Mathematical modelling of the surface roughness parameters R_p and R_v in hard turning of steel C 55 (DIN) using mixed ceramics MC 2 (Al2O3 + Ti C)

Mevludin Shabani, Simeon Simeonov, Bujar Pira, Naim Ostergllava

Abstract - As the techniques for measuring the roughness profile and the roughness parameters changed, as well as the software capabilities for the realization of the DOE (Design of Experiments), so did the approach and techniques for predicting and developing mathematical models for the roughness parameters. The past has shown that the works or contribution of each new approach in this direction was recognized by the professional community and found direct practical applicability in academic and industrial circles. Other than dealing with the most researched roughness parameters R_a (R_a - the arithmetic mean of the absolute values of the roughness profile ordinates) and R_z (the arithmetic mean value of the single roughness depth R_{zi} of consecutive sampling lengths), this paper investigates the roughness profile, through inclusion of the roughness parameters R_p (maximum peak height of the roughness profile within one sampling and R_v (maximum valley depth of the roughness profile within one sampling), that are directly measurable and related to the position of the midline of the roughness profile. The position of the midline of the roughness profile is in direct function with the shape of the roughness profile with the ultimate goal of obtaining empirical results which are expected to have practical applicability; their application in the metal processing industry can create conditions for process optimization and gaining economic benefits from their application.

Key words: Ceramics, Feed, Parameters, Profile, Radius, Roughness, Speed, Turning

1. INTRODUCTION

Nowadays, the manufacturing community is increasingly looking for and exploring different ways of realizing of products with a quality that meets requirements such as aesthetic and functional (both require high surface roughness accuracy). Obviously, these properties require numerous technological methods; in this course, hard turning proved to be one of the most efficient technological methods in accomplishing of these requirements at metal production [1]. According to the literary sources, "hard materials" or materials with increased hardness are considered materials (steels) of which strength exceeds 45 HRC. Due to the properties, their application has recently increased significantly in the automotive, military industries, etc.

Author:

- Mevludin Shabani is currently pursuing PhD program in mechanical engineering in *in the University "Goce Delcev" Stip, N. Macedonia.* E-mail: mevludin.3265@student.ugd.edu.mk

Co-authors:

- *Simeon Simeonov, Associate Professor at university "Goce Delcev" Stip, N.Macedonia, Email:simeon.simeonov@ugd.edu.mk*
- *Bujar Pira,Vice Rector for int. relations and quality assurance at University of Applied Sciences in Ferizaj, Kosovo, E-mail: bujar.pira@ushaf.*net
- *Naim Ostergllava is currently pursuing PhD programin mechanical engineering in the University "Goce Delcev" Stip, N. Macedonia. E-mail: naimostergllava@hotmail.com*

Achieving a better surface quality, tool life and dimension accuracy are the crucial concerns in turning of hardened steels [2].

Traditionally hardened steels have been machined by the grinding process [3]. Hard turning is an alternative to traditional grinding in the manufacturing industry for hardened ferrous alloy material above 45 HRC [4].

According to Zhao et al. hard turning can offer attractive advantages in term of its higher removal rate, shorter setup time, and reduced production cost, it has become a potential substitute for conventional grinding We can also add an additional advantage which is the fact that no fluid is necessary at hard turning process [5].

We can see that the material represents one of the key factors of metal processing. However, the metal processing represents a complex task; among the factors with equally important impact in the quality of the machined surface are resistant forces, which emerge as a result of penetration of the tip of the cutting tool inside the material. In order to overcome reaction forces during cutting process, there is one another key factor in metal processing which - cutting tools that has received the attention of the metal cutting community, thus great efforts have been made to design them properly; each tool is described by angles or geometry. Each shape of the tool has its specific purpose. Effective cutting requires the use of a tool for the accurate shape of the task. The first goal in machining is to achieve the most efficient removal of chip from a work piece; the edges of the cutting tool, driven by the power of the machine, make metal particles to move away off the cutting tool edge. This displacement causes the metal to split into chips along this line.

Taking into account above mentioned, numerous literature and empirical experiences, point out, that the use of coated ceramic tool, has shown high efficiency in chip removal.

In the investigation conducted by Chou et al. the surface roughness was found to be strongly influenced by tool nose radius and tool wear, and the results manifested that large tool radius can obtain finer surface finish, but it also increase tool wear [6].

According to the Bartarya and Choudhury [7] if the right combination of insert nose radius and feed rate is used, hard turning process can produce better surface finish than grinding process. Multiple hard turning operations may be performed in a single set-up than multiple grinding set-ups [7]. B. Fnides at al. concludes that the test of slide-lathing carried out on grade X38CrMoV5-1 treated at 50 HRC, machined by a mixed ceramic tool (insert (CC650), enables us to study the influence of the following parameters: feed rate, cutting speed, depth of cut and flank wear on cutting forces and on surface roughness [8].

The right selection of tool geometry directly affects the quality, however over time the geometry of the tool due to thermal and physical impacts undergoes structural changes in the form of consumption, the phenomena which is intended to be controlled by proper tool design. Lot of research has been done so far in this regard, as well.

Chou et al. [9] performed surface finish tool wear (SF-TW) test on hardened to 61-63 HRC AISI 53 100 steel specimens under finishing conditions and revealed that the transferred layer on the flank wear land of CBN tools may result in adhesion of the binder compound and significantly affect the tool wear process.

Grzesik, in his work: "*Influence of tool wear on surface roughness in hard turning using differently shaped ceramic tools*" [10] concluded that in finish MC-HT (mixed ceramic hard turning) wear of tool flank face are mainly concentrated on the tool corner and the active secondary cutting (trailing) edge. During the life-time of about 15 minutes comparable values of the width of the flank wear land at the tool corner were determined for conventional (CT) and wiper ceramics (WT) tool used.

Today, one can find a large number of literary sources that explore various approaches to modeling and predicting roughness parameters when machining by turning materials with increased hardness, despite this situation, we can literally conclude that in the existing research, only a small number of roughness parameters are studied, and most often parameters R_a and R_z.

It is also important to note here, that a roughness profile at approximately equal rate for the parameters Ra and R_z may have different shapes of roughness profiles and behave differently under exploiting conditions. So, in this research, in order to extend a qualitative contribution on topic, the roughness parameters R_p, R_v, will be considered, i.e. mathematically modeled, than statistically analyzed, ultimate purpose of which is optimization of the process.

In this paper we used computer software CADEX (Computer Data Analysis of Experiment) dedicated to the analysis and selection of an adequate mathematical model, developed at the Faculty of Mechanical Engineering in Skopje, and Mat lab for the graphical interpretation of the mathematical models.

2. Experimental Procedure

Work piece, Material and Tool - Hard turning is performed on rings, specially made for this purpose, from material improved steel C 55 (DIN). The rings have been additionally heat-treated to the required hardness of 52 ± 2 HRC. Dimensions of the rings are φ 102 x Φ 82 x 20 mm, figure 1. The rings are mounted on a device specifically designed for this purpose, to investigate the roughness of the surface layer in order to increase the stiffness of the rings, figure 2.

Figure 1. Rings of material C 55 (DIN), with hardness 52 ± 2 HRC

The rings have previously been subjected to heat treatment by annealing; in order to remove the residual stresses remained from the previous treatments and achieve approximately equal structural condition in all rings before the start of the experiment.

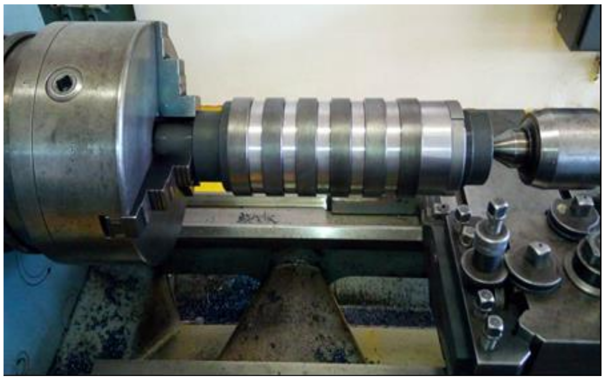

Figure 2. Special set up for exploring the characteristics of the surface layer during turning.

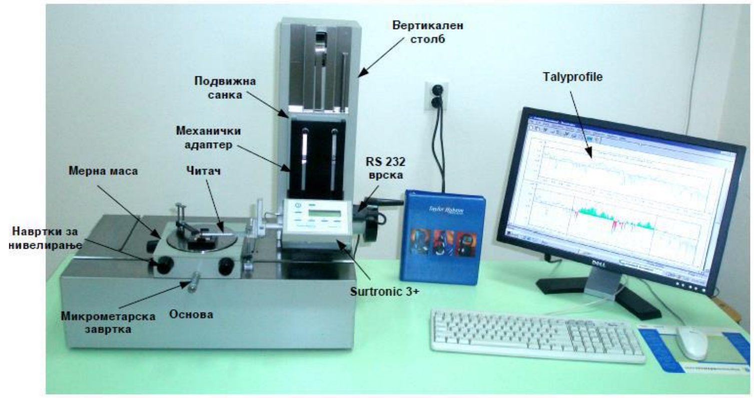

Figure 4. Computerized measuring device model "Surtronic 3+" from Taylor Hobson and Talyprofile software for measurements of the profiles.

Research equipment

The cut-off insert holder CSRNR 25x25 M12H3, made by the company HERTEL, figure 3. is used in the hard turning process**.**

a)

b)

Figure 3. a) Cutting board holder from HERTEL, b) Cut-off inserts from mixed ceramics MC 2 (Al2O3 + TiC) from the company HERTEL.

Hard turning is performed using SNGN 120708-120712-120716 from mixed ceramics MC 2 (Al2O3 + Ti C), made by HERTEL, Figure 3. with the cutting tool geometry: κ=750; κ 1=150; γ = -60; α = 60; λ = - 60; r = 0.8-1.2-1.6 mm; γ_f = 200; b_f = 0.2 mm.

A conventional lathe model TVP 250 from the company "Prvomajska", with a spindle power P = 11.2 (Kw), with the following speed revolutions 16 - 2240 (rot. /min.), and feed rate 0.025-1.12 (mm/rev), was utilized.

Roughness measuring device

The measurement of the roughness parameters of the treated surface obtained during machining is performed on Faculty of Mechanical Engineering in Skopje by using a computerized measuring device, model Surtronic 3+, by the company Taylor Hobson, shown in fig. 4, in accordance with the recommendations of international standards.

3. Analysis of research results

The machining is performed by changing four independently variable parameters, namely: speed *(v*), feed rate (*f*), depth cut (*a*) and insert radius (*r*), using a four-factorial experiment (2^4 + 4).

The change in independently variable sizes is shown in Table 1. The designed planning and the experimental results obtained are presented in Tables 2-4. After computing and collecting data by the appropriate software, the variations in parameter size can be represented by mathematical model (1).

$$R_p = C \cdot v^x \cdot f^y \cdot a^z \cdot r^q \qquad (1)$$

TABLE 1. INDEPENDENTLY VARIABLE VARIATION RATES

Characteristics of independent variables					
Nr.	Parametrs	Level	High	Medium	Low
		Code	1	0	-1
1.	v (m/min)	X1	133.00	94.00	67.00
2.	f (mm/rot)	X2	0.315	0.177	0.1
3.	a (mm)	X3	0.8	0.56	0.4
4.	r (mm)	X4	1.6	1.13	0.8

Four-factorial plan of first-order experiments is performed by real plan matrix and coded plan matrix;
Correlation of the input-output information for a mathematical model of the first order with/without interaction and with/without significance assessment of the factors (b1);

In the same manner variation of interactions of input parameters and assessments of the significance were performed, where established confidence interval level of 95%.

TABLE 2. ASSESSMENT OF THE IMPORTANCE OF THE MODEL (IN THIS CASE WITHOUT ASSESSMENT AND WITHOUT IMPORTANCE OF THE PROCESS VARIABLES).

NO ASSESSMENT OF THE IMPORTANCE OF FACTORS b(i)							
First-order mathematical model without interaction							
Coefficients of the mathematical model			Degree of freedom F(i)	Sum of squares S(i)	Dispersion S(i)/F(i)	Dispersion relations FR(i)	Assessment of the significance of the factors b(i)
index i	Koded b (i)	**Decoded p (i)**					
0	1.114	**108.167**	1	24.832	24.832	4527.6	Significant
1	-0.06917	**-0.2017567**	1	0.076547	0.076547	14.0	Significant
2	0.82217	**1.433**	1	10.816	10.816	1972.0	Significant
3	0.03038	**0.0876579**	1	0.014767	0.014767	2.7	Insignificant
4	-0.34902	**-1.007**	1	1.949	1.949	355.4	Significant
If FR (i) <10.130 => insignificant				**If FR (i)> = 10.130 => significant**			

For more detailed analysis, mathematical models with/without interaction and with/without significance assessment of the factors have been adopted; where all varied independently variables included. This enables us to explain the effects of input parameters *v, f, a* and *r* on subsequent changes, these models are characterized by a high coefficient of multiple regression 95%. Performed analysis, after completed and computed, showed adequacy of obtained mathematical model

$$R_p = 108.167 \cdot v^{-0.20175567} \cdot f^{1.433} \cdot a^{0.0876579} \cdot r^{-1.007}$$

Following similar procedures we obtain mathematical model for roughness parameter Rv:

$$R_v = 19.459 \cdot v^{-0.0488042} \cdot f^{1.121} \cdot a^{0.1439891} \cdot r^{-0.7140308}$$

Due to the standard limits of the paper format, only a few graphical interpretations of the mathematical model for roughness parameter Rp, will be displayed with respective variable process parameters:

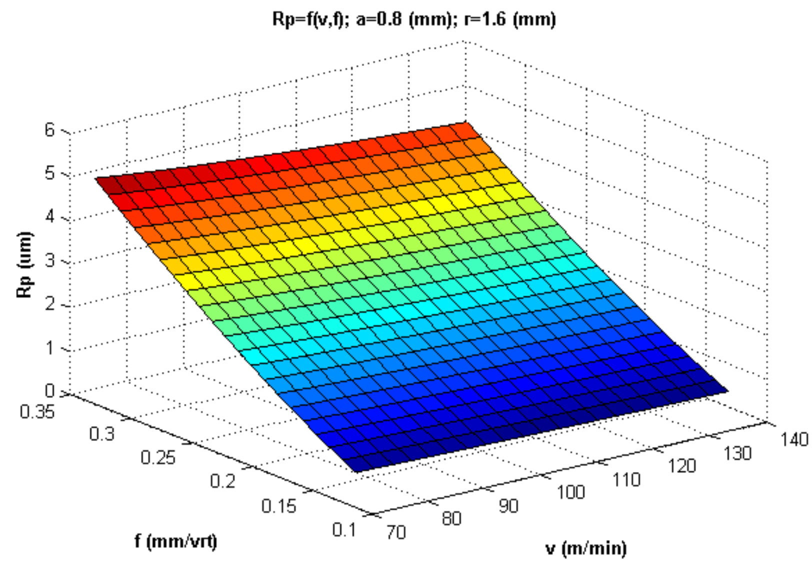

Figure 6. Rp = *f* (v,f); a=0.8 (mm); 3=1.6

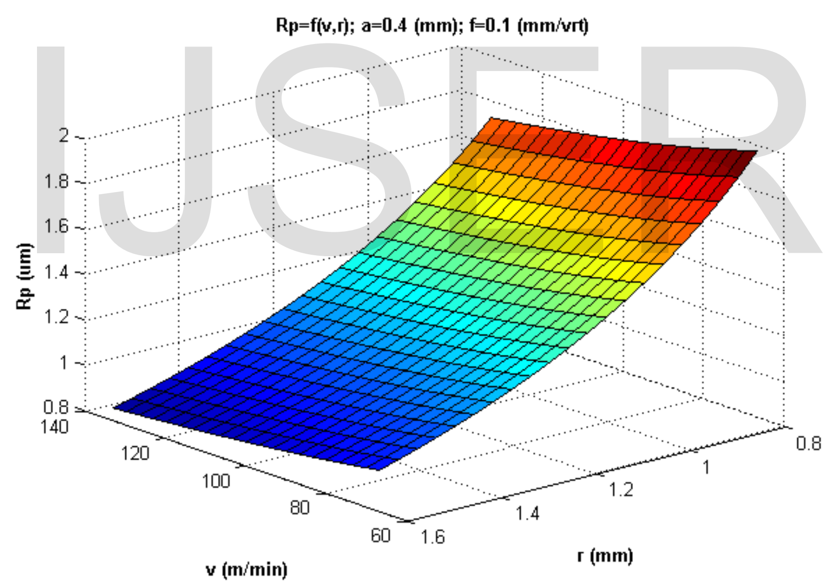

Figure 7. Rp = *f* (v,f); a=0.4 (mm); f=0.1 (mm/rot.)

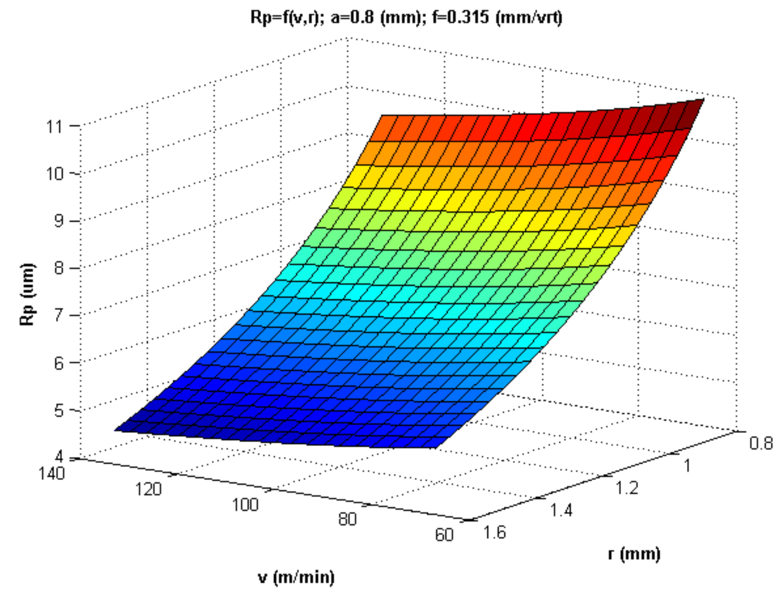

Figure 8. Rp= *f* (v,f); a=0.8 (mm); f=0.315 (mm/rot)

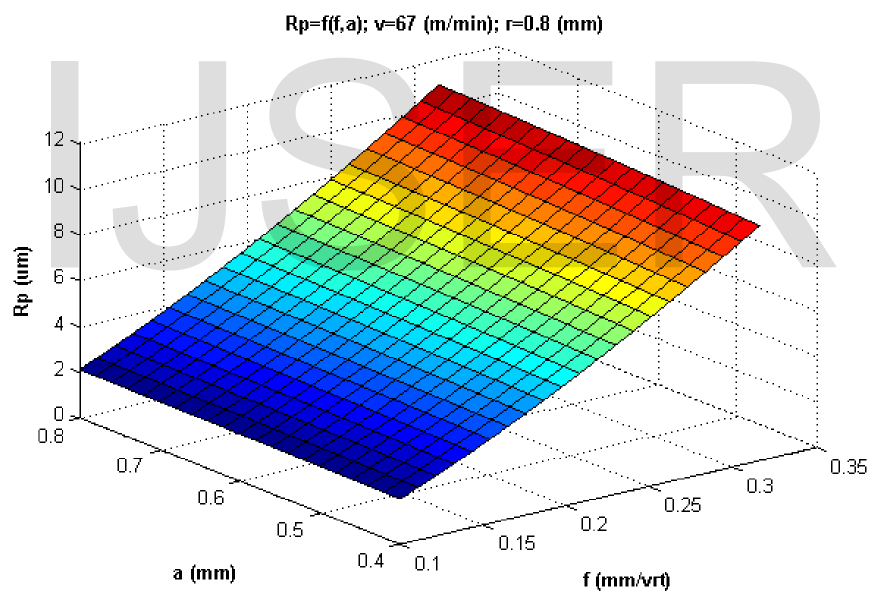

Figure 9. Rp = *f* (v,f); v=67 (m/min); r=0.8 (mm)

Note that the same procedure will be applied for the Roughness parameter R_v, results will be utilized for conclusion purposes.

Recommendations

Inclusion of the roughness parameters R_p and R_v, in this paper, that are directly measurable and related to the position of the midline of the roughness outlined with the obtained results, should represent useful contribution to the direction of conventional description of the roughness profile (the position of the midline of the roughness profile is in direct function with the shape of the roughness profile), due to the fact that the above mentioned, gives the scientific justification of the proposed topic.

The empirical results obtained from this research are expected to have practical applicability. Their application in the metal processing industry can create conditions for process optimization and gaining economic benefits from.

Concussion

Roughness parameters, as part of the parameters that describe geometric structure of the surface, are often set as a criterion for quality in obtaining machine parts, regardless of how they are obtained; this is because most phenomena such as lubrication, friction/ ear, reflection, etc., directly depend on the geometric structure of the surface and the roughness profile of the surface.

Therefore, the roughness profile and the roughness parameters have always been the target of research by a large number of researchers, whether materials with normal or increased strength are at stake.

As the techniques for measuring the roughness profile and the roughness parameters changed, as well as the software capabilities for the realization of the DOE, so did the approach and techniques for predicting and developing mathematical models for the roughness parameters.

The past has shown that the works or contribution of each new approach in this direction was recognized by the professional community and found direct practical applicability in academic and industrial circles.

Reference

[1] Shabani, M.,Simeonov, S., Pira,B., Ostergllava, N., *2020, Statistical analysis of the effect of cutting parameters on the surface roughness profile*

[2] Chris Koepfer, *Hard turning as an Alternative to grinding* – https://www.productionmachining .com/articles/hard-turning-as-an-alternative-to-grinding, 1/22/2010)].

[3] Bauacha, K., Yallese, M.A., Khamel, S., amd Belhadi, S., 2014, *Analysis and Optimization of hard Turning Operation Using Cubic Boron, International Journal of Refractory Metals & Hard Materials, 45:160-178.*

[4] Agrawal, A., Goel, S., Rashid, W.B., and Price, M., 2015. *Prediction of surface Roughness during Hard Turning of AISI 4340 Steel (69 HRC).* Applied Soft Computing. 30: 279-286.

[5] Zhao, T., Zhou, M., Bushlya, V., Stahl, J.E., 2017, *Effect of Cutting edge radius on surface roughness and tool wear I hard turning of AISI 52100 steel*, Int J Adv Manuf Technol. DOI 100.1007.s00170-017-0065-z.

[6] Chou YK, Song, H, 2004, *Tool nose radius effects on finish hard turning [J].* J Mater Process Technol 148(2):259-268.)

[7] Bartarya, G., Choudhury S.K., 2012, *State of the art in hard turning.* International Journal of Machine Tools & Manyufacture 2012; 53: 1-14.

[8] B. Fbides, H. Aouici, M.A.Yallese, *Cutting forces and surface roughness in hard turning of hot work steel X38CrMoV5-1 using mixed ceramic, ISSN 1392-1207.MECHANICA.2008.Nr.2(70).*[9] K.Y.Chou, J.C. Evans, M.M.Barash, *Experimental investigation on CBN turning of hardened AISI 53100 steel,* J.Mat.Proc.Technol.124 (2002) 274-283.

[10] Grzesik, W., *Influence of tool wear on surface roughness in hard turning using differently shaped ceramic tools*, ScinceDirect, Wear 265 (2008) 327-335.