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POWER OPTIMIZATION OF CUTTING TOOL INSERT´S MADE OF OXIDE CUTTING CERAMIC WITH ZIRCONIUM MACHINING OF GREY CAST IRON

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Abstract
In this article there you can find comparisons of several types of cutting tool insert's of oxide cutting ceramics with zirconium machining of grey cast iron. Experiments had to serve the realization of long-term durability tests. Very important angle for balance was the index of Taylor's equation that represents the influence of cutting speed on the durability and power optimization. By experimenting, there were discovered precious features of some kinds of compared cutting tool insert's and their references to the power optimization for machining grey cast iron.
Keywords:
machining of metal, cutting ceramics, durability, tool wear

1. INTRODUCTION

In these times in the front of the interests of development of machining is the research of known cutting materials. In the first place because of escalation of the productivity of labour that depend on cutting conditions (cutting speed, the feed and the depth of the cut) [5].

Out of the board of known cutting materials, the cutting ceramics got its specific position in machine industry for its characteristic features and possibilities of utilization. Mainly it is used in machining of grey cast iron, heath-resisting alloy and for machining of the steel. For each of these sections, it is suitable to use specific kind of cutting ceramics that features its characteristics.

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 can be divided to oxide (based on Al_2O_3) and nitrous (based on Si_3N_4). Oxide cutting ceramics (OCC) has, in confrontation to nitrous cutting ceramics, lower persistence and conduct in heath shock but it has better chemical constancy for machining the steel [1].

OCC can be based on pure Al_2O_3 (pure OCC), based on $Al_2O_3+ZrO_2$ (half-compound OCC), which has in contrast with pure OCC better solidity attributes and subtle-solid structure. Last type can be OCC based on Al_2O_3+TiC, consequently with adding metal phase (compound OCC). In contrast with both previous types of OCC, it has lower predispositions for fractures and good persistence which is comparable to sintered carbides [4].

In machining and metrology laboratories of Technical university of Liberec there were in the case of solving several graduation theses compared three various types of CTI square intersection of half-compound oxide cutting ceramic (see tab. 1).

Tab. 1 Compared CTI made of oxide cutting ceramic

CTI	Producer
C-TM-1-5	zahraniční výrobce
DISAL 210	Saint Gobain,ČR (Turnov)
DISAL 230	Saint Gobain, ČR (Turnov)

2. DURABILITY AND TOOL WEAR

The durability of tool edge is most frequently presented as the time of cutting process expressed in minutes. Determination of the durability is derived from the quantity of wear of cutting tools, nominally the value of mean flunk wear **[mm]**.

The values of the tool edge wear differ with changes of cutting conditions and it depends also on the features of the tool material.

The durability of cutting tool is significant dependent on three cutting conditions, under the condition of constant circumstances:
1) The cutting speed $\mathbf{v_c}$ **[m/min]**,
2) The depth of the cut $\mathbf{a_p}$ **[mm]**,
3) The feed **f [mm/rev]**.

Very important reference for evaluating CTI is Taylor´s equation in its simple form which utters relation of the durability **T [min]** on cutting speed **v_C [m/min]**.

$$T = \frac{C_T}{v_c^m}\ [\text{min}] \tag{1}$$

where : **C_T** ... constant of the Taylor's equation

m ... exponent of the Taylor's equation according which the CTI can be compared

The value of an exponent **m** used to be mentioned in the catalogues of the producers of CTI. The higher value of exponent **m** is, the more perpendicular is the inclination of the schedule (the angle of inclination of the schedule □; see fig. 6) and CTI are more sensible to changes of the cutting speed (see tab. 2). The value of exponent of the Taylor's equation **m [-]** is intended from the graphical dependency **log T = f (log v_c)** approximating the schedule (see fig. 1) from detected durability **T_1, T_2, T_3** and cutting speeds **v_{c1}, v_{c2}, v_{c3}** (according to equation 2).

$$m = tg(\alpha) \tag{2}$$

where: α ... is the inclination of the schedule (α = 50° to 86°)

Tab. 2 The values of the exponent m for tool materials

m [-]	α [°]	tool material
8 - 12	83 - 86	tool steel
5 - 8	79 – 83	high-speed steel
2,5 - 5	68 - 79	sintered carbides
1,2 - 2,5	50 - 68	ceramic tools

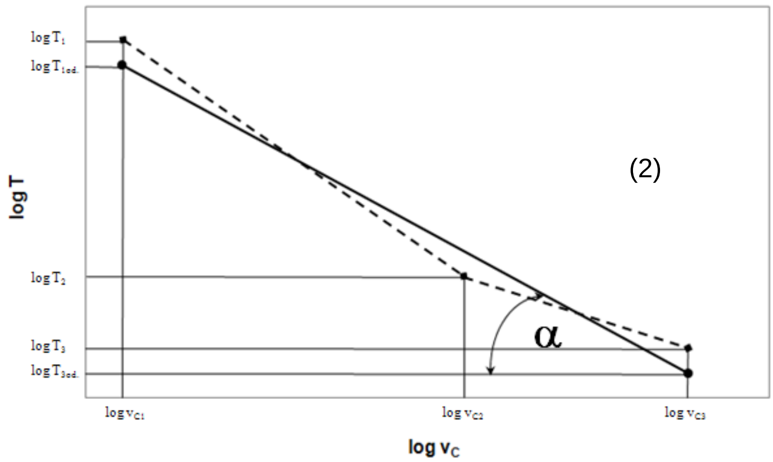


Fig. 1 General graphical formulation of the exponent of the Taylor's equation m

Out of this generally approximated schedule made in graph of dependency **log T = f (log v_c)** we find out the values **log $T_{1od.}$** for **log v_{C1}** and **log $T_{3od.}$** for **log v_{C3}** (see fig. 1). From the general formula for explication exponent of the Taylor's equation **m** (see equation 2) we achieve the formula for our case (see equation 3).

$$m = \frac{\log T_{1od.} - \log T_{3od.}}{\log v_{c3} - \log v_{c1}} \tag{3}$$

where :

$T_{1od.}$ ... reproached durability from the dependence **log T = f (log v_c)** for cutting speed **v_{C1}**

$T_{3od.}$ ... reproached durability from the dependence **log T = f (log v_c)** for cutting speed **v_{C3}**

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.

For implementation long-term test of durability it is recommended to use turning-machine with continuous changes of rev which enables to store constant cutting speed in the process of the test while the intersection of the work-piece is changing. Because of there was no chance to do experiments on such a machine, the cutting speed was maintained in the closest period by changing work-piece after explicit number of overruns the length of the mechanized area (see fig. 2). From all the rates of the cutting speed (v_{C1} to v_{Cn}) used work-pieces was appointed the average cutting speed **v_{Cp} [m/min]** (according to equation 4), which was determinant for Taylor's equation

$$v_{Cp} = \frac{1}{n} \cdot \sum_{i=1}^{n} v_{Ci}\ \ [\text{m/min}] \tag{4}$$

where : **n** ... is the number of measures of given edge CTI

To provide accurate results, it is recommended to do measures on as much edges of given CTI as possible and for as much number of cutting speed **v_C** as can be.

3. THE SETUP FOR THE EXPERIMENT

3.1 Used material and equipment

In all experiments there was used material made of grey cast iron alloyed 42 2425, concretely cylinder sleeve molten to sand mold by method of centrifugal foundry which supplies equable features of all casts (see fig. 2).

Before experiments, there was dispatched disparity of the surface relinquished by casting incrustation. It was accomplished by lathing by a toll with CTI from sintered carbide. Cylinder sleeves were fixed by internal diameter into three-jaw chuck and on the second side with support of preparation enforced with tailstock.

Material was worked in the direction of the indicator (from location **0** to location **1 ;** see fig. 2) on turning lathe SU 50 with supply 11 kW. On this turning lathe there is not continuous change of speed (cutting speed is changing with the diameter pd work-piece), which would be more suitable in this case.

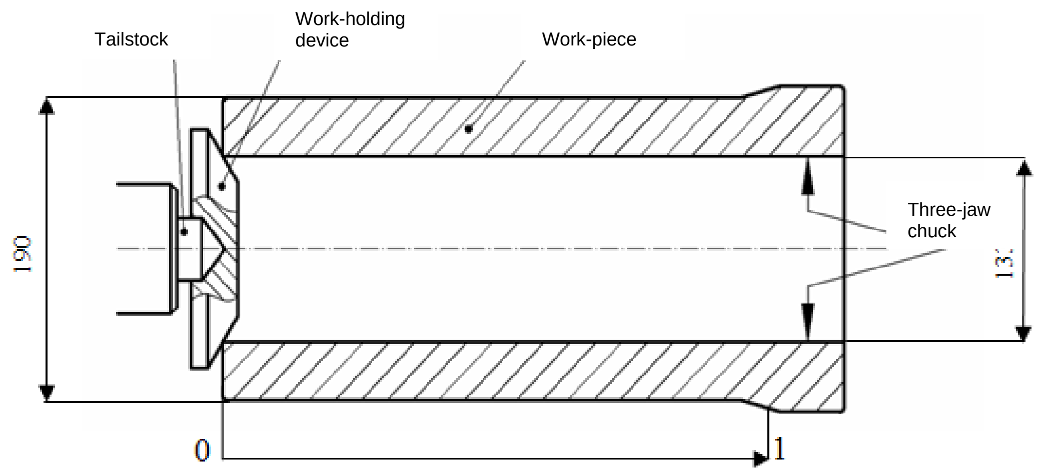


Fig. 2 Cylinder sleeve made of grey cast iron alloyed 42 2425 [6]

Measuring of real speed $\mathbf{n_s}$ **[min^{-1}]** was made by digital measure of speed ONO SOKKI HT 3100 with exactness of ±0,1 min^{-1}.

For measuring quantity spread abrasion on ridge of the tool **VB [mm]** was chosen workshop microscope CARL-ZEISS JENA, type 970, which measures with exactness of 0,01 mm.

3.2 Cutting conditions

Choosing of cutting conditions was determined first of all from the type of used machine (SU50).

One of the cutting conditions which was necessary to choose was the depth of the cut $\mathbf{a_p}$ **[mm]**. In all experiments this value was chosen to be $a_p = 1\ mm$.

Next from the cutting conditions is the feed **f [mm/rev]**. It was also in all experiments chosen the same and its value was **f = 0,2 mm/rev**.

Last of all, for us the most important cutting conditions out of all, is the cutting speed $\mathbf{v_C}$ **[m/min]**, which depends not only on the diameter of the work-piece but also on speed of the spools of the machine. Experiments had confirmed that the cutting speed $\mathbf{v_C}$ has out of all three cutting conditions (v_C, a_P, f) the greatest influence on the durability of the edge of the tool [7]. In our case both two other conditions stay without any change for all CTI. In the calculation there was used Taylor's equation in its basic form (see equation 1), where the only influence has the cutting speed $\mathbf{v_C}$. For contrast CTI it was very important to have the values of the cutting speed in very near periods.

Experiments themselves were made with cutting speed $\mathbf{v_{C1}}$ **≈ 250 m/min** (for n_1 = 450 rev/min), $\mathbf{v_{C2}}$ **≈ 310 m/min** (for n_2 = 560 rev/min), $\mathbf{v_{C3}}$ **≈ 370 m/min** (for n_3 = 710 rev/min).

3.3 Solidity 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 solidity. The solidity was discovered by measuring of solidity 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 solidity according to Brinell had confirmed that the cylinder sleeves had approximately the same values of solidity 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 solidity in very close range.

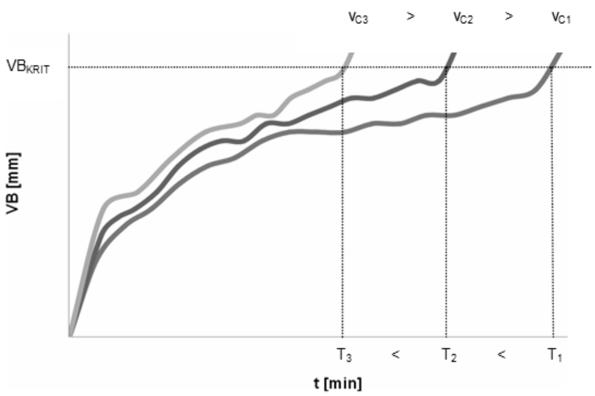


Fig. 3 Reached durability T for every cutting speed v_c

4. EVALUATION OF EXPERIMENT

4.1 Durability T [min]

The graph of the dependence of the depth of the abrasion on the ridge of the tool **VB [mm]** in the reliance on time **t [min]** needs to be construed. With this we obtain characteristic schedules of dulling for every one cutting speed $\mathbf{v_{C1}}$, $\mathbf{v_{C2}}$, $\mathbf{v_{C3}}$ (see fig. *3*). For chosen criteria of abrasion on the ridge of the tool $\mathbf{VB_{KRIT}}$ we have to reproach the durability $\mathbf{T_1}$, $\mathbf{T_2}$, $\mathbf{T_3}$ for every cutting speed. Criteria of abrasion on the ridge of the tool $\mathbf{VB_{KRIT}}$ is a status when we consider the edge CTI for dulled and when it is not economic to continue in the process of machining.

Now we need to construct graphical dependences **VB = f (t)** according to universal example (see fig. 3) for all kinds of CTI (see fig. 4).

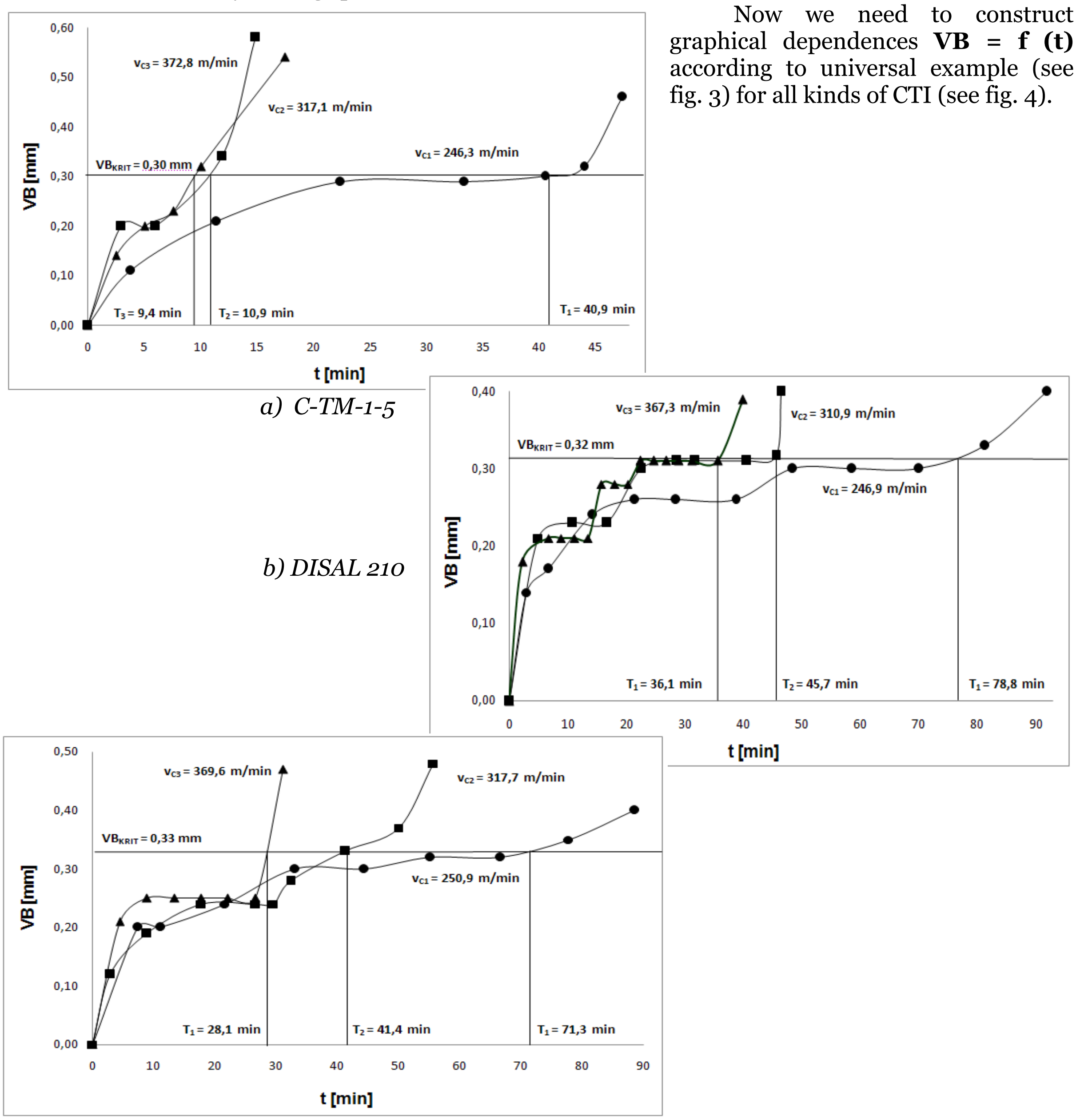


Fig. 4 Reached durability for cutting speeds v_{C1}, v_{C2}, v_{C3} for every CTI [4]

Out of behavior of dependence **VB = f (t)** for all kinds of confronted CTI (see fig. 4) it is transparent that for CTI signed as C-TM-1-5 the durability is the briefest. For cutting speed $\mathbf{v_{C3}}$ we achieved the value only T_3 = 9,4 min, while for other CTI there was their durability attained about half an hour.

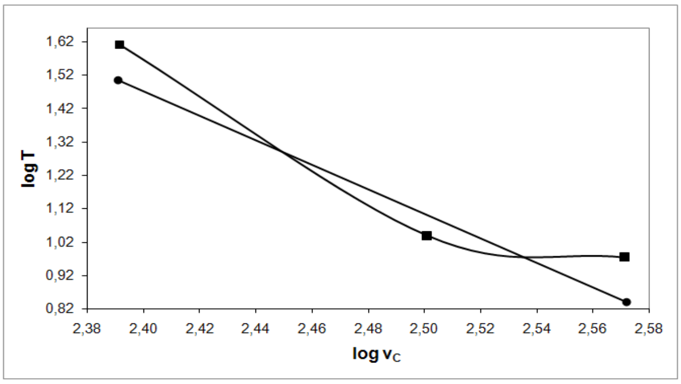
Discovered values for every durability from the graphical illustration of dependence **VB = f (t)** for every kind of CTI (see fig. 4) we can make a summary for next usage (see tab. 3).

Tab. 3 The values of reached durability of compared CTI

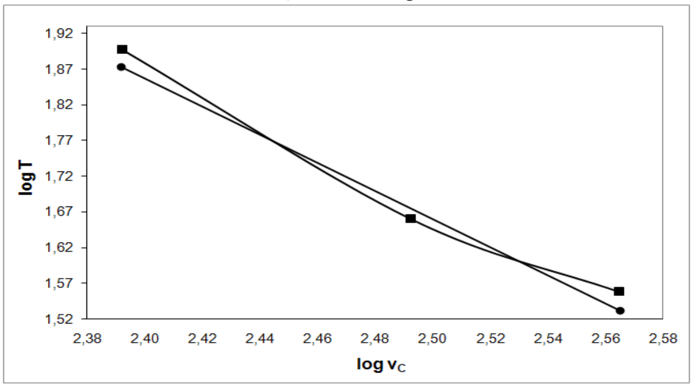
VBD	VB_{KRIT} [mm]	v_c [m/min]			T [min]		
		v_{C1}	v_{C2}	v_{C3}	T_1	T_2	T_3
C-TM-1-5	0,30	246,3	317,1	372,8	40,9	10,9	9,4
DISAL 210	0,32	246,9	310,9	367,3	78,8	45,7	36,1
DISAL 230	0,33	250,9	317,7	369,6	71,3	41,4	28,1

4.2 The exponent of the Taylor's equation m and the constant of the Taylor's equation C_V, C_T

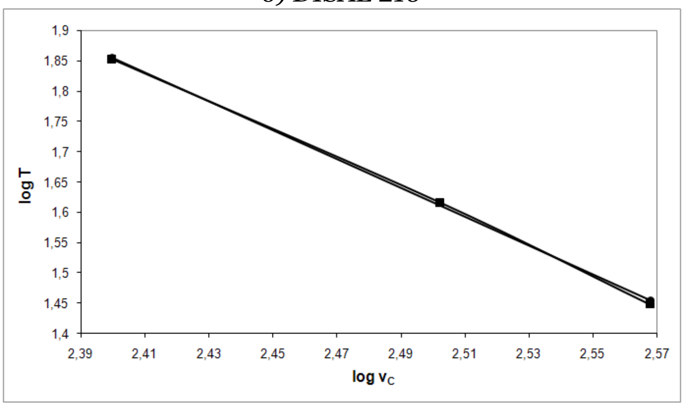
For all compared types of CTI now we construe the graphical subservience **log T = f (log v_c)** (see fig. 1) to find out concrete values of the durability $\mathbf{T_{1od.}, T_{3od.}}$ (see fig. 5) for equation 3.



a) C-TM-1-5



b) DISAL 210



c) DISAL 230

Fig. 5 The subservience of log T = f (log v_C) for every CTI

The biggest divergence between durability $\mathbf{T_1}$, $\mathbf{T_3}$ discovered from the dependency **VB = f (t)** (see fig. 4) and durability $\mathbf{T_{1od.}}$, $\mathbf{T_{3od.}}$ discovered from the dependency **log T = f (log** $\mathbf{v_C}$**)** (see fig. 5) is for the CTI signed C-TM-1-5. For other CTI is the divergence minimal.

From the constructed graphs (see fig. 5) we can find out values of **log** $\mathbf{T_{1od.}}$ out of **log** $\mathbf{v_{C1}}$ and values of **log** $\mathbf{T_{3od.}}$ out of **log** $\mathbf{v_{C3}}$. Then we take a delogarithm for finding real durability $\mathbf{T_{1od.}}$, $\mathbf{T_{3od.}}$ for given cutting speeds v_{c1}, v_{c3} (see tab. 4).

Tab. 4. The values of durability for every kind of CTI

CTI	$v_{C1} \approx 250$ m/min		$v_{C3} \approx 370$ m/min	
	log $T_{1od.}$	$T_{1od.}$ [min]	log $T_{3od.}$	$T_{3od.}$ [min]
C-TM-1-5	1,53	33,9	0,84	6,8
DISAL 210	1,87	74,1	1,53	33,9
DISAL 230	1,86	72,4	1,46	28,8

From these values we count down the exponent of the Taylor's equation **m** (according to equation 3) for all kinds of compared CTI (see tab. 5)

From the basic Taylor's equation (according to equation 1) we develop the equation for calculation of the constant from the Taylor's equation $\mathbf{C_T}$ and we calculate it (see tab. 5) out of known values (see tab. 4) for concrete type of CTI.

From the Taylor's not so used equation (according to equation 5) we derivate a formula for calculation of the constant from the Taylor's equation $\mathbf{C_V}$ and we calculate it (see tab. 5) from known values (see tab. 4) for concrete type of CTI.

$$v_c = \frac{C_V}{T^{\frac{1}{m}}} \quad [\text{m/min}] \qquad [5]$$

where: **T [min]** ... durability of CTI for cutting speed $\mathbf{v_C}$ **[m/min]**

$\mathbf{C_V}$ **[-]** ... constant of the Taylor's equation

Concrete calculated values of the exponent of the Taylor's equation **m** and constants of the Taylor's equation $\mathbf{C_T}$, $\mathbf{C_V}$ for every type of CTI are summed in tab. 5.

Tab. 5. Tabular summary of resulting values

VBD	m [-]	□ [°]	C_V [-]	C_T [-]
C-TM-1-5	3,86	75,5	614	5,8E+10
DISAL 210	1,98	63,2	2172	4,1E+6
DISAL 230	2,37	67,1	1528	3,5E+7

4.3 Power optimization of CTI

For power optimization it is important the highest power while machining (the highest cutting conditions). In our case we consider with cutting speed $\mathbf{v_C}$, which has out of all three cutting conditions (v_C, a_P, f) the greatest influence on the power 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 tab. 6). 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 tab. 6).

WE proceed out of the main Taylor's equation (according to equation 1), where we substitute **T** with values of the durability stated above (see tab. 4).

Tab. 6 The values of the cutting speeds v_{cT} *for chosen durability after approximation*

VBD	T [min]			
	3	5	10	
C-TM-1-5	460	400	340	v_{cT} [m/min]
DISAL 210	1250	960	680	
DISAL 230	960	780	580	

5. THE EVALUATION AND THE CONCLUSION

From the tab. 5 it is evident that the value of the exponent **m** for CTI signed C-TM-1-5 do not belong to the interval of the values for cutting ceramic (confrontation with the tab. 2). While machining grey cast iron, this CTI has a value of the exponent of the Taylor's equation **m** in the interval of the values correspond to sintered carbides. It is much more responsive for the changes of the cutting speed. The lowest value of the exponent **m** was found for CTI signed DISAL 210 (see tab.

5). This CTI has the lowest sensibility for the changes of the cutting speed while machining grey cast iron. With higher speed of the cutting speed the durability changes less then for other compared CTI.

From the process of the dependency **VB = f (t)** for all types of compared CTI (see fig. 4) it is evident that the CTI signed C-TM-1-5 had the worst score. It reached in the comparison with other CTI just in very little time the criteria of abrasion $\mathbf{VB_{KRIT}}$. On the other hand CTI signed DISAL 210 had its critical abrasion reached in the longest period of time out of all compared CTI.

Out of the aspect of the power optimization, the best values reached CTI signed DISAL 210. With durability **T = 3 to 5 min**, when the durability of CTI should take time for the power optimization, there was determined the interval of theoretical cutting speeds $\mathbf{v_{cT}}$ = **960 to 1250 m/min** (see tab. 6). This excellent result shows that this compared CTI is recommended for the power optimization and high-speed machining. The second best valued CTI signed DISAL 230 was found that the interval of the theoretical cutting speeds $\mathbf{v_{cT}}$ = **780 to 960 m/min** for durability **T = 3 to 5 min** again shows its propriety for using this CTI for power optimization, but the exponent of the Taylor's equation m is going to the upper border of cutting ceramic (see tab. 6). The worst valuated was the CTI signed C-TM-1-5, for which the maximal theoretical cutting speed didn't exceed the value of $\mathbf{v_{cT}}$ = **500 m/min**, in which it demonstrated its unfitness for power optimization.

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