Lower Grinding Costs and Better Workpiece Quality by High Performance Grinding with CBN Wheels

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Introduction

A considerable improvement in the performance of the machining of hard to grind materials can be achieved by means of CBN wheels. CBN wheels feature resistance to wear and to heat development, and thus enable considerable reductions in production time without loss of quality.

However, the advantages offered by the abrasive CBN have to be weighed against disadvantages such as high wheel costs and technological and machine problems. Thus, considerable difficulties may be involved in:

- the correct grinding preparations for the CBN wheel with respect to the trueing and sharpening, and the selection of optimum machine parameters;
- the optimum selection of wheel specifications (grit size, concentration, bond type, bond hardness) for various applications, especially for high material removal rates and cutting speeds; and
- the inadequate capabilities of existing grinding machines with respect to cutting speeds and feed rates, drive power and rigidity.

Definition of terms:
Trueing: generating the macrogeometrical wheel shape within the required tolerances
Sharpening: generating a microgeometrical surface capable of grinding
Dressing: trueing and dressing taken together

This article is concerned with the complex problems outlined above. The optimization of the trueing and sharpening processes is vital for adaptation of the grinding wheel topography to the high requirements of the grindig process. A report is, therefore, given of trueing and sharpening systems that permit the generation of the required grinding wheel topography, assuming that the proper setting parameters are selected.

Additionally, an outline is given of the significance of the grinding wheel specification for the economic design of the process, and a survey is made of the influence of the machine parameters on the grinding result.

The article is concluded with an economic comparison between high-speed grinding with CBN and corumdum grinding.

Test Set-up and Test Parameters

The grinding process used in this test was drill flute grinding (Fig. 1). The drill flutes were ground in the creep-feed technique in a single pass.

The most important data for the test machine and constant test conditions are summarized in Table 1.

The workpiece material was hardened high-speed steel M2

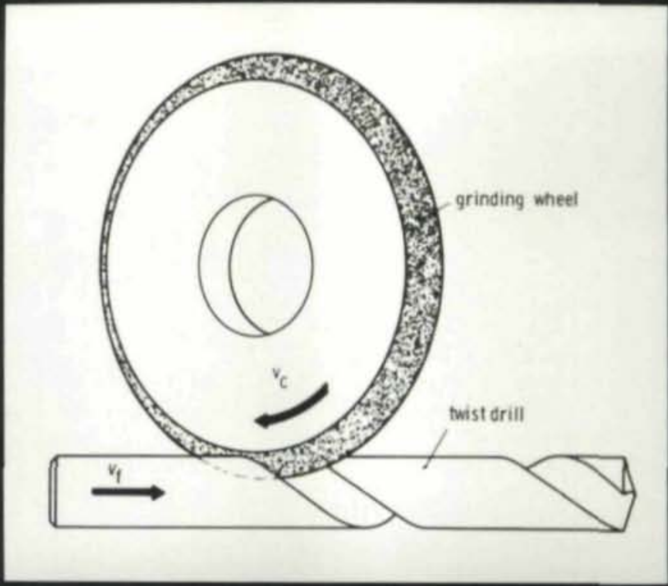

Fig. 1 – Process configuration for drill flute grinding

Drill flute grinding machine	
Type:	Gühring NS 335
Cutting speed:	v_c = 6500-23500 fpm (33-120 m/s)
Wheel diameter:	d_s = 16 in (400 mm)
Max. drive power:	P_{smax} = 80 hp (60 kW)
Feed rate:	v_f = 0-108 in/min (0-2750 mm/min)
Constant grinding parameters	
Material:	M2 (S 6-5-2) 64 HRC
Cutting speed:	v_c = 23500 fpm (120 m/s)
Feed rate:	v_f = 39;78 in/min (1;2 m/min)
Infeed:	a = 0,16 in (4,1 mm)
Material rem. rate:	Q'_w = 6,3 ;12,6 in^3/in · min (63;136 mm^3/mm · s)
Flute length:	l_n = 3,7 in (93,5 mm)
Workpiece diameter:	d_w = 0,4 in (10 mm)
Grinding width:	b_s = 0,2 in (5 mm)
Coolant:	Oil
Coolant supply:	Pressure chamber
Coolant flow:	Q_s = 32 gallon/min (120 l/min)

Table 1: Machine Data and Constant Grinding Parameters

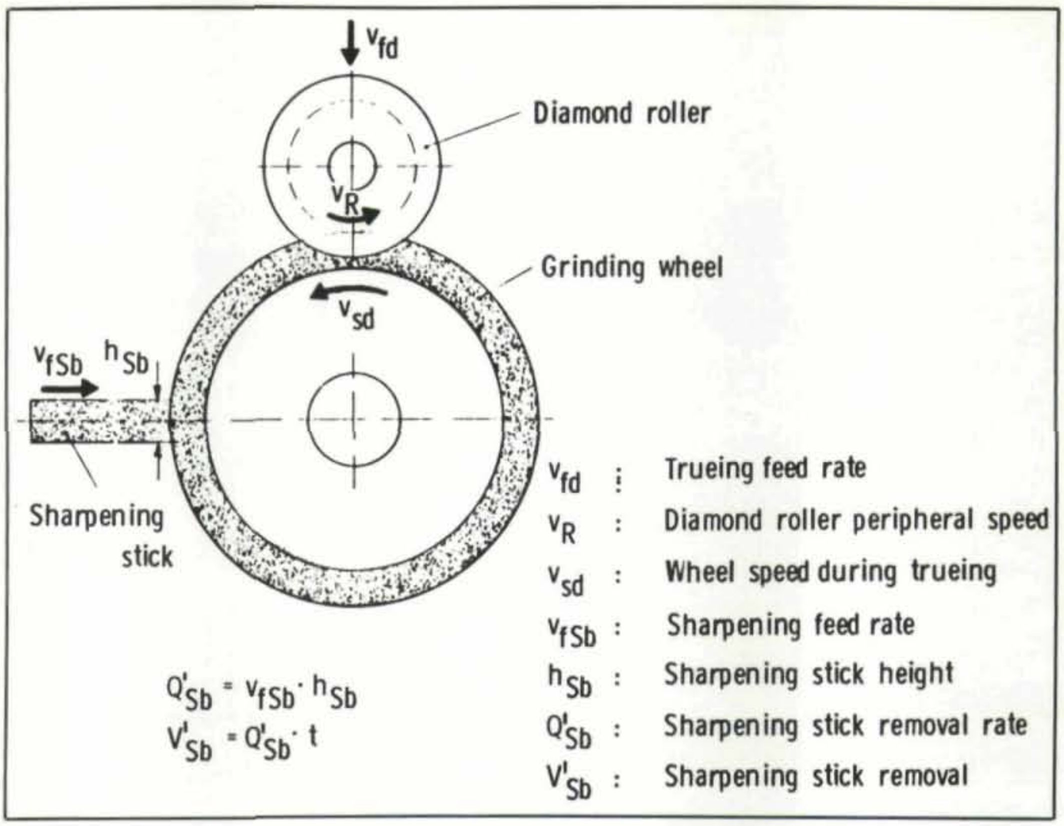

Fig. 2—Configuration of trueing and sharpening tools

(65 Rockwell cone). The coolant supply was effected with the aid of a pressure chamber system. The resinoid bond CBN wheels were trued with a diamond profile roller, and then sharpened with a corundum stick in a plunge technique. The schematic arrangement of a grinding wheel, trueing roller and sharpening stick is shown in Fig. 2.

Grinding Preparation of CBN Wheels

The grinding preparation of a multiple layer CBN wheel, divided into the trueing and sharpening operations, is one of the main problems of CBN grinding technology.

CBN wheels in resinoid bonds, permitting high grinding speeds ($v_c \geq 17,650$ fpm), can be trued quickly and accurately without dismounting them from the grinding spindle, by the means of a diamond trueing roller, or profile roller.[2,3]

After trueing with a diamond roller, the surface of the CBN grinding wheel has no more grit protrusion (Fig. 3, top). The CBN grits and their bonds are cleanly cut. Additionally, there are recesses, or holes, in the bond—this is where the grits have been partly or completely removed from their bonds.[1,4]

The grinding wheel is not capable of cutting when it is in this condition. The bond material between the CBN grits must be set back by a certain amount in order for the coolant to be transported to the contact zone, and also to provide enough space for chip removal from the contact zone. The process of setting back the bond is known as sharpening. This is done by feeding a corundum sharpening stick into the grinding wheel surface at a constant feed rate. Variations in the sharpening parameters cause a considerable variation in the wheel topography, so that the optimization of the sharpening process is extremely important.

The middle row of the photos shows the wheel surface that is generated with comparatively small sharpening stick removal rates and removal volumes. The cutting edges of the grits protrude from the bond, and they are supported at the

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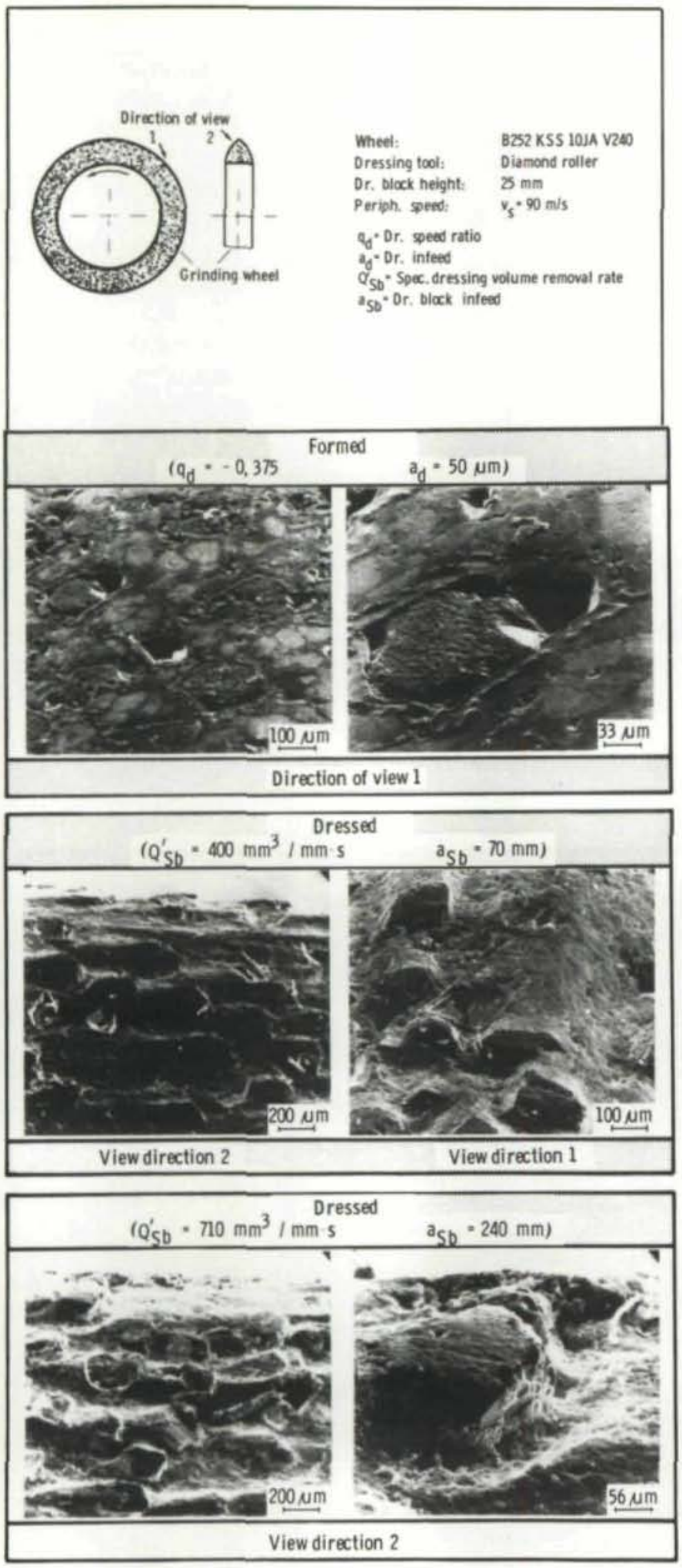

Fig. 3—The wheel cannot grind until it has been sharpened

rear by a bond backing that helps to retain them during the grinding process.

If the sharpening stick is fed in at a very high feed rate, there is a topography change due to the considerable increase in grit protrusion. This decreases the retention of the CBN grits in the bond with considerable grit breakout due to the forces exerted. If the sharpening process is too long, i.e. too

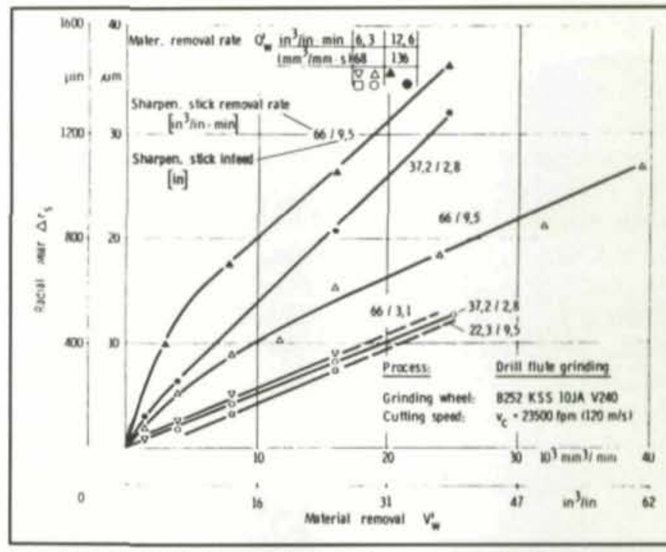

Fig. 4—Optimization of sharpening process minimizes wear

much sharpening stick volume is removed, wheel topography is likewise changed due to bond erosion.

The bottom row of the pictures shows part of the surface of a grinding wheel which has been sharpened with approximately double the feed rate, and three times the volume of corundum sharpening stick. Bond removal is particularly great in the immediate vicinity of the grit, as the corundum particles pile up in front of the CBN grit and flow around its sides.

The sharpening stick feed, or sharpening stick removal rate, and the sharpening stick removal must thus be set in such a way as to generate an optimum grinding wheel topography for the subsequent grinding process, that is dependent on the grinding wheel specification and machine parameters.

The effect of sharpening behaviour on the grinding process will now be illustrated by considering wheel wear, as shown in Fig. 4. If the sharpening conditions are too hard, this has a negative effect on wear behaviour, as can be seen from the lower family of curves for $Q'_w = 6.3$ in^3/in.min. The bond is set back a long way and the CBN grits are loosened by excessively long sharpening ($Q'_{Sb} = 66$ in^3/in.min, $a_{Sb} = 9.5$ in), which causes a considerable increase in the wheel wear. An optimization of the sharpening conditions provides considerable reduction in initial radial wear.

The sharpening stick removal rate at which the specified wheel topography, characterized by the peak-to-mean-line height R_{ps} of the wheel, is generated, can at present be calculated by the application of a mathematical model. Further parameters which are included in the model are the wheel specification and the wheel peripheral speed during sharpening:

$$Q'_{Sb} = 0.95\, q_m^{-1} \sqrt{c_k \left(1 - \frac{R_{ps}}{w_m\, q_m\, \epsilon_{crit}}\right) R_{ps}^{5/2}\, v_c} \qquad (1)$$

Where:

- q_m : longitudinal stretch coefficient of the CBN grits ($q_m = 1.41$
- c_k : no. of grits per volume unit of grinding layer
- R_{ps} : peak-to-mean-line height of grinding wheel
- w_m : mean mesh width
- ϵ_{crit} : critical grit protrusion related to grit diameter
- v_c : cutting speed during sharpening

The number of grits c_k and the mean mesh width w_m are dependent on the grinding wheel specification, and can be taken from the corresponding tables.[1]

The critical grit protrusion ϵ_{crit} is an expression for the amount that a grit can protrude over the bond level without breaking out under the forces exerted during sharpening. Tests gave a value of $\epsilon_{crit} = 44\text{-}46\%$ for resinoid bond wheels. The peak-to-mean-line height of the wheel R_{ps} describes the chip space generated by the bond removal. Due to the integral character of this expression, its reaction to individual holes in the bond caused by grit breakout is relatively insensitive. An R_{ps} value of 25-30% of grit diameter has led

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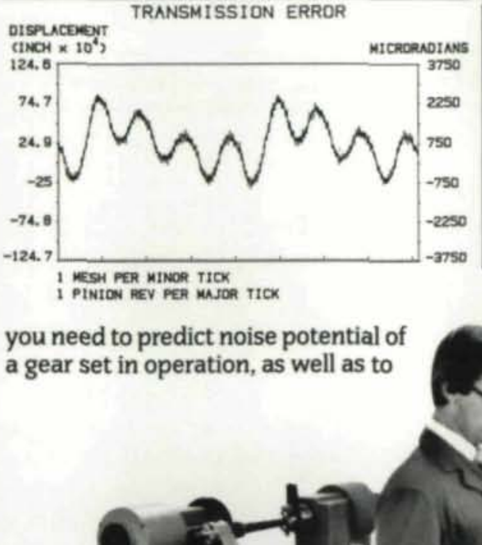

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AVG T-T TRANS. ERROR	+.0002	+.00020	REJECT
# OF BURRS OVER TOL	+3.0000	+0.00000	
MAX EFFECTIVE PROF VAR	+.0003	+.00010	++++
AVG EFFECTIVE PROF VAR	+.0002	+.00010	+++
COMB. ACC. PITCH VAR	+.0050	+.00500	REJECT
COMB. MAX PITCH VAR	+.0007	+.00050	++++
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to satisfactory results in the investigations made so far. Research work is at present being carried out for a precise description of the peak-to-mean-line height R_{ps} adapted to the process parameters (cutting speed v_c, specific material removal rate Q'_w, workpiece material characteristics).

Fig. 5 shows the functional relationships with the aid of a nomogram. This form of presentation makes it possible to determine the specific sharpening stick removal rate for any values of the above variables, starting from the wheel specification, and proceeding via the critical grit protrusion ϵ_{crit}' peak-to-mean-line height R_{ps} and cutting speed v_c.

The specification of the sharpening stick removal rate must be followed by the determination of the sharpening stick removal. The characteristic of sharpening force or grinding power can be used for this purpose. During the sharpening process, these two characteristics drop from high initial values to steady state final levels. In this steady state phase, the bond removal has practically come to a standstill. If the sharpening process is stopped here, this results in the favorable linear wear behaviour of the grinding wheel, which is possible with this sharpening stick removal volume. Further infeed of the sharpening stick beyond this time gives no major bond removal, but in any case it loosens the CBN grits and, thus, causes excessive initial wear.

A further measure for the optimization of the sharpening process would be simultaneous trueing and sharpening.[5] This modified procedure, i.e. the infeed of a sharpening block during the trueing process itself, not only gives a reduction in trueing time, but also permits the achievement of considerably longer dressing roller life as shown in Fig. 6.

Here the sharpening stick has the task of setting back the bond continuously, so that the dressing roller simply removes the protruding CBN grits, and does not come into contact with the bond. Without the sharpening stick infeed, the diamond crystals of the dressing roller would not only cut the CBN grits, but also the tough bond mass, resulting in high friction, high temperatures and consequently high wear of the diamond grits. A further advantage of simultaneous trueing and sharpening is that the wheel has a slightly rough surface after a profiling process of this kind. This reduces the time required for the subsequent sharpening process.

Influence of Grinding Wheel Specification

In addition to optimization of the trueing and sharpening parameters, careful wheel selection has also the purpose of achieving the best possible combination of workpiece quality, machining time and tool life. A comparison is therefore made below of the grinding behaviour of resinoid bond CBN

$$Q'_{Sb} = 0{,}95\, q_m^{-1} \sqrt{c_k \left(1 - \frac{R_p}{w_m\, q_m\, \varepsilon_{krit.}}\right)}\, R_p^{2,5}\, v_c$$

Longit. stretch coeff. $q_m = 1.41$ (CBN)

Grit size US-Mesh	Grit size FEPA	Mesh w_m [µm]	Grit concentration $K \cdot 10^3$: 60	120	180	240	300
240	64	58	416	833	1250	1666	2082
180	91	83	142	284	426	569	711
150	107	98	86	173	259	345	432
120	126	117	51	101	152	203	254
100	151	137	32	63	95	126	158
80	181	165	18	36	54	72	90
60	251	231	6,6	13	20	26	33
			Grit density c_k [mm^{-3}]				

$$c_k = \frac{6}{\pi} \frac{K}{q_m w_m}$$

$q_m = 1,41$

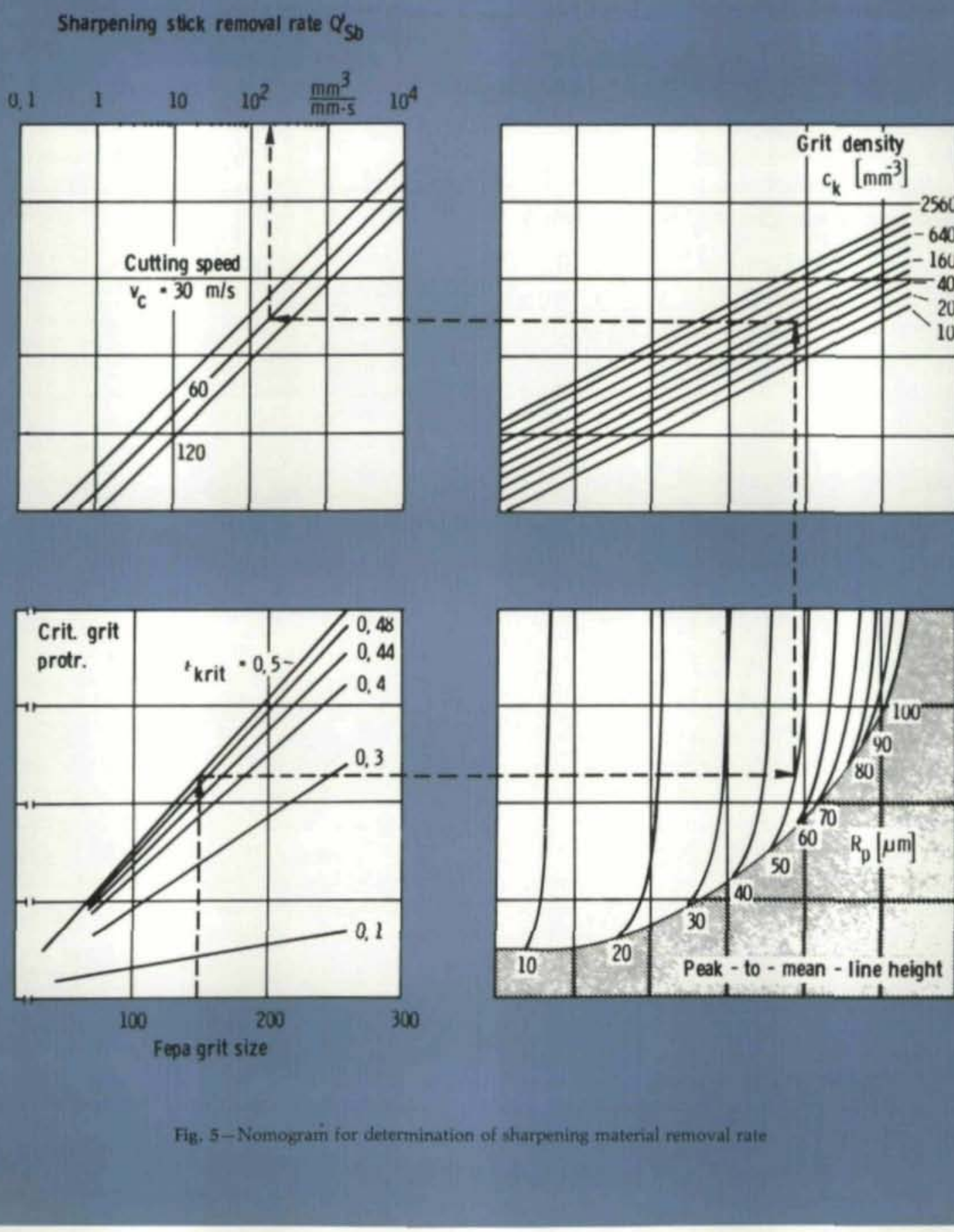


Fig. 5—Nomogram for determination of sharpening material removal rate

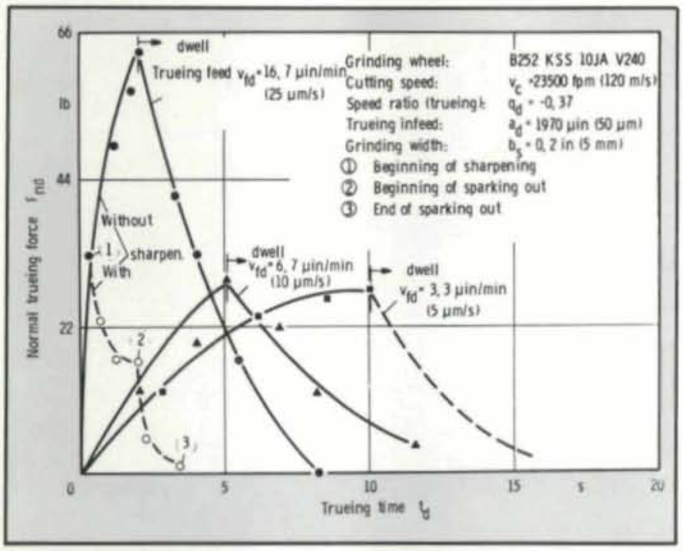


Fig. 6 – Simultaneous trueing and sharpening minimizes dressing time and increases trueing tool life

wheels of different grit size, concentration and bond hardness.[6] The advantages and disadvantages of electroplated wheels in high-speed grinding are subsequently discussed.[7]

Resinoid Bond Wheels

One of the causes of progressive wear of a grinding wheel is a change in grit geometry during the machining process. Thermal, chemical or mechanical stresses result in a dulling of the cutting edges that are engaged in the cutting process; this is designated as grit wear Δr_k.

However, grit geometry changes are not the only reason – wheel wear is also caused by breakout of complete grits. The factors determining grit breakout are the combination of the stress attacking the individual grit and the capability of the bond material to retain the grit under this stress. Fig. 7 shows the principle of the chain of effects leading to grit breakout, neglecting the influences from machine parameters and grinding wheel specifications.

Dulling of the grits causes greater friction with the workpiece material, increasing the individual grit force F_k. Considering the material characteristics of the bond as a constant for the moment, the depth of bond embedding is decisive for whether or not the grit breaks out under the load. The embedding depth and, thus, the grit protrusion is determined by the cutting products which set back the bond in the area of the grit so far that there is sufficient chip space available. In order to maintain this space, the embedment depth is constantly reduced with increasing grit wear Δr_k, so that the force $F_{k\,max}$ required for grit breakout also constantly decreases. The opposite tendency of the individual grit force F_k and the grit breakout force $F_{k\,max}$ automatically leads to grit breakout when the equilibrium of force is attained.

Considering the effect of changes in machine parameters and grinding wheel specifications, it is possible to differentiate between those that affect individual grit force and those that affect grit breakout force. Grit loading is determined by

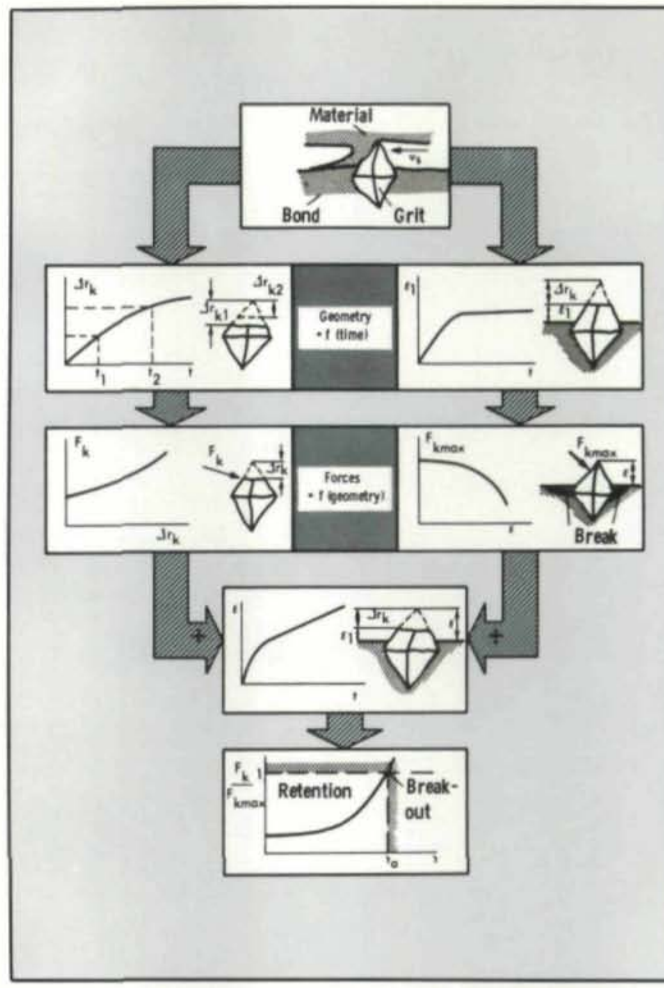


Fig. 7 – Wear on grit and bond lead to grit breakout

the number of cutting edges which, depending on the wheel specifications and the machine parameters, are involved in the cutting process and to which the cutting forces are distributed. Thus, a higher grit load might either be caused by an increase in material removal rate or by a decrease in cutting edge density c_k (number of grits per volume unit, Fig. 8), as results from larger grit size or lower grit concentration.

The level of grit breakout force and the embedment depth at which grit breakout occurs depends decisively on the bond material and on the grit use. Larger grits are better anchored in the bond and thus permit higher cutting edge load. Model investigations on ideal octahedral grits showed a load capability rising with the square of the grit diameter for constant relative embedment depth.

With all the grinding wheels examined, a doubling of the material removal rate resulted in a considerable decrease in the grinding ratio, which was to be expected in view of the higher grit load and the greater chip room requirement.

A comparison of grit sizes shows that the smaller grit B 151 is considerably superior to B 252 for both the bond types and removal rates as shown in Fig. 9.

Assuming that the kinematic cutting edge number $N_{k\,in}$, i.e. the number of grits involved in the cutting process, changes in the same proportions as grit density, it is only 21%

Grit size US-Mesh	Grit size FEPA	Mesh w_m [µm]	Grit concentration, $K \cdot 10^3$: 60	120	180	240	300
240	64	58	416	833	1250	1666	[illegible]
180	91	83	142	284	426	569	711
150	107	98	86	173	259	345	432
120	126	117	51	101	152	203	254
100	151	137	32	63	95	126	158
80	181	165	18	36	54	72	90
60	251	231	6,6	13	20	26	30
			Grit density c_k [mm^{-3}]				

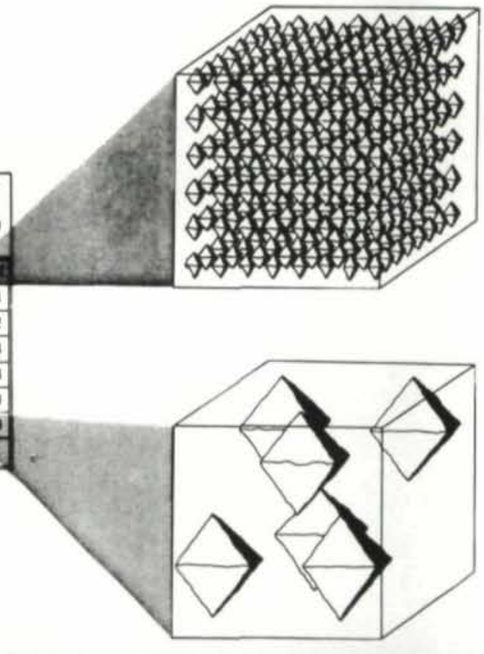


Fig. 8 – Grit density increases progessively with decreasing grit size

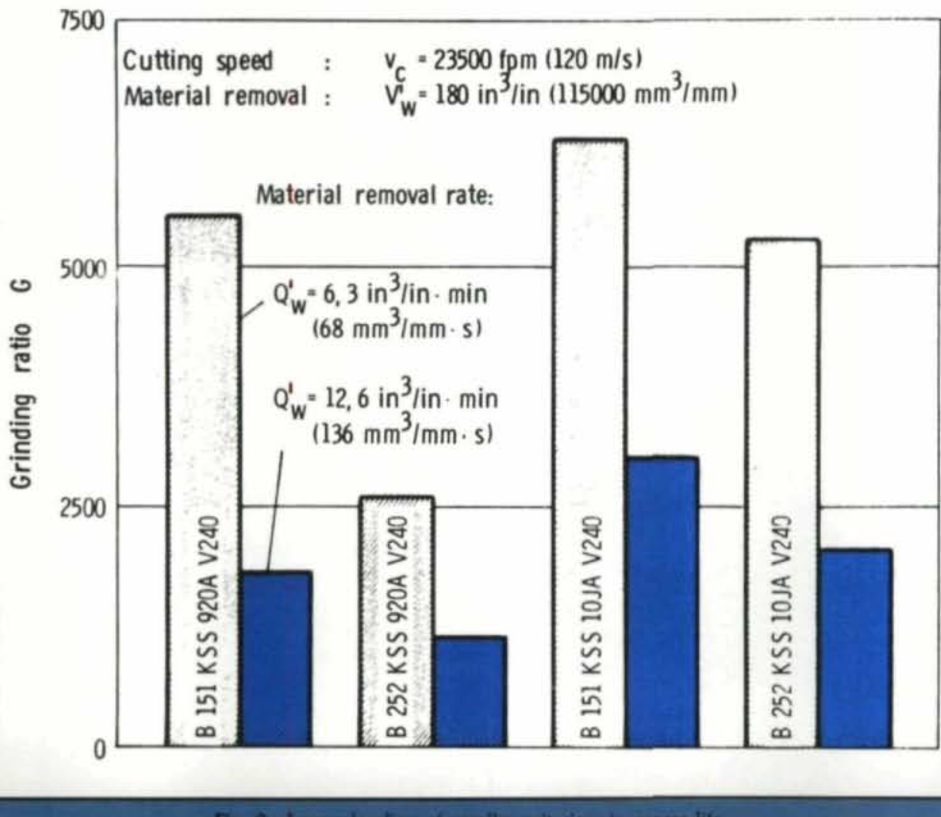


Fig. 9 – Lower loading of smaller grit sizes increases life

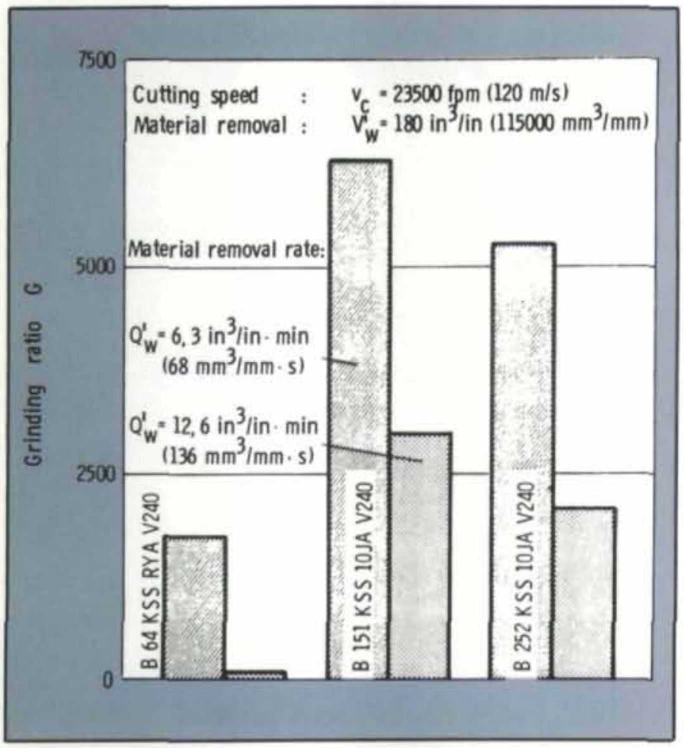


Fig. 10 – Bond wear and grit load determine optimum grit size

for B 252 in relation to B 151. This means that the individual grit load is 5 times as high for B 252. This is opposed by an increase of grit breakout force of only 2.8 times. The larger grit is, thus, subject to relatively higher load, and this results in earlier grit breakout, i.e. faster wear. However, these considerations are only applicable if bond wear caused by the chips plays only a subsidiary role. If the grit size is reduced, e.g. to B 64, this brings no further improvement in the G-ratio as shown in Fig. 10.

Although the smaller grit (B 64) has a more wear resistant bond (hardness R), the G-ratio is only a fraction in comparison with larger grits, especially for a material removal rate $Q'_w = 12.6$ in^3/in.min.

Although chip thicknesses and grit loads continue to decrease in accordance with the above considerations, the long chip lengths typical of the creep-feed grinding process are still present. As the possible grit protrusion is only small, the abrasive attack of the chips on the bond is obviously too great. Therefore, it requires little wear for the grits to break out, since bond level constantly drops below the critical embedment level. The material removal rate is well above the limits for this wheel.

The wear effect of "grit load" and "bond removal" are opposed when plotted against grit size. This means there is a maximum G-ratio, which is in the range of grit size B 151 for the grinding parameters considered here. For milder grinding parameters, i.e. lower material removal rates, this optimum will shift towards smaller grit sizes and vice versa.

A comparison of the bonds shows that in the high-speed grinding process considered, the 10J bond is clearly superior to the 920 bond. In particular for high material removal rate and coarse grit, i.e. with the parameters which make the highest demands on bond strength, the G-ratio is about twice as high for the 10J bond as it is for the 920 bond.

In addition to grit size and bond hardness, the grit concentration, also, has a considerable influence on the working result.

Fig. 11 shows the results of investigations carried out with two wheels of different concentration. The grit concentration was 18% and 30% by volume respectively, and the bond hardness was further increased by selection of the bond type RY.

If there is a lower grit concentration in the grinding layer (V 180), there are fewer cutting edges involved in the cutting process, which means that the load on the individual cutting edges is higher. This negative influence on the individual grit forces can, however, be compensated by greater bond hardness, i.e. by increase of the force necessary for grit breakout. This means that with very hard bond and low grit concentration (B 252 KSS RY A V 180) the G-ratio is already the same as for grinding wheel with soft bond and higher grit content (B 252 KSS 10J A V 240).

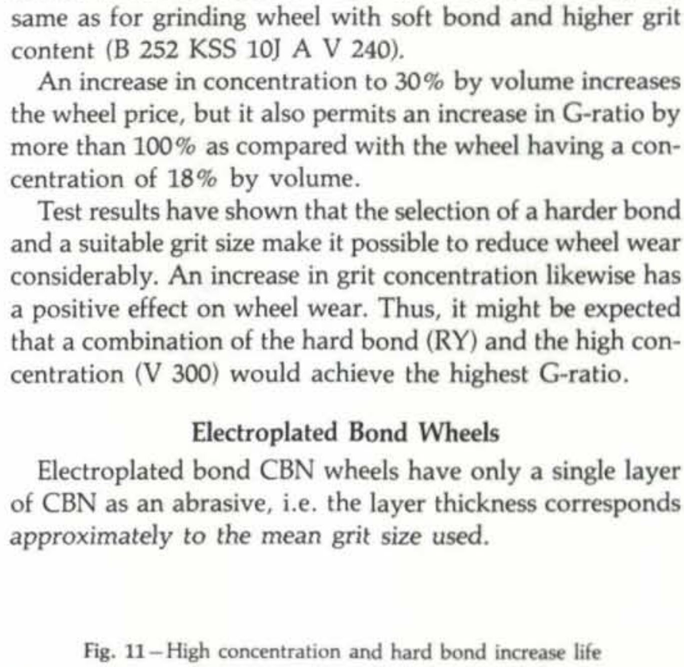
An increase in concentration to 30% by volume increases the wheel price, but it also permits an increase in G-ratio by more than 100% as compared with the wheel having a concentration of 18% by volume.

Test results have shown that the selection of a harder bond and a suitable grit size make it possible to reduce wheel wear considerably. An increase in grit concentration likewise has a positive effect on wheel wear. Thus, it might be expected that a combination of the hard bond (RY) and the high concentration (V 300) would achieve the highest G-ratio.

Electroplated Bond Wheels

Electroplated bond CBN wheels have only a single layer of CBN as an abrasive, i.e. the layer thickness corresponds approximately to the mean grit size used.

Fig. 11 – High concentration and hard bond increase life



The production of these wheels is based on deposition of nickel or nickel alloy on the appropriate bases, and simultaneous inclusion of CBN grits in the bond. Single layered wheels of this kind permit cost effective production of complicated shapes, since profiling is effected on the base and it is not necessary to manufacture sintering molds, which is very expensive for small quantities.

A further advantage of electroplated bond wheels is that they do not have to be dressed. There is no necessity for the complicated trueing and sharpening devices or for the required technologies, which are often difficult to master unless a very high profile quality is not needed.

The position of the CBN grits in the bond structure has a favorable effect with respect to thermal boundary layer influence. The individual grit is not a part of a multiple grinding layer, where some of the grits cutting the workpiece material are dulled by dressing. Here the CBN grit protrudes undamaged from the bond. Electroplated bond CBN wheels are, therefore, always sharp and in new condition, and permit grinding without thermal problems at the usual material removal rates.

However, there are also disadvantages. Whereas with multiple layer wheels, minor radial runout can be eliminated by trueing, time consuming adjustment is required with electroplated bonds. Axial runout likewise has to be minimized during this adjustment in order to ensure satisfactory working of the wheel at high cutting speeds.

A serious disadvantage of this type of bond in high speed grinding is the fact that the grinding behavior of the wheel, and thus, the result of the grinding process does not remain constant. With a new wheel only the CBN grits that protrude the furthest from the bond level engage the workpiece. The sharpness of the cutting edges and their small number give small cutting forces and large roughness heights. As the engagement time progresses the sharp grits are gradually dulled, so that the lower lying grits come into engagement causing the number of grits increases. The cutting forces and the mateial removal rate increase, while the roughness height decreases. As the grinding wheel topography cannot be regenerated by a trueing process, electroplated bond wheels continue to provide uneven grinding results up to the end of their service life.

Four electroplated bond CBN wheels were used in the investigations into drill flute grinding, these had identical GSS bond, but differed in their grit type and grit size. Two wheels contained CBN grit of microcrystalline structure with friable characteristics, and thus greater self-sharpening capability (CBN B), while the other two contained a conventional, more monocrystalline CBN grit (CBN A). The grit sizes B 151 and B 252 were investigated for each grit type.

The grinding tests were continued until the end of the life of the respective wheels, which is annnounced by the smoothing of the wheel surface, and by the progressive increase in cutting forces and grinding power input. With the wheels using the conventional CBN A grit, the grinding layer was already loose after grinding a small number of flutes.

The influence of the number of flutes, i.e. the removal volume, on the cutting forces is shown in Fig. 12. For all wheels, the cutting forces increase with increasing removal

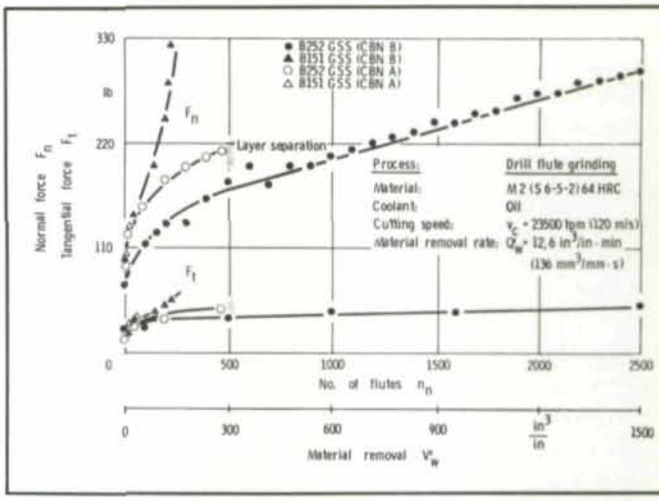


Fig. 12 – Electroplated wheels with small grit size generate higher cutting forces and have much shorter life

volume, whereby, this increase is degressive with the coarse grit wheels and progessive with the fine grit wheels.

Due to smaller mean grit diameter, the CBN grits are obviously not retained firmly enough in the bond with the specification B 151, and break out when subjected to relatively small loads. In addition the bond is subjected to a greater load with the fine grit wheels, since the chip room is not large enough for the chips. There is a crushing process between chip, bond and grit. The simultaneous loading of bond and grit increases wear and the number of grit breakouts. The fast dulling of the grits increases the friction area, and the number of cutting edges increases rapidly. This causes progressive increase in forces as described above.

With the larger specification grit (B 252), grit abrasion and grit breakout are slower. The bond is subject to a smaller load due to the large chip spaces. The number of cutting edges increases more slowly, and the force characteristic shows only a degressive increase.

Fig. 12 also shows that the grit (CBN B) causes smaller forces than the conventional grit (CBN A). The tendency to friability and self-sharpening of grit type CBN B has a positive effect in this connection. Thus, grit type B 252 gives a force level that is 30-40% lower than grit type CBN A.

The electroplated bond CBN wheels examined give a high average roughness height, unlike corundum wheels or multiple layer CBN wheels. This is mainly because the CBN grits protrude from the electroplated bond. The resulting large chip thicknesses lead to a rough workpiece surface. The average roughness height R_z, which was measured in each case at the flute flanks, was about 160 micro inches at the beginning of the grinding process. However, due to the dulling of the sharp edges and to the sharp corners of the CBN grits, these high initial values decreased to 80 micro inches with the increasing number of flutes ground.

With the wheel in unworn condition, a low number of cutting edges combined with the high workpiece roughnesses and low cutting forces mean that no thermal problems should be expected in the grinding processs. All the wheels tested permitted grinding without damage at low removal volumes and low number of flutes ground ($n_n = 1 - 10$).

However, the longer the grinding process continues, the more the wheel becomes dull with consequent increase of cutting forces as described above. The frictional heat and contact zone temperature likewise rise, with consequent thermal boundary layer influence in the workpiece. (Fig. 13)

Thus after grinding of 500 flutes with the wheel B 252 (CBN B) there was already a clearly visible thermal damage zone which becomes wider from the flute center towards its back. Finally, after grinding of 2600 flutes the entire cross section is affected, so that the major cutting edge of the drill is likewise damaged.

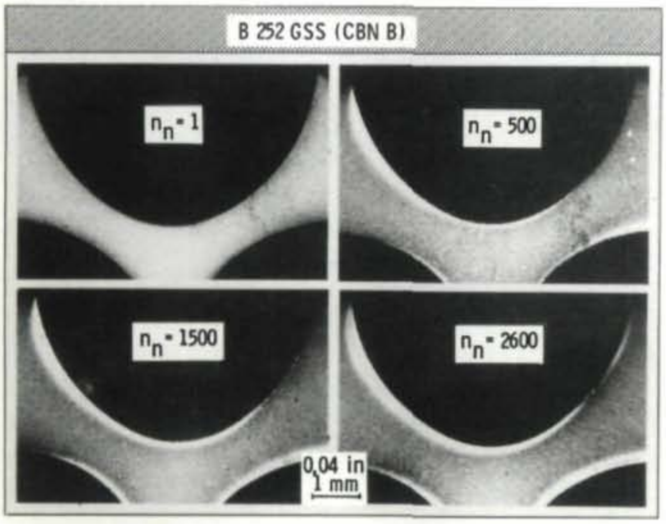
If thermal damage is a limit criterion for workpiece quality, the tool life of the electroplated bond CBN wheel is relatively low for the thermally critical high speed grinding process considered. In addition, adaptation of the tool to the respective machining tasks is only possible by selection of grit size and type. With resinoid bonds this adaptation can be done much more precisely by additional optimization of the concentration, bond hardness and trueing and sharpening parameters.

Machine Concepts

The potential performance increases possible with high speed grinding can only be realized, if the machine design is suited to the extreme requirements of the process. First of all the positioning drives must be designed to handle the speed and torque necessary for high material removal rates and reaction forces, whereby, uniformity of the movements is especially important for a stable process.

The large material removal rates involved necessitate grinding spindles capable of handling forces up to about 2200 lb per inch grinding width in the speed range 6000 to 9000 rpm. In extreme cases, motors with drive power up to 340 hp per inch grinding width are required for the grinding spindle drive. The high spindle speeds and large coolant flow rates result in extreme idling powers – e.g. for drill flute grinding they may be up to 15 hp.

Fig. 13 – Thermal damage in workpiece increases steadily with increasing removal rate



The high cutting speeds and forces necessitate high rigidity of the machine set-up for suppression of the increased process dynamics at high cutting speeds and forces, and extremely low-vibration grinding spindle motor systems. And balancing, which is not unproblematic at high wheel speeds, likewise plays an important role in the production of precision workpieces. Here it is advisible for hydro-dynamic balancing units to be built into the machine control system.

Optimization of coolant supply is necessary in order to combat the increased thermal loads. It is essential to use grinding oil as the coolant; copious amounts of coolant must be supplied under high pressure. The only way to achieve the high material removal rates required in the drill flute grinding tests, without causing thermal damage to the workpieces, was to enclose the grinding zone with a chamber sealed by the grinding wheel itself and the drill blank with the coolant forces into the chamber.

Automation of the trueing and sharpening process is essential, and the necessary components for this must be integrated into the machine. The development and design of these devices is particularly important, as wheel dressing is critical both for the working result and for the economy of the process. Fig. 14 shows some indications for the design of profiling and sharpening devices.

Economic Aspects

The economics of a CBN grinding process can only be assessed by an overall cost calculation, setting off the higher tool costs against the lower time costs.

The production costs per flute K_N may be approximated as follows:

$$K_N = k_{sLM} \left(\frac{V'_w}{Q'_w}\right) + \left(\frac{K_S}{n_d \cdot i_d}\right)$$

The left-hand side of the equation describes the labor and machine costs, while the right-hand side describes the tool costs, i.e. the grinding wheel costs. The symbols are defined as follows:

k_{sLM}: Labor and machine cost per hour

$\frac{V'_w}{Q'_w}$: Grinding time per flute

K_S : Grinding wheel costs

n_d : No. of flutes per trueing

i_d : No. of possible trueings per grinding wheel

Thus $n_d \cdot i_d$ is an expression for the total quantity of flutes that could be ground with the grinding layer used.

A comparison between resinoid bond and electroplating bond wheels shows major differences in the economics. (Fig. 15)

The production costs for resinoid bond wheels are about 50% lower. This is because the set-up time required for the electroplated bond CBN wheel is lower, and in addition, only a relatively small number of drill flutes can be ground without thermal damage to the workpiece. Thus, the proportional tool costs are considerably higher than for the resinoid bond CBN wheel.

With resinoid bond CBN wheels it is possible to reduce the production costs by about 20% by doubling the material removal rate from 6.3 in^3/in. min. to 12.6 in^3/in. min.; here

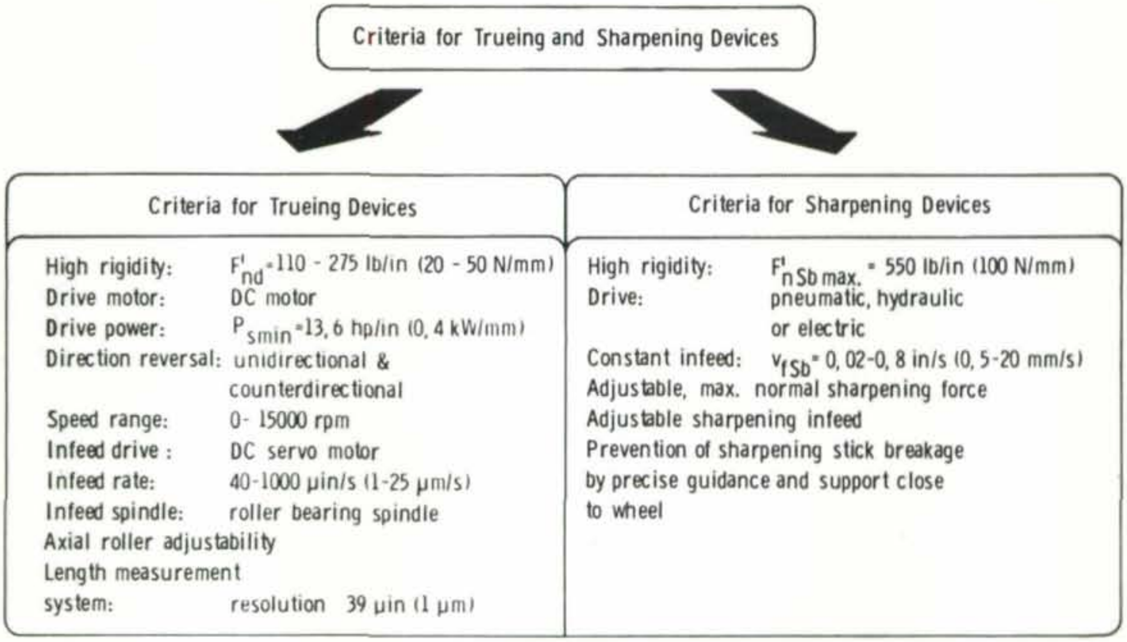


Fig. 14 – Design of trueing and sharpening devices

labor and machine cost per hour only plays a minor role. (Fig. 16)

At material removal rate of $Q'_w = 12.6$ in³/in. min. it was only possible to grind 536 flutes before the tolerance limits were reached (2000 in). Since the wear was 5 times as high, but the production time was cut in half, and labor and machine costs were reduced, this became the dominant factors in production cost.

The results described above can be seen in the chart as shown on Fig. 17, which compares the best CBN grinding wheel with a typical corundum wheel. The higher cutting speed with CBN permits doubling of the material removal rates, whereby, the surface quality of the workpieces is even somewhat better than in corundum grinding. The grinding ration with CBN is about 20 times as high as with corundum.

This results in the time and tool costs shown; together with

(continued on page 48)

Fig. 15 – Resinoid bond wheels are more economical than electroplated wheels

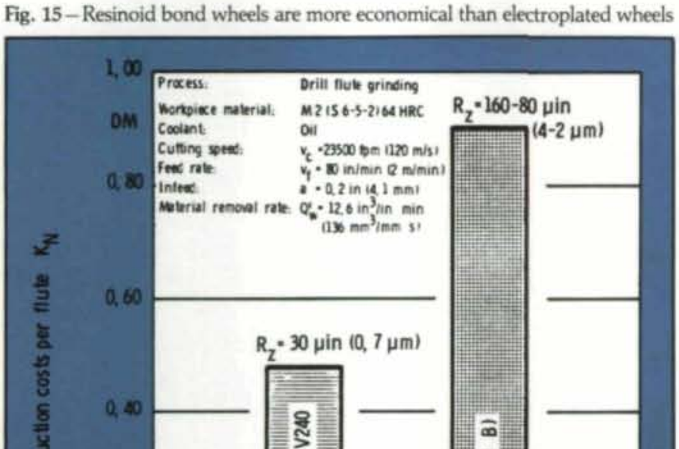
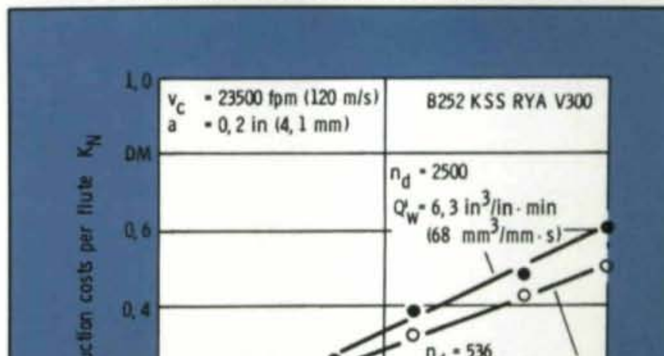
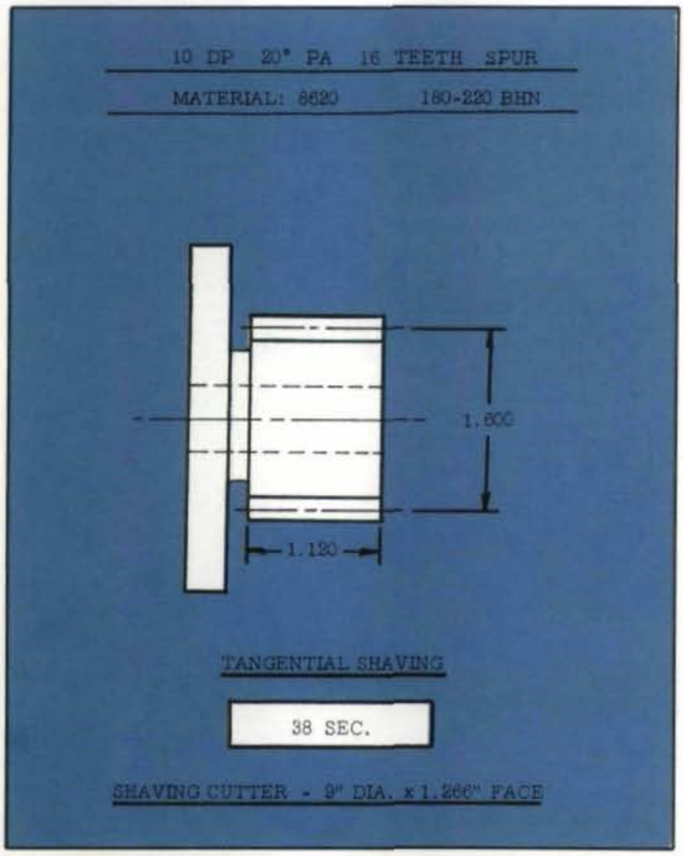


Fig. 16 – Doubling material removal rate reduced production cost by 20%



THE PROCESS OF GEAR SHAVING . . .
(continued from page 46)



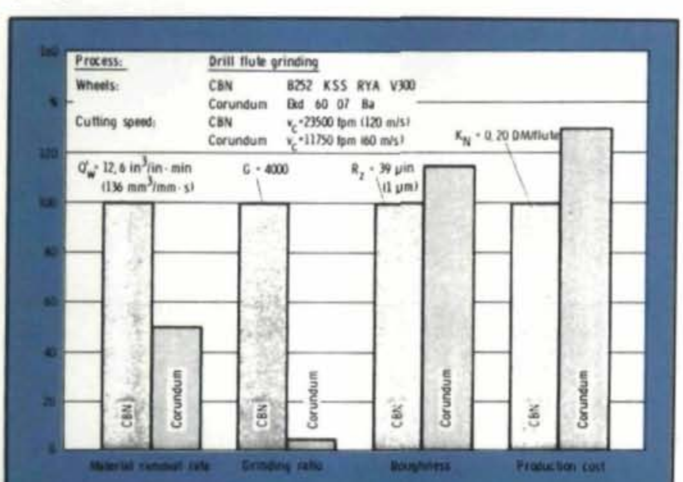
Supplementary 7

E-5 ON READER REPLY CARD

LOWER GRINDING COST . . .
(continued from page 21)

the trueing costs (not included here) these constitute the production costs per flute. This shows that corundum grinding is about 30% more expensive than CBN grinding. The superioity of CBN is likely to increase still further, assuming a rise in the labor and machine costs which determine production costs. Moreover, further developments may be expected in the relatively young CBN technology, on the basis of ongoing progress in fundamental knowledge.

Fig. 17—CBN grinds more economically than corundum and gives better quality



Summary

One of the main problems in the application of CBN wheels is the correct economical and technological design of the dressing process, i.e. trueing and sharpening. This paper presents methods for optimizing the dressing process, and in particular, the sharpening process. A process model for sharpening with a corundum sharpening stick is presented. The chip space of the grinding wheel is described as a function of wheel specification, setting parameters and duration of the sharpening process. The model for description of sharpening results can be used directly in practical application, since it includes only variables that can be regarded as known when the process design is made.

The technological advantages offered by the use of CBN must be offset against the main disadvantage of high grinding wheel cost. As the tool costs per workpiece are mainly influenced by wheel wear, the result of the present investigations show possibilities of improving wear behavior by adaptation of the grinding wheel specification. Possible measures might be the selection of suitable grit size, the use of a harder bond and an increase in grit concentration. An increase in grit concentration makes the grinding wheel more expensive, but in return it gives a clear improvement in the length of service life.

The machine concepts were also discussed as the prerequisite for economic application of this process. The following must be particularly stressed: high rigidity of the machine, high cutting speeds and drive powers and automated trueing and sharpening systems.

If the process is properly designed, it is at present possible to reduce the production costs per drill flute by approximately 30% as compared with corundum grinding.

E-1 ON READER REPLY CARD

EFFECT OF SHOT PEENING . . .
(continued from page 36)

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E-4 ON READER REPLY CARD