



From graphs 4.11.1, 4.11.2, 4.11.3, 4.11.4, it can be concluded that all the values are within the control range, indicating that there is no obvious pattern and unusual structure and also the residual analysis does not indicate any model inadequacy. Hence these values yield better results in future predictions.

Table 4.7 Analysis of Variance

Symbol	Cutting Parameters	DF	Adj SS	Adj MS	F	P	Contribution (%)
	Regression	3	1.05254	0.35085	34.59	0.000	
A	**Log S**	1	0.05101	0.05101	5.03	0.035	4.80
B	**Log f**	1	0.98635	0.98635	97.26	0.000	92.81
C	**Log d**	1	0.01518	0.01518	1.50	0.234	1.42
Error		23	0.23326	0.01014			0.95
Total		26	1.28580				100

4.12 Regression Equation

Log Ra = 1.920 - 0.479 Log S - 0.1204 Log d + 0.5863 Log f

$Ra = 83.1763\ S^{-0.479}\ d^{-0.1204}\ f^{0.5863}$

Table 4.8 Calculated Surface Roughness from Regression Equation

S.No.	Log S	Log d	Log f	Log Ra	Ra (μm)	Calculated Ra (μm)
1.	1.85508	-0.698970	-1.39794	0.232996	1.71	1.98
2.	1.85508	-0.698970	-0.85387	0.690196	4.90	4.12
3.	1.85508	-0.698970	-0.61979	0.769377	5.88	5.65
4.	1.85508	-0.397940	-1.39794	0.161368	1.45	1.82
5.	1.85508	-0.397940	-0.85387	0.499687	3.16	3.79
6.	1.85508	-0.397940	-0.61979	0.686636	4.86	5.20
7.	1.85508	-0.221849	-1.39794	0.290035	1.95	1.73
8.	1.85508	-0.221849	-0.85387	0.698101	4.99	3.60
9.	1.85508	-0.221849	-0.61979	0.640481	4.37	4.95
10.	1.98002	-0.698970	-1.39794	0.181844	1.52	1.72
11.	1.98002	-0.698970	-0.85387	0.636488	4.33	3.59
12.	1.98002	-0.698970	-0.61979	0.681241	4.80	4.92
13.	1.98002	-0.397940	-1.39794	-0.014574	0.97	1.58
14.	1.98002	-0.397940	-0.85387	0.756636	5.71	3.30
15.	1.98002	-0.397940	-0.61979	0.665581	4.63	4.53
16.	1.98002	-0.221849	-1.39794	0.336460	2.17	1.50
17.	1.98002	-0.221849	-0.85387	0.450249	2.82	3.14
18.	1.98002	-0.221849	-0.61979	0.592177	3.91	4.31
19.	2.07693	-0.698970	-1.39794	0.206826	1.61	1.55
20.	2.07693	-0.698970	-0.85387	0.606381	4.04	3.23
21.	2.07693	-0.698970	-0.61979	0.541579	3.48	4.42
22.	2.07693	-0.397940	-1.39794	0.227887	1.69	1.42
23.	2.07693	-0.397940	-0.85387	0.522444	3.33	2.97
24.	2.07693	-0.397940	-0.61979	0.537819	3.45	4.07
25.	2.07693	-0.221849	-1.39794	0.123852	1.33	1.35
26.	2.07693	-0.221849	-0.85387	0.387390	2.44	2.83
27.	2.07693	-0.221849	-0.61979	0.545307	3.51	3.88

From Table 4.8, it can be concluded that the optimum combination process parameters for minimum SR is obtained at speed 119.380m/min (1000rpm), feed 0.04mm/rev and depth of cut 0.6mm which gives 1.33µm surface roughness.

CHAPTER 5

RESULTS AND CONCLUSION

This thesis has presented an application of the parameter design of the Taguchi method in the optimization of turning operations. The Taguchi experimental design was used to obtain optimum cutting parameters in turning of mild steel. Experimental results were analyzed using ANOVA. The following conclusions can be drawn based on the experimental results:

- Feed rate is the major parameters among the three controllable factors (speed, feed rate and depth of cut) that influence the surface roughness in turning of mild steel.
- In turning, use of higher speed (119.380 m/min), low feed rate (0.04 mm/rev) and high depth of cut (0.6 mm) are recommended to obtain better Surface Roughness for the specific test range.
- Surface Roughness can be improved through this approach instead of using engineering judgments. As per ANOVA the percentage contributions of speed, feed rate and depth of cut are 9.02%, 85.82% and 2.82%, respectively for the range of parameters.

This thesis demonstrates how to use Taguchi parameter design for optimizing machining performance with minimum cost and time.

5.1 Scope for future work

The machining variables are divided into three main categories. These are tool variables, work piece variables and set-up variables. Tool variables includes tool material, nose radius, tool wear, tool geometry, tool vibration, machine tool rigidity, and tool overhang etc. Work piece variables include work piece material, hardness, length and diameter etc. Set-up variables include cutting speed, feed rate, depth of cut etc.

In the present work only set-up variables are considered. Tool variables and work piece variables can also be studied. There is also scope for considering more factors levels, interactions to optimize a selected set of parameters.

Also, further study could consider the outcomes of Taguchi parameter design when it is implemented as a part of management decision-making processes.

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