KAUNAS UNIVERSITY OF TECHNOLOGY
MECHANICAL ENGINEERING AND DESIGN FACULTY

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INVESTIGATION OF SURFACE CUTTING SPEED INFLUENCE ON SURFACE ROUGHNESS

Master's Degree Final Project

Supervisor

Prof. Dr. Povilas Krasauskas

KAUNAS, 2018

KAUNAS UNIVERSITY OF TECHNOLOGY

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INDUSTRIAL ENGINEERING AND MANAGEMENT (code 621H77003)

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KAUNAS, 2018

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" Investigation of surface cutting speed influence on surface Roughness"

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20

Kaunas

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Approved:
Head of
Production engineering
Department ***Kazimieras Juzėnas***

MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT

Study Programme INDUSTRIAL ENGINEERING AND MANAGEMENT

The final project of Master studies to gain the master qualification degree, is research or applied type project, for completion and defense of which 30 credits are assigned. The final project of the student must demonstrate the deepened and enlarged knowledge acquired in the main studies, also gained skills to formulate and solve an actual problem having limited and (or) contradictory information, independently conduct scientific or applied analysis and properly interpret data. By completing and defending the final project Master studies student must demonstrate the creativity, ability to apply fundamental knowledge, understanding of social and commercial environment, Legal Acts and financial possibilities, show the information search skills, ability to carry out the qualified analysis, use numerical methods, applied software, common information technologies and correct language, ability to formulate proper conclusions.

1. Title of the Project

Investigation of surface cutting speed influence on surface roughness.

Approved by the Dean Order No. V25-11-12, 11 December 2017

2. Aim of the project

The aim of this research work is to investigate cutting speed, cutting feed and workpiece shape (diameter) influence cutting on curvilinear surface (curve-shaped) surface roughness during turning operation. Using constant surface speed and variable surface speed.

3. Structure of the project

Introduction, Literature review, Turning process description, Experiment techniques, Surface roughness prediction, Conclusions, References.

4. Requirements and conditions

CNC Machine; Measurement tester for Surface roughness measurements; Cutting parameters measurements and tools; Turning tool; Theoretical analysis; Regression analysis, dry turning. Statistical data book.

5. This task assignment is an integral part of the final project

6. Project submission deadline: 21 December 2017

Student Sarang Ganeshrao Banore ______________________
(*Signature, date*)

Supervisor Prof. Dr. Povilas Krasauskas ______________________
(*Signature, date*)

Sarang Ganeshrao Banore. (PAVIRŠINIO PJOVIMO GREIČIO ĮTAKOS PAVIRŠIAUS ŠIURKŠTUMUI TYRIMAS). / Magistro Pramonės inžinerijos ir vadybos baigiamasis projektas / vadovas prof. Dr. Povilas Krasauskas, Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas, gamybos inžinerijos katedroje.

Mokslo kryptis ir sritis: gamybos Inžinerija, technologijos mokslai
Reikšminiai žodžiai: *ruošinys, paviršiaus šiurkštumas, suklio greitis, pjovimo greitis, regresinė analizė.*

Kaunas, 2018. 65p.

Santrauka

Darbe nagrinėjama paviršiaus pjovimo parametrų ir ruošinio formos įtaka paviršiaus šiurkštumui naudojant įprastinį ir kontroliuojamąjį tekinimą. Pirmuoju atveju, panaudojant programines (CNC) tekinimo stakles, naudojamas programavimo kodas G01 ir kuriame suklio ir pastūmos greičiai programuojami adresais (S) ir (F). Priklausomai nuo ruošinio formos pjovimo greitis (V) tekinimo metu gali kisti. Kontroliuojamasis tekinimo būdas programuojamas kodu G96, kuriame nustatomas pastovus paviršinis pjovimo greitis (S), reiškiantis tai, kad esant pastoviam pjovimo ir pastūmos greičiui suklio sukimosi greitis tekinimo metu staklių kompiuterio pagalba valdomi taip, kad ruošinio paviršinis pjovimo greitis visada būtų nekintantis, nepriklausomai nuo ruošinio formos kitimo. Tam, kad įvertinti šių apdirbimo būdų įtaką detalės paviršiaus šiurkštumui buvo pasirinktas kūginio paviršiaus tekinimas, nes proceso metu jo skersmuo kinta nuo pradžių tekinimas. Po operacijos trijose sektoriuose – pradžioje, per vidurį ir pabaigoje buvo matuojamas detalės paviršiaus šiurkštumas tam kad įvertinti tekinimo metu kintančių pjovimo režimų įtaką paviršiaus šiurkštumui. Buvo gautos paviršiaus šiurkštumo priklausomybės nuo ruošinio skersmens, pjovimo ir pastūmų greičio bei atliktas eksperimente gautų rezultatų palyginimas su teoriniais skaičiavimais. Siekiant prognozuoti ruošinio paviršiaus šiurkštumą nepriklausomai nuo apdirbimo parametrų, buvo atlikta keturių kintamųjų, įvertinančių ruošinio skersmenį, suklio sukimosi dažnį, pjovimo ir pastūmų greičius regresinė analizė, kuri parodė pasirinkto modelio priimtinumą. Pateiktos išvados ir rekomendacijos tolesniems tyrimams.

Sarang Ganeshrao Banore. (INVESTIGATION OF SURFACE CUTTING SPEED INFLUENCE ON SURFACE ROUGHNESS). /Master 's thesis in Industrial Engineering and management / Supervisor Prof. Dr. Povilas Krasauskas, Kaunas University of Technology, The Faculty of Mechanical Engineering and Design, Department of Production Engineering.

Research area and field: Production engineering, Technological sciences.
Key words: *turning, workpiece, surface roughness, cutting speed, cutting feed, regression analysis.*
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Summary

This study examines the role of influence of surface cutting parameters on the surface roughness for conical workpieces turning operations. The conventional and constant surface speed control turning experiment was carried out CNC turning machine. Conventional turning was performed using programming code G01 and addresses spindle speed (S) and feed (F), which during turning are kept constant. Constant surface speed control turning was programmed using G96 code and constant surface cutting speed address (S). Conical surface turning process was identified as scope of experiments due to variable diameter the surface speed will not be constant. Determining the change and effectiveness in the surface roughness using these both methods the relationship between surface roughness and workpiece diameter, cutting speed and feed during conventional turning and constant surface speed control using was performed.

Previous studies and literature in this area has focused almost exclusively on constant cutting speed turning processes and also concluded that surface roughness is qualitative function of the feed rate with cutting speed and depth also playing a minor part. This study advances our understanding of correlation between all these machining parameters with the surface roughness. To date, no systematic investigation has considered the constant surface speed and here we have established that parallel. We conducted a laboratory experiment to test and study the surface roughness of curvilinear turning with CNC machining where different diameter workpieces were employed for the test with combination of different machining parameters.

The comparison of the experimental surface measurement results to the theoretical values was performed. In order to predict surface roughness for the various cutting conditions four variable regression analysis, including workpiece diameter, surface cutting speed, spindle speed and cutting feed was performed. Analysis showed that proposed regression model adequacy describes cutting parameters variation influence on surface roughness. Conclusions and recommendations are presented for further investigations.

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INTRODUCTION

During turning of the cylindrical surfaces, cutting speed and feed is set and remains stable because workpiece diameter is constant. The surface roughness for cylindrical workpieces is also stable and varies depending only on workpiece diameter. If the diameter is constant – surface roughness is also constant and surface roughness depends on selected/calculated cutting regimes. If the workpiece diameter varies in very large limits cutting speed also varies and cutting regimes should be selected in right way to ensure required surface roughness. To avoid excess spindle rotation, the spindle limitation code G92 with speed address *S* in (rpm)is used.

The problem actuality

There are two surface turning modes used in CNC machining. First mode is with programing constant cutting speed by setting the surface interpolation codes G01, G02 or G03 and feed code G97 with feed address *F*. It means that for the cylindrical or conical surface code G01 sets linear interpolation and for curve-shaped surfaces is selected G02 or G03 codes which describes cylindrical interpolation programing. The second turning mode is to program machining with constant surface speed control function using code G96 S20, S16, S12 it means that despite workpiece diameter changing during turning always is set to constant surface speed in m/min. During curvilinear surfaces turning cutting feed remains constant, however due to workpiece diameter increasing or decreasing, the actual cutting speed is kept constant by means of programmable spindle rotation speed control. It means that to keep constant surface cutting speed during turning number of spindle revolution increases when workpiece diameter decreases and vice versus – when workpiece diameter during machining increasing spindle revolution decreases.

AIM

Investigation of surface roughness changing during workpieces containing conical shaped surfaces turning and the comparison to the conventional machining of the workpieces with linear surfaces was the main aim of this work.

OBJECTIVES

- Investigate surface cutting parameters.
- Workpiece shape influence on surface roughness during conventional and constant surface speed control turning operation.
- Experimental surface roughness comparison to the theory.
- Perform regression analysis of the cutting process factors influence prediction on surface roughness.

1. LITERATURE OVERVIEW

In this section I have discuss the theoretical aspect of the experiment that will take place in research. The main goal is to gather all the necessary information that will be used to identify, monitor, and test the experiment.

The study article "Yasuo yamanea", "Tanaka ryutaroa", "Tahanorib defeated", "Israel martinez ramireza", "yamada keijiait"[1] noted that the method of quantitative analysis of the cutting process was made from the metal working and processing base from the treated surface The profile (roughness profile and primary profile) is based on the cutting process that can be achieved, the process should be accurately simulated.

The predicted value of the cutting tool can be determined by the shape and position of the cutting tool, depending on the cutting phenomena and the position of the handle and edges, which is based on the cutting face and actual surface. By vibration, the advanced adjacent position and precision must be fixed to a gradual machining system. The spindle becomes too large. There is proposed a method by which it has been described as three variables that include surface effects of different constituents and vibrations that influence the control of feed but leave the mark. In this article, the cutting surface was evaluated by cutting edges. These properties can be used as a result of the proposed method.

In order to determine the ideal machining conditions as a surface quality, which was mentioned in the study submitted by a.b. Abdullah, l.y. Chia and z [2]. The factors studied were feed rate (fr), cutting speed (Vc), cutting depth (d) and surface roughness (Ra). This method shows that each surface roughness is affected by machining parameters, such as Cutting speed, cutting depth and feed rate. This study uses Turbo C ++ programming to evaluate the properties of mechanically treated surfaces using cutting parameters using arbitrary test estimates. its differentiated capacity according to the proposed state, which is the characteristics of the near-deviation sensitivity due to the nature of the roughness of a clearly known surface. During the last previous test, an experiment was conducted to confirm the logical results that were observed that the result showed that the processing parameter, which had a significant influence on surface roughness, was the rate of supply, while the cutting depth and cutting speed also had a certain amount of effect.

If the cutting speed increases, the result indicates that cutting the cutting material will reduce the cutting speed of the multi-component material, improve the surface finish and the edges of the shape. Increasing the cutting power will further increase the dynamic blurring of the cutting process.

The surface finish becomes effective due to the fact that a large part of the back-surface forms on the surface which is processed in the processing process. In one article by Rodrigues l.l.r.1, kantharaj a.n.1, kantharaj b.2 freeth w. R. C.2 and murthy b.r.n. [3], the effect of the cutting conditions is determined from the rotational strength of the light steel material and the surface imperfections. In this study, they describe cutting power, feed rate, surface roughness, cutting depth and cutting speed when a light steel material offers a turning process using a quick steel cutter. The accuracy of the influence of the focusing machine on parameters and parameters of the cutting parameters was performed and analyzed using the adjusted version. Interaction of supply speed and cutting depth will change the condition of linear relief when cutting speed and interaction between feed speed and cutting depth. The main impact on these sites is based on a detailed invoice design, cutting power, which is chosen from a cutting parameter with three levels and an ideal surface roughness level. If surface roughness occurs due to a certain condition that affects the cutting speed d of the interaction elements.

In the assembly industry, the HSS process is one of the most important ways in which the mechanical cleaning process is used, and the disclosure is intended to improve the cutting parameters. In order to control the use of the rotation process, it is necessary to emphasize the proper mixing depth and speed measurement. It is important that the roughness of the surface perfectly matches the ideal cutting speed, cutting the rats and cutting depth to the light steel material should be> 450 rpm, <0.11 mm / rev and> 0.75 mm.

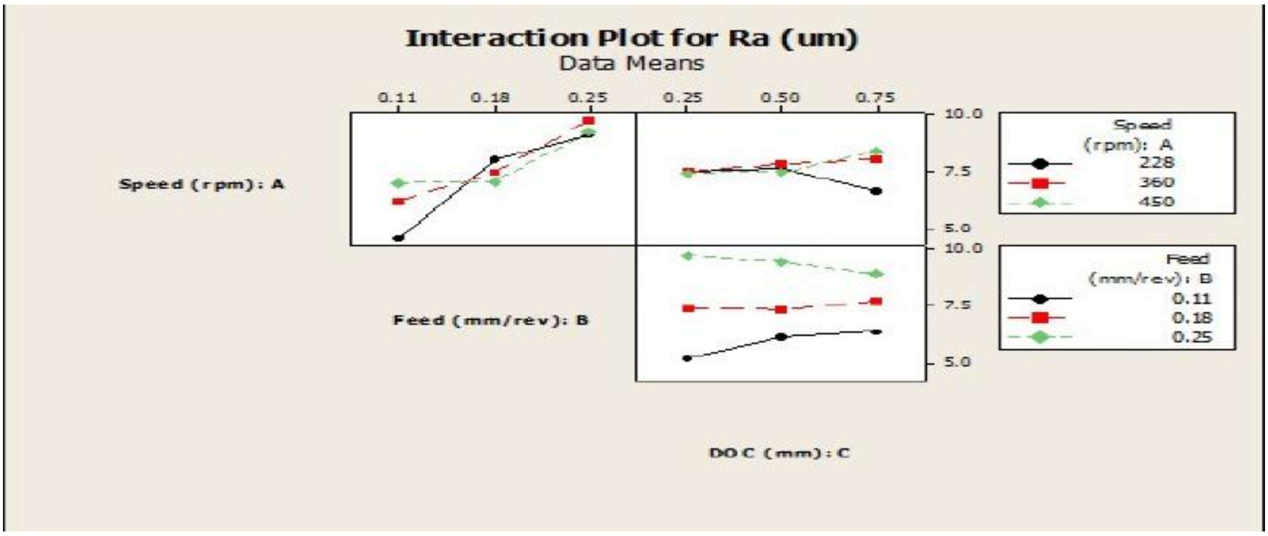


Fig. 1.1. Interaction plot for Ra [3]

It can be concluded that the supply frequency, which has a critical effect on the surface moistening and cutting speed. The cutting force does not affect the cutting speed and the surface roughness of the cutting process material. The effect parameter is the cutting power of the cutting force, but it does not show the roughness of the surface of the main cutting material. This study has shown that an adapted approach can also be effectively used to fit a meaningfully developed and aggregate developed model, which is a solid design, in contrast to the coherent approach adopted in many modern research

The effect of the cutting tool parameters on surface roughness. The paper, which suggested Mehmet alper ince1, İlhan asilitürk2 efgj [4], affects the surface hardness of a compound of Co28Cr6Mo treated with CNC machines. Cutting parameters that include nose rays, shaft speed, cutting depth and feed rate. This article analyzes in detail the effect of the cutting tool parameters on surface roughness. The paper describes the effect of cutting parameters on a graphic frame in order to better understand the roughness of the surface of the substrate, which can ideally be understood by reference to the resulting cutting speed, feed rate, cutting depth and nose radius, which is 318 rpm, 0.1 mm / rev, 0.7 mm, and 0.8 mm.

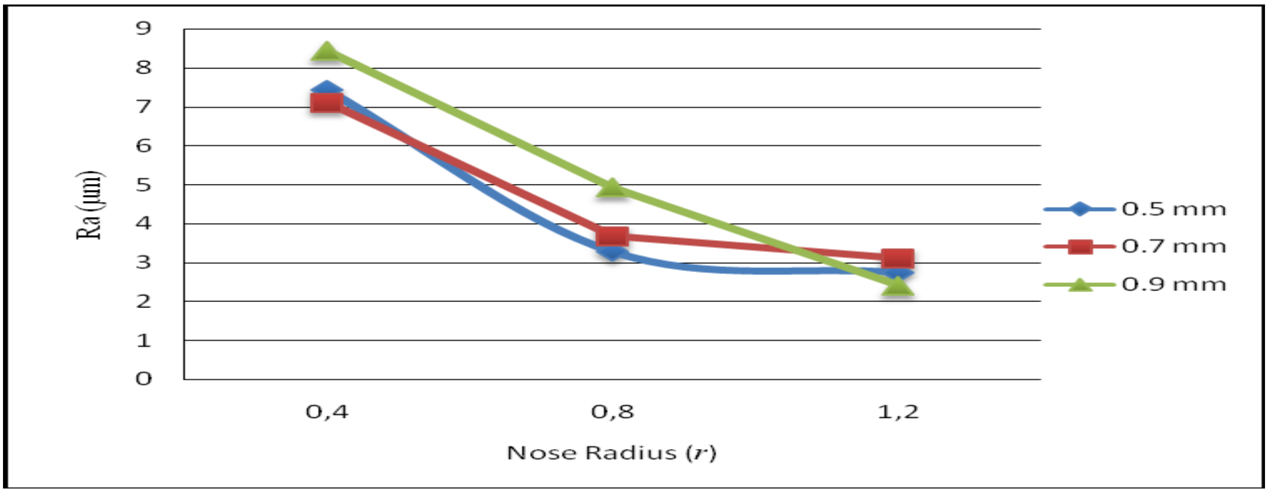


Fig. 1.2. Surface Roughness(Ra) and Nose radius(r) [4]

In the experiment Mehmet analyzed that the obtained machining conditions and roughness measurements experimental parameters and the recorded average roughness values and it is concluded that the most influence parameter is the nose radius on surface roughness. The surface roughness which has been more deflated with the effecting quality is obtained for rpm, feed rate, depth of cut and nose radius are 318 rpm, 0,25 mm/rev, 0,9 mm, and 0,4 mm respectively.

Metal-based composites are used in cosmic space, space, naval navigation and other structural applications, due to their remarkable physical and mechanical correction in one of the articles proposed by prakash rao cra, bhagyashekar m.sb, narendraviswanathc [5]. Surface roughness of processing parameters. Metal network composites are manufactured using a variety of advancements to address market demand, such as heat resistance, which reduces one-part costs, reduces density, and increases wear resistance. Composite materials are classified as hard materials. The heterogeneous structure of composite materials determines the frustration of the cutting tool during the processing of composites, which are mainly related to the hardness of the particles, resulting in higher surface roughness.

In this way, the paper shows the results of the roughness estimates for the surface of the K10 class carbide and polystyrene diamond (PCD), and the Al6061 foam composites containing 0% -15% of the flame are 5%. Parametric studies were performed in accordance with ISO 3685 standards, taking into account the dry state of treatment. The machining parameters are cutting speed 300m / min to 600m / min 100m / min. In the tube, 0.06mm / restlessness up to 0.24mm / 0.06mm / partition upright, using a constant cutting depth of 1.2mm, which is three times the nose radius of the cutting unit. The results showed that PCD inserts show that the surface roughness is reduced when composites containing 10% filler material are glued compared to embedded K10 class volfram carbides.

The author concludes that the processing of aluminum melt ash composites, although the roughness of its surface decreases, the cutting speed increases. As feed increases the surface roughness (Ra), the feed is directly proportional to the Roughness. A low surface roughness has been measured for all machining conditions for the machining of an aluminum alloy metal matrix composition containing 10% filler. Find high-level roughness of the surface of composites containing 15% filler, this may be due to the proximity of the miniaturized scale pairs. Surface roughness is measured on aluminum ash composites when processed using PCD devices, measured in a small amount compared to the K10 class carbide, placed under the same conditions.

The article analyzes the surface roughness optimization in facial rotation operation by processing en-8 k. adarsh kumar1, ch.ratnam2, bsn murthy3, b.satish ben4, k. raghu ram mohan reddy5 [6]. The main objective of this study was to establish a link between various parameters such as feed rate, cutting speed and cutting depth, and improved metal working conditions, taking into account surface roughness. Different surface roughness values of a renewable surface will determine the relationship between the operating parameters. Various experiments were carried out to control the predicted surface roughness value by turning the process with different parameters. This work examines the effect of cutting conditions on the operation of EN-8. Surface finish is a prerequisite for mechanical parts customers. The reason for this study document is to investigate the ideal cutting conditions to minimize the roughness of the surface when looking for a re-inspection. This document presents the effect of cutting factors, such as Shaft speed, feed and cutting depth, surface finish EN-8. Another relapse test (RA) is added, which uses fluctuations to determine the performance of test estimates and shows the effect of cutting factors on surface roughness. The treatment was carried out using a solid carbide. This work examines the effect of cutting conditions on the operation of EN-8. The processing was carried out using cemented carbide space.

The purpose was to determine the relationship between cutting speed, feed rate and cutting depth and return conditions, considering surface roughness. These connections are obtained by various relapses (RA). Surface finish is one of the most important customer needs for machined parts. The motivation for this exam paper is to investigate the ideal cutting conditions to minimize surface roughness by looking at the repeat examination. This paper presents a pilot study aimed at examining the effects of cutting parameters, such as spindle speed, feed rate and cutting depth on EN-8. A number of relapsing examinations (RAs) are used to determine the performance of test estimates and show the influence of cutting parameters on surface roughness. Different relay modeling is provided to predict surface roughness using processing parameters. The article deals with the influence of mechanical working parameters and the process of cutting power and surface finishes, when the light steel and aluminum are rotated by the ball on the track j1, leela krishna j2, tejomurthy p3 [7]. This method is used to improve surface finishes and reduce control needs by reducing the cutting power used in the treatment process.

The productivity and nature of machining parts are the main difficulties of the metalworking industry during the turning process. In this way, the cutting parameters must be taken and simplified in order to control the required surface quality. Therefore, measurable research models and measurable / digital models are widely used for updating. The research project was developed on the basis of two factor procedures, a difference study was conducted to determine the influence of cutting factors on surface finishes, and cutting forces were created using a large number of repeat examinations. The coefficients were calculated using a relay test, and the ideal was built. The ideal test is due to its adequacy, with a 95% confidence level. Using a scientific model, the effects of primary and interaction on different process factors in the turning process were investigated.

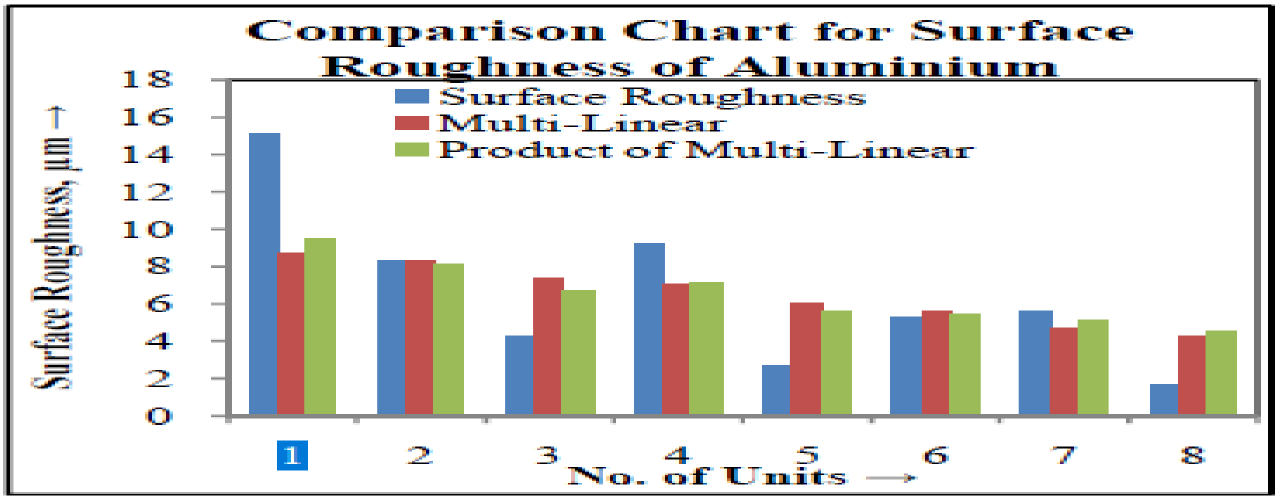


Fig. 1.3. Comparison of Surface Roughness for MS [7]

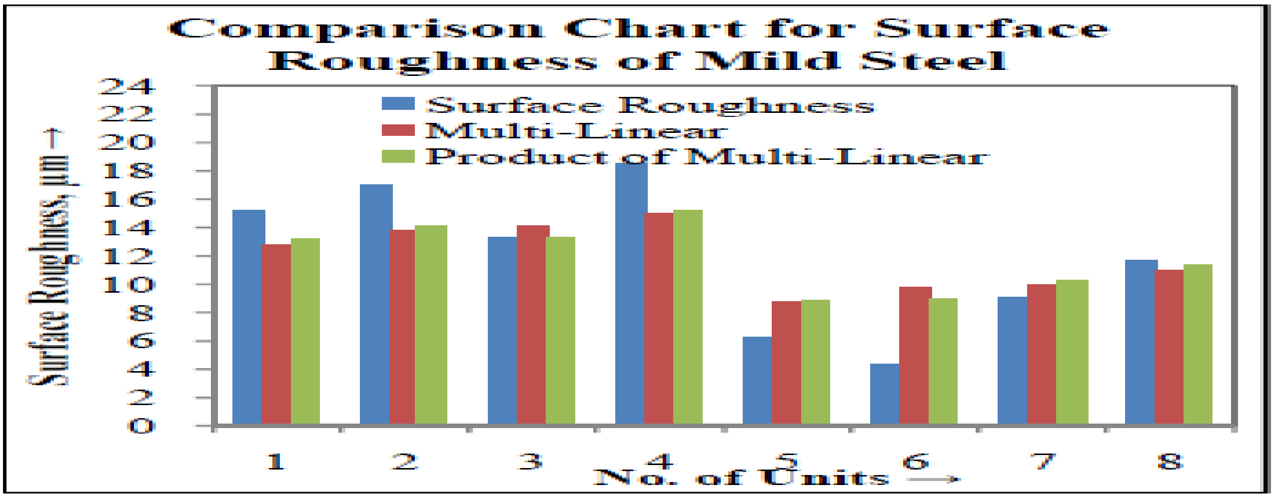


Fig. 1.4. Comparison of Surface Roughness for MS [7]

Comparison of surface roughness according to MS [8] The test values and ideal surface machining and cutting power values are significantly above the aluminum and mild steel margin points. Light steel surface finish and cutting power are higher compared to aluminum. When the feed increases, the surface finish and cutting power increase, keeping the speed, and cutting depth consistent. When the speed increases, the surface finish is reduced and the cutting power increases while maintaining the feed and cutting depth.

Cutting depth increases, surface finish and cutting power increase while maintaining speed and feed. Surface treatment and turning cutting power depend on the type of cutting fluid used for various parameters, such as the geometry of the device. To sum up, it can be argued that an elaborated model can reflect surface treatment and cutting power as far as processing parameters are concerned with the range of factors investigated. On the other hand, it also extracts powerful process parameters in order to calculate the approximate surface treatment and cutting power. The influence of various process factors, such as shaft speed, feed, cutting depth on surface quality and cutting power, is investigated according to their predicted values. Subsequently, parameters such as the diameter of the shaft, cutting fluid, cutting edge, material extraction speed, etc. can be performed. Effect on treated surfaces during turning process.

In the research work, investigate the inconel surface roughness experiment under different machining conditions: sunil kumar, dilbag singh, nirmal s. Calamus[8] . "Inconel 718" was used to produce "Inkolin 718" surface with a variety of scouring tools. The use of nickel-containing super components of Inconel 718 is increasing in many complex applications such as aviation, the nuclear industry, the automotive industry, and gas turbines. They are hard to resist machines, depending on their high quality and weight ratio. Improved surface quality is one of the main treatments for worries. Due to the low conductivity and high quality of the Inconel 718, there are various inconveniences. The high amount of heat in the cutting area also complicates the processing of this material. Later, cooling at the cutting site appeared to be necessary during a powerful process. The results show an unmatched execution of MQL processing compared to dry and wet conditions. The results show unmatched performance in MQL treatment for dry and wet conditions

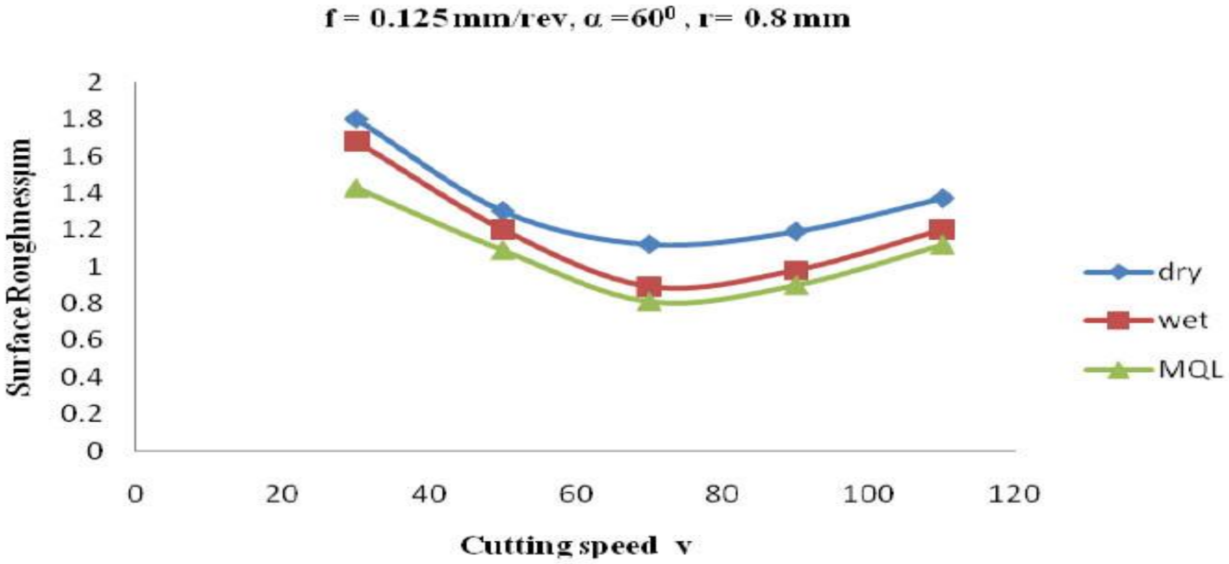


Fig. 1.5. Surface roughness Vs cutting speed

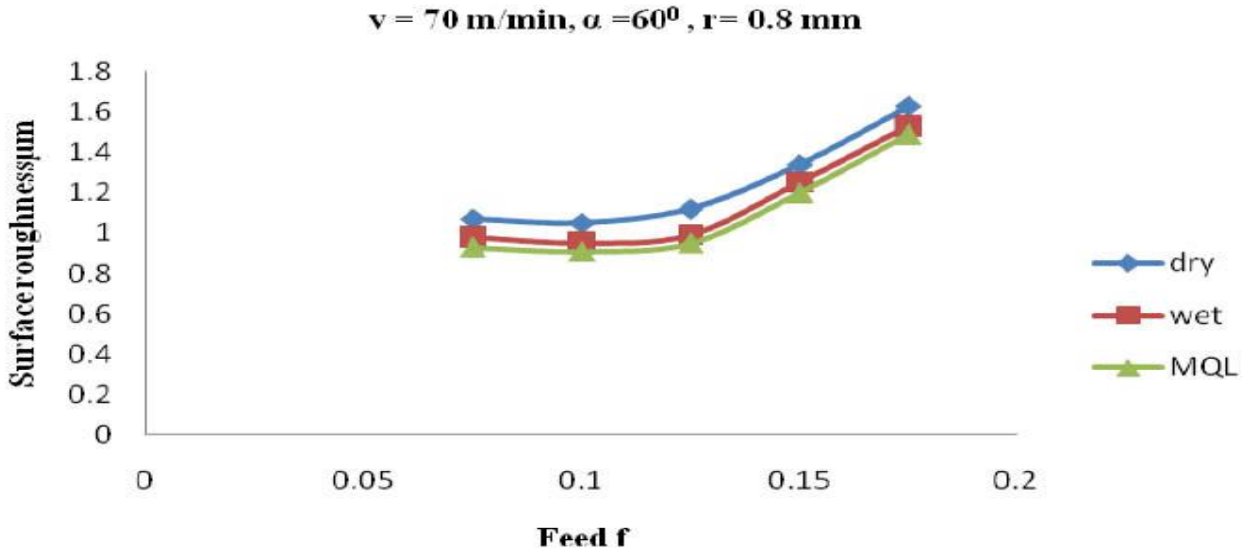


Fig. 1.6. Surface roughness Vs feed rate

These graphs show that the nose radius most influences surface roughness, followed by feed and speed. The design studies that the best surface value is with the organization of MQL. This could be due to the fact that the process of wearing the coolant tool was gradual, as the temperature dropped in the cutting area, resulting in increased quality and high hardness. It is also clear from the sites that better surface quality is achieved at an average supply speed, nose radius, and cutting speed. The roughness of their substrates (Ra) is found to be 0.91mm and the MQL partner processes them

In summary, the study shows that the nose radius of a tool is the main factor affecting surface roughness, as well as the approach and propagation coefficient. A square model created using RSM is sufficiently precise and can be used to guess by parameters. Consumption of MQL contributes to the development of valuable surface quality. The surface finish changes from about 12 to 17% using MQL.

Nexhat Qehaja, Kaltrine Jakupi, Avdyl Bunjaku, Mirlind Brui, Hysni Osmani describing the effect of machine time and factor on the surface roughness during the process of turning[9]. This paper, surface roughness of the model, was developed on the basis of the reaction surface method, which deals with mechanical processing parameters such as Feed rate, tool geometry, nose radius and machining time, affecting the surface roughness of the extrusion turning process. The analysis was developed and based on the premise of three levels of different designs. The most important surface quality measurements are medium surface roughness (Ra), mainly due to many machining parameters such as the actual drill edge and edge, cutting speed, feed rate, depth of cutting, nose radius, machining time, etc. The results are in line with the published field results, confirming the viability of the relay test when simulating surface roughness in a dry turning process.

In conclusion the results open that feed rate looks to affect the surface roughness more basically than nose radius and cutting time. With the relapse condition generated, the best blend of design independent factors for achieving the streamlining of cutting procedures was presented. This paper presents research of different cutting parameters influencing the surface roughness in desiccated turning of coated tungsten carbide embeds. The examinations of this study indicate that the cutting factors like feed rate, nose radius and cutting time are the foremost impacting factors, which influence surface roughness. Factual model's deduction defined the spot of influence of each cutting administration component on surface roughness criteria

In summary, it can be concluded that the supply speed more influences surface roughness than the radius of the nose and cutting time. By creating a recovery condition, the best combination of independent design factors was presented to simplify cutting procedures. This paper presents studies of different cutting parameters influencing surface roughness of tungsten carbide coatings. The results of this study indicate that cutting factors such as feed rate, nose radius and cutting time are the most important factors influencing surface roughness. The actual model deduction defines the influence of each cutting component on surface roughness criteria

The Taguchi method performed by Anirban bhattacharya (2009) [10] is a way to solve the rationalization process and control the surface roughness factors such as cutting depth, cutting speed and feed rate. This study mainly focused on surface roughness and the use of power in high-speed machining operations. The evaluated results showed the critical effect of surface roughness on the power utilization and cutting speed, and different parameters have no influence on surface roughness, as previously investigated by other parameters. The results showed the critical effect of cutting speed on surface roughness and power utilization, and the alternative parameters did not have a significant effect on the reactions. Since then, the ideal cutting factors have been obtained. Combining the strategy with the orthogonal array and examining the changes was used to determine the limit, the supply speed and the cutting speed commitment, and the effect on three surface roughness parameters and power utilization. The research study shows that the influence of cutting parameters on the finishing surface and energy utilization using the Taguchi system method.

Overview of the literature showed that cutting regimes influence on surface roughness (Ra) is investigated only for constant cutting speed (rpm) and feed (mm/rev), meanwhile workpiece shape and the influence of constant surface cutting speed control using constant surface cutting control code G96 on surface roughness during facing and profile operations is not investigated. Overview also showed that statistical surface roughness prediction, including workpiece diameter and surface cutting speed as additional independence variables in the regression analysis is not investigated.

2. TURNING PROCESS ANALYSIS

2.1. Cutting process description

Turning is the removal of material from the outer diameter of a rotating cylindrical workpiece. Turning process uses are very common process in automotive industry.

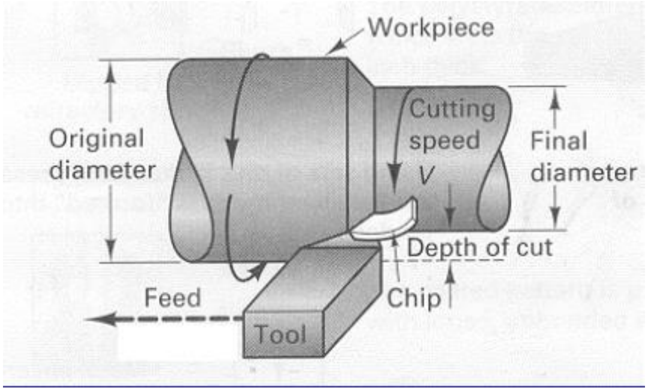


Fig 2.1 Turning process.

Taper turning is practically the similar, except that at an angle to the work axis of the cutter path. Similarly, in contour turning, the distance of the work axis from the cutter is varied to produce the required shape. Even though a single-point tool is specified, this does not exclude multiple-tool setups, which are often employed in turning. In such setups, each tool operates independently as a single-point cutter.

2.2. Cutting factors in turning

The three basic factors in turning process are cutting speed, cutting feed, depth of cut. Rather than this factors the factors like material, type of cutting tool has huge influence, obviously, beside these speed feed and depth of cut factors can be adjusted by adjusting the control by operating machine in real time

Speed:

Speed can be referring to Cutting speed of work piece and spindle speed. After starting in rpm, it specifies their rotary speed. but the most important application in turning process is surface speed or the movement of workpiece material passing through the cutting tool. It is the artefact of rotational speed times the circumference of the workpiece right before the cut operation is starting. It is measuring unit is (m/min) meter per minute. And only refers to workpiece. Even if the rotational speed if remain the same still the different diameter will have different cutting speed on workpiece diameter [11]

$$v = \frac{3.14 * d * n}{1000}\ (\mathrm{m/min}) \tag{2.1}$$

Where, v is the cutting speed m/min in turning process, d is the initial diameter of the work piece in mm, and n is the spindle speed in RPM.

Feed:

Cutting feed mostly refers to the cutting tool and the rate at the tool for cutting of a material of workpiece. It is always related to spindle speed we can say directly proportional to spindle speed and its unit is mm per revolution (mm/rev)

$$f = f_m \cdot n\ (\mathrm{mm/min}) \tag{2.2}$$

Where f_m is the feed in mm per minute, f is the feed in mm/rev and n is the spindle speed in rpm.

Depth of Cut:

Depth of cut is also one of basic parameter in turning operation. It can be understandable. Depth of cut is the thickness of the material we remove from workpiece in a single time, or the cut to uncut surface distance. The unit is mm. it removes material by two times it is because of both side layer of the work.

$$d = (D - d) \div 2\ \text{mm.} \tag{2.3}$$

Where D and d represent initial and final diameter (in mm) of the workpiece respectively.

3. EXPERIMENT TECHNIQUE

3.1. Experimental setup

The experimentation was setup at CNC lab and carried out with the help of RAYO CNC 165-750/100 lathe showed in Fig 3.1. CNC machine used for turning of workpiece with several experiments with different G-Codes for programming the CNC machine for turning operation. Program was made according to G-codes. In the first experiment we used nine workpieces for turning operation where use of G97 which is variable surface speed by setting feed rate constant.

Fig. 3.1. Rayo Pinacho CNC turning machine

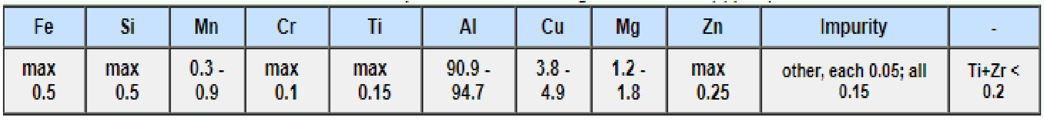
3.2. Workpieces

Figure 3.2. shows the workpiece having conical shape for turning process. The material of workpiece was selected aluminium alloy Al3Zn6. Aluminium alloy is the best material for machining process and for experimental uses. Uses of aluminium alloy mostly of the automotive industries incredible because of its chemical and chemical properties. Aluminium alloy turning is quite impressive.

Fig. 3.2. Conical shape workpieces after machining

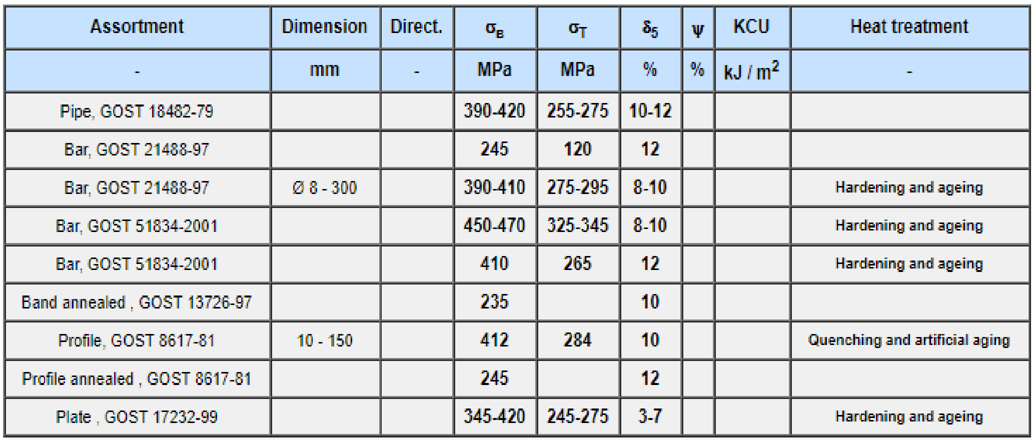
Table 3.1 and Table 3.2 shows the chemical composition and mechanical properties of the material.

Table 3.1.Chemical composition of the material [9]



Fe	Si	Mn	Cr	Ti	Al	Cu	Mg	Zn	Impurity	-
max 0.5	max 0.5	0.3 - 0.9	max 0.1	max 0.15	90.9 - 94.7	3.8 - 4.9	1.2 - 1.8	max 0.25	other, each 0.05; all 0.15	Ti+Zr < 0.2

Table 3.2. Mechanical properties of material [9]



Assortment	Dimension	Direct.	σ_B	σ_T	δ_5	ψ	KCU	Heat treatment
-	mm	-	MPa	MPa	%	%	kJ / m^2	-
Pipe, GOST 18482-79			390-420	255-275	10-12			
Bar, GOST 21488-97			245	120	12			
Bar, GOST 21488-97	Ø 8 - 300		390-410	275-295	8-10			Hardening and ageing
Bar, GOST 51834-2001			450-470	325-345	8-10			Hardening and ageing
Bar, GOST 51834-2001			410	265	12			Hardening and ageing
Band annealed , GOST 13726-97			235		10			
Profile, GOST 8617-81	10 - 150		412	284	10			Quenching and artificial aging
Profile annealed , GOST 8617-81			245		12			
Plate , GOST 17232-99			345-420	245-275	3-7			Hardening and ageing

3.3. Surface roughness measurement

Surface roughness tester is used to know measurement of Surface roughness of a material after turning process complete. To find the quality of a surface, Surface roughness is important criteria. It is very important parameter. Using “Mitutoyo” surface roughness tester surface finish can be measured. Its small, exact, light in weight and easy to use instrument for surface roughness findings.it shows surface roughness waveform on color LCD display screen. Which gives us excellent readability from display. As its provided by backlight we can see measurements in dark environment in which has internal memory to store up to 10 measurements of measured profiles. Also, it has several important buttons to see different values like *R*a, *R*q, *R*z and waveform of measured surface.

Fig. 3.3. Mitutoyo of surface roughness tester

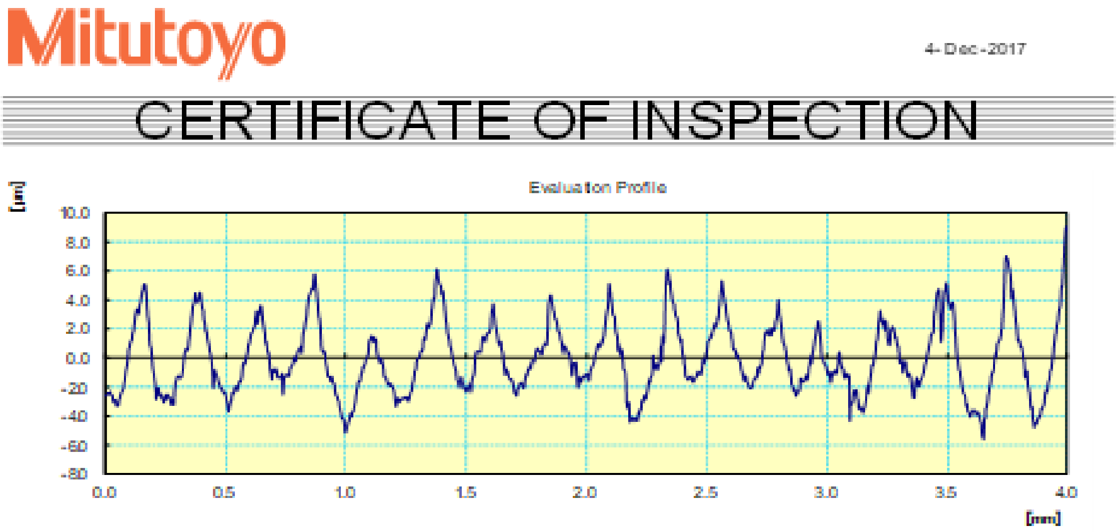
Table 3.3. shows the specification of model SJ-210 Mitutoyo of surface roughness tester.

Table 3.3. Specification of Mitutoyo of surface roughness tester[12]

Measuring Axis:	X and Z axis
Measuring Range:	(360 µm/0.02 µm)
Measuring Speed:	Measuring 0.01, 0.02, 0.03 in/s. 0.5mm/s, 0.75 mm/s.
Measuring Force:	0.75Mn
Skid Force:	Less than 400mN
Evaluation Parameters:	Ra, Rc, Rz, Rp, Rv, Rku, Rpc, Rmax, Rmr
Analysis Graph:	Bearing area curve/ Amplitude distribution curve
Filters:	Gaussian, 2CR75, PC75
Cut off length:	0.003, 0.01, 0.03, 0.1
Sampling length:	0.003, 0.01, 0.03, 0.1
Number of Sampling Length:	X1, x2, x3, x4, x5, x6, x7, x8, x9, x10
LCD Dimensions:	1.45 × 1.93. (36.7 × 48.9 mm)

Calculation Result:	3 parameter vertically display / 1 Parameter / Trace to measurements Horizontal measurements 1 Parameters / 4 parameters / Trace to measurements
Printing Functions:	Measurements conditions / Calculation Results

Surface roughness measuring example is presented in Fig. 3.4 (a, b) as follow.



Mitutoyo

4-Dec-2017

CERTIFICATE OF INSPECTION

a

Work Name	Sample	Oprator	Mitutoyo
Measuring Tool	SurfTest	Comment	Ver2.00
Standard	ISO 1997	N	5
Profile	R	Cut-Off	0.8mm
λs	2.5µm	Filter	GAUSS
Ra	2.012 µm		
Rq	2.435 µm		
Rz	10.940 µm		

b

Fig. 3.4. (a, b) Surface roughness measuring example

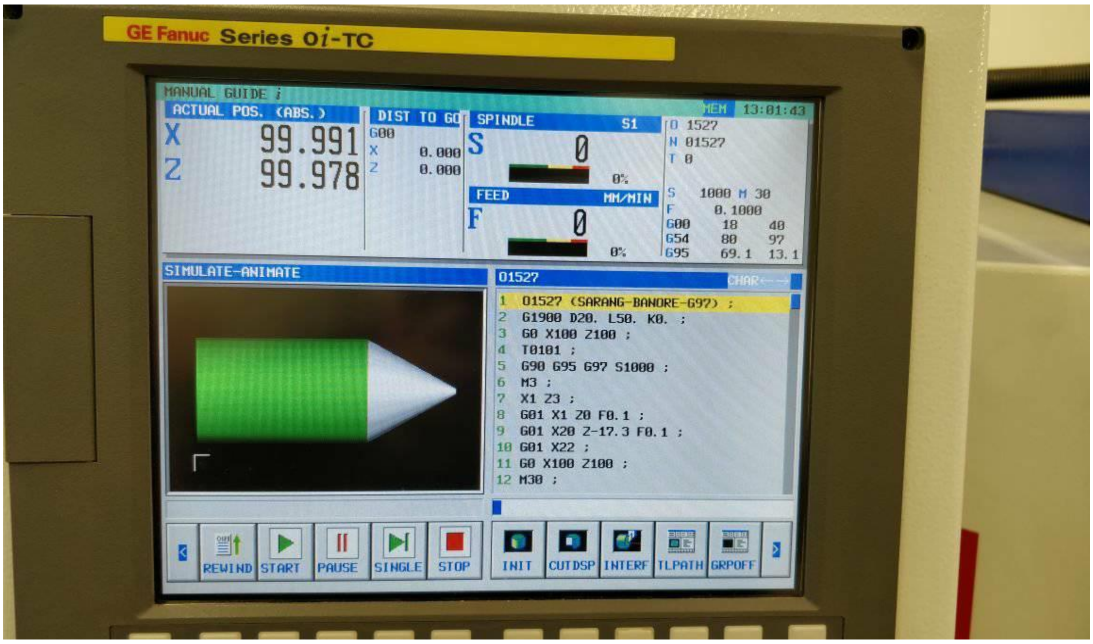
Fir 3.4 ‘a’ shows the calculated surface roughness in wave form and fig 3.6. ‘b’ shows Measured surface roughness data. Here Ra value is presented 2.012 µm.

Turning tool used in the experiment is showed in Fig. 3.5. The workpiece was machined using "Kennametal" turning tool with the insert tip radius of 0.8 mm.

Fig. 3.5. Turning process cutting tool

3.5. Turning process programing

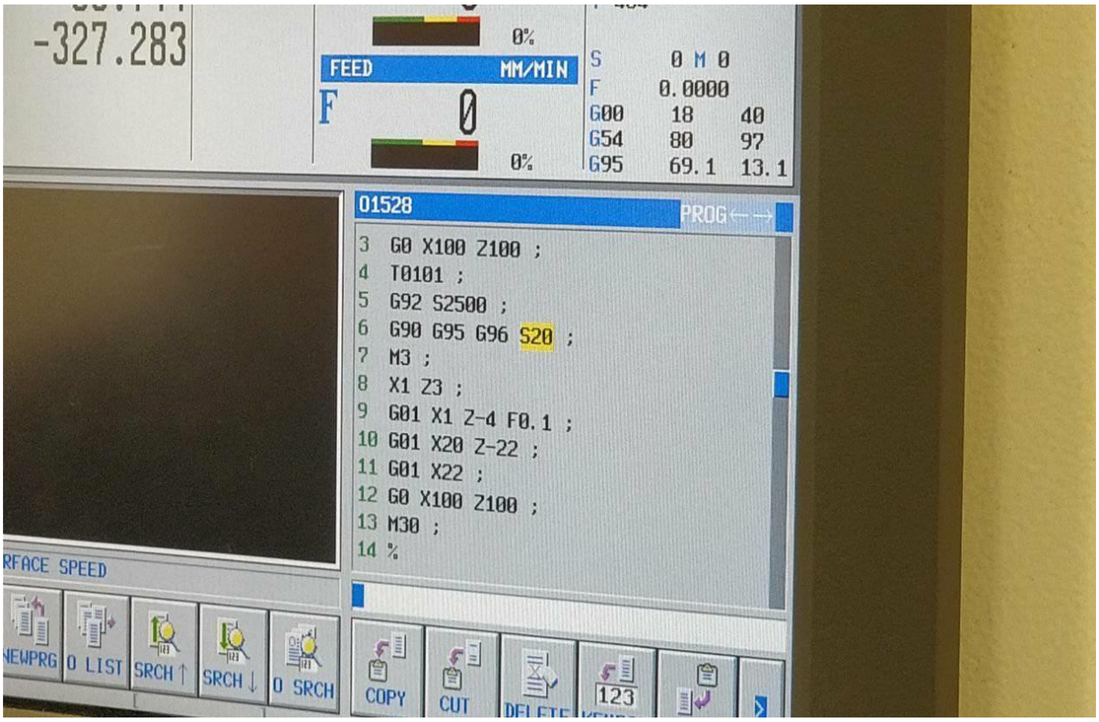
Fig 3.6. shows the machining program for Variable Cutting Speed G97). The program of G-code G97 which also known as variable cutting speed. In the program specify the cutting diameter D 20mm, cutting feed which is F 0.1mm/rev. with this program variable cutting speed turning process take place. This process is conventional turning process.



```
01527 (SARANG-BANORE-G97) ;
G1900 D20. L50. K0. ;
G0 X100 Z100 ;
T0101 ;
G90 G95 G97 S1000 ;
M3 ;
X1 Z3 ;
G01 X1 Z0 F0.1 ;
G01 X20 Z-17.3 F0.1 ;
G01 X22 ;
G0 X100 Z100 ;
M30 ;
```

Fig. 3.6. Machining program of the Variable Cutting Speed

Figure 3.7. shows the program of G96 constant surface speed in which Spindle speed kept at 2500rpm and Constant surface speed kept at S 20 m/min. with D 20 mm Diameter. From this program turning process of 9 workpiece experiments take place.



```
G0 X100 Z100 ;
T0101 ;
G92 S2500 ;
G90 G95 G96 S20 ;
M3 ;
X1 Z3 ;
G01 X1 Z-4 F0.1 ;
G01 X20 Z-22 ;
G01 X22 ;
G0 X100 Z100 ;
M30 ;
%
```

Fig. 3.7. Machining program of Constant Surface Speed turning

4. EXPERIMENTAL PART

In order to evaluate surface roughness on the surface of the conical workpieces during turning and it dependence on cutting regimes and workpiece diameter changing two types of the experiment was performed. The first was carried out using conventional turning, when is set constant cutting speed (*V*) and feed (*f*) and variable surface cutting speed (*S*) due to workpiece diameter (*d*) change during conical workpiece. These regimes were programed on CNC lathe by means the linear interpolation code G01 and programming constant spindle speed (*n*) in revolution per minute (rpm/rev) and cutting feed (*f*) in millimeters per minute (mm/min).

After turning surface roughness was measured in three sectors of the conical workpiece: - 4 mm from the workpiece face, in the middle of the conical surface which corresponds to 9 mm from the workpiece face and the third sector of the surface that corresponds to 17 mm from the workpiece face.

The second experiment was carried out using surface cutting speed control during turning, when constant surface cutting speed (S) and cutting was feed (f) was set. Constant surface cutting speed was programmed using special code G96 with programmable function S (in m/min) what means that despite workpiece diameter changing surface cutting speed remains constant. During conical surface turning this condition is ensured by the lathe computer depending on programmed address S. if workpiece diameter increases, controller automatically decrease spindle speed in order to keep the surface cutting speed constant; and vice versus – if the workpiece diameter decreases lathe controller automatically increase spindle revolution to keep predicted surface cutting speed if due to workpiece diameter (d) change during conical workpiece.

4.1. Surface roughness investigation during conventional turning

Surface cutting regimes in this experiment was set using code G01 with spindle speed values of 1000, 1500, 2000 rpm and cutting feed of 0.1, 0.15, 0.2 mm/rev. These regimes were programed on CNC lathe by means the linear interpolation code G01 and programming constant spindle speed (n) in revolution per minute (rpm/rev) and cutting feed (f) in millimeters per minute (mm/min). Surface cutting speed V was calculated according the formula.

$$V = \frac{\pi * d * n}{1000} \ rpm \tag{4.1}$$

where *d* is workpiece diameter; *n* is spindle rotation speed.

Cutting regimes used in this experiment, calculated cutting speed and workpiece diameter values and measured surface roughness are presented in Table 4.1.

Table 4.1. Experimental values conventional turning experiment

No.	Workpiece diameter d, mm	Cutting feed f, mm/rev	Spindle speed n, rpm	Cutting speed V, mm/min	Surface roughness Ra, µm
1d1	2.199	0.10	1000	6.905	2.885
d2	8.931	0.10	1000	28.043	2.783
d3	17.113	0.10	1000	53.733	2.681
2d1	2.193	0.15	1000	6.886	2.326
d2	8.931	0.15	1000	28.044	1.900
d3	17.113	0.15	1000	53.733	1.878
3d1	2.193	0.20	1000	6.886	2.571
d2	8.931	0.20	1000	28.044	2.066
d3	17.113	0.20	1000	53.733	1.891
4d1	2.193	0.10	1500	10.329	0.948
d2	8.931	0.10	1500	42.066	0.701
d3	17.113	0.10	1500	80.600	0.611
5d1	2.193	0.15	1500	10.329	3.810
d2	8.931	0.15	1500	42.066	3.279
d2	17.113	0.15	1500	80.600	3.030
6d1	2.193	0.20	1500	10.329	2.854
d2	8.931	0.20	1500	42.066	2.824
d3	17.113	0.20	1500	80.600	2.012
7d1	2.193	0.10	2000	13.772	1.337
d2	9.250	0.10	2000	58.090	1.221
d3	17.000	0.10	2000	106.760	0.779
8d1	2.193	0.15	2000	13.772	2.817
d2	8.931	0.15	2000	56.088	2.441
d3	17.113	0.15	2000	107.467	2.418
9d1	2.193	0.20	2000	13.772	4.096
d2	8.931	0.20	2000	56.088	3.665
d3	17.113	0.20	2000	107.467	3.083

Cutting speed growing during turning when workpiece diameter is increasing during conical surface turning with constant spindle speed for various cutting speed and feed values is presented in Fig. 4.1 and Fig 4.2.

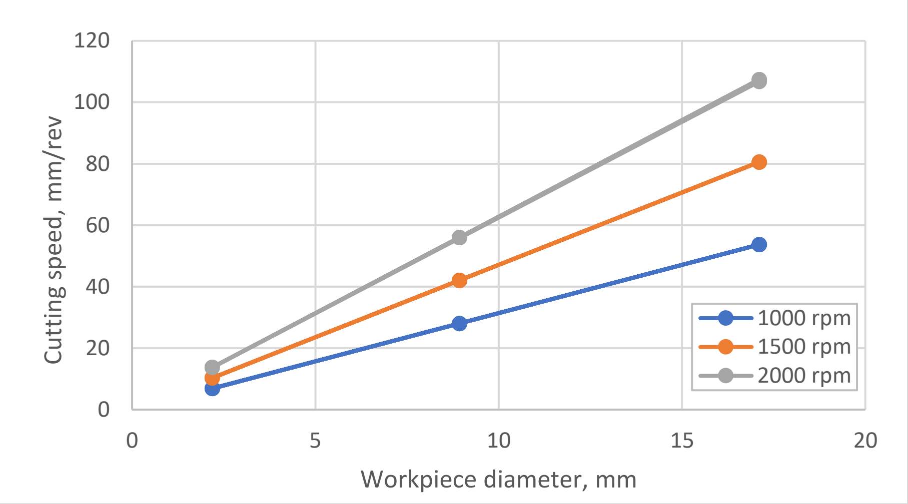


Fig. 4.1. Cutting speed (mm/rev) depends on spindle speed (rpm) and workpiece diameter

As seen from the Fig.4.1 surface cutting speed *V* increases in dependence on the workpiece diameter. If the spindle speed is set the constant cutting speed for the conical shaped workpieces according formula (4.1). The cutting speed increases when diameter increases. higher is the difference among diameter change of the workpiece higher the cutting speed. This effect finally results on the tool life-time, so this factor is important and should be evaluated when are curve-shaped workpieces are turned.

How cutting speed on the workpiece conical surface varies depending on spindle speed is showed in Fig. 4.2.

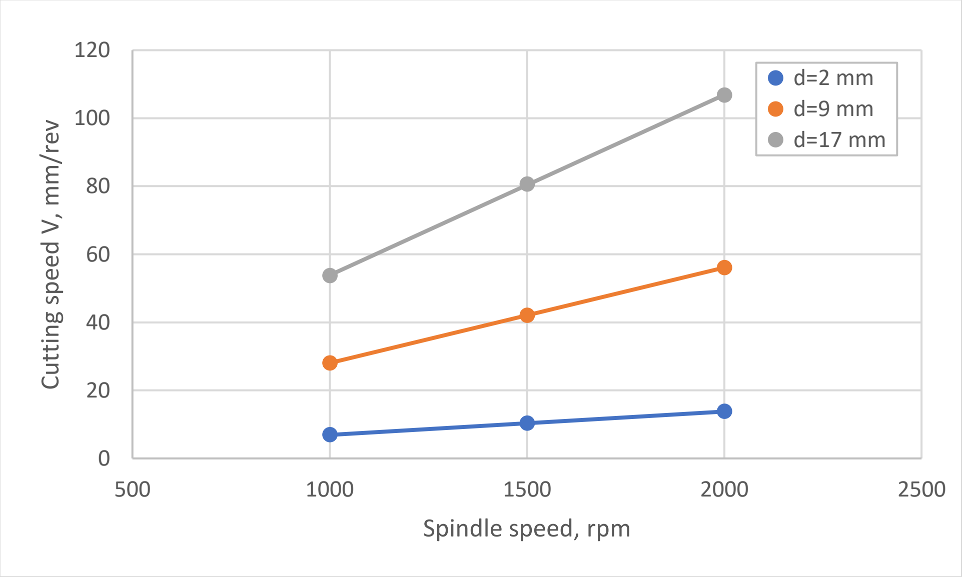
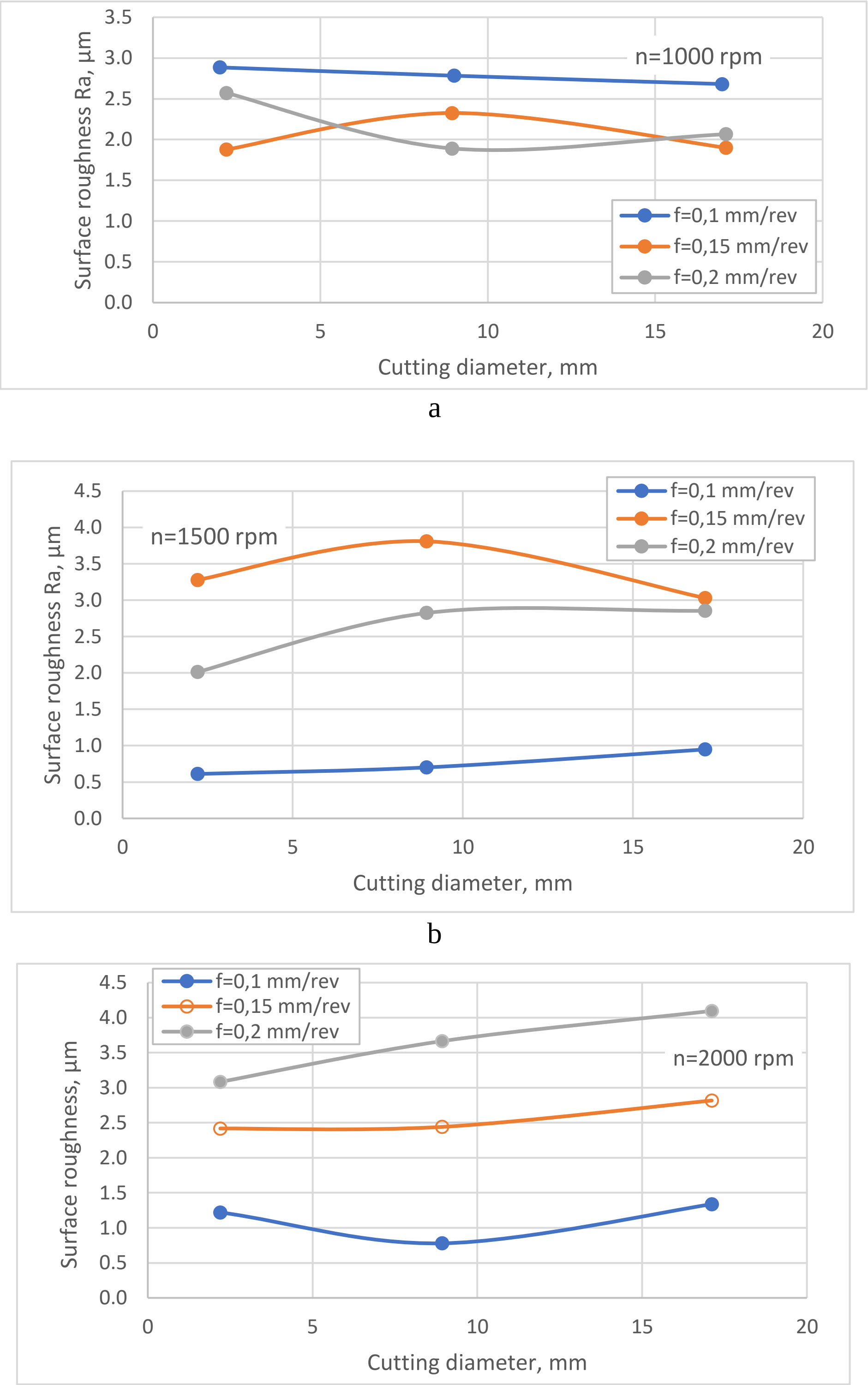


Fig. 4.2. Cutting speed variation vs. spindle speed in dependence on workpiece diameter change

This figure shows that cutting speed on the workpiece conical surface for fixed spindle speed values using code G01 depends on workpiece diameter. When workpiece diameter increases cutting speed proportionally increase. It means that for conical or another curve-linear surface cutting speed is not constant, and it results on the tool insert tool life.

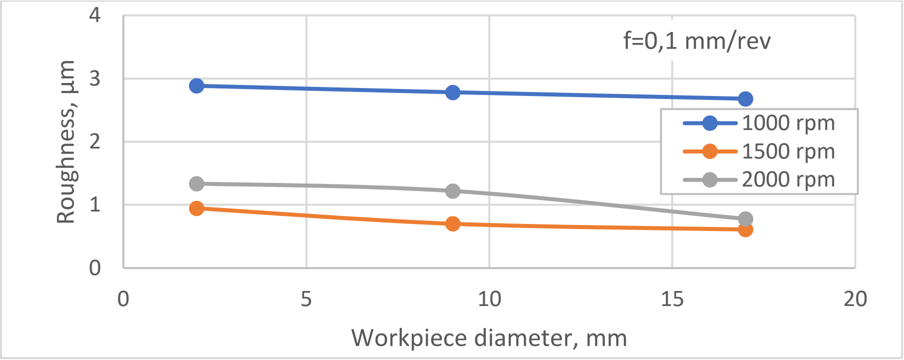
4.1.1 Workpiece diameter influence on surface roughness

The influence of the conical workpiece diameter change on the surface roughness during turning with constant spindle speed using code G01 for various cutting speed and feed values are presented in Fig. 4.3 and Fig 4.4.

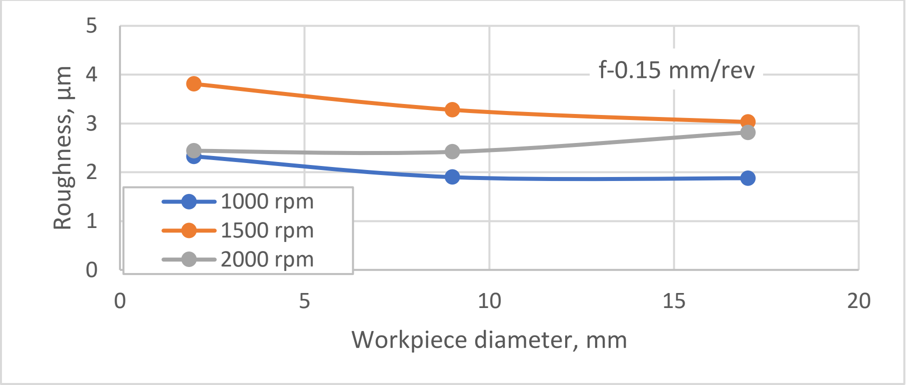


c

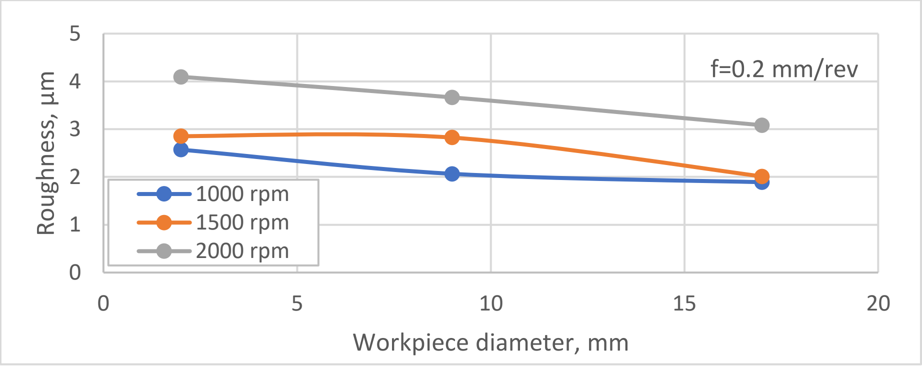
Fig. 4.3. Surface roughness during conical workpiece turning with constant spindle speed using code G01: a - *f*=0.1 mm/rev; b - *f*=0.15 mm/rev.; c - *f*=0.2 mm/rev



a



b



c

Fig. 4.4. Surface roughness during conical workpiece turning with constant spindle speed using code G01: a - n=1000 rpm; b - n=1500 rpm; c - n=2000 rpm

As is seen from Fig. 4.3 and Fig 4.4 surface roughness on the conical surface of the workpiece during conventional turning with G01 surface roughness stays the same or slightly decrease.

Highest surface quality is given for 2000 rpm, lowest - for 1000 rpm. If cutting speed is increasing surface quality is increasing (Ra values became lower) It means that in order to get higher surface quality spindle rotation speed should be higher. When feed and speed are constant surface roughness in all measured sections of the workpieces are similar, therefore for later analysis was used averaged values.

4.1.2 Spindle speed and cutting feed influence on surface roughness

Surface roughness on the conical workpieces surface was measured on the conical workpiece sectors 4 mm from the workpiece face, in the middle of the conical surface what correspond 9 mm from the workpiece face and on the third sector of the surface that correspond 17 mm from the workpiece face (Table 4.1). Measurement results are presented in Fig. 4.5 and Fig. 4.6.

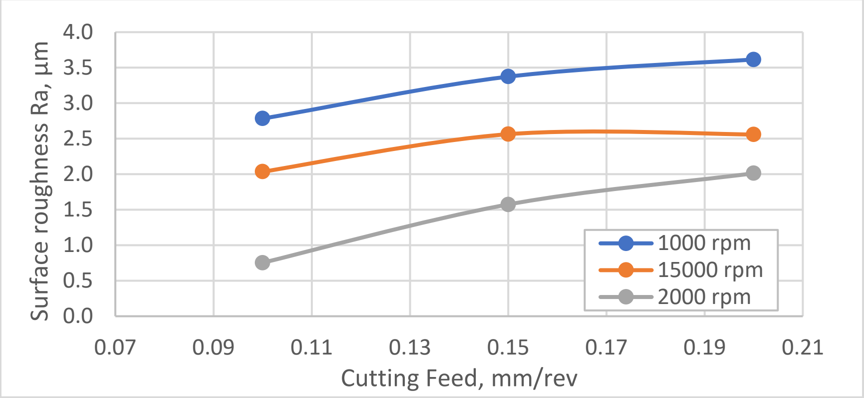


Fig. 4.5. Surface roughness variation on the workpiece conical surface for various spindle speed

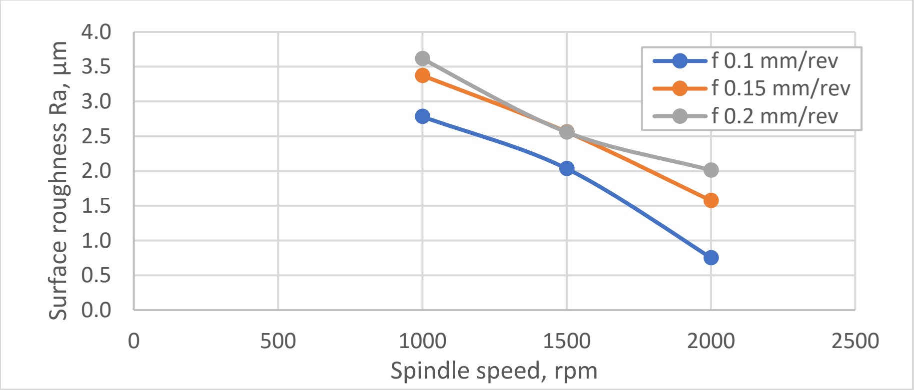


Fig. 4.6. Surface roughness variation on the workpiece conical surface depending on cutting feed

The spindle speed and cutting feed effects on surface roughness showed in Fig. 4.5 and 4.6. The surface roughness changes with variation of cutting feed rate, spindle speed. Surface roughness changing when spindle speed increases and decreasing with least and largest feed rate. Figure 4.5 and Figure 4.6 shows Cutting speed and feed influence on surface roughness (variable surface cutting speed) It shows the surface roughness values are much bigger when cutting feed is bigger.

When cutting feed is changing. Cutting feed are f 0.1, 0.15,0.2 mm/rev and spindle speed is 1000rpm, 1500rpm, 2000rpm. Change in spindle speed with change in cutting feed rate surface roughness values are changing. When spindle speed was 2000 rpm and cutting feed was 0.1mm/rev the quality surface roughness results was found better. If spindle speed is more and feed rate is lower the surface roughness can be better. If cutting feed is increasing surface quality is decreasing (Ra values became bigger). Highest surface quality is given for 2000 rpm, lowest surface quality is given - for 1000 rpm.

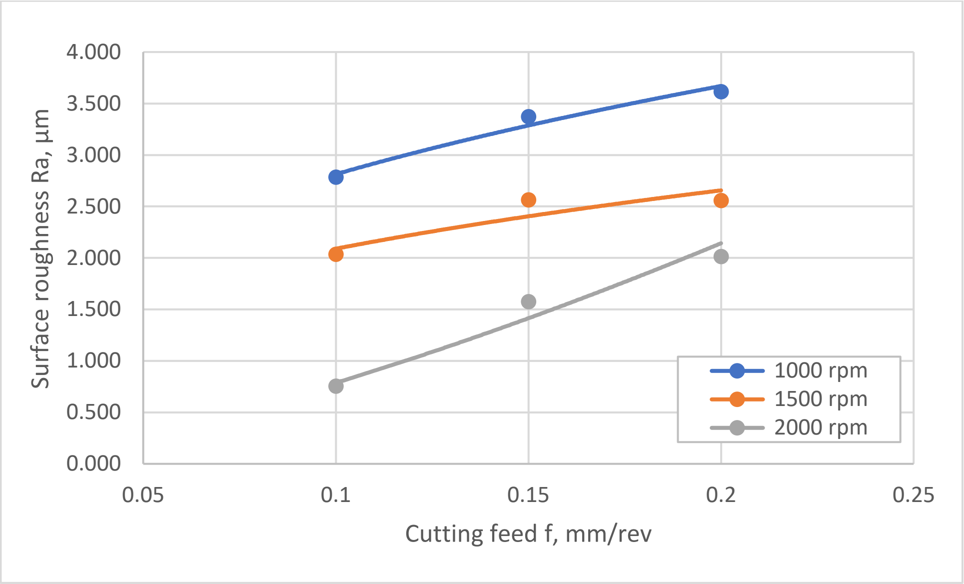


Fig. 4.7. Cutting feed influence on surface roughness of the conical surface during conventional turning with G01 code experimental

4.2. Surface roughness investigation during constant surface cutting speed control turning

This turning experiment was carried out using constant surface cutting speed control code G96., when surface cutting speed (S) was controlled constant and cutting was feed (f) was set. Constant surface cutting speed was programmed using programming codes G96 S150, G96 S100, G96 S50, G96 S20, G96 S16 and G96 S12, where the numbers beside address (S) according to the programming format express surface cutting speed in (m/min). In order to avoid lathe overload was programmed another limitation code G92, which for turning with G96 S150, G96 S100, G96 S50 was set using code G92 S2000 what means that if the actual spindle speed in (rpm) reached and exceeds (according formula (4.1) 2000 rpm, subsequent turning is going under 2000 rpm.

Initially experiment was performed with constant surface speed control codes G96 S50, S100 and 150 m/min surface speed. The cutting speed rate was set with different cutting feed rate values of 0.10, 0.15, 0.20 mm/rev.

In order to avoid machine overload spindle speed in this experiment was limited by the code G92 S2000. When the spindle speed depending on diameter changing on the conical workpiece surface increases, the speed of 2000 rpm limited actual spindle speed (Fig. 4.8).

Theoretical spindle speed calculated using formula (4.2) gave much bigger values therefore workpiece turning from the minimal diameter to the maximal goes like spindle speed was set the constant of n=2000 rpm. These values were calculated according to the formula (4.2) and are presented in Table 4.2.

$$n = \frac{1000 \cdot V}{\pi \cdot d} \tag{4.2}$$

where *n* is the spindle speed in rpm, *V* is cutting speed in mm/min, *d* is diameter of the workpiece in mm.

This phenomenon was given for turning with G96 S100 and G96 S150, meanwhile for G96 S50 actual spindle speed so decreases in order to keep constant surface cutting speed in the range of 50 m/min. Spindle speed limitation using code G92 S222 for turning with programmed constant surface speed control codes G96 S50, G96 S150 and G96 S100 is presented in Table 4.2 and showed in Fig. 4.8.

Table 4.2. Constant surface cutting speed control with codes G96 S50, G96 S150 and G96 S100 experimental results

No.	Workpiece diameter d, mm	Cutting feed f, mm/rev	Spindle speed n, rpm	Cutting speed V, mm/min	Surface roughness Ra, µm
1d1	5.81	0.10	2739	0.05	2.192
1d2	10.95	0.15	1455	0.05	2.915
1d3	16.08	0.20	991	0.05	3.707
2d1	5.68	0.10	5603	0.10	1.276
2d2	10.79	0.15	2953	0.10	1.811
2d3	15.10	0.20	2109	0.10	2.340
3d1	5.40	0.10	8845	0.15	1.352
3d2	11.11	0.15	4300	0.15	1.424
3d3	16.82	0.20	2840	0.15	2.726
4d1	5.89	0.10	2704	0.05	2.310
4d2	11.25	0.15	1415	0.05	3.954
4d3	16.76	0.20	950	0.05	4.892
5d1	5.24	0.10	6080	0.10	3.208
5d2	10.92	0.15	2916	0.10	3.618
5d3	16.60	0.20	1918	0.10	3.917
6d1	6.05	0.10	7893	0.15	2.601
6d2	11.43	0.15	4179	0.15	3.480
6d3	16.83	0.20	2839	0.15	4.076
7d1	5.52	0.10	2887	0.05	1.562
7d2	11.16	0.15	1427	0.05	2.758
7d3	16.80	0.20	948	0.05	3.915
8d1	5.35	0.10	5958	0.10	3.038
8d2	11.05	0.15	2882	0.10	3.193
8d3	16.76	0.20	1901	0.10	3.275
9d1	5.91	0.10	8089	0.15	3.507
9d2	11.31	0.15	4224	0.15	3.537
9d3	16.71	0.20	2858	0.15	3.921

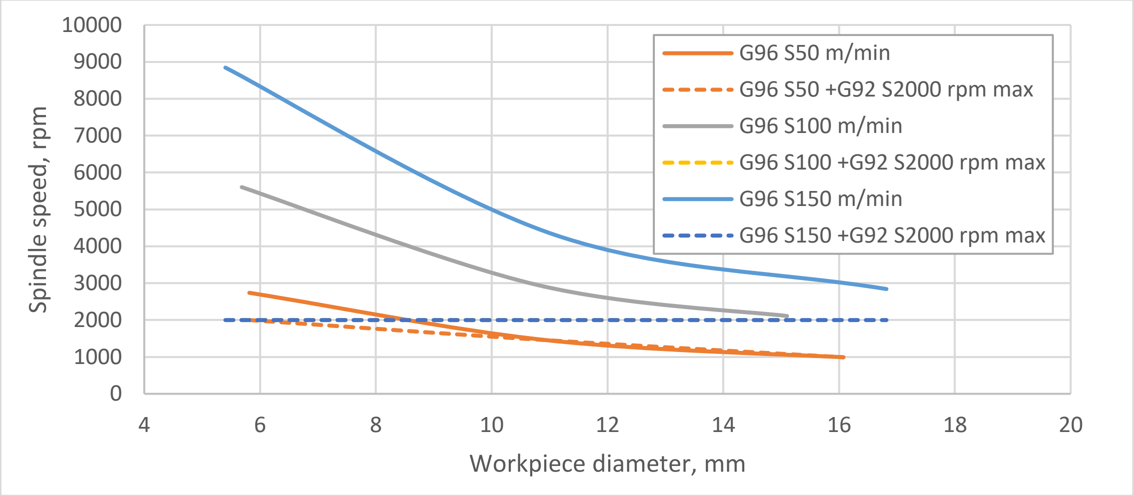


Fig. 4.8. Spindle rotation speed limitation during constant surface speed control: solid lines - calculated speed; dashed lines - limited speed

4.2.1. Workpiece shape influence on surface roughness during surface cutting speed control turning

As it is seen from the table 4.1 constant surface speed control experiments programed with G96 S150 and G96 S100 and limited by the code G92 S2000 in fact were performed while constant spindle rotation speed of 2000 rpm. Surface roughness dependency from the workpiece diameter during constant surface speed control G96 S100 and S150 m/min limited by code G92 S2000 is showed in Fig. 4.8. In order to evaluate surface cutting speed influence on conilal surface surface roughness was selected three sectors on the workpiece surface in such way that measured workpiece diameters noted as d1, d2 and d3 comprised 6, 11 and 17 mm (Table 4.2, Fig. 4.8).

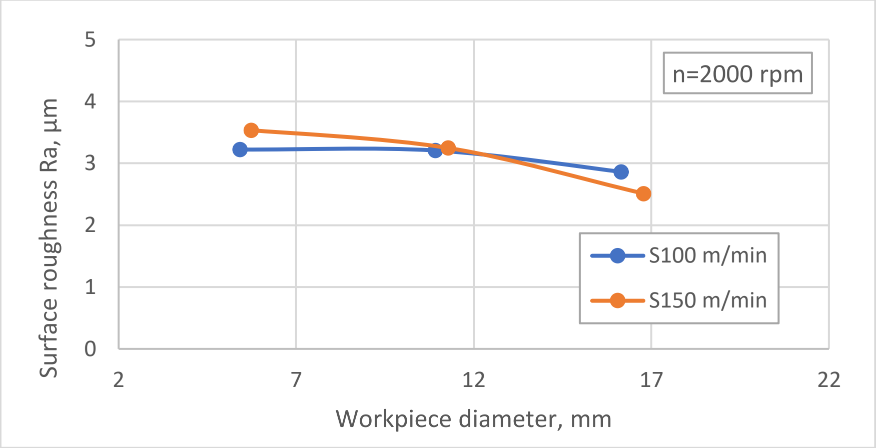


Fig. 4.9. Surface roughness dependency from workpiece diameter during constant surface speed control using code G96 S100 and S150 m/min limited by code G92 S2000

Surface roughness dependency from the workpiece diameter during constant surface speed control G96 S100 is showed in Fig. 4.10.

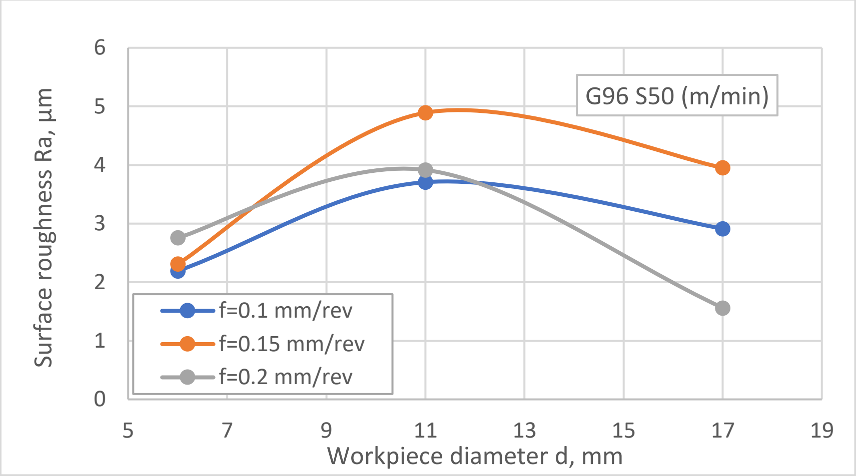


Fig. 4.10. Surface roughness dependency from the workpiece diameter durnig constant surface speed control G96 S100

How surface roughness depends on workpiece diameter and cutting feed is showed in Fig. 4.11.

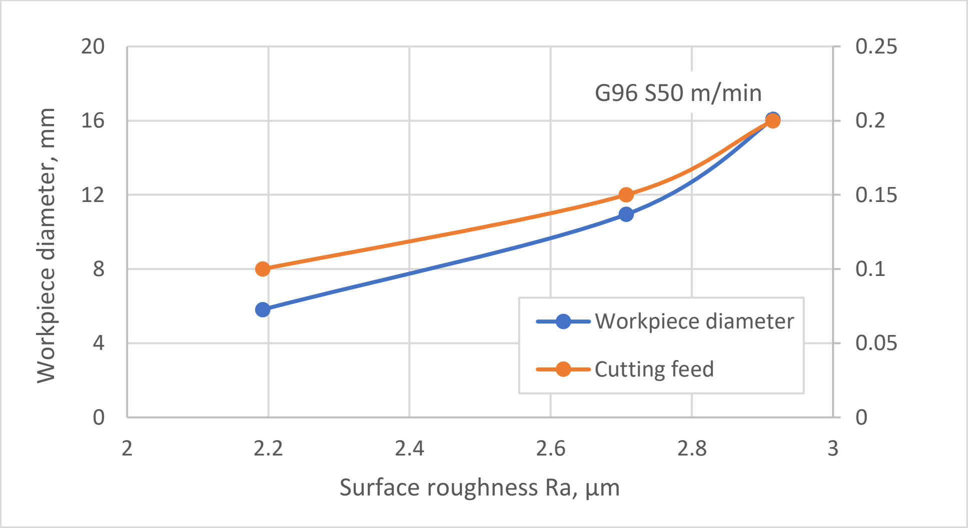


Fig. 4.11. Surface roughness variation depending on workpiece diameter and cutting feed during constant surface speed control G96 S50 m/min

As it is seen from Fig. 4.11 if the workpiece diameter increses surface roughnes also increases {surface quality is worst, because spindle rotation speed is decreasing (Table 4.2). The same surface roughness changing tendency is given with respect cutting feed: than bigger cutting feed value - than lower surface quality.

In order to evaluate surface cutting speed influence on the conical surface roughness additional experiment was performed in which surface speed codes were selected to get spindle rotation speed of 1000, 1500 and 2000 rpm in the measured workpiece sectors defined as d1, d2 and d3. In all these sections was measured surface roughness, calculated averade workpiece diameter, calculated actual surface cutting speed (m/min and mm/min) and spindle rotation speed (rpm).

Surface cutting speed was programmed with G96 S20, S16, S12 what means that surface cutting speed was 12, 16 and 20 m/min respectively.codes. Because surface cutting speed using G96 S20, S16, S12 codes do not exceeded limited spindle speed value which for this experiment was set of 3000 rpm, this experiment clearly showed spindle rotation decreasing with the workpiece diameter increasing.

Surface roughness was measured in the workpiece sectors which were calculated geometrically. These values are: d1= 2.199mm, d2 =8.931mm, d3= 17.133mm. Cutting feed rate was used the same as in the earlier experiments f=0.1, 0.15 and 0.2 mm/rev. Actual spindle speed was calculated using formula (4.2). These results are presented in Table 4.3. Spindle speed variation using programming codes G96 S12, G96 S16 and G96 S20 is presented in Fig. 4.15.

Workpiece diameter influence on spindle speed variation depending on workpiece diameter change depending on surface cutting speed control by code G96 and spindle speed limitation code G92 S3000 is presented in Fig.4.13.

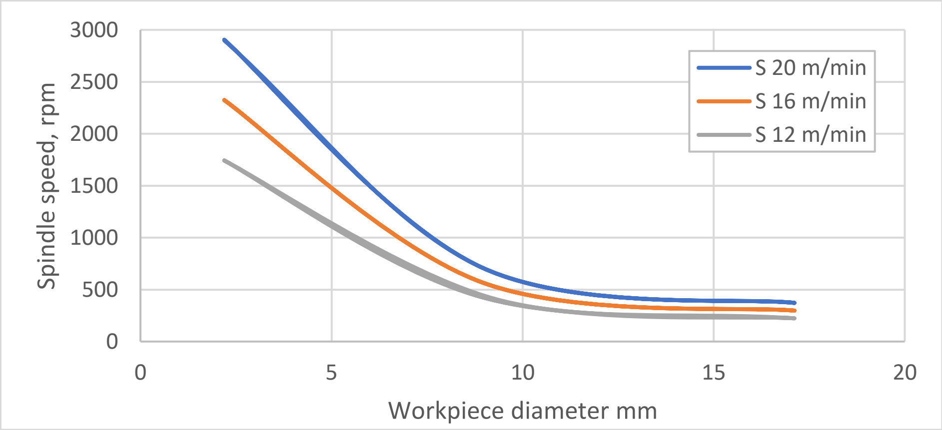


Fig. 4.12. Workpiece diameter influence on spindle speed variation depending on surface cutting speed control using code G96 S3000

Fig. 4.15. shows turning process of the conical workpiece using G96 code to control cutting speed. From the initial diameter (2 mm) up to final diameter (17 mm) spindle speed consequently decreases from its maximal value (3000 rpm) to its minimal value (see Table 4.3) in such way that surface cutting speed will remain the constant (12, 16 or 20 m/min) during workpiece turning.

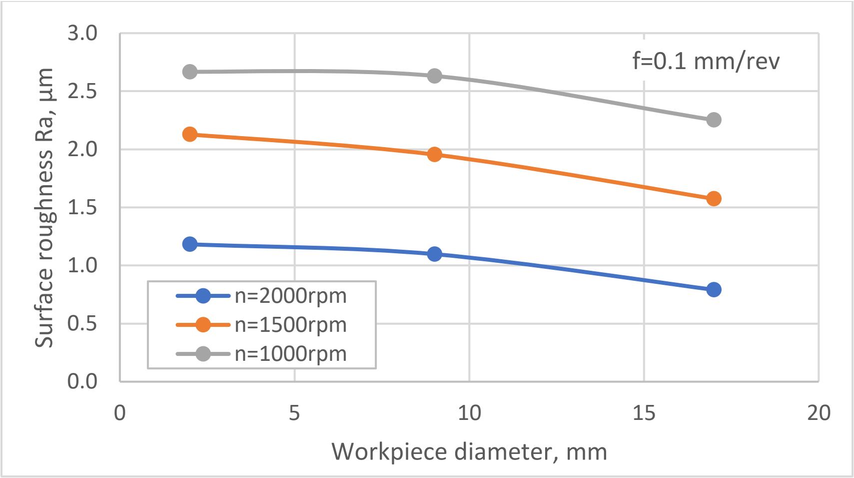
4.2.2. Cutting speed and feed influence on surface roughness during surface cutting speed control turning

Workpiece diameter influence on surface roughness during spindle speed control turning is showed in Fig. 4.3.1. How workpiece roughness during surface speed control turning using cutting speed control code G96 depends from the spindle speed and cutting feed during conical workpiece turning is showed in Fig. 4.13 and Fig. 4.14.

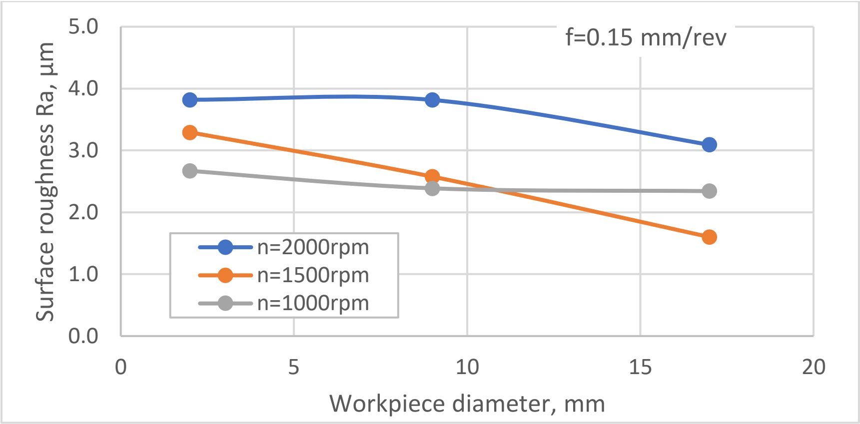
These graphs clearly show that during conical surface turning, using constant cutting speed control code G96 surface roughness compared to the turning with code G01, consequently decreases. It could be explained by increasing of the workpiece diameter and decreasing spindle rotation speed from the initial diameter (2 mm) up to final diameter (17 mm) spindle speed consequently decreases.

Table 4.3. Surface cutting speed control turning experiment result.

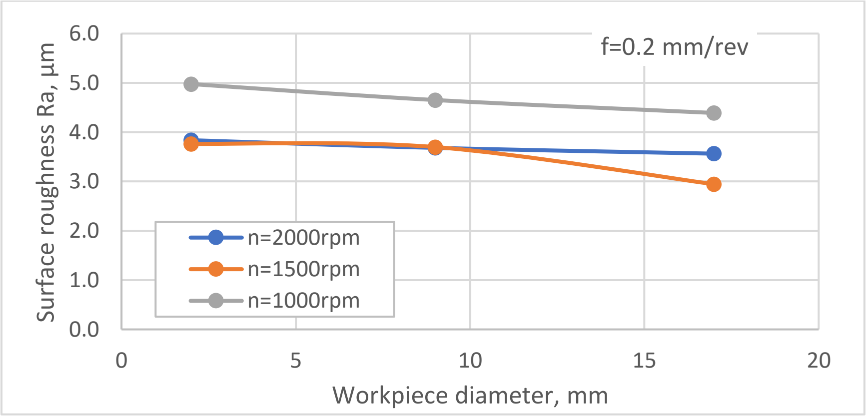
No.	Workpiece diameter d, mm	Cutting feed f, mm/rev	Spindle speed n, rpm	Cutting speed V, mm/min	Surface roughness Ra, μm
1d1	2.20	0.10	2897	0.020	1.183
d2	8.93	0.10	713	0.020	1.098
d3	17.11	0.10	372	0.020	0.791
2d1	2.19	0.15	2904	0.020	4.149
d2	8.93	0.15	713	0.020	3.820
d3	17.11	0.15	372	0.020	3.092
3d1	2.19	0.20	2904	0.020	4.132
d2	8.93	0.20	713	0.020	3.564
d3	17.11	0.20	372	0.020	3.816
4d1	2.19	0.10	2324	0.016	2.128
d2	8.93	0.10	571	0.016	1.955
d3	17.11	0.10	298	0.016	1.574
5d1	2.19	0.15	2324	0.016	3.292
d2	8.93	0.15	571	0.016	2.576
d2	17.11	0.15	298	0.016	1.600
6d1	2.19	0.20	2324	0.016	3.762
d2	8.93	0.20	571	0.016	3.698
d3	17.11	0.20	298	0.016	2.944
7d1	2.19	0.10	1743	0.012	2.668
d2	9.25	0.10	413	0.012	2.632
d3	17.00	0.10	225	0.012	2.252
8d1	2.19	0.15	1743	0.012	2.670
d2	8.93	0.15	428	0.012	2.343
d3	17.11	0.15	223	0.012	2.388
9d1	2.19	0.20	1743	0.012	6.425
d2	8.93	0.20	428	0.012	5.289
d3	17.11	0.20	223	0.012	4.390



a



b

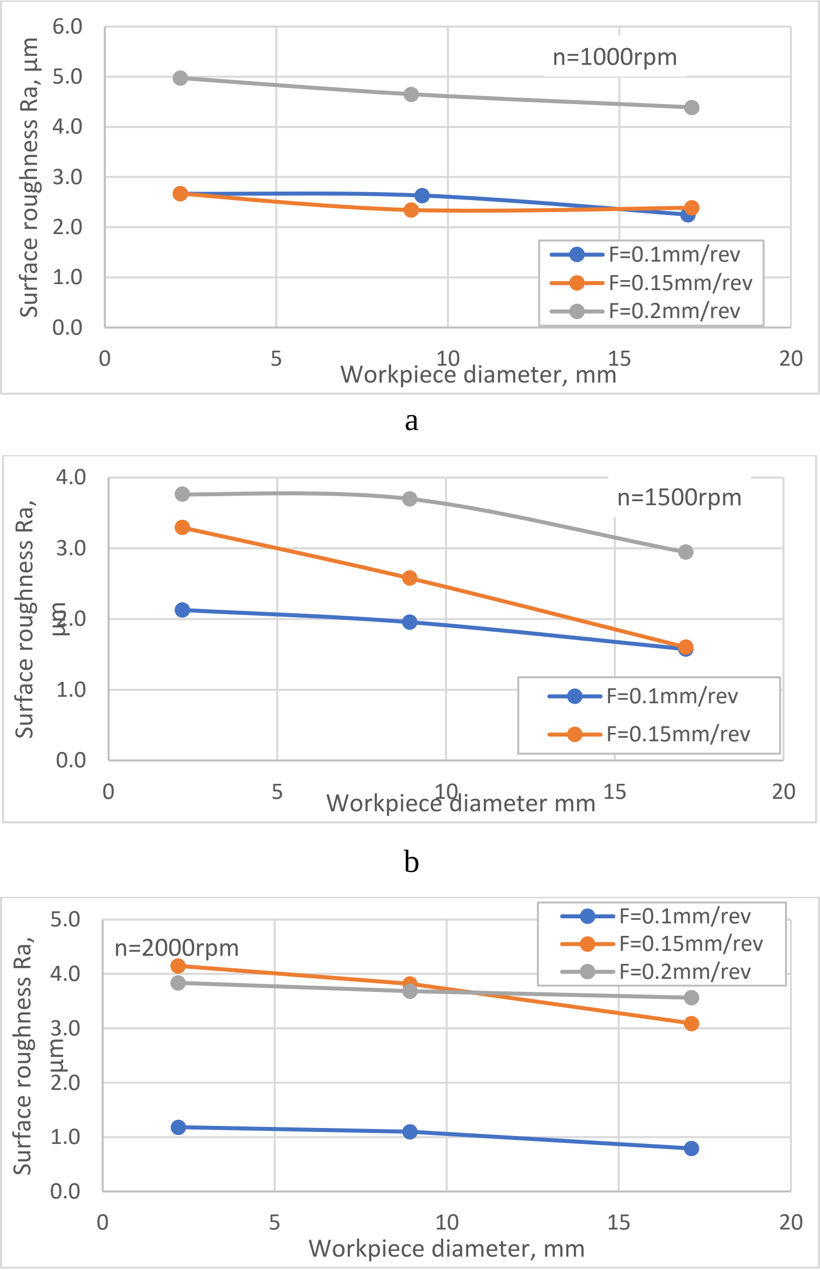


c

Fig. 4.13. Workpiece roughness vs. workpiece diameter during surface speed control turning using cutting speed control code G96: a – f=0.1 mm/rev; b - f=0.15 mm/rev: c - f=0.2 mm/rev.

Conical workpiece diameter influence on surface roughness for various spindle speed values controlled by the code G96 and spindle speed limitation code G92 S3000 is presented in Fig.4.13.

When diameter is changing with the feed rate the surface roughness values are changing. When spindle speed was kept at 2000 rpm and feed rate kept at 0.1, 0.15, 0.2 mm/rev simultaneously. The surface roughness was measured and figure (4.2, a, b, c) showing the resulting graphical values. The spindle speed then changed to *n*=1500rpm with same feed rate of 0.1, 0.15, 0.2 mm/rev. and measured surface roughness results shows that if the diameter is increasing surface roughness values are decreasing it is a general trend of surface roughness.



c

Fig. 4.14. Workpiece diameter influence on surface roughness during spindle speed control turning: a – 1000 rpm; b – 1500 rpm; c – 2000 rpm.

This figure shows that surface roughness during conical surface turning decreasing with workpiece diameter increasing. It means that using G96 code for curve shaped workpieces is ambiguity, because surface roughness varies depending on workpiece shape.

Cutting feed influence on surface roughness for various spindle speed values controlled by the code G96 and spindle speed Fig. 4.12 shows the dependancy of surface roughness from the workpiece diameter during constant surface speed control G96 S50

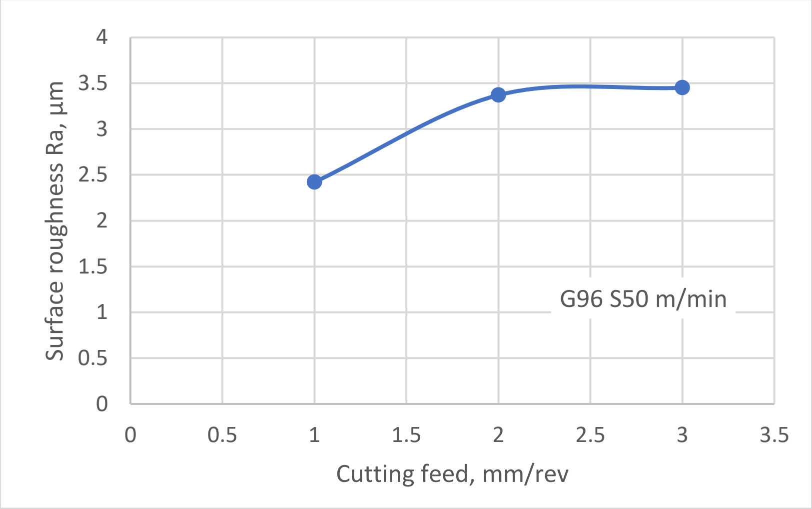
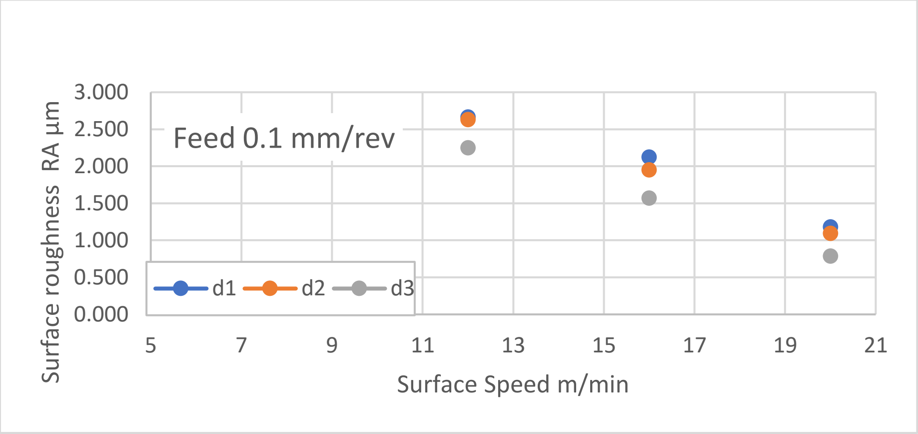
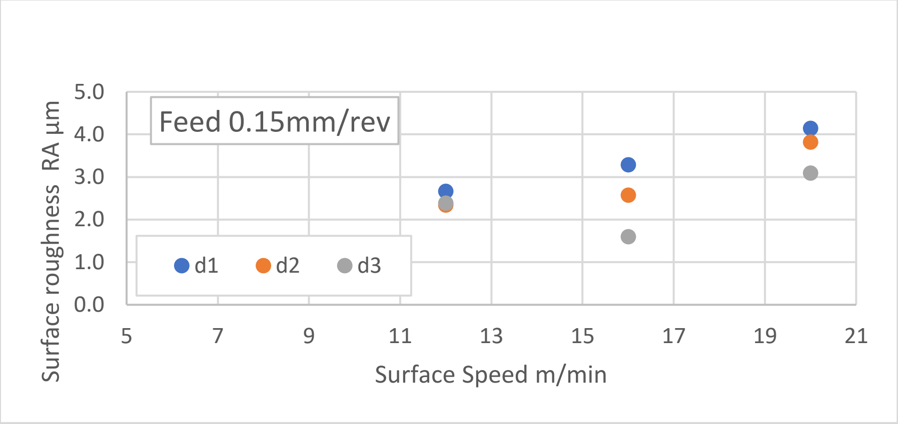


Fig. 4.15. Constant surface speed control using G96 S50 (m/min) code influence on surface roughness

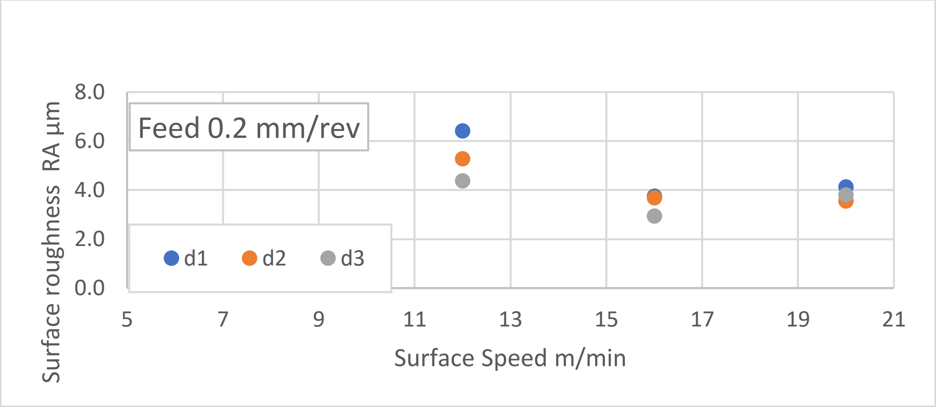
It is seen from the Fig. 4.12 that if the diameter of the workpiece increases surface roughness decreases. It happends because in order to keep constant surface cutting speed in a range of 50 m/min, spindle speed automatically is decresing by the lathe controller.



a



b



c

Fig. 4. 16. Constant surface speed control using G96 S12, S16, S20 (m/min) code influence on surface roughness: a feed 0.1 mm/rev b feed 0.15 mm/rev and c feed 0.2 mm/rev

It is seen from Fig. 4.16. a,b,c the best surface quality was given for constant surface speed of 20 m/min.

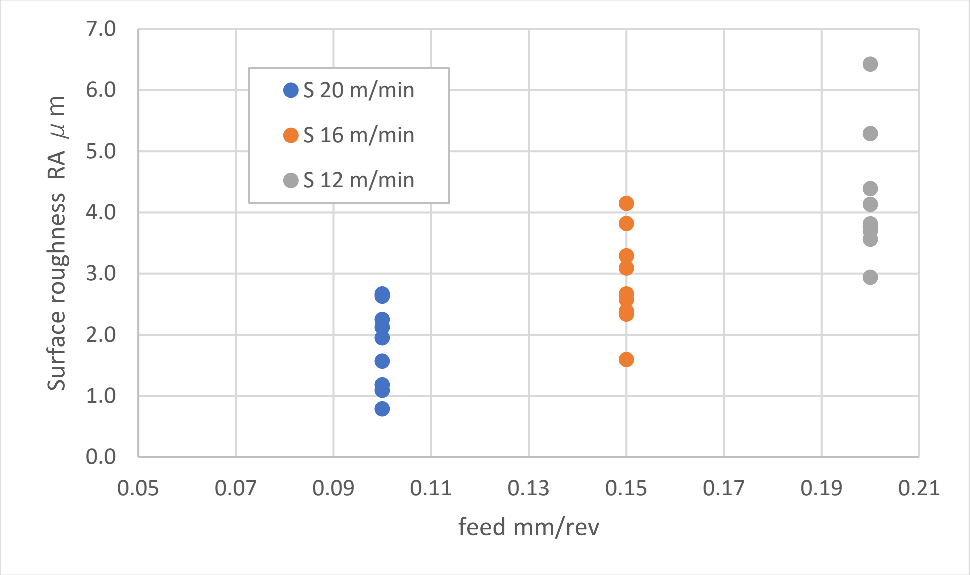


Fig. 4. 17. Cutting feed influence on surface roughness during constant surface speed control using G96 S20 S16 S12 (m/min) code influence on surface roughness

Fig. 4.17 shows the experimental scattered values from constant surface speed turning process. The feed rate is changes for different workpieces and surface roughness values also decreasing it means increasing in feed rate with different spindle revolution the quality also differs

4.3. Experimental surface roughness comparison to the theory

The theoretical surface prediction models used for comparison of experimental surface roughness results. The results have been observed to be closely comparable to the actual experimental measurements of surface characteristics with theoretical surface roughness results. Theoretical methods are based on fundamental, machining theories on cutting tool characteristics and develop analytical model present the machined surface.

Theoretical investigation always plays key part to predict, calculate and analyzing the surface roughness. The recommended formula to find surface roughness to evaluating machine parameters which is closed to experimental parameters. By different analysis surface roughness values are analyzed. Figure 4.18 shows the Geometric surface profile with sharp nose radius.

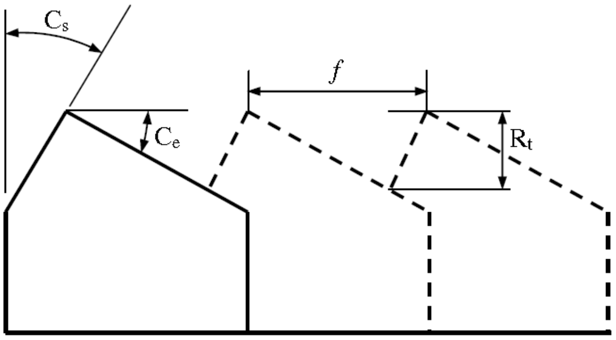


Fig. 4.18. Geometric surface profiles with sharp nose edge [8]

The theoretical arithmetic mean value of surface roughness can be expressed by the following formula [8]. This figure shows that for fixed spindle speed using code G01 cutting speeds depends on workpiece diameter. It means that for conical or another curve-linear surface cutting, cutting speed is not constant and it results on the tool insert tool life.

$$Ra = \frac{f^2}{32 \cdot r} \tag{4.3}$$

where f is the cutting feed (mm/rev.); r is the tool insert tip radius (mm).

Theoretical surface roughness was calculated using cutting feed values of 0.1, 0.15 and 0.2 mm/rev, in the experiment was used tool with noise radius of 0.8 mm.

4.3.1. Surface roughness comparison to the theory for conventional turning process

Comparison of the experimental Ra values to the theoretical ones for the conventional turning is presented in Fig. 4.17. The figure shows average surface roughness values when cutting feed rate is 0.1, 0.15, 0.2 respectively.

The figure 4.17 shows the theoretical curve which shows the Surface roughness values which formulated by using feed rate and nose radius. These values are theoretical based for surface roughness findings. It says the surface roughness depends on matching coefficient and feed rate.

Average experimental surface roughness values vs theoretical values for experiment first showing the different average values of surface roughness and compared with theoretical values and it shows not so good agreement with theoretical values.

Comparison of the experimental values of the surface roughness during conventional turning process to the theoretical ones is presented in Fig. 4.17.

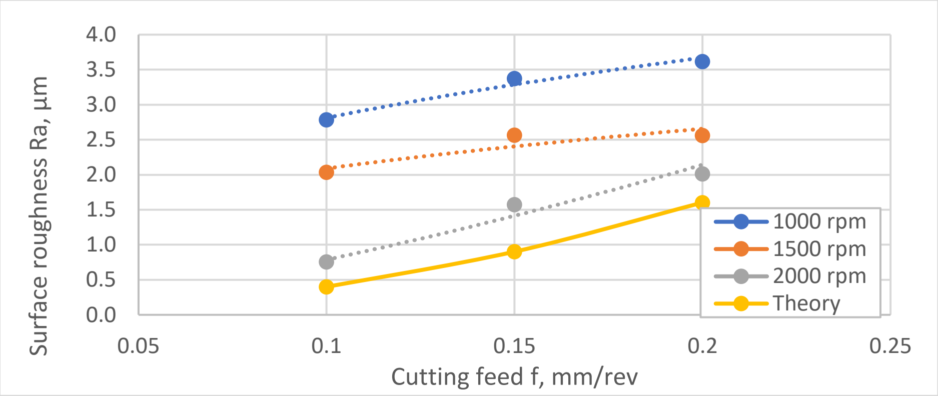


Fig. 4.19 Experimental surface roughness comparison to the theory for conventional turning using G01 code

As it is seen from the Fig. 4.17 for turning with G01 the coincidence of the experiment to the theory is satisfactory only for turning with spindle speed of 2000 rpm. For the lower spindle speed experiment coincidence to the theory was not given good. This could be explained that calculation of cutting regimes for aluminum alloy on turning requires much higher spindle speed (4000 rpm and more in dependence of the workpiece diameter). However, in this experiment was used CNC lathe with maximal spindle speed of 3000 rpm therefore to increase spindle rotation speed was not able in order to avoid machine overload. Another reason may be that was used dry turning without cooling.

4.3.2. Surface roughness comparison to the theory for constant surface speed turning

This comparison is showed in Fig. 4.18. The comparison shows that surface cutting speed control using G96 code describe experimental Ra values in the same manner like for G01 experiment, but the scatter of the experimental values is given bigger because surface roughness was measures in three places of the workpiece and as was showed in the chapter 4.2 surface roughness during surface cutting speed control turning varies depending on cutting regimes and workpiece diameter change.

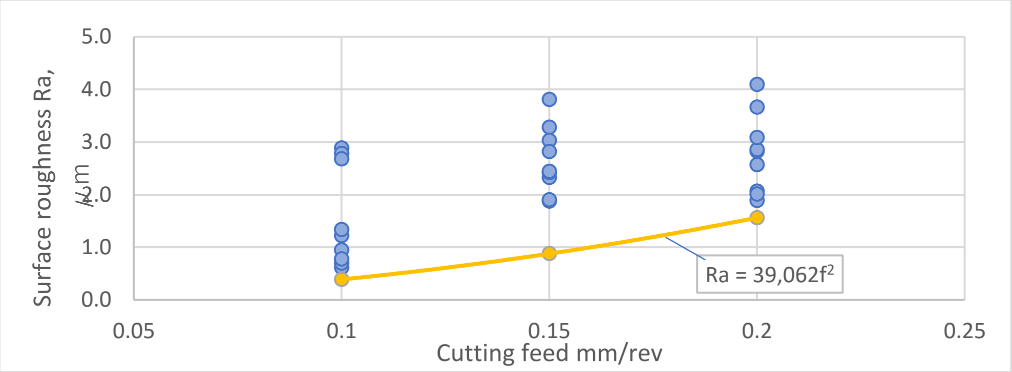


Fig. 4.20. Experimental surface roughness scattered comparison to the theory for conical workpiece during constant surface cutting speed control turning with code G96.

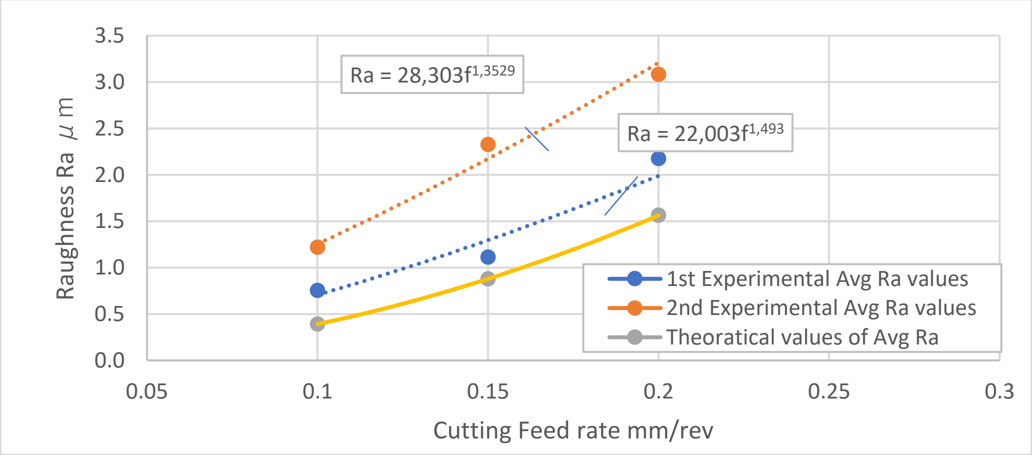


Fig. 4.21. Comparison of the average surface roughness values to the theory for conventional (surface cutting speed varies depending on workpiece diameter changing) with G01 code and constant surface cutting speed controlled by G96 code

Fig. 4.19 shows that the theoretical curve (in yellow) do not matching the experimental results because while turning with G96 of a conical shape workpiece the spindle speed differs it mean when the diameter was small in constant speed turning process the spindle speed is maximum, and it decreases when diameter increases and the roughness values showing big difference.

The comparison of conventional turning process and constant surface speed experiment with theoretical average showed that surface roughness values and from these average roughness value we can say that the average roughness values of convention turning process are satisfy and shows good agreement with theoretical values but with constant surface speed (2nd experiment) it is not enough to satisfy the result with theoretical values.

From figure it states that the experimental values and theoretical values difference is not considerable because of the difference is very big. So, the experimental values and theoretical values have not good agreement. Also, it shows that the constant surface speed has influence but it is not correctly described by theoretical formula.

The comparison showed that theoretical formula could be applied successfully only for conventional turning with programming code G01, however for the constant surface speed control turning with programming code G96 due to the wide roughness scatter, application of the formula (4.1) is ambiguous.

5. SURFACE ROUGHNESS PREDICTION

In order to evaluate cutting regimes and workpiece shape changing during turning and predict surface roughness Ra from all these parameters regression analysis was performed.

To find surface roughness there are various approaches which discuss in The Experimental Investigations Different Approaches chapter. And one of them is Regression Analysis Approach what is used to forecast of surface roughness. the principle of this approach utilizes to predict the surface roughness is reliability to take in to consideration like feed, cutting speed, spindle speed and Cutting dimeter with investigational surface roughness value. The regression analysis approach is less demanding to expect the surface roughness, at a time using this forecast approach formula called as regression matrix formula, there are some variety in calculated experimental values of the surface roughness.

Investigation of the experimental information displayed in the experiment part empowered to conclude that surface roughness Ra relationship to the cutting process could be approximated by the multivariable direct regression analysis approach. The forecast of surface roughness formula is given as follow.

$$y = a0 + a1x1 + a2x2 + a3x3 + a4x4 \tag{5.1}$$

where $x1$ is F (feed mm/rev); $x2$ is n (spindle speed rpm); $x3$ is V (cutting speed), $x4$ is d (cutting diameter); $a0$, $a1a2$, $a3$, $a4$ are linear constants and utilize from the regression table.

The forecast of surface roughness done with experimental parameters. The experimental constraints are displayed in the table 5.1.

5.1. Conventional turning process regression analysis

The forecast of surface roughness done with conventional experimental parameters. The experimental constraints are displayed in Table 5.1, regression summary, ANOVA and regression coefficients are presented in tables 5.2, 5.3 and 5.4. Comparison actual and predicted surface Ra values is presented in Fig. 5.1.

Table 5.1. Experimental values conventional turning experiment

Workpiece diameter d, mm	Cutting feed f, mm/rev	Spindle speed n, rpm	Cutting speed V, mm/min	Surface roughness Ra, µm	Ra Predicted
2.20	0.10	1000	6.90	2.783	2.276
8.93	0.10	1500	28.04	2.035	1.651
17.11	0.10	2000	53.73	0.753	0.880
2.19	0.15	1000	10.33	3.373	3.227
8.93	0.15	1500	42.07	2.563	2.403
17.11	0.15	2000	80.60	1.574	1.391
2.19	0.20	1000	13.77	3.615	4.179
8.93	0.20	1500	56.09	2.559	3.156
17.11	0.20	2000	106.76	2.012	1.915

Table 5.2. Regression Statistics of conventional turning experiment

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.985954
R Square	0.972104
Adjusted R Square	0.944209
Standard Error	0.209374
Observations	9

Table 5.3. Analysis of Variance of conventional turning experiment

ANOVA					
	df	SS	MS	F	Significance F
Regression	4	6.110557	1.527639	34.8479	0.002291
Residual	4	0.175349	0.043837		
Total	8	6.285906			

Table 5.4. Regression coefficients and standard error of conventional turning experiment

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	3.609498	2.711893	1.330989	0.25399	-3.91992	11.13892
X Variable 1	-0.09295	0.209105	-0.44451	0.679664	-0.67352	0.487619
X Variable 2	5.795287	3.160558	1.833628	0.140634	-2.97983	14.5704
X Variable 3	-0.00112	0.003061	-0.36619	0.732768	-0.00962	0.007378
X Variable 4	0.009956	0.009066	1.098203	0.33378	-0.01521	0.035128

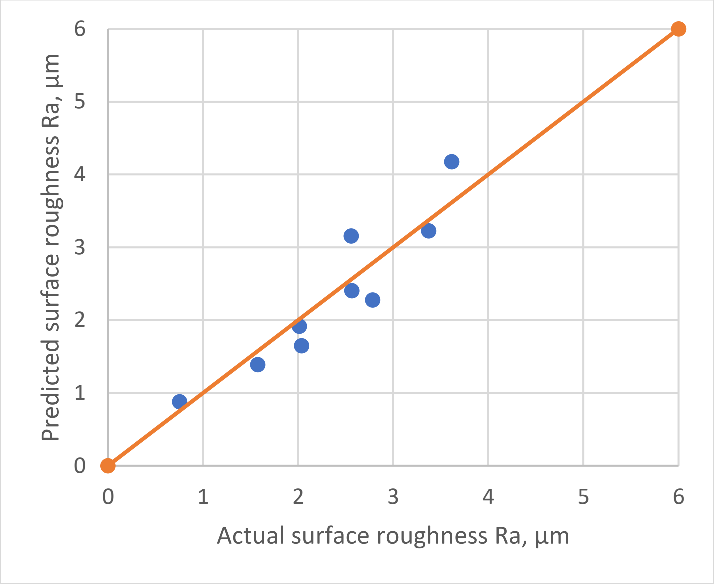


Fig. 5.1 Comparison of experimental and predicted surface roughness analysis

Fig. 5.1 shows the comparison of predicated and experimental surface roughness analysis. Diagonal line shoes the predicted surface roughness values which are compared with conventional turning experiment values.

Regression analysis for conventional turning process shown in above tables 5.2, 5.3 and 5.4. It says the conventional turning process experimental data and predicted data which is regression matrix formulated values are giving completely agreement. In summary output of this experiment proposed regression model gives “R^2” value is 0.97 which indicates very good correlation of the actual and predicted Ra values.

5.2. Constant surface cutting speed turning process regression analysis

The forecast of surface roughness done with experimental parameters. The experimental constraints are displayed in the table 5.5. Regression summary, ANOVA and regression coefficients are presented in tables 5.6, 5.7 and 5.8. Comparison actual and predicted surface Ra values is presented in Fig. 5.2.

Table 5.5. Experimental data for Constant Surface Speed Turning (Second part)

Workpiece diameter d, mm	Cutting feed f, mm/rev	Spindle speed n, rpm	Cutting speed V, mm/min	Surface roughness Ra, µm	Ra Predicted
5.81	0.10	2000	0.05	2.192	2.621
10.95	0.15	1455	0.05	2.915	2.088
16.08	0.20	991	0.05	3.707	1.703
5.89	0.10	2000	0.05	2.31	3.638
11.25	0.15	1415	0.05	3.701	3.104
16.76	0.20	950	0.05	3.954	2.719
5.24	0.10	2000	0.10	3.208	4.654
10.92	0.15	2000	0.10	3.48	4.119
16.60	0.20	1918	0.10	3.618	3.735
6.05	0.10	2000	0.15	2.601	2.556
11.43	0.15	2000	0.15	3.917	2.072
16.83	0.20	2000	0.15	4.076	1.695
5.52	0.10	2000	0.05	1.562	3.572
11.16	0.15	1427	0.05	2.758	3.087
16.80	0.20	948	0.05	3.915	2.710
5.35	0.10	2000	0.10	3.038	4.588
11.05	0.15	2000	0.10	3.193	4.103
16.76	0.20	1901	0.10	3.275	3.726
5.91	0.10	2000	0.15	3.507	2.490
11.31	0.15	2000	0.15	3.537	2.040
16.71	0.20	2000	0.15	3.921	1.691
5.81	0.10	2000	0.05	2.192	3.506
10.95	0.15	1455	0.05	2.915	3.071
16.08	0.20	991	0.05	3.707	2.702
5.89	0.10	2000	0.05	2.31	4.522
11.25	0.15	1415	0.05	3.701	4.087
16.76	0.20	950	0.05	3.954	3.718

Table 5.6 Regression Statistics for speed control experiment

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.841754
R Square	0.70855
Adjusted R Square	0.65556
Standard Error	0.762173
Observations	27

Table 5.7 Analysis of Variance for speed control experiment

ANOVA					
	df	SS	MS	F	Significance F
Regression	4	31.06975	7.767436	13.37119	1.13E-05
Residual	22	12.77999	0.580908		
Total	26	43.84973			

Table 5.8. Regression coefficients and standard error for speed control experiment

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	1.144165	1.02982	1.111033	0.278549	-0.99155	3.279881
X Variable 1	24.14194	3.592926	6.719299	9.39E-07	16.69067	31.59322
X Variable 2	-4.7E-05	0.000339	-0.13852	0.891088	-0.00075	0.000655
X Variable 3	-72.222	50.19755	-1.43876	0.164296	-176.325	31.88133
X Variable 4	-0.06247	0.050896	-1.22747	0.232617	-0.16803	0.043078

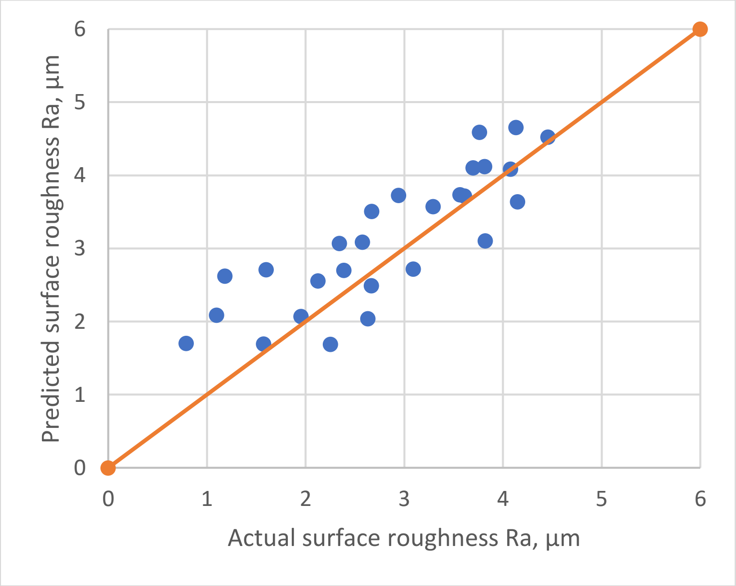


Fig. 5.2. Comparison of experimental and predicted surface roughness analysis

Fig. 5.2 shows the comparison of theoretically predicated surface roughness values and experimental surface roughness data analysis. Diagonal line shoes the predicted surface roughness values which are compared with experimental values conventional turning experiment.

The Constant Surface Speed Turning Process experimental values of regression analysis model using regression matrix formula displayed in Tables 6.6, 6.7and 6.8 shows the regression analysis results. And it says that with 70% probability (R^2 =0.70) the experimental data has average agreement to the predicted ones.

In order to evaluate surface roughness prediction for conventional and controlled surface cutting regression analysis was performed as combination of all experimental results gave in the chapter 4. Experimental regression matrix for conventional and constant surface speed control turning is presented as combine Table 5.9. as follow.

5.3. Combine regression analysis of Conventional and Constant surface cutting speed turning process

Table 5.9. Measurements of conventional turning and constant surface speed control turning.

Workpiece diameter d, mm	Cutting feed f, mm/rev	Spindle speed n, rpm	Cutting speed V, mm/min	Surface roughness Ra, µm	Ra Predicted
1st					
2.20	0.10	1000	6.90	2.783	2.276
8.93	0.10	1500	28.04	2.035	1.651
17.11	0.10	2000	53.73	0.753	0.880
2.19	0.15	1000	10.33	3.373	3.227
8.93	0.15	1500	42.07	2.563	2.403
17.11	0.15	2000	80.60	1.574	1.391
2.19	0.20	1000	13.77	3.615	4.179
8.93	0.20	1500	56.09	2.559	3.156
17.11	0.20	2000	106.76	2.012	1.915
2nd					
2.20	0.10	2897	0.02	1.183	2.621
8.93	0.10	713	0.02	1.098	2.088
17.11	0.10	372	0.02	0.791	1.703
2.19	0.15	2904	0.02	4.149	3.638
8.93	0.15	713	0.02	3.820	3.104
17.11	0.15	372	0.02	3.092	2.719
2.19	0.20	2904	0.02	4.132	4.654
8.93	0.20	713	0.02	3.816	4.119
17.11	0.20	372	0.02	3.564	3.735
2.19	0.10	2324	0.02	2.128	2.556
8.93	0.10	571	0.02	1.955	2.072
17.11	0.10	298	0.02	1.574	1.695
2.19	0.15	2324	0.02	3.292	3.572
8.93	0.15	571	0.02	2.576	3.087
17.11	0.15	298	0.02	1.600	2.710
2.19	0.20	2324	0.02	3.762	4.588
8.93	0.20	571	0.02	3.698	4.103
17.11	0.20	298	0.02	2.944	3.726
2.19	0.10	1743	0.01	2.668	2.490
9.25	0.10	413	0.01	2.632	2.040
17.00	0.10	225	0.01	2.252	1.691
2.19	0.15	1743	0.01	2.670	3.506
8.93	0.15	428	0.01	2.343	3.071
17.11	0.15	223	0.01	2.388	2.702
2.19	0.20	1743	0.01	4.456	4.522
8.93	0.20	428	0.01	4.077	4.087
17.11	0.20	223	0.01	3.612	3.718

The forecast of surface roughness done with experimental parameters. The experimental constraints of the combine values of conventional turning and constant surface speed control turning are displayed in the table 5.9. Regression summary, ANOVA and regression coefficients are presented in tables 5.10, 5.11 and 5.12. Comparison actual and predicted surface Ra values of conventional turning and constant surface speed control turning is presented in Fig. 5.3.

The surface roughness co-connection was examined by utilizing the regression investigation. The regression examination is finished by employing the machining parameters with Experiment surface roughness values. For this Experiment, the forecast of surface roughness computed by using the Regression steady and with machining parameters. The regression investigation comes about, outline (Table 5.10, 5.11, 5.12), examination of results and parameters values for different straight regression values are displayed in the following tables.

Table 5.10. Regression Statistics of conventional and speed control experiment

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.866601
R Square	0.750997
Adjusted R Square	0.718868
Standard Error	0.534157
Observations	36

Table 5.11. Analysis of Variance Regression Statistics of conventional and speed control experiment

ANOVA					
	df	SS	MS	F	Significance F
Regression	4	26.6768	6.669201	23.37417	5.53E-09
Residual	31	8.845029	0.285324		
Total	35	35.52183			

Table 5.12. Regression coefficients and standards Regression Statistics of conventional and speed control experiment

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.851037	0.505345	1.684071	0.102213	-0.17962	1.881696
X Variable 1	17.78633	2.208374	8.054036	4.28E-09	13.28232	22.29033
X Variable 2	-8.9E-05	0.000161	-0.55503	0.582855	-0.00042	0.000239
X Variable 3	-0.01091	0.004747	-2.29876	0.028422	-0.02059	-0.00123
X Variable 4	-0.062	0.022628	-2.73994	0.010101	-0.10815	-0.01585

The percentage of regression analysis gave 75% co-relation utilizing regression matrix. This is possibility to accept the prediction of surface roughness. This can predict for likewise parameters investigations. And the results can be acceptable.

Using formula comparison of surface roughness is calculated, and actual investigated results is displayed in Fig 5.10, 5.11 and 5.12. Which displays the satisfying agreement, and regression analysis shows 75% probability (R^2=0.75) satisfied experimental data.

By utilizing the eq. (5.1) we can discover the prediction of surface roughness. The steady in the regression table is relevant to the comparative parameters. By utilizing the regression consistent, the surface roughness can foresee with satisfactory ratio.

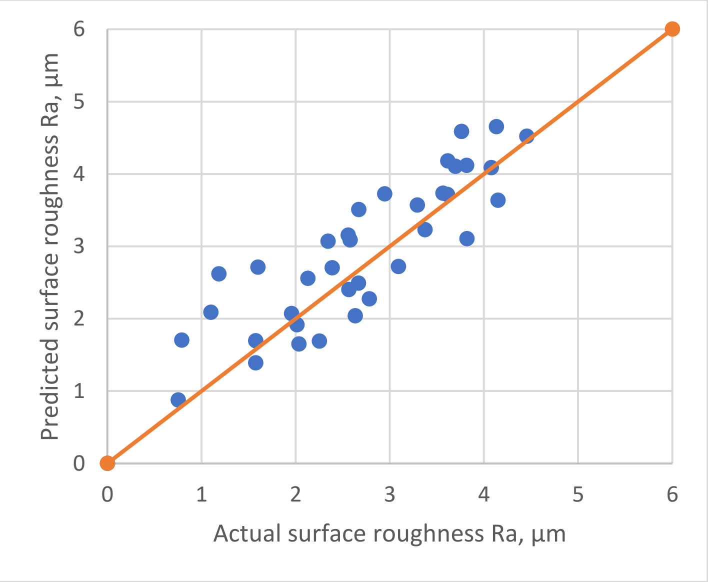


Fig. 5.3. Comparison of experimental and predicted surface roughness analysis

Fig. 5.3 shows that the scatter of experimental and predicted values is closed to liner position in the figure and it says that the predicted surface roughness values and experimental values can be compare closely and effectively. The analysis and resulting values verifies that machining parameters has influence on surface roughness. and it depends on coefficient value of the regression analysis. The surface roughness coefficient is the most considerable and important factor in prediction of surface roughness values.

The regression investigation additionally empowered to assess noteworthiness of the cutting parameters. The most remarkable regression coefficient value demonstrates that this parameter has most critical impact on surface roughness, consequently presenting on information introduced in Table, it can be presumed that most elevated effect on surface roughness has cutting feed and cutting surface speed and spindle speed, cutting diameter. Cutting rate and processing turning impact is gotten as less critical.

The above investigation and result demonstrates that machining parameters has critical effect on surface roughness. The regression investigation appeared, it relies upon regression show coefficient value. The greatest values in investigation indicates most noteworthy impact in surface roughness value. It is critical factor to be considered in foreseeing surface roughness value.

After comparing of regression and residual values we can state that the given results are excellent. And it satisfies the experiment. The model verification could be evaluated by Fisher criterion (F-criteria). In the statistical research is applied coincidence interval α=0.05 what means evaluation probability of 95 %, and Fisher criteria $F_{(\alpha=0.05)}$ value for the given degree of freedom (*df*) $(\nu_1 = 4)$ and $(\nu_2 = 31)$ is found from F-tables [13]. As is seen from table 5.11 calculated F-value F=23.4 and table value F_{table} = 2.69. Because F_{calc} =23.4> F_{table} =2.69 could be concluded that regression model adequate evaluates cutting parameters influence on surface roughness variation so from that we can say the proposed model adequate represents regression factors influence on surface roughness.

CONCLUSIONS

Experimental and theoretical investigation of cutting regimes such as cutting speed (V), cutting feed (f) and tool shape (r) influence on surface roughness (Ra) for turning operation usually is performed using cylindrical workpieces what means that during experiment surface cutting speed (S) is accepted constant. Research works related to the surface roughness investigation using curve-shaped in part on the conical workpieces when surface cutting speed varies depending on workpiece diameter was not found. Therefore, the goal of this work was to investigate cutting regimes influence during constant surface speed using conical workpieces and to compare it to the results given on the same shape workpieces without surface cutting speed control. The research was performed on CNC turning machine "*Rayo Pinacho*" with "*Fanuc*" controller and variable cutting speed was set using programmable code G01 and constant surface speed by code G96 with various surface speed values (S12, S16, S20, S50, S100 and S150 m/min) values. The workpiece was machined using "Kennametal" turning tool with the insert tip radius of 0.8 mm. The research enabled to give following results:

1. Surface roughness investigation of the conical workpieces during conventional turning, with fixed cutting speed of 1000, 1500 and 2000 rpm and cutting feed of 0.1, 0.15 and 0.2 mm/rev has showed that workpiece diameter has minimal influence on the surface roughness and despite surface cutting speed increasing due to the conical workpiece diameter varies in the limits *R*a 2.783 – 3.615 µm for 1000 rpm, *R*a 2.035 – 2.563 µm for 1500 rpm and *R*a 0.753 – 2.012 µm for 2000 rpm.

2. Surface roughness Ra measurements during conventional turning when cutting feed was fixed but spindle rotation speed has been changed has showed that best surface quality when cutting feed was set minimal (*f*=0.1 mm/rev) and cutting speed was set maximal (*n*=2000 rpm) and this is in the agreement to the cutting theory.

3. Surface roughness investigation of the conical workpieces turning during constant surface cutting speed (S) control using G96 code has showed that workpiece diameter changing has significant influence of surface roughness, because spindle rotation speed during machining is not constant and varies depending on workpiece diameter: when the workpiece diameter is minimal spindle rotation speed is maximal and when the diameter increases, spindle rotation speed decreases to the minimal value in such way that surface cutting speed always is set constant.

4. The constant surface cutting speed control experiment has showed that measured Ra values on selected minimal, medium, and maximal workpiece diameter, marked as d1, d2 and d3 showed that surface roughness on the workpiece conical surface is not constant and changes because spindle

rotation speed is not constant. Surface roughness values for surface cutting speed control with S12, S16, S20 and S50 m/min and cutting feed of 0.1, 0.15 and 0.2 mm/rev has showed that workpiece diameter changing during turning has significant influence on the surface roughness and varies in the limits *R*a 1.628 – 3.612 µm for 1000 rpm, *R*a 1.628 – 3.820 µm for 1500 rpm and *R*a 1.628 – 3.4561 µm for 2000 rpm.

5. Comparison of the experimental results to the theory showed that good agreement to the theory was given for minimal cutting feed (*f*=0.1 mm/rev) and maximal spindle speed (*n*=2000 rpm). For bigger cutting feed and lower spindle speed values difference between theory and experiment was given bigger. It means that surface roughness depends not only cutting feed and tool tip radius according formula ($R_a = f^2/32\,r$), but also depends on workpiece diameter and surface cutting speed.

6. The regression analysis is carried out to show the ability of evaluation the turning parameters influence on surface roughness and ability to predict surface quality during changeable machining regimes showed that proposed four variables linear regression model in a form

$Y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4$, where X_1 is cutting feed in mm/rev, X_2 is spindle rotation speed in rpm, X_3 is the surface cutting speed and X_4 is the workpiece diameter in mm adequacy describe cutting parameters influence on surface roughness variation.

7. Regression analysis was performed separately for the conventional turning and constant surface cutting speed control turning results. For conventional turning regression gave 98% prediction probability, meanwhile for the constant surface cutting speed control turning model was given 75% prediction probability. The same prediction probability is given from combined matrix developed from both experiments results. Regression model verification was performed using *F*- criterion. Comparison calculated and table $F_{(0.05)}$ values showed model acceptability to evaluate cutting parameters influence on surface roughness variation.

Recommendations

1. Conventional turning with G01 code or constant surface speed control turning with code G96 is recommend to program with spindle speed limitation in order to avoid CNC lathe overload.

2. Further investigation is recommended to carry out on curve-shaped workpieces with spherical surfaces to investigate more in detail surface roughness variation when during turning workpiece diameter permanently increases and decreases depending on detail contour shape.

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