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EXPERIMENTAL TOOL LIFE TESTS OF INDEXABLE INSERTS FOR STAINLESS STEEL MACHINING

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Original scientific paper

The paper is focused on the issue of cutting tools for group of materials M, according to ISO 513, more exactly the area of stainless steel machining. The aim is to analyse and compare the current range of milling tools, namely Pramet Tools and competition (Mitsubishi, Sandvik and Seco). The main objective is to make a practical comparison of selected milling cutters and their inserts. In terms of experimental machining tests an aimed experiment on tool life comparison will be conducted under real cutting conditions in Pramet Tools testing laboratory. Tests are performed on the milling centre - Kovosvit MAS MCV 1270 Power and stainless steel X2CrNiMo17-12-2 was selected as machined material. In conclusion photographs are shown of tool wear on tool faces and flanks, tool wear progress for both groups and final results.

Keywords: *experimental testing, indexable cutting inserts, machining, stainless steel, tool life*

Experimentalna ispitivanja trajanja radnog vijeka izmjenjivih umetaka za obradu nehrđajućeg čelika

Izvorni znanstveni članak

Rad je usmjeren na rezne alate za grupu materijala M, u skladu s ISO 513, točnije obradu nehrđajućeg čelika. Cilj je analizirati i usporediti postojeći niz alata za glodanje, odnosno Pramet Alate i konkurenciju (Mitsubishi, Sandvik and Seco). Osnovna je svrha napraviti praktičnu usporedbu izabranih glodala i njihovih umetaka. U okviru eksperimentalnih obradnih ispitivanja izvršit će se usporedba trajanja alata u stvarnim uvjetima u ispitnom laboratoriju Pramet Alata. Ispitivanja su obavljena u centru za glodanje - Kovosvit MAS MCV 1270 Power, a kao obradni materijal izabran je nehrđajući čelik X2CrNiMo17-12-2. U zaključku su prikazane fotografije trošenja vrha i bočne strane alata, porast trošenja za obadvije grupe i konačni rezultati.

Ključne riječi: *eksperimentalno ispitivanje, izmjenjivi umetci za rezanje, nehrđajući čelik, strojna obrada, trajanje alata*

1 Introduction

Indexable cutting inserts, square and round positive inserts, are the best two kinds of shapes for stainless steel machining.

Square inserts are characteristic for their tool flank (usually 20°) and other geometrical parameters which are size of facet, cutting edge radius, positive tool face angle and related geometrical surfaces. Circular inserts are not significantly different from squared ones.

Milling tools for machining stainless steels are characterized by their geometry which is prima facie. Mill sharpness is the basic visible parameter. The proof is a positive axial angle and negative radial angle of bed cutter. The main goal is to minimize negative impacts during the machining process using the sharp geometry of the insert with an appropriate chip breaker. Stainless steels are prone to sticking to the cutting edge. The aim of insert geometry is to be the sharpest and minimize surface contact with cutting chips and cutting edge. It should be noted that these types of mills have tool minor cutting edge angle $\kappa_r = 45°$.

2 Experimental part

2.1 Description and tools characterization

The three main representatives were chosen from the list of competing manufacturers of milling tools for machining stainless steels. These manufacturers have been subjected to experimental machining tests. These manufacturers have a significant position in the home market. Mill concepts are among the most successful in planar milling. Tab. 1 shows the basic technical parameters of competitive milling cutters for planar milling of stainless steels.

Table 1 Milling cutters - Basic technical data [2, 3, 4, 5]

Manufacturer's logo	Marking milling cutter	Tool minor cutting edge angle κ_r / °	Geometry (γ_p / γ_f) / °	Axial depth of cut $a_{p\,max}$ / mm	Marking indexable cutting insert (ISO 513)
MITSUBISHI	ASX445	45	+20 / -13	6,0	SEET 13T3AGEN-JL SEMT 13T3AGSN-JM SEMT 13T3AGSN-JH
SECO	220.53-12	45	+20 / -5	6,0	SEEX 1204AFTN-M14 SEEX 1204AFN-M10 SEMX 1204AFTN-ME12 SEMX 1204AFTN-M15
SANDVIK	345	45	not stated	6,0	345R-1305E-PL 345R-1305M-PL
PRAMET	S45SE12F-A	45	+18 / -6	6,5	SEET 1204AFSN SEEW 1204AFSN

2.2 Machining centre

Machining tests are performed in Pramet laboratory. The laboratory is equipped with a CNC Milling Centre MCV 1270 Power, manufacturer Kovosvit MAS, Sezimovo Ústí (Fig. 1).

High-speed machining centres are identified for precision and quick machining of disparate components. There are both power spindles with the gearbox for power machining (as many as 620 N·m) and high-speed spindles with 24 000 rpm, which are great at form machining. Company KOVOSVIT MAS is the traditional and the largest Czech producer of modern metal-working centres and CNC lathes with a very strong development and technical background. Production range: Milling centres (vertical, horizontal, five axes), CNC lathes and high speed turning centres, Multioperational turning-milling centres, production cooperation and casts of grey iron [1].

Figure 1 Milling Center – MCV 1270 Power

2.3 Tested material

Function tests were performed on stainless steel, grade 17 349.4 (EN ISO: X2CrNiMo17-12-2, DIN: X2 CrNiMo 18 14 3), hardness 165 HB. The mechanical properties and chemical composition are shown in Tabs. 2 and 3. One of the most widely used precipitation hardening grades in the business. While soft and ductile in the solution annealed condition, it is capable of high properties with a single precipitation or aging treatment. It is characterized by good corrosion resistance, high hardness, toughness and strength [6].

Table 2 Mechanical properties - Stainless steel - 17 349 grade (X2CrNiMo17-12-2) [7]

Name	Size
Ultimate tensile strength R_m / MPa	440 ÷ 690
Minimal yield strength R_e / MPa	176
Minimal elongation A_5 / %	35
Impact energy KV / J	68

Table 3 Chemical composition - Stainless steel - 17 349 grade (X2CrNiMo17-12-2) [7]

Chemical composition (%)								
C_{max}	Mn_{max}	Si_{max}	P_{max}	S_{max}	Cr	Ni	Mo	others
0,03	2,00	1,00	0,045	0,03	16,5 up to 18,5	11,0 up to 14,0	2,00 up to 2,50	

Milling cutters are always fully equipped with the appropriate type of indexable cutting inserts before starting their own tests. Semi-product has the dimensions (height: 300 mm, width: 300 mm, depth: 100 mm).

2.4 Selection of cutting conditions

Manufacturers recommend starting cutting conditions according to ISO 513 for each machining area. The conditions are related to each insert geometries and materials. For our selected range of milling cutters and inserts (Mitsubishi, Seco, Sandvik and Pramet) cutting conditions are shown in Tab. 4.

Table 4 Comparison of recommended cutting conditions [1, 2, 3, 4]

Manufacturer	Marking - indexable cutting insert (ISO 513)	Cutting speed v_c (m/min)	Feed range f_z (mm/tooth)
MITSUBISHI	SEET 13T3AGEN-JL	150 - 270	0,10 - 0,20
	SEMT 13T3AGSN-JM		0,10 - 0,30
	SEMT 13T3AGSN-JH		0,20 - 0,40
SECO	SEEX 1204AFTN-M14	130 - 220	0,15 - 0,30
	SEEX 1204AFN-M10		0,10 - 0,20
	SEMX 1204AFTN-ME12		0,10 - 0,20
	SEMX 1204AFTN-M15		0,10 - 0,20
SANDVIK	345R-1305E-PL	150 - 250	0,08 - 0,18
	345R-1305M-PL		0,08 - 0,18
PRAMET	SEET 1204AFSN	110 - 160	0,20 - 0,40
	SEEW 1204AFSN		0,15 - 0,40

3 Description of tool life testing

The aim of tool life tests is to obtain the actual value of the cutting edge in a real machining process. Cutting tests on tool life are conducted at the same cutting parameters and the meshing conditions [13]. Testing inserts have a wide range of geometries and of use, defined by the manufacturer, so the main guideline to classify the geometry is the information about the recommended application range feed per tooth f_z.

The inserts divided into two groups were based on the recommended range of feeds (Tab. 4). The first group marked with the capital letter A represents the geometry of inserts which are recommended for the middle of feed per tooth $f_z = 0,15$ mm/tooth. The second group marked with the capital letter B represents the geometry of inserts, recommended for the middle of the feed per tooth $f_z = 0,25$ mm/tooth. Cutting conditions for comparison of tool life tests were determined separately for these groups (Tab. 5 and Tab. 6).

Table 5 Cutting conditions for A group ($f_z = 0,15$ mm/tooth)

Term	Value
Cutting speed	$v_c = 150$ m/min
Feed	$f_{min} = 114$ mm/min
Axial depth of cut	$a_p = 2,0$ mm
Radial depth of cut	$a_e = 50$ mm
Manufacturer	**Marking - indexable cutting insert**
PRAMET	SEEW 1204AFSN; 8230
SECO	SEEX 1204AFN-M10; F40M
SECO	SEMX 1204AFTN-ME12; F40M
MITSUBISHI	SEET 13T3AGEN-JL; VP30RT
SANDVIK	345R-1305E-PL; 2030

Table 6 Cutting conditions for B group ($f_z = 0,25$ mm/tooth)

Term	Value
Cutting speed	$v_c = 140$ m/min
Feed	$f_{min} = 177$ mm/min
Axial depth of cut	$a_p = 2,0$ mm
Radial depth of cut	$a_e = 50$ mm
Manufacturer	**Marking – indexable cutting insert**
PRAMET	SEET 1204AFSN; 8230
SECO	SEEX 1204AFTN-M14; F40M
SECO	SEMX 1204AFTN-M15; F40M
MITSUBISHI	SEMT 13T3AGSN-JM; VP30RT
MITSUBISHI	SEMT 13T3AGSN-JH; VP30RT

Comparison tool life tests are always performed by milling cutter that is equipped with only one indexable cutting insert. All insert geometries are tested on at least two samples of inserts. If there is a high variance value of tool wear, the other insert is tested subsequently.

Tool life tests are performed according to ČSN-ISO 8688-1 [8]. The inserts are measured periodically for tool wear on tool flank and tool tip after a certain time interval. The interval depends on the length of machined surfaces. Images (photos) of tool wear are also continuously collected. The criterion for tool life is to achieve a value of tool wear on tool flank $VB_B = 0,3$ mm, according to ISO 8688-1. We can assume that the criterion VB_B will not be achieved at stainless steels machining. Tool life will be terminated as a result of cutting edge breaking.

3.1 Evaluation of measurement

The cutting tests results on tool life tests can be summarized as follows:

a) tool life results (Tab. 7) were obtained according to cutting conditions shown in Tab. 5, A group inserts,
b) Seco (SEEX 1204AFN-M10) Mitsubishi (SEET 13T3AGEN-JL) inserts achieved the best results in tool life at given cutting conditions,
c) Sandvik inserts achieved the worst result of tool life, so we can say, that its geometry is not optimal for stainless steel machining although this area is recommended for machining,
d) values of cutting power K were within results of tool life test related to current design and geometry of the Pramet insert (SEEW 1204AFSN),
e) cutting power values are calculated to the average value of tool life average values of T and show dispersion Δ ,
f) tool life results (Tab. 8) were obtained according to cutting conditions shown in Tab. 6, B group inserts,
g) Mitsubishi (SEMT 13T3AGSN-JM) inserts achieved the best tool life results with predominance at given cutting conditions,
h) Pramet (SEET 1204AFSN) inserts achieved the worst results of tool life, so we can say, that their geometry is not optimal for stainless steel machining although this area is recommended for machining,
i) the values of cutting power K were within the results of tool life test related to current design and geometry of the Pramet insert (SEET 1204AFSN),
j) cutting power values are calculated to the average value of tool life average value of T and show dispersion Δ,
k) the pictures of increasing tool wear on tool face and tool flank were taken continuously during the cutting tests with A group inserts,
l) the pictures of front surfaces (tool faces) with increasing growth of tool wear in relevant minute after beginning of the cutting tests are shown in Tab. 9,

Table 7 Tool life results for inserts in A group ($f_z = 0,15$ mm/tooth)

Cutting conditions	**Milling cutter - diameter**	**63 mm**	**Number of inserts in milling cutter**			**1 pcs**	
Cutting speed	$v_c = 150$ m/min		Machining length			300 mm	
Spindle revolutions	$n = 758$ 1/min		Surface crust			No	
Feed	$f_{min} = 114$ mm/min		Interrupted cutting			No	
Axial depth of cut	$a_p = 2$ mm		Coolant			No	
Radial depth of cut	$a_e = 50$ mm		Engagement time			2,6 min	
Manufacturer	**Marking**		**Sample**	**T / min**	**Avg T / min**	**K / %**	**Δ / %**
PRAMET	SEEW 1204AFSN; 8230		A3	18,2	19,5	100	6,7
			A5	20,8			
SECO	SEEX 1204AFN-M10; F40M		B3	44,2	45,5	233	2,9
			B5	46,8			
SECO	SEMX 1204AFTN-ME12; F40M		J3	26,0	26,0	133	-
			J5	26,0			
MITSUBISHI	SEET 13T3AGEN-JL; VP30RT		C2	46,8	44,2	227	5,9
			C4	41,6			
SANDVIK	345R-1305E-PL; 2030		D1	5,2	9,1	47	42,9

Table 8 Tool life results for inserts in B group (f_z = 0,25 mm/tooth)

Cutting conditions	**Milling cutter - diameter**	**63 mm**	**Number of inserts in milling cutter**		**1 pcs**	
Cutting speed	v_c = 140 m/min		Machining length		600 mm	
Spindle revolutions	n = 707 1/min		Surface crust		No	
Feed	f_{min} = 177 mm/min		Interrupted cutting		No	
Axial depth of cut	a_p = 2 mm		Coolant		No	
Radial depth of cut	a_e = 50 mm		Engagement time		3,4 min	
Manufacturer	**Marking**	**Sample**	***T* / min**	**Avg *T* / min**	***K* / %**	***Δ* / %**
PRAMET	SEET 1204AFSN; 8230	E1	13,6	11,9	100	14,3
		E3	10,2			
SECO	SEEX 1204AFTN-M14; F40M	F2	13,6	13,6	114	-
		F5	13,6			
SECO	SEMX 1204AFTN-M15; F40M	G2	23,8	22,1	186	7,7
		G4	20,4			
MITSUBISHI	SEMT 13T3AGSN-JM; VP30RT	H2	40,8	39,1	329	4,3
		H5	37,4			
MITSUBISHI	SEMT 13T3AGSN-JH; VP30RT	I1	20,4	20,4	171	-

m) the pictures of flank surfaces (tool flanks) with increasing growth of tool wear in relevant minute after beginning of the cutting tests are shown in Tab. 10,

n) pictures of increasing tool wear on tool face and tool flank were again taken continuously during the cutting tests with B group inserts,

o) pictures of front surfaces (tool faces) with increasing growth of tool wear in relevant minute after beginning of the cutting tests are shown in Tab. 11,

p) pictures of flank surfaces (tool flanks) with increasing growth of tool wear in relevant minute after beginning of the cutting tests are shown in Tab. 12,

q) within the machining tests on tool life for both groups of inserts (A, B), the tool wear size of the main cutting edge VB_B and tool wear size on the tip of the main cutting edge VB_{C1} were measured at regular intervals on the tested inserts.

Table 9 Tool wear progress on tool face - A group (f_z = 0,15 mm/tooth)

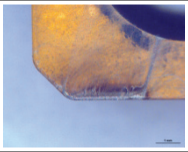
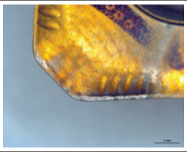
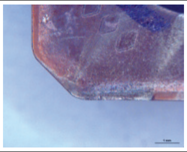
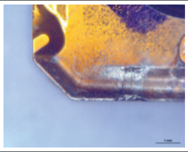
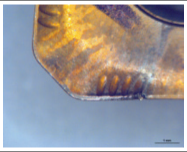
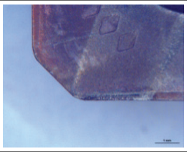
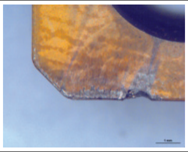
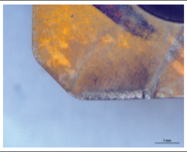
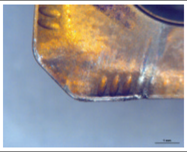
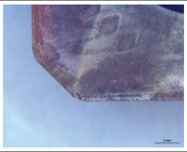
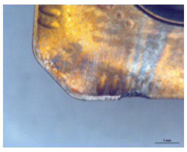
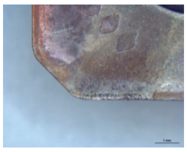
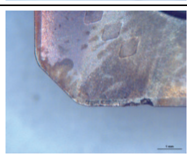
Manufacturer	**PRAMET**	**SECO**	**SECO**	**MITSUBISHI**	**SANDVIK**
Marking	SEEW 1204AFSN; 8230	SEEX 1204AFN-M10; F40M	SEMX 1204AFTN-ME12; F40M	SEET 13T3AGEN-JL; VP30RT	345R-1305E-PL; 2030
Sample	A3	B3	J3	C2	D1
5 minutes					
16 minutes					
21 minutes					
31 minutes					
42 minutes					
47 minutes					

Table 10 Tool wear progress on tool flank - A group (f_z = 0,15 mm/tooth)

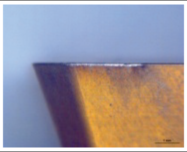
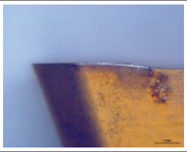
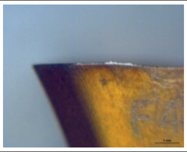
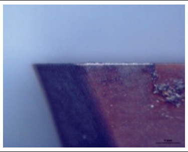
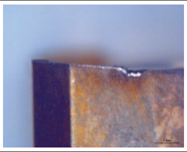
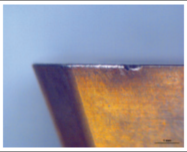
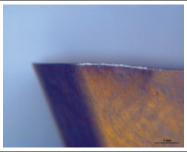
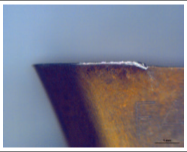
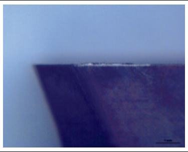
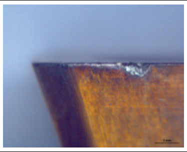
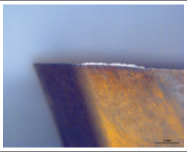
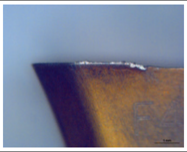
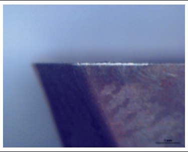
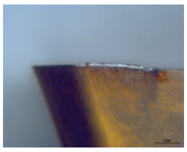
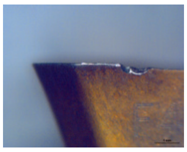
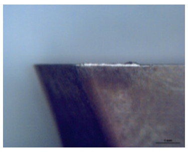
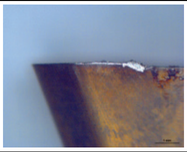
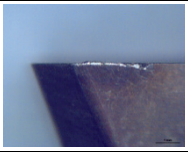
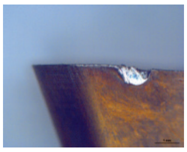
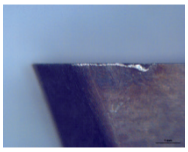
Manufacturer	**PRAMET**	**SECO**	**SECO**	**MITSUBISHI**	**SANDVIK**
Marking	SEEW 1204AFSN; 8230	SEEX 1204AFN-M10; F40M	SEMX 1204AFTN-ME12; F40M	SEET 13T3AGEN-JL; VP30RT	345R-1305E-PL; 2030
Sample	A3	B3	J3	C2	D1
5 minutes					
16 minutes					
21 minutes					
31 minutes					
42 minutes					
47 minutes					

Table 11 Tool wear progress on tool face - B group (f_z = 0,25 mm/tooth)

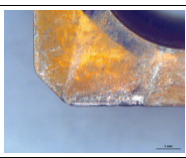
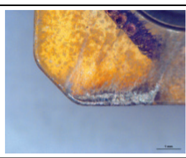
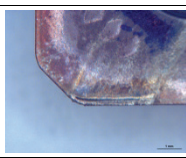
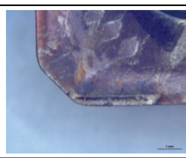
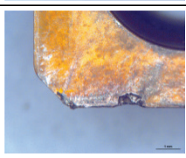
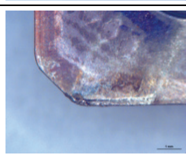
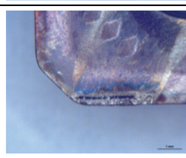
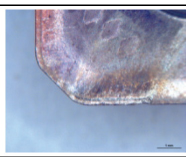
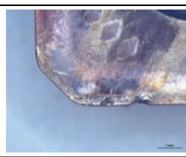
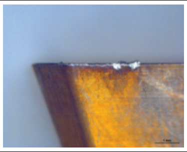
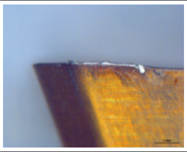
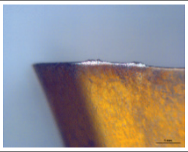
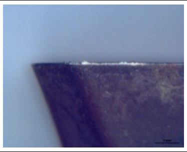
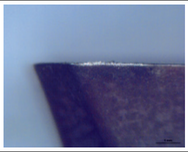
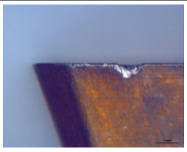
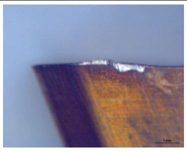
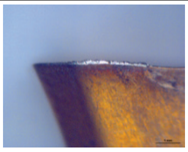
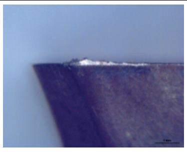
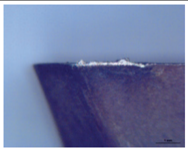
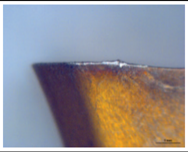
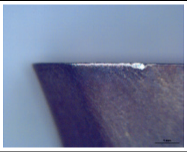
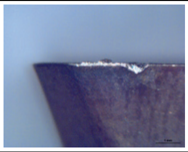
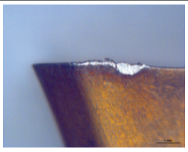
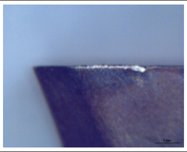
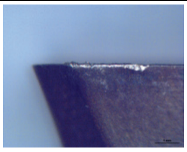
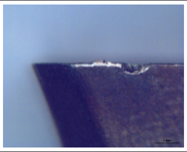
Manufacturer	**PRAMET**	**SECO**	**SECO**	**MITSUBISHI**	**MITSUBISHI**
Marking	SEET 1204AFSN; 8230	SEEX 1204AFTN-M14; F40M	SEMX 1204AFTN-M15; F40M	SEMT 13T3AGSN-JM; VP30RT	SEMT 13T3AGSN-JH; VP30RT
Sample	E1	F2	G2	H2	I1
7 minutes					
14 minutes					
20 minutes					
24 minutes					

Table 12 Tool wear progress on tool flank - B group (f_z = 0,25 mm/tooth)

Manufacturer	**PRAMET**	**SECO**	**SECO**	**MITSUBISHI**	**MITSUBISHI**
Marking	SEET 1204AFSN; 8230	SEEX 1204AFTN-M14; F40M	SEMX 1204AFTN-M15; F40M	SEMT 13T3AGSN-JM; VP30RT	SEMT 13T3AGSN-JH; VP30RT
Sample	E1	F2	G2	H2	I1
7 minutes					
14 minutes					
20 minutes					
24 minutes					
27 minutes					
34 minutes					
41 minutes					

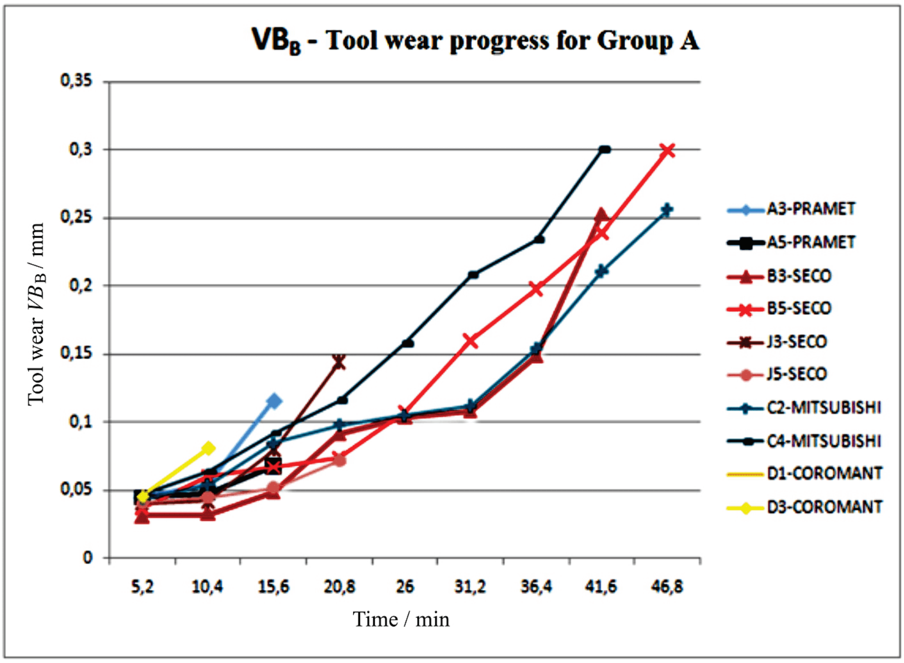


Figure 2 Tool wear progress for A group of inserts

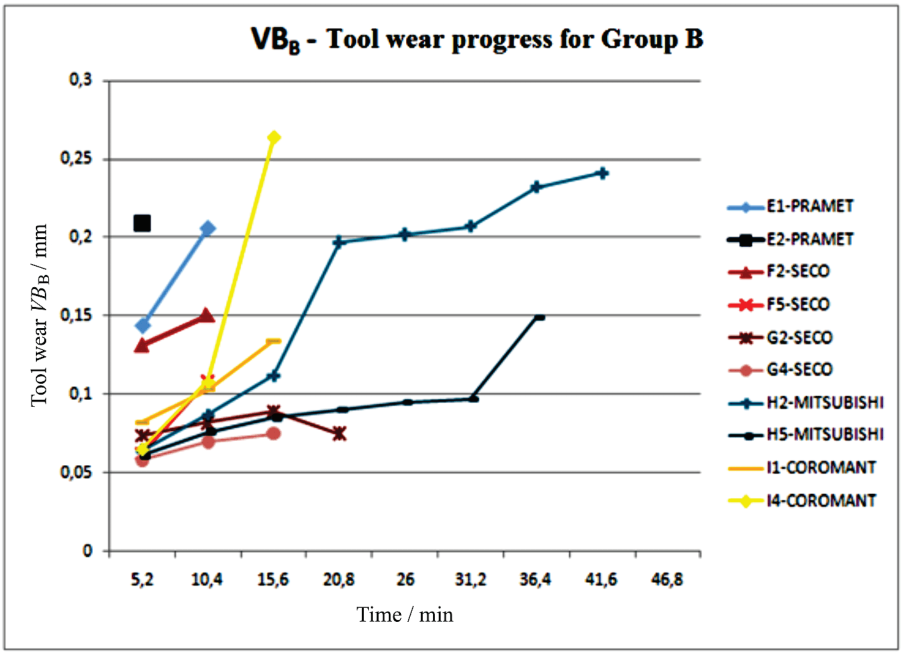


Figure 3 Tool wear progress for B group of inserts

4 Conclusions and discussion

The aim was to test face milling of stainless steels in terms of the current construction tools solutions in comparison with selected competitive tools in domestic market (manufacturer Pramet Tools s.r.o. Šumperk). The obtained results suggest the following conclusions:

a) current Pramet insert design, with S45SE12F-A type marking - namely milling cutter type 60A05R-S45SE12F-A, is already outdated and does not meet convenient current customer demands placed on utility properties, productivity and lifetime,

b) current Mitsubishi Materials insert design, with S45SE12F-A type marking - namely milling cutter type 60A05R-S45SE12F-A, is in conjunction with the supplied assortment of indexable cutting inserts highly progressive and innovative tool's solution for the stainless steel machining,

c) current Seco Tools insert design, with R220,53-12 type marking - namely milling cutter type R220-53-0063-12-5A, is also a high-tech solution for stainless steel machining and provide the largest range of the inserts on the market,

d) current Sandvik Coromant insert design, with 345 type marking - namely milling cutter type 345-063Q22-13M, is represented in conjunction with supplied assortment of indexable cutting inserts new solutions in the tool construction which uses two-sides inserts and increases the number of cutting edges on eight,

e) a high level of the tools' functional properties was confirmed by tool life machining tests. These milling cutters achieved outstanding machining results on tool life in combination with recommended inserts,

f) machining test with Sandvik Coromant (type 345) milling cutter and recommended type of inserts 345R-1305M-PL and 345R-1305E-PL did not confirm suitability of using this tool for stainless steel machining, although the manufacturer recommended this tool and set the recommended cutting conditions for them,

g) the machining test confirmed the low level of construction solutions for Pramet (type S45SE12F-A) milling cutter, Tested cutter 63A05R with recommended inserts SEET 1204AFSN and SEEW 1204AFSN showed good properties in terms of machining method of chip formation, its visual aspect, shape, size and trajectory of chip leaving. The machining test on tool life confirmed the low utility properties in conjunction with recommended inserts. Low utility properties are reflected in the tool life times and can be assessed as inadequate and very low at stainless steel machining,

h) experimental machining and results confirmed that the best solutions for stainless steel milling are companies such as Mitsubishi Materials (type ASX445) and Seco Tools (type R220.53-12), The same milling cutter geometry (positive - negative), the individual types of inserts in terms of construction, construction and geometry, are on a high level and can be recommended for new construction solutions, for machining in the area of group M material, for Pramet Tools s.r.o. Šumperk.

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