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CUTTING TOOL LIFE TESTS OF CERAMIC INSERTS FOR CAR ENGINE SLEEVES

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Original scientific paper

This article is focused on the experimental determination of tool life tests for indexable ceramic cutting inserts. The set criterion of tool wear was VB_{Bmax} = 0,6 mm (in accordance with ISO 3685) or 30 pieces of machined sleeves. After at least one of the mentioned parameters was achieved, the tests were stopped and evaluated. Two types of cutting material by Saint Gobain Advanced Ceramics s.r.o. Company – ZTA 7 NI and D 250 were tested. We monitored their tool life at the same cutting parameters. The experiments were performed on machine tool – CHEMNITZ NILES N22. The machined material was the cast iron 25P mainly used for car engines. Tool wear was monitored on every fifth machined sleeve. Microgeometry was measured after tool wear test on each fifth sleeve. The aim was to determine the arithmetic tolerance of *Ra* profile, the greatest height of *Rz* profile and the external diameter *D*. The measurement was carried out four times; arithmetic average was performed subsequently as it is shown in the tables.

Keywords: *cutting tool tests, machining, surface roughness, tool wear*

Ispitivanje trajnosti reznog alata keramičkih uložaka za tuljke automobilskih motora

Izvorni znanstveni članak

Ovaj članak je usredotočen na eksperimentalno određivanje trajnosti alata za indeksiranje keramičkih reznih uložaka. Postavljen je kriterij trošenja alata VB_{Bmax} = 0,6 mm (sukladno ISO 3685) ili 30 komada obrađenih tuljaka. Kada je postignut barem jedan od ovih parametara, ispitivanje je zaustavljeno i procijenjeno. Ispitivane su dvije vrste reznog materijala uz pomoć tvrtke Saint Gobain Advanced Ceramics s.r.o. – ZTA 7 NI i D 250. Pratili smo njihovu trajnost kod istih parametara obrade. Eksperimenti su izvedeni na alatnom stroju – CHEMNITZ NILES N22. Obrađivani materijal bio je lijevano željeza 25P koje se koristi za motore automobila. Trošenje alata praćeno je za svaki peti obrađeni tuljak. Mjerena je mikrogeometrija nakon ispitivanja trošenja alata na svakom petom tuljku. Cilj je bio odrediti aritmetičku toleranciju *Ra* profila, najveću visinu *Rz* profila i vanjski promjer *D*. Mjerenje je provedeno četiri puta, aritmetička sredina je izvedena naknadno i prikazana je u tablicama.

Ključne riječi: *ispitivanje reznog alata, hrapavost površine, obrada rezanjem, trošenje alata*

1 Introduction
Uvod

Tool wear tests belong to one of the basic parameters of machining technology. The results of successful application, which were obtained in practice, remarkable increase of the quality of production and indirect affect on the position of the enterprise in the sharp competition [3, 4]. That experimental determination of tool life can provide additional information about cutting process in next tests [5].

Roughness is a sum of surface imperfections with a small distance. These phenomena arise from the production or effect of production effect [6]. Surface defects not assumed as the roughness are: random irregular geometry (lines, crevices, etc.) and defects which arise by material production [2].

2 Experimental part
Eksperimentalni dio

2.1 Machine tool
Alatni stroj

The machine tool CHEMNITZ NILLES N22 (Fig. 1) was used for test sample machining. The machine tool has rigid structure and it provides a sufficient clamping condition. Jaws have recessed cone with the same apical angle as the cast iron sleeves.

Figure 1 *Machine tool CHEMNITZ NILES N22*
Slika 1. *Alatni stroj CHEMNITZ NILES N22*

2.2 Measuring machines
Mjerni strojevi

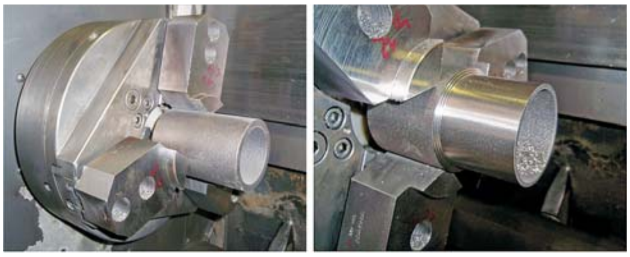
Ra and *Rz* values were evaluated on portable surface roughness tester - Mitutoyo Surftest SJ-400. A wide range, high-resolution detector and an ultra-straight drive unit provide a class-leading accuracy. Cylinder surface roughness is possible to be evaluated by the skid less measurement and R-surface compensation functions.

An external diameter was determined by SOMET micrometer (ČSN 25 1420; 50÷75 mm).

2.3 Machined material
Obrađeni materijal

As the machining material were used sleeves for car engines (Fig. 3), which were supplied by the contracting authority. The class of material was 25P. Due to conical shape of sleeves it was necessary to machine a cylindrical surface and the same diameter. Supposing we had not done it, a constant depth of cut a_p would not have been maintained during tests.

Figure 2 *Portable Surface Roughness Tester Mitutoyo Surftest SJ-400* [1]
Slika 2. *Prijenosni mjerač hrapavosti površine Mitutoyo Surftest SJ-400* [1]



a) b)

Figure 3 *Clamped sleeves: before machining (a) and after machining (b)*
Slika 3. *Stegnuti tuljci: prije obrade (a) i nakon obrade (b)*

Table 1 *Chemical composition of the material*
Tablica 1. *Kemijski sastav materijala*

C / %	Si / %	Mn / %	P / %	S / %	Ti / %	Cu / %
2,8÷3,3	1,8÷2,5	0,6÷0,8	0,5÷0,8	< 0,1	0,03÷0,1	≤ 0,8

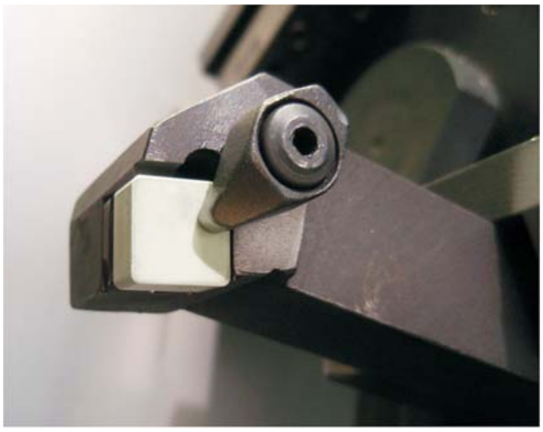


Figure 4 *The tool-holder with clamped ceramic cutting insert*
Slika 4. *Držač alata s pričvršćenim keramičkim uloškom*

2.4 Used tools
Korišteni alati

A tool-holder CSSNR 2525 M12-K (Fig. 4) was used in accordance with ISO 3685, with defined by an angle κ_r = 45°. Machining system is shown in (Fig. 5).

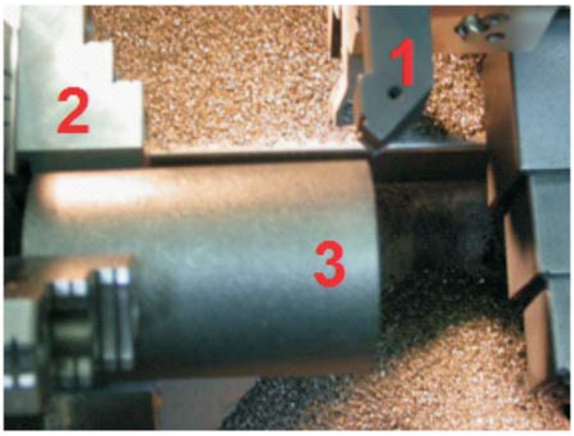


Figure 5 *Machining system: 1 - tool-holder, 2 - chuck, 3 - workpiece*
Slika 5. *Obradni sustav: 1 - držač alata, 2 - glava, 3 - izradak*

2.5 Indexable cutting inserts
Rezne pločice

Two types of ceramic cutting inserts were tested in total (the first type – 2 pieces and the second type – 4 pieces). Only one cutting edge was tested on the plate of each type. The cutting plates had the following marks:

- D 250_1
- ZTA_7_NI_2
- ZTA_7_NI_1
- D 250_2
- D 250_3
- D 250_4

2.6 Cutting parameters
Parametri rezanja

Cutting parameters were selected on the basis of experience and consultations of the research team with a contracting authority. The aim was to get as near as possible to real operation conditions.

- cutting speed v_c = 500 m/min
- feed f = 0,4 mm
- cutting depth a_p = 2 mm
- number of chips per one sleeve: 4
- machining length: 1st chip 61 mm, 2nd chip 60 mm, 3rd chip 59 mm, 4th chip 58 mm
- total machining length: 238 mm
- dry machining.

3 Experiments' evaluation
Procjena eksperimenata

The contracting authority supplied a semi-product of machined materials and two kinds of ceramic cutting inserts. The criterion of tool wear was chosen VB_{Bmax} = 0,6 mm. If the 30th sleeve was machined and the critical value of tool wear was not reached, the tests were stopped. The tool life was determined as follows:

$$T = t \cdot p \tag{1}$$

$$t = \frac{4 \cdot l}{n \cdot f}, \tag{2}$$

where:
T – tool life, min
t – machining time, min
p – number of machined pieces, –
l – machining length, mm
n – spindle speed, 1/min
f – feed, mm.

Microgeometry was measured after the tool wear test - on each 5th, 10th, 15th, 20th, 25th and 30th machined sleeve. The aim of this experiment was to determine the arithmetic tolerance of *Ra* profile, the greatest height of *Rz* profile and the external diameter *D*.

Arithmetic tolerance of *Ra* profile, the greatest height of *Rz* profile and the external diameter *D* are shown in the following tables. Measurements were evaluated four times – as shown in (Fig. 6). The arithmetic average was calculated from these measurements.

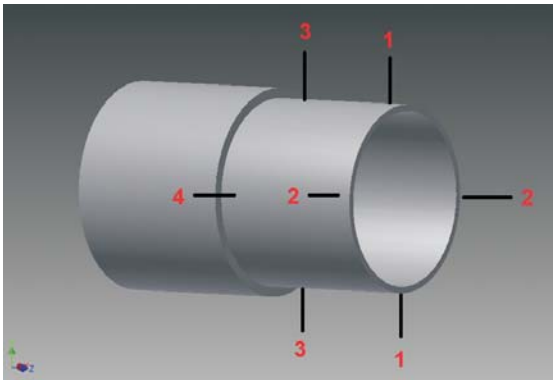


Figure 6 *Measured surface – machined insert*
Slika 6. *Mjerena površina – obrađen uložak*

3.1 Tool life and tool wear – individual cutting inserts
Vijek i trošenje alata – pojedinačni rezni ulošci

The number of machined pieces by individual ceramic cutting inserts is shown in the following graph (Fig. 7). D 250 series of cutting inserts machined the maximum number of 30 pieces except for D 250_1 insert. The D 250_1 insert probably reached this maximum as well. There was a crack of sleeve (at machining the 27th sleeve) and it resulted in cutting edge destruction. ZTA_7_NI inserts reached the criteria of tool wear at 26th, respectively at 15th machined sleeves. Fig. 8 shows the tool life of plates calculated according to formula (1) and (2) in minutes.

Table 2 *The number of machined pieces for individual cutting inserts*
Tablica 2. *Broj obrađenih komada za pojedinačne rezne uloške*

	D 250_1	ZTA_ 7_NI_2	ZTA_ 7_NI_1	D 250_2	D 250_3	D 250_4
Machined pieces	27	26	15	30	30	30

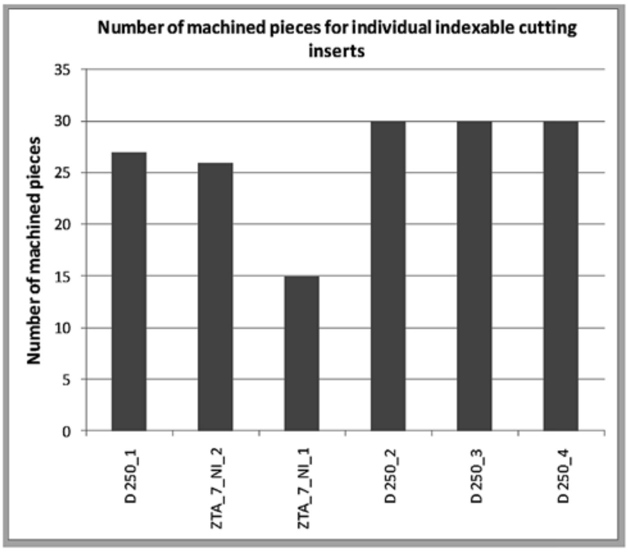


Figure 7 *The number of machined pieces for individual indexable cutting inserts*
Slika 7. *Broj obrađenih komada za indeksirane rezne uloške*

Table 3 *Tool life for individual indexable cutting inserts*
Tablica 3. *Postojanost alata za pojedine rezne pločice*

	D 250_1	ZTA_ 7_NI_2	ZTA_ 7_NI_1	D 250_2	D 250_3	D 250_4
Tool life, min	8,03	7,74	4,46	8,93	8,93	8,93

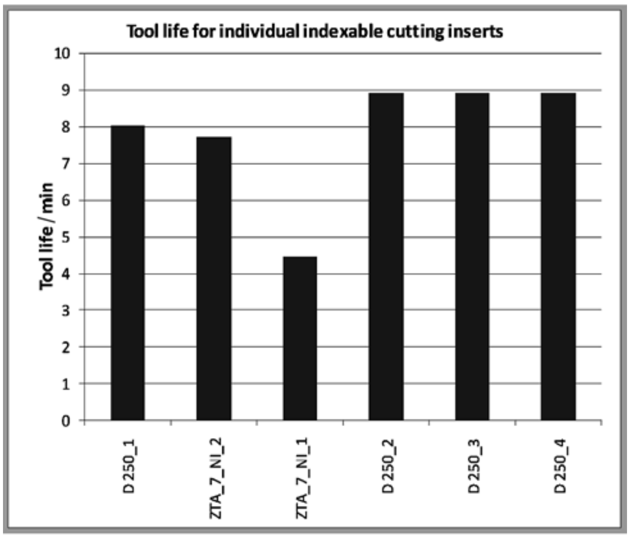
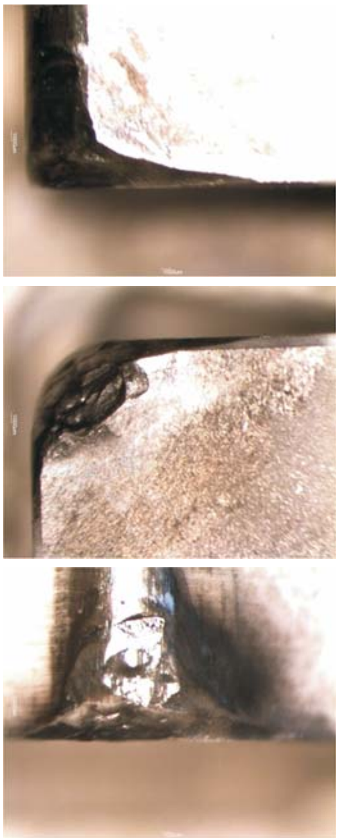


Figure 8 *Tool life for individual indexable cutting inserts*
Slika 8. *Vijek alata za indeksirane rezne uloške*



a) tool flank

b) tool face

c) tip

Figure 9 *Tool wear – indexable cutting insert type D 250_1*
Slika 9. *Trošenje alata – rezna pločica tipa D 250_1*

a) tool flank

b) tool face

c) tip

Figure 10 *Tool wear – indexable cutting insert type ZTA_7_NI_2*
Slika 10. *Trošenje alata – rezna pločica tipa ZTA_7_NI_2*

a) tool flank

b) tool face

c) tip

Figure 11 *Tool wear – indexable cutting insert type ZTA_7_NI_1*
Slika 11. *Trošenje alata – rezna pločica tipa ZTA_7_NI_1*

a) tool flank

b) tool face

c) tip

Figure 12 *Tool wear – indexable cutting insert type D 250_2*
Slika 12. *Trošenje alata – rezna pločica tipa D 250_2*

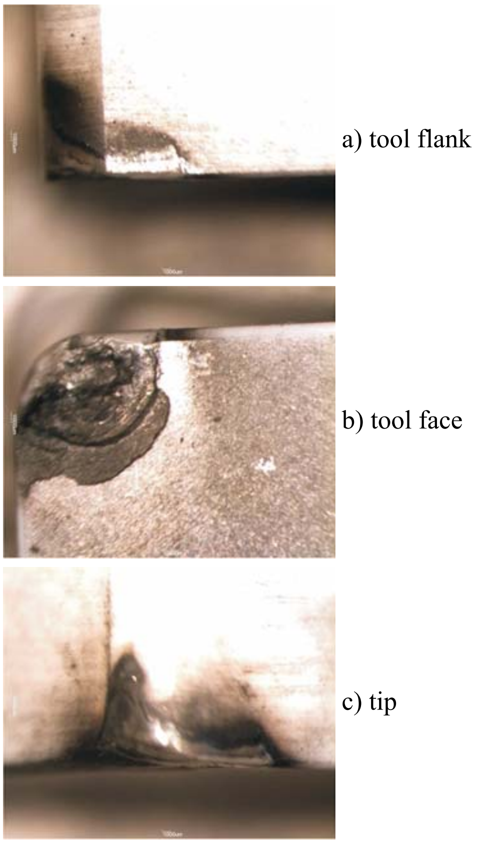


Figure 13 *Tool wear – indexable cutting insert type D 250_3*
Slika 13. *Trošenje alata – rezna pločica tipa D 250_3*

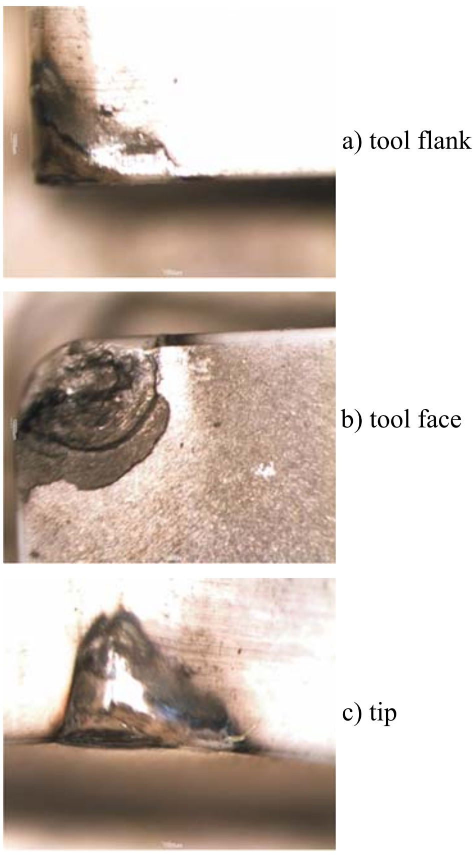


Figure 14 *Tool wear – indexable cutting insert type D 250_4*
Slika 14. *Trošenje alata – rezna pločica tipa D 250_4*

Comment (Fig. 9):
- Tool face chipped from 17th piece;
- 28th piece – workpiece snapped and destroyed insert.

Comment (Fig. 10):
- 25th piece – tool wear on lateral tool flank;
- Tool wear increases very slowly.

Comment (Fig. 11):
- Insert sparks almost from the beginning;
- 14th piece - significant deterioration of the surface and significant sparks;
- 15th piece - unsatisfactory roughness - terminated.

Comment (Fig. 12):
- Calm cut without sparking;
- Tool wear is very small and almost not growing;
- Chipped tool face – at the end of tests.

Comment (Fig. 13):
- 16th piece - inserts begin to sparkle slightly;
- 28th piece - spark ceased;
- Small tool wear.

Comment (Fig. 14):
- 8th piece - inserts begin to sparkle;
- 24th piece - spark is of low intensity;
- Small tool wear.

3.2 Surface roughness
Hrapavost površine

Table 4 *Values of arithmetic tolerance of Ra profile*
Tablica 4. *Vrijednosti aritemetičke tolerancije Rz profila*

Number workpiece	*Ra* / µm					
	D 250_1	ZTA_ 7_NI_2	ZTA_ 7_NI_1	D 250_2	D 250_3	D 250_4
5	3,17	6,09	4,22	5,68	6,58	5,94
10	4,07	5,7	2,76	4,72	2,33	5,77
15	2,39	5,23	10,61	5,06	1,69	4,70
20	1,82	4,26	not measured	4,15	1,78	4,03
25	1,61	3,03	not measured	3,54	2,28	3,70
27	1,98	-	-	-	-	-
30	-	not measured	not measured	4,37	1,97	2,02

The value of surface roughness (*Ra*) decreases with the number of machined pieces of almost all sleeves. It is a characteristic for the ceramic cutting tools. If we want to achieve maximum performance, we have to "wear down" lightly these inserts. If the plate achieved the maximum tool life, roughness would begin to rise slightly. This could be caused by increasing tool wear.

ZTA 7 NI_1 inserts caused sparking that increased with the number of machined sleeves. This test was finished for unsatisfactory roughness at the 15th piece as shown in the graph.

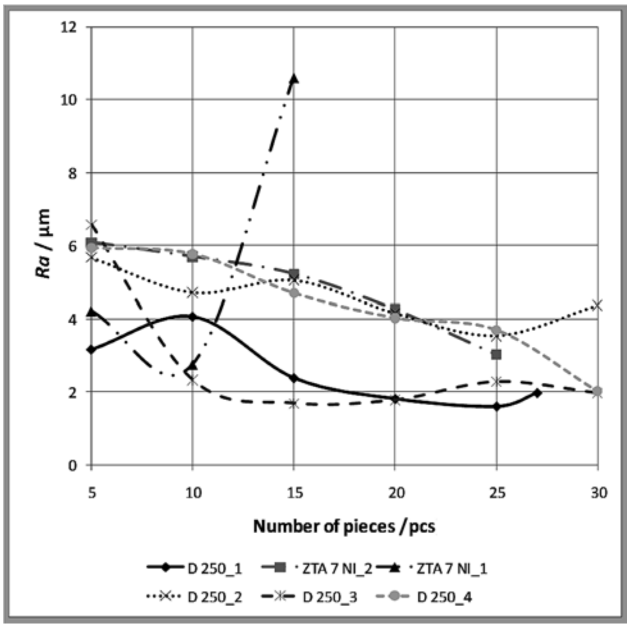


Figure 15 *Arithmetic tolerance of Ra profile*
Slika 15. *Aritemetička tolerancija Ra profila*

Table 5 *Values of the greatest height of Rz profile*
Tablica 5. *Vrijednosti najveće visine Rz profila*

	Rz / µm					
Number workpiece	D 250_1	ZTA_ 7_NI_2	ZTA_ 7_NI_1	D 250_2	D 250_3	D 250_4
5	20,33	28,50	19,80	29,33	36,90	28,23
10	20,20	26,50	19,80	22,45	15,35	26,50
15	17,60	25,10	53,95	26,58	11,25	23,83
20	12,80	19,85	not measured	22,70	11,48	20,15
25	10,20	16,75	not measured	21,68	15,73	18,63
27	14,50	-	-	-	-	-
30	-	not measured	not measured	27,53	14,20	14,43

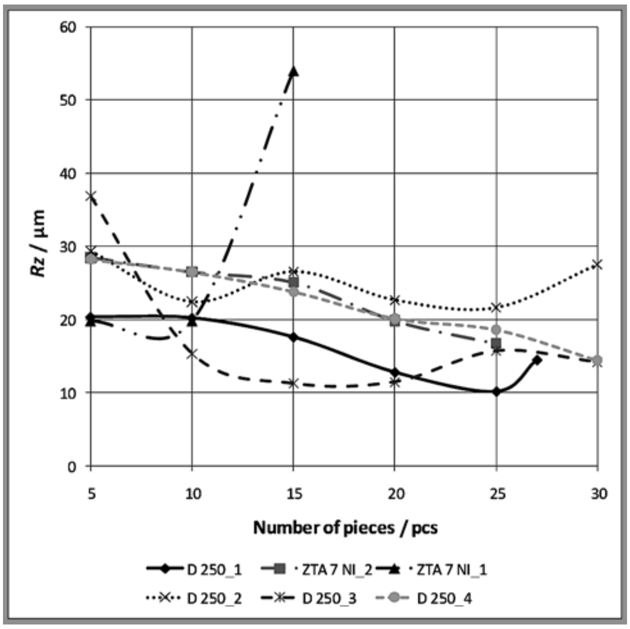


Figure 16 *The greatest height of Rz profile*
Slika 16. *Najveća visina Rz profila*

Roughness is the most correlated with the *Ra* value. This parameter is the most common in engineering practice in the Czech Republic. Unfortunately, it is influenced by unique extreme surface roughness.

Parameter of roughness of *Rz* profile decreases with the number of machined pieces of almost all inserts with slight deviations, as shown in the previous measurement. *Rz* parameter nearly replicates *Ra* parameter.

3.3 External diameter
Vanjski promjer

Table 6 *Values of the external diameter D*
Tablica 6. *Vrijednosti vanjskog promjera D*

	Ø *D* / mm					
Number workpiece	D 250_1	ZTA_ 7_NI_2	ZTA_ 7_NI_1	D 250_2	D 250_3	D 250_4
5	73,56	73,51	73,49	73,50	73,58	73,47
10	73,56	73,55	73,64	73,60	73,64	73,51
15	73,72	73,59	74,03	73,70	73,69	73,63
20	73,75	73,62	not measured	73,83	73,72	73,64
25	73,81	73,71	not measured	73,86	73,79	73,90
27	73,81	-	-	-	-	-
30	-	not measured	not measured	73,88	73,89	73,96
Δ	0,25	0,20	0,534	0,38	0,31	0,49

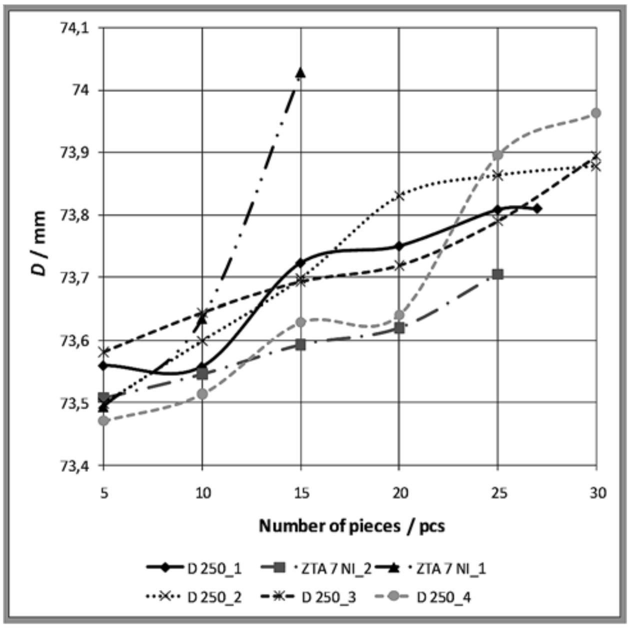


Figure 17 *External diameter D*
Slika 17. *Vanjski promjer D*

The value of external diameter *D* growths with increasing number of machined sleeves. This process is caused by the tool wear. The tool wear was created especially on lateral tool flank (edge) and on the tip which was "burned". It changed a decrease in dimensional accuracy (first and last piece did not have the same diameter). The difference was in several tenths of

millimetres (see in Tab. 6). Abrasion and peeling off were created at the tool face of inserts. This phenomenon should not have any significant effect on dimensional accuracy.
Tool wear is caused by high thermal and mechanical load. The tool is not able to perform its function (after a period) as a result of this process. Tool wear arises from abrasive wear, plastic deformation and brittle fracture.

4 Conclusion
Zaključak

The requirements are very high on the parameters of surface integrity in engineering practice. Cutting speed is being constantly increased. This leads to the CNC machining; these machines can secure the optimal working conditions so it is possible to produce products with the finest precision.

ZTA 7 NI inserts did not reach the maximum number of 30 machined inserts. The reason was impaired surface roughness in both cases. Tests were finished for unsatisfactory surface. The cutting inserts reached the prescribed criterion of tool wear (VB_{Bmax}).

D 250 inserts had significantly better results. Almost all plates machined the maximum number of inserts at tool wear (VB_{Bmax}) about 0,2 mm, except the first. The D 250_1 insert could reach this maximum as well. The sleeve cracked (hollow in the casting) – the result was the destruction of the cutting edge. We will need to focus more on these parameters in other experiments – secondary edge, tool tip and tool face. The tool wear arises on the secondary edge and the tip. There is reduction of dimensional accuracy as a consequence (first and last piece have not the same diameter). The difference is in several tenths of millimetres.

Figures 15 and 16 show that the value of both roughness parameters is lower after 30 pieces machined. Roughness (*Ra*) is below 6,3. Roughness (*Ra*) gets even under 3,2 with an increasing number of machined inserts – D 250 series. This can be attributed to the properties of ceramics material which must be "abrade" first and then its potential can be fully realized.

D 250 inserts are suitable for cutting inserts made from 25P material at given cutting parameters and cutting geometry. The whole machining was carried out in dry (without using the liquid process) and it is environmentally friendly.

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