NEW DIAMOND FORUM—A RÉSUMÉ OF THE PAST OR A CHALLENGE FOR THE FUTURE OF DIAMOND/CBN TOOLS

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Diamond has been used for centuries as an industrial tool. It is the hardest material on earth, and it is this which makes it indispensable to industry for the machining of a wide range of materials from tungsten carbide, glass and plastics to granite, marble and concrete. There are, however, other outstanding physical characteristics, such as compressive strength and optical, thermal and electrical properties, which have been less exploited so far and which should be regarded as potentially large new application areas. Industrial diamond is only one of the ultrahard materials available today, however. Industrial diamond is complemented by CBN in both grit and polycrystalline products. Creep-feed grinding, which was introduced some fifteen years ago, is now an established grinding method both with diamond and CBN in Europe, Japan and North America. One major new development is the use of CBN in high-speed grinding, which results in vastly increased removal rates. This paper will refer to some of the latest findings in this regard.

1. Introduction

“A diamond which has points can be used to engrave or inscribe the surface of metal vessels”. This statement\textsuperscript{1}, written in about 300 BC, shows the very early realisation that diamond is eminently suitable as a tool to machine other materials. In 1906 Leitz filed a patent for a metal-bond diamond grinding wheel for machining optical glass, and this was the first appearance of a bonded grit tool. In 1934 Diametal filed a patent for a resin-bond diamond wheel for grinding the newly invented cemented tungsten carbide.

The most dramatic milestones in the increase in the importance and growth of industrial diamonds have undoubtedly been the advent of synthetic diamonds and the penetration of diamond tools into the stone and construction industries. Figure 1 illustrates this growth to an estimated 220 million carats this year, and Figure 2 shows the growing significance of +80 US mesh material, mainly in the natural stone and construction sawing and drilling businesses.

Fig. 1. Estimated consumption of natural and synthetic diamond abrasives—non-communist world.

Fig. 2. Estimated growth in consumption of +80 grit versus all other grit.

ABN, SYNDIE, SYNDRILL, SYNPICK and the name De Beers are Trade Marks of De Beers Industrial Diamond Division.

Science and Technology of New Diamond, edited by S. Saito, O. Fukunaga, and M. Yoshikawa, pp. 375–381.
The next step was the introduction of cubic boron nitride (CBN) in 1969 as the second-hardest material known to man, synthesised on systems identical to those used for diamond synthesis and used by diamond toolmakers in the same bond systems as were developed for diamond grits. CBN’s penetration in industry has accelerated, and the present world consumption is expected to be in the region of 15 million carats (Fig. 3).

This picture would not be complete without reference to polycrystalline products. First polycrystalline diamond (PCD) and, later, polycrystalline cubic boron nitride (PCBN) have emerged as highly viable products which have revolutionised certain turning and milling, wire-drawing, mining and oil-well drilling applications (Fig. 4).

![Carats [millions] vs Year](image)

Fig. 3. Estimated CBN consumption, 1979 to 1987.

![Index vs Year](image)

Fig. 4. Estimated growth in consumption of polycrystalline products.

2. Diamond properties

One feature which most of the present applications have in common is diamond’s extreme hardness. However, outstanding optical, thermal and electrical properties also make diamond eminently suitable for applications where these properties are of major significance. These will be covered in some of the papers presented at this conference.

3. Applications

Looking at the major existing fields of application, it is probably fair to say that there are only limited ranges of diamond and CBN types and bond systems available. It is the size and shape of tools, the purpose-built machines and the optimisation of parameters which have so dramatically expanded the areas of application and achieved such outstanding results.

A few examples should illustrate this point.

4. 3.5 m blade saw

Granite is usually cut into slabs with large circular saws. On computer-controlled block saws, 3.5 metre diameter blades are used, each utilising 180 diamond-impregnated segments of approximately 22 mm in length.

On South African Impala granite, a depth of cut of 14 mm is achieved at a traverse rate of 2.5 metres per minute. At these parameters, the blade has a life expectancy of 1000 m² before retipping. The computer control enables these machines to be programmed for 250 separate cuts on two blocks of granite and to be left over the weekend to complete the work.

5. Wire saw

Because of granite’s hardness, the traditional method of extracting blocks from the quarry face is by means of explosives. However, blocks produced by this method are irregular in form and subsequent processing is both time-consuming and wasteful. The latest development for quarrying granite is the use of a wire with diamond-impregnated beads, and this is likely to become standard in granite quarries within the next few years.

6. ABN360 pelleted grinding wheel

In the grinding of hardened-steel guillotine
knives, a wheel with resin-bond CBN pellets is used. Pelleted wheels not only present more effective cutting edges to the metal, but permit better coolant application and swarf removal.

7. **SYNDIE PCD compacting dies for stranded, round, copper conductors**

This application, previously the domain of tungsten carbide dies, has now been successfully accomplished with SYNDIE PCD, using a 40151 die blank (40 mm diameter×15.1 mm thick). The development by De Beers of such large PCD blanks resulted in the following advantages over tungsten carbide dies:

—Considerably lower coefficient of friction, resulting in a much smoother finish of the stranded conductors.
—Considerably higher compaction allowing for significantly smaller conductor diameters.
—Accurate control of diameter is now more easily achieved.
—Die life is virtually unlimited and is generally independent of the amount of compaction applied.
—There is a considerable reduction in the energy consumed by the stranding machine.
—A minimum of die maintenance is required.
—Stranding machine downtime is minimised.

8. **SYNDRILL oil-well drilling**

PCD combines the abrasion resistance of diamond with the impact strength of cemented tungsten carbide. PCD bits, which are mainly used to drill soft to medium-hard formations, remove the rock formation by shearing rather than crushing and, therefore, achieve considerably faster penetration rates. 1988 saw a trend towards larger cutters from 13.3 to 19.05 and 25.4 mm diameter, and some North Sea wells are already using 100% PCD bits.

9. **Coal mining with SYN/PICK**

Underground coal mining is now becoming a highly mechanised industry with modern, high-powered machinery such as longwall shearsers. Modern examples of these machines have up to 750 kW installed power and can remove coal from the face at up to 15 tonnes per minute under the best conditions. Over the last five years, De Beers has been developing a mining pick—SYN/PICK—with a polycrystalline diamond cutting tip for use on longwall shearsers, and this is currently being used in a number of collieries in Europe.

10. **Ceramics grinding**

A feature that all the previously mentioned applications have in common is that conventional tooling materials are available to perform the same operation, albeit at a lower rate of efficiency. There is, however, an increasing area where only diamonds are able to carry out the required machining operations. Of these, ceramics for engineering applications have probably the highest growth potential, and it is in this area that most research efforts are concentrated, attempting to achieve a better understanding of the removal processes and increase removal rates and grinding efficiencies. The latest developments are directed towards ultra-precision machining by either turning or grinding; ultra-fine finishes with a surface roughness peak-to-valley height of $R_z = 2-3$ nm can be achieved.

11. **Creep-feed grinding**

Creep-feed grinding was initiated in the late 60’s and today is an established grinding process for both diamond and CBN grinding wheels.

Although no strict dividing line exists to separate oscillating grinding and creep-feed grinding, it is generally accepted that the amount of material to be removed is taken off in one single pass in the creep-feed grinding process, whatever depth of cut this may imply.

Today, too, the theoretical differences are far better understood, and a few of these may be highlighted. With increasing depth of cut, the contact length $l_k$ between wheel and workpiece increases (Fig. 5). If the specific stock-removal rate remains constant, the longer contact length means longer but thinner chips, with an overall increase in chip volume $V_{cu}$.

The thinner chips mean that only those diamond
or CBN grit particles with the highest protrusion are involved in the stock-removal process, and, therefore, the number of active or, according to Koenig and Schleich, 'kinematic' cutting edges $S_{\text{kin}}$ per contact area is in fact reduced.

12. High-speed grinding

As there is no exact definition of the borderline between oscillating and creep-feed grinding, there is also no clear-cut division between standard and high wheel speeds. It is, however, safe to state that, by today’s standards, wheel peripheral speeds of up to 45 m/s (2700 m/min) can be regarded as standard speeds and that 60, 90 and 120 m/s (3600, 5400, 7200 m/min) may be classified as high-speed grinding. We have seen applications of these speeds, particularly for CBN grinding wheels, in industry today, and, in research, wheel speeds in excess of 200 m/s (12000 m/min) have been attained.

Figure 6 shows the principal advantages obtained in the high-speed grinding mode, and Figure 7 illustrates the actual specific stock-removal rates achieved.

This graph reveals various interesting points:

1. In high-speed grinding, specific removal rates of up to 1000 mm$^3$/mm-s can be achieved.
2. Due to the high dynamic hardness of the workpiece at these speeds, no thermal damage is likely to occur to the workpiece.
3. The high dynamic hardness widens considerably the range of materials which can be economically ground with CBN.

This positive scenario should not lead to the conclusion that all grinding will be carried out in the high-speed grinding mode in the foreseeable future. Limitations will continue to exist on the design, availability and price of the machines. The benefit of vastly reduced grinding times disappears if handling time for workpiece changes becomes substantial. It is, therefore, a method which is only suitable for large batch or mass production.

Finally, there are limitations on the types of wheel which can be employed. Whilst resin, metal and vitreous bonds may be used in the 60 to 90 m/s (3600 to 5400 m/min) range, special wheel designs in these bonds are necessary to cope with 120 m/s (7200 m/min). Above this speed only electroplated and, in a few cases, sintered metal-bond wheels will withstand the high centrifugal forces.

In all cases, special care has to be taken with regard to trueing, dressing and balancing these wheels, as any out-of-balance at these speeds would not only lead to deterioration in the results achieved, but would also have a detrimental effect on the life of the spindle bearings.

Two examples may illustrate the results which
can be achieved: Grinding grooves into a hardened steel roll illustrates the advantage of employing higher wheel speeds (Fig. 8). A radial wear of 40 μm is achieved after 1400 grooves at 90 m/s (5400 m/min), whereas double that number, 2800 grooves, could be ground for the same degree of wear at 140 m/s (8400 m/min). All this was achieved with an electroplated CBN wheel, containing 60/80 US mesh grit, at a specific removal rate of $Q' = 144 \text{ mm}^3/\text{mm} \cdot \text{s}$.

Finally let us consider the grinding of 300 mm long, 9 mm deep and 1.8 mm wide grooves in hardened steel (Fig. 9). With a metal-bond CBN wheel, containing 120/140 US mesh in 150 concentration, this groove is ground in 15 sec at a peripheral speed of 150 m/s (9000 m/min).

13. Conclusion

New Diamond Forum—A résumé of the past or
a challenge for the future of diamond and CBN tools?

The answer is clear. Whilst diamonds and, for that matter, CBN, have been with us for a long time, and consumption has increased substantially over the decades, exciting new areas of application and new machining processes lie in front of us. This, coupled with new synthesis processes, such as CVD diamond or diamond-like thin films, should open up new markets so far closed to products derived from existing high-pressure synthesis technology, thus making this conference important as a forum for the exchange of ideas and as a guide to the most promising directions of future development.

REFERENCES