

Influence of Depth of Cut on Quality of Ground Surface and Cutting Force when Grinding Cermet

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Grinding of cermet was studied to determine the impact of the depth of the cut on the grinding process and the final quality of the finished surface. Depth of cut is an important cutting parameter which affects the whole grinding process in terms of grinding stability, cutting forces, vibrations, spindle load, etc. It is also connected with other cutting parameters such as cutting speed and feed rate which should be optimized to ensure the required surface quality in the required process time. The effect of different depths of cuts on the surface quality in terms of roughness was observed during grinding of two types of cermet rods. An IFM G4 optical device was used for monitoring the surface roughness during tests. The progress of the spindle load was monitored on the grinding machine during grinding. This was used for calculating the resulting cutting forces. Experimental grinding was carried out with a diamond grinding wheel which was dressed before each grinding test. The results of this work will be used for better understanding of the process of grinding cermet.

Keywords: Cermet, Grinding, Roughness, Cutting force

1 Introduction

Modern CNC machine tools provide higher performance for faster and more accurate production of engineering components. New modern construction materials have great mechanical, physical and chemical properties. However, these properties are also associated with worse machinability. This has led to the development of new cutting tool materials such as ceramics and cermet. Cermet is now being widely investigated due to its great mechanical properties at high temperatures and its low density. In addition, cermet is widely used in the aerospace industry, for example for dry sliding bearings and gyros [1, 2]. Research [5] deals with the resistance of cermet to thermal shocks. The experiment refuted the assumption that cermet has higher susceptibility to thermal shocks than carbide. This finding was also confirmed by simulation. Grinding technology with a diamond grinding wheel is the most appropriate way for machining cermet materials. Grinding cermet is very difficult and causes many problems. The high hardness of cermet increases the cutting forces during grinding and affects the grinding stability. It also has an impact on the degradation of the grinding wheel which wears out very quickly. In addition, little cermet particles stick to the grinding wheel and cause loading and clogging of the wheel, which decreases the grinding ability. Grinding wheel performance plays a major role in the workpiece quality and process efficiency [11]. To machine cermet productively and economically we must first understand the whole grinding process and find the best way. Several studies have already dealt with the issue of grinding cermet in terms of the impact of the grinding wheel [9, 10].

To find the optimum grinding conditions it is necessary to know the influence of each parameter on the grinding process. One of these parameters is the depth of the cut, which determines the volume of the material removed during the pass. The influence of a 0.5 mm depth

cut in combination with other cutting parameters on cutting temperature was investigated in research [3]. In this research, a thermocouple was used to measure the temperature at the contact between the wheel and the ground cermet. A considerable influence of grinding conditions on temperature was observed.

A deeper cut leads to greater material resistance to cutting and this leads to the assumption of a higher cutting force. The structure of cermet also affects the cutting force during grinding. Research [4] deals with impact of TiN/TiC ratio in cermet on normal and tangential cutting forces during grinding with different cutting conditions. It was found that a higher content of TiN causes higher normal and tangential forces which lead to higher specific energy. Cutting forces also increased as the feed rate decreased.

Cermet products such as cutting tools and slide bearings require high surface quality to ensure good friction properties and durability. Surface roughness is one common parameter of quality which is important for precise production. Different grinding conditions lead to changes in the stability of the grinding process which affect the resulting surface of the workpiece. Varying combinations of cutting conditions were tested in terms of their influence on surface roughness in [6]. The research shows that high-precision surfaces can be achieved by grinding and it can replace other finishing technologies such as super-finishing or honing [6]. Properties of the finished surface are also important for the application of thin layers. Surface damage induced by grinding was investigated in [8] where the magnetoelastic response of the surfaces obtained during wet and dry grinding was compared. Poor quality of the ground surface or residual stress in the surface layer could cause poor adhesion between the surface and a thin layer. Coating adhesion and wear behaviour of coated cermet in interrupted cutting was investigated in [7]. It was found that the surface topography and integrity of the substrate material is important for meeting the requirements for sufficient adhesion of the coating [7]. The

appropriate modification of the surface integrity of cermet could increase the cutting tool life by a factor of 1.5.

This paper deals with grinding cermet with different depths of cut ranging from 0.05 mm to 0.7 mm. The main aim is to determine the influence of the depth of cut on the surface roughness of the ground surface and the cutting force during grinding. The roughness of the ground surface was measured on an IFM G4 where each sample was scanned. The cutting forces were calculated from the spindle load on the grinding machine. This research will be used in further experiments to better understand the process of grinding cermet.

2 Preparation of the experiment

Grinding was carried out on a CNC 5-axis tool grinder. A diamond grinding wheel with high quality diamonds and medium-soft bond was used for all the experiments. The parameters of the grinding wheel are shown in Tab. 1. Cermet material was in the form of cermet rods with a diameter of 8 mm. Two types of cermet materials were used in the experimental grinding to observe the differences in grinding behaviour. Both cermets were subjected to material analysis to compare the chemical composition and structure (Tab. 2). The whole grinding experiment was composed of several tests with different depths of cuts. Other grinding conditions and strategies were constant for all tests. Tab. 3 shows the values of the grinding conditions for each test. The grinding strategy is shown in Fig. 1. The grinding wheel was dressed between

each test to ensure the same conditions in terms of grinding ability of the wheel. The dressing was performed using an aluminium oxide stick. Dressing is very important to remove old and dull diamonds and expose new sharp diamonds. It also helps to clean the grinding wheel from sticking material. This is important especially when grinding cermet, where high wheel wear and clogging occur.

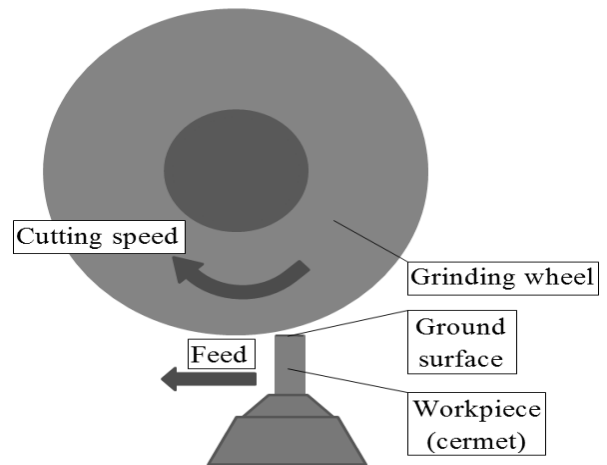


Fig. 1 Strategy of grinding

Spindle load in percentage terms was monitored during grinding. This was used for calculation of cutting force during grinding according to equation (1).

$$P = M \cdot \omega. \quad M = F \cdot r; \quad \omega = 2 \cdot \pi \cdot n \Rightarrow F = \frac{P \cdot p_p / 100}{2 \cdot \pi \cdot n} \quad [\text{N}] \quad (1)$$

Where:

P... Spindle performance [W]

M... Torque [Nm]

ω ... Angular speed [rad/sec]

r... Grinding wheel radius [m]

p_p ... Percentage of spindle load [%]

n... Revolutions [rev./sec]

F... Cutting force [N]

Tab. 1 Grinding wheel parameters

Wheel shape	Diameter [mm]	Width [mm]	Abrasive	Bond	Grain size
1A1	100	10	Diamond	Resin-bond	D64

Tab. 2 Chemical composition of cermets

	Ti [%]	W [%]	C [%]	Ta [%]	Ni [%]	Co [%]	N [%]	Mo [%]	Nb [%]	O [%]
Cermet A	40.4	20.1	9.5	11.9	5.9	5.3	4.3	1.3	1.2	-
Cermet B	49.9	11.9	15.1	-	2.5	3.9	-	14.6	-	2.1

Tab. 3 Grinding conditions

Cutting speed v_c [m/s]	20	Grinding fluid	Mineral oil
Feed rate [mm/min]	30	Strategy	Down grinding
Test	Cermet	Depth of cut [mm]	
T1A	Cermet A	0.05	
T2A	Cermet A	0.1	
T3A	Cermet A	0.3	
T4A	Cermet A	0.5	
T5A	Cermet A	0.7	
T1B	Cermet B	0.05	
T2B	Cermet B	0.1	
T3B	Cermet B	0.3	
T4B	Cermet B	0.5	
T5B	Cermet B	0.7	

Maximum spindle performance of the machine is $P = 20$ kW. Equation (1) can be simplified using cutting speed during grinding to equation (2).

$$v_c = 2 \cdot \pi \cdot n \Rightarrow F = \frac{200 \cdot p_p}{v_c} \quad [\text{N}] \quad (2)$$

Where:

v_c ... Cutting speed during grinding [m/s]

p_p ... Percentage of spindle load [%]

F... Cutting force [N]

3 Grinding experiment and discussion

Several different grinding conditions in terms of depths of cut were used during the grinding of two cermet materials to find the influence of the depth of the cut on the quality of the ground surface and the grinding force.

The grinding was performed using mineral oil, which is a high-performance grinding fluid designed for all grinding applications. The number of passes was the same for all tests to ensure the same cutting time. However, material removal volume was different because of the different depths of the cut. The roughness of the ground surface was measured after each test using an optical scanning device. Roughness was measured perpendicular to the grinding marks.

The grinding of cermet A during test T1A was characterized by high roughness after grinding. Roughness decreased with increasing depth of cut during tests T2A and T3A. After that, roughness slowly increased again with further increasing depth of cut in test T4A and T5A. These results are inconsistent with our assumption that a shallower cut leads to lower roughness and better surface quality. However, higher roughness at a shallower depth of cut can be caused by inappropriate choice of the other grinding conditions. Increases in the cutting speed or the feed rate could lead to better surface roughness due to different grinding behaviour. Therefore it is necessary to choose an appropriate combination of the cutting speed and the feed rate for shallow cuts to achieve better results on the ground surface.

The best results in terms of surface roughness were achieved in test T3A with a depth of cut of 0.3 mm for cermet A. Deeper cuts (T4A and T5A) lead to worse surface roughness. This could be caused by greater resistance of the material due to a greater volume of ground material during one pass which affects the grinding force. A higher volume of material removed also leads to higher grinding wheel wear which could affect the roughness of the ground surface. Fig. 2 shows the progress of roughness Ra and Rq during the grinding of cermet A.

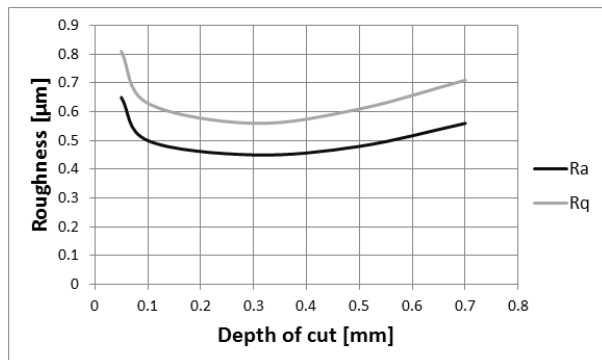


Fig. 2 Progress of roughness Ra and Rq during grinding cermet A

Grinding of cermet B was similar to cermet A. The worst result in terms of surface roughness was achieved during test T1B which was characterized by the shallowest cut. Surface roughness decreased with increasing depth of cut until test T4B. Test T5B was characterized by higher roughness than test T4B. The best results were achieved in test T4B with depth of cut 0.5 mm for cermet B. The change of roughness Ra and Rq when grinding cermet B is shown in Fig. 3.

Fig. 4 shows the comparison of the surface roughness achieved when grinding cermets A and B. It can

be seen that cermet A achieved better roughness values with a shallower cut than Cermet B. However, cermet B achieved better roughness values with depths of cut 0.5 mm and deeper.

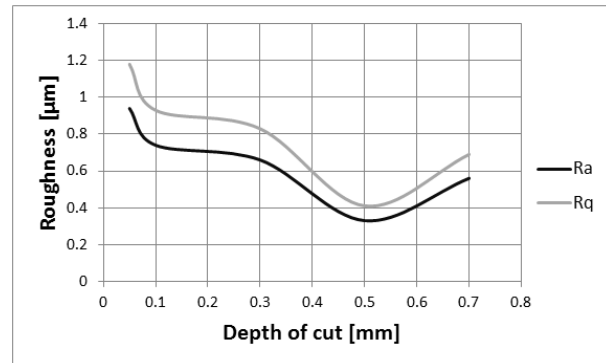


Fig. 3 Change of roughness Ra and Rq during grinding cermet B

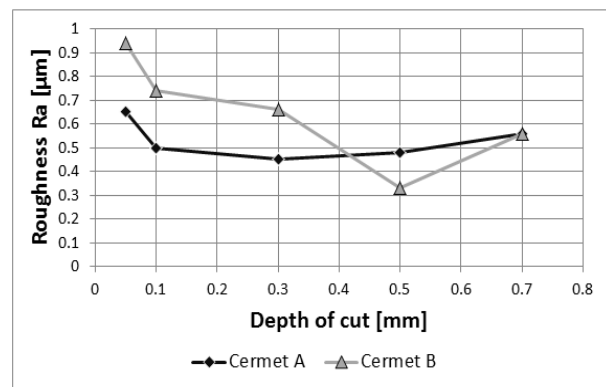


Fig. 4 Comparison of the surface roughness after grinding cermet A and B

Tab. 4 shows the volume of material removed during each test. The spindle load was monitored during each test to observe the impact of the depth of cut on the cutting force during grinding. Cutting forces were calculated using equation (2). The relationship between cutting force and depth of cut for both cermet materials is shown in Fig. 5. The cutting force was very small and approximately the same for both materials with shallow cuts. This was due to the small volume of material removed. As the depth of cut increased, the material resisted grinding which led to increasing cutting forces. With cuts deeper than 0.3 mm cermet B shows higher cutting force than cermet A. Cutting force reached 112 N when grinding cermet B compared to cermet A where the maximum value of cutting force was 88 N. This higher cutting force when grinding cermet B could be caused by its different chemical composition and structure leading to different mechanical and physical properties.

Fig. 6 shows the changes of the spindle load during 20 passes of several tests. It can be seen that the cutting force grows faster when grinding cermet A compared to cermet B. However, cermet B reached higher values of cutting forces. The increase of cutting force for cermet A can be caused by a slow loss of the grinding ability of the grinding wheel during passes. This is caused by clogging of

the grinding wheel. At the beginning of each test, the grinding wheel is characterized by sharp and dressed abrasive grains which lead to lower cutting forces. As the grinding wheel becomes clogged during passes the cutting force increases. Grinding of cermet B was characterized by a higher cutting force even at the beginning of each test and it slightly increases during passes. This behaviour during grinding shows that cermet B is harder than cermet A, which is tougher.

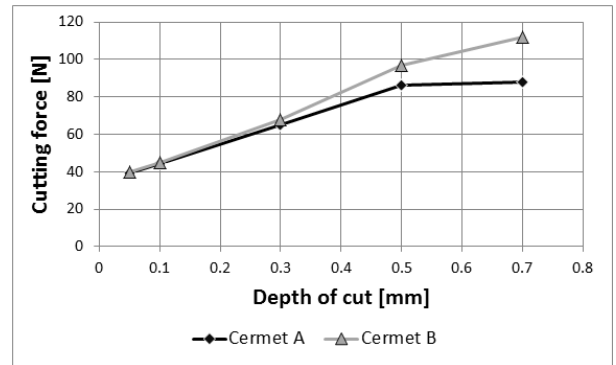


Fig. 5 Relationship between depth of cut and cutting force

Tab. 4 Volume of material removed during each test

Test	Depth of cut [mm]	Number of passes	Volume of material removed [mm ³]
T1A, B	0.05	20	50.27
T2A, B	0.1	20	100.53
T3A, B	0.3	20	301.59
T4A, B	0.5	20	502.66
T5A, B	0.7	20	703.72

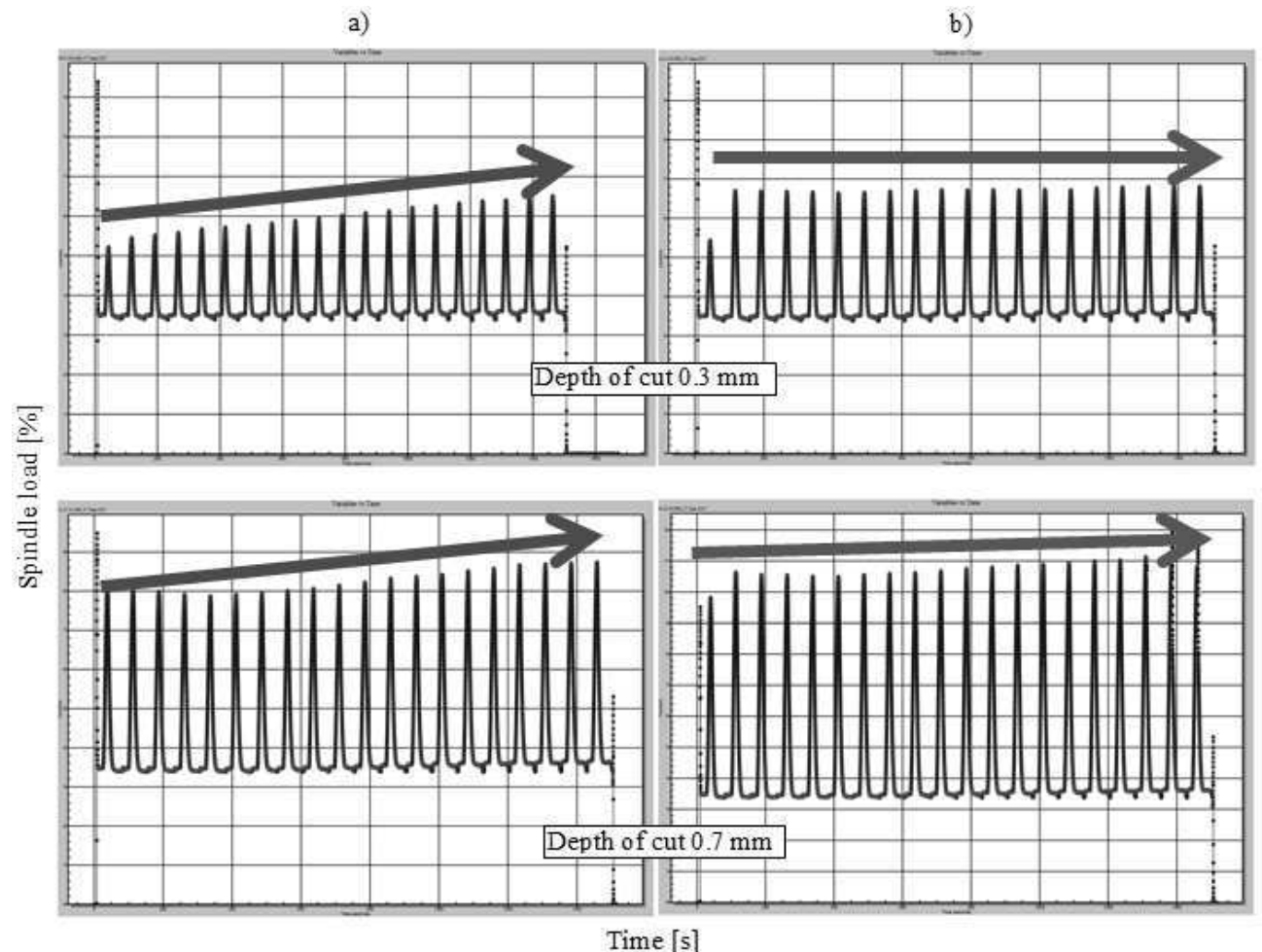


Fig. 6 Changes of the spindle load during 20 passes of several tests of cermet A (a) and B (b)

4 Conclusions

The main aim of this work was to determine the influence of the depth of cut on the surface quality and the cutting force during the down grinding of two different

cermet materials. The grinding experiment was divided into several tests with different depths of cuts. Other cutting conditions were constant for the whole experiment. The influence of the depth of cut on the surface roughness after grinding was found. The worst roughness was

achieved with the lowest depth of cut for both cermet materials, where probably higher heat and rubbing occurred. The best roughness was achieved for depth of cut 0.3 mm for cermet A and depth of cut 0.5 mm for cermet B. Deeper cuts caused higher roughness. Cermet A shows better roughness after grinding at smaller depth of cut than cermet B which has slightly better roughness for deeper cuts. The values of other cutting conditions such as the cutting speed and the feed rate must be taken into account for these results. The appropriate combination of all cutting parameters is necessary in order to achieve the best surface roughness. The spindle load was measured during the experiment to calculate the cutting force during grinding. As expected, the cutting force increased with the depth of cut due to the higher material resistance for both cermets. Cermet B reached a higher cutting force than cermet A during grinding with depth of cut 0.3 mm or deeper. This shows that cermet B is characterized by higher hardness. Cermet A achieved lower cutting force, but during the passes of each test it had a rising tendency. This could be caused by clogging of the grinding wheel during grinding. Grinding cermet B with 0.5 mm deep cut achieved better results in terms of surface roughness than cermet A. However, cermet A reached a lower spindle load during grinding. Future studies will need to focus on the combination of different cutting conditions in terms of cutting speed and the feed rate and their impact on the surface quality and grinding process when grinding cermet materials.

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