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Roughness in External Cylindrical Tangential Oblique Turning

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Abstract

The quality of the surfaces is an important characteristic pursued when processing the parts used in the construction of machines. There is a constant search for new, original processing schemes and tools, which lead to the best possible results. For this, the authors have designed an original lathe tool, with inclined tangential cutting edge with adjustable inclination, for which a patent application has been submitted. By using this tool, a large number of tests with representative processing parameters were performed on 42CrMo4QT steel specimens, considering a complete research plan. All tests were performed with the same depth of cut, but different speeds, feed rates and inclination of the cutting edge of the tool. The roughness of the obtained surfaces was measured using a high-performance electronic roughness meter. For comparison, processing under similar conditions was performed using a normal turning tool. The present paper presents a mathematical model for the theoretical roughness in turning with an inclined tangential edge, analyses the influence of the working parameters on the roughness and compares the ideal values with values obtained experimentally.

Keywords

roughness, oblique turning, analytical model, experimental results

1. Introduction

In this article, is analysed the surface quality of the cylindrical bodies obtained by turning. The real technical surface is defined as *the superficial layer of a machined object, considered up to a depth equal to the height of the irregularities from the machining, especially when machining with edged or abrasive tools* [1].

The surface layer of the parts obtained by mechanical processing has a complex structure [2], made up of successive layers: an outer layer I (thickness 2...3 Å) made up of adsorbed gas molecules, a layer II (thickness 10...50 Å) consisting of particles loosely connected to each other (oxides, nitrides, impurities) whose composition and structure depend on the processing method, temperature, surface phenomena that occur during processing, and a layer III (thickness 1...50 μm) formed from the base material hardened in the chip removal process by cold plastic deformation. The degree of hardening is maximum towards the outside (where at a small depth the crystalline structure can be destroyed - the "flow layer") and gradually decreases towards the inside, until reaching the base material unaffected by the mechanical processing process.

The quality of the surfaces of the parts is an important characteristic for their behaviour in operation and can be assessed by two categories of criteria [3]:

- geometric criteria – macro-irregularities, undulations and roughness. Macro-irregularities and undulations are within the limits of dimensional accuracy; the roughness is assessed by the usual parameters (arithmetic average deviation R_a of the profile and average height R_z of the micro-irregularities) and depends on the final mechanical processing operation;
- physical-mechanical criteria - structure, hardness and residual stresses.

Surface roughness (roughness, for short) is a component of surface texture [3]. This is quantified by the deviations of the real surface from its ideal shape in the direction of the latter's normal vector. If these deviations are large, the surface is rough; if the deviations are small, the surface is smooth. Roughness represents the micro-geometric scale value of the variations in height of a physical surface, Figure 1. The real profile of the surface of a part can be measured and visualized by different methods: with mechanical probes, optical or three-dimensional optical methods.

The roughness value is determined by calculating parameters defined by standards [4, 5]. The roughness value can be calculated either on a profile (line) or on a surface (area, zone). Profile roughness parameters are most commonly used, but surface parameters give more significant values.

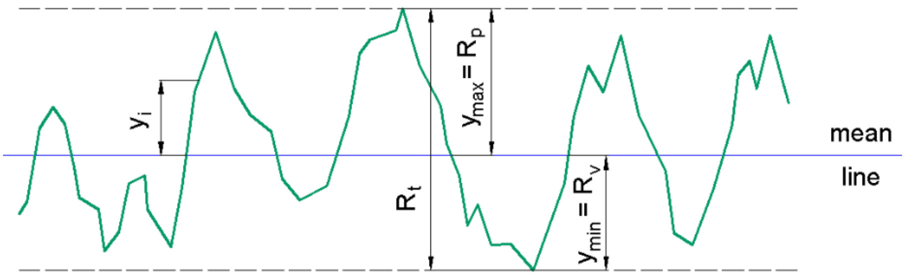

Fig. 1. Profile of a surface obtained through cutting

There are several parameters in use of the profile roughness, the most used being: R_a, R_p, R_v, R_t, R_q and R_z (cf. DIN) [3].

R_a is the arithmetic mean deviation of the evaluated profile and represents the arithmetic mean of the absolute values of the profile ordinates, within the limits of a base length l of the roughness profile:

$$R_a = \frac{1}{l} \cdot \int_0^l |y(x)| dx \tag{1}$$

R_p is the maximum height of the profile and represents the distance between the largest peak and the mean line of the roughness profile within the base length:

$$R_p = \max_i y_i \tag{2}$$

R_v is the maximum void depth of the profile and is the distance between the deepest void and the mean line within the base length limits:

$$R_v = \min_i y_i \tag{3}$$

R_t is the total height of the profile, i.e. the distance between the highest peak and the deepest hollow:

$$R_t = R_p + R_v \tag{4}$$

R_q is the mean square deviation of the evaluated profile and represents the standard deviation of the distribution of profile heights:

$$R_q = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} y_i^2} \tag{5}$$

is the height in s points of the profile, i.e. the average of the absolute values of the heights of the upper $s/2$ projections and the deeper $s/2$ hollows within the limits of the reference length l:

$$R_z = \frac{1}{s} \cdot \sum_{i=1}^{s} (R_t)_i \tag{6}$$

Each of the listed formulas assumes that the roughness profile has been filtered from the raw profile data and the mean line has been calculated. The roughness profile contains n equidistant points and is the vertical distance from the mean line to point. The height is assumed to be positive in the upward direction (towards the outside of the surface).

2. Theoretical roughness of surfaces obtained by turning

Turning is the technological operation of generation by cutting most frequently found for obtaining surfaces of revolution. The parts subjected to processing are made of a wide variety of materials, steel being predominant. Various processing schemes are used, adapted to the geometry of the surface to be processed and the type of tool used.

For usual turning schemes, an example in Figure 2, the specialized literature [6 – 10] presents a whole series of mathematical relationships intended to highlight the geometrical correlation between the heights of asperities on the one hand and the feed f, the tip connection radius tool r_ε, the angles of attack χ and χ_1 on the other hand.

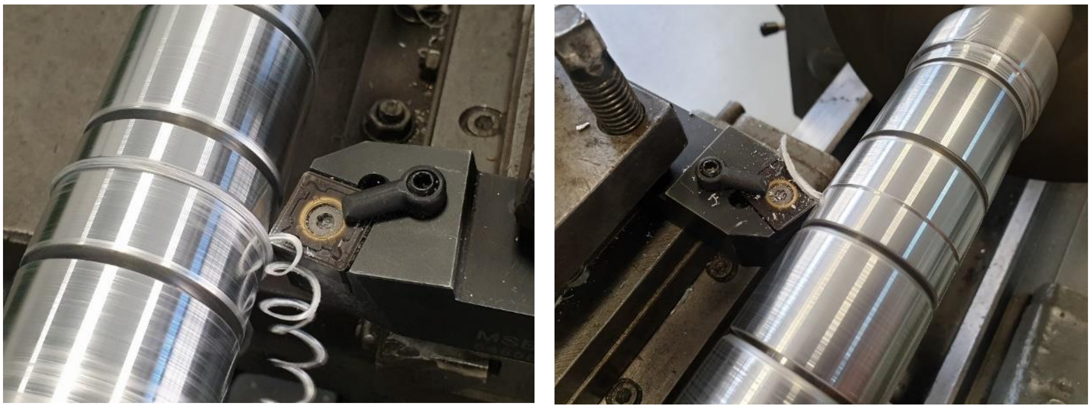

Fig. 2. Machining with an ISO 1 tool

Some of the relationships indicated for establishing the theoretical roughness value for turning are (f represents the feed rate) [6]:

$$R_z = \frac{f}{\operatorname{ctg}\chi + \operatorname{ctg}\chi_1} \quad \text{(for the tool tip radius } r_\varepsilon = 0\text{)} \tag{7}$$

$$R_z = \frac{f^2}{8r_\varepsilon} \quad (\text{for } f > r_\varepsilon,\ r_\varepsilon \neq 0) \tag{8}$$

$$R_z = \frac{f}{\operatorname{ctg}\chi + \operatorname{ctg}\chi_1}\left[f - r_\varepsilon\left(\operatorname{tg}\frac{\chi}{2} + \operatorname{tg}\frac{\chi_1}{2}\right)\right] \quad \left(\text{for } \chi < \arcsin\frac{f}{2r_\varepsilon};\ \chi_1 < \arcsin\frac{f}{2r_\varepsilon}\right) \tag{9}$$

An original relationship proposed by a research group from the Technical University of Iasi [6] is

$$R_a = \left(m - \sqrt{r_\varepsilon^2 - \frac{f^2}{4}}\right) - \frac{r_\varepsilon^2}{2f}\left[2\arcsin\frac{f}{2r_\varepsilon} - \sin\left(2\arcsin\frac{f}{2r_\varepsilon}\right)\right] + \frac{r_\varepsilon^2}{f}\left[2\arcsin\frac{\sqrt{r_\varepsilon^2 - m^2}}{r_\varepsilon} - \sin\left(2\arcsin\frac{\sqrt{r_\varepsilon^2 - m^2}}{r_\varepsilon}\right)\right], \tag{10}$$

where

$$m = \frac{\sqrt{4r_\varepsilon^2 - f^2}}{4} + \frac{r_\varepsilon^2}{f}\arcsin\frac{f}{2r_\varepsilon} \tag{11}$$

is the distance from the center of the circle corresponding to the connection radius r_ε of the tool tip to the mean line of the profile.

Various manufacturing cutting tools companies indicate in their product catalogues relationships for roughness values. For example, the SECO Company [11] indicates the relationships:

- for the arithmetic mean deviation (in μm)

$$R_a = \frac{f^2 \times 50}{r_\varepsilon} \tag{12}$$

or

$$R_a \approx 770 \cdot \left(1 - \frac{\frac{f}{2 \cdot r_\varepsilon}}{\arcsin\left(\frac{f}{2 \cdot r_\varepsilon}\right)} \right) \cdot r_\varepsilon \tag{13}$$

relation valid for

$$f \leq 2\sqrt{a_p \cdot (2r_\varepsilon - a_p)} \leq 2r_\varepsilon \tag{14}$$

where a_p is the depth of cut.

- estimated total profile height (k – constant; k = 1 for stainless steel) (in μm)

$$R_t = k \cdot \frac{f^2 \cdot 1000}{8 \cdot r_\varepsilon} \tag{15}$$

or

$$R_t = 3.5 \cdot R_a \tag{16}$$

As a result of the experimental research, empirical relations of dependence of some roughness parameters on the different factors that characterize the cutting conditions were also obtained. As an example, a valid relationship for turning OLC 45 / C45 steel with cutting speeds above 100 m/min is the following [6]:

$$R_a = 43.85 \cdot v^{-0.159} \cdot f^{1.457} \cdot r_\varepsilon^{-0.428} \tag{17}$$

v being the cutting speed.

The interpretation of the experimental results allowed the highlighting of some findings:

- the roughness of the machined surface is to a small extent dependent on the size of the cutting depth [6];
- with the increase of the connection radius r_ε, the value of the roughness R_a decreases [6, p. 171, fig. 8.16];
- with the increase in the value of the feed rate f, the value of the roughness R_z increases [6, p. 171, fig. 8.17];
- by reducing the value of the feed rate f below certain limits, not only is it not possible to decrease the height of the asperities to any value, but it is possible that the roughness increases [6];
- the roughness of the surface is affected by the presence of cutting liquids, especially in machining with low cutting speeds [6, p. 181, fig. 9.4]. Of particular importance are the additive liquids, which contribute to the reduction of plastic deformations, cutting and friction forces and which allow to reduce the possibilities of formation of the deposition edge,

and recommendations based on experience [6, p. 48]:

- the chipping depth should not be less than the tip radius of the tool;
- the maximum advance must be considerably smaller than the tip radius of the tool;
- a larger radius at the tip of the tool leads to a better surface finish.

3. Particular schemes of machining by turning

The authors of the present paper are also interested in other machining schemes for turning that favour the obtaining of very good quality revolution surfaces. In this sense, they identified the possibility of turning with tools with a linear active edge arranged tangent to the (external cylindrical) surface to be processed and much inclined in relation to the axis of rotation of the part. They named this processing scheme "turning with inclined tangential linear edge" [12, 13].

There are few researchers and rare works that address this method of machining by turning. Perhaps for this reason, the name of the procedure is different from author to author: Monka et al. [14] uses the phrase "*turning tools with linear cutting edges*", and Grzesik and Żak [15] "*oblique machining*", both works treating with priority the machining scheme where the tool release surface is oriented towards the side of the feed direction. In the framework of a PhD thesis, Zamfirache [16, 17] developed detailed theoretical and experimental research using an original tool that he called a "no-tip", a particular constructive solution of a tool with a linear edge arranged tangent to the surface of processed. Kasian (cited by Zamfirache [16]) also conducted research with a "no-tip" monoblok cutting tool, for the fine turning of non-ferrous metals and alloys. The good experimental results were justified by the fact that with the "no-tip" tool the release face is strongly inclined and allows the free flow of the chip. Mikolajczyk et al. [18] uses the name "*oblique turning*" and presents new, original constructive solutions of special tools with continued edge and high value of cutting angle λ_s, for which patent protection was requested [19]. The name "*oblique turning*" is also used by Filippov [20]. To avoid ambiguities, it is expected that the name "*tangential oblique turning*" proposed by the authors of the present paper will be imposed.

Various other researchers [21 – 23] address the subject of machining with a single edge inclined to the feed direction, but without using the same name.

4. Theoretical surface roughness obtained by tangential oblique turning

Determining the analytical expression of the roughness size and then comparing it with experimental results is practiced.

In tangential oblique turning, the generated instantaneous surface is given by the cutting edge of the tool in actual contact with the layer of material that is removed from the workpiece, M being the point of tangency between the linear cutting edge and the generated cylindrical surface (of radius r_p). The distance from the workpiece axis to the various points of the linear cutting edge is variable, depending on the angle λ_s of the cutting edge and the radius r_p. In an Oxyz coordinate system with the origin in the workpiece axis, Figure 3, the mentioned distance is given by the hypotenuse of the right triangle where one side is the distance O'M' from the workpiece axis to the vertical plane (tangent to the workpiece) containing the bevelled cutting edge of the tool , O'M' = r_p, and the other side is the distance M'P from the horizontal plane of the part axis to the current point P of the inclined cutting edge, M'P = $z(x) = x \cdot \mathrm{tg}\lambda_s$, is expressed by the relation

$$\overline{O'P} = y(x) = \sqrt{r_p^2 + z^2(x)} = \sqrt{r_p^2 + x^2 \cdot \mathrm{tg}^2(\lambda_s)} \qquad (18)$$

which is a hyperbola.

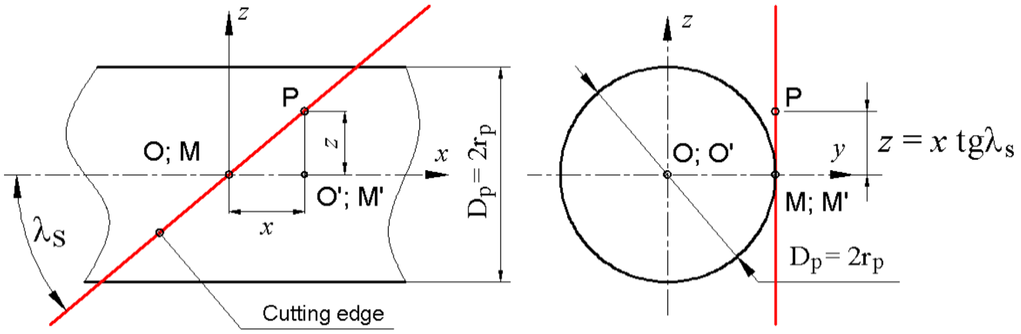

Fig. 3. The position of the cutting edge in oblique tangential turning

It should be specified that the distance between the axis of the part and the linear edge of the tool, measured in a transverse plane located at a distance *x* from the origin of the coordinate system (plane containing the current point P of the inclined cutting edge), is identical to the distance from the axis to the generated instantaneous surface measured in any of the axial planes of the part, therefore also in its horizontal axial plane. As a result, relation (18) also expresses the profile (the generatrix) of the surface that makes the transition from the machined surface, the cylinder of radius r_p, and the surface of the workpiece, a cylinder of radius $r_p + a_p$, where a_p is the depth of cut.

In the horizontal plane of the workpiece axis, the Mxy coordinate system can be defined in relation to which the hyperbola (18) is expressed by the following relation

$$y_M(x) = \sqrt{r_p^2 + x^2 \cdot \mathrm{tg}^2(\lambda_s)} - r_p \tag{19}$$

which describes the distance from the ideal (completely smooth) surface and the actual theoretical surface of the workpiece, i.e. the instantaneous theoretical height of asperities.

As a result of the longitudinal advance movement of the tool, with the feed rate *f*, in the horizontal axial plane of the piece the trace left by the cutting edge of the tool is an equidistant succession of hyperbola arcs. Expressed in the same coordinate system with the origin O, the various hyperbolas are expressed by the relation

$$y_j(x) = y(x + j \cdot f) = \sqrt{r_p^2 + (x + j \cdot f)^2 \cdot \mathrm{tg}^2(\lambda_s)}\ , \tag{20}$$

where *j*) is an integer number, $j \in \mathrm{Z}$.

Each two such neighbouring hyperbolas intersect in a point situated, from the surface of the cylinder of radius r_p, at the distance $h = R_t$, which represents the distance between the largest peak and the deepest hollow, Figure 4, i.e. the total theoretical height of the surface profile.

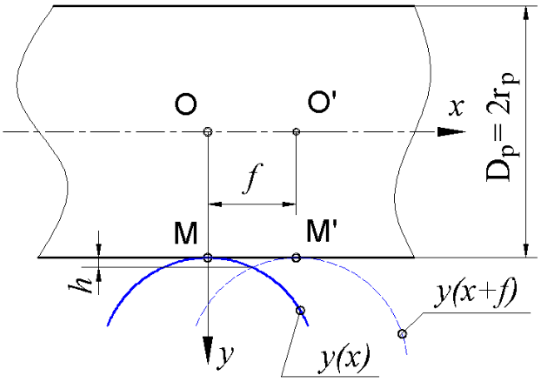

Fig. 4. Theoretical profile in oblique tangential turning
(equidistant succession of hyperbola arcs)

Considering the neighbouring hyperbolas *y*(*x*-*f*) and *y*(*x*), their point of intersection is the solution of the equation

$$y(x - f) = y(x) \quad \leftrightarrow \quad \sqrt{r_p^2 + (x - f)^2 \cdot \mathrm{tg}^2(\lambda_s)} = \sqrt{r_p^2 + x^2 \cdot \mathrm{tg}^2(\lambda_s)}\,, \tag{21}$$

has the abscissa

$$x = \frac{f}{2} \tag{22}$$

and the ordinate

$$y\left(\frac{f}{2}\right) = \sqrt{r_p^2 + \frac{f^2}{4} \cdot tg^2(\lambda_s)}\ . \tag{23}$$

Consequently, the total theoretical height R_{t0} of the profile of the irregularities of the cylindrical surface generated by oblique turning can be determined with relation (24):

$$R_{t0} = \sqrt{r_p^2 + \frac{f^2}{4} \cdot \mathrm{tg}^2(\lambda_s)} - r_p \,. \tag{24}$$

Considering the relations (1) and (19), the analytical expression R_{a0} of the roughness for the studied case is

$$R_{a0} = \frac{1}{\frac{f}{2}} \cdot \int_0^{\frac{f}{2}} \left(\sqrt{r_p^2 + x^2 \cdot \mathrm{tg}^2(\lambda_s)} - r_p \right) dx = \frac{2}{f} \cdot \mathrm{tg}(\lambda_s) \cdot \int_0^{\frac{f}{2}} \sqrt{x^2 + \frac{r_p^2}{\mathrm{tg}^2(\lambda_s)}}\, dx - r_p. \tag{25}$$

Knowing that [24, p. 571]

$$\int \sqrt{a^2 + x^2} dx = \pm \frac{a^2}{2}\, \mathrm{argsh} \frac{x}{a} + \frac{x}{2} \cdot \sqrt{a^2 + x^2} + C \tag{26}$$

and that [25]

$$\mathrm{argsh} x = \ln\left(x + \sqrt{x^2 + 1} \right), \tag{27}$$

then

$$R_{a0} = \frac{\mathrm{tg}(\lambda_s)}{2} \cdot \sqrt{\frac{f^2}{4} + \frac{r_p^2}{\mathrm{tg}^2(\lambda_s)}} + \frac{r_p^2}{f \cdot \mathrm{tg}(\lambda_s)} \cdot \ln\left(\frac{\mathrm{tg}(\lambda_s)}{r_p} \cdot \frac{f}{2} + \sqrt{\left(\frac{\mathrm{tg}(\lambda_s)}{r_p} \cdot \frac{f}{2} \right)^2 + 1} \right) - r_p. \tag{28}$$

The relation (28) differs significantly from the one determined "*empirically*" by Zamfirache [17, p. 148].

The theoretical total height of the profile ("*total roughness*") R_{t0}, relation (24), and the theoretical arithmetic mean deviation ("*average roughness*") R_{a0}, relation (28), depend on the angle of inclination λ_s of the tool edge, on the feed rate f and of the obtained radius r_p of the part subjected to processing. The influence of each of the mentioned parameters was studied considering for them variations in the domains $\lambda_s \in \{10; 20; 30; 40; 50; 60; 70; 80\}$, in degrees, $f \in \{0.12; 0.16; 0.24; 0.32\}$, in mm/rev, $r_p \in \{10;15; 20; 25; 30; 35; 40; 45; 50; 55; 60; 65; 70; 75; 80\}$, in mm. Numerical results are given in Tables 1, 2 and 3, and suggestive graphical representations in Figures 5, 6 and 7 respectively.

Table 1

λ_s [°]	R_{a0} [μm]	R_{t0} [μm]
10	0.000746	0.002239
20	0.003179	0.009538
30	0.008	0.024
40	0.016898	0.050694
50	0.034087	0.10226
60	0.072	0.215999
70	0.181166	0.543496
80	0.771901	2.31566

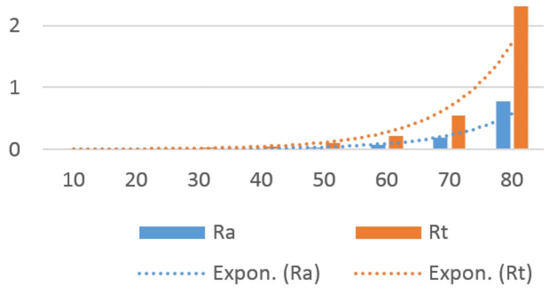

Fig. 5

The variation of the roughness R_{a0} and R_{t0} depending on the angle λ_s, for $f = 0.12$ mm/rev and $r_p = 25$ mm

Table 2

f [mm/rev]	R_{a0} [μm]	R_{t0} [μm]
0.12	0.034087	0.10226
0.16	0.060598	0.181795
0.2	0.094685	0.284054
0.25	0.147945	0.443833
0.32	0.242392	0.727171

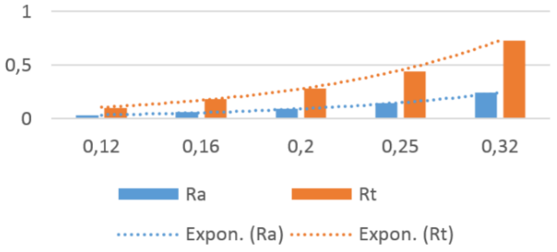

Fig. 6

The variation of the roughness R_{a0} and R_{t0} depending on the feed rate f, for $\lambda_s = 50°$ and $r_p = 25$ mm

Table 3

r_p [mm]	R_{a0} [μm]	R_{t0} [μm]
10	0.085216	0.255647
15	0.056811	0.170432
20	0.042608	0.127824
25	0.034087	0.10226
30	0.028406	0.085216
35	0.024348	0.073043
40	0.021304	0.063912
45	0.018937	0.056811
50	0.017043	0.05113
55	0.015494	0.046482
60	0.014203	0.042608

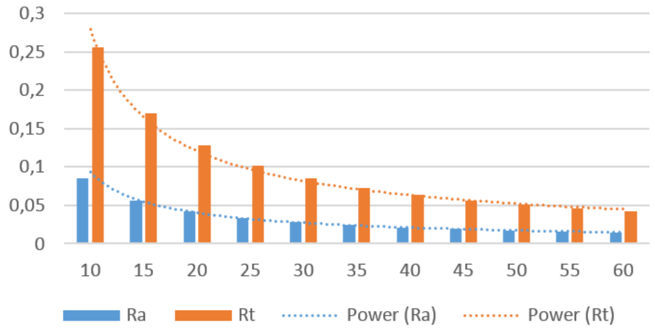

Fig. 7

The variation of the roughness R_{a0} and R_{t0} depending on the radius r_p of the workpiece, for λ_s = 50° and f = 0.12 mm/rev

In all cases the ratio between the roughness R_{t0} and R_{a0} is R_{t0} / R_{a0} = 3, with extremely small deviations. It should therefore be noted that, at least from the perspective of analytically determined values, relation (16) is not confirmed.

5. Real Roughness of Surfaces Machined by Oblique Turning

5.1. Status Art

Several researchers present in their works experimental results and assessments regarding the quality of cylindrical surfaces processed by oblique turning with a tool with an inclined tangential edge. Mikolajczyk et al. [18] states that oblique cutting *is suitable for obtaining a low R_a surface at relatively high feed rates*, that the roughness of the obtained surface increases with the increase of the feed rate and that it decreases significantly (almost linearly) with the increase of the diameter of the machined part, with reference to an analytical relation for roughness given by Latoś [22]. Grzesik and Żak [15] that present and analyse experimental results obtained during oblique turning of four different steels. In three of these (C45, X6CrNiTi18-10, and EN-GJS 500-7) depth of cut (a_p = 0.27 mm), feed (f = 0.17 mm/rev) and cutting edge angle (λ_s = 55°) are identical. Small values for roughness, R_a = 0.27 ... 0.8 μm, were obtained at medium and high cutting speeds, v = 140 ... 280 m/min.

Zamfirache [17] presents sets of experimental results obtained when processing titanium alloys (TiAl6V4, TiAl5Fe25, TiMo32) using a "no-tip" cutting tool equipped with a removable insert (K20, K30, P20), the clearance surface being oriented against the direction of advance.

For the different combinations of the parameters of the cutting regimes, the obtained absolute values of the roughness R_a were in the range of 1.05 ... 4.5 μm [17, p. 157]. It is also stated that *the roughness of the surface processed with a no-tip cutting tool is 2...3 classes higher than the smoothness of the surface obtained with ordinary tools used for fine turning*.

As part of an exploratory research [26], the authors of the present paper studied the influence of feed and cutting speed on the surface roughness obtained in tangential oblique turning. A specially made lathe tool was used, with an angle of inclination λ_s = 70°, without the possibility of adjusting the inclination of the edge. For all processing, the cutting depth was a_p = 0.5 mm, and the feed in the range f = 0.12 ... 0.20 mm/rev. For steels, very good results, roughness R_a = 0.15 ... 0.5 μm, were obtained especially at speeds in the v = 25 ... 50 m/min range. When processing aluminium alloy 6061, good results were obtained at a speed of approx. 60 m/min.

5.2. Methodology

The systematic extension of the research was motivated by the good results obtained by the authors in the exploratory research. The aim was to identify the influence of the feed rate, the cutting speed and the angle λ_s of the linear cutting edge on the quality of the cylindrical outer surfaces in tangential oblique turning. Specimens of two types of steel were tested – OLC45 / C45, a frequently used quality carbon steel, and 42CrMo4QT / 1.7225QT, an all-purpose heat-treated alloy steel, especially for use in mechanical engineering.

All machining tests were performed with a depth of cut of 0.5 mm and without cooling. It should be noted that the lack of cooling is a strong disfavouring factor, which leads to a roughness value 2-3 times higher or even more than in the processing carried out with cooling [6, pp. 177-181].

For the experimental research, an original special tool was designed [12], Figure 8, which was made within the Engineering and Industrial Management department at Transilvania University in Brasov. The tool was equipped with an ISO SNMG 190616 insert [27]. For comparison, all tests were performed with the same technological parameters (feed, speed, depth of cut). Both tools, tangential and right-hand turning tool, DIN 4971 (ISO 1), were equipped with the same type of insert. All the tests were performed on a Romanian SN280 lathe.

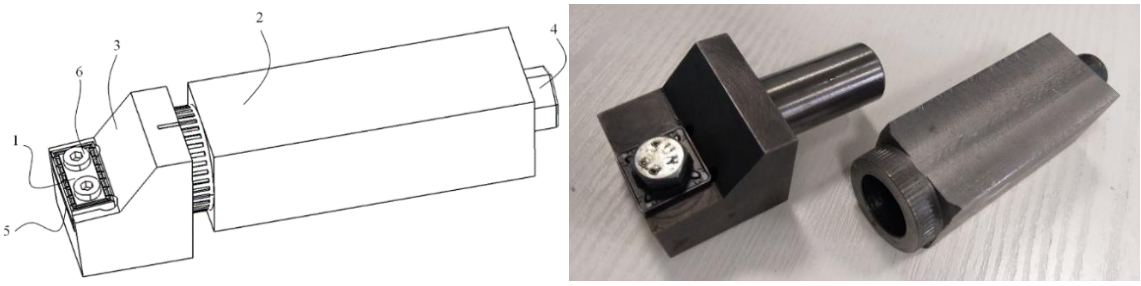

Fig. 8. Special tool for tangential oblique turning. Project and product
1 - insert; 2 – basic body; 3 – support-body for insert, orientable; 4 - screw;
5 – plate for insert; 6 – screw for insert

Advance values $f \in \{0.12; 0.16; 0.20\}$, in mm/rev, were chosen, and speeds corresponding to revolutions $n \in \{160; 250; 400; 630; 1000\}$, in rev/min.

Specimens with five delimited cylinders, Figure 9, were used in the experiments, one for each of the selected speeds. Only one specimen was used for each material. Successive processing of the samples determined a gradual reduction in their diameter. The initial geometric characteristics of specimens are presented in Figure 9 below.

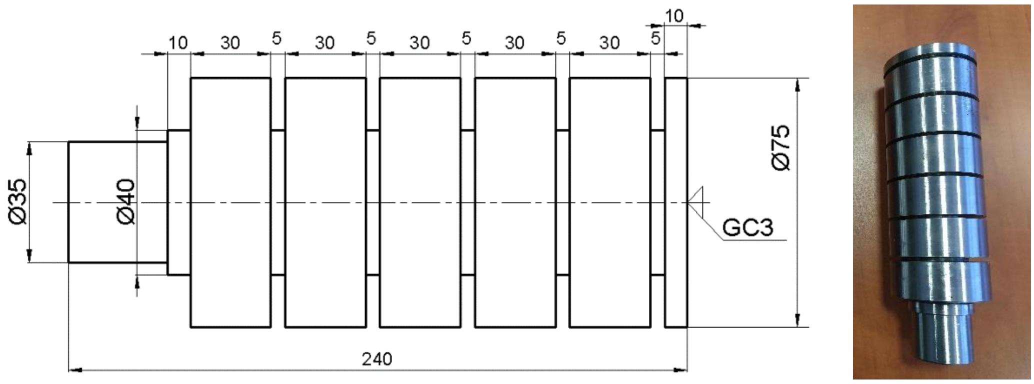

Fig. 9. The specimen made of 42CrMo4QT / 1.7225QT

For each tool and for each material, three passes were made, one for each value of the feed. At each pass, the speed of the specimens took all five values, one for each sector of it. An image during machining with an ISO 1 tool is shown in Figure 2 and an image during machining with a special tool with oblique tangential edge is shown in Figure 10.

The roughness measurement was performed with a professional electronic roughness meter, TESA-rugosurf 10-G, (Figure 11). For each machined surface, roughness measurement was made along three equiangular disposed generatrix (0°, 120° and 240°) and the average value was calculated.

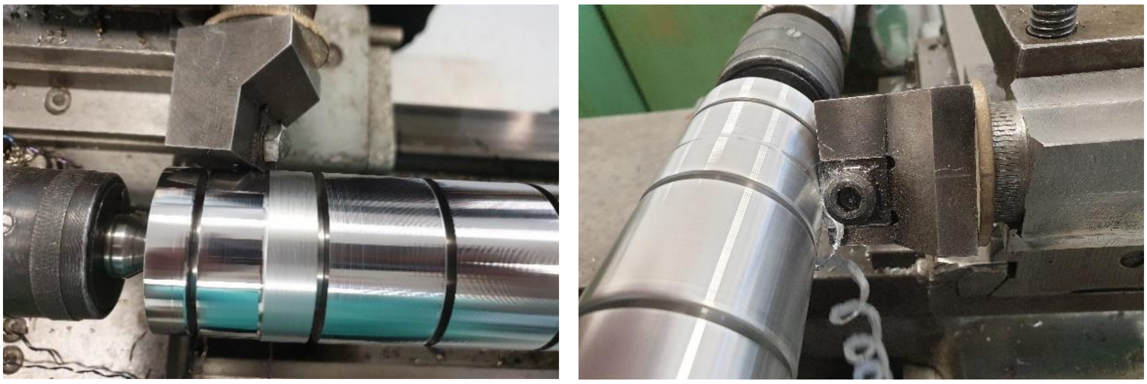

Fig. 10. Machining with an original special tool with oblique tangential cutting edge

Fig. 11. Rugosimeter TESA-rugosurf 10-G [28]

5.3. Experimental results and discussion

Tables 4 and 5 contain the experimental results obtained, for the roughness R_a and for 42CrMo4QT / 1.7225QT steel. The values in the tables represent the average values for roughness of the three measured values for each sector of the specimen and for each pass.

Table 4. Roughness values at turning 42CrMo4QT / 1.7225QT steel with conventional ISO 1 tool, equipped with ISO SNMG 190616 insert (in µm)

f [mm/rev]	Φ sample [mm]	*n* [rev/min]				
		160	250	400	630	1000
0.12	53	4.482	4.502	0.634	0.823	0.979
0.2	52	6.116	3.269	1.131	1.176	1.398
0.28	51	7.122	2.055	1.984	1.901	1.855

Table 5. Roughness values at turning 42CrMo4QT / 1.7225QT steel with special tool for tangential oblique turning, with cutting edge inclined at the angle $\lambda_s \in \{45°; 60°; 70°\}$, equipped with ISO SNMG 190616 insert (in µm)

λ_s	*f* [mm/rev]	Φ sample [mm]	*n* [rev./min]				
			160	250	400	630	1000
45°	0.12	44	0.238	0.656	1.947	0.759	1.127
	0.2	43	1.074	1.306	1.367	1.025	0.989
	0.28	42	1.683	1.493	1.256	0.995	0.922
60°	0.12	47	0.224	0.195	0.660	1.351	1.421
	0.2	46	0.671	1.619	2.161	1.193	1.540
	0.28	45	1.107	1.772	1.972	0.569	1.197
70°	0.12	50	0.536	1.360	1.903	1.119	1.155
	0.2	49	1.139	0.687	1.313	3.291	1.971
	0.28	48	1.258	1.096	1.331	2.615	1.984

When turning with conventional ISO 1 tool, the quality of the surfaces is reduced (R_a > 2 µm) if the processing is carried out at speeds lower than 60-65 m/min, even for small feed values. As expected, machining with higher cutting speeds, v = 65 – 150 m/min leads to obtaining surfaces with good or even very good quality: R_a = 0.6 ... 1.0 µm if operated with low feed f = 0.12 mm/rev., R_a = 1.1 ... 1.4 µm if operated with advance f = 0.2 mm/rev., and R_a = 1.8 ... 2.0 µm if operating with moderate feed f = 0.28 mm/rev.

When turning with the tool for tangential oblique turning, the quality of the surfaces is good or very good (R_a = 0.4 ... 1.5 µm) for all the processing performed, with very few exceptions. Experimental research has shown that tangential oblique turning where the angle of inclination of the cutting edge has high values λ_s = 70° leads to less efficient results. The special influence of the cutting speed on the quality of the surface obtained when processing by tangential oblique turning is noted: very good results, some even exceptional, are obtained at low processing speeds (v = 20-30 m/min). As the cutting speed increases, the quality of the generated surfaces decreases, but still maintaining the characteristics of fine turning ($R_a \leq 1.6$ µm) even for moderate values of the feed value (f = 0.28 mm/rev).

The roughness of the resulting surfaces increases with the increase of the feed rate, this variation being obvious for the area of low processing speeds (corresponding to speeds of 160 and 250 rev/min).

At cutting speeds above 65 m/min, the R_a roughness values for surfaces processed by tangential oblique turning and with conventional ISO 1 tool are most often comparable, regardless of the feed value.

In all cases the experimentally determined roughness $R_a = (R_a)_{\text{exp}}$ is higher or much higher than the theoretically determined roughness R_{a0} with relation (28): $(R_a)_{\text{exp}} / R_{a0}$ = 1.5 ... 10. This percentage approach can give the impression that the difference between the results based on the theoretical model and those determined experimentally is striking. But in absolute value, the difference between the roughness determined experimentally and the "theoretical" rarely exceeds 2 µm.

6. Conclusions

The quality of the surfaces of the parts is an important characteristic for their behaviour in operation and can be assessed by two categories of criteria: geometric (macro-irregularities, undulations and roughness) and physical-mechanical (structure, hardness and residual stresses). The roughness is appreciated by the usual parameters (arithmetic average deviation R_a of the profile and average height R_z of the micro-irregularities) and depends on the processing operation. In fact, roughness represents the micro-geometric scale value of the variations in height of a real surface. Profile roughness parameters are the most commonly used.

Various profile roughness parameters are used, R_a being very common.

For usual turning processing schemes, the specialized literature presents a diversity of mathematical relationships intended to determine the theoretical value of the roughness depending on the geometry of the tool and the feed rate with which the processing is done. Based on experimental research, mathematical expressions were also obtained that allow the roughness value to be anticipated, taking into account both the geometric characteristics of the tool and the parameters of the processing.

For new machining schemes or for tools with particular geometry, both the analytical expressions describing the theoretical roughness and relations for roughness estimation based on experimental data must be determined.

The work addresses a very rare particular machining scheme: turning with a tool with an inclined tangential edge of external cylindrical surfaces. For this case, the calculation relationship of the theoretical value of the roughness R_a was determined, with demonstration, and the influence of some parameters (feed, angle of inclination of the cutting edge, radius of the processed piece) on its value was studied.

The experimental research was carried out using an original tool, designed and made by the authors, and the data obtained were compared with those determined with the help of the calculation relationship of the theoretical value of the roughness R_a. Both the values obtained experimentally, as well as the comparison made with the "ideal" ones determined using the elaborated analytical model, allowed the statement of pertinent conclusions, useful for the subsequent research in mind.

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