

Effects of Grinding Conditions and Strategy on the Quality of the Cutting Edge

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This article deals with the experimental grinding of cemented carbide cutting tools. Several carbide milling tools with the same geometry were ground under the different grinding conditions and strategy described in this research. The main aim is to determine the influence of the grinding process on the quality of the cutting edge. Different grinding conditions and strategies were used in grinding of the primary radial relief on the peripheral cutting edge. The cutting edge was analysed after grinding by an optical-scanning device and an electron microscope to determine the quality of the cutting edge and radial relief face of the tool. EDX analysis was used for the chemical characterization of the ground surface. The chipping of the cutting edge occurred when the grinding feed rate and the wheel spin direction was changed. The influence of the grinding conditions and strategy on the chipping formation was determined. The mean radius of the cutting edge after grinding was also measured. The results of this work will be used for further research and cutting experiments.

Keywords: Tool grinding, Radial relief, Cutting edge, Chipping, Grinding conditions

1 Introduction

Cemented carbides perform excellently as a cutting material due to the combination of hard carbide particles and a tough metallic binder. This composite material with great hardness, strength and fractural toughness is an excellent choice for the production of cutting tools used in the machining of metal alloys. The grinding process is the main process in the production of solid cutting tools to obtain the required geometry of the cutting tool. During grinding material is removed by geometrically undefined cutting edges [4]. In addition to geometry, the surface integrity after grinding is also a significant factor which affects the quality of the cutting edge and the cutting performance of the cutting tool. The grinding process causes changes to the surface by deformation, micro-cracking and residual stresses. The grinding process depends on the grinding wheel, the grinding conditions and the strategy. Diamond grinding wheels are commonly used for grinding carbide materials. The appropriate selection of wheel parameters such as grain size and concentration depend on the specific grinding operation and the required quality. The effects of grinding on surface integrity are described in [1, 12]. Micro-cracks are formed on the deformed and damaged surfaces after grinding. A thin layer containing fragmented carbides and compressive stress occurs at a depth of 12 μm [1].

The peripheral cutting edge of the solid carbide tool is created by several grinding operations depending on the tool geometry. Two major operations for grinding the cutting wedge are flute grinding and radial relief grinding. Flute parameters such as helix angle, rake angle, flute width and flute depth depend on the wheel geometry and its position during the grinding process [2]. An appropriate rake angle on the peripheral cutting edge and quality of flute surface and shape is necessary for good chip flow and optimal cutting performance. [2] deals with an accurate method for five-axis grinding of the flute with standard grinding wheels. The method described by Ren et al. [2] accurately calculates the wheel position to ensure the

accuracy of the rake angle, core radius and flute width.

Radial relief grinding creates the relief surface (radial flank) with the relief angle on the peripheral cutting edge. The rake and relief angles are the most important design factors [3]. The number and shape of relief lands depends on the design and intended use of the tool. Three shapes of the radial relief face are used for end mills: flat, eccentric and concave. The resulting shape is based on the grinding wheel geometry and the grinding method. The relationship between the grinding wheel position and the geometry of the end mill is described in [3].

Klocke et al. [4] describe a method for analysing the material behaviour during grinding of cemented carbides by a single grain cutting test, where the transition from predominantly ductile to brittle material is investigated by determining the critical chip thickness.

Complete planning and an analysis of the grinding processes for end mills on a five-axis CNC tool grinder is described in [5] where the kinematics of the grinding operations are shown.

The grinding wheel has a significant influence on the grinding process. Diamond grinding wheels proved to be suitable for grinding cemented carbides. It was found that grinding with the use of a resin bond grinding wheel provides significantly lower grinding force components during grinding [6]. In addition to grinding wheel parameters, the preparation of the grinding wheel is also an important factor which influences the material removal rate, the grinding forces and the quality of the ground surface [7]. The dressing process of an abrasive diamond grinding wheel is described in [8].

The surface damage mechanism during high spindle speed grinding was investigated in [9], where the ground surface was characterized by plastic deformed grinding grooves, extruded Co and WC dislodgement. The different wheel wear mechanisms were also observed.

The grain size of the cemented carbide affects the grinding process and the resulting surface. It was found that cemented carbides with submicron grain size have a higher surface strength after ultraprecision grinding than

carbides with micron grain size. This is due to the higher compressive residual stress of the ground submicron-structured carbides [10].

This work is mainly focused on the effect of the grinding conditions on the quality of the cutting edge. Several conditions for radial relief grinding are used by changing the feed rate and the spin direction of the grinding wheel. The resulting end-mills were analysed by electron microscope and an optical-scanning measuring device. [11] deals with the correct measuring procedure for cutting tool parameters on the cutting edge.

Tab. 1 Specification of the carbide grade

Grain size	WC [%]	Co [%]	Density [g/cm ³]	Hardness HRA	Hardness HV30	TRS [MPa]
Sub-micron	90	10	14.35	91.8	1580	3800

The grinding was performed using grinding oil SintoGrind TTK which is a high-performance grinding fluid designed for all grinding applications, especially for grinding cemented carbide.

All cutting tools were produced on a CNC 5-axis tool grinder ANCA MX7. The cutting tool geometry was constant for all variants. Specification of cutting tool parameters and geometry is shown in Tab. 2 Resin bond diamond grinding wheels were used for all grinding processes. The object of investigation was the peripheral cutting edge of the end-mill which was created by two grinding operations - flute grinding and radial relief grinding. The influence of the flute grinding on the grinding process is described in many research papers therefore this research is focused on radial relief grinding and its effect

2 Grinding details

Cemented carbide was used as the material for grinding the cutting tools. Tab. 1 shows the specifications and properties of the carbide grade. This carbide grade is produced by standard suppliers and is suitable for the production of precision cutting tools for turning, drilling and milling. The same carbide grade was used in previous research work.

on the cutting edge. The geometry of the end-mills shows two radial facets (reliefs) - primary and secondary. The primary relief is smaller and forms the flank face of the cutting edge, while the secondary relief forms a reduction of the cutting edge. The radial reliefs were ground using a straight cup diamond wheel. The specifications of the wheel are given in Tab. 3. Radial reliefs were ground by the front side of the wheel in the direction from the end of the tool to the shank of the tool. There was a small pivot angle of 3° between the wheel and the cutting tool to provide line contact of the wheel with the ground surface. The pivot angle should be small enough to ensure the flat shape of the primary relief. The grinding position is schematically shown in Fig. 1.

Tab. 2 Cutting tool parameters

Diameter D [mm]	Number of teeth	Helix angle [°]	Radial rake angle [°]	Radial primary relief angle [°]	Primary land width [mm]
8	2	30	8	10	0.3

Tab. 3 Grinding wheel parameters

Wheel shape	Diameter [mm]	Abrasive rim width [mm]	Abrasive rim height [mm]	Edge radius [mm]	Grain size	Concentration
6A9	100	5	5	0.15	D54	C125

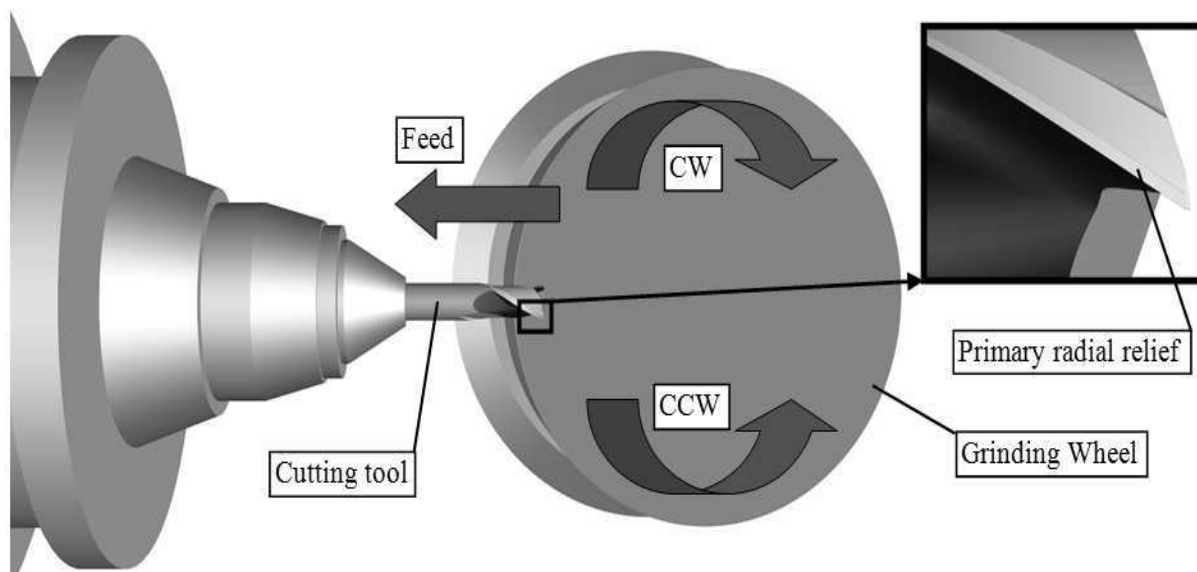


Fig. 1 Grinding wheel position and strategy of grinding

3 Grinding experiment and analysis

Several variants with different feed rates for the primary relief grinding were created to find out the influence of the feed rate on the quality of the cutting edge. By changing the feed rates of each grinding operation it is possible to change the time of the whole grinding process. Reduction of the grinding time would lead to greater productivity and efficiency of the grinding process. Grinding wheel speed was constant for all variants. Different grinding strategies were carried out by changing the spin direction of the wheel. The effect of the wheel spin direction on the cutting edge was also observed. All variants with grinding conditions are shown in Tab. 4.

The spindle load was monitored during the grinding of the primary radial relief. Changing the feed rate and the spin direction shows no difference in the spindle loads. This is due to the small amount of material removed during the grinding of the primary relief when the spindle load is always under 4%.

All the cutting tools were analysed after grinding using the optical device IFM G4, where the cutting edge of each tool was scanned. Fig. 2 shows the cutting edges of several cutting tools after grinding. The mean radius ρ_r of

the cutting edge was measured during scanning and it was used as one of the evaluation parameters. The cutting edges were scanned by a lens which corresponds to the expected value of the cutting edge radius.

Tab. 4 Grinding feed rate and strategy

Tool	Wheel speed $v_c = 20$ m/s	
	Feed rate v_f [mm/min]	Wheel spin direction
T1	20	CCW
T2	50	CCW
T3	80	CCW
T4	110	CCW
T5	140	CCW
T6	170	CCW
T7	200	CCW
T8	230	CCW
T9	260	CCW
T10	20	CW
T11	80	CW
T12	170	CW
T13	260	CW

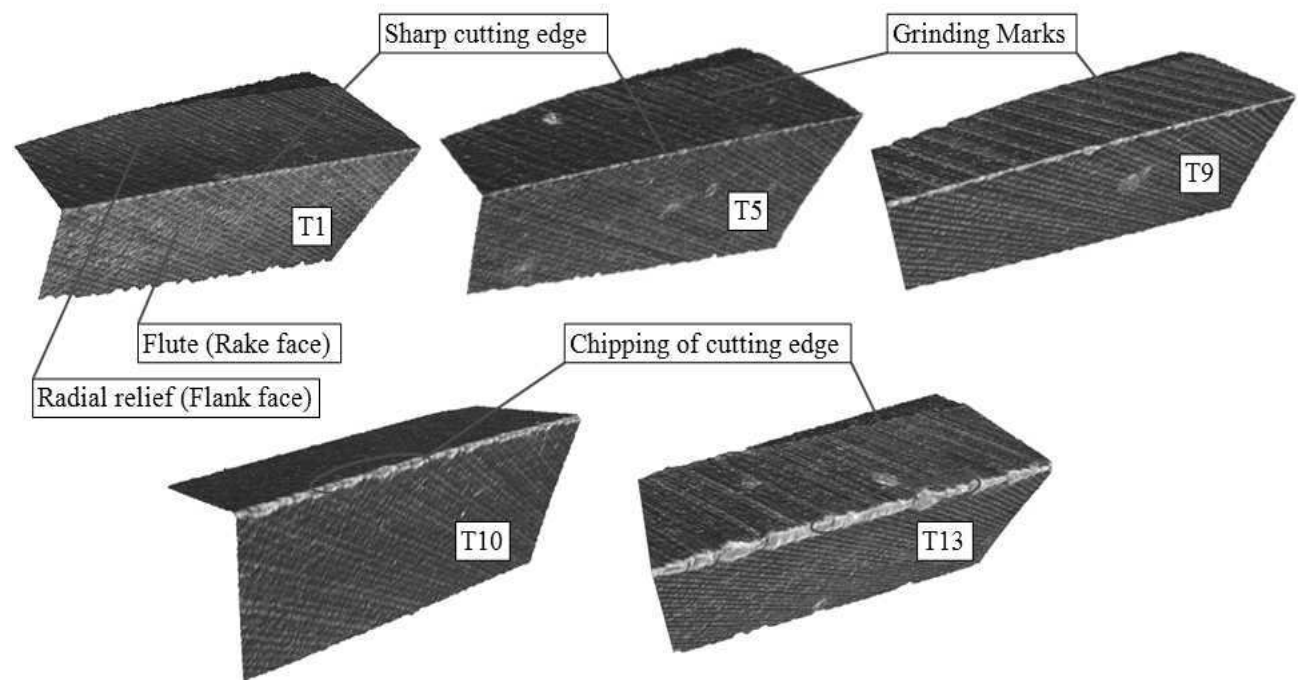


Fig. 2 Cutting edges scanned by IFM G4 optical device

Cutting tools T1 and T5 were characterized by a sharp cutting edge without chipping. The value of the mean radius ρ_r of the cutting edge was under $3 \mu\text{m}$. Fine marks left by grinding are seen on the flank face of the cutting edge. Increasing the grinding feed rate up to 260 mm/min (tool T9) shows no significant changes on the cutting edge, but some traces of slight chipping were observed. Also the marks left by grinding are rougher as the feed rate increases. However, significant changes to the cutting edge are seen when the wheel spin direction is changed from counter clockwise (CCW) to clockwise (CW). Even at a low feed rate (20 mm/min), chipping on

the cutting edge occurred on the tool T10 (Fig. 2). Chipping was more significant when the feed rate increased. Cutting tool T13 achieved the worst quality of the cutting edge after grinding because of chipping formation. The value of the mean radius ρ_r was changed from $8 \mu\text{m}$ (T10) to $13 \mu\text{m}$ (T13).

Cutting edges were analysed using a SEM-FIB Cross-Beam Auriga electron microscope to detect the initiation of the micro-cracks formation after the grinding operation. The EDX analytical technique was used for chemical characterization of the ground surface to determine the percentage content of W and Co. EDX analysis was

performed on the radial relief and the cutting edge. The result of EDX showed that changing the grinding conditions and strategy had no influence on the content of W and Co in ground surface. The width of the chipping was

measured on several cutting edges to determine an approximate relationship between the grinding process and the cutting edge quality. The width of the chipping in correlation with the mean radius ρ_r is shown in Fig. 3.

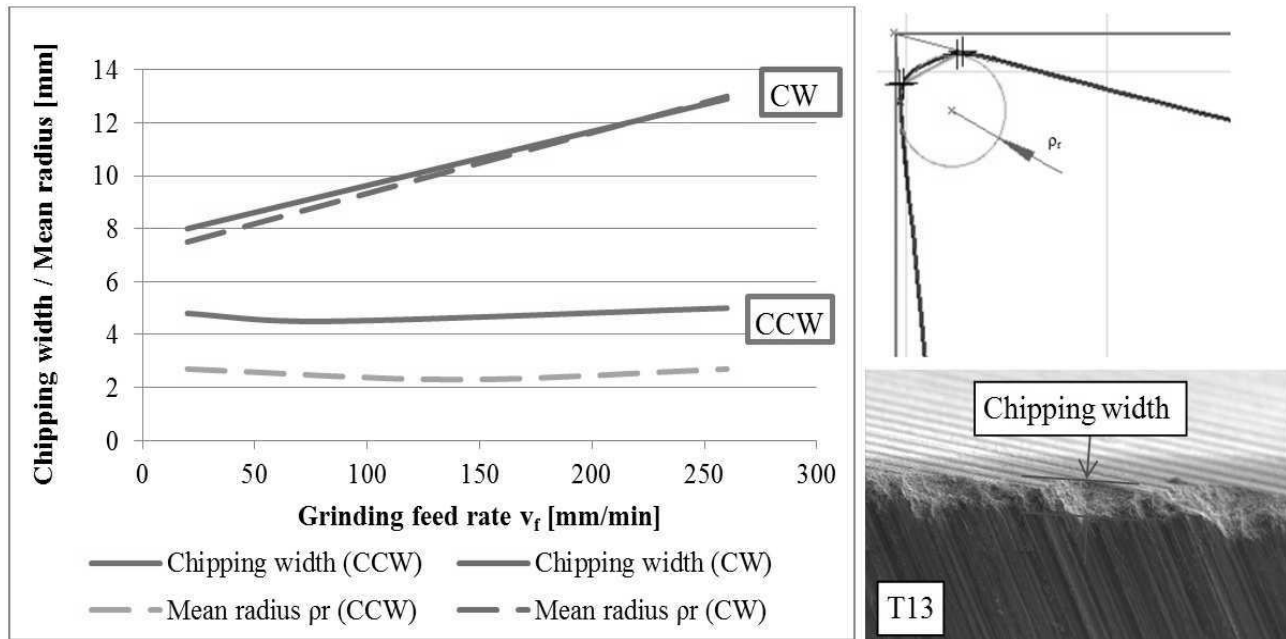


Fig. 3 Influence of grinding conditions and strategy on the chipping width and the mean radius on the cutting edge

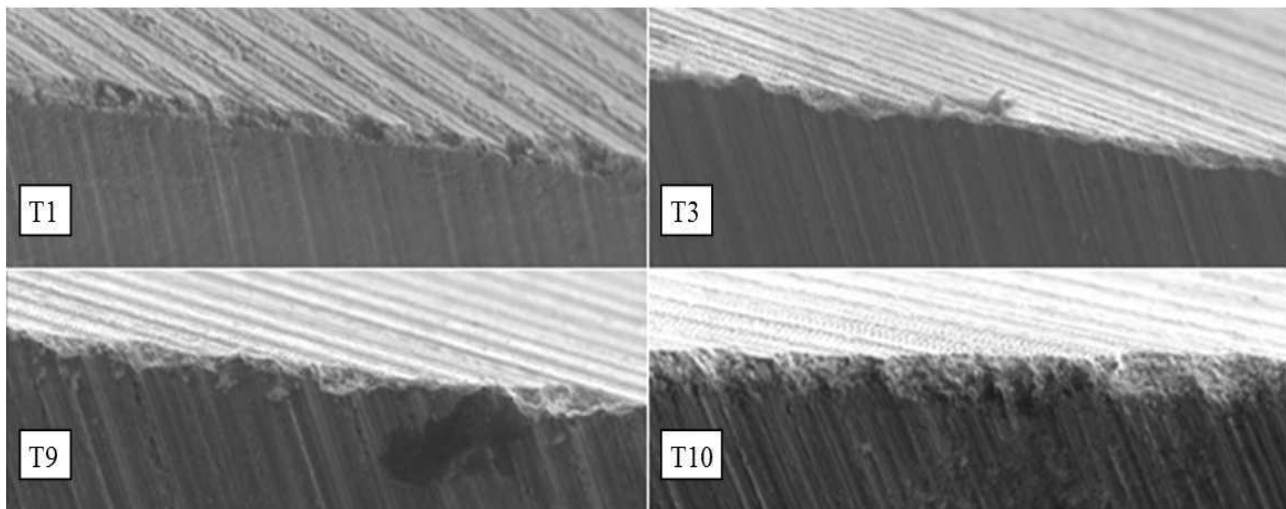


Fig. 4 Cutting edges of several cutting tools after grinding

It seems that cutting tool T1 ground at the lowest feed rate of 20 mm/min achieved a slightly worse cutting edge quality than tool T3 ground with feed a rate of 80 mm/min. This could be due to higher heat generation with a slower feed speed of the grinding wheel. Cutting tools ground using the CW strategy show significantly higher chipping formation and worse cutting edge quality, which confirmed the results obtained from the IFM G4 optical device. Fig. 4 shows the cutting edges of four of the cutting tools after grinding.

4 Conclusions

This research is focused on the influence of the grind-

ing process on the quality of the cutting edge. Several cemented carbide cutting tools were ground with different grinding conditions and strategies. Several feed rates ranging from 20 to 260 mm/min were used for grinding the radial relief face. CCW (counter clockwise) and CW (clockwise) grinding strategies were used to find out the effect of the wheel spin direction. All the cutting tools were analysed using an optical-scanning device and an electron microscope. It was found that increasing the grinding feed rate with the CCW strategy has no significant influence on the cutting edge where the value of the mean radius ρ_r of the cutting edge was under 3 μm . Slight chipping occurred when the grinding feed rate increased up to 260 mm/min. Marks after grinding on the radial re-

lief face were rougher as the feed rate increased. Changing the wheel spin direction from CCW to CW showed a significant effect on the quality of the cutting edge. Chipping of the cutting edge occurred even at a low grinding feed rate of 20 mm/min. The chipping formation increased as the grinding feed rate increased. The value of the mean radius ρ_r of the cutting edge increased up to 13 μm when the CW strategy and a feed rate of 260 mm/min was used. The spin load during radial relief grinding was always under 4%. The EDS analysis was performed on the cutting edge and the radial relief face using an electron microscope. The chipping width was also measured on the cutting edge. The influence of the grinding conditions and the strategy on the chipping width and the mean radius on the cutting edge was determined. The results of this work will be used for further research and cutting experiments.

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