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EXPERIMENTAL TESTING OF EXCHANGEABLE CUTTING INSERTS CUTTING ABILITY

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Original scientific paper
The article deals with experimental testing of the cutting ability of exchangeable cutting inserts. Eleven types of exchangeable cutting inserts from five different manufacturers were tested. The tested cutting inserts were of the same shape and were different especially in material and coating types. The main aim was both to select a suitable test for determination of the cutting ability of exchangeable cutting inserts and to design such testing procedure that could make it possible to compare and evaluate the cutting ability of the selected cutting inserts. After the testing the necessary calculations were performed for comparison of the cutting abilities and recording the tool-wear using a microscope. The cutting ability was compared and discussed.

Keywords: *cutting ability, cutting tool, experiment, machining, tool-life*

Eksperimentalno ispitivanje rezne sposobnosti izmjenjivih reznih umetaka

Izvorni znanstveni članak
Članak se bavi eksperimentalnim ispitivanjem rezne sposobnosti izmjenjivih reznih umetaka. Testirano je 11 tipova izmjenjivih reznih umetaka od pet različitih proizvođača. Ispitivani su rezni umetci bili istog oblika a razlikovali su se naročito po materijalu i vrsti površinskog sloja. Glavni je cilj bio izabrati odgovarajući test za određivanje rezne sposobnosti zamjenjivih reznih umetaka te kreirati takav postupak ispitivanja koji bi omogućio usporedbu i ocjenu rezne sposobnosti odabranih reznih umetaka. Nakon ispitivanja izvršeni su potrebni proračuni za usporedbu rezne sposobnosti i bilježenje trošenja alata korištenjem mikroskopa. Uspoređena je i prodiskutirana rezna sposobnost.

Ključne riječi: *eksperiment, radni vijek alata, rezni alat, rezna sposobnost, strojna obrada*

1 Introduction

Cutting and machining ability are not the absolute properties of cutting or machined materials [1]. It is basically the relationship of the cutting material, machined material and environment that also depends on the given work conditions. Among these conditions are cutting speed, feed rate, depth of cut and the tool's geometry. Indicators of the cutting and machining ability are the monitored machining forces, durabilities, surface roughnesses, dimensional accuracies and the shapes of chips. We can observe the machining ability of the materials or cutting abilities of the tools by observing mutual effects of all these properties at given working conditions.

The cutting ability of a tool is related to the type of cutting material. The cutting material properties are evaluated according to its development and usage. The cutting ability is represented by the sum of properties that express the ability of a cutting material to cut the machining material under physical conditions that are characteristic for the cutting processes. This is closely related to the physical and mechanical properties of a cutting tool, and also other things, like cutting methods, geometry, cutting parameters and tool coating. Also different demands on tool materials stem from different work conditions. For a long life and high durability it is necessary to select the type of cutting material on the basis of deeper knowledge of phenomena that take place in the cutting zone. A simple criterion is the T-v_c relationship. In general the material with the higher C_T constant and lower value of the exponent m has better cutting abilities.

2 Experimental part

2.1 Test description

Due to a large number of tested inserts it was better to select the direct short-term cutting test, considering its lower time demands and smaller volume of cut material during the tests [1]. After careful consideration necessary for closer investigation and comparison of the cutting ability of the chosen exchangeable cutting inserts, the face turning method was selected for testing the tool cutting abilities (Fig. 1).

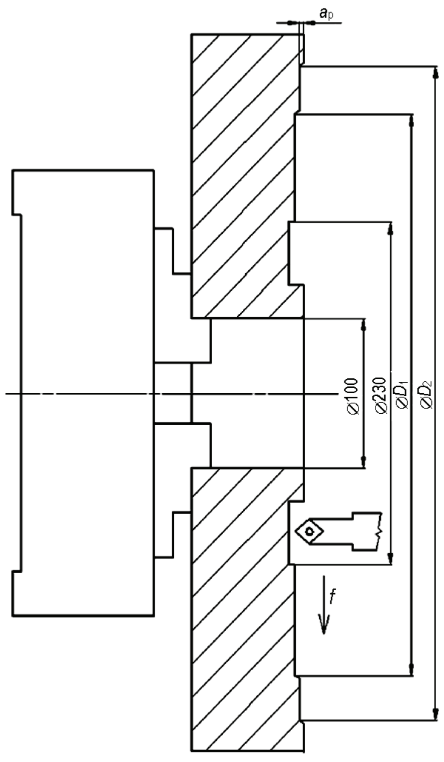


Figure 1 The face turning method for testing - scheme

The cutting ability test is to be performed by the face turning method. It is necessary to select a sufficiently large diameter of the machined material in order for the inserts with a higher cutting ability not to cut away the whole material, and not to be sufficiently worn out under the selected cutting parameters at the same time. In this way it would not be possible to measure the requested diameters on the face of the tested material.

It is advisable to select a higher quality of the machined material with worse machinability for more impartial testing, and also the inserts should be exposed to machining of harder material [2, 3]. The 15 142 (CSN 41 5142) (42CrMo4) material with the diameter of 480 mm was selected. This is a chrome-molybdenum steel suitable for being tempered in oil, with favourable values of notch toughness and high resistance. It has the increased resistivity against drawing and can be used in increased temperatures up to approximately 500 °C. It is treated for the tensile strength above 1050 MPa and has increased resistivity against wear. It is suitable for surface tempering (tempering temperature: 540 ÷ 680 °C; re-heat to tempering temperature, hold one hour per 25 mm of section - 2 hours minimum, and cool in air). It is not susceptible to drawing brittleness.

We selected eleven types of exchangeable cutting inserts from five manufacturers as the tested material (see Tab. 1). In total 33 tests were performed, each plate was tested three times.

Table 1 Tested cutting materials

Item	Manufacturer	Marking	Material
1	Manuf 1	CCMT 120408E	Qt 1
2	Manuf 2	CNMG 120408E	Qt 2
3	Manuf 3	CCMT 120408E	Qt 3
4	Manuf 4	CNMG 120412E	Qt 4
5	Manuf 5	CCMT 120408E	Qt 5
6	Manuf 6	CCGT 120408ER	Qt 6
7	Manuf 7	CCMT 120404	Qt 7
8	Manuf 8	CCMT 120408	Qt 8
9	Manuf 9	CCMT 120408	Qt 9
10	Manuf 10	CCMT 120412	Qt 10
11	Manuf 11	CCMT 120408	Qt 11

* Manuf = Manufacturer
** Qt = Quality type

During the selection of cutting conditions it is necessary to consider that the tested inserts are used especially for semi-rough cutting. The cutting parameters, i.e. feed rate and depth of cut are identical for each test. Only spindle speed will change. The depth of cut must be selected not to be larger than or equal to the biggest radius of the tip of the selected exchangeable cutting insert, in opposite case the inserts would not cut material, but compress and strengthen the chip layer before the next turn. This would cause faster tool-wear of the insert and non-objectivity of the test.

The spindle speed must be selected so that the cutting speed increases with the increasing diameter in order to completely wear out the tool insert or destroy it before the insert manages to machine away the whole front of the machined material.

The test cutting parameters:

- spindle speed n = 355 and 450 rpm,
  → cutting speed was variable,
- feed f_n = 0,2 mm,
- cutting depth a_p = 1,2 mm.

With regard to the experiment requirements we selected the turning lathe SU 50A for the testing (Fig. 2) with the turning diameter above the bed 500 mm and the maximum spindle speed 1400 rpm, what is sufficient for the testing.

Figure 2 SU 50A turning lathe

It was necessary to provide maximum rigidity for the machine and tool - machined part system. The testing material was supported by a tailstock for increased safety.

2.2 Test course and evaluation

As $\varnothing D_0$ we selected ∅230 mm. First inserts were tested at 355 rpm. Then the exchangeable cutting insert was turned to the other edge in the cutter block and the test was performed at 450 rpm. First time we measured the diameter (see Tab. 2) before the inserts were completely worn down. The time when the edge was sufficiently worn out was always unequivocally clear from the machined surface. This was recognizable by naked eye by the change of the surface roughness or recognizable change in dimension of surface cut by a sharp edge. The diameter measurements were performed by a slide gauge with the range of 0 ÷ 500 mm. After each measurement of a single cutting insert the front was evened up. The final wear of the edge in some of the inserts was accompanied by a piercing squeak caused by friction between the tool back and the machined surface. We performed three measurements for each cutting insert. The whole experiment was performed without cooling. For the exchangeable cutting insert manufacturers specify the necessary torques for holding of the insert in a cutter block. Therefore we used a special screwdriver with a torque handle by which we set the required torque for the experiment. 11 sorts of inserts were chosen for testing and the manufacturer marking was under ISO code. The diameters were measured during testing by a calliper and the other values were obtained by calculation and other calculating methods.

The values such as a piercing squeak and naked eye were not the main aim and will be points of our attention in the next researching. The main goal was the tool-life and roughness.

Table 2 Measured and average values with description - testing

Item	Manufacturer	Marking	Insert material	Measurement number	$\varnothing D_1$ / mm	$\varnothing D_2$ / mm
1.	Manuf 1	CCMT 120408E-48	Qt 1	1.	471	475
				2.	465	472
				3.	453	475
				$\overline{\varphi D_n}$	463,0	474,0
	- The chips broke for the whole test period excellently					
2.	Manuf 2	CNMG 120408E-M	Qt 2	1.	434	459
				2.	425	445
				3.	420	440
				$\overline{\varphi D_n}$	426,3	448,0
	- The chip was long, untwisted, with low break frequencies and created clusters - The final wear phase was accompanied by strong sound effect					
3.	Manuf 3	CCMT 120408E-48	Qt 3	1.	343	374
				2.	327	358
				3.	330	360
				$\overline{\varphi D_n}$	333,3	364,0
	- The chip was long, untwisted, with low break frequencies and created clusters					
4.	Manuf 4	CNMG 120412E-M	Qt 4	1.	275	296
				2.	282	301
				3.	280	298
				$\overline{\varphi D_n}$	279,0	298,3
	- The chip was long, untwisted, with low break frequencies and created clusters - The final wear phase was accompanied by strong sound effect					
5.	Manuf 5	CCMT 120408E-48	Qt 5	1.	279	298
				2.	285	305
				3.	288	321
				$\overline{\varphi D_n}$	284,0	308,0
	- The chips were spiral shaped with 1 ÷ 3 threads with 8 mm diameter, sometimes a twisted chip was created with a smaller diameter and length of up to 200 mm					
6.	Manuf 6	CCGT 120408ER-SI	Qt 6	1.	263	281
				2.	250	262
				3.	254	267
				$\overline{\varphi D_n}$	255,7	270,0
	- Small chips accompanied by fast wear					
7.	Manuf 7	CCMT 120404-MM	Qt 7	1.	284	330
				2.	295	314
				3.	278	296
				$\overline{\varphi D_n}$	285,7	313,3
	- Long, spiral chips with length of up to 400 mm and chip's curvature diameter - 7 mm					
8.	Manuf 8	CCMT 120408	Qt 8	1.	301	349
				2.	309	340
				3.	306	338
				$\overline{\varphi D_n}$	305,3	342,3
	- Long, spiral chips with length of up to 400 mm and chip's curvature diameter - 7 mm - Fast progress in required wear					
9.	Manuf 9	CCMT 120408	Qt 9	1.	327	372
				2.	332	379
				3.	320	394
				$\overline{\varphi D_n}$	326,3	381,7
	- Twisted chips with the length of 30 ÷ 40 mm and chip's curvature diameter - 4 mm					
10.	Manuf 10	CCMT 120412	Qt 10	1.	331	358
				2.	310	335
				3.	285	340
				$\overline{\varphi D_n}$	308,7	344,3
	- The chip was long, untwisted, with low break frequencies and created clusters					
11.	Manuf 11	CCMT 120408-BSM	Qt11	1.	302	335
				2.	308	340
				3.	305	335
				$\overline{\varphi D_n}$	305,0	336,7
	- At low spindle speed the chip was breaking, with increased cutting speed it was long in spiral - At higher spindle speed broken, at higher cutting speed – created chip clusters					

2.3 Summary of calculation expressions

Cutting speed:

$$v_\mathrm{c} = \frac{\pi \cdot D \cdot n}{1000}, \text{ m/min.} \tag{1}$$

Edge durability:

$$T_n = \frac{D_2 - D_1}{2} \cdot \frac{1}{f \cdot n_1}, \text{ min} \tag{2}$$

or

$$T_n = \frac{500 \cdot (v_2 - v_1)}{\pi \cdot f \cdot n_2^2}, \text{ min.} \tag{3}$$

C_T constant:

$$C_\mathrm{T} = T_n \cdot v_\mathrm{c}^m, \tag{4}$$

$$\int_{v_1}^{v_2} v^m \mathrm{d}v = \frac{v_2^{m+1} - v_1^{m+1}}{m+1}, \tag{5}$$

$$v_\mathrm{c}^m = \frac{v_2^{m+1} - v_1^{m+1}}{(m+1) \cdot (v_2 - v_1)}, \tag{6}$$

$$C_\mathrm{T} = \frac{500}{\pi \cdot f \cdot n_2^2} \cdot \frac{v_2^{m+1} - v_1^{m+1}}{m+1}, \tag{7}$$

$$C_\mathrm{T} = \frac{500}{\pi \cdot f \cdot n_1^2} \cdot \frac{v_1^{m+1}}{m+1} = \frac{500}{\pi \cdot f \cdot n_2^2} \cdot \frac{v_2^{m+1}}{m+1}. \tag{8}$$

Exponent m:

$$C_\mathrm{T} = \frac{500}{\pi \cdot f \cdot n_1^2} \cdot \frac{v_1^{m+1}}{m+1} = \frac{500}{\pi \cdot f \cdot n_2^2} \cdot \frac{v_2^{m+1}}{m+1}$$

$$\Rightarrow \left(\frac{v_1}{v_2}\right)^{m+1} = \left(\frac{n_1}{n_2}\right)^2.$$

After making a logarithmic calculation:

$$\Rightarrow m = 2 \cdot \frac{\lg \frac{n_2}{n_1}}{\lg \frac{v_2}{v_1}} - 1. \tag{9}$$

Angle α:

$$m = \tan\alpha \Rightarrow \alpha = \arctan m. \quad (10)$$

T_n – tool-life for cutting edge; v_2 – cutting speed at higher spindle speed; v_1 – cutting speed at lower spindle speed; v_c – cutting speed; f – feed rate; n_2 – higher spindle speed; n_1 – lower spindle speed; D_2 – maximal diameter; D_1 – minimal diameter; D – diameter; m – directive angle.

Table 3 Table of measured and calculated values

Item	Manufacturer	Marking	Insert material	$\varnothing D_1$ / mm	$\varnothing D_2$ / mm	v_{c1} / m/min	v_{c2} / m/min	m / –	C_T / –	T_{n1} / min	T_{n2} / min
1	Manuf 1	CCMT 120408E	Qt 1	474,0	463,0	528,4	654,2	1,2	$3,15\times10^3$	1,72	1,29
2	Manuf 2	CNMG 120408E	Qt 2	448,0	426,3	499,4	602,4	1,5	$1,67\times10^4$	1,53	1,09
3	Manuf 3	CCMT 120408E	Qt 3	364,0	333,3	405,8	471,0	2,2	$3,97\times10^5$	0,94	0,57
4	Manuf 4	CNMG 120412E	Qt 4	298,3	279,0	332,5	394,2	1,8	$2,4\times10^4$	0,48	0,27
5	Manuf 5	CCMT 120408E	Qt 5	308,0	284,0	343,3	401,3	2,0	$1,06\times10^5$	0,55	0,30
6	Manuf 6	CCGT 120408ER	Qt 6	270,0	255,7	301,0	361,3	1,6	$6,6\times10^3$	0,28	0,14
7	Manuf 7	CCMT 120404	Qt 7	313,3	285,7	349,2	403,7	2,3	$4,06\times10^5$	0,59	0,31
8	Manuf 8	CCMT 120408	Qt 8	342,3	305,3	381,6	431,4	2,9	$1,54\times10^7$	0,79	0,42
9	Manuf 9	CCMT 120408	Qt 9	381,7	326,3	425,5	461,1	4,9	$3,58\times10^{12}$	1,07	0,53
10	Manuf 10	CCMT 120412	Qt 10	344,3	308,7	383,8	436,2	2,7	$6,41\times10^6$	0,80	0,44
11	Manuf 11	CCMT 120408	Qt 11	336,7	305,0	375,3	431,0	2,4	$1,25\times10^6$	0,75	0,42

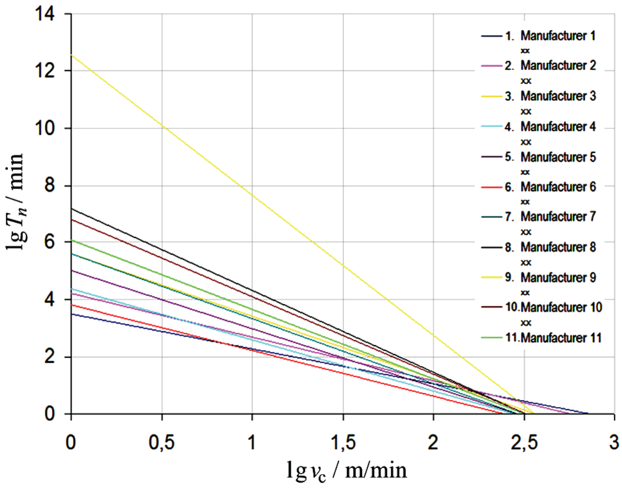


Figure 3 Dependency graph of durability on cutting speed for all types cutting inserts

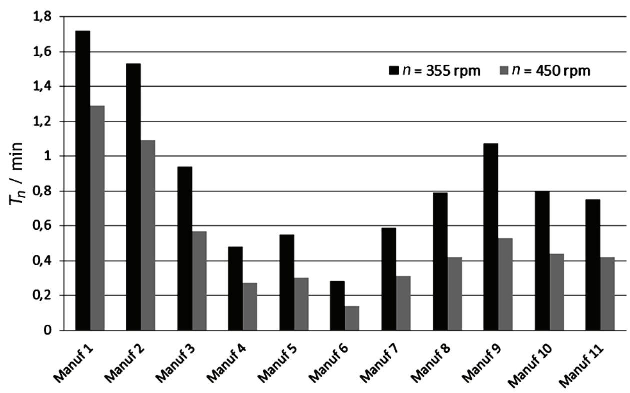


Figure 4 Durability graph of individual inserts

2.4 Comparison of cutting ability

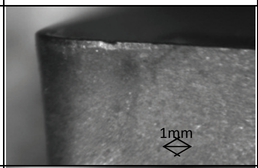
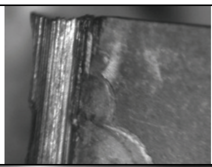
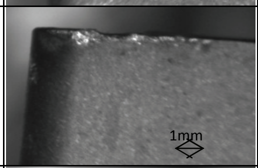
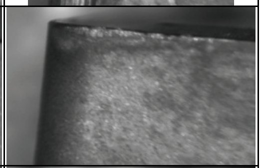
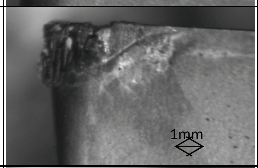
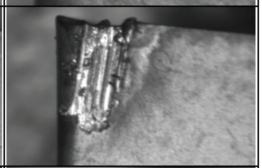
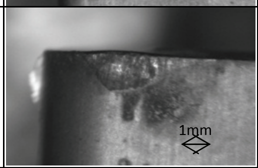
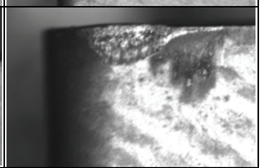
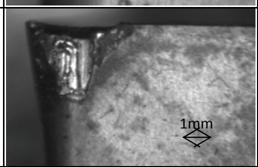
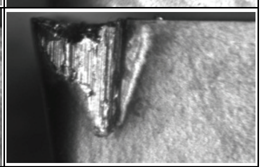
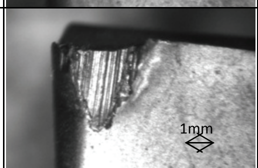
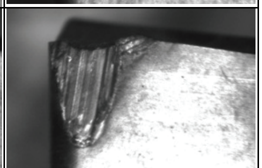
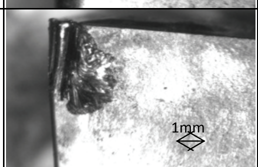
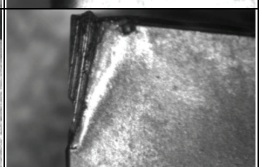
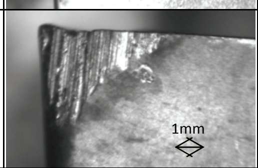
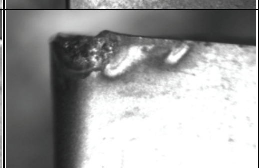
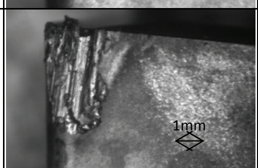
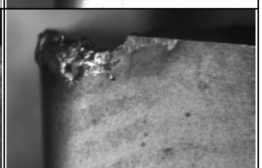
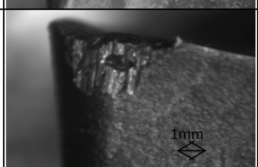
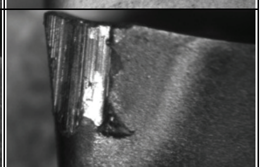
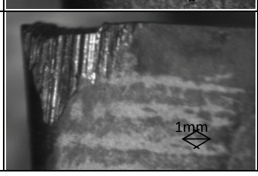
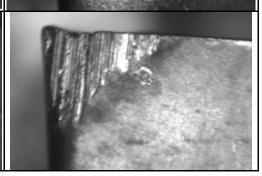
If we want to compare the cutting ability of insert, it is necessary to select some parameter. In case of this experiment it would be most suitable to select the time T_n which is the time of durability for one edge under selected cutting conditions.

Thanks to Fig. 3 and Fig. 4, where we could compare the dependency of durability on the cutting speed and with other inserts, we can reach a clear conclusion. In Fig. 3 we can see logarithmic dependencies of tool-life on cutting speed. Fig. 4 shows dependency of tool-life for individual manufacturers.

Among the inserts with the best cutting ability are numbers Manufacturer 1 and Manufacturer 2. Both inserts are made from Quality type 1. With regard to the chip creation with these inserts we can say that the Manufacturer 1 has much better chip creation, which is very important in a machining process. We can further say that the cutting inserts with zero flank angles have smaller cutting ability than the inserts with the flank angle of 7°. This phenomenon can be noticed also with the Manufacturer 4 and Manufacturer 5 with the same insert material but different flank angles. The item Manufacturer 4 has worse durability and, at the same time, zero flank angle. The suitable insert for semi-rough cutting to finishing would also be the insert from Manufacturer 9.

One of different causes of cutting ability for the inserts (Quality type 1, 2 and Quality type 4, 5) from Manufacturer 1 ÷ 6 [5] is also different coating material. For Quality type 4, 5 it is a thin coat with TiCN support layer applied by the MTCVD method and for Quality type 1, 2 it is a thick coating with the Al_2O_3 support layer applied by the MTCVD method. This will have a major influence on better cutting ability of the Quality type 1, 2, especially for cutting inserts with the zero flank angles, since a larger friction occurs here between the back and the machined material, which is hard on a used coating.

Table 4 Photos - achieved tool-wear at testing (10×)

Item	Manufacturer Marking Insert Material	Achieved tool wear at 355 rpm	Achieved tool wear at 450 rpm
1	Manuf 1 CCMT 120408E Qt 1		
2	Manuf 2 CNMG 120408E Qt 2		
3	Manuf 3 CCMT 120408E Qt 3		
4	Manuf 4 CNMG 120412E Qt 4		
5	Manuf 5 CCMT 120408E Qt 5		
6	Manuf 6 CCGT 120408ER Qt 6		
7	Manuf 7 CCMT 120404 Qt 7		
8	Manuf 8 CCMT 120408 Qt 8		
9	Manuf 9 CCMT 120408 Qt 9		
10	Manuf 10 CCMT 120412 Qt 10		
11	Manuf 11 CCMT 120408 Qt 11		

Between the best and the worst cutting ability insert that is more than 80 % worse than the number 1 lies number 6 with an atypical shape and Quality type 6. For a better cutting ability comparison it would be best to test on different quality materials and change the feed rate or depth of chips.

2.5 Investigation of tool-wear

The investigation of the insert tool-wear was performed on the Intracomicro microscope with recording equipment. We could take a photo of the tool-wear for each insert. The maximum magnification of this microscope is 10× [6]. The measurement of tool wear does not have a greater meaning in this experiment and the measured sizes of tool wear have not got further information. The verification of tool wear was carried out for more findings and identifies the type of created tool wear achieved at the extreme edge's load.

The magnitudes of dullness which can be seen at the attached pictures are primarily influenced by the high cutting speed. The target of this experiment was to achieve complete tool-wear, i.e. the tool-wear when the insert cannot cut any more [4, 7]. The photographs show the main insert and the tip radius from the side. There were a larger number of insert damage types under such extreme edge loads. The photographs show build-ups and high back wear, which are consequences of the high cutting speed. Then can be seen the plastic deformation of tips and in some cases destruction of the edge or tip. From this can be deduced that we have achieved the insert wear at this experiment.

3 Conclusion

The main aim of this experiment was to select exchangeable cutting inserts from the assortment used for semi-rough and finishing work and compare their cutting ability and create the relation of their durability on the cutting speed. We selected eleven types of inserts from five manufacturers (Manufacturers 1 ÷ 6, Manufacturer 7, Manufacturers 8 ÷ 9, Manufacturer 10 and Manufacturer 11). The differences are in the used materials and geometries. Regarding the geometry the differences were in the tip radius, flank angle and the shape of form. The inserts had a diamond shape with the top angle 80° and the thickness 4,76 mm.

For cutting ability testing it was necessary to select a short-term test due to the lesser demand on time and also due to financial demands on machined material in case the long-term tests were selected. Therefore the short-term face turning method for testing was selected also with regard to the fact that these tests were insert tests for machining. The material selected for the tests was 15 142 with the machinability 10b and the hardness 280 HB. These material properties created more demanding machining conditions for the tested insert.

The cutting insert durability values T_{n1} and T_{n2} were calculated from the measured values for processing of the machined pieces. The cutting conditions were n_1 = 355 rpm and n_2 = 450 rpm, depth of cut a_p = 1,2 mm and feed rate f = 0,2 mm. As the criterion for the cutting ability comparison we selected the insert durability.

These tests showed that the best cutting ability was performed by Manufacturer 1 and 2 inserts, made of the Quality type 1 and 2, and marked as CCMT 120408E-48 and CNMG 120408E-M. Another advantage of Manufacturers 1 ÷ 6 inserts was also their low purchase price.

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