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COMPARISON OF CUTTING TOOLS INSERTS MADE OF COATED CARBIDE USED IN TURNING OF GREY CAST IRON

Abstract:
This article presents comparisons of coated carbide cutting tool inserts used in machining of cylinder liners made of grey cast iron. The comparison has been realized through the tool life tests. The measurement has been carried out at three cutting speeds at constant cutting conditions. From the obtained values, the regression coefficients have been evaluated. Subsequently, extrapolation has been carried out by means of the regression line for the cutting speed in the range of 250 – 500 m/min, and for this the extended cutting speed range the interval reliability has been evaluated.

Keywords:
metal machining, coated carbides, cutting tool inserts, tool life tests, Taylor's equation

INTRODUCTION

Carbides are the most prevalent tool materials, they are tough and they can be used for machining using high feed rate speed, and for difficult intermittent machining.

Coated carbides consist of a hard carbide base and coating, which increases the thermo-chemical stability (carbides, nitrides, oxides and their combinations). As a result we get high-quality materials for a high rate of material removal and intermittent machining.

The basic carbides for production of common types of carbides for machining are tungsten carbide (WC) and titanium carbide (TiC), the bonding metal is cobalt (Co). As the other compounds the following are the most used: tantalum carbide (TaC), niobium carbide (NiC) and chromium carbide (Cr_3C_2). Uncoated carbides are divided into three groups: K-grade, P-grade and M-grade. According to the ISO standards, K-grade is a category that includes carbide cutting tools best suited for machining cast irons and nonferrous metals and alloys; M-grade is a category that includes carbide cutting tools best suited for machining ductile irons, harder steels, stainless steels, and high-temperature alloys; P-grade is a category that includes carbide cutting tools best suited for machining a variety of steels. Coated carbides are produced in the following way: the base made from common carbide (K-grade, M-grade, or P-grade) is coated with a material with high hardness and excellent abrasion resistance.

In the laboratories of the Department of Machining and Assembly, Faculty of Mechanical Engineering, Technical University of Liberec, within various diploma thesis two types of the coated carbide inserts (CCI) have been compared. Both CCIs, type CNMA 12 04 08 AC 300G and CNMA 12 04 08 AC 700G (thereinafter AC 300G, AC 700G), were manufactured by the Sumitomo Electric Company. Through the long-time tool life tests the flank wear of the CCI have been evaluated.

LONG-TIME TOOL LIFE TESTS

TOOL LIFE DETERMINATION

The life of the cutting tool is expressed by the time of work of the cutting tool from its sharpening to its blunting. The tool life, T, is given as the time, at which the flank wear criterion VB_{Crit} is reached. To obtain the values of the flank wear criterion the method of the linear interpolation was used. The interpolation was counted from the nearest higher and the nearest lower wear value. The final tool life, T, at a given cutting speed v_c, is expressed as:

$$T = t_A + \left[\frac{t_B - t_A}{VB_B - VB_A} \cdot (VB_{krit} - VB_A) \right] [\min] \qquad (1)$$

where:

t_A – time, at which the nearest lower value than VB_{Crit} of the flank wear VB_A [min] was reached,

t_B – time, at which the nearest higher value than VB_{Crit} of the flank wear VB_B [min] was reached.

EVALUATION OF THE EXPONENT "M" IN THE TAYLOR'S EQUATION

An important criterion for comparison of the CCIs is the exponent m in the Taylor's equation. It expresses the influence of the cutting speed on the cutting edge life. The higher the value of the m exponent, the more sensitive the CCIs to the cutting speed change. The value of this exponent is usually listed in the catalogues provided by the manufacturers of the CCIs, and it is in a range of m = 1 to 12.

To determine the values of the regression coefficients a, b in the linear regression equation it is possible to use the least square method. Subsequently, the standard deviations s_a, s_b are evaluated, as well as the intervals of reliability $L_{(a)1,2}$, $L_{(b)1,2}$ for both regression coefficients. The equations used for a, b, s_a, s_b $L_{(a)1,2}$, $L_{(b)1,2}$ evaluation are given in [9].

The interval of reliability $L_{1,2}$ for a range of the cutting speeds is then determined from (2).

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

where:

Y_i values counted from the regression equation for corresponding x_i values

t_α critical value of the Student's distribution

$s_{y,x}$ standard deviation, which characterizes the dispersion around the regression line

n number of values

x_i value of the logarithm of the cutting speed

$\bar{x}$ average value of the independent variable x

To evaluate the m exponent and the constants C_v, C_t in the Taylor's equation, the regression coefficients a, b are used according to the relations (3), (4), (5). Equations (3), (4) and (5), were according to sources [9].

$$m = -b \qquad (3)$$

$$C_T = 10^a \qquad (4)$$

$$C_V = C_T^{\frac{1}{m}} \qquad (5)$$

EXPERIMENT PREPARATION

BASIC CHARACTERISTICS OF THE CARBIDES UNDER TEST

As mentioned above, for the life test we have used CCIs manufactured by the Sumitomo Electric Company: AC 300G, AC 700G. These CCIs are modern materials for machining the grey cast iron and ductile cast iron. The AC 300G CCI is suitable for continuous machining and the AC 700G CCI is suitable for rough turning and intermittent machining.

Among the main benefits of the AC 300G and AC 700G CCI belongs the newly invented superfilm alpha - Al_2O_3, which increases the thermal resistance by up to 30% in comparison with the commonly used Al_2O_3. These CCIs exhibit up to 150% higher resistance to abrasive flank wear. In comparison with other materials, these CCIs have, at the same machining conditions, considerably higher durability and they are ideal for dry machining.

MATERIAL, MACHINERY AND EQUIPMENT

The tool life tests were performed on the cylinder liners made from grey cast iron alloy, ČSN 42 24 25, that were produced by the AGS Jičín Company (see Figure 1).

The material was machined by a turning machine SU 50, from the point A to the point B. The material was gripped in the machine by its inner diameter, in the 3-jaw chuck on one side of the cylinder, and in a supporting device clamped in a tailstock pin on the other side. The tool wear was evaluated on its clearance face out of the machine, with the aid of the microscope CARL - ZEISS JENA with an accuracy of 0.01 mm. We used a digital revolution meter ONO SOKKI HT – 3100, with the measuring pin positioned in the spindle centreline, to measure the revolutions.

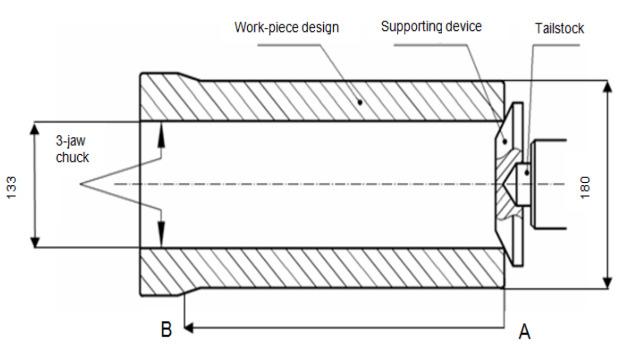

Fig. 1 Cylinder liner [3]

Both types of the CCIs had a rhombic profile and the same geometry of the cutting edge (clearance angle α_o = 5°, cutting edge angle β_o = 90°, rake angle γ_o = -5°, back rake angle λ_o = -5°, end cutting edge angle χ_r = 95°). We used a tool holder, PCLNR 25 25 M12 T, for fastening the CCI.

CHOSEN CUTTING CONDITIONS

Among the recommended machining parameters for the AC 300G CCI are the cutting speed of v_c = 100 to 350 m/min and the feed rate of f = 0.1 to 0.6 mm/rev. For the AC 700G CCI the recommended cutting speed is of v_c = 100 to 350 m/min and the feed rate of f = 0.1 to 0.8 mm/rev [7]. With respect to these parameters, the cutting conditions were established.

The main influence on the cutting tool life exhibit the cutting speed, depth of cut, and the feed rate speed. For both CCIs (AC 300G, AC 700G) were chosen three series of the theoretical cutting speeds: $v_{c1} \approx 280$ m/min, $v_{c2} \approx 350$ m/min, $v_{c3} \approx 460$ m/min. In Table 1, the cutting conditions are shown for individual CCIs.

Tab. 1 Cutting conditions of compared CCI

CCI	f [mm/rev]	a_p [mm]
AC 300G	0.1	2
AC 700G	0.3	2

We used so called dry machining. The benefits of dry machining are: decreasing the investments in cutting fluids, environment and health protection and higher machining productivity. When using this method of machining, the temperature is higher and also more stable. That often means better chip formation, and therefore the power needed is decreased.

CCI EVALUATION

AC 300G CCI

To specify the relation VB = f (t), it was necessary to determine the average machining cutting speed. As the SU 50 turning machine does not have a smooth range of revolutions, it was not easy for the long-time tool life tests to secure a constant cutting speed. The counted average cutting speeds are shown in Table 2.

Tab. 2 Average values of cutting speeds v_c for the experimental AC 300G cutting insert

AC 300G CCI		
v_{c1} [m/min]	v_{c2} [m/min]	v_{c3} [m/min]
285.5	348.3	434.5

Within the solution it was necessary to choose the value of the flank wear criterion VB_{Crit}, while demanding the maximal use of the area of the stabilized machining at the same time. In consequence of the remarkably different courses of wear for each tested CCI, it was necessary to choose a different VB_{Crit} value for each of them.

The relation VB = f (t) was crucial for establishing the value of the flank wear criterion VB_{Crit}. Based on this relation, the value of the flank wear criterion VB_{Crit} was set to VB_{Crit} = 0.20 mm for AC 300G. The dependence of the wear on time VB = f (t) is shown in Figure 2.

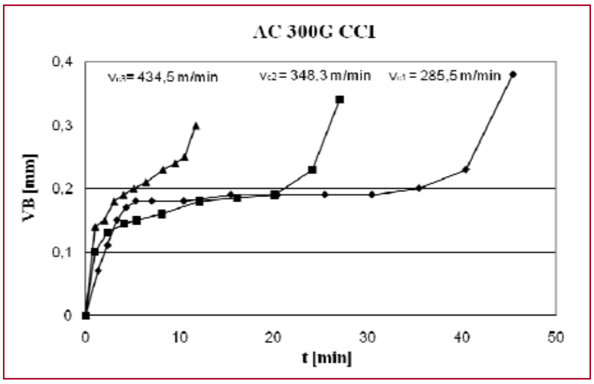

Fig. 2 Graphic dependence of VB=f(t) for the experimental AC 300G cutting insert

The cutting edge durability was for individual average cutting speeds determined by the method of linear interpolation, using the relation (1). The durability counted for all cutting edges AC 300G is listed in Table 3.

Tab. 3 Values of calculated tool life for the experimental AC 300G cutting insert

v_c [m/min]	VB_{Crit} [mm]	t_A [min]	t_B [min]	VB_A [mm]	VB_B [mm]	T [min]
285.5	0.20	30.4	40.4	0.19	0.23	32.9
348.3		20.1	24.1	0.19	0.23	21.1
434.5		4.0	6.4	0.19	0.21	5.2

The measurement was performed at three cutting speeds. Subsequently, extrapolation was carried out with the aid of the regression line for values in a range of 250 – 500 m/min and the interval reliability was determined for this extended cutting speed band, see Table 4. Student's distribution was used for the calculation, for the significance level of t_α = 3.078, α = 90%, f = 1 [4,5].

Tab. 4 Corresponding intervals of reliability for the experimental AC 300G cutting insert

v_c [m/min]	L_1 (-)	L_2 (+)	T [min]
250.0	17.4	272.7	68.8
285.5	14.5	101.2	32.9
300.0	13.2	71.3	30.7
348.3	8.5	29.6	21.1
400.0	3.9	18.8	8.6
434.5	2.2	16.1	5.2
500.0	0.8	13.3	3.2

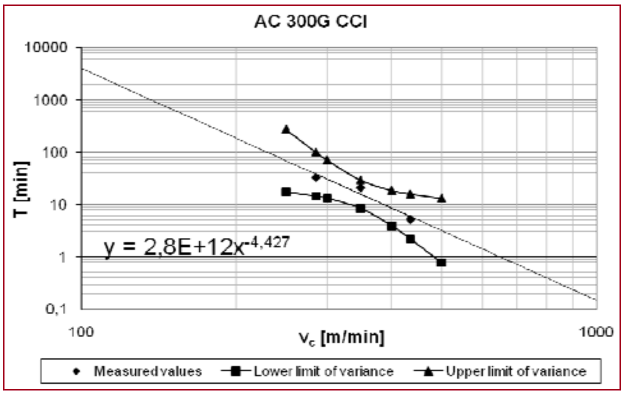

Fig. 3 Experimental relationship between tool life data and different cutting speeds for the experimental AC 300G cutting insert

In Figure 3 you can see the dependency of the durability on the cutting speed $T = f(v_c)$ together with the confidence band for the linear regression dependence.

AC 700G CCI

When evaluating the experiment performed with AG 700G CCI we were following the same steps as for the AC 300G CCI. The counted average cutting speeds for three sets of the cutting speeds are shown in Table 5.

Tab. 5 Average values of cutting speeds v_c for the experimental AC 700G cutting insert

AC 700G;		
v_{c1} [m/min]	v_{c2} [m/min]	v_{c3} [m/min]
283.0	353.9/345.0	445.7

Based on the relation VB = f (t), the value of the flank wear criterion VB_{Crit} was set to VB_{Crit} = 0.30 mm for AC 700G. The dependence of the wear on time VB = f (t) is shown in Figure 4.
When machining the AC 700G CCI, at the speed of v_{c2} = 353.92 m/min and time t = 17.2 min from the test start, the cutting edge broke at the peak of the CCI. Then it was experimented with avarage cutting speed v_{c2} = 345.0 m/min.

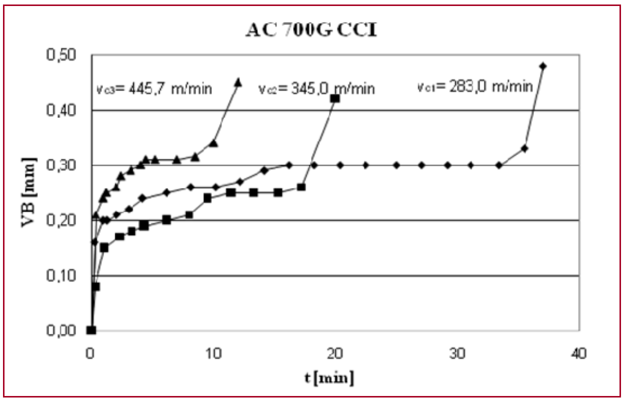

Fig. 4 Graphic dependence of VB=f(t) for the experimental AC 700G cutting insert

Tab. 6 Values of calculated tool life for the experimental AC 700G cutting insert

v_c [m/min]	VB_{Crit} [mm]	t_A [min]	t_B [min]	VB_A [mm]	VB_B [mm]	T [min]
283.00	0.30	14.20	35.50	0.29	0.33	19.50
345.00		10.50	20.10	0.28	0.32	15.30
445.70		3.25	7.00	0.29	0.31	5.10

The durability counted for the CCI with the AC 700G is listed in Table 6. To compare the CCIs we chose the value of the flank wear criterion VB_{Crit} = 0.30 mm for the AC 700G. The interval reliability for the extended cutting speed band for the AC 700G is shown in Table 7.

Tab. 7 Corresponding intervals of reliability for the experimental AC 700G cutting insert

v_c [m/min]	L_1 (-)	L_2 (+)	T [min]
250.0	11.4	90.8	32.2
283.0	10.3	47.5	19.5
300.0	9.7	35.7	18.6
345.0	7.4	20.1	15.3
400.0	4.3	14.3	7.8
445.7	2.5	12.6	5.1
500.0	1.4	11.5	4.0

In Figure 5 you can see the dependency of the durability on the cutting speed $T = f(v_c)$ together with the confidence band for the linear regression dependence.

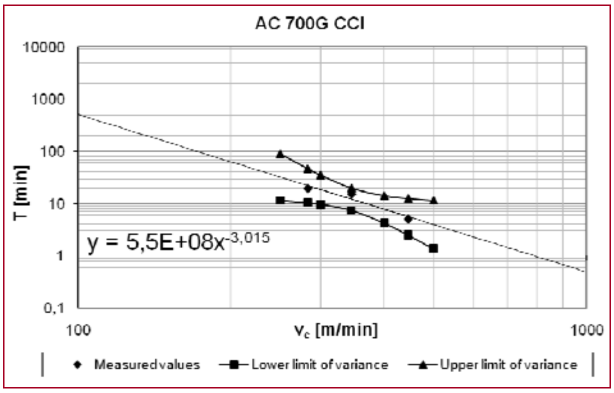

Fig. 5 Experimental relationship between tool life data and different cutting speeds for the experimental AC 700G cutting insert

COUNTED VALUES OF CCI

Concrete counted values of the regression coefficients a, b, standard deviations s_a, s_b, exponent m and the constants C_T, C_V in the Taylor's equation are listed in Table 8.

Tab. 8 Tabulated summary of resulting values

CCI	a	b	s_a	s_b	m	C_T	C_V
AC 300G	12.45	-4.42	3.00	1.18	4.43	2.84E+12	650.45
AC 700G	8.73	-3.01	2.20	0.87	3.02	5.49E+08	791.06

ANALYSIS AND CONCLUSION

We have performed long-time life tests for coated carbide inserts (CCI) of a type CNMA 12 04 08 AC 300G (AC 300G), CNMA 12 04 08 AC 700G (AC 700G), which were manufactured by the Sumitomo Electric Company. The measurement was performed with cylinder liners made from grey cast iron alloy ČSN 42 24 25. Their evaluation was carried out within linear regression.

The crucial influence on the tool life has the cutting speed. Therefore, the tool life of the CCI was assessed at three cutting speeds. To gain an extended cutting speed band, we obtained tool life values from the regression relations. We chose the cutting speed band for both CCIs of 250 – 500 m/min.

For each CCI we selected different values of the VB_{Crit} when performing the experiment. The reasons were extremely different courses of wear for each tested CCI, and the use of the area of stable machining.

The highest evaluated tool life for the AC 300G CCI was T = 68.8 min for the cutting speed of v_c = 250 m/min, and the lowest tool life value was T = 3.2 min for the cutting speed of v_c = 500 m/min. The AC 300G CCI is intended for the cutting speed up to 350 m/min; this value corresponds with the manufacturer's data. For the speed of $v_c > 500$ m/min it is not possible to recommend this CCI, due to the low tool life value. Under these measurement conditions it is not possible to recommend the AC 300G CCI for high-speed machining.

For the lower value of the cutting speed v_c = 250 m/min, the tool life of the AC 700G CCI was counted as T = 32.2 min. In comparison with the AC 300G CCI, the tool life is, at the given conditions, lower by 36.6 min. For the upper value of the cutting speed v_c = 500 m/min, the tool life was counted as T = 4.0 min.

The AC 700G CCI is, as well as the AC 300G, intended for the cutting speed up to 350 m/min max. Under the conditions we used for our experiments we cannot recommend the AC 700G CCI for high-speed machining.

From the comparison of the two types of CCI made from carbides it seems that, in terms of the tool life attained within given conditions, the better CCI is the one identified as AC 300G.

For machining the grey cast iron continuously it seems to be preferable to use the cutting tool inserts (CTI) made from cutting ceramics. During experiments, it has been proved that these CTIs have, at the same cutting conditions, higher tool life [8]. When machining intermittently it seems to be preferable to use the cutting tool inserts made from carbides.

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