ANALYSIS OF FUNCTION APPROXIMATION OF THE WEAR TOOLS FOR TURNING OF THE CAST IRON GG-25 BY NITRIDE CERAMIC CUTTING TOOLS

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Abstract: In this paper is analised the dependence regression between flank wear tools or wear out of belt width on the back surface VB and cutting time t in the form of complex power-exponential regression equation for turning of cast iron GG-25 of cutting tools from nitride ceramic for the different values of the cutting speed v=60, 90 and 120 [m/min]. Correlation coefficient for given examples of experimental researching is most R=0,998 and mean relative error of experiment is less $\overline{\alpha}_{rel}$ =1,25 %.

Keywords: metalworking, turning, ceramic cutting tool, wear tool

1. INTRODUCTION

Metal cutting causes several types of wear mechanisms depending on cutting parameters (primarily cutting speed and feed), work piece material and cutting tool material. Like most wear applications, tool wear has proved difficult to understand and predict. However, most tool wear can be described by a few mechanisms, which include: abrasion, adhesion, chemical reaction, plastic deformation and fracture. These mechanisms produce wear scars that are referred to as flank wear, crater wear, notch wear and edge chipping as illustrated in figure 1 [23]. Standard parameters of wear independent of type of tool material are defined with international standard ISO 3685:1993 [19]. Most commonly as a parameter of wear is used flank wear tools or wear out of belt width on the back surface VB because of this size in significant amount depends the capability of tools to perform the cutting. In figure 2 is illustrates typical tool wear features in finish turning and defines VB and VB_{max} and its measure [2, 3].

Monitoring of changes of individual parameters of tools wear in the process of cutting it comes to so called curve wear which represent an image of wear process in definite time interval. Existence of more parameters of cutting axle pin wear refers to conclusion that one and the same process of wear can be presented with more curve wear that can be by its shape and position in coordinate system VB,t very different.
Application of ceramic cutting tools in fields of metalworking is given in paper [1, 4, 5, 7, 9, 10, 11, 14, 25, 32, 34, 35].

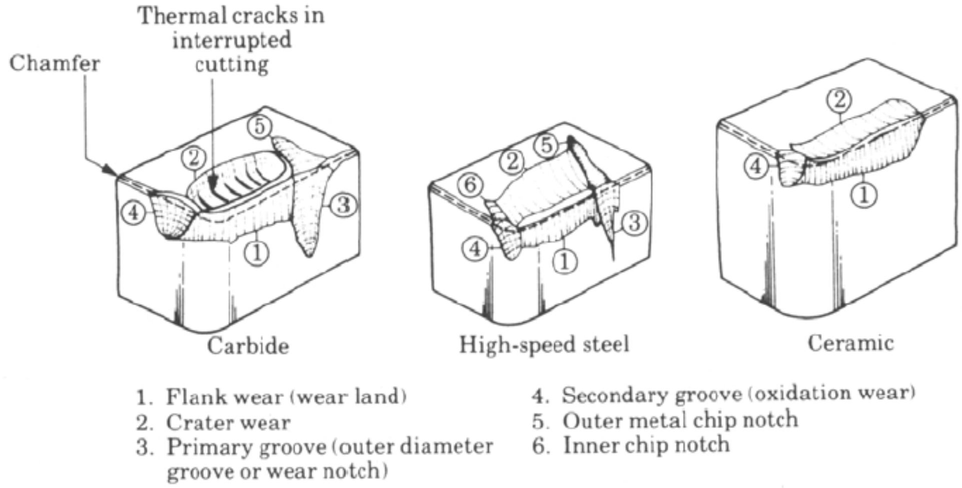

Fig. 1. Tools wear mechanisms for different tool materials [23]

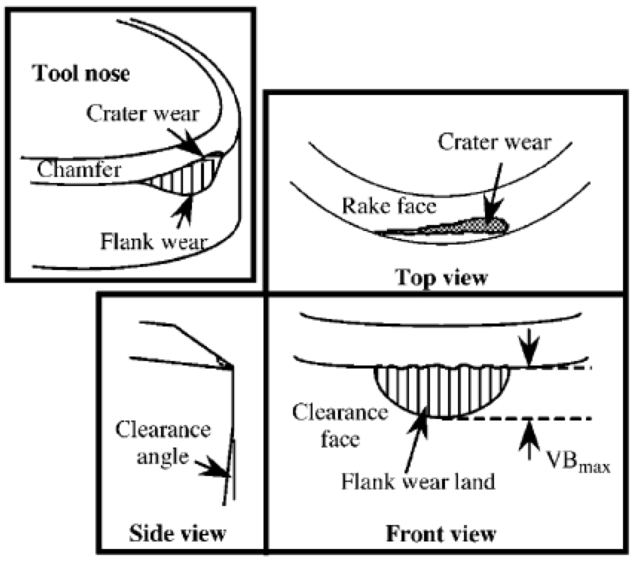

Fig. 2. A drawing showing typical tool wear in finish turning and the definition of VB and VB_{max} [2, 3]

2. POSSIBLE FORMS OF FUNCTION APPROXIMATION OF TOOLS WEAR

Dependence function of tool wears h and time of finishing t:

$$VB = f(t) \quad (1)$$

is of complex form and is derivated experimental.

In literature are present different approaches of approximation of experimental curve wear tools with regression equation of different form.

Approximation function of tools wear is performed mostly with one or two power function, which is parable [15, 16, 17, 19, 20, 21, 22, 24, 28, 31]. If it is used approximation with two power function, first is applied to first phase of wear (usually until appearance of flank wear tools or wear out of belt width on the back surface from 0,1 do 0,3 mm):

$$VB = a \cdot t^{b_1} \Big|_{t=0}^{t=t_1} \tag{2}$$

And the second phase which lasts until peariance of critical wear of cutting tools:

$$VB = c + a \cdot t^{b_1} \Big|_{t=t_1}^{t=t_k} \tag{3}$$

In modern cutting tools with coated hard metal limitations to which lasts the first phase of wear tools process is shifted by set conditions of finishing and to 0,4 mm and even more.

Process of tools wear is of continual nature and that means that in transformation from first to second phase in point of contact both parabols (2) and (3) have common tangent. In research practice, however apears experimental curves of tools wear that can be aproximated with two parabols but which do not have common tangent in the point of transformation from first phase to second phase but they cross in that point. Existance of cross point implicates to aperance of discontiuntality in development of tools wear process for which is hard to find practical explenation.

Among power function, as approximating function of tools wear, proposed is power-exponential function form [7, 9, 14]:

$$VB = a \cdot t^{b_1} \cdot e^{b_2 \cdot t} \Big|_{t=0}^{t=t_k} \tag{4}$$

Theoretical consideration, as approximation function of tools wear can be applied polinomial m level form [7, 9, 33]:

$$VB = P_m(t) = b_1 \cdot t + b_2 \cdot t^2 + b_3 \cdot t^3 + ... + b_m \cdot t^m = \sum_{j=0}^{m} b_j \cdot t^j \tag{5}$$

Form curves of complex power-exponential function (4) and polinomial m level (5) are defined all zones of tools wear, while in the same case two curves of power function form are needed.

Approximation function of tools wear with complex exponential function (4) and polinomial m level (5) are far more reliable determinates and presents cross point during the transformation from first to second phase in relation to power function.

In this paper is given an effort of approximation regresion, that is functional, dependance between flank wear tools or wear out of belt width on the back surface VB and cutting time t by complex power-exponential function.

3. EXPERIMENTAL RESEARCH

Using the experimental methods it could be possible to establish regression dependence between the flank wear tools or wear out of belt width on the back surface VB and cutting time t and influential factors for certain kind of material and cutting tools, too. For establishing the dependence between flank wear tools VB and cutting time t during turning of cast iron GG-25 with nitride ceramic cutting tools, experimental testing had been performed in Faculty of Mechanical Engineering in Kragujevac under the following conditions:

- *operation:* external turning,

- *material:* cast iron SL-250 (according to JUS C.J2.020 standard) or GG-25 (according to DIN 1691 standard), which characteristics are: R_m=160-210 [N/mm^2] and 75 HB,
- *machine for turning:* CNC lathe,
- *cutting tools:* indexable inserts made of nitride ceramic,
- *nose radius:* r= 1,2 [mm],
- *elements of the cutting regime:* cutting depth a=1,5 [mm], number of passes i=1, feed s=0,25 [mm/rev] and cutting speed v=200, 250 and 320 [m/min],
- processing without cooling or lubrication means and
- *device for measure of wear tools:* microskop.

In the process of testing it was monitored the value of flank wear tools or wear out of belt width on the back surface VB in [mm], whose measured values in dependence from cutting time in [min], shown in the table 1 and figure 3.

Table 1. The table review of experimental values of dependence VB=f(t) for the different values of the cutting speed v=60, 90 and 120 [m/min], for turning of cast iron GG-25 by nitride ceramic cutting tools

Experimental values of dependence VB=f(t) for v=200 [m/min]			Experimental values of dependence VB=f(t) for v=250 [m/min]			Experimental values of dependence VB=f(t) for v=320 [m/min]		
No. exper.	t [min]	VB [mm]	No. exper.	t [min]	VB [mm]	No. exper.	t [min]	VB [mm]
1.	2,00	0,17	1.	2,00	0,20	1.	2,00	0,26
2.	4,00	0,25	2.	4,00	0,28	2.	4,00	0,38
3.	6,00	0,30	3.	6,00	0,35	3.	6,00	0,48
4.	8,00	0,35	4.	8,00	0,41	4.	8,00	0,56
5.	9,50	0,38	5.	9,50	0,45			
6.	11,00	0,41	6.	11,00	0,48			
7.	12,50	0,44	7.	12,50	0,54			
8.	13,83	0,46						
9.	15,17	0,50						
10.	16,50	0,54						
11.	17,83	0,55						
12.	19,17	0,57						

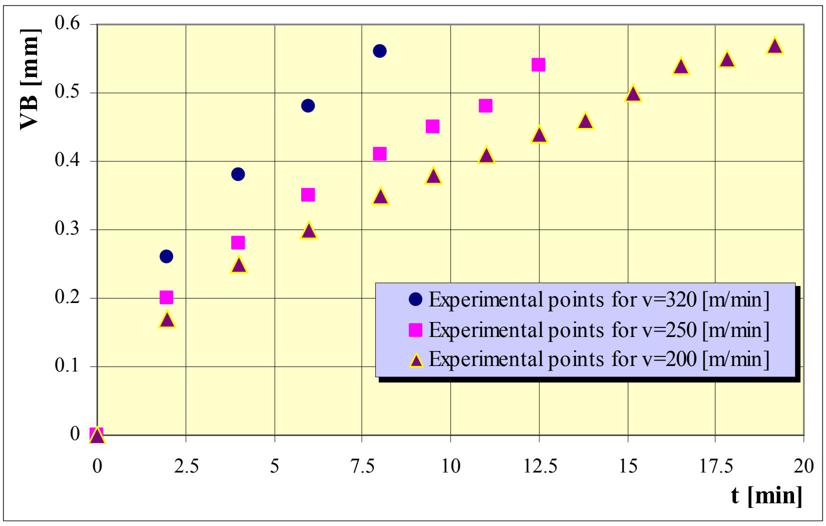

Fig. 3. The graphic review of experimental values of dependence VB=f(t), for the different values of the cutting speed v=200, 250 and 320 [m/min], for turning of cast iron GG-25 by nitride ceramic cutting tools

4. APPROXIMATION EXPERIMENTAL DATA BY COMPLEX POWER-EXPONENTIAL REGRESSION EQUATION FOR FUNCIONAL DEPENDENCE OF BETWEEN WEAR TOOLS AND CUTTING TIME

For measured experimental data (table 1) regression dependence was analyzed between VB=f(t) in form of complex power-exponential regression equation:

$$VB = a \cdot t^{b_1} \cdot e^{b_2 \cdot t} \tag{6}$$

Mathematical process of experimental data consists of determination of numerical values of parameters b_0, b_1, b_2 and a of complex power-exponential regression equation and correlation analysis of observed equations of regression, which is performed by software [8], which has been described in monograph [7, 9] and theory on regression and correlation analysis in books [17, 18, 30]. In papers [4, 5, 6, 7, 9, 11, 12, 13, 14] are given some examples of use of this software.

In order to find complex power-exponential regression equation by the use of smallest squares linerisation is performed by logarithm and it shows that:

$$\ln VB = \ln a + b_1 \cdot \ln t + b_2 \cdot t \tag{7}$$

If for equation (4) are imported shifts:

$$\begin{aligned} y &= \ln VB \\ X &= t \\ b_0 &= \ln a \end{aligned} \tag{8}$$

Equation (4) gains linear form:

$$Y = b_0 + b_1 \cdot \ln X + b_2 \cdot X \tag{9}$$

Applying for equation (9) which represents straight line, method of smallest-squares, it can be determined parameters of cubic regression b_0, b_1 and b_2.

The best shape of approximate curve (7) of assembly of experimental points with coordinates (VB, t) is one which addition of squares variations around regression has minimal value:

$$S^2 = \sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2 = \sum_{i=1}^{n}(Y_i - b_0 - b_1 \cdot \ln X_i - b_2 \cdot X_i)^2 \rightarrow \min \tag{10}$$

With the partial differentiate of the function S^2, equation (10), measured with the parameters b_0 and b_1 and to equal those partial perorate with the zero we can get the system of linear algebra equation for determination of the parameters b_0, b_1 and b_1:

$$\begin{aligned} & b_0 \cdot n + b_1 \cdot \Sigma \ln X_i + b_2 \cdot \Sigma X_i = \Sigma Y_i \\ & b_0 \cdot \Sigma \ln X_i + b_1 \cdot \Sigma(\ln X_i)^2 + b_2 \cdot \Sigma X_i \cdot \ln X_i = \Sigma(\ln X_i) \cdot Y_i \\ & b_0 \cdot \Sigma X_i + b_1 \cdot \Sigma X_i \cdot \ln X_i + b_2 \cdot \Sigma X_i^2 = \Sigma X_i \cdot Y_i \end{aligned} \tag{11}$$

The systems solution of the linear algebra equations (8) can be realized by inversion of the matrix. In general case the normal system equations (8) can be expressed in the following matrix shape:

$$\begin{bmatrix} n & \Sigma \ln X_i & \Sigma X_i \\ \Sigma \ln X_i & \Sigma(\ln X_i)^2 & \Sigma X_i \cdot \ln X_i \\ \Sigma X_i & \Sigma X_i \cdot \ln X_i & \Sigma X_i^2 \end{bmatrix} \cdot \begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} \Sigma Y_i \\ \Sigma(\ln X_i) \cdot Y_i \\ \Sigma X_i \cdot Y_i \end{bmatrix} \quad (12)$$

Or shorter in the shape of the matrix equation:

$$X \cdot b = Y \quad (13)$$

Parameter calculation of the linear regression value b_0 and b_1 is realized in the matrix shape by matrix equation.

$$b = X^{-1} \cdot Y \quad (14)$$

4.1. Determination complex power-exponential regression equation for functional dependence of between wear tools and cutting time for cutting speed v=200 [m/min]

Parameter calculation b_0, b_1 and b_2 of the linear regression for the mentioned example is consisted in the solving of the normal system equation (12) with the following shape:

$$\begin{bmatrix} 12 & 27{,}10931 & 135{,}5 \\ 27{,}10931 & 66{,}30982 & 345{,}4718 \\ 135{,}5 & 345{,}4718 & 1866{,}546 \end{bmatrix} \cdot \begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} -11{,}33803 \\ -22{,}91469 \\ -106{,}83019 \end{bmatrix} \quad (15)$$

on the base of which is: b_0=-2,1021, b_1=0,4754, b_2=0,007376 and a=0,1222.

From that point the equation of the complex power-exponential regression equation has the shape:

$$VB = 0{,}1222 \cdot t^{0{,}4754} \cdot e^{0{,}007376 \cdot t} \quad (16)$$

Confidence interval of parameter b_0, for level of significance α=5 [%] and 9 freedom level number, is:

$$b_0 = b_0 + \Delta b_0 = -2{,}1021 \pm 0{,}2121 \Rightarrow -2{,}1021 + 0{,}2121 < b_0 < -2{,}1021 - 0{,}2121 \quad (17)$$

or:

$$-2{,}3142 < b_0 < -1{,}8900 \quad (18)$$

Confidence interval of parameter b_1, for level of significance α=5 [%] and 9 freedom level number, is:

$$b_1 = b_1 + \Delta b_1 = 0{,}4754 \pm 0{,}0601 \Rightarrow 0{,}4754 - 0{,}0601 < b_1 < 0{,}4754 + 0{,}0601 \quad (19)$$

or:

$$0{,}4153 < b_1 < 0{,}5355 \quad (20)$$

Confidence interval of parameter b_2, for level of significance α=5 [%] and 9 freedom level number, is:

$$b_2 = b_2 + \Delta b_2 = 0{,}007376 \pm 0{,}007377 \Rightarrow 0{,}007376 - 0{,}007377 < b_2 < 0{,}007376 + 0{,}007377 \quad (21)$$

or:

$$-0{,}000001 < b_2 < 0{,}014753 \quad (22)$$

The correlation coefficient R is:

$$R = \sqrt{1 - \frac{S^2}{S_y^2}} = \sqrt{1 - \frac{0,002941529}{1,442452}} = 0,99898 \tag{23}$$

The analogous table value R_t for the result of significance coefficient correlation, for the level of significance α=5 [%] and the freedom level number k=12-3=9, by the table in the monography [8], is: R_t=0,6021.

Because it is:

$$R = 0,99898 > R_t = 0,6021 \tag{24}$$

there is the base that the hypothesis about significance of the correlation coefficient acceptation, i.e. the correlation coefficient r is significant (important), on R-test base, for the significant level α=5 [%] (assumed complex power-exponential regression equation (16) is good at representation of experimental data).

The determinate coefficient R^2 is:

$$R^2=0,99796 \tag{25}$$

and mean relative error of experiment is:

$$\bar{\alpha}_{rel} = 1,2143\ \%. \tag{26}$$

Calculate value F_r for marking of adequate of regression equation is:

$$F_r = \frac{S_r^2}{S_e^2} = \frac{1,439507}{0,0003268366} = 4404,363 \tag{27}$$

The analogues table value F_t for the result of adequate regression equation, for the level of adequate regression equation, for the level of significance α=5 [%] and freedom scale number: k_1=1 and k_2=12-3=9, by the table in the monography [8], is: F_t=5,1174.

Because it is:

$$F_r = 4404,363 > F_t = 5,1174 \tag{28}$$

there is the base that the hypothesis of adequate regression equation acceptation, i.e. hypothesis about complex power-exponential regression (16) is adequate (consistent) with the experimental data, on the F-test, base, for the significance α=5 [%] (assumed complex power-exponential regression equation (16) is good at representing of experimental data).

The same conclusion is derived and on the base of the significance the result of the correlation coefficient (R-test), in equation (24).

Table view of testing of statistical hypothesis for this example is shown in table 2. The dependence between flank wear VB and cutting time t, for cutting speed v=200 [m/min], is graphic shown on the figure 4.

Table 2. The table view of testing of statistical hypothesis for presented example

Title hypothesis	Freedom level number k	Calculate values of test	Table values of test	Mark of hypothesis for α=5[%]
Mark of significance parameter of regression b_0 on the basis t-test	9	-22,42286	2,2622	significance
Mark of significance parameter of regression b_1 on the basis t-test	9	17,88911	2,2622	significance
Mark of significance parameter of regression b_2 on the basis t-test	9	2,26187	2,2622	insignificance
Mark of significance correlation coefficient R on the basis R-test	9	0,99898	0,6021	significance
Mark of adequate regression equation on the basis F-test	1; 9	4404,363	5,1174	adequate

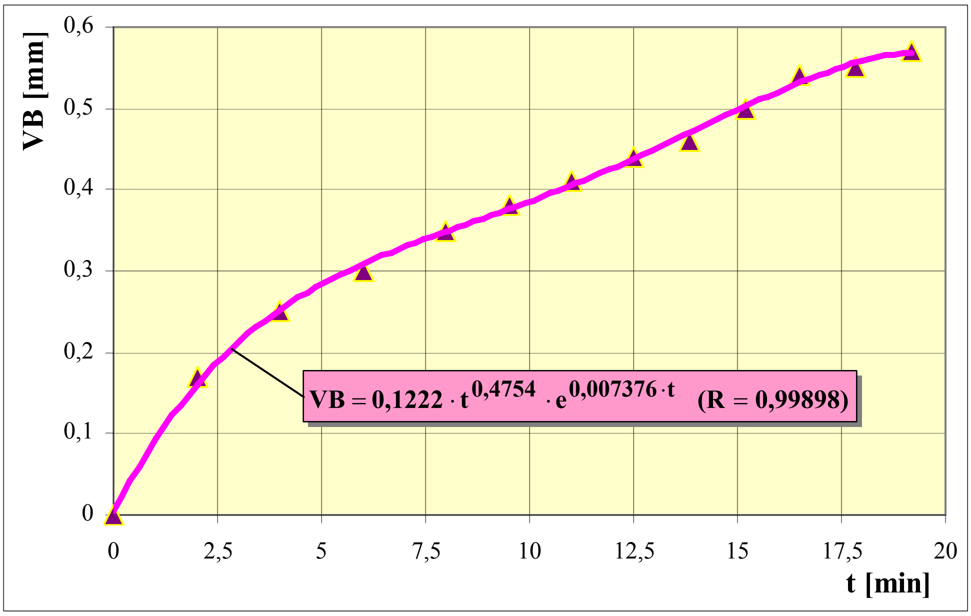

Fig. 4. Graphic review of experimental data and calculated values of dependence VB=f(t), for the cutting speed v=200 [m/min], for turning of the cast iron GG-25 by nitride ceramic cutting tools

4.2. Determination complex power-exponential regression equation for functional dependence of between wear tools and cutting time for cutting speed v=250 [m/min]

Parameter calculation b_0, b_1 and b_2 of the linear regression for the mentioned example is consisted in the solving of the normal system equation (12) with the following shape:

$$\begin{bmatrix} 7 & 13,12556 & 53 \\ 13,12556 & 27,13427 & 113,6533 \\ 53 & 113,6533 & 487,5 \end{bmatrix} \cdot \begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} -6,972487 \\ -11,72931 \\ -45,10427 \end{bmatrix} \tag{29}$$

on the base of which is: b_0=-1,9513, b_1=0,4507, b_2=0,01455 and a=0,1421.

From that point the equation of the complex power-exponential regression equation has the shape:

$$VB = 0,1421 \cdot t^{0,4507} \cdot e^{0,01455 \cdot t} \quad (30)$$

Confidence interval of parameter b_0, for level of significance α=5 [%] and 4 freedom level number, is:

$$b_0 = b_0 + \Delta b_0 = -1,9513 \pm 0,3318 \Rightarrow -1,9513 - 0,3318 < b_0 < -1,9513 + 0,3318 \quad (31)$$

or:

$$-2,2831 < b_0 < -1,6195 \quad (32)$$

Confidence interval of parameter b_1, for level of significance α=5 [%] and 4 freedom level number, is:

$$b_1 = b_1 + \Delta b_1 = 0,4507 \pm 0,1028 \Rightarrow 0,4507 - 0,1028 < b_1 < 0,4507 + 0,1028 \quad (33)$$

or:

$$0,3479 < b_1 < 0,5535 \quad (34)$$

Confidence interval of parameter b_2, for level of significance α=5 [%] and 4 freedom level number, is:

$$b_2 = b_2 + \Delta b_2 = 0,01455 \pm 0,01759 \Rightarrow 0,01455 - 0,01759 < b_2 < 0,01455 + 0,01759 \quad (35)$$

or:

$$-0,00304 < b_2 < 0,03214 \quad (36)$$

The correlation coefficient R is:

$$R = \sqrt{1 - \frac{S^2}{S_y^2}} = \sqrt{1 - \frac{0,0008748232}{0,7187344}} = 0,99939 \quad (37)$$

The analogous table value R_t for the result of significance coefficient correlation, for the level of significance α=5 [%] and the freedom level number k=7-3=4, by the table in the monography [8], is R_t=0,8114.

Because it is:

$$R = 0,99939 > R_t = 0,8114 \quad (38)$$

there is the base that the hypothesis about significance of the correlation coefficient acceptation, i.e. the correlation coefficient r is significant (important), on R-test base, for the significant level α=5 [%] (assumed complex power-exponential regression equation (30) is good at representation of experimental data).

The determinate coefficient R^2 is:

$$R^2=0,99878 \quad (39)$$

and mean relative error of experiment is:

$$\overline{\alpha}_{rel} = 0,8049\ \%. \quad (40)$$

Calculate value F_r for marking of adequate of regression equation is:

$$F_r = \frac{S_r^2}{S_e^2} = \frac{0,7178611}{0,0002187058} = 3282,314 \quad (41)$$

The analogues table value F_t for the result of adequate regression equation, for the level of adequate regression equation, for the level of significance α=5 [%] and freedom scale number: $k_1=1$ and $k_2=7-3=4$, by the table in the monography [8], is: F_t=7,7086. Because it is:

$$F_r = 3282{,}314 > F_t = 7{,}7086 \qquad (42)$$

there is the base that the hypothesis of adequate regression equation acceptation, i.e. hypothesis about complex power-exponential regression (30) is adequate (consistent) with the experimental data, on the F-test, base, for the significance α=5 [%] (assumed complex power-exponential regression equation (30) is good at representing of experimental data).

The same conclusion is derived and on the base of the significance the result of the correlation coefficient, in equation (38). Table view of testing of statistical hypothesis for this example is shown in table 3. The dependence between flank wear VB and cutting time t, for cutting speed v=250 [m/min], is graphic shown on the figure 5.

Table 3. The table view of testing of statistical hypothesis for presented example

Title hypothesis	Freedom level number k	Calculate values of test	Table values of test	Mark of hypothesis for α=5[%]
Mark of significance parameter of regression b_0 on the basis t-test	4	-16,32958	2,7764	significance
Mark of significance parameter of regression b_1 on the basis t-test	4	12,17159	2,7764	significance
Mark of significance parameter of regression b_2 on the basis t-test	4	2,29671	2,7764	insignificance
Mark of significance correlation coefficient R on the basis R-test	4	0,99939	0,8114	significance
Mark of adequate regression equation on the basis F-test	1; 4	3282,314	7,7086	adequate

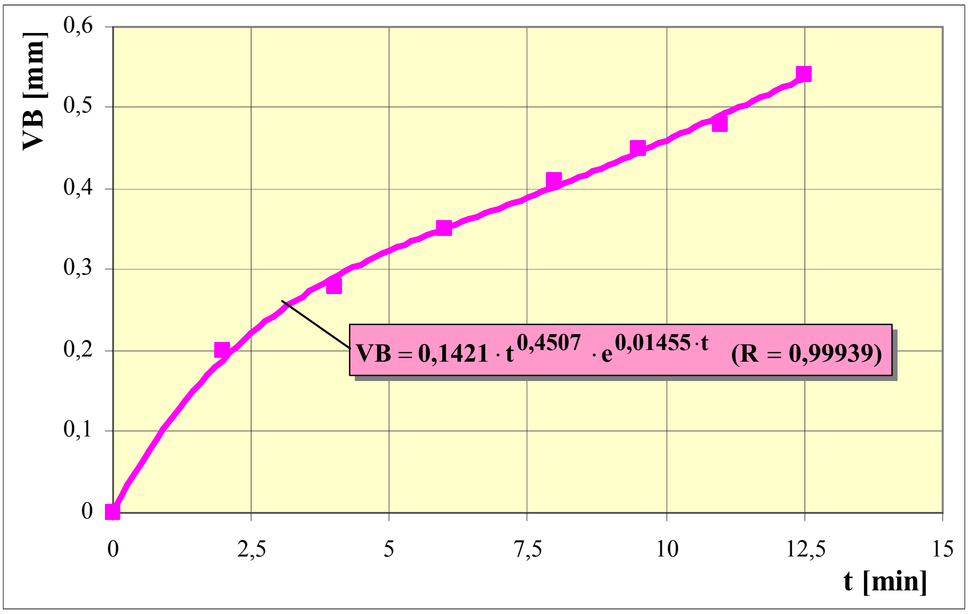

Fig. 5. Graphic review of experimental data and calculated values of dependence VB=f(t), for the cutting speed v=250 [m/min], for turning of the cast iron GG-25 by nitride ceramic cutting tools

4.3. Determination complex power-exponential regression equation for functional dependence of between wear tools and cutting time for cutting speed v=320 [m/min]

Parameter calculation b_0, b_1 and b_2 of the linear regression for the mentioned example is consisted in the solving of the normal system equation (12) with the following shape:

$$\begin{bmatrix} 4 & 5,950643 & 20 \\ 5,950643 & 9,936745 & 34,31756 \\ 20 & 34,31756 & 120 \end{bmatrix} \cdot \begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} -3,628445 \\ -4,795872 \\ -15,60685 \end{bmatrix} \quad (43)$$

on the base of which is: b_0=-1,7316, b_1=0,5502, b_2=0,001214 and a=0,1770.
From that point the equation of the complex power-exponential regression equation has the shape:

$$VB = 0,1770 \cdot t^{0,5502} \cdot e^{0,001214 \cdot t} \quad (44)$$

Confidence interval of parameter b_0, for level of significance α=5 [%] and 1 freedom level number, is:

$$b_0 = b_0 + \Delta b_0 = -1,7316 \pm 1,1055 \Rightarrow -1,7316 - 1,1055 < b_0 < -1,7316 + 1,1055 \quad (45)$$

or:

$$-2,8371 < b_0 < -0,6261 \quad (46)$$

Confidence interval of parameter b_1, for level of significance α=5 [%] and 1 freedom level number, is:

$$b_1 = b_1 + \Delta b_1 = 0,5502 \pm 0,3792 \Rightarrow 0,5502 - 0,3792 < b_1 < 0,5502 + 0,3792 \quad (47)$$

or:

$$0,1710 < b_1 < 0,9294 \quad (48)$$

Confidence interval of parameter b_2, for level of significance α=5 [%] and 1 freedom level number, is:

$$b_2 = b_2 + \Delta b_2 = 0,001214 \pm 0,0883 \Rightarrow 0,001214 - 0,0883 < b_2 < 0,001214 + 0,0883 \quad (49)$$

or:

$$-0,087086 < b_2 < 0,089514 \quad (50)$$

The correlation coefficient R is:

$$R = \sqrt{1 - \frac{S^2}{S_y^2}} = \sqrt{1 - \frac{0,00003790061}{0,3343227}} = 0,99994 \quad (51)$$

The analogous table value R_t for the result of significance coefficient correlation, for the level of significance α=5 [%] and the freedom level number k=4-3=1, by the table in the monography [8], is: R_t=0,9969.
Because it is:

$$R = 0,99994 > R_t = 0,9969 \quad (52)$$

there is the base that the hypothesis about significance of the correlation coefficient acceptation, i.e. the correlation coefficient r is significant (important), on r - test base, for the significant level α=5 [%] (assumed complex power-exponential regression equation (44) is good at representation of experimental data). The determinate coefficient R^2 is:

$$R^2=0,99989 \tag{53}$$

and mean relative error of experiment is:

$$\overline{\alpha}_{rel}=0,2705\ \%. \tag{54}$$

Calculate value F_r for marking of adequate of regression equation is:

$$F_r=\frac{S_r^2}{S_e^2}=\frac{0,3342842}{0,00003790061}=8820,023 \tag{55}$$

The analogues table value F_t for the result of adequate regression equation, for the level of adequate regression equation, for the level of significance $\alpha=5$ [%] and freedom scale number: $k_1=1$ and $k_2=4-3=1$, by the table in the monography [8], is: $F_t=161,45$. Because it is:

$$F_r=8820,023>F_t=161,45 \tag{56}$$

there is the base that the hypothesis of adequate regression equation acceptation, i.e. hypothesis about complex power-exponential regression (44) is adequate (consistent) with the experimental data, on the F-test, base, for the significance $\alpha=5$ [%] (assumed complex power-exponential regression equation (44) is good at representing of experimental data).

The same conclusion is derived and on the base of the significance the result of the correlation coefficient, in equation (52).

Table view of testing of statistical hypothesis for this example is shown in table 4. The dependence between flank wear VB and cutting time t, for cutting speed v=320 [m/min], is graphic shown on the figure 6.

Table 4. The table view of testing of statistical hypothesis for presented example

Title hypothesis	Freedom level number k	Calculate values of test	Table values of test	Mark of hypothesis for $\alpha=5$[%]
Mark of significance parameter of regression b_0 on the basis t-test	1	-19,90289	12,7062	significance
Mark of significance parameter of regression b_1 on the basis t-test	1	18,43233	12,7062	significance
Mark of significance parameter of regression b_2 on the basis t-test	1	0,17468	12,7062	insignificance
Mark of significance correlation coefficient R on the basis R-test	1	0,99994	0,9969	significance
Mark of adequate regression equation on the basis F-test	1; 1	8820,023	161,45	adequate

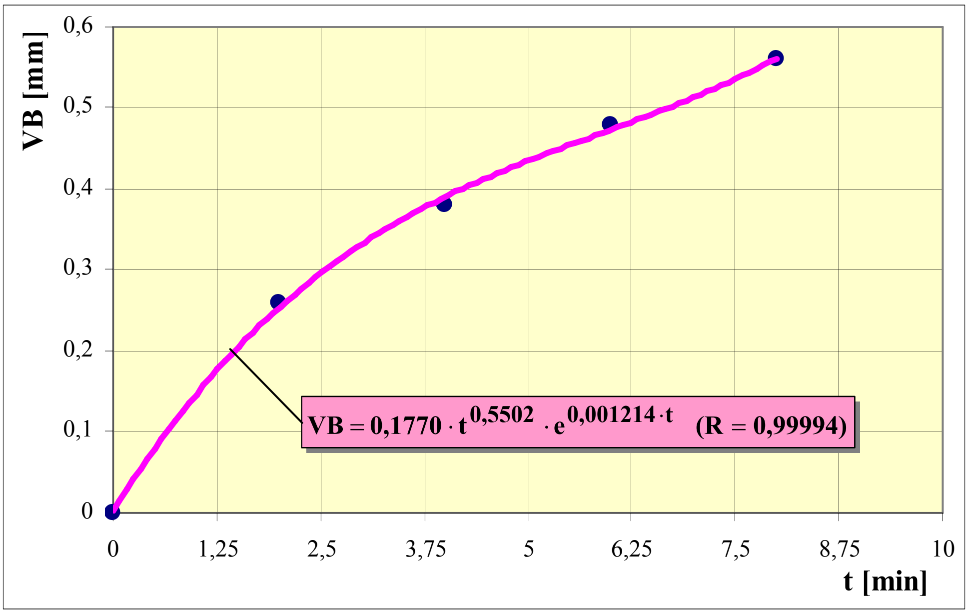

Fig. 6. Graphic review of experimental data and calculated values of dependence VB=f(t), for the cutting speed v=320 [m/min], for turning of the cast iron GG-25 by nitride ceramic cutting tools

5. CONCLUSION

The complex power-exponential regression equation (16) for functional dependence of between wear tools VB and cutting time t for turning of cast iron GG-25 by nitride ceramic cutting tools for cutting speed v=200 [m/min], is good at representation of the experimental data (R=0,99898, R^2=0,99796 and $\overline{\alpha}_{rel}$=1,2143 %).
The complex power-exponential regression equation (30) for functional dependence of between wear tools VB and cutting time t for turning of cast iron GG-25 by nitride ceramic cutting tools for cutting speed v=250 [m/min], is good at representation of the experimental data (R=0,99939, R^2=0,99878 and $\overline{\alpha}_{rel}$=0,8048 %).

The complex power-exponential regression equation (44) for functional dependence of between wear tools VB and cutting time t for turning of cast iron GG-25 by nitride ceramic cutting tools for cutting speed v=320 [m/min], is good at representation of the experimental data (R=0,99994, R^2=0,99989 and $\overline{\alpha}_{rel}$=0,2705 %).

On the base of R - test and F - test, for the level of significance α=5 [%], the hypothesis about approximation of the mentioned experimental data by the complex power-exponential regression equations (16), (30), and (44), is consistent.

According to analysis of t-test for parameters b_0, b_1 and b_2 (table 2, 3 and 4) can be sighted that the biggest effect on function VB=f(t) have parameters b_0 and b_1, and minimal effect has parameter b_2 and for all three regression equations (16), (30) and (44) is insignificant.

REFERENCES

[1] Chneider G.: *Applied Cutting Tool Engineering,* Tooling & Productions, 2001. Available on Web-site: http://toolingandproduction.com/.
[2] Chou, Y. K.; Evans, C. J.:Hard turning of M50 steel with different microstructures in continuous and intermittent cutting. *Wear*, Vol. 255 (2003.), pp. 1388-1394. ISSN 0043-1648.
[3] Chou, Y. K.; Evans, C. J.: Tool wear mechanism in continuous cutting of hardened tool steels. *Wear*, Vol. 212 (1997.), pp. 59-65. ISSN 0043-1648.

[4] Dašić, P.: Research of processed surface roughness for turning hardened steel by means of ceramic cutting tools. In *Proceedings of papers from 2nd World Tribology Congress*, Vienna, Austria, 3 - 7. september 2001. Edited by Friedrich Franek, Wilfried J. Bartz, Andreas Pauschitz. Vienna: Österreichische Tribologische Gesellschaft - ÖTG (The Austrian Tribology Society), 2001, pp. 522. ISBN 3-901657-08-8 (for Abstracts Proceedings in hard copy) and pp. 1-6. ISBN 3-901657-09-6 (Proceedings in electronic form on CD-ROM). Available on Web site: http://www.oetg.at/website/wtc2001cd/html/M-51-29-055-DASIC.pdf.

[5] Dašić, P.: Choice analysis of regression depended on quality characteristics. In: *Proceedings of 5th Balkan Conference on Operational Research*, Banja Luka, Republic of Serbs, 22 - 25. May 2000. Banja Luka: Faculty of Electronics Engineering, 2000.

[6] Dašić, P.: Interactive dependence of processed surface roughness parameters for turning of the steel C60 by mixed ceramic cutting tools, *Journal of Optimum Technologies, Technologic Systems and Materials in the Machines Building Field – MSTM*, Bacau (Romania): Romanian Technical Sciences Academy and University of Bacau, MSTM-11 (2005.), No. 1, pp. 206-212. ISSN 1224-7499.

[7] Dasic P.: *Research of harder materials for finished turning by means of ceramic cutting tools* (in preparation in Serbian language), Monography in preparation

[8] Dašić P.: *Software for choice of regression depended between two variables*, ver. 1.0, Kruševac, 2000.

[9] Dašić P.: *Statistical processing of experimental data,* Book 1: *One-factoring regression analysis* (in Serbian language), Monography in preparation

[10] Dašić, P.; Ječmenica, R.: Analysis of the machining efficiency by application of the ceramic cutting tools (in Serbian language). *Journal of Tribology in Industry*, Kragujevac: Faculty of Mechanical Engineering, University in Kragujevac, Vol. XIII (1991.) No. 2, pp. 51-55. ISSN 0351-1642.

[11] Dašić, P.; Ječmenica, R.; Radovanović, M.: Analysis of the wear tools for turning by modern cutting tools. *Journal of Optimum Technologies, Technologic Systems and Materials in the Machines Building Field – MSTM*, Bacau (Romania): Romanian Technical Sciences Academy and University of Bacau, MSTM-11 (2005.), No. 1, pp. 213-218. ISSN 1224-7499.

[12] Dašić, P.; Petropoulos, G.: Dependence regression of the processed surface roughness parameters for turning of cutting tools made of coated carbides (in Serbian language). *Journal of IMK-14 Research and Development*, Kruševac: Institute IMK ″14. October″, Vol. VIII (2002.), No. (14-15) 1-2/2002, pp. 93-98. ISSN 0354-6829.

[13] Dašić, P.; Petropoulos, G.: Research of interdependence of the 2D parameters of processed surface roughness for turning (in Serbian language). Keynote and invitted paper. In *Scientific Book of 5th International Scientific Conference on Production Engineering ″Development and Modernization of Production – Razvoj i modernizacija proizvodnje - RIM 2005″*, Bihać, Bosnia and Herzegovina, 14-17. September 2005. Edited by Isak Karbegović, Milan Jurković and Vlatko Doleček. Bihać (Bosnia and Herzegovina): Society for Robotics of Bosnia and Herzegovina, 2005, pp. 53-70. ISBN 99-589262-0-2.

[14] Dašić, P.; Radovanović, M.: Analysis of the wear cubic boron nitride for turning of the hardened steel. *International Journal of Applied Mechanics and Engineering – IJAME*. Zielona Góra (Poland): University Press, Vol. 7 (2002.) Special issue (Papers from the Second International Tribology Conference SITC 2002, 25 - 28. August 2002), pp. 341-346. ISSN 1425-1655.

[15] Dawson, G.: *Machining hardened steel with polycrystalline cubic boron nitride cutting tools.* Dissertation. Georgia (Atlanta): Georgia Institute of Technology, 2002. – 264 pp.

[16] Ekinović, S.: *Obrada rezanjem*, Zenica: Dom štampe, 2001, s. 307. ISBN 9958-42-062-7.

[17] Грановский, Г. И.: *Обработка результатов экспериментальных исследований резания металлов.* Москва: Машиностроение, 1982. – 112 с.

[18] Hadživuković, S.; Zegnal, R.; Čobanović, K.: *Regression analysis* (in Serbian language). Belgrade: Privredni pregled, 1982. – 262 pp.

[19] ISO 3685:1993 Tool life testing with single-point turning tools. Geneve: International Organization for Standardizations (ISO).

[20] Ivković, B.: *Theory of cutting* (in Serbian language). Kragujevac: Absolutely authors edition, 1991. – 354 pp. COBISS.SR-ID 512174229.

[21] Janáč, A.; Bátora, B.; Baránek, I.; Lipa, Z.: *Technológia obrábania*. Bratislava: Slovenská technická univerzita (STU), 2004. – 288 s. ISBN 80-227-2031-3.

[22] Kalajdžić, M.: *Tehnology of metalworking I* (in Serbian language). 9th Edition. Belgrade: Faculty of Mechanical Engineering, 2004. – 407 pp. ISBN 86-7083-487-1.

[23] Kalpakjian, S.: *Manufacturing processes for engineering materials*. 3rd Edition. Menlo Park (California): Addison Wesley Longman Inc., 1997. – xxx pp. ISBN 0-2018-2370-5.

[24] Kocman, K.; Prokop, J.: *Technologie obrábění*. Brno: Vysoké učení techické v Brně, Fakulta strojního inženýrství, 2001. – 270 s. ISBN 80-214-1996-2.

[25] Kuzin, V. V.; Dašić, P.: Prospects of coated ceramic cutting tools use. In: *Proceedings of 3rd International Conference ″Research and Development in Mechanical Industy - RaDMI 2003″*, Herceg Novi, Serbia and Montenegro, 19 - 23. September 2003. Edited by Predrag Dašić. Trstenik: High Technical Mechanical School, Kruševac: Institute IMK ″14. October″ and Podgorica: Institute of Faculty of Mechanical Engineering, 2003, pp. 289-292. ISBN 86-83803-06-6 (for Proceedings Volume 1 in hard copy, published in 2004) and ISBN 86-83803-10-4 (for Proceedings in electronic form on CD-ROM, published in 2003).

[26] Momper, J. F.: *Untersuchung zum standvermogen keramischer werkzeugschneiden beim drehen unter besonderer berucksichtigung der schneideneingriffsverhaltnisse*. Dissertation. Kaiserslautern: Vom Fachbereich Maschinenwesen der Universitat Kaiserslautern, 1985. s. 157.

[27] Momper, J. F.; Friedrich, K. M.; Fripan, M.: Keramische Schnidstoffe, Entwicklungsstand - Tendenzen – Anwendungen. *VDI-Z Special* Bd. 129 (1987.), Nr. 4, s. 4-15. ISSN 0042-1766.

[28] Radovanović, M: *Metalworking technology, Cutting work.* Niš: Faculty of Mechanical Engineering, 2002. – 328 s. ISBN 86-80587-39-7.

[29] Radovanović, M.; Dašić, P.; Ječmenica, R.: Advanced cutting tool materials. In *Proceedings of 2nd International Conference ″Research and Development in Mechanical Industy - RaDMI 2002″*, Vrnjačka Banja, Yugoslavia, 01 - 04. September 2002. Edited by Predrag Dašić and Miroslav Radovanović. Kruševac: Institute IMK ″14. October″, Trstenik: IHP ″Prva petoletka″ and High Technical Mechanical School, 2002, pp. 346-351. ISBN 86-83803-02-3 (for Proceedings Volume 1 in hard copy) and COBISS.SR-ID 112742924 (for Proceedings in electronic form on CD-ROM).

[30] Stanić J.: *Method of engineering measuring, Basic of mathematical theory of experiment* (in Serbian language). 5th Edition. Belgrade: Faculty of Mechanical Engineering, 1990. – 250 pp. ISBN 86-7083-143-0.

[31] Stanić, J.: *Theory of metalworking I* (in Serbian language). 2nd Edition. Belgrade: Faculty of Mechanical Engineering, 1989. – 268 pp. ISBN 86-7083-108-2.

[32] Старков, К. В.; Кузин, В. В.; Попов, Ф. В.; Исходжагов, Р. Р.: Повышение эксплуатационных характеристик изделий из керамических материалов методами механической и термической обработки. *Машиностроительное производство, Серия: Прогресивное технологические процессы в машиносроении, Обзорная информация*, Москва: ВНИИТЭМР, выпуск 4, 1989. – 64 с. ISSN 0131-8322.

[33] Tadić, B.: Contribution to analztical definition of wear curves (in Serbian language). *Journal of Tribology in Industry*, Vol. XII (1990.) No. 4, pp. 117-120. ISSN 0351-1642.

[34] Tanović, LJ.: *Production technology of modern cutting tools elements* (in Serbian language). Belgrade: Faculty of Mechanical Engineering, 1997. – 99 pp. ISBN 86-7083-294-1.

[35] Whitney, E. D.: *Ceramic cutting tools, Materials, development and performance*. Gainesville: Noyes Publications, 1994. – 352 pp. ISBN 0-8155-1355-0.