DOI: 10.2507/33rd.daaam.proceedings.xxx

The Effect of Cutting Edge Radius Sizes on Tool Life in Machining Nickel Alloy Inconel 718

Tomas Vopat*, Robert Straka, Marcel Kuruc & Jozef Peterka

This Publication has to be referred as: Straka, R[obert]; Vopat, T[omas] & Peterka J[ozef] (2022). The effect of cutting edge radius sizes on tool life in machining nickel alloy Inconel 718, Proceedings of the 33rd DAAAM International Symposium, pp.xxxx-xxxx, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-xx-x, ISSN 1726-9679, Vienna, Austria
DOI: 10.2507/33rd.daaam.proceedings.xxx

Abstract

This article deals with the edge preparation of cemented carbide cutting inserts. Several cutting edge radius sizes were manufactured by drag-finishing. The influence of cutting edge radius sizes on the tool life was investigated. Cutting tests were carried out during the machining of a difficult-to-cut material, in particular, a nickel alloy Inconel 718. The cutting parameters were selected with respect to the semi-finishing turning operation. The longest tool life was reached with the cutting edge radius of 35 µm which was the middle value between the three radii tested. The dependence of tool life on the cutting edge radius size was determined. The results can be applied to increase the efficiency of the Inconel 718 the turning process of nickel alloy Inconel 718

Keywords: Edge preparation; Tool life; Tool wear; Surface finishing; Drag-finishing

1. Introduction

The tool life of the cutting tool and the roughness of the machined surface are the two most important parameters as a result of the cutting process. The ever-increasing efficiency and productivity in the production process require constant new research into the manufacturing processes and the tools used in production. Therefore, there is a need to increase the life of the tool, which can be done by changing parameters such as the material of the tool, the geometry of the tool [1], and the coating [2]. There are various ways to describe the tool geometry accurately, the simplest being to describe it using the cutting edge radius, but this description only works with symmetrical cutting edges. The so-called K factor was created to describe more complex cutting edges, which uses the parameters S_γ, S_α, Δr, and the ratio $K = S_\gamma / S_\alpha$, to describe such geometries [3]. To achieve those geometries on the cutting edge of the tool, one of the preparation methods must be applied to the tool after it has been manufactured. The most commonly used are drag-finishing and brushing [4], [5], [6]. In addition to those, several other methods are used for preparation, such as abrasive jet machining [7], grinding, laser machining, magneto abrasive machining [8], or using plasma discharges in electrolyte [9]. The machining process with a geometrically undefined cutting edge, where the workpiece is inserted into a container with free abrasive grains, is called drag finishing. Abrasive grains can consist of ceramic, plastic, silicon, carbide, or walnut shells, corundum, and quartz. The material is removed inside the container due to the rotation of the workpiece and moves through abrasive particles

[8]. When parts need to have good surface quality, this technology is used because of its advantage, which is the short time needed to obtain the required results. Increasing the relative speed between the media and surface and media pressure in the workpiece, makes drag finishing a faster and more efficient process when compared to others. It can also be used for the preparation of cutting tools by modifying some process parameters such as the feed rate, the processing time, or the type of grain [4], [10]. From cutting theory, we know four physical causes of the formation of the machined surface [11]. Theoretical roughness of the machined surface, the so-called geometric roughness, we can calculate, simulate [12] and predict. Other causes, such as the existing vibration [13] of the machine-tool-workpiece system and the occurrence of the increase, cannot be unambiguously calculated by analytical equations. In these cases, we help ourselves with experiments [14], [15], [16]. Zhang and Zhuang researched the effect of cutting edge microgeometry on surface roughness in the turning of AISI 52100 steel. They found that increasing the chamfer width can reduce the surface roughness, but a reasonable chamfer geometry must be selected because the increase in a chamfer angle leads to an extreme change in the surface roughness value. They also found out that the enhancement of chamfer length and angle can contribute to the formation of the white layer [17]. Ventura et al. found that asymmetric geometry increases tool life. They demonstrated the application of prepared cutting inserts and proved that the use of those microgeometries is adequate in hard turning [18]. Uhlmann et al. compared brush polishing, polish blasting, magnet finishing, and immersed tumbling as preparation methods for micro-milling tools. They found that magnet finishing, and immersion tumbling improved the tool performance in a matter of resulting forces F_z by 7.5 %, and 14 %, respectively, compared to brush polishing and polish blasting. Tool wear was reduced by 9 % compared to brush polishing and by 13.2 % compared to polish blasting [19]. The effect of cutting temperature on the tool life of cemented carbide drill was examined in the publication [20]. The effect of cutting edge rounding on tool life was determined in the publication [21]. The influence of cutting edge radius sizes on cutting forces was investigated in the publication [22]. The authors in the paper [23] determined the accuracy of the solid cemented carbide cutting tools manufactured on the grinding machine and determined the influence of drag finishing on the macro geometry of the solid cemented carbide cutting tools.

The purpose of this paper is to examine the difference between three cutting edge radii of 10, 35, and 50 µm and their influence on cutting inserts in terms of tool life in turning difficult-to-cut material, in particular Inconel 718 equivalent to DIN 2.4668, EN NiCr19FeNbMo or UNS N07718.

2. Materials and Methods

CNMG 120408-SM coated cutting inserts were used in the experiment (Fig. 1). They were made of WC-Co cemented carbide. The hardened steel has the designation PCLNL 2020K16 (Fig. 1). The cemented carbide cutting inserts were made by the tool manufacturer Dormer Pramet and the toolholder was made by the tool producer Seco. These cutting inserts are suitable for roughing and semi-finishing turning operations. The used cutting inserts were prepared by drag-finishing. The grade of cemented carbide and coatings are not specified further due to ongoing research. The prepared cutting edge radii were 10 µm, 35 µm, and 50 µm. The example of measurement of the cutting edge radius is shown in Fig. 2. It was carried out by the Alicona Infinite Focus SL measurement device. Table 1 shows the parameters of the cutting tool. The optical three-dimensional measurement principle was used to measure the radius of the cutting edge. The objective magnification was 50x, where the working distance is 10.1 mm, the vertical resolution is 20 nm, and the minimum measurable radius is 2 µm. In the experiment, DMG CTX Alpha 500 multi-axis turning centre was used. The parameters of the machine tool are described in Table 2. The longitudinal turning was used during cutting tests.

Fig. 1. Toolholder with cemented carbide cutting inserts

Parameter	Value	Parameter	Value
Length [mm]	12.90	Recommended f [mm]	0.15 – 0.45
Thickness [mm]	4.76	Recommended a_p [mm]	0.80 – 4.00
Nose radius [mm]	0.80	Cutting edge angel [°]	80.00

Table 1. Parameters of the CNMG 120408-SM cutting insert

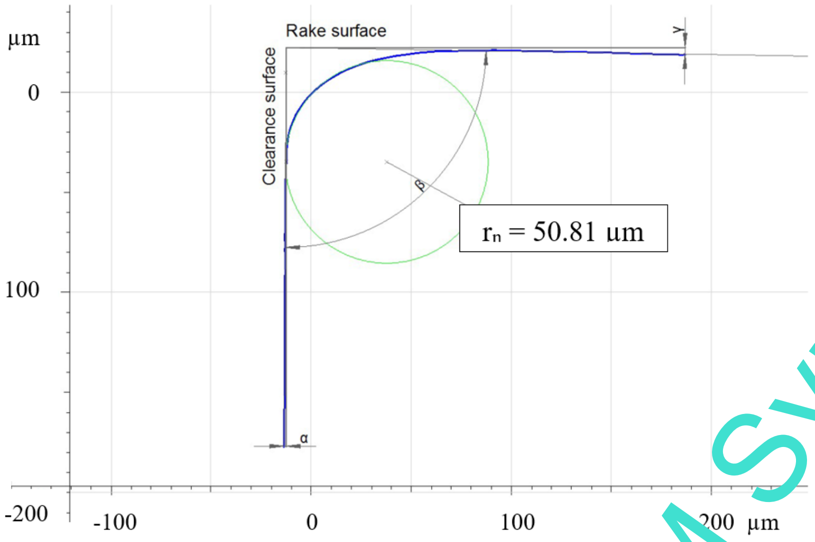


Fig. 2 Measurement of the cutting edge radius r_n

Travel distance	
X [mm]	100
Y [mm]	± 40
Z [mm]	525
Main spindle	
Drive power [kW]	20
Max. rotation frequency [min^{-1}]	6000
Tool revolver head	
Number of tool positions [-]	12
Drive power [kW]	5.4
Max. rotation frequency [min^{-1}]	5000
Operating software	Heidenhain Plus IT

Table 2. Parameters of DMG CTX Alpha 500 multi-axis turning centre

The cutting parameters were kept constant during the entire machining. The cutting speed of v_c = 40 m·min^{-1}, the feed of f = 0.15 mm, and the depth of cut of a_p = 1 mm were selected as process parameters. They were used to control the development of wear at the cutting edges. Inconel 718 (equivalent to DIN 2.4668, EN NiCr19FeNbMo or UNS N07718) was used as tested workpiece material. The chemical composition of Inconel 718 is in Table 3. It was an annealed nickel-chromium-based alloy. The tested workpiece material was a rounded bar with a diameter of 101.6mm that was produced by cold working.

C	Si	Mn	N	Cr	Mo	Ni	Cu	Co	Ti	Al	Nb	Fe
0.023	0.070	0.11	0.006	17.780	2.990	53.6	0.06	0.35	0.92	0.49	5.16	18.29

Table 3. Chemical composition of Inconel 718 (wt. %)

The chosen value of the tool wear criterion on the main flank was VB_K = 0.22 mm. After the tool wear reached this value on the cutting edge, the tool wear started to increase significantly, or edge chipping was observed on the cutting insert. The flank wear in areas namely VB_N and VB_B, was measured by a Dino-Lite Edge AM73915MZT Dino-Lite Edge 3.0 microscope with a resolution of 2560 × 1920 pixels. This microscope uses magnification in the range of 10-220x. The frame rate was 15 fps at 5M pixels. Before the experiment, the cutting inserts were cleaned in an Elmasonic P ultrasonic cleaning device due to possible impurities on the cutting edges. Three cutting inserts with the same cutting edge radius were used to machine the workpiece material that was clamped into the three-jaw hydraulic chuck (SMW Autoblok 210RB) of the main spindle. The length of the machined surface was 60 mm. The top layer of the workpiece was strain hardened by the cold work process during the manufacturing the workpiece. This layer has a thickness of less than 0.3 mm. This layer was machined with another cutting insert so as not to affect the results of the experiment. The diameter of the tested workpiece material after the top layer was 101 mm. The cutting length of the first cutting insert was 0 to 20 mm. For the second cutting insert, the cutting length ranged from 20 to 40 mm, and for the last one it was from 40 to 60 mm. After the first minute of machining, the cutting inserts were cleaned by cleaning plasticine. Then, they were placed in the special holder that was manufactured on a 3D printer. The microscope was focused on the cutting edge of the cutting insert. Then it was captured in the photo so that the cutting insert could not be moved by external influences, which could distort the measurements of tool wear. Subsequently, the value of the flank wear was measured in the image. After the first measurement, tool wear was measured every 2 minutes of machining until tool wear criterion VB_K was reached. The workplace of the machine tool is shown in Fig. 3.

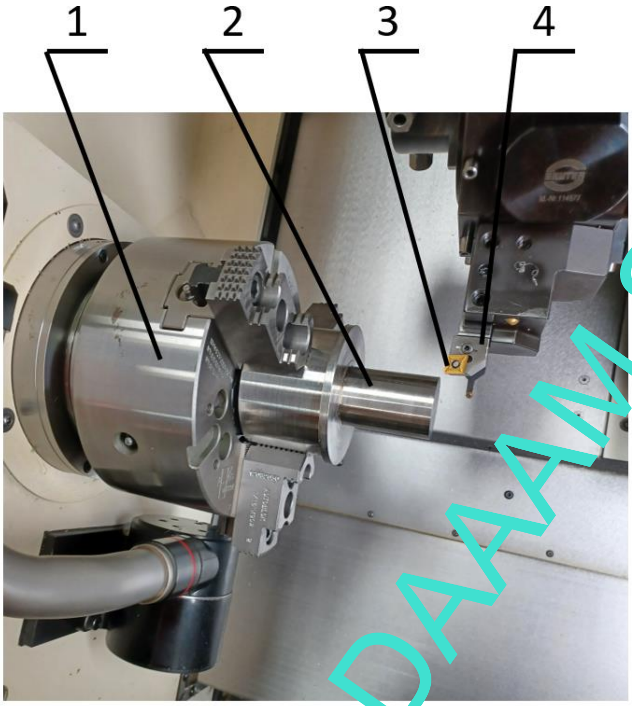
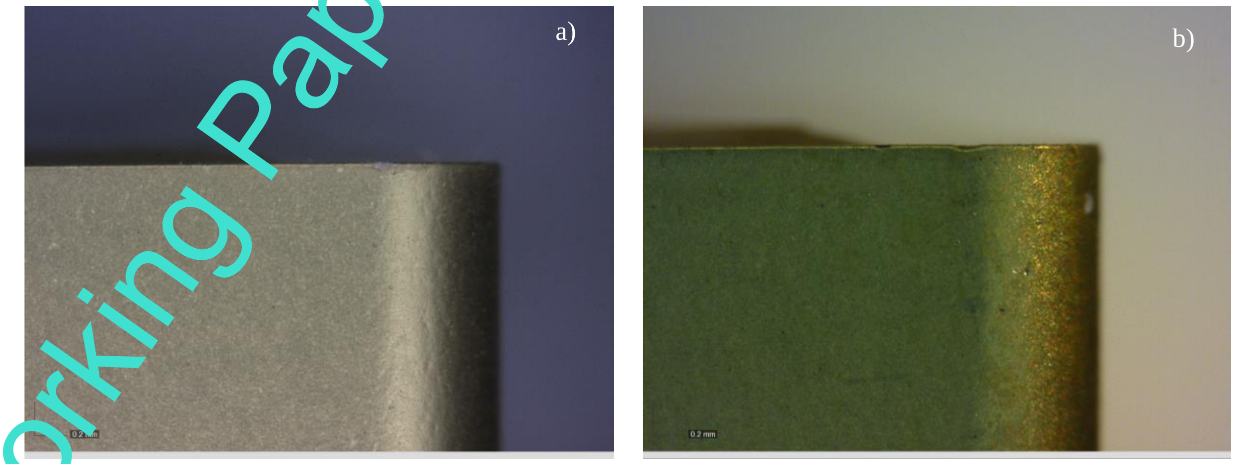


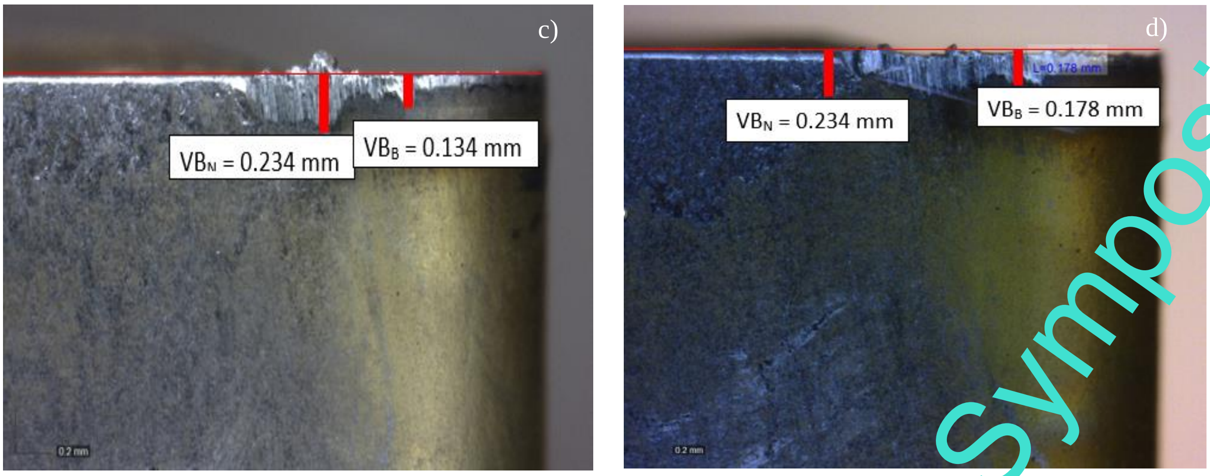
Fig. 3. Workplace of machine tool
1 - hydraulic chuck, 2 - machined material, 3 – cemented carbide cutting insert,
4 – toolholder of cutting insert

3. Results and Discussion

Fig. 4 shows the development of the tool wear on the flank face in time for 2 different radii. The figure shows the cutting edges before the machining and then after exceeding the tool wear criterion. As can be seen in Fig. 4, the largest flank wear values were observed in the area VB_N. It is a typical tool wear type for machining hard materials or materials that are strain hardened after machining. The time dependence of tool wear (VB_N) with respect to the cutting edge radius is shown in Fig. 5. There are tool wear curves of average values of individual flank wear. For the experiment, three cutting inserts were used for each cutting edge radius r_n. The calculated average values of tool lives and standard deviations for cutting inserts with different cutting edge radii can be seen in Table 4.



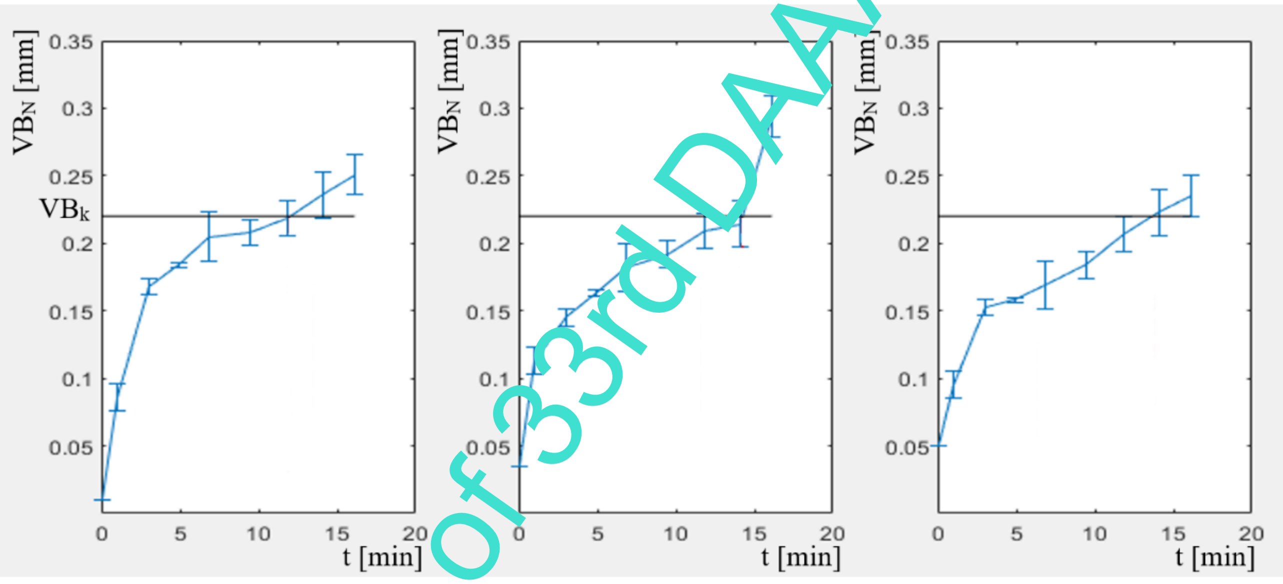
$r_n = 10$ µm, t = 0 min $r_n = 35$ µm, t = 0 min



r_n = 10 µm, t = 11.84 min

r_n = 35 µm, t = 20.64 min

Fig. 4. Development of the tool wear on the flank for
a) r_n = 10 µm before the experiment and b) r_n = 35 µm before the experiment
c) r_n = 10 µm after 11.84 minutes of machining d) r_n = 35 µm after 20.64 minutes of machining



r_n = 10µm

r_n = 35 µm

r_n = 50µm

Fig. 5. Graphs of the time dependence of the VBN width of flank wear value

Cutting insert with	Average tool life	Standard deviations
r_n = 10 µm	12.00	2.08
r_n = 35 µm	15.13	4.08
r_n = 50 µm	13.6	1.81

Table 4. Average tool life of cutting inserts

The longest tool life was achieved by cutting the radius of 35 µm. The tool life of the cutting insert with r_n = 35 µm was increased by 25.83% compared to the cutting edge radius of 10 µm. The tool life of the cutting insert with r_n = 50 µm was increased by 13.33% compared to the cutting edge radius of 10 µm. The increased tool life of the cutting insert can be explained by the fact that the cutting edge with r_n = 10 µm is not as strong as with the larger radii of rounding of the cutting edge. For this reason, the cutting edge with r_n = 10 µm is more prone to tool breakage and fatal failure. On the other hand, the usage of too large cutting edge radii leads to higher friction and thermal load of the cutting edge due to the larger contact area of the cutting tool with the workpiece [24], [25]. When machining difficult-to-cut material such as a nickel alloy, the development of tool wear is difficult to predict. Therefore, it sometimes happens that the cutting tool fails sooner than expected. For this reason, the standard deviation values are higher in some cases.

The average values of the tool life were determined from the individual graphs of the time dependence of the VBN of the width of flank wear value for every sample. These values were evaluated by one-way ANOVA (Table 5). After verifying the normal (Gaussian) distribution of the measured values, the data were tested for equality of variances, and it was confirmed that the variances were not statistically different, therefore, the Tukey method of pairwise comparison of the average values of tool lives was used (Fig. 6). The α significance level was 0.05.

Based on the results of the one-way ANOVA, it can be concluded ($p > 0.05$) that the durability values for the individual radii of the rounding of the cutting edges are not statistically significant.

Cutting insert with r_n	**DF**	**F-value**	**p-value**
r_n = 10 µm and r_n = 35 µm	1	1.4	0.302
r_n = 10 µm and r_n = 50 µm	1	1.01	0.372
r_n = 35 µm and r_n = 50 µm	1	0.35	0.584

Table 5. One-way ANOVA

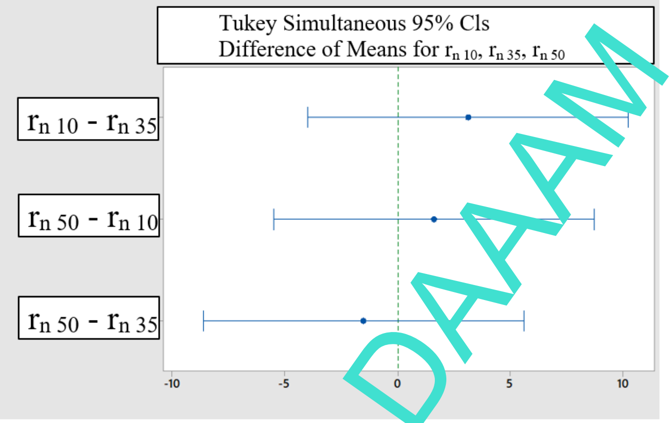


Fig. 6. Tukey method of pairwise comparison of the average values of tool lives

The graphical dependence of the tool life on the cutting edge radius is shown in Fig. 7. The equation in Fig. 7 is a mathematical expression of this dependence, where y is the tool life and x is the size of the cutting edge radius. It shows that the longest tool life was achieved by a cutting edge radius of 35 µm. The cutting edge radius of 35 µm seems to be the best option. However, the results obtained from the research are limited by adjusted variables. It means that the results could be properly applied only for turning nickel alloy Inconel 718. And they are valid for cutting parameters: cutting speed 40 m·min^{-1}, the feed 0.15 mm, and the depth of cut of 1 mm. If the workpiece material or cutting parameters were changed, the results would be different (but probably similar). Moreover, different cutting insert geometry could also lead to different results. The presented results could be used to increase the productivity of nickel alloy machining, and it can also serve as a background for experiments for increasing the productivity of machining other metals.

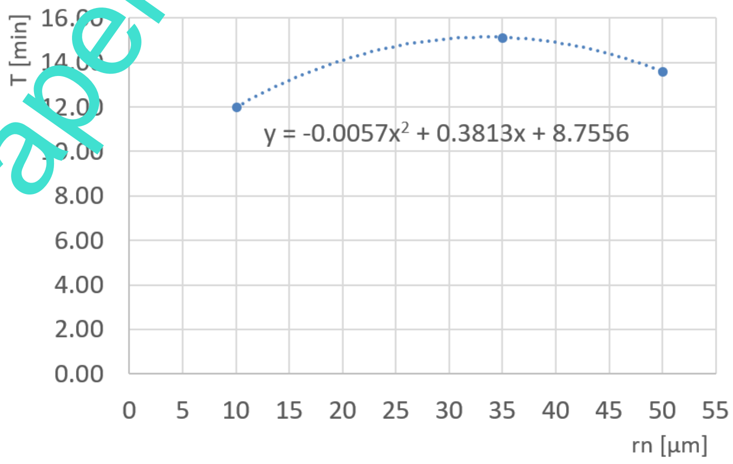


Fig. 7. Graph of the dependence of tool life on the cutting edge radius sizes r_n

4. Conclusion

This article deals with the edge preparation of cemented carbide cutting inserts. The influence of cutting edge radius sizes on the tool life was investigated when machining the difficult-to-cut material, in particular a nickel alloy Inconel 718. The cutting inserts were prepared by drag-finishing. The cutting parameters were selected with respect to the semi-finishing turning operation. This article presents the new finding on the impact of cutting edge preparation on selected aspects of the Inconel 718 machining of nickel alloy Inconel 718.
The longest tool life was achieved with a cutting edge radius of 35 µm. The average tool life for this cutting edge radius was 15.13 minutes. The tool life of the cutting insert with r_n = 35 µm was increased by 25.83% compared to the cutting edge radius of 10 µm. The tool life of the cutting insert with r_n = 50 µm was increased by 13.33% compared to the cutting edge radius of 10 µm.
Further research will examine the effect of cutting edge radius sizes prepared by various edge preparation methods on the tool life, cutting forces, and surface roughness during the milling and turning operations.

5. Acknowledgements

This research was funded by research projects APVV–16–0057 and APVV-21-0071. The authors are also grateful to the Dormer Pramet Tool Producer, who participated in this research.

6. References

[1] Peterka, J.; Hrbál, J.; Buranský, I. & Vozár, M. (2020). Design and manufacturing of cutting tools for milling. *MM Science Journal March 2020*, 3818-3821. ISSN 1805-0476.

[2] Denkena, B.; Michaelis, A.; Herrmann, M. & Pötschke, J. (2020). Influence of tool material properties on the wear behavior of cemented carbide tools with rounded cutting edges. *Wear 456*, 1-8. ISSN 0043-1648.

[3] Bergs, T.; Schneider, S. A. M.; Amara, M. & Ganser, P. (2020). Preparation of symmetrical and asymmetrical cutting edges on solid cutting tools using brushing tools with filament-integrated diamond grits. Procedia CIRP 93 (53), 873-878. ISSN 2212-8271.

[4] Peterka, J.; Pokorný P.; Václav, Š.; Pätoprstý, B. & Vozár, M. (2020). Modification of cutting tools by drag finishing. *MM Science Journal March 2020*, 3822-3825. ISSN 1805-0476.

[5] Peterka, J.; Vozár, M.; Vopát, T.; Pätoprstý, B. & Pokorný, P. (2020). Using multi-criteria analysis to evaluate the impact of drag-finishing technological parameters on the carbide tool radius. Materials Today: Proceedings 22, 205-211. ISSN 1876-6102.

[6] Pokorný, P.; Pätoprstý, B.; Vopát, T.; Peterka, J.; Vozár, M. & Šimna, V. (2020). Cutting edge radius preparation. Materials Today: Proceedings 22 (2), 212-218. ISSN 2214-7853.

[7] Wang, W.; Biermann, D.; Aßmuth, R.; Arif, A. F. M. & Veldhuis, S. C. (2020). Effect on tool performance of cutting edge prepared by pressurized air wet abrasive jet machining (PAWJAM). Journal of Materials Processing Technology 277, 116456. ISSN 0924-0136.

[8] Denkena, B. & Biermann, D. (2014). Cutting edge geometries. CIRP Annals - Manufacturing Technology 63, 631-653. ISSN 1726-0604.

[9] Vopát, T.; Podhorský, Š.; Sahul, M. & Haršáni, M. (2019). Cutting edge preparation of cutting tools using plasma discharge in the electrolyte. Journal of Manufacturing Processes 46, 234-240. ISSN 1526-6125.

[10] Malkorra, I.; Salvatore, F.; Arrazola, P. & Rech, J. (2020). The influence of the process parameters of drag finishing on the surface topography of aluminum samples. CIRP Journal of Manufacturing Science and Technology 31, 200-209. ISSN 1775-5817.

[11] Peterka, J. (2004). A new approach to calculating the arithmetical mean deviation of profile during copy milling. Strojniski Vestnik – Journal of Mechanical Engineering 50, 594-597. ISSN 0039-2480.

[12] Polakovic, M.; Buransky, I. & Peterka, J. (2008). Simulation concept for machined surface roughness and shape deviations prediction. Annals of DAAAM & Proceedings 19, 1089-1090. ISSN 1726-9679.

[13] Sentyakov, K.; Peterka, J.; Smirnov, V.; Božek, P. & Sviatskii, V. (2020). Modeling of boring mandrel working process with vibration damper. Materials 13(8). ISSN 1996-1944.

[14] Jurko, J.; Panda, A. & Behún, M. (2012). Prediction of a new form of the cutting tool according to achieve the desired surface quality. Applied Mechanics and Materials 268-270, 473-476. ISSN 1662-7482.

[15] Peterka, J. & Pokorný, P. (2014). Influence of the lead angle from the vertical axis milling on effective radius of the cutter. Precision Machining 581, 44-49. ISSN 1662-9795.

[16] Vopát, T.; Peterka, J.; Šimna, V. & Kuruc, M. (2015). The influence of different types of copy milling on the surface roughness and tool life of end mills. Procedia Engineering 100, 868-876. ISSN 1877-7058.

[17] Zhang, W. & Zhuang, K. (2020). Effect of cutting edge microgeometry on surface roughness and white layer in turning AISI 52100 steel. Procedia CIRP 87, 53-58. ISSN 2212-8271.

[18] Ventura, C. E. H.; Köhler, J. & Denkena, B. (2013). Cutting edge preparation of PCBN inserts by means of grinding and its application in hard turning. CIRP Journal of Manufacturing Science and Technology 6(4), 246-253. ISSN 1755-5817.

[19] Uhlmann, E.; Oberschmidt, D.; Kuche, Y.; Löwenstein, A. & Winker, I. (2016). Effect of different cutting edge preparation methods on micro milling performance. Procedia CIRP 46, 352-355. ISSN 2212-8271.

[20] Kolesnyk, V.; Kryvoruchko, D.; Hatala, M.; Mital, D.; Hutyrova, Z.; Duplak, J. & Alowa, M. (2015). The effect of cutting temperature on carbide drilling life in the process of CFRP/Steel stacks drilling. Manufacturing Technology. 15(3), 28-29. doi:10.21062/UJEP/X.2015/A/1213-2489/MT/15/3/357

[21] Pätoprstý, B.; Pokorný, P.; Vozár, M.; Vopát, T. & Buranský, I. (2019). The influence of grinding process and drag finishing on the milling tools macro geometry. Annals of DAAAM and Proceedings of the International DAAAM Symposium 2019; 30:1008–13. https://doi.org/10.2507/30TH.DAAAM.PROCEEDINGS.140.

[22] Vopát, T.; Kuruc, M.; Šimna, V.; Zaujec, R. & Peterka, J. (2017). Cutting edge microgeometry and preparation methods. Annals of DAAAM and Proceedings of the International DAAAM Symposium 2017:384–91. https://doi.org/10.2507/28TH.DAAAM.PROCEEDINGS.054.

[23] Šimna, V.; Jurina, F.; Vopát, T. & Kuruc M. (2019). Edge preparation of cutting tools and it impact on cutting forces during milling. Annals of DAAAM and Proceedings of the International DAAAM Symposium 2019; 30:764–9. https://doi.org/10.2507/30TH.DAAAM.PROCEEDINGS.105.

[24] Basset, E.; Köhler, J. & Denkena, B. (2012). On the honed cutting edge and its side effects during orthogonal turning operations of AISI1045 with coated WC-Co inserts. CIRP Journal of Manufacturing Science and Technology. Vol. 5, issue 2, 108-126. ISSN 1755-5817.

[25] Enders, W. J. & Kountanya, R. K. (2002). The Effects of Corner Radius and Edge Radius on Tool Flank Wear. Journal of Manufacturing Processes. Vol. 4, issue 2, 89-86. ISSN 1526-6125.