Utilization of new modified materials in creep-feed grinding

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Abstrakt

Creep feed grinding is one of the progressive machining technologies. This method ranks among roughing technologies where the goal is to remove as much material as possible in the shortest time. Creep feed grinding has been developed due to hard-machining materials that can not be effectively machined in another way (for example nickel alloys used for turbine blades in aviation engines). The development of a new machining method goes hand in hand with the development of machining tools, in this case grinding wheels. The grinding wheel is very different from the classic tool, so the development is adapted to varios requirements. In creep feed grinding the higher porosity of the wheel is important due to the possible distribution of the cooling medium to the cutting point. However, considerable attention is paid to the shape of the grain itself, or to the self-sharpening ability of the grinding wheel. The development of new materials has come so far that today we can talk about defined blade geometry, which was not possible with classical materials.

Key words: Grinding; Creep-feed grinding; modified grain

1. Grinding

Grinding, as the primary technology of finishing machining operations, is a technology that creates a surface with higher accuracy requirements. This technology achieves the resultant surface most commonly with the use of grinding wheel, which connects different kinds of abrasive material grains to itself by binder. With respect to the increasing demands on the quality of the machined areas, the environmental aspects and the effort to optimize or minimize the production costs, it is important to adapt to these conditions even in the grinding field. One of the major developmental directions may be the use of new materials, or new types of abrasive grains, which have a directed mode of fracture or even a defined geometry of the blade.

1.1. Grinding tool

Tool generally means the physical, geometric, or any other changes of properties of the workpiece. From the point of view of the shape of the grinding tool, it may be grinding wheels, segments, bodies, powders or abrasive pastes. [1]

1.1.1. Characteristics of the grinding wheel

The grinding wheel is a set of abrasive grains, binders and pores. The outer view of the wheel then determines its shape and its basic dimensions - outer diameter, width, clamping hole, or recess.

The outer diameter plays an important role because it determines the cutting speed of the grinding wheel. The inside diameter is particularly important to the machine used for which (the mandrel) the wheel is intended. Both diameters are in a relationship that best describes the smallest possible usable outer diameter to the given grinding wheel bore. This smallest diameter is dependent on the mechanical properties as a whole, especially on cohesion and strength. Unfortunately, the grinding wheel can not have the shape of any thin-walled ring because of its brittleness.

The internal structure of the grinding wheel is interesting too, because in the entire volume of the wheel there is an indeterminate number of grains estimated within a certain range. The orientation of these grains and geometry is more or less random and therefore the paradox is that the tool of indeterminate geometry and indefinite number of cutting wedges is far more successful in terms of precision than other tools with defined geometry and number of cutting wedges.

The binder must retain the individual abrasive grains until they wear out. At the same time, the porosity of the blade must be sufficient enough for smooth chip removal. Unfortunately, porosity causes clogging of the wheel and therefore the wheel must be designed with respect to the workpiece and the chip removal ratio. [1]

1.1.2. Abrasive materials

Thanks to new production technologies, new types of abrasive grains are created, which significantly increase the technical and economic parameters of the grinding wheels and thus also the grinding itself as technology. The development of abrasive grains gradually shifts to modify the basic types of Al_2O_3 and SiC abrasives, the production of refined grain, and completely new types of abrasives. According to the time of origin, we can divide abrasive into classic, performance and modified. [2]

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a) Classic abrasive

These materials include Al_2O_3 and SiC. Both of these materials have been known for a very long time and they are widely used. SiC, however, at temperatures above 750 ° C shows a high affinity for iron and nickel. This limits its use to grinding hard non-ferrous metals. [3]

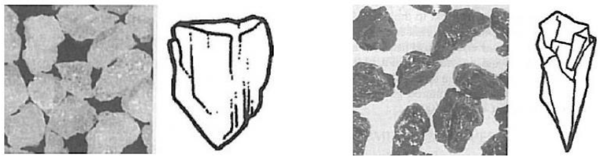


Fig. 1. White Al_2O_3 in the left, SiC in the right [3]

b) Performance abrasive

Diamond and CBN are the two hardest known materials. The diamond is resistant to all chemical influences at normal temperatures, but due to its high iron affinity at high temperatures (above 700 ° C) it is not used for machining steels. CBN, unlike a diamond, has a higher chemical stability and temperature resistance up to 1200 ° C. Against classic abrasive materials, Diamond and CBN discs offer unmatched benefits and savings (up to initial costs). The greatest benefits include high grinding performance, productivity, durability and wheel shape stability. [3]

c) Modified abrasive

If part of the grain breaks out due to wearing, this loss of particle can cause a great deal of damage to the whole grain. This can result in the use of inefficient grain in the cut. The way to prevent this effect can be to substantially reduce the size of the grain. These innovated materials are based on Al_2O_3, but the difference is in their production and other physical properties (higher hardness and better strength). Modified materials are produced by Sol-Gel technology based on controlled crystallization. The result of the process is regular grain shape and longer cutting edge durability compared to classic Al_2O_3. This group of abrasive materials is presented in practice by, for example, SG grain, which allows the cutting edges to form sharp secondary edges that allow the self-sharpening process during the grinding. [2, 4]

a) b) c) d)

Fig. 2. Grain wear: a) Al_2O_3 beforeuse, b) Al_2O_3 after use, c) grain SG before use, d) grain SG after use [3]

Innovations in the shape of abrasive grains over time have come to a defined cutting edge geometry in the form of pyramid grains. This innovation almost allow the transition from grinding to micro-milling. The grain density with this innovated type of abrasive is determined according to the FEPA methodology with a + sign (eg 60+). It is because of grain which is similar to conventional abrasive, however the expected material sampling is considerably larger due to the defined grain size. By defining the geometry, the heat is significantly more efficiently removed from the cutting point and the heat influence of both the workpiece and the wheel is minimized. It leads to less wear on the wheel itself. [5]

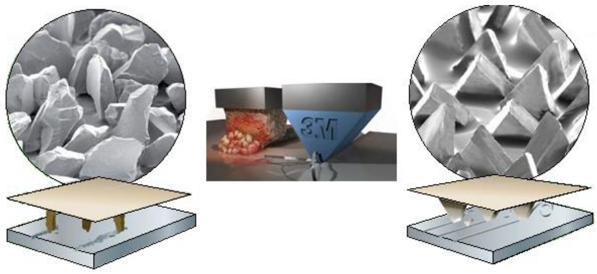


Fig. 3. Method of cutting by conventional and pyramidal ceramic grains [5]

1.2. Creep-feed grinding

In creep-feed grinding, a considerable amount of workpiece material is removed during one pass of the wheel, with a depth of cut of several millimeters. Figure 4 shows a diagram of classical and creep-feed grinding, where it is seen that unlike conventional grinding, a long contact arc is present in the creep-feed, meaning that a large circumferential part of the wheel is engaged. In general, creep-feed grinding is characterized by a high depth of cut and a low feed rate, but with new modified abrasive materials, this process can be redefined by high cutting speeds (over 125 m / s) and feed rates. In most cases, the cutting speed is about 35-40 m/s, which is a limit value for corundum grinding wheels for creep-feed grinding. For lower cutting speeds (below 125 m/s) a ceramic and resin binder is used. For creep-feed grinding, it is recommended to dress the wheel continuously to obtain the best surface, but at least it is recommended to dress it after each wheel passage. At the same time, it is important that there is enough process fluid. However, the basic problem of creep-feed grinding is that there is sufficient stiffness of machines and high power of electric motor. [6, 7, 8]

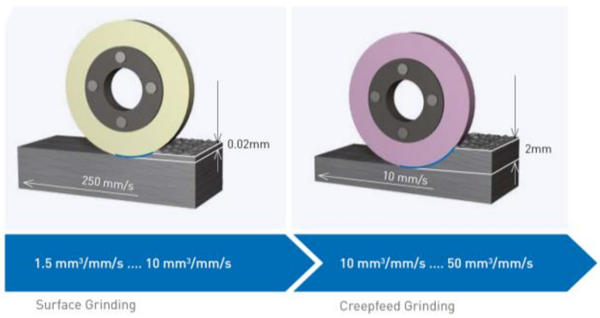


Fig. 4. Classical and creep-feed grinding [5]

1.2.1. Comparison of grinding technologies

Table 1 is an approximate comparison of conventional grinding with creep-feed grinding technology. As already mentioned above, deep grinding allows the machine to perform much more efficiently with the same result (thanks to continuous dressing), so the total machining time can be dramatically reduced under the appropriate conditions.

Tab. 1. *Grinding technologies comparison*

Technology	**Classical grinding**	**Creep-feed grinding**
Cutting speed [m/s]	to 50 (also 100 or more)	until 125, normally 35-40
Depth of cut [mm]	0.01	several mm
Number of cuts	several	one
Ra [μm]	1,6 - 0,2	1,6 - 0,2
Cooling	at higher v_c	allways
Dressing necessity	No	Yes
Pe [W]	2	20

2. Comparison of grinding wheels

The aim of the experiments was to compare the individual wheels of different producers (Tyrolit Strato Ultra, Norton Altos and 3M Cubitron ™ II - 30% and 99%) with the effort to find the optimal one for creep-feed grinding and to find the most suitable cutting conditions in terms of the ratio of force and wheel wear. The most favorable ratio of forces is considered to be where the highest cutting force and the smallest passive force.

Each producer represents another group of abrasive materials. Tyrolit Strato Ultra is a wheel with a classic grains and ceramic binder for flat oscillating and creep-feed grinding .

The structure of the Norton Altos wheel contains long cylinders with a side-to-diameter ratio of 8:1, resulting in low wheel density and the possibility of creating a radially oriented structure.

he Cubitron ™ II is characterized by a defined geometry of the grain, where the grains are triangular in shape. A large part of the resulting heat is immediately discharged by the chip, which, due to the defined grain geometry, is formed immediately after the grain has entered the material and thus there is less thermal stress (99% signifies a larger grain-to-binder ratio).

Fig. 5. *Tyrolit STRATO-ULTRA 240x15x51 mm 33A 702GG11V B1/40 (left) and NORTON ALTOS 01 225x15x50,8 mm TGX80D13VCF5 (right)*

Fig. 6. *Cubitron™ II 99% 240x15x50,8 mm 99DA54/80 F15VPLF901W (left) and Cubitron™ II 30% 240x15x50,8 mm 93DA80/80 H15VPMF601W (right)*

2.1. Microstructure

Wheels for deep grinding are generally more porous than conventional grinding wheels. The grains used in the individual wheels vary according to the producer and according to the wheel type from the classical grains to the modified with the defined cutting geometry.

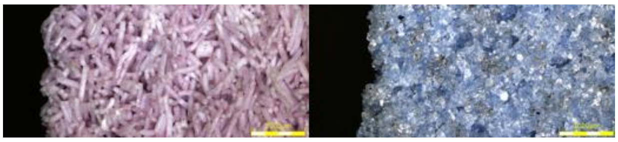
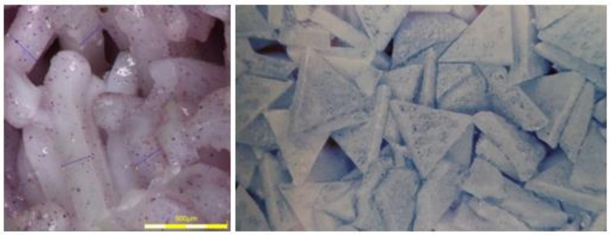


Fig. 7. *Microstructure of Norton (left) and Tyrolit (right)*



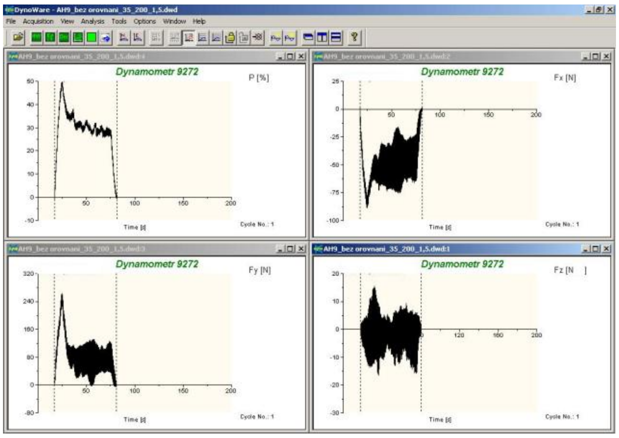
Obr. 8. *Microstructure of Norton (left) and Cubitron (right)*

2.2. Measurement of cutting forces

Fig. 9. *An example of measuring cutting forces and power with Kistler dynamometr (v_c=35 m/s, f=200 mm/min, a_p=1,5 mm)*

During the experiment, five combinations of cutting conditions were identified according to the producer's recommendations (v_c= 16-35 m/s, a_p= 0,3-1,5 mm, f= 100-400 mm/min) for which the cutting forces were measured for all four wheels. The experiment was performed in such a way that the wheel was the only variable under the same cooling conditions, the NC code and the same setting of the measuring technique.

All measurements were considered as roughing operations, as the roughing results in the largest wear of the wheel, and the highest load force. The aim of the experiments was to find the most suitable conditions and the tool for the roughing operations, which will also improve and accelerate finishing operations.



Obr. 10. *Dynamometer record in Dynoware software (v_c=35 m/s, f=200 mm/min, a_p=1,5 mm)*

Due to the different widths of all the dressing wheels and the resulting different cutting widths, the forces were recalculated and based on the millimeter of the width of the wheel. These forces are designated Fc', Fp' [N/mm]. In the same way, the power was converted to a specific power Pe' [W/mm].

Tab. 2. *Measured and calculated data from the Kistler dynamometer (v_c = 35 mm/s ; a_p = 0,8 mm ; f = 400 mm/ min)*

Grinding wheel	Fc [N]	Fp [N]	Pe [w]	Pe´ [W/mm]	Fc´ [W/mm]	Fp´ [W/mm]
Norton	38,3	110	27	87	5,6	16,2
Tyrolit	54,3	154	40	129	8	22,6
Cubitron 30%	59	123	42	133	8,48	17,67
Cubitron 99%	58	150	27,2	84	8,12	21,01

Tab. 3. *Measured and calculated data from the Kistler dynamometer (v_c = 35 mm/s ; a_p = 1,5 mm ; f = 200 mm/ min)*

Grinding wheel	Fc [N]	Fp [N]	Pe [W]	Pe´ [W/mm]	Fc´ [W/mm]	Fp´ [W/mm]
Norton	35,6	74,8	19,1	621	5,2	11
Tyrolit	100,5	325	50,7	164	14,8	47,8
Cubitron 30%	---	---	---	---	---	---
Cubitron 99%	58,5	86	27	83	8,19	12,04

Tab. 4. *Measured and calculated data from the Kistler dynamometer (v_c = 16 mm/s ; a_p = 0,3 mm ; f = 400 mm/ min)*

Grinding wheel	Fc [N]	Fp [N]	Pe [W]	Pe´ [W/mm]	Fc´ [W/mm]	Fp´ [W/mm]
Norton	42,3	93,7	30,3	98	6,2	13,8
Tyrolit	35,7	75	28	91	5,2	11
Cubitron 30%	80,5	161	61	193	11,57	23,13
Cubitron 99%	46	96,5	29	89	6,44	13,52

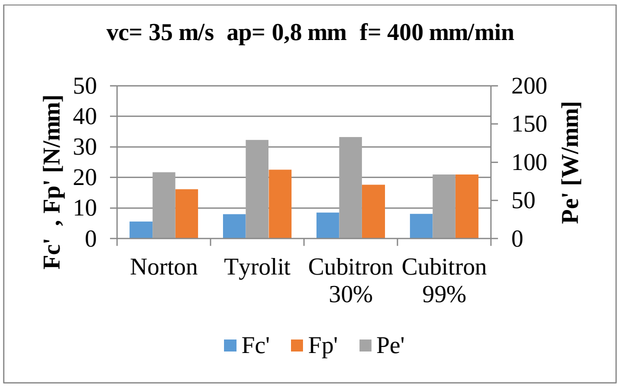


Fig. 11. *Evaluation of measured data from Kistler dynamometer (v_c=35 m/s, f=400 mm/min, a_p=0,8 mm)*

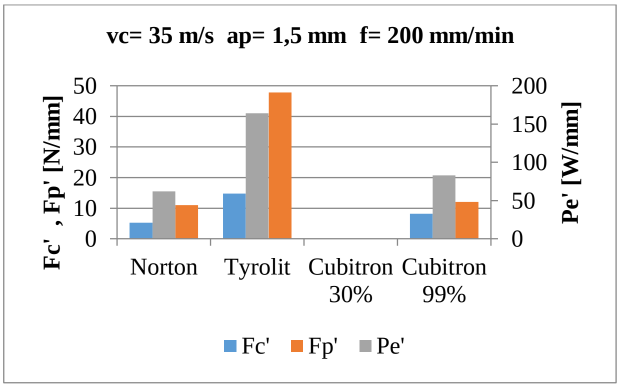


Fig. 12. *Evaluation of measured data from Kistler dynamometer (v_c=35 m/s, f=200 mm/min, a_p=1,5 mm)*

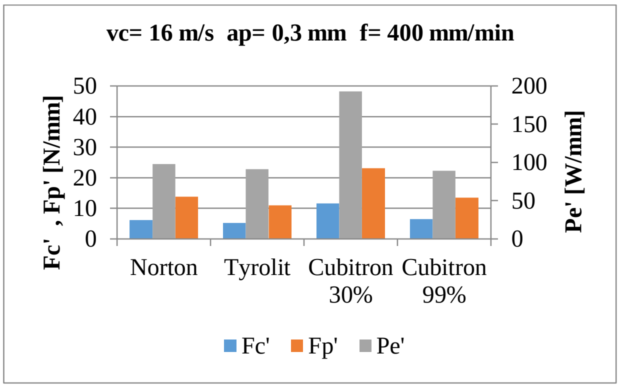


Fig. 13. *Evaluation of measured data from Kistler dynamometer (v_c=16 m/s, f=400 mm/min, a_p=0,3 mm)*

Generally, in the graphs can be seen that with a smaller machine spindle load at higher cutting speeds, with higher cutting depths, modified materials achieve considerably better performance than conventional grains.

2.2. Wear of the grinding wheels

After each passage of the grinding wheel through the groove, the wheel was dressed and a decrease in the radius of the wheel was recorded (see Table 4). The loss of the radius, as well as wheel edge wear, is an important element for determining grinding parameters. In the event of great wear of the wheel, the wheel should not be sufficiently dressed, the further grinding operations would not achieve the required precision or the wheel will need to be changed more frequently.

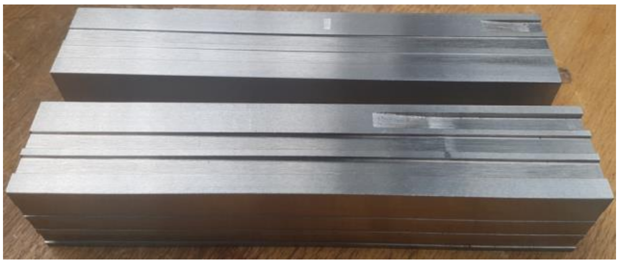


Fig. 14. *Workpices with grooves after creep-feed grinding*

Tab. 4. *Wear of the grinding wheels after one grinding cycle*

Grinding wheel	v_c [m/s]	a_p [mm]	f [mm/min]	Wear of the grindin wheel [mm]
Norton	35	0,8	400	0,06
Tyrolit				0,05
Cubitron 30%				0,07
Cubitron 99%				0,01
Norton	35	1,5	200	0,12
Tyrolit				0,12
Cubitron 30%				---
Cubitron 99%				0,05
Norton	16	0,3	400	0,04
Tyrolit				0,07
Cubitron 30%				0,03
Cubitron 99%				0,01

It is clear from the table that the loss on the radius of the wheel is approximately equal for the Norton, Tyrolit and Cubitron ™ II - 30% wheels. The smallest wear has the Cubitron ™ II - 99%, where a significant wear of 0.05 mm occurs only at high cutting speeds with high cutting depths.

3. Conclusion

By creep-feed grinding technologies are produced, for example, turbine blade locks, drill bits and milling tools, etc. Inconel 713 LC (Low Carbon) has been subjected to experimental grinding. There were measured cutting forces and load of the Mikronex BRH 20 CNC grinder with power of 2.2 kW. As tools were used 4 grinding wheels (Norton, Tyrolit Strato Ultra, Cubitron ™ II - 30%, and Cubitron ™ II - 99%).

Five combinations of cutting conditions (v_c = 16-35 m/s, a_p = 0.3-1.5 mm, f = 100-400 mm/min) were determined for the experiment, for which the cutting forces were measured with all four wheels. The experiment was performed so that the grinding wheel was the only variable, ie under the same cooling conditions, the same NC code and the same setting of the measuring technique.

In creep-feed grinding there is a long contact arc. Under some experimental conditions, this contact arc was up to 19 mm in length. This results in insufficient cooling over the entire length of the cut and possible thermal changes or cracking of the workpiece. Therefore an important aspect is sufficient coolant intake, nozzle shape, pressure and its amount. For real-condition application, it would be advisable to carry out further experimental measurements on the effect of the liquid and to find the most suitable combination of nozzle shape, pressure, and the way the coolant is delivered to the cutting point for optimal process progress with minimal thermal load.

Absolutely inappropriate conditions were the experiments with cutting speed v_c = 16 m/s. There was a high load on the electric motor. Variants with a cutting speed v_c = 35 m/s appeared to be productive.

The Norton grinding wheel seemed to be the best option with the lowest load and load on the electric motor. Unfortunately, this wheel did not suit in the shape stability evaluation. During the cutting, the edge was worn and a radius was up to 2 mm was formed at the end of the grinded groove. For shape grinding is therefore inappropriate.

As the second best was the Cubitron ™ II - 99%. It was able to maintain its shape within the allowed deviation throughout the grinding cycle and showed the smallest decrease of the wheel. However, due to the wear and resulting rounding of the cutting edge, the Cubitron ™ II - 99% must be dressed with the same infeed value as the other wheels.

The experiment generally shows the suitability of using modified grinding materials for creep-feed grinding, which are actually better in terms of stability and especially the required machine performance than using conventional grains.

List of symbols

a_p depth of cut (mm)
f feed rate (mm·min^{-1})
F_c cutting force (W)
F_c' cutting force based on 1 mm of disc width (N·mm^{-1})
F_p passive force (W)
F_p' passive force based on 1 mm of disc width (N·mm^{-1})
P_e power (W)
P_e' power based on 1 mm of disc width (W·mm^{-1})
Ra arithmetical mean deviation of the assessed profile (μm)
v_c cutting speed (m·s^{-1})

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