SQUARE SHAPED INSERT´S LIFETIME WHEN MILLING INCONEL 718

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This article is focused on the analysis of tool wear in milling of Inconel 718. Inconel 718 is tough and highly temperature resistive material, which is used due to its excellent properties especially in aggressive corrosive environment. Machining of this alloy is still complicated. The feasibility of three inserts tested for milling of Inconel 718 has been shown in this work. Different cutting speeds and feeds were used. Experimental tests were performed in order to analyze wear evolution. It was found that cutting conditions and type of insert strongly affects tool wear mode. Surface roughness was studied as well as cutting force as a function of tool wear.

KEYWORDS

milling, Inconel 718, cemented carbide, lifetime, cutting inserts

1 INTRODUCTION

Nickel-based super alloys are widely used in aerospace applications due their excellent mechanical properties maintained at high temperature and their corrosion resistance. These super alloys are frequently used in advanced for aero-engine components such as turbine blades, turbine vanes, turbine vane rings, turbine nozzles, engine, and turbine casings. Machining of these alloys is still a challenge, especially in aggressive conditions such as dry cutting. Characteristics of super alloys (high temperature tensile and shear strength, strong work hardening, reduced thermal conductivity, built-op edge (DUE) and the presence of abrasive particles in their microstructures) induce severe thermo-mechanical loads at the tool-chip interface resulting in significant wear of the tool [Ezegwu 2005],[Olovsjö 2012], [Youssef 2016].

Tool wear strongly influences production costs and affect surface integrity of the tool [Xue 2011]. Cutting tool selection is an important factor when machining Ni based alloys. Tool material should exhibit elevated wear resistance, high strength and toughness, high hardness at high temperature, chemical stability and thermal shock resistance. Cemented carbides have been used for decades and the use of multilayer coatings have improved their suitability for machining Ni-based alloys [Mrkvica 12a], [Ezegwu 1992], [Ezegwu 1996].

2 INCONEL 718

Inconel 718 is a recently developed precipitation hardened Ni-base alloy, containing significant amounts of iron, niobium and molybdenum, along with lesser amounts of aluminium and titanium, which is designed to display exceptionally high yield, and creep rupture properties at a temperature up to 700 °C [High Temp Metals 2017]. It is typically used in applications where properties of temperature resistance, corrosion resistance, and loading resistance are most desired.

This material belongs to group of nickel alloys, which are intended for manufacturing of parts with high resistance to corrosion and high temperatures. It is high strength, stainless, precipitation hardened alloy intended for temperature range -252°C to +700°C [Neslusan 2012]. Operating temperatures are often in the vicinity of 1100°C, without a damaging reduction in strength and hardness [Groover 2010].

Due to its wide temperature range Inconel 718 is used in aerospace for manufacturing of components placed in parts of motors which are exposed to high temperatures. Chemical composition is shown in table 1. Mechanical properties: R_m = 1240 MPa, HRC=36 [Mrkvica 2012b].

Element	C	Mn	Nb+Ta	Cr	Ni	Co	Fe
Min.(%)			4,75	17	50		rest
Max.(%)	0,08	0,35	5,5	21	55	1	
Element	B	Ti	Al	Mo	Zr	Cu	S
Min.(%)		0,65	0,2	2,8	0,02		
Max.(%)	0,01	1,15	0,8	3,3	0,12	0,1	0,02

Table 1: Inconel 718 – chemical composition [Janos 2016]

3 CONDITIONS OF EXPERIMENT

The most published works on machining Inconel 718 have been concerned mainly with single-point tools (turning), while milling has received little attention due to the process complexity [Choundhury 1998], [Fernández-Valdivielso 2016], [Mrkvica 2013]. Alauddin et al. presented a study into the machinability of Inconel 718 during end-milling when using uncoated carbide inserts under dry conditions. Their main objective was to optimize the machining conditions regarding to the tool life and surface quality [Alauddin 1996]. HSM using ball nose end mills to machine aero-foils made of Inconel 718 was investigated by Ng et al. [Ng 2000]. The best tool life was realized when cutting was performed using high pressure cutting fluid. The tool life was twice longer than that performed under the dry condition. Hood et al. studied the effect of operating variables on tool life and surface integrity when end-milling of Ni-based Haynes 282. According to their plan, only four machining levels were chosen based on the suggested operating parameters (two speeds and two feeds) and specified by tool manufacturers. The highest operating parameters were high cutting speed and high feed rate of 0,1 mm, whereas the lowest parameters were low cutting speed and a small feed rate of 0,05 mm. Unfortunately, commercial restrictions preclude the reporting of the exact cutting speeds, although these may be within the range of 14-75 $m.min^{-1}$. It was also depicted that the three force components increased with increasing flank wear, and the machinability performance of Hayes 282 during milling was found to be similar to Inconel 718 [Hood 2012].

Our milling tests were carried out on FNG 32 CNC milling machine with application of cutting fluid. The workpiece was in the form of prism (70x115x320mm) of Inconel 718. Milling cutter FMA01-080-A27-SE12-06 (external diameter 91 mm, number of teeth = 6, tool back rake γ_p = +20°, tool side rake γ_f = -5° [ZCC.CT 2017]) was employed for machining (Fig. 1.).

Figure 1. Milling cutter FMA01-080-A27-SE12-06 with cemented carbide inserts [ZCC.CT 2017]

Three commercial coated carbide inserts (micro-grain hard metal and nano-structured nc-TiAlN PVD coating [ZCC.CT 2017], resp. MT-CVD coating Ti(C,N)+Al_2O_3+TiN [Sandvik Coromant 2017] (recommended for machining Ni alloys) were analyzed with the different cutting geometries. CVD coatings are more suitable than PVD for turning applications, basically because the technology is defined for mass-production and is cheaper than the PVD one. However there are also inserts coated with PVD technology. On the other hand, there are standards neither for tool geometry nor tool shanks for milling. For instance, this is the case of the shoulder, 45° lead angle and round inserts [Mrkvica 2014]. There are a lot of different types of milling tools, but the methodology explained in this paper can be very useful.
Cutting parameters are stated in table 2. Tests were carried out by combinations of feeds and cutting speeds. Depth of cut was constant - 1mm.

Type of insert	f_1 [mm]	f_2 [mm]	f_3 [mm]
SEET 12T3-CF	0,1	0,15	0,2
SEET 12T3-EM	0,1	0,15	0,25
R245-12 T3 E-ML	0,08	0,14	0,2
Type of insert	v_{c1} [m.mim^{-1}]	v_{c2} [m.mim^{-1}]	v_{c3} [m.mim^{-1}]
SEET 12T3-CF	20	30	40
SEET 12T3-EM	20	30	40
R245-12 T3 E-ML	25	30	40

Table 2. Cutting conditions [Janos 2016]

The devices for tool wear and roughness monitoring were located next to the milling machine to reduce idles times and achieve a systematic way of testing. Microscope INTRACOMICRO with software Motic Image Plus 2.0 ML and portable roughness was a MITUTOYO Surftes 211 with Gaussian filter and cut-of 2,5 or 0,8 mm (with measurement range in Ra between 0,1 up to 40 μm) were employed. Cutting forces were recorded with KISTLER 9255 A dynamometer, connected to the analog-digital converter PCL 818 HG. The signals were sampled with the frequency 5 kHz, recorded and analyses in the software DASYLab 3.5.

Figure 2. SEET 12T3-CF (YBG102-nc-TiAlN-PVD)

Figure 3. SEET 12T3-EM (YBG202-nc-TiAlN-PVD)

Figure 4. R245-12 T3 E-ML (2040-MT-Ti(C,N)+Al_2O_3+TiN**)**

4 RESULTS OF EXPERIMENTS

4.1 TOOL WEAR

Decision about the most convenient cutting parameters for cutting inserts was made through the measuring of machining time until critical wear of inserts. As soon as the insert attains the critical wear level corresponding with poor surface quality (surface roughness) the experiment was stopped. This way the critical flank wear for established to be equal VB_B = 0,7 mm. The test was carried out on all types of cutting inserts. Each of this inserts was employed for milling at 3 different cutting speeds and 3 different feeds. Depth of cut during test was constant - 1mm.
Figures 5, 9 and 13 show all tested carbide inserts after reaching the tool life criterion VB_B. Tool wear patterns indicate that friction and attrition mechanisms dominate, whereas adhesion occurs when the coated layer was destroyed [Liao 1996], [Bhatt 2010]. In no case the usual notch wear pattern was detected. The higher tool wear the worse chip removal mechanism. Increasing heat originating from plastic deformation results in diffusion and adhesion - adhered layers in both the rake and relief edge faces can be found, known as BUL (Built up layer) [Qi 2000].

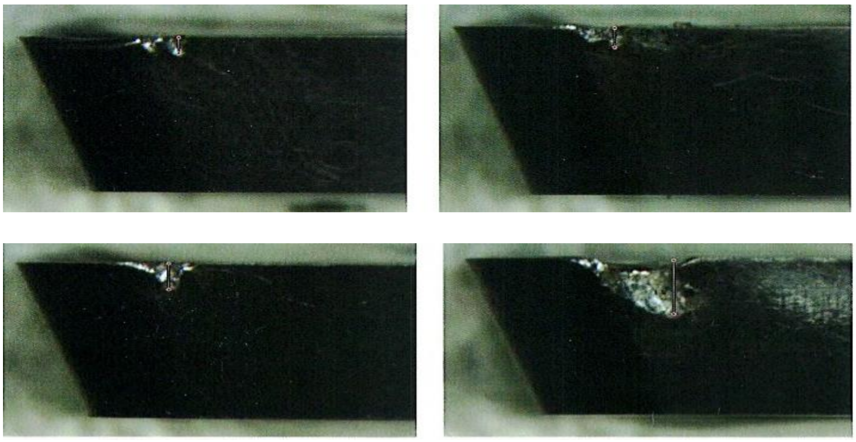


Figure 5. Flank wear of SEET 12T3-CF (YBG102-nc-TiAlN-PVD) insert (from left VB_B = 0,21 mm; 0,35 mm; 0,52 mm; 0,74 mm)

Figures 6-8, 10-12 and 14-16 show flank wear along machining time T_c. Chipping, or fracture of the tool edge is also observed during machining of nickel-based, being reported as the dominant mechanism when milling Inconel 718 [Cantero 2013], [Kadirgama 2011], [Czan 2003].

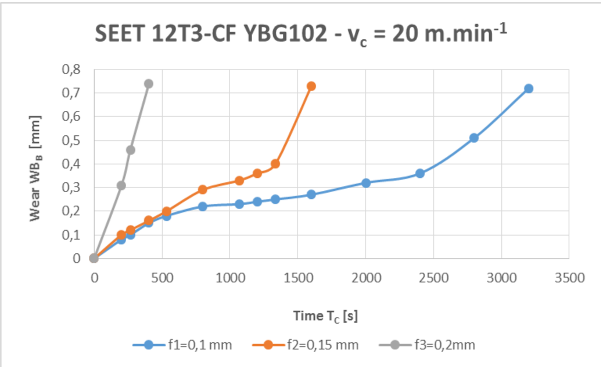


Figure 6. Flank wear along with machining time, SEET 12T3-CF (YBG102-nc-TiAlN-PVD) by cutting speed v_c = 20 m.min^{-1} and different feeds

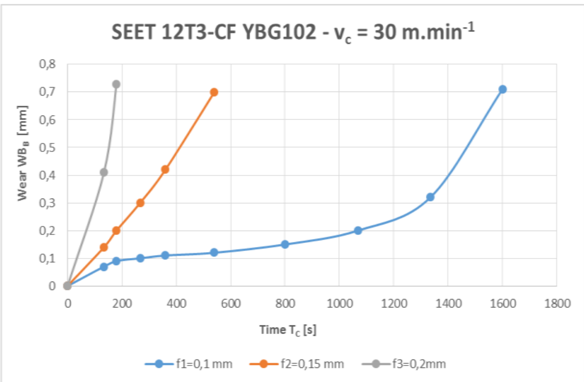


Figure 7. Flank wear along with machining time, SEET 12T3-CF (YBG102-nc-TiAlN-PVD) by cutting speed v_c = 30 m.min^{-1} and different feeds

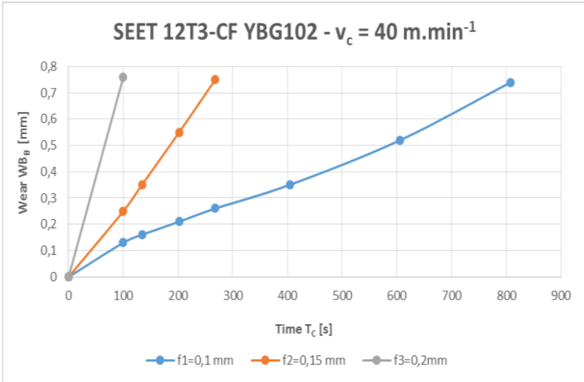


Figure 8. Flank wear along with machining time, SEET 12T3-CF (YBG102-nc-TiAlN-PVD) by cutting speed v_c = 40 m.min^{-1} and different feeds

Figures 6-8 show, that only four inserts reached life time more than ten minutes and wear pattern changed above 20 minutes. After 20 minutes of milling, divergence started, being blue line variant (v_c = 20 m.min^{-1}, f_z = 0,1 mm) the last reaching the wear threshold value. The best results are reached by the smallest feeds. That applies to all cutting speeds. Feed value is determined for wear progress.

Tool performance of SEET 12T3-EM (YBG202) insert (Fig. 10-12) is similar to the tool performance SEET 12T3-CF (YBG102) insert. The cause of this is the same shapes and cutting conditions. The consequence of different results are different chipbreaker shapes and coating layers. The longest life time also can be obtained at the smallest cutting conditions, primarily feed.

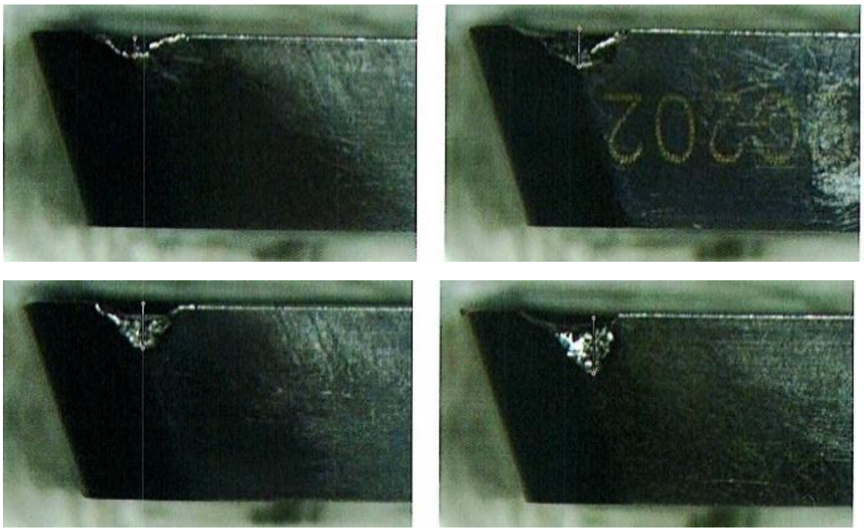


Figure 9. Flank wear of SEET 12T3-EM (YBG202-nc-TiAlN-PVD) insert (from left VB_B = 0,13 mm; 0,26 mm; 0,55 mm; 0,71 mm)

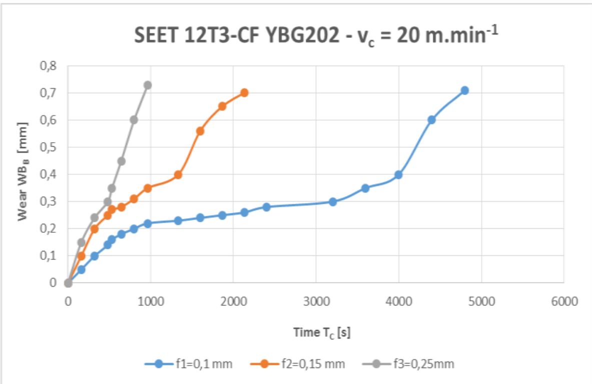


Figure 10. Flank wear along with machining time, SEET 12T3-EM (YBG202-nc-TiAlN-PVD) by cutting speed v_c = 20 m.min^{-1} and different feeds

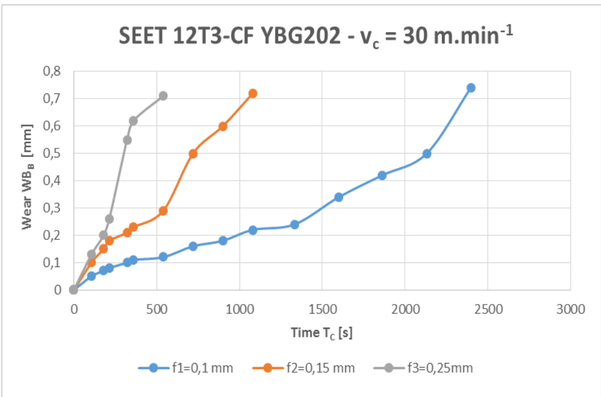


Figure 11. Flank wear along with machining time, SEET 12T3-EM (YBG202-nc-TiAlN-PVD) by cutting speed v_c = 30 m.min^{-1} and different feeds

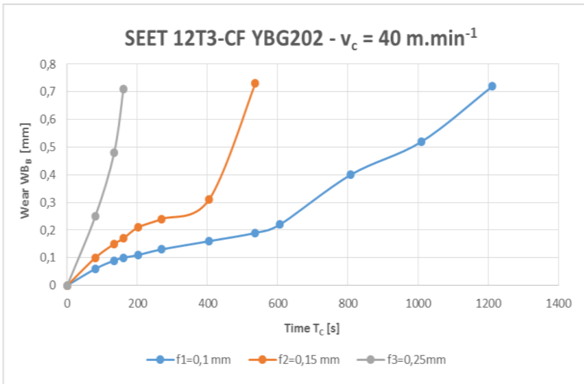


Figure 12. Flank wear along with machining time, SEET 12T3-EM (YBG202-nc-TiAlN-PVD) by cutting speed v_c = 40 m.min^{-1} and different feeds

The best results can be obtained for R245-12 T3 E-ML (2040) insert. It is due to specific coating layer and chipbreaker shape. The reduction in tool engagement into material in all cases allows a 50% longer tool life. Abrasion dominates during the first minutes of milling till the coating protective layer disappeared. Next milling process results in micro chipping of carbide substrate. In this moment crater and adhesion wear affected all tools. Figures 5, 9 and 13 show how wear develops along with milling time.

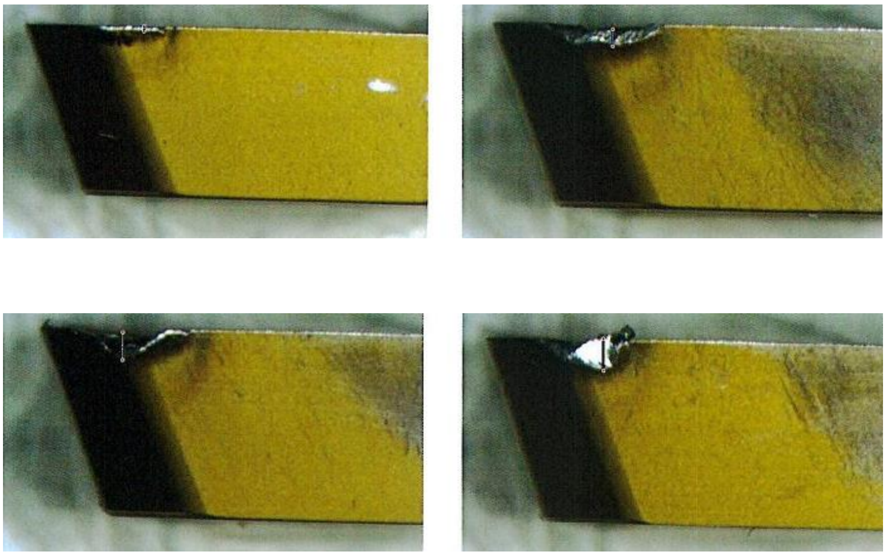


Figure 13. Flank wear of R245-12 T3 E-ML (2040-MT-Ti(C,N)+Al_2O_3+TiN)) insert (from left VB_B = 0,11 mm; 0,37 mm; 0,58 mm; 0,70 mm)

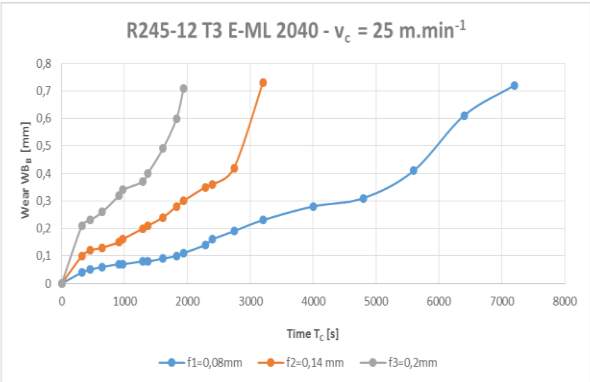


Figure 14. Flank wear along with machining time, R245-12 T3 E-ML (2040-MT-Ti(C,N)+Al_2O_3+TiN) by cutting speed v_c = 25 m.min^{-1} and different feeds

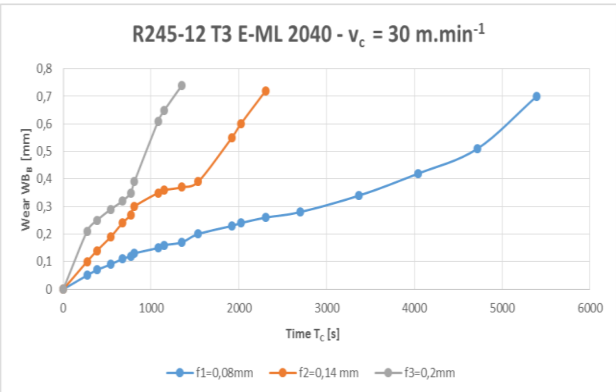
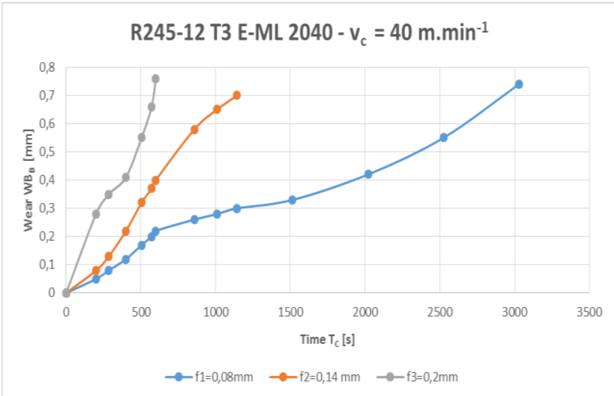


Figure 15. Flank wear along with machining time, R245-12 T3 E-ML (2040-MT-Ti(C,N)+Al_2O_3+TiN) by cutting speed v_c = 30 m.min^{-1} and different feeds

Figure 16. Flank wear along with machining time, R245-12 T3 E-ML (2040-MT-Ti(C,N)+Al_2O_3+TiN) by cutting speed v_c = 40 m.min^{-1} and different feeds



Graphs could be used for evaluation of particular machining time. For example, when we want have a lifetime of cutting inserts T_c = 1500 s = 25 minutes (VB_B = 0,5 mm), then graphs can be used to find the highest possible cutting conditions:

- SEET 12T3-CF : v_c = 30 m.min^{-1} a f_z = 0,1 mm
- SEET 12T3-EM = 20 m.min^{-1} a f_z = 0,15 mm
- R245-12 T3 E-ML v_c = 25 m.min^{-1} a f_z = 0,2 mm

Comparison of cutting inserts for v_c = 30 m.min^{-1} and feed f = 0,1 mm is described on figures 17 and 18. The first one compares life times whereas the second one compares volume of removed material within the life time.

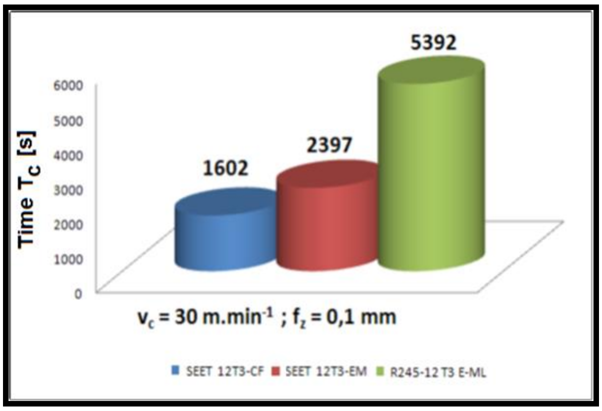


Figure 17. Comparison of life time

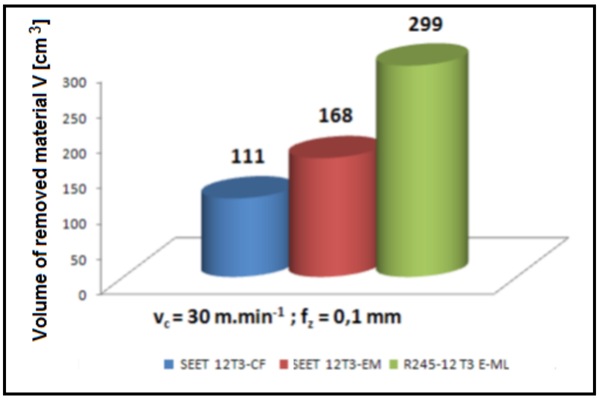


Figure 18. Comparison of removal material volume

4.2 SURFACE ROUGHNESS

Figures 19-21 show three graphs of mean roughness (Ra) in relation with used cutting conditions. These figures show that Ra usually increases with increasing cutting speed. Comparing the values of Ra for the same VB_B, and the different cutting speeds (constant feed) Ra increases only gently. The steepest increase of Ra can be found when the cutting speed is kept constant and feed increases.

The best results (comparing all three type of square inserts) can be found for R245-12 T3 E-ML insert. Ra = 0,35 µm can be obtained for machining time 5392 seconds – see Fig. 22.

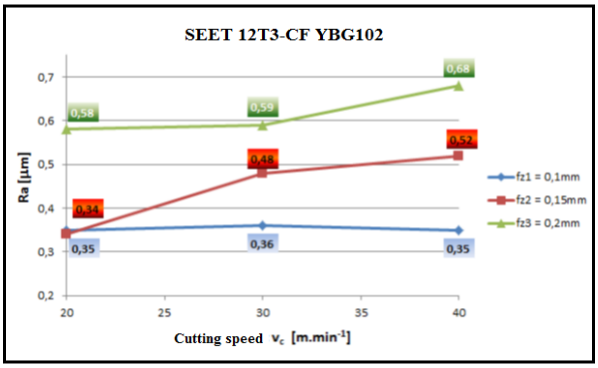


Figure 19: Comparison of achieved Ra values at different cutting conditions SEET 12 T3-CF (YBG102-nc-TiAlN-PVD)

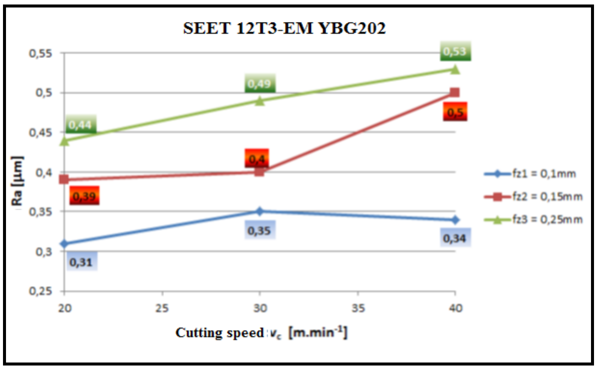


Figure 20. Comparison of achieved Ra values at different cutting conditions SEET 12 T3-EM (YBG202-nc-TiAlN-PVD)

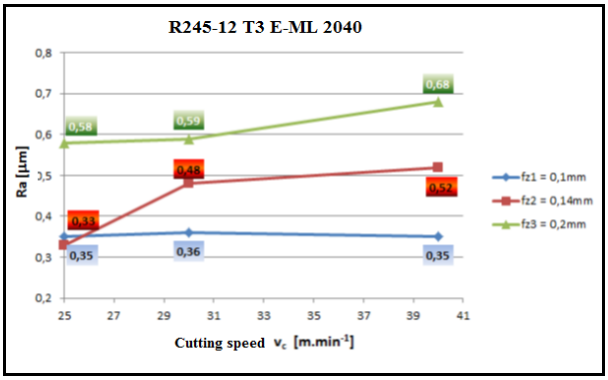


Figure 21. Comparison of achieved Ra values at different cutting conditions R245-12 T3 E-ML (2040-MT-Ti(C,N)+Al_2O_3+TiN)

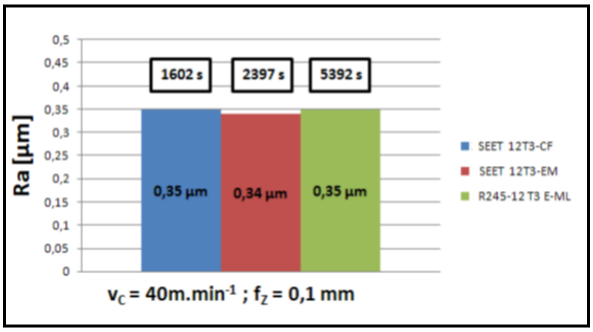


Figure 22. Comparison of achieved Ra for VB_B = 0,7 mm

4.3 CUTTING FORCES

Milling forces were measured at all cutting conditions. Figures 24 – 29 show values of the three cutting force components, namely cutting force (F_c) in the tangential direction or in the cutting speed direction, feed force (F_f) in direction of feed and thrust force (F_p) in direction of milling cutter axis – see Fig. 23.

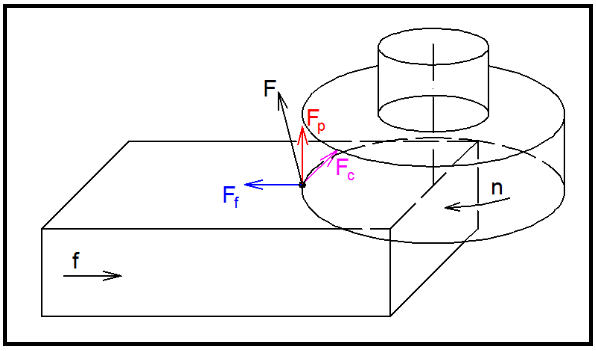


Figure 23. Force components during face milling

The lowest cutting conditions were set as follows: cutting speed v_c = 20 m.min^{-1} for SEET 12 T3-CF and SEET 12T3-EM inserts and v_c = 30 m.min^{-1} for R245-12 T3 E-ML insert. Feed was kept constant f_z = 0,1 mm for all inserts. The values of cutting force components were not changed along time. It was found that cutting forces F_c reached the highest values whereas the thrust forces F_p reached the lowest values. Despite the higher cutting speed the force load was the lowest by the use of R245-12 T3 E-ML insert.

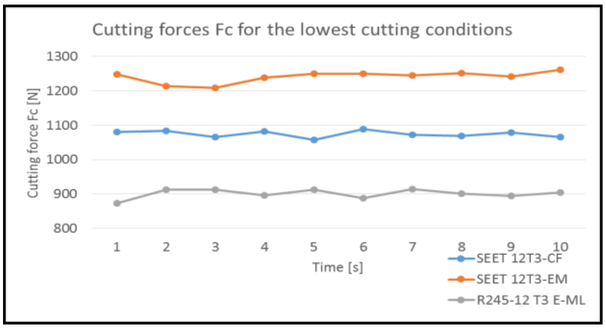


Figure 24. Comparison of cutting force values for the lowest cutting conditions, low pass filter 10 Hz

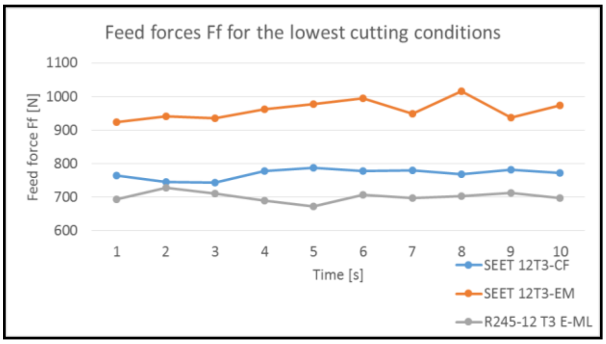


Figure 25. Comparison of feed force values for the lowest cutting conditions, low pass filter 10 Hz

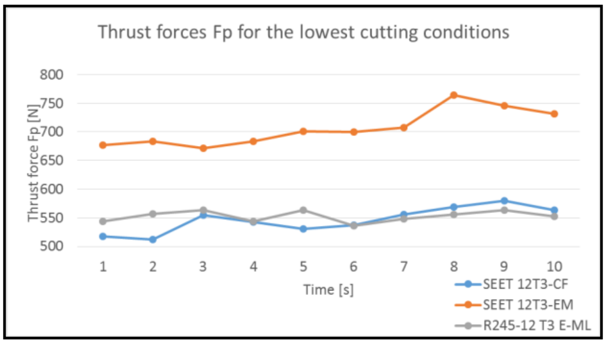


Figure 26. Comparison of thrust force values for the lowest cutting conditions, low pass filter 10 Hz

The highest cutting conditions were set up as follows: cutting speed v_c = 50 m.min^{-1} for SEET 12 T3-CF and SEET 12T3-EM inserts and v_c = 60 m.min^{-1} for R245-12 T3 E-ML insert. Feed was kept constant f_z = 0,2 mm for all inserts. The use of higher cutting conditions results in higher values of cutting force components. These cutting conditions also lead to faster wear of inserts, which corresponds to results mentioned in chapter 4.1. Usage of higher cutting conditions result in increase of mechanical load of inserts expressed in cutting force components. The highest values of cutting force components can be found for R245-12 T3 E-ML inserts. The main reason can be found in cutting speed.

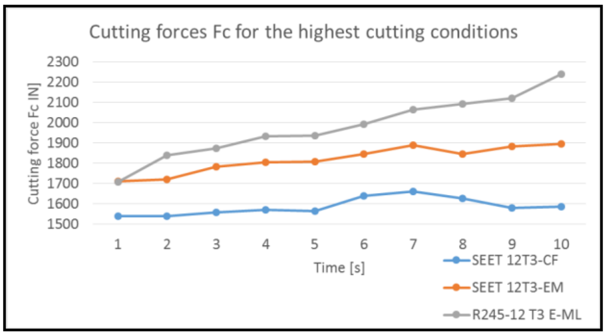


Figure 27. Comparison of cutting force values for the highest cutting conditions, low pass filter 10 Hz

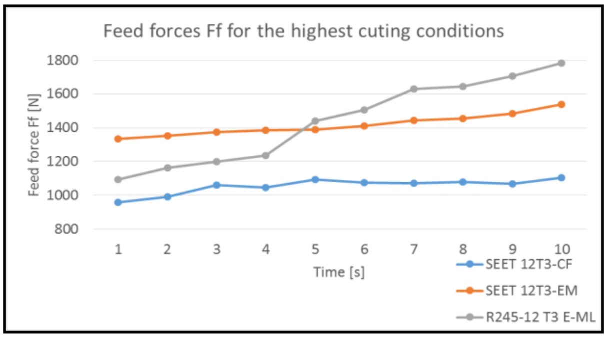


Figure 28. Comparison of feed force values for the highest cutting conditions, low pass filter 10 Hz

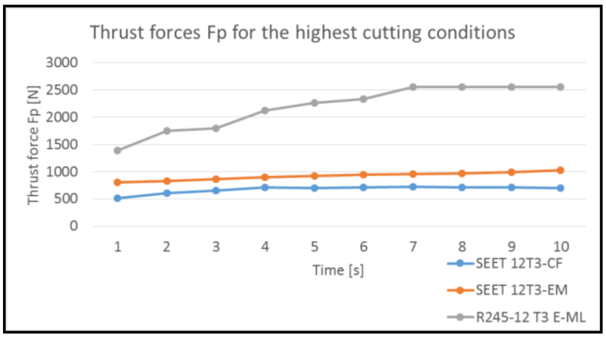


Figure 29. Comparison of thrust force values for the highest cutting conditions, low pass filter 10 Hz

5 CONCLUSIONS

Tool wear course during milling of Inconel 718 have been analyzed in this paper. Inserts from cemented carbide from different manufacturers were performed with coolant. Some conclusions concerning the cutting behavior and wear course of the inserts tested in milling Inconel 718 can be established from this work. Tool wear presented two periods, well defined. A first one, when the protective insert coating slow down tool wear. The second period is associated with damage of insert coating. Then the carbide matrix is exposed to adhesion and micro chipping mechanism.

Flank wear was dominant in all cutting conditions. From the point of view of highest cutting speed v_c = 30 m.min^{-1} and feed f = 0,1 mm was the cutting inserts R245-12 T3 E-ML found as the most suitable from the point of view removed material volume of approximately 299 cm^3 in 90 minutes (as shown on Fig. 17 and 18).

Surface roughness was obtained from measurement of the average roughness (Ra between 0.7 and 3.2 µm) depending on cutting conditions. Based on the results it can be reported than acceptable surface roughness can be obtained at suitable cutting conditions and tool geometry.

Cutting force components are strongly affected by tool wear, showing that force increase long with tool wear. All analyzed aspects such as surface roughness and forces are negatively affected by tool wear, because of alterations in cutting edge geometry (strongly affect process of plastic deformation). However this paper indicates all measured aspects (roughness and surface roughness) can be kept at the acceptable level; therefore can be applied in lot of industrial applications.

In the near future new tools would be launched to the market, but coated carbide inserts will be still the dominant industrial solution for finishing operations. This study will be surpassed but the method could be the same or similar.

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REFERENCES

[Alauddin 1996] Alauddin, M., El Baradie, M. A. and Hashmi, M. S. J. End-milling Machinability of Inconel 718. Proceedings of the Institut of Mechanical Engineers, Part B : Journal of Engineering Manufacture, 1996, Vol. 210, pp. 11-23. ISSN 0954-4054.

[Bhatt 2010] Bhatt, A. et al. Wear Mechanisms of WC Coated and Uncoated Tools in Finish Turning of Inconel 718. Tribology International, 2010, Vol. 43, No. 5-6, pp. 1113-1121. ISSN 0301-679X.

[Cantero 2013] Cantero, J. L. et al. Analysis of Tool Wear Patterns in Finishing Turning of Inconel 718. Wear, 2013, Vol. 297, No. 1-2, pp. 885-894. ISSN 0043-1648.

[Czan 2003] Czan, A. et al. The Temperature Monitoring in Milling and Drilling for Computer Simulation. CEEPUS Science Report. Zilina : University of Zilina, Department of Machining and Manufacturing Technologies, 2003.

[Choudhury 1998] Choudhury, I. A., El Baradie, M. A. Machining Nickel-base Supper Alloys : INT708. End-milling Machinability of Inconel 718. Proceedings of the Institut of Mechanical Engineers, Part B : Journal of Engineering Manufacture, 1998, Vol. 212, pp. 165-206. ISSN 0954-4054.

[Ezegwu 1992] Ezegwu, E. O., Pashby, I. R. High Speed Milling of Nickel-based Superalloys. Journal of Materials Processing Technology, 1992, Vol. 33, No. 4, pp. 429-437. ISSN 0924-0136.

[Ezegwu 1996] Ezegwu, E. O., Wang, Z. M. Performance of PVD and CVD Coated Tools when Machining Nickel-based Inconel 718 Alloy. In : N. Naratuki, ed. Progress of Cutting and Grinding, 1996, pp. 102-107.

[Ezegwu 2005] Ezegwu, E. O. Key Improvements in the Machining of Difficult-to-cut Aerospace Superalloys. International Journal of Machine Tools and Manufacture, 2005, Vol. 45, pp. 1353-1367.

[Fernandez-Valdivielso 2016] Fernandez-Valdivielso, A. et al. Detecting the Key Features of Carbide Inserts for the Turning of Nickel-based Alloys Concerning Surface Integrity. Proceedings of the Institution of Mechanical Engineers, Part C : Journal of Mechanical Engineering Science, 2016, Vol. 230, No. 20, pp. 3725-3742. ISSN 0954-4062.

[Groover 2010] Groover, M. P. Fundamentals of Modern Manufacturing : Materials, Processes and Systems. West Sussex : John Wiley & Sons. Inc., 2010. ISBN 978-0470-467008.

[High Temp Metals 2017] Inconel 718 Technical Data. URL : https://www.hightempmetals.com/techdata/hitempInconel718data.php [8. 8. 2017]

[Hood 2012] Hood, R. et al. Radius End Milling of Haynes 282 Ni-based Superally. Proceedings of the Institut of Mechanical Engineers, Part B : Journal of Engineering Manufacture, 2012, Vol. 226, No. 10, pp. 1745-1753. ISSN 0954-4054.

[Janos 2016] Janos, M. Milling Possibilities of Nickel Alloys (in Czech). Dissertation, Ostrava : VSB-TU Ostrava, 2016.

[Kadirgama 2011] Kadirgama, K. et al. Tool Life and Wear Mechanism when Machining Hastelloy C-22 HS. Wear, 2011, Vol. 270, No. 3-4, pp. 258-268. ISSN 0043-1648.

[Liao 1996] Liao, Y. S., Shiue, R. H. Carbide Tools Wear Mechanism in Turning of Inconel 718 Superalloy. Wear, 1996, Vol. 193, No. 1, pp. 16-24. ISSN 0043-1648.

[Mrkvica 2012a] Mrkvica, I., Konderla, R. and Faktor, M. Turning of Inconel 718 by Cemented Carbides. Key Engineering Materials, 2012, Vol. 496, pp. 138-143. ISSN 1662-9795.

[Mrkvica 2012b] Mrkvica, I., Janos, M. and Sysel, P. Contribution to Milling of Materials on Ni Base. Applied Mechanics and Materials, 2012, Vols. 217-219, pp. 2056-2059. ISSN 1662-7482.

[Mrkvica 2013] Mrkvica, I. et al. Force Load of Cutting Tool by Turning of Nickel Alloy Inconel 718 with Sintered Carbide Insert. Applied Mechanics and Materials, 2013, Vol. 372, pp. 441-444. ISSN 1662-7482.

[Mrkvica 2014] Mrkvica, I., Janos, M. Comparison of Round Insert´s Lifetime when Milling Inconel 718. Key Engineering Materials, 2014, Vol. 581, pp. 26-31. ISSN 1662-9795.

[Neslusan 2012] Neslusan, M. et al. Heat Distribution when Nickel Alloys Grinding. Tehnicki Vjesnik/Technical Gazette, 2012, Vol. 19, No. 4, pp. 947-951. ISSN 1330-3651.

[Ng 2000] Ng, E. G. et al. High Speed Nose End Milling of Inconel 718. CIRP Annals-Manufacturing Technology, 2000, Vol. 49, No. 1, pp. 41-46. ISSN 0007-8506.

[Olovsjö 2012] Olovsjö, S., Nyborg, L. Influence of Microstructure on Wear Behaviour of Uncoated WC Tools in Turning of Alloy 718 and Waspaloy. Wear, 2012, Vol. 282-283, pp. 12-21. ISSN 0043-1648.

[Qi 2000] Qi, H. S., Mills, B. Formation of a Transfer Layer at the Tool-chip Interface during Machining. Wear, 2000, Vol. 245, No. 1-2, pp. 136-147. ISSN 0043-1648.

[Sandvik Coromant 2017] Cutting Inserts Coro Mill 245 for Milling. URL : http://www.sandvik.coromant.com/cs-cz/products/pages/productdetails [8. 8. 2017]

[Xue 2011] Xue, Ch., Chen, W. Adhering Layer Formation and its Effect on the Wear of Coated Carbide Tools during Turning of a Nickel-based Alloy. Wear, 2011, Vol. 270, No. 11-12, pp. 895-902. ISSN 0043-1648.

[Youssef 2016] Youssef, H. A. Machining of Stainless Steel and Super Alloys. West Sussex : John Wiley & Sons. Inc., 2016. ISBN 978-1118-919569.

[ZCCT.CT 2017] ZCC Cutting Tools Europe GmbH – Milling. URL: http://zcccteurope.com/documents/Produkte/Katalog gesamt/Fraesen.pdf [8. 8. 2017]

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