DESIGN AND MANUFACTURING OF CUTTING TOOLS FOR MILLING

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The paper deals with the design and manufacturing of a cutting tool for milling alloy Inconel 718. The tool geometry was obtained by optical scanning method. The tool from SECO Company was used as reference. The cutting tool was manufactured on a WZS 60 REINECKER tool grinding machine. Geometric parameters were checked and compared by means of optical measuring instrument ZOLLER Genius 3s.

KEYWORDS

Grinding, the cutting tools, superalloys, the tool geometry, cemented carbide

1 INTRODUCTION

Nickel-based superalloys are widely used in the manufacturing of gas turbines, nuclear and aerospace industry [Rinaldi *et al.*, 2019]. Machining superalloy is a challenging process because of its low thermal conductivity, high strength and hardness, high adhesion characteristics, high plasticity and high reactivity with the tool materials [Lu 2019]. Poor machinability results in increased cutting tool wear. Due to resulting high adhesion characteristics, changes to geometry of the cutting wedge occur. Inconel 718 may contain particles of hard abrasives and carbides that result in tool wear and tool life being reduced [Zou 2019]. Surface roughness was studied as well as the cutting force as a function of tool wear. Tool material should exhibit elevated high hardness at high temperatures, wear resistance, chemical stability, high strength, high toughness and thermal shock resistance [Mrkvica 2017].

Cemented carbides are composite materials consisting of tungsten carbide grains cemented WC in a metallic binder, usually cobalt Co. The cutting material cemented tungsten carbide has excelent mechanical properties such as wear resistance, toughness and hardness. They are produced by means of powder metallurgy [Prakash 2014]. The authors in [Hoier 2017] investigated tool wear in machining the Inconel 718 with a high pressure coolant supply. Cemented carbide milling tool was used in this experiment. An impact of the coolant on the tool surface was observed in the experiment. Author [Çelik, 2017] observed wear milling tools made of SiAlON cutting ceramics. The main mechanism of tool wear was diffusion at high cutting speeds. The author [Kasim 2019] observed quality of the Inconel 718 surface during the milling process. Ball nose end milling tools of PVD coated TiAlN/AlCrN were used in the experiment. The experiments involved varying cutting speeds, feed rate and an axial depth and width of a cut. It was found that the width of a cut causes the variation in Ra; and the feed rate influenced the quality of machined surface.

Drilling and milling operations [Baranek 2013] [Peterka 2008] require a precision geometry [Peterka 2018] and cutting tool material [Chaus 2010]. The geometry of the cutting edge sets high demands on the dimensional quality, shape and size. Material and precise shaped cutting edge is very important for accurate machining performance. The basic mechanical properties of cutting materials are toughness and hardness at high temperatures [Tönshoff 2000]. Geometry of the cutting tool has an impact on the cutting forces, chip formation, as well as on the workpiece surface integrity [Borysenko 2019]. In the paper, [Vortel 2019] deals with the determination of the effect of a controlled tool cutting edge preparation for aluminium alloy. By controlled tool cutting edge preparation the rounding of the cutting edges is achieved. Cutting edge preparation will be the goal of further research on manufactured tools.

The macro geometry milling tools is obtained during the tool grinding operation [Tönshoff 2000]. The relative motion between the workpiece and grinding wheel makes geometry of cutting tool. This process is called grinding [Karpuschewski 2011]. Grinding is a machining method for the removal of workpiece material. The grinding wheel is generally composed of a binder with abrasive material that is uniformly distributed in the whole volume. The performance of grinding wheels depends on the type of operation, coolant system, grinding parameters, machine dynamics or worn grinding wheels [Macerol 2019]. Wear of grinding wheels causes the grinding errors. Liu 2019 proposed an error compensation method based on an interaction of worn grinding wheels and the workpiece. The grinding process generated high heat in the contact area between a workpiece and a grinding wheel. High heat affects metallurgical properties of the workpiece. The company Urdiamant recommends to use coolant. Heat in the contact area between a workpiece and the wheel influenced the size of abrasive material and the wheel speed [Urdiamant 2007].

2 MATERIALS AND METHODS

Inconel 718 is a nickel-based superalloy with high corrosion resistance and superior mechanical properties at high temperatures [Çelik 2017]. This material is used for manufacturing parts which are exposed to high temperatures. It is typically used in applications where corrosion resistance, temperature resistance, and loading resistance are most desired [Mrkvica 2017]. Tab. 1 shows Inconel 718 - chemical composition.

Element	**Ni**	**Cr**	**Fe**	**Nb**
[%]	50-55	17-21	rest	4.75-5.5
Element	**Al**	**Co**	**C**	**Mn**
[%]	0.2-0.8	Max 1	Max 0.08	Max 0.35
Element	**Ti**	**S**	**B**	**P**
[%]	0.65-1.15	Max 0.015	Max 0.006	Max 0.015
Element	**Mo**	**Si**	**Cu**	
[%]	2.8-3.3	Max 0.35	Max 0.3	

Table 1. Inconel 718 - chemical composition [Mrkvica 2017]

The material for the cutting tool was made of cemented carbide. The grade of cemented carbide was K20-K40 by ISO. The properties of cemented carbide are shown in Tab. 2. The dimensions of the tool blank were Ø10h6 x 73 mm. This material is used to produce high-performance tools for machining hard-to-machine materials. The material offers high industrial quality with a price / performance ratio. Tab. 1 shows basic properties of the material. The milling tools will be used for milling superalloy Inconel 718.

Density	**Hardness**	**Binder [m %]**	**Transverse rupture**

[g.cm^{-3}]	HRA		strength [MPa]
14.10	91.7	12.0	4000

Table 2. Basic properties cutting material [Ceratizit 2019]

The tool geometry was obtained by an optical measuring method. The tool from SECO Company was used as reference. ZOLLER Genius 3s measuring machine was used to measure macro geometry of cemented carbide milling tool by SECO Company. ZOLLER Genius 3s e.g. see Fig. 1 is a measuring machine for checking and measuring all kinds of cutting tools. The measuring machine is equipped with a CNC-driven, adjustable 3D CCD camera and LED lighting. It is controlled by an optical measuring software Pilot 3.0. The flank angle of the helix at the end of the tool, the flank and rake angle, the helix angle and the total diameter and core were the parameters that were measured. Tab. 3 shows the measured macro geometry of the reference tool.

	The reference tool
Cutting length [mm]	12.5
Rake angle γ [°]	8.46
Flank angle α [°]	8.51
Flank angle α (on helix) [°]	14.22
Core diameter [mm]	5.140
Helix angle [°]	32.43
Diameter of the tool [mm]	9.970
Chamfer width 1 [mm]	1.041

Table 3. Measured macro geometry of the reference tool

Figure 1. ZOLLER Genius 3s measuring machine

The tool used for manufacturing cemented carbide was milling tool Reinecker WZS 60 grinding machine by company ULMER WERKZEUGSCHLEIFTECHNIK. The tools used for grinding were grinding wheels by the producer URDIAMANT Slovakia s.r.o. These grinding wheels were made of synthetic diamond with average grain size ranging from 50 to 62 µm. Tab. 4 shows basic properties of grinding wheels.

Grain size	D 64
Application	For medium grinding, cutting tools sharpening
Surface roughess Ra [µm]	0.4
Amount of abrasive [g.cm^{-3}]	0.88
Type of bond	Resinoid
Abrasive concetration	K 100
Cooling	Yes

Table 4. Basic properties grinding wheels [Urdiamant 2007]

The tool geometry was made by using grinding wheels with a designation 1V1, 12V9 and 11V9 [Urdiamant, 2007]. The grinding wheel 1V1 with spindle rotation speed 3634 min^{-1} was used for the operation Flute of the tool, the grinding wheel 12V9 with Spindle rotation speed 3058 min^{-1} was used for the operation Tip gash out. The grinding wheel 11V9 with Spindle rotation speed 4750 min^{-1} was used for the operations Relief 1, Relief 2 and Relief 3. The total tool manufacturing time was 9 minutes and 6 seconds. Tab. 5 shows the grinding operations and parameters.

Operation No.	The Operation	Grinding wheels type	Feed [mm.min^{-1}]	Grinding speed [m.s^{-1}]
Op.1	Flute of the tool	1V1	55	14.27
Op.2	Tip gash out	12V9	20	20
Op.3	Relief 1	11V9	30	24.92
Op.4	Relief 2	11V9	30	24.92
Op.5	Relief 3	11V9	30	24.92

Table 5. The grinding parameters

The software NUMROTOplus by the company NUM was used to create an NC code for the grinding machine. The 2D and 3D simulation is an integral part of NUMROTOplus. This software provides a complete simulation of the grinding operations. The software is equipped with an integrated collision control. Fig. 2 shows the geometry milling tool in the software NUMROTOplus.

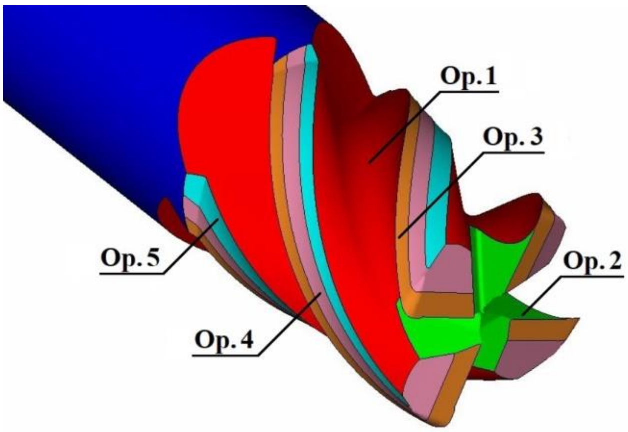

Figure 2. The geometry milling tool in software NUMROTOplus

3 RESULTS AND DISCUSSION

In this experiment, the macro geometry of cemented carbide milling tools were compared to a milling tool by SECO Company. The following parameters were compared - core diameter, tool diameter, chamfer width, helix angle and rake and flank angle. ZOLLER Genius 3s measuring optical machine was used to measure these parameters. In the following Tab. 6 the average values macro geometry of the cemented carbide tools after grinding can be seen.

	The average values macro geometry of grinded tools

Cutting length [mm]	12.467
Rake angle γ [°]	7.17
Flank angle α [°]	7.30
Flank angle α (on helix) [°]	15.77
Core diameter [mm]	5.17
Helix angle [°]	32.379
Diameter of the tool [mm]	9.979
Chamfer width [mm]	1.152

Table 6. The average values macro geometry of the manufatured milling tools

From Fig. 3, 4 the parameters of manufactured carbide tools can be seen. The biggest differences arose between the flank angle of the helix, the rake and flank angle. The minimum rake angle was 7.17° and the maximum angle was 8.46°, which means that the difference between the rake angles was 1.29°. The difference between the flank angle of the helix was 1.55° and the difference between the flank angle was 1.21°. The difference between chamfer widths was 0.111 mm. The difference between other parameters was insignificant and in the core diameter it was 0.03 mm, in tool diameter it was 0.009 mm and in the helix angle it was 0.051°.

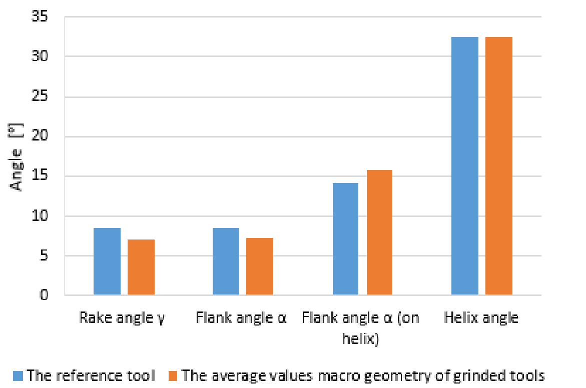

Figure 3. Comparison of parameters rake angle γ, flank angle α, flank angle α (on helix) and helix angle

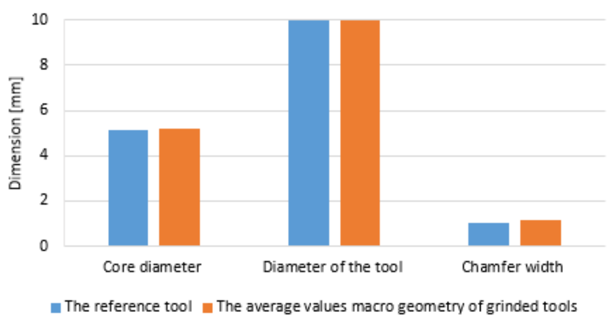

Figure 4. Comparison of parameters Core diameter, diameter of the tool and chamfer width

The previous tables showing the parameters of the milling tools after grinding indicate that the biggest differences arose between the flank angle of the helix and between the rake and flank angle. The inaccuracy could be caused by the grinding wheel wear, thermal expansion between grinding wheels and tool material or by measurement inaccuracy of the ZOLLER Genius 3s measuring optical machine.

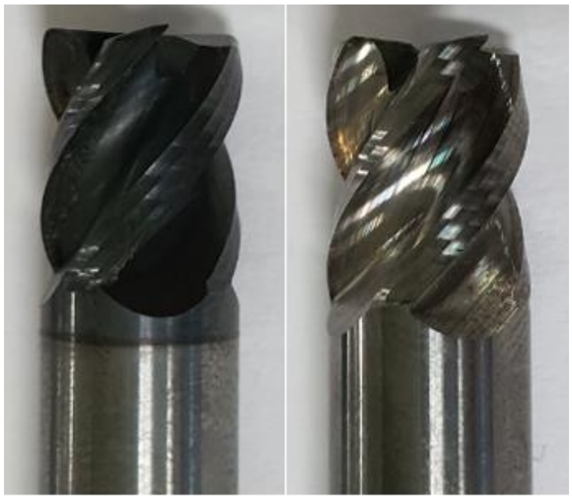

Figure 5. The geometry reference tool and grinded tool

4 CONCLUSIONS

The aim of the paper was to design and manufacture cutting tools for milling of super alloy Inconel 718. ZOLLER Genius 3s measuring machine was used in this research for measuring the milling tools. The NC code for manufacturing cemented carbide tools was created in NUMROTOplus. WZS 60 REINECKER grinding machine was used for manufacturing tools. There were investigaded differences between the parameters of the tool by SECO company and the grinding tools. The most significant differences were observed in the rake and flank angles of the helix and also on the face of the tool. The difference between the rake angles was 1.29°. The difference between the flank angle of the helix was 1.55° and the difference between the flank angle was 1.21° and in core diameter it was 0.03 mm. The difference in chamfer width was only 0.111 mm. The difference in diameter of the tool was only 0.009 mm and the difference in helix angle was less than 0.051°. The differences between the parameters of the tool by SECO Company and the grinding tools could be caused by heat in the process, wear of the grinding wheels or thermal expansion. Purpose of the research was to determine the accuracy of the grinding machine and to manufacture tools that will be used for future experiments dealing with wear behaviour of edge prepared solid carbide tools. The accuracy of the tool geometry was deviated by 0.111 mm from the diameter of the tools and 1.55° from the tool angles. The increasing number of manufactured tools reduces the accuracy of the grinding wheels. The wear of the grinding wheels increases inaccuracies in macro geometry parameters of the tools.

The accuracy of grinding wheels can be achieved by the dressing and the truing of the wheels. These operations will be subject to further research. Future research will be aimed at investigating the impact of wear of grinding wheels on macro geometry of manufactured tools and heat in contact area between a workpiece and a grinding wheel.

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