Statistical analysis of the effect of cutting parameters on the surface roughness profile height parameter Ra in hard turning of steel C 55 (DIN)

Mevludin Shabani, Simeon Simeonov, Bujar Pira, Naim Ostergllava

Abstract

The study investigates the surface height roughness parameter Ra (roughness arithmetic average) as a technological effect on the quality of the of the steel C 55 (DIN) surface in hard turning; the variation of the input process parameters cutting speed (v), feed rate (f), depth of cut (a) and nose radius of the cutting insert (r) were considered by multiple measurements for each input variable, then processed statistically, in order to determine the effects on output surface profile roughness parameter Ra.

Keywords: lathe, surface roughness, height parameters,

1. Introduction

The surface roughness is used as a major quality indicator for the machined surfaces, which is the direct result of process parameters such as cutting conditions and tool geometry. In today's manufacturing industry, a special attention is being paid to the dimensional accuracy as well as surface finish, hence, measuring and characterizing the surface finish can be considered as a machining performance index [1]. In order to achieve a sustainable product quality, e set of requirements, both technological quality (material properties, dimensional accuracy, and surface layer characteristics) and exploiting quality (wear resistance, wear resistance on contact surfaces, corrosion resistance, and surface reflectivity) must be fulfilled [2]. Hence, the technological term quality includes, in addition to the characteristics of the material, the accuracy of dimensions, shape and position, as well as the geometric characteristics of the treated surface, which often affect the quality of the product [3]. Nowadays, the manufacturing community is increasingly looking for and exploring different ways of realizing a product with a quality that meets requirements such as aesthetic, above all functional (both require high surface roughness accuracy). Of course, these properties are accomplished by various technological methods; however, in steel processing, to this day, technological process hard turning is prevalent in the field of production. Otherwise, this paper uses this processing technique as a tool to conduct the experiment.

Achieving a better surface quality, tool life and dimension accuracy are the crucial concerns in turning of hardened steels [4]. Many industrial steel components, under the influence of critical loads from automotive and aerospace parts to bearing and forming tool, are made of hardened steel. These parts are produced by a series of sequential operations like turning, grinding and polishing, which are time consuming and costly. Therefore, hard turning is gaining importance to replace operations by single setup and single operation [5]. As hard turning can offer attractive advantages in term of is higher removal rate, shorter setup time, and reduced production cost, it has become a potential substitute for conventional grinding [6].

A large number of works and researches in the field of surface quality of the hardened steel processed by turning operation have been done to date. The common factors of the researches are mostly the cutting parameters such as cutting speed (v), feed rate (f), cutting depth (a), radius of the cutting tool (r) and their mutual effects.

Garav Batarya et al. conclude that depth of cut was found to be the most influential parameter affecting the three cutting forces followed by the feed [7]. B. Fnides, et al. in the study of cutting parameters feed rate (f), cutting speed (v), depth of cut (a) and flank wear of cutting forces on the surface roughness, undertook the test of slide-lathing carried out on grade X38CrMoV5-1 steel treated at 50 HRC, machined by mixed ceramic tool (insert CC650), noted that tangential cutting force is very sensitive to the variation of cutting depth what affects the cutting forces in a considerable way. They also noted that surface roughness is very sensitive to the variation of the feed rate and that the wear has a great influence on the evolution of cutting force components and on the criteria of surface roughness [8]. From the studies above, we note that all the factors (parameters) that affect surface roughness have a functional relation between them. This functional connectivity is reflected in different mathematical models; hence, the results obtained are the product of such models and statistical analyses, the ultimate goal of which is optimization of the conditions that obtain better results.

Among the most used statistical analysis models today are DOE (Design of Experiment) which represents a statistical/mathematical model for planning the experiment so that appropriate data can be analysed by statistical methods, resulting in valid and objective conclusion (Montgomery, 2001) [9]. Taguchi method, which involves identification of proper control factors to obtain the optimum results of the process. Orthogonal Arrays (OA) are used to conduct a set of experiments. Results of these experiments are used to analyse the data and predict the quality of components produced (Wikipedia); response surface methodology (RSM); Regression analysis and so on.

A useful number of statistical analysis software is used to process variance of gathered data obtained by various techniques of measurements or experiments such as ANOVA. This paper uses computer software CADEX 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

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structural condition in all rings before the start of the experiment.

Research equipment

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

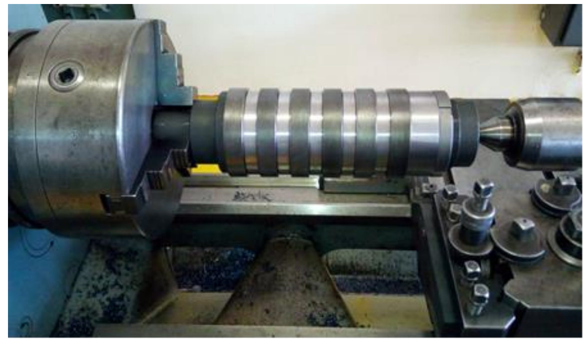
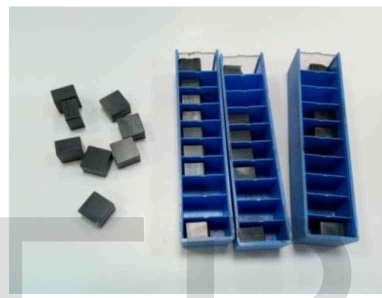


Figure 2. Special set up for exploring the characteristics of the surface layer during turning.

a)



b)

Figure 3. a) The CSRNR 25x25 M12H3 cutting board holder from HERTEL, b) Cut-off inserts SNGN 120708-120712-120716 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 (Al_2O_3 + T_i C), made by HERTEL, Figure 4. with the cutting tool stereometry: $\kappa=75^0$; $\kappa_1=15^0$; $\gamma = -6^0$; $\alpha = 6^0$; $\lambda = -6^0$; r = 0.8-1.2-1.6 mm; $\gamma_f = 20^0$; $b_f =$ 0.2 mm.

A conventional lathe model TVP 250 from the company Prvomajska, Figure 6, 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.

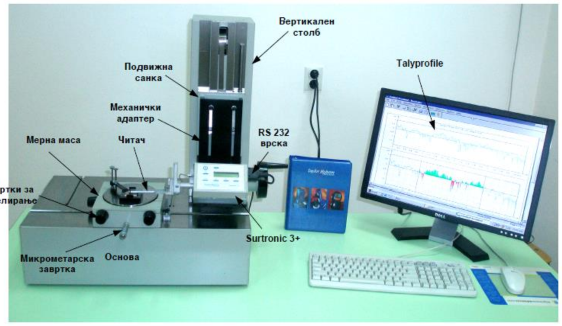


Figure 4. Computerized measuring device model Surtronic 3+ from Taylor Hobson and Talyprofile software for measurements of the profiles.

3. Analysis of research results

The machining is performed by changing four independently variable parameters, namely: cutting speed (*v*), cutting feed rate (*f*), cutting depth (*a*) and the cutting 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 (2).

$$R_a = Cv^x f^y a^z r^q \quad ...2$$

Table 1.

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

Table 2.

Four-factorial plan of first-order experiments					
Nr.	**Real plan matrix - independent variables**				**Measured values**
	v (m/min.)	**f (mm/vr.)**	**a (mm)**	**r (mm)**	**Ra (um)**
1.	67.00	0.1	0.4	0.8	0.546
2.	133.00	0.1	0.4	0.8	0.514
3.	67.00	0.315	0.4	0.8	3.353
………………………………………………………………………………					
19.	94.00	0.177 (0.18)	0.566	1.13 (1.2)	0.932
20.	94.00	0.177 (0.18)	0.566	1.13 (1.2)	0.884

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Table 3.

Correction of the input-output information for a mathematical model of the first order without interaction and without assessment of the significance of the factors (bi).				
Nr.	**Actual Ra (um)**	**Predicted Ra (um)**	**Error (%)**	**95% - Confidence interval**
1.	0.546	0.538	1.520	0.514 - 0.563
2.	0.514	0.506	1.521	0.484 - 0.530
3.	3.353	3.348	0.156	3.198 - 3.504
…………………………………………………………………………………………				
19.	0.932	0.949	-1.780	0.931 - 0.966
20.	0.884	0.949	-7.307	0.931 - 0.966

Table 4.

Without assessment of the significance of the factors (bi)							
Mathematical model of the first order without interaction							
Coefficients of the mathematical model			**Degree of freedom F(i)**	**Sum of squares S(i)**	**Dispersion S(i)/F(i)**	**Dispersion relation FR(i)**	**Evaluation of the significance of factors b (i)**
Index (i)	**Coded (i)**	**Decoded p(i)**					
0	-0.05278	26.419	1	0.055712	0.055712	11.3	**significant**
1	-0.03020	-0.0881016	1	0.014596	0.014596	3.0	**insignificant**
2	0.91437	1.594	1	13.377	13.377	2703.8	**significant**
3	0.02899	0.0836496	1	0.013447	0.013447	2.7	**insignificant**
4	-0.34549	-0.9968644	1	1.910	1.910	386.0	**significant**
If FR(i) < 10.130 = > insignificant				**If FR(i) >= 10.130 = > significant**			

For more detailed analysis, mathematical models without interaction and 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, from 92 to 95%.

Performed analysis, after completed and computed, showed adequacy of obtained mathematical model (3),

$$R_a = 26.419 v^{-0.0881016} f^{1.594} a^{0.0836496} r^{-0.9968644} \ldots 3$$

The graphical interpretation of the mathematical table 1, 2, 3, is presented in fig. 5 - 14.

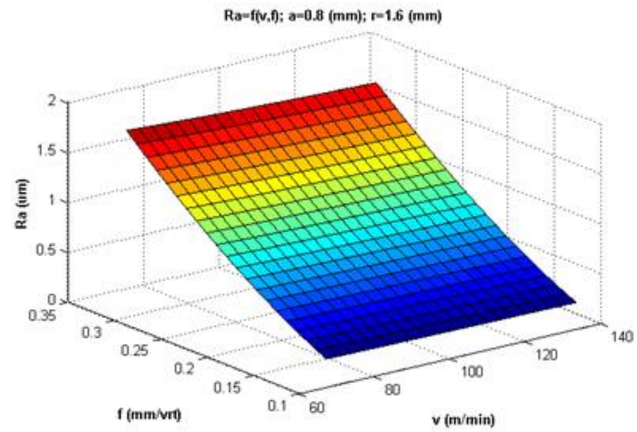

Figure 5. Surface roughness vs Speed and radius Feed

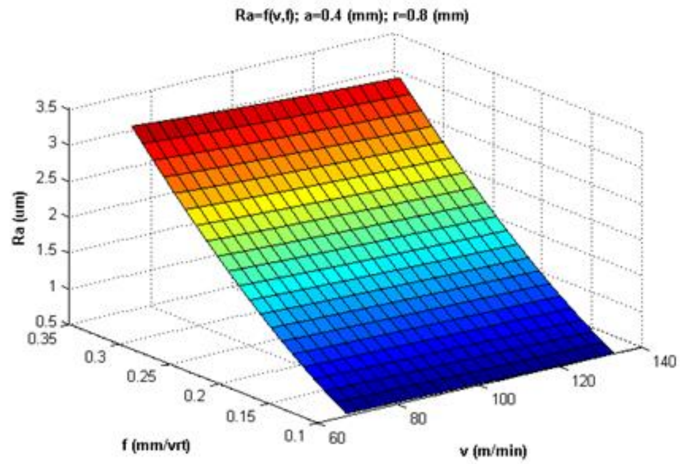

Figure 6. Surface roughness vs Speed and

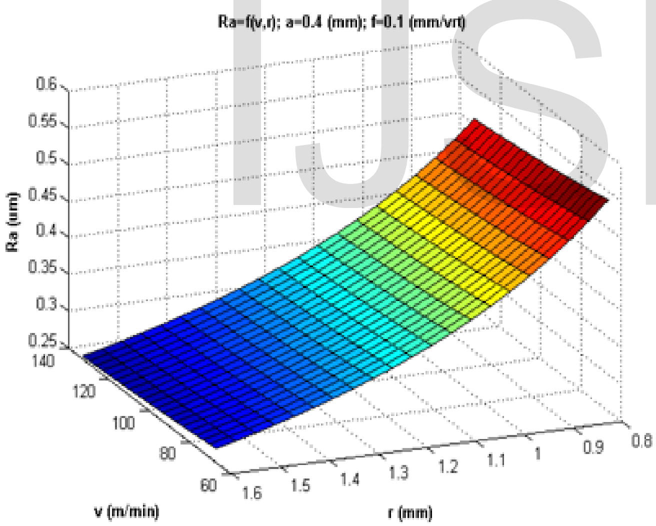

Figure 7. Surface roughness vs Speed and radaius radius

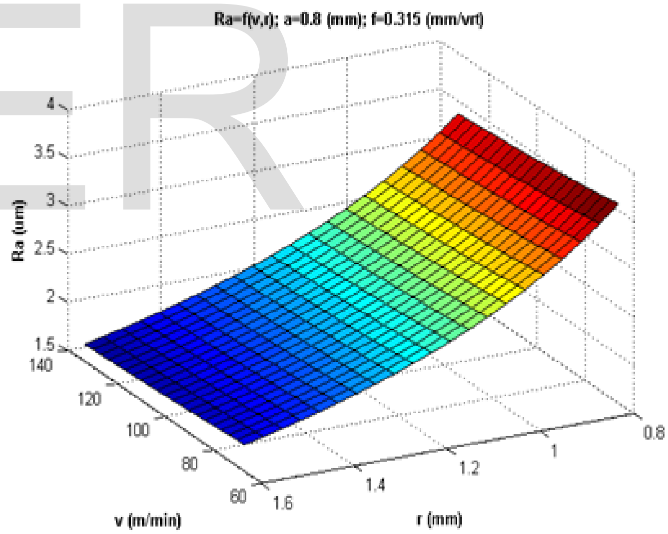

Figure 8. Surface roughness vs Speed and

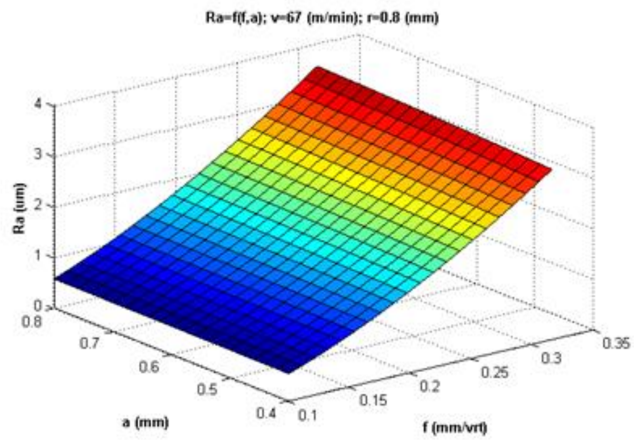

Figure 9. Surface roughness vs depth and Feed

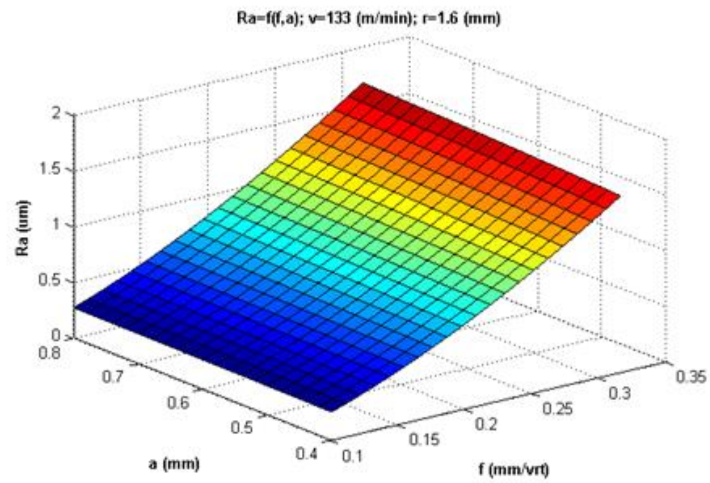

Figure 10. Surface roughness vs depth and Feed

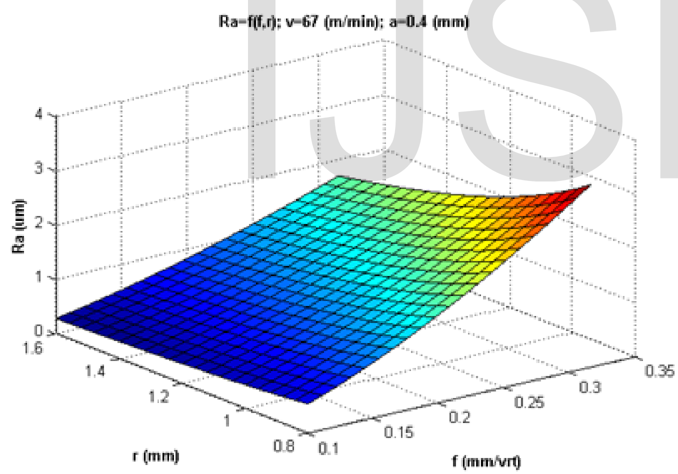

Figure 11. Surface roughness vs Feed and radius

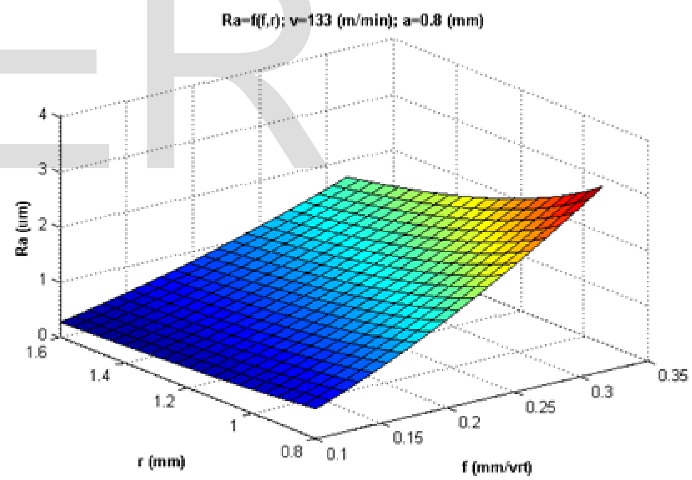

Figure12. Surface roughness vs Feed and radius

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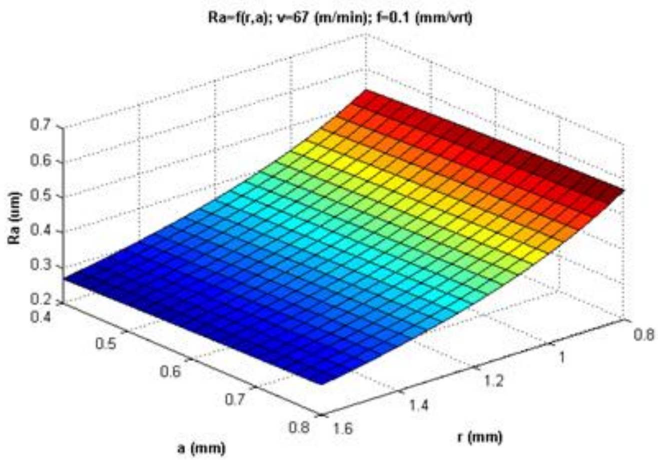

Figure 13. Surface roughness vs depth and radius

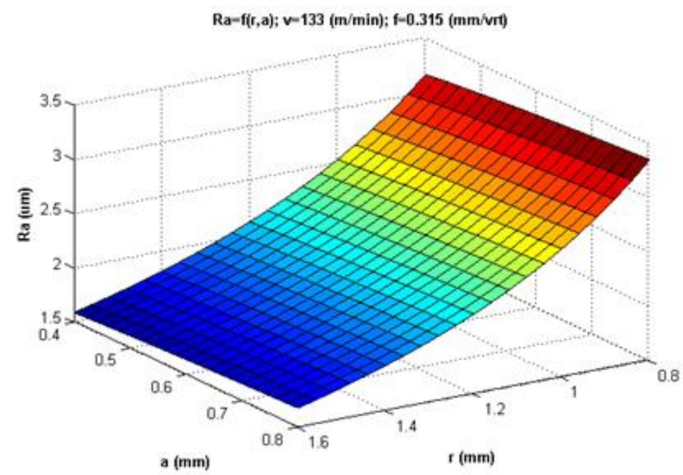

Figure 14. Surface roughness vs depth and radius

3. Discussion

Based on the examination of mathematical models obtained by experimental analysis of the machined surface roughness parameter Ra, as the result of the cutting parameters cutting speed (*v*), feed rate cut (*f*), cutting depth (*a*) and the nose radius of the cutting tool (*r*), the following conclusions are drawn:

Variations in the output surface roughness parameter Ra, is closely related with input process parameters cutting speed (*v*), feed rate (*f*), cutting depth (*a*) and nose radius (*r*), and all together may be expressed by power function;

Input parameter, the cutting speed (*v*) does not have any distinct impact on the variations of the parameter Ra; this has been established during the experimental measurements.

Feed rate (*f*) has shown substantial impact on the variations of the output parameter Ra; as the feed rate increases, an increase in the Ra height roughness parameter is observed. Based on the results of the experiment combined with the information on the literature, we come up with the conclusion that this impact, first of all, is due to the cinematic-geometric reflection of the edges of the cutting instrument on the worked surface.

The results of the experiment did not show the influence of the cutting depth (*a*) on any significant change in the surface roughness parameter Ra. The fact that this parameter is represented on the formula as a proportionally direct effect does not prove any significant difference; this influence, first of all, appears as changes occur due to vibrations as a result of resistance during cutting.

The nose radius input parameter (*r*) did not show any significant effect on the output surface roughness parameter Ra.

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 program in mechanical engineering an University "Goce Delcev" Stip, N. Macedonia. E-mail: naimostergllava@hotmail.com*

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