EXPERIMENTAL STUDY OF SURFACE ROUGHNESS IN THE CASE OF TURNING OF FREE-CUTTING STEEL AUT20 (22S20)

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ABSTRACT: A steel part (AUT20 / 22S20) was turned with various cutting parameters for different cylindrical sections and the roughness was measured for each section with the Hommel T500 tester. On the other hand, purely geometric calculations of surface roughness were used. The ***measured values*** were compared with the ***calculated values***. All calculations were done in ***MS Excel*** which helped us obtain the graphs of cutting parameter influence on roughness. The interpretation of the graphs led to drawing important conclusions regarding the cutting parameters of the above-mentioned steel.

KEY WORDS: roughness, surface micro-profile, roughness parameters, roughness total depth, mean arithmetic deviation of roughness, average roughness depth.

1 INTRODUCTION

Theoretical considerations

The surface roughness is the sum of all micro-irregularities of the real surface, resulting from machining a part. This is made visible by creating a section with a perpendicular plane of the machined surface and thus obtaining the micro-profile of the section.

The most frequently used *parameters for measuring the roughness of the machined surface* (fig. 1), according to STAS 5730/1-79 are:

a) Total roughness depth:

$$R_{max} = y_{max} - y_{min} \quad (1)$$

b) Mean arithmetic deviation of roughness (with reference to the mean line):

$$R_a = \frac{1}{L}\int_0^L |y(x)| \cdot dx \quad (2)$$

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a) Average roughness depth (measured in 10 points):

$$R_z = \frac{z_1 + z_2 + z_3 + z_4 + z_5}{5}$$
$$R_z = \frac{(R_1 + R_2 + R_3 + R_4 + R_5) - (R_6 + R_7 + R_8 + R_9 + R_{10})}{5} \quad (3)$$

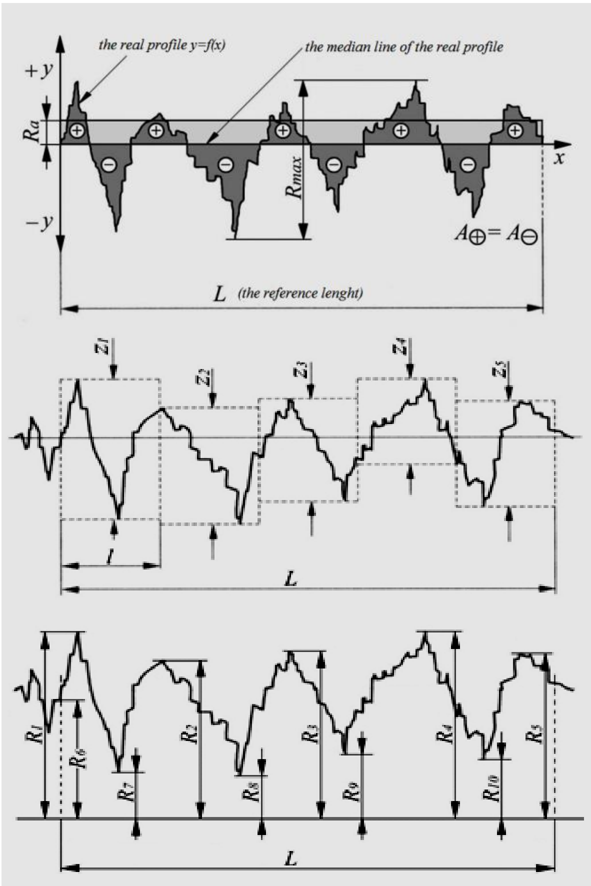

Fig.1 Parameters for measuring the roughness of the machined surface

The geometric relations for the determination of total roughness depth, in the case of longitudinal turning of a cylindrical part by using a tool bit with finite nose radius ($r_\varepsilon \neq 0$) and no nose radius ($r_\varepsilon = 0$), result from figure 2.

Although these relations don't express the real value of the roughness, they are important for choosing the machining conditions in order to obtain optimal roughness [1]. The relation for $r_\varepsilon = 0$ applies to frontal milling as well.

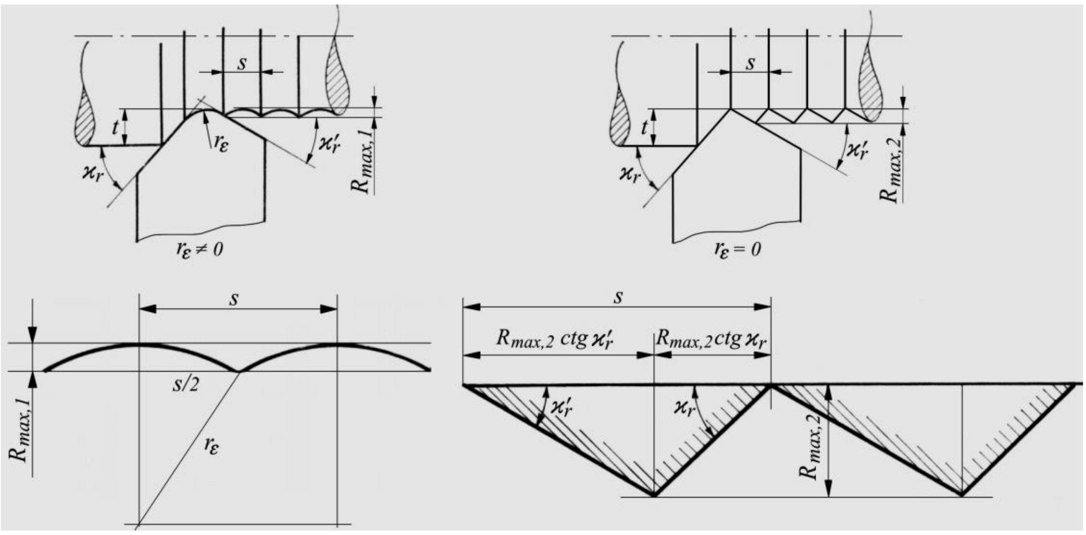

Fig.2 Necessary elements for the geometric calculation of total roughness depth.

$$\begin{cases} r_\varepsilon \neq 0 \\ r_\varepsilon - R_{\max} = \sqrt{r_\varepsilon^2 - s^2/4} \end{cases} \quad \Downarrow \quad R_{\max} \cong \frac{s^2}{8 \cdot r_\varepsilon} \qquad \begin{cases} r_\varepsilon = 0 \\ s = R_{\max} \cdot \mathrm{ctg}\chi_r' + R_{\max} \cdot \mathrm{ctg}\chi_r \end{cases} \quad \Downarrow \quad R_{\max} = \frac{s}{\mathrm{ctg}\chi_r + \mathrm{ctg}\chi_r'} \tag{4}$$

2 INFLUENCE OF THE TECHNOLOGICAL PROCESS ELEMENTS ON THE MACHINED SURFACES' ROUGHNESS

The roughness of the machined surface is the result of simultaneous action of all the machining process phenomena and factors, such as:

- *The elasto-plastic properties of the machined material.* During machining, compressive, tensile and shear strains develop, that lead to elastic and plastic deformations, both in the cut and the superficial layer of the machined surface. In the case of machining with a low feed, the deformations due to friction between the flank and the surface also have an influence. The uneven elastic deformations (elastic recovery) of the material can modify the computed value of roughness sometimes with even more than 10%. The plastic deformations influences roughness by decreasing with the contraction of the chip, approaching the theoretical value. The increase of harness and of the tensile strength determine a reduction of plastic deformations and of the friction between the chip and the rake face of the tool, and thus a reduction of the micro-irregularities.
- *Cutting parameters: feed s, cutting speed v, depth of cut t.* Roughness is at its maximum when cutting speeds are between 20-30 m/min, due mainly to the deposits on the cutting edge (which have a variable stability up to speeds close to 100 m/min), after which it decreases as the speed increases. Cutting speed influences roughness through the conditions in which the tool edge cuts and has no influence on the geometrical roughness. In specialized literature [2] it is mentioned that at low feed rates the dependence is non-linear, due to deposits on the active area of the tool that worsens the roughness. At high feed rates, due to high cutting forces, the deposits stop appearing, and the dependency becomes linear. The depth of

- cut has less influence on the roughness compared with the other parameters.
- *The geometrical tool parameters: the nose radius r_ε, the cutting-edge bend radius r_n, the α, γ, χ'_r, λ_S angles*. Specialized literature [3] unanimously accept the increase in surface quality with the increase of r_ε is due the decrease of the straight section of the cutting edge that take part in the cutting process (which can also be observed geometrically, as in figure 2, where $R_{max,1} > R_{max,2}$). By decreasing the side relief angle α , roughness generally increases, due to the friction between the flank and the machined surface. Increasing the side rake angle γ, roughness decreases as the elastic and plastic deformations of the superficial layer of material decrease. The back rake angle λ_S influences roughness through the fact that at negative values the chip is directed at the finished surface, which it can scratch. By reducing the end cutting edge angle χ_r' the quality of the surface is improved.

Cutting liquid. Correctly using cutting liquid has a positive effect on the surface roughness by reducing friction forces and preventing deposits from forming.

3 EXPERIMENTAL RESEARCH

For this experimental study two free-cutting steel test probes were used with an average carbon content of 0.2%, symbolized AUT20 (22 S 20). The test probes had identical sections that were machined with different values of the independent variables that were taken into account, feed and cutting speed (see table 1). After determining the values, the test were performed. To exclude the influence of tool wear, sintered carbide coated tools were used and each trial was done with a new edge.

When measuring roughness, five measurements were done that were statistically analyzed to outline their variance.

The results were processed by using an Excel spreadsheet that allowed both statistical calculations and graphical representation of the studied dependencies to be made.

The measurement of the roughness parameters of the machined surface *(R_{max}; R_a)* were obtained by directly touching the surface with the Hommel T500 tester.

The test probes are 320 mm long and an initial diameter of ϕ 35 mm. Each section is 20 mm long, the separating groove being 2 mm wide.

Machine-Tool: Normal Universal Lathe SNA 560x1000
Cutting liquid: Dry machining
Tool: Straight tool bit with metal carbide plate
Cutting edge material: P20
Tool geometry:

α_o [^{0}]	γ_o [^{0}]	λ_S [^{0}]	χ_r [^{0}]	χ_r' [^{0}]	r_ε [mm]
6	6	0	60	20	0,4

Part material: AUT20 (22 S 20)
Roughness tester: Hommel T500 tester

Tab.1. Experimental data table

Nr. crt.	D [mm]	t [mm]	s [mm/rot]	n [rot/min]	v [m/min]	χ_r' [^{0}]	φ [^{0}]	r_ε [mm]	$R_{a,măs}$ [µm]	$R_{max,măs}$ [µm]	$R_{max,calc}$ [µm]
1	35	1	0,09	400	43,98	20	6,46	0,4	4,478	19,018	**2,53**
2	35	1	0,14	400	43,98	20	10,08	0,4	5,36	24,602	**6,13**
3	35	1	0,2	400	43,98	20	14,48	0,4	5,874	27,008	**12,50**
4	35	1	0,25	400	43,98	20	18,21	0,4	6,746	30,62	**19,53**
5	35	1	0,4	400	43,98	20	30,00	0,4	9,036	38,312	**15,09**
6	35	1	0,63	400	43,98	20	51,95	0,4	11,97	58,764	**26,74**
7	35	1	0,2	250	27,48	20	14,48	0,4	7,824	33,506	**12,5**
8	35	1	0,2	315	34,63	20	14,48	0,4	7,076	32,676	**12,5**
9	35	1	0,2	500	54,97	20	14,48	0,4	6,758	30,434	**12,5**
10	35	1	0,2	630	69,27	20	14,48	0,4	6,742	30,008	**12,5**
11	35	1	0,2	800	87,96	20	14,48	0,4	6,572	28,628	**12,5**
12	35	1	0,2	1000	109,95	20	14,48	0,4	5,314	24,248	**12,5**
13	35	1	0,2	400	43,98	0	14,48	0,4	6,652	31,014	**12,5**

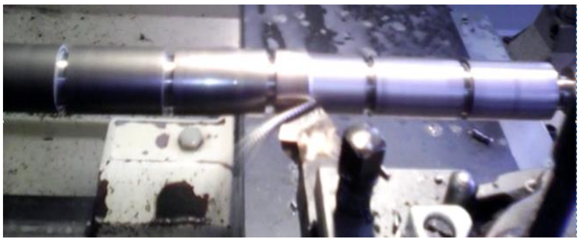

Fig.3. Machining of a section on SNA560x1000

Fig.4. Roughness measurement of the sections with the Hommel T500

Tab.2 Total roughness depth measured values - R_{max}

measurement / section	Rmax. [µm]					
	1	2	3	4	5	Medie
1	19.5	19.18	18.78	18.95	18.68	19.018
2	23.47	25.83	24.75	24.5	24.46	24.602
3	27.58	26.8	29.04	25.7	25.92	27.008
4	30.82	29.81	31.65	30.64	30.18	30.62
5	38.16	38.5	37.93	39.31	37.66	38.312
6	57.38	58.75	57.7	62.15	57.84	58.764
7	32.78	34.06	33.43	33.2	34.06	33.506
8	32.06	33.62	33.3	33.16	31.24	32.676
9	28.39	29.81	30.35	31.84	31.78	30.434
10	29.09	28.42	31.47	31.19	29.87	30.008
11	27.06	29.33	28.68	28.54	29.53	28.628
12	24.63	23.04	24.57	23.85	25.15	24.248
13	29.79	32.78	30.24	31.65	30.61	31.014

Tab.3 Values for mean arithmetic deviation of roughness - R_a

measurement / section	Ra [µm]					
	1	2	3	4	5	Medie
1	4.85	4.51	4.48	4.35	4.2	4.478
2	5.45	5.34	5.27	5.39	5.35	5.36
3	6.17	5.95	5.92	5.68	5.65	5.874
4	7.12	6.47	6.79	6.85	6.5	6.746
5	9.43	8.91	8.67	9.16	9.01	9.036
6	11.9	11.94	11.5	12.51	12	11.97
7	7.86	7.92	7.79	7.64	7.91	7.824
8	6.73	7.31	6.99	7.48	6.87	7.076
9	6.52	6.23	6.89	7.12	7.03	6.758
10	6.69	6.25	7.11	6.79	6.87	6.742
11	6.09	6.81	6.55	6.39	7.02	6.572
12	5.26	4.88	5.47	5.09	5.87	5.314
13	6.23	7.32	6.85	6.55	6.31	6.652

The calculations used for filling in the experimental values table (Tab.1) are presented briefly bellow:

$$\textit{Cutting speed:}\quad v=\frac{\pi\cdot D\cdot n}{1000}\quad[m/\min]; \tag{5}$$

$$\textit{Angle calculation } \varphi:\ \varphi=\arcsin\frac{s}{2\cdot r_\varepsilon} \tag{6}$$

Geometrical relations for determining total roughness depth R_{max} :

$$if\quad r_\varepsilon=0 \qquad\Rightarrow\quad R_{\max}=\frac{s}{ctg\chi_r+ctg\chi_r^{'}} \tag{7}$$

$$if\quad r_\varepsilon\neq0\ si\ \begin{cases}\chi_r>\varphi\\ \chi_r^{'}>\varphi\end{cases}\quad\Rightarrow\quad R_{\max}\cong\frac{s^2}{8\cdot r_\varepsilon} \tag{8}$$

$$if\quad r_\varepsilon\neq0\ si\ \begin{cases}\chi_r<\varphi\\ \chi_r^{'}<\varphi\end{cases}\quad\Rightarrow\quad R_{\max}=\frac{\sin\chi_r\cdot\sin\chi_r^{'}}{\sin\left(\chi_r+\chi_r^{'}\right)}\cdot\left(s-r_\varepsilon\cdot\tan\frac{\chi_r}{2}\cdot\tan\frac{\chi_r^{'}}{2}\right) \tag{9}$$

$$if\quad r_\varepsilon\neq0\ si\ \begin{cases}\chi_r<\varphi\\ \chi_r^{'}>\varphi\end{cases}\quad\Rightarrow\quad R_{\max}=\left[\begin{array}{l}r_\varepsilon\cdot(1-\cos\chi_r)+s\cdot\sin\chi_r\cdot\cos\chi_r\\ -\sin\chi_r\sqrt{s\cdot\sin\chi_r\left(2\cdot r_\varepsilon-s\cdot\sin\chi_r^{'}\right)}\end{array}\right] \tag{10}$$

$$if\quad r_\varepsilon\neq0\ si\ \begin{cases}\chi_r>\varphi\\ \chi_r^{'}<\varphi\end{cases}\quad\Rightarrow\quad R_{\max}=\left[\begin{array}{l}r_\varepsilon\cdot(1-\cos\chi_r^{'})+s\cdot\sin\chi_r^{'}\cdot\cos\chi_r^{'}\\ -\sin\chi_r^{'}\sqrt{s\cdot\sin\chi_r^{'}\left(2\cdot r_\varepsilon-s\cdot\sin\chi_r^{'}\right)}\end{array}\right] \tag{11}$$

4 GRAPHS AND CONCLUSIONS

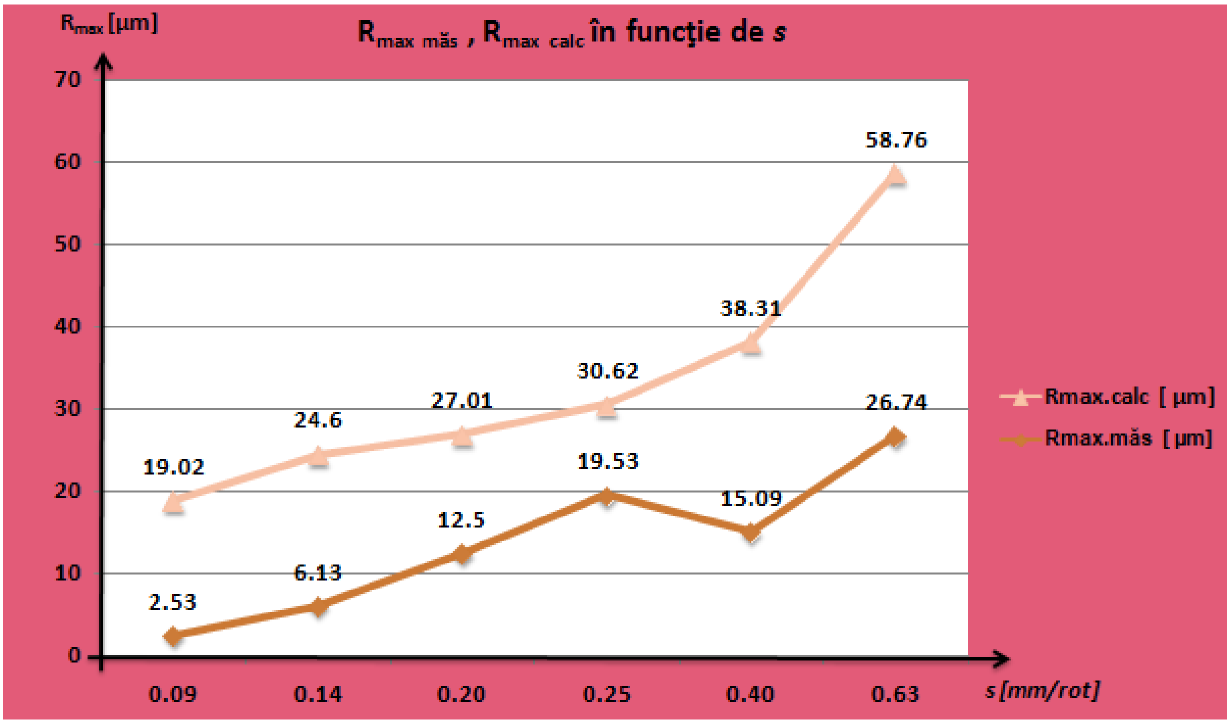

Fig.5 $R_{max\ measured}$, $R_{max\ comp}$ dependent on s, sections 1-6

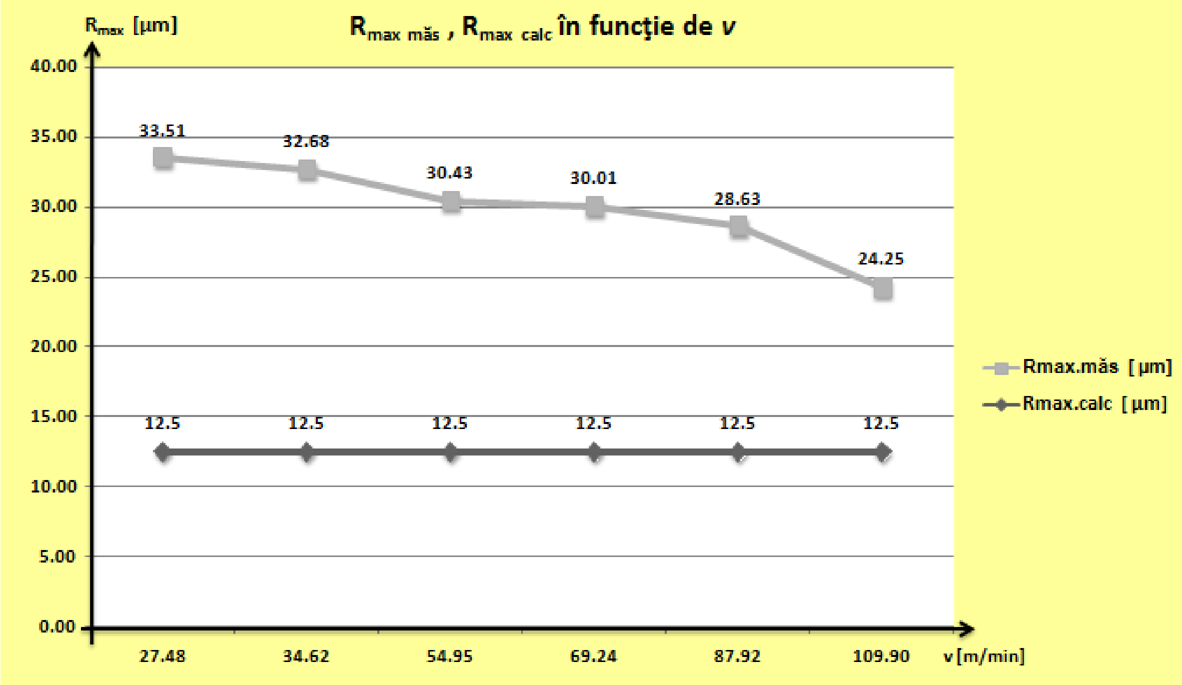

Fig.6. $R_{max\ measured}$ depending on v, sections 7-12

The experimental machining of the AUT20 (22 S 20) free-cut steel, as in table shown above, the measurement and calculation of roughness of the machined surface, helped us draw the graphs presented in the paper and with their help reach the following conclusions:

- The measured and computed values for the total roughness depth R_{max}, were compared and significant differences were noticed.
- Increasing the feed leads to an increase in roughness (while maintaining other technological process parameters constant)
- Increasing cutting speed leads to a decrease in roughness (while maintaining other technological process parameters constant). Regarding the computed roughness remaining constant ($R_{max,calc}$), at different cutting speeds it can be explained through the fact that equations (3) – (7) don't take this parameter into account, because they are purely geometrically determined. The roughness values obtained with these equations are up to 40% lower that real values, as they don't take into account plastic deformations that take place in the cutting process
- Reducing the side rake angle leads to the decrease of surface roughness (while maintaining other technological process parameters constant)

5 REFERENCES

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