Impact of Cutting Speed on Grinding Wheel Wear and Cutting Force when Grinding Cermet

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This study is focused on research in the field of grinding cermet materials. Different grinding conditions in terms of several cutting speeds were used for grinding two cermets with different chemical compositions. A diamond grinding wheel and the same grinding strategy was used for each test. The influence of the cutting speed on the spindle load and the calculated cutting force was observed. It was found that higher cutting speed causes lower calculated cutting force but higher spindle load because of the higher RPM of the grinding wheel. This affects the grinding process and the resulting quality of the ground surface. Cracks and breakout occurred on the surface when the higher grinding wheel speed was used. The grinding wheel was dressed before each test to ensure the same grinding ability. The profile of the grinding wheel was scanned during grinding using an optical device to see the effect of the cutting speed and dressing on the wheel wear. The results of this work will be used for a better understanding of the process of grinding cermet.

Keywords: Grinding, Cutting speed, Cermet, Wheel wear, Cutting force

1 Introduction

There are a lot of different cutting tool materials on the market, which are used in many engineering applications. Modern and productive cutting tool materials such as ceramics and cermet are processed using grinding technology. The grinding process significantly influences the resulting quality of the cutting tool and its cutting properties. Grinding cermet is very difficult and has many problems associated with it, leading to long cycle times and high wheel wear. These problems are different from those encountered when grinding cemented carbide or HSS. Factors which affect the grinding process and the qualitative character of the ground surface can be characterized from several perspectives. The first factor is the machined material and its mechanical and physical properties. These properties are the result of the chemical composition and structure. The effect of the structure and chemical elements on the cermet properties has been the subject of much research [1-3]. Another factor which affects the grinding process is the grinding wheel and its properties. It was found that diamond grinding wheels are the most suitable for grinding cermet. One of the most important factors which affect the grinding process are the cutting conditions. Varying combinations of cutting conditions were tested in terms of their influence on surface roughness in [4]. The basic parameter of the cutting conditions is the cutting speed which is determined by the diameter of the grinding wheel and spindle speed.

The cutting speed in combination with other cutting parameters such as depth of cut and feed rate has a significant impact on the productivity and quality of grinding. The grinding of cermet with a cup wheel was described in research [5] where the influence of the aggressiveness of grinding on the grinding wheel was investigated. It was found that lower cutting speed and higher feed rate increases the aggressiveness of grinding which leads to lower specific energy, better self-sharpening of the grinding wheel and lower wheel wear.

Very interesting results were found in research [6] where the effect of the cutting speed on heat generation was investigated. It is commonly assumed that it is better to use a lower cutting speed when grinding cermet to reduce heat generation. It was found that when grinding cermet at a lower cutting speed (14.7 m/s), the effect called "burnout" occurred along the whole length of the contact arc between the grinding wheel and the cermet. This effect also depends on the feed rate. It was found that a higher cutting speed (29.3 m/s) leads to a higher temperature but less burnout. This was caused by better cooling during grinding. No burnout occurred when the cutting speed was increased up to 41.9 m/s. Research shows that a higher cutting speed contributes to a higher cooling effect. The impact of cutting parameters on the temperature of grinding is also described in [7]

However, this only applies to certain cutting speeds. If the cutting speed is too high the cooling effect is lost and the material is exposed to higher thermal stress. Thermal and mechanical stress during grinding affects the residual stress in the material surface. The ground surface is commonly affected by compressive stress immediately under the surface. Surface damage induced by grinding was investigated in [8] where the magnetoelastic response of the surface obtained after wet and dry grinding was compared. These stresses, however, are reduced as the cutting speed increases during grinding because of the higher proportion of tensile stress caused by extreme grinding temperature [9]. Tensile stress leads to microcrack formation and thus to damage to the surface after grinding. This is the cause of rapid tool wear, for example in the form of craters. Research [9] shows the influence of increasing the cutting speed during grinding on the depth of the craters formed when cutting 42CrMo4V steel.

Grinding cermet is accompanied by high cutting forces. This is caused by hard particles of TiC and TiN in cermet, which resist cutting. The impact of the TiN/TiC ratio on the normal and tangential cutting forces during grinding is investigated in [10]. It was found that higher content of TiN causes higher normal and tangential forces, which also leads to higher specific energy. Cutting forces during grinding are also affected by cutting conditions. The progress of the cutting forces was constant during the grinding with a cutting speed of 41.9 m/s [10]. Decreasing the cutting speed leads to a rapid increase of normal force due to burnout.

This work is focused on the impact of cutting speed on grinding two different cermet grades. The grinding wheel was measured between tests to see the influence of cutting speed on the wheel wear. Cutting forces during grinding were calculated from the spindle load measured on the machine. This research will be used in further experiments to better understand the process of grinding cermet.

2 Grinding experiment

Experimental grinding of two cermet grades from different suppliers was carried out under different cutting conditions (different cutting speeds) to observe their effect on the grinding process. Grinding was performed on a CNC 5-axis tool grinder with high precision. The same diamond grinding wheel with standard shape was used for all the experiments. The parameters of the grinding wheel are shown in Tab. 1.

***Tab. 1** Grinding wheel parameters*

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

Both cermet grades were in the form of a cermet rod with a diameter of 8 mm. Tab. 2 shows the chemical composition of both cermet materials. As we can see, cermet A is characterized by a higher tungsten content while cermet B is characterized by higher titanium content. Cermet B also has higher molybdenum and carbon content. The specification and some mechanical properties declared by the supplier are shown in Tab. 3.

***Tab. 2** Chemical composition of cermet grades*

	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** Specification of the cermet grade by suppliers*

Grade	Density [g/cm^3]	Hardness HRA	TRS [MPa]	Grain size [µm]	K_{IC} [MPa*m$^{1/2}$]	Classification of ISO
Cermet A	7.12	92.5	1900	-	-	P01 – P10 M01 – M10
Cermet B	6.40	91.8	2000	0.8 – 1.3	8.5	K05 – K10

***Tab. 4** Cutting conditions*

Feed rate [mm/min]	Depth of cut [mm]	Grinding fluid	Strategy
30	0.5	Mineral oil	Down grinding

Test	Cermet	Cutting speed v_c [m/s]
T1A	Cermet A	10
T2A	Cermet A	20
T3A	Cermet A	30
T4A	Cermet A	40
T5A	Cermet A	50
T1B	Cermet B	10
T2B	Cermet B	20
T3B	Cermet B	30
T4B	Cermet B	40

Cermet rods were cut into 60 mm lengths and clamped into the precise and stiff collet in the machine. The front face of the cermet rod was ground during each test using down grinding strategy to ensure the better stability of the grinding process. The strategy of the grinding is shown in Fig. 1. Cutting conditions during each test were different in terms of cutting speed. The remaining cutting conditions such as feed rate and depth of cut were constant for all the tests. Tab. 4 shows all the testing variants of the cutting conditions. High-performance grinding fluid was used during grinding to ensure better lifetime of the grinding wheel and stability of the grinding process.

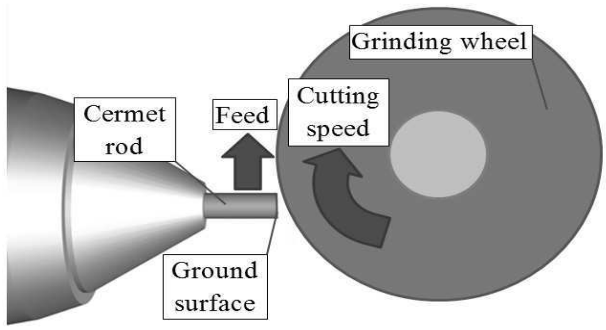

***Fig. 1** Grinding strategy*

3 Measurement and analysis

Two cermet grades were ground under different cutting conditions using a diamond grinding wheel. Degradation of the grinding wheel occurs during grinding cermet due to dulling of the abrasive grains and clogging of the grinding wheel, which is caused by cermet particles sticking on to the grinding wheel surface. Therefore dressing the wheel is very important to remove old, dull diamonds and expose new, sharp diamonds. The dressing was performed between each test using an aluminium oxide stick.

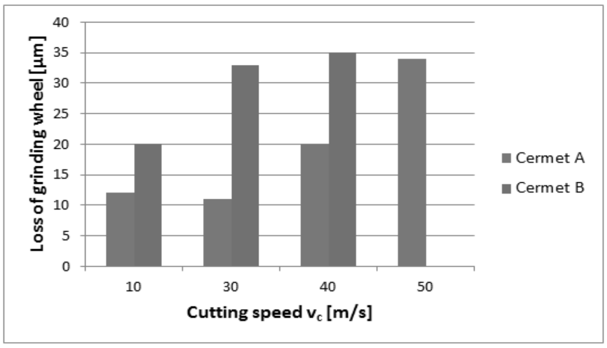

Fig. 2 *Grinding wheel wear*

Each test was composed of 20 passes with constant cutting conditions except the cutting speed. The shape of the grinding wheel was measured between each test to determine the grinding wheel wear. It was found that higher cutting speed leads to higher wheel wear intensity, which confirms the assumption of machining theory. Higher cutting speed causes higher thermal stress of the grinding wheel which leads to faster dulling of the diamond grit. Fig. 2 shows the losses of the grinding wheel after 20 passes of grinding at different cutting speeds. It can be seen that grinding of cermet B was characterized by higher wheel wear than cermet A at all cutting speeds. The greatest wheel wear of 35 µm occurred during grinding Cermet B at a cutting speed of 40 m/s (test T4B).

Too high cutting speed in combination with greater depth of cut leads to high stress which may cause damage to the surface. This happened when grinding cermet A in test T5A with a cutting speed of 50 m/s where part of the material broke away (Fig. 4). The same effect occurred when grinding cermet B at a cutting speed of only 40 m/s. Therefore cermet B was not tested at a higher cutting speed. Cracks on the ground surface were formed at a cutting speed of only 30 m/s for cermet B (Fig. 3). Relatively high brittleness and the low thermal conductivity of cermet leads to crack formation on the surface during grinding which then leads to breakage of the material. These results show that cermet B is more brittle than cermet A, which is tougher and can resist higher temperatures caused by higher cutting speeds.

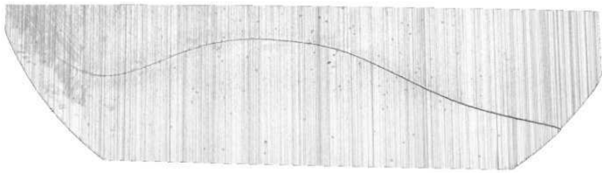

Fig. 3 *Crack formation after test T3B*

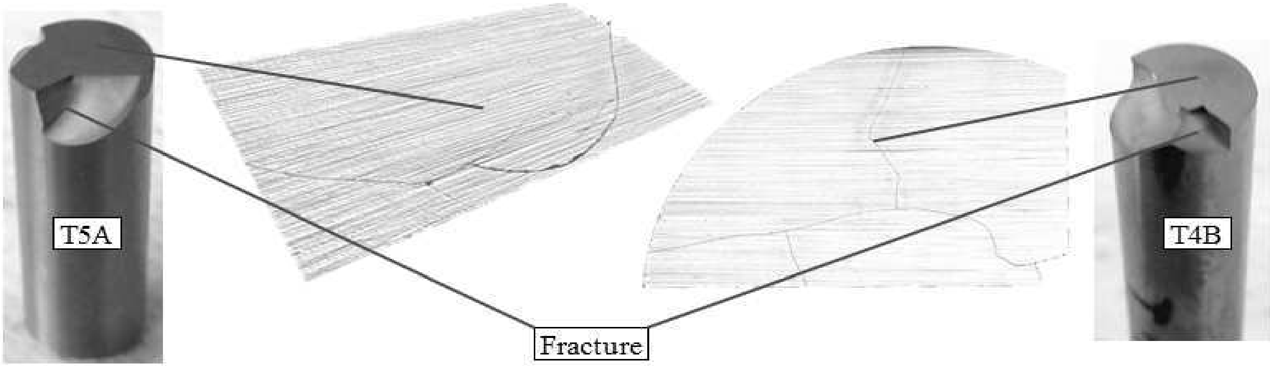

Fig. 4 *Damage to the workpiece during test T5A and T4B*

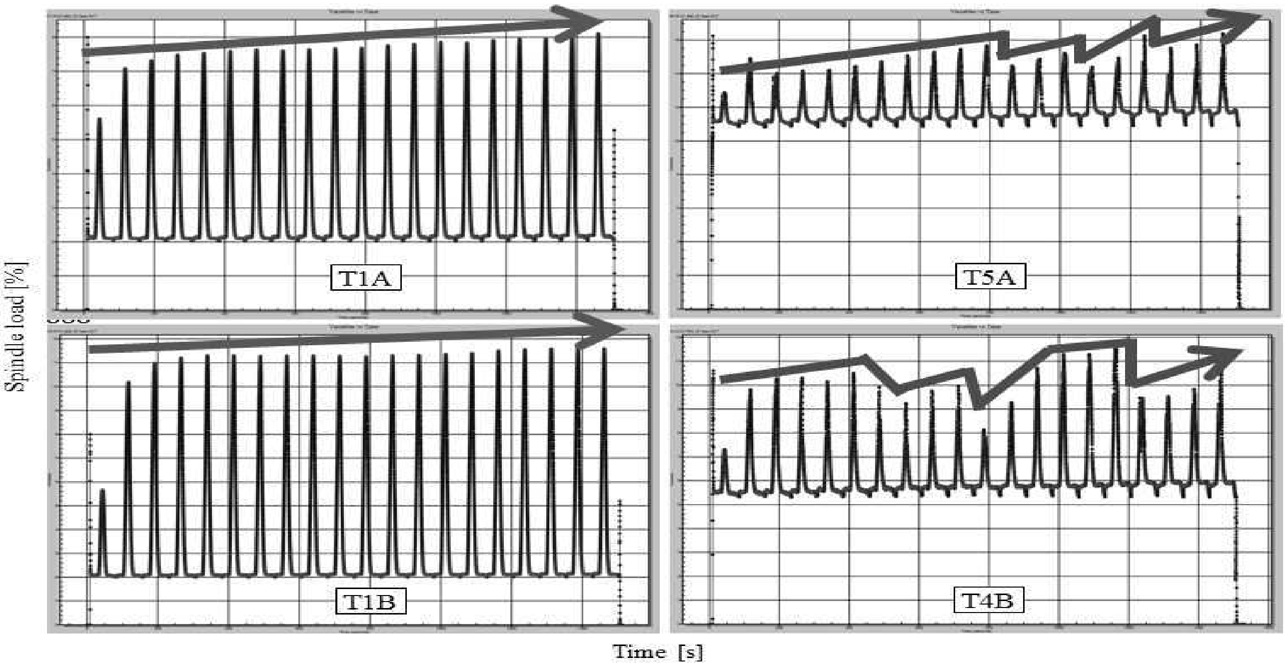

Fig. 5 *Changes to the spindle load during 20 passes*

The spindle load was monitored on the grinding machine during all the tests to observe the influence of the cutting conditions on the grinding process. Fig. 6 shows the progress of the spindle load at different cutting speeds for both cermet grades. The spindle load when grinding cermet A was about 8 % at cutting speeds up to 30 m/s. Higher cutting speeds led to an increase of the spindle load up to a value of 16 % at a cutting speed of 50 m/s. Cermet B was characterized by a slightly higher spindle load, which was constant between 10 % and 12 % for all cutting speeds. Breakage of the workpiece occurred with both cermet grades at the highest tested cutting speed. This breakage can be observed in the change of the spindle load during the last 20 passes at the highest cutting speed (Fig. 5). As can be seen, the spindle load increases during several passes and then drops sharply. This cycle is repeated during all 20 passes. The sharp drops of the spindle load are caused by breakage of a part of the workpiece, which leads to less material removal during the next pass. The breakage is more significant when grinding cermet B.

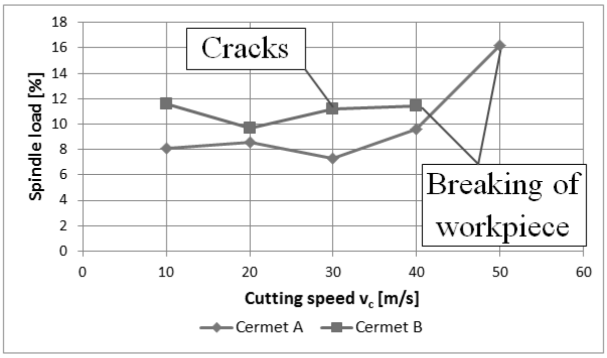

Fig. 6 *Changes to the spindle load at different cutting speeds*

Previous results show that higher cutting speed leads to higher spindle load. However, it is necessary to point out that spindle load is the total load composed of cutting force during grinding and torque required to achieve a certain cutting speed. The calculation was performed using the spindle load to determine the cutting force during grinding. Cutting force can be calculated according to equation (1).

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

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]

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

$$v_c = 2.\pi.n.r \;\Rightarrow F = \frac{200.p_p}{v_c}\,[N] \qquad (2)$$

Where:
v_c... Cutting speed during grinding [m/s]
p_p... Percentage of spindle load [%]
F… Cutting force [N]

Several measurements of the spindle load at different cutting speeds without grinding (no-cut) were carried out to see the effect of the spindle speed on the spindle load. As expected, the spindle load increases with spindle speed. Spindle load values were used to calculate cutting force according to equation (2). Fig. 7 shows the calculated cutting forces under different cutting conditions. The figure shows the changes to the cutting force during grinding (in-cut) and without grinding (no-cut). The difference between these two values is the resulting cutting force caused only by the grinding process. As can be seen, the calculated cutting force is higher at the lower cutting speed for both materials. As the cutting speed increases, the cutting force during grinding decreases.

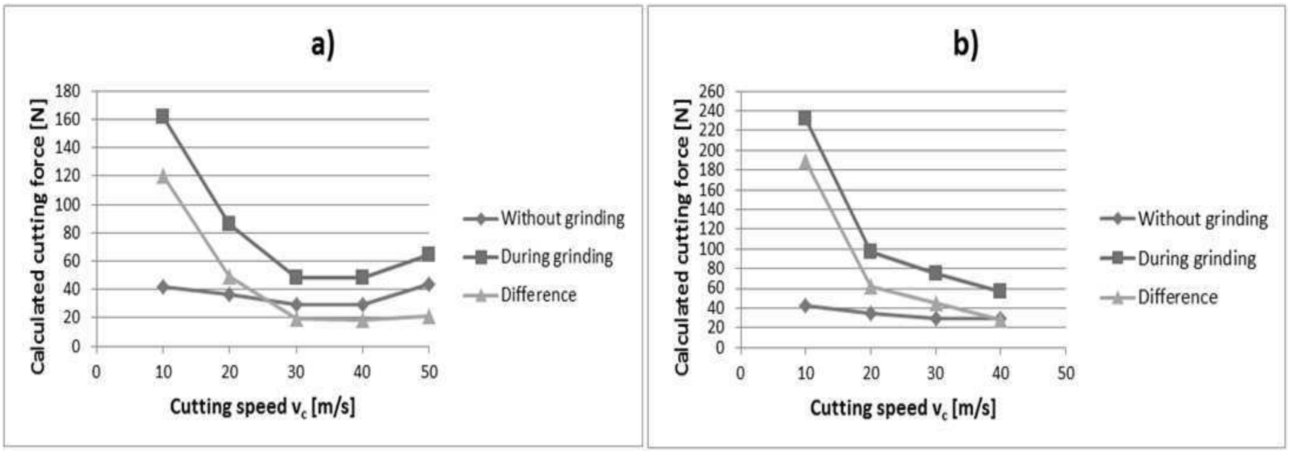

Fig. 7 *Changes to the cutting force at different cutting speeds when grinding cermet A (a) and B (b)*

The lowest cutting forces were achieved when grinding cermet A at cutting speeds of 30 to 50 m/s. However, the low cutting force at the cutting speed of 50 m/s is probably caused by breakage of the workpiece during grinding. The highest cutting force was achieved when grinding cermet B at a cutting speed of 10 m/s.

4 Conclusion

This article deals with the influence of different cutting conditions on the grinding of cermet. Two cermet grades from different suppliers were ground at different cutting speeds to see the effect of the cutting speed on the grinding wheel wear and the cutting forces. The experiment was composed of several tests with different cutting speeds and the same number of passes. Other cutting conditions were constant. The grinding wheel was measured after each test to see the losses from the grinding wheel. It was found that higher cutting speed during grinding leads to higher grinding wheel wear for both cermet grades. Grinding cermet B causes higher wheel wear than cermet A. The grinding wheel had to be dressed between each test because of significant clogging from grinding the cermet. The spindle load was monitored during grinding to see the effect of the cutting speed on the grinding process. It was found that the spindle load increases with cutting speed. Grinding cermet B was characterized by higher spindle load than cermet A. Breakage of the workpiece occurred at high cutting speeds with both cermet grades. Breakage of cermet A occurred at a cutting speed of 50 m/s while breakage of cermet B occurred at only 40 m/s. Some surface damage in the form of cracks was also observed during grinding of cermet B at a cutting speed of 30 m/s. It can be said that high cutting speeds are not suitable for grinding cermet in combination with other selected conditions. Spindle load values were used to calculate the cutting force caused only by grinding. It was found that the highest cutting forces occurred at low cutting speed and increasing the cutting speed leads to lower cutting forces. The results of this work will be used for further study of the process of grinding cermet.

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