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LONG-TERM TOOL LIFE TESTS OF AMERICAN MADE NITRIDE CERAMIC INSERT'S USED TO TURN GREY CAST IRON WORK-PIECE MATERIALS

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Abstract:
In these papers is presented comparison of tool lifes of American made nitride ceramic insert's type NS260, NS260C used to turn grey cast iron work-piece materials. Experiments had to serve the realization of tool life tests of nitride ceramic. Important angle for the comparison was the optimization of the cutting speeds for achievement of desired quality of work-piece surface considering temperature, stiffness and lower machining time which is important for economic stand-point of every machinery company. By experimenting, there were discovered precious features of both of compared cutting tool insert's and their suggestion for high speed cutting.
Keywords: turning, grey cast iron, nitride ceramic insert's, tool life, Taylor's equation, Student's distribution

1. INTRODUCTION

Cutting Tool Insert's (CTI) made from cutting ceramics are noted especially for its good-class solidity, it warrants good durability of tool and can be used for express cutting speeds (up to 1000 m/min). Other advantage of this material is its resistance to high temperatures (up to 1750°C). Cutting ceramics are used in large series and mass production, where we would want to achieve maximum efficiency at the difficult conditions of machining. They are suitable for machining materials which are difficult workable tools by sintered carbides. Machines on which used to cutting ceramics must to have high power, large extent of speed ranges and high stiffness.

Cutting ceramics can be divided to oxide (based on Al_2O_3) and nitride (based on Si_3N_4). Nitride cutting ceramics has, in confrontation to oxide cutting ceramics, better persistence and conduct in heath shock but it has lower chemical constancy for machining the steel.

In machining and metrology laboratories on department of Technical university of Liberec there were in the case of solving several graduation theses compared two various types of CTI square intersection of nitride cutting ceramic from the USA producer called „Sumitomo Electric Carbide, Inc." (NS260, NS260C).

2. REPORTED DATA ON TOOL LIFE TESTS: AN ABBREVIATED LITERATURE REVIEW

2.1 Long-term tests of durability

The subject of the experiments was the realization long-term tests of durability, which elaborate for their time and material intensity but are much more accurate and approach to reality against short-term tests of durability which. on the contrary, are much faster but do not give very truthful results.

2.2 Durability of tool „T" and the exponent of the Taylor´s equation „m"

The durability of tool edge is presented as the time of cutting tool from sharpened to blunting. Determination of the durability is derived from the quantity of wear of cutting tools. Nominally the value of mean flunk wear *VB [mm]*.

The durability of the cutting tool is significant dependent upon cutting speed v_C [m/min].depth of the cut a_P [mm] and feed f[mm/rev], other cutting conditions being constant.

The durability *T [min]* is expressed as a time, which was control wear VB_{CONT}. To discover real time of control wear it was used the method of linear interpolation. This interpolation was accomplished between the nearest higher value of VB_{CONT} and the nearest lowest value of VB_{CONT} of the wear (see the equation 1).

$$T = t_1 + \left[\frac{t_2 - t_1}{VB_2 - VB_1} \cdot (VB_{KRIT} - VB_1) \right] [min] \qquad (1)$$

where :
t_1 *[min]* is time needed to achieve the nearest lower value of VB_{CONT} of the tool flank wear VB_1 ;
t_2 *[min]* is time needed to achieve the nearest higher value of VB_{CONT} of the tool flank wear VB_2

The value of an exponent *m* used to be mentioned in the catalogues of the producers of CTI (m = 1.2 to 12 ; 1.2 to 2.5 – cutting ceramics ; 2.5 to 5 – sintered carbides ; 5 to 8 – high speed steels ; 8 to 12 – tool steels). The higher value of the exponent *m* have CTI. the more sensible to ganges of the cutting speed.

2.3 Linear regresession

Linear regression presents the approximation of given values by multi-nominal of the first order (the straight line) of the smallest quadrants. It is made by interlay of measured points in the graph by the straight line where the summary of all squares of divergence of every point of the bisector is minimal. Regressive coefficients *a* and *b*, in the state that the application of the linear regression, have the value of equations 2 and 3.

$$b = \frac{\left(\sum x\right) \cdot \left(\sum y\right) - n \sum xy}{\left(\sum x\right)^2 - n \sum x^2} \qquad (2)$$

$$a = \frac{1}{n}\left(\sum y - b \sum x\right) \qquad (3)$$

Regressive coefficients *a, b* are results of regressive analysis where they state the exponent of the Taylor's equation *m* (from coefficient *b*; see the equation 4) and the constant of the Taylor's equation C_T (from coefficient a ; see the equation 5). The equation 6 holds for the constant of Taylors's equation C_V (dependent on C_T).

$$m = -b \qquad (4)$$

$$C_T = 10^a \qquad (5)$$

$$C_V = C_T^{1/m} \qquad (6)$$

2.4 Statistical anylysis

Standard deviations enable us to assess, how these values are closer to their average in the data set. Estimation of standard deviation of the coefficient *b* (it is s_b) is determined by the equation 7.

$$s_b = \frac{\sqrt{\frac{\sum (y_i - Y_i)^2}{n - 2}}}{\sqrt{\left[\sum x^2 - \frac{\left(\sum x\right)^2}{n}\right]}} \qquad (7)$$

where :
y_i *is* experimentally found values ; Y_i is values determined by regressive formula for corresponding values x_i ; *n* is the number of values

Now it is possible to reveal the interval of reliability of the values of the coefficient *b* by using appropriate standard deviation (according to the equations 8).

$$L_{(b)1,2} = b \pm s_b \cdot t_\alpha \qquad (8)$$

Now it is possible to reveal the interval of reliability of the values of the coefficient *b* by using appropriate standard deviation (according to the equations 8). Furthermore, it is possible to reveal the interval of reliability of the values Y_i from regression equation (according to the equation 9).

$$L_{1,2} = Y_i \pm t_\alpha \cdot s_{y,x} \cdot \sqrt{\left[\frac{1}{n} + \frac{\left(x_i - \bar{x}\right)^2}{\sum x_i^2 - \frac{\left(\sum x_i\right)^2}{n}}\right]} \qquad (9)$$

where: t_α ... critical value of the Student's distribution for α and for $\upsilon = n - 2$ (*n* is number of measured values)

3. THE PREPARING OF EXPERIMENTS

3.1 Used material, cutting tool and equipment

In all experiments there was used material made of grey cast iron 422425. The highest diameter of the workpiece was *D = 185 mm* and the machined length of the workpiece was *L = 400 mm* (see Figure 1).

The material was worked on a turning lathe SU 50 (11kW). This turning lathe has no continuous change of speed (i.e. cutting speed doesn't change with diameter pd work-piece).

CTI are square-cross section with the dimensions l x d x t (12,9 x 12,7 x 4,76), these CTI were clamped securely to right cutting turning tool CERATIZIT PCLNR 25 25 M12 T with geometry $\alpha_O = 5°$, $\beta_O = 90°$, $\gamma_O = -5°$, $\lambda_S = -5°$, $\kappa_r = 95°$.

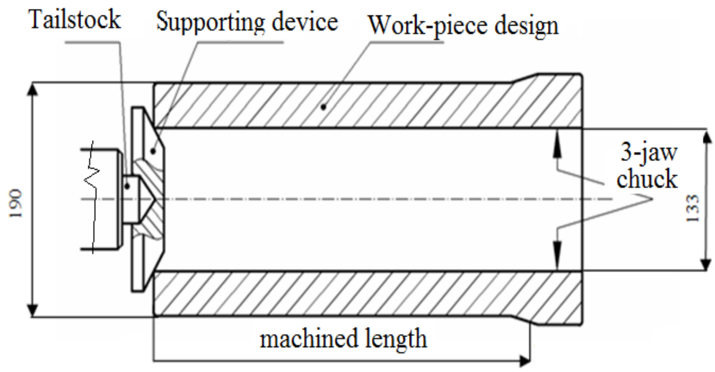


Figure 1. The actual design of experimental work-piece material [2]

For measuring of real spindle speeds was chosen digital measurer of spindle speed ONO SOKKI HT 3100 (exactness of 0.1rpm), quantity spread abrasion on ridge of the tool VB [mm] was chosen workshop microscope CARL-ZEISS JENA (exactness of 0.01 mm). CTI „NS260" (CNMA 120408 NS260) is nitride ceramic without metal coating and CTI „NS260C" (CNMA 120408 NS260C) is nitride ceramic with metal coating of Al_2O_3 + TiN. They can be used with cooling fluid or without cooling fluid.

3.2 Hardness of work-piece

Before long-term test itself, it was necessary to find out if the work-pieces are suitable for these tests. One of the most important perspectives is the hardness. The hardness was discovered by measuring of hardness according to Brinell when there were made three control measuring on every one of the swatches. Then it was determinate the arithmetical average and conclusive divergence. The range of measured values of the cylinder sleeves proceeded in the range between 263 and 275 HB. The test of hardness according to Brinell had confirmed that the cylinder sleeves had approximately the same values of hardness and that they are suitable to be used for long-term test of the durability. When doing the experiment itself, generally for obtaining one schedule of dulling were used some cylinder sleeves which were targeted chosen to have their values of the hardness in very close range.

3.3 Setting machine, Cutting conditions

Constant cutting conditions for our experiments are depth of the cut a_p *(a_P = 1 mm)* and next from the cutting conditions is the feed *f (f = 0,2 mm/rev)*.

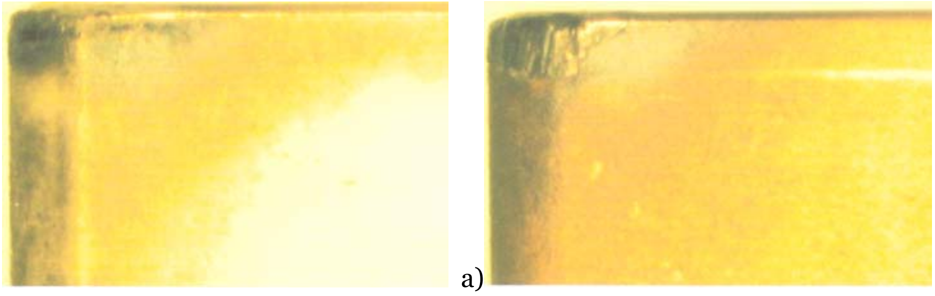
The cutting speed v_C has out of all three cutting conditions (v_C, a_P, f) the greatest influence on the durability of the edge of the tool. The cutting speed depends on spindle speed and diameter of work-piece. For CTI „NS260" were chosen spindle speeds *n = 560rpm, 710rpm and 900rpm*. For CTI „NS260C" were chosen higher spindle speeds *n = 710rpm, 900rpm and 1100rpm* (for coated ceramic). The higher spindle speed could not be chosen for reasons of a small power of machine.

In the experiments was applied "Dry machining", that is machining without cutting fluid. A tearing of the ceramic CTI is caused by thermal shocks, which arise during temperature fluctuations.

4. RESULTS OF EXPERIMENTS AND THEIR ANALYSIS

4.1 Criteria of abrasion on the ridge of the tool "VB_{CONT}"

We need to provide criteria concerning the abrasion on the ridge of the tool VB_{CONT} for the calculation of durability. It is a status when we consider the edge CTI for dulled and when it is not economic to continue in the process of machining. The chosen criteria of abrasion on the ridge of the tool for all CTI is $VB_{CONT} = 0.35$ *mm*.



a) b)

Figure 2 Photograph showing the actual flank wear of compared CTI - NS260 (a), NS260C (b) [7]

Just for illustration are shown the tool flank wears of both compared CTI – NS260 (see Figure 2a, v_C = 350.66 m/min), NS260C (see Figure 2b, v_C = 543.38 m/min).

4.2 Calculation of "m", "C_V" and "C_T"

For determination of the exponent of the Taylor's equation *m* and the constant of the Taylor's equation C_T, C_V we come out formulas (according to equations 4, 5, 6). Into these equations we substitute the parameter **x** by the logarithm of the cutting speed (x = log v_C ; v_C – see Table 1) and the parameter y by the logarithm of measured durability ($y = log\ T$; *T* – see Table 1).

Table 1. The values of calculated durability of compared CTI

CTI	v_C [m/min]	VB [mm]		t [min]		T [min]
		VB_1	VB_2	t_1	t_2	
NS260	288.55	0.34	0.39	29.2	29.5	29.3
	350.66	0.34	0.44	22.5	24.4	22.7
	438.06	0.33	0.40	14.5	16.5	15.1
NS260C	354.66	0.31	0.35	25.5	30.5	30.5
	442.03	0.34	0.41	20.5	23.1	20.9
	543.58	0.33	0.45	15.1	16.1	15.3

In the next table (see Table 2) there are introduced the determined coefficients of regressive linear relations *a*, *b* and consequent value of exponent (*m*; according to the equation 4) and constants (C_T, C_V ; according to the equations 5, 6) of the Taylor's equation.

Table 2. Tabulated summary of resulting values

CTI	a	b	m	C_V	C_T
NS260	5.39	-1.59	1.59	2432	$2.5 \cdot 10^5$
NS260C	5.60	-1.62	1.62	2924	$4.0 \cdot 10^5$

4.3 Standard deviation „s_b" and interval of reliability „m"

Standard deviation of regressive coefficient *b* (s_b) is calculated using equations (7). Interval of reliability of regressive coefficient *b* (i.e. $L_{(b)1,2}$) is calculated using equations (8). We must provide critical value of Student's distribution $t_\alpha(n)$ for the calculation of the intervals of reliability. This value we can find in statistical tables for numbers of degrees of freedom $f = 1$ and $Q = 90\%$ $(\alpha = 0{,}2)$, tj. $t_{0,2}(3) = 3{,}078$ [2]. Resulting values of standard deviation of regressive coefficient *b* and intervals of reliability for the exponent of Taylor's equation *m*, are shown in Table 3.

Table 3. Standard deviation for „b" and corresponding intervals of reliability for „m"

CTI	s_b	m	
NS260	0.157	1.11	2.07
NS260C	0.172	1.09	2.15

4.4 Extrapolation cutting speeds

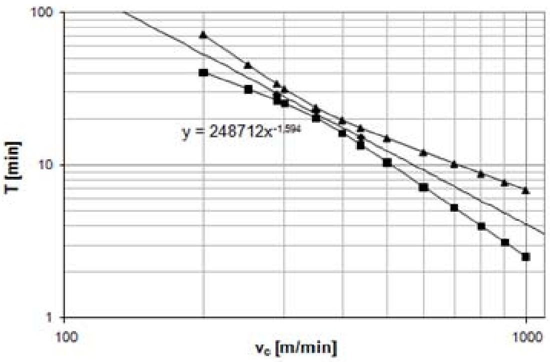
This measurement was done at cutting speed v_{C1} , v_{C2} , v_{C3}. If we want to view the band interval of individualy compared CTI. it was necessary to extend the cutting speed zone to the range of cutting speeds v_C = *200 – 1000* m/min (see Figure 3). This zone on graphic dependence $T = f\ (v_C)$ in logarithmic coordinates, which contains upper and lower limits of the variance, being the interval of reliability of individual durability for measured and extrapolated cutting speeds.

The results of the graphical dependences $T = f\ (v_C)$ in logarithmic coordinates (see Figure 3a, 3b) are the experimental equations for the tool life of these CTI (see Figure 3d). We can approximately detect the cutting speeds of these CTI with the aid of corresponding equations.

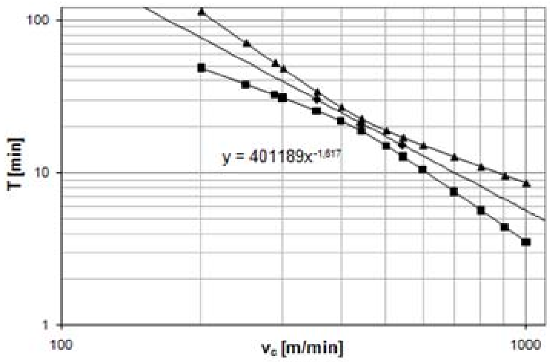
4.5 An experimental approach used in optimizing the cutting speeds

For optimization it is important the highest cutting conditions. In our case we consider with cutting speed v_C, which has out of all three cutting conditions (v_C, a_P, f) the greatest influence on the optimization (a little machine time with good skid resistance. power of machine etc.).

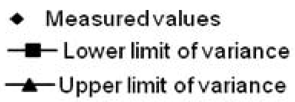
The values of the optimal durability *T [min]* for powerful machining were determined in the line $T = 3\ min$ and $T = 5\ min$. In this interval the profitable durability of the edge tool should be placed (see Table 4). For the completeness it is inducted also the value of the cutting speed for optimal durability $T = 10\ min$. which is the criteria for relative validating of the cutting power (see Table 4).



(a)



(b)



(c)

$$NS260: \ y = 248712 \cdot x^{-1.594} \rightarrow T = 2.5 \cdot 10^5 \cdot v_C^{-1.59}$$

$$NS260C: \ y = 401189 \cdot x^{-1.617} \rightarrow T = 4.0 \cdot 10^5 \cdot v_C^{-1.62}$$

(d)

Figure 3. Graphic dependence of T = f (v_C) for all CTI (a to b); including symbols (c) and corresponding Equations (d)

Table 4 The values of the cutting speeds v_{cT} for selected tool life data

CTI	T [min]			
	3	5	10	
NS260	1220	880	570	v_{cT} [m/min]
NS260C	1480	1080	710	

We proceed out of the main Taylor's equation in form of $v_C = f\ (T)$, where we substitute T with values of the durability stated above (see table 1) and we can make a summary for the end (see Table 4).

5. CONCLUSIONS

The cutting efficiency of the three CTI was experimentally assessed and compared using the linear regression analysis, coupled with the method of the smallest squares. It allowed establishing the trends, and calculating the corresponding standard deviations, regression coefficients as well as the intervals of reliability.

Both of the compared CTI - NS260, NS260C - have a similar values of the exponent of Taylor's equation (NS260: m = 1.59, NS260C: m = 1.62; see Table 2). They have a similar sensitive to the changes of the cutting speed. Both of them are shown on graphic dependence $T = f\ (v_C)$ with the range of cutting speeds $v_C = 200$ *to* 1000 m/min in the logarithmic coordinates (see Figure 3).

In a type NS260 CTI were found the cutting speeds, v_{cT} for the tool life ranging from 3 to 5 minutes, in the interval of 880 to 1 220 m/min which is considered as high-speed machining (see Table 4). Standard deviation for the coefficient of the linear regression *b*, which is related the exponent of Taylor's equation m is $s_b = 0.157$ and the interval of reliability $m = 1.11$ *to* 2.07 (see Table 3).

In a type NS260C CTI with metal coating were found the cutting speeds v_{cT} for the tool life ranging from 3 to 5 minutes, in the interval of 1 080 to 1 480 m/min (higher values of v_{cT} than type NS260) which is considered as high-speed machining (see Table 4). Standard deviation for the coefficient of the linear regression *b*, which is related the exponent of Taylor's equation m is $s_b = 0.171$ and the interval of reliability $m = 1.05$ *to* 2.15 (see Table 3).

Both of the compared CTI made of nitride ceramic – NS260, NS260C – have excellent cutting properties for machining of grey cast iron while using high cutting speeds.

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