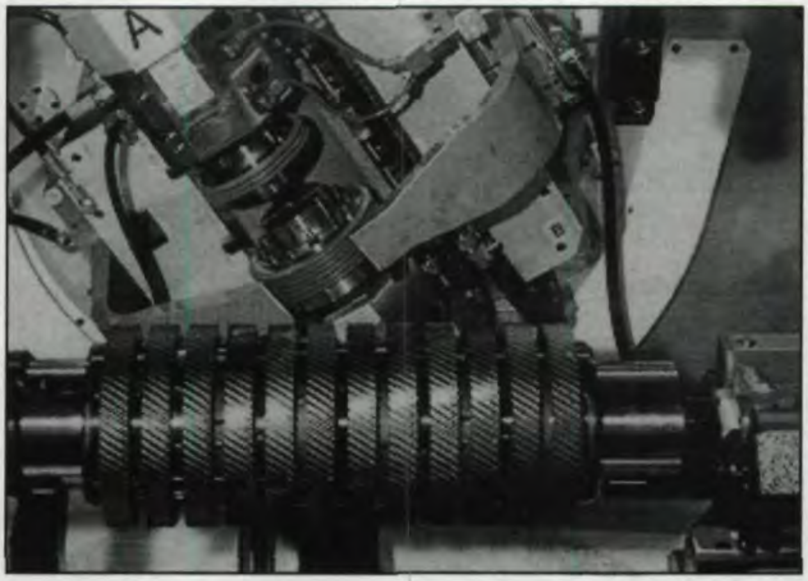
Hard Gear Finishing With CBN–Basic Considerations

Paul Brazda

For over 50 years, grinding has been an accepted method of choice for improving the quality of gears and other parts by correcting heat treat distortions. Gears with quality levels better than AGMA 10–11 or DIN 6–7 are hard finished, usually by grinding. Other applications for grinding include, but are not limited to, internal/external and spur/helical gear and spline forms, radius forms, threads and serrations, compressor rotors, gerotors, ball screw tracks, worms, linear ball tracks, rotary pistons, vane pump rotors, vane slots, and pump spindles.

Grinding as discussed in this article is the process of using abrasive grains for shaping workpieces into more precise form. A number of materials can be used for grinding. They include:

- Aluminum oxide (corundum) — for soft or hardened steel grinding;
- Silicone carbide — for cast iron, nonferrous metals and nonmetallic materials;
- Diamond — for cemented carbides, glass, ceramics and hardened tool steels;
- Cubic Boron Nitride (CBN) — a synthetic superabrasive used for grinding hardened steel and wear-resistant superalloys. The cubic shape of the CBN particles results in grains that have very pronounced cutting edges. The mechanical strength of CBN is more than double that of corundum. CBN also has the capacity to withstand thermal loads twice as high as those of diamond. These make CBN a good choice for a grinding abrasive.



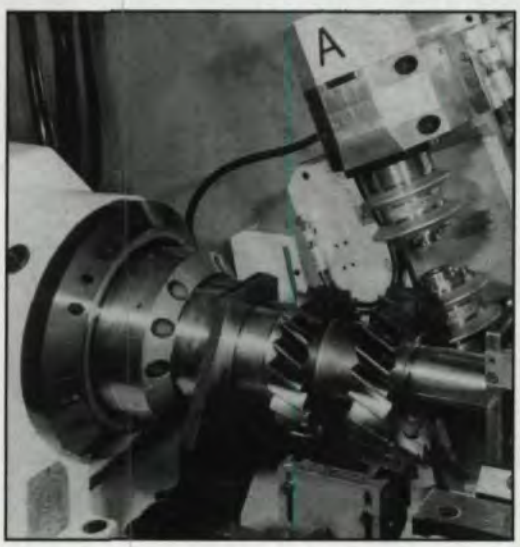


Fig. 1 — Multiple workpieces can be clamped in one setup for improved productivity.

Fig. 2 — Multiple spindle machines can grind dissimilar cluster gear members in one setup.

Several different types of bonds attach abrasive particles to the grinding wheel.

- Vitrified bond. Uses an inert, glass-like material. Not affected by grinding fluids or high temperatures generated during normal grinding. Vitrified wheels are impact-sensitive.
- Resinoid bond. Uses a highly flexible thermosetting plastic. Resinoid bonded wheels are often selected for their high operating speeds. These wheels have high impact resistance.
- Rubber bond. Gives more flexibility than resinoid bonded wheels.
- Metal bond. Used with diamond and CBN electroplated wheels.

The choice of which bonds to use is largely application-dependent and is a function of the varying degrees of softness in the bonds. Rubber-bonded wheels are the softest and metal-bonded the hardest.

Rubber-bonded wheels are useful in cut-off applications. When they make a cut, their flexibility will leave a very smooth, almost burr-free edge. A vitrified or metal bond wheel will roll a small piece of material over the cut end of the workpiece, leaving a sharp edge.

Resinoid-bonded wheels are harder than rubber, but softer and more flexible than vitrified wheels. If the workpiece is of an unknown type of metal or if the ground stock varies in thickness, resinoid-bonded wheels may be a good choice. Because they are flexible, they will give if they hit a high or rough spot on the material and will not shatter like a vitrified wheel. But there is a trade-off in terms of accuracy. Grinding with resinoid wheels cannot achieve the same degree of accuracy as grinding with vitrified wheels.

More than half of the grinding done today is done with vitrified wheels. They can produce a highly accurate profile and are used when a more accurate form is necessary than can be achieved with milling, lathing or other machining. The downside of using vitrified wheels is their fragility and the fact that the profiles must be dressed often to the desired form. They are impact sensitive. If they are suddenly bumped, or if they encounter an irregularity in the workpiece, they can shatter. This not only ruins the wheel, but also can damage the workpiece and, conceivably, injure the machine operator.

Metal-bonded CBN wheels are the hardest grinding wheels. They consist of a thin coat of CBN grit fixed to a hardened steel wheel, thereby eliminating the breakage problem found with vitrified wheels. They also provide the greatest degree of accuracy. This is why one of the biggest customers for CBN wheels is the aerospace industry, where the limits of profile tolerances are pushed every day. Only CBN wheels can provide the degree of accuracy required in aerospace quality gears.

However, there are other applications for CBN wheels as well. Because they provide a very stable profile, they are very useful in mass production situations. When several hundred gears of the same type need to be produced, CBN wheels can save significant amounts of setup and wheel dressing time. A third application for CBN wheels is for very large gears (say over 50") with many teeth. Again, because of their stable profiles, CBN wheels prevent first-to-last tooth errors and save setup and redressing time.

On the other hand, CBN wheels are more expensive than vitrified wheels. In prototype production, short runs or in applications where high accuracy is not required, they simply may not be economical.

Dressable or Nondressable Wheels

Both types are available and each has its uses. Dressable grinding wheels are used extensively in production grinding. They can be used in standard and specialized grinding machines for both form and generating grinding.

Most of our attention in this article will be devoted to nondressable CBN grinding wheels. While dressable CBN wheels are available, most CBN form grinding is characterized by the use of a non-dressable, single layer of CBN grains electroplated on a hardened and precision-ground steel body. Such grinding wheels must be manufactured and plated with the required profile form, since the machine operator may make little or no profile form adjustment.

Fig. 3 — In Coroning, cutting takes place when the crossed axes of the tool and the workpiece roll with each other.

This system is capable of simultaneously grinding both flanks, the root and, if desired, even a tip chamfer. This method improves load, noise and wear characteristics of the finished gear. It will also produce excellent accuracy and finish with no truing and dressing for the life of the wheel.

A non-continuous process of form grinding requires the part to be indexed after each grinding pass. Achievable metal removal rates depend on the grain size used, the required part geometry accuracy and specified surface integrity. Improved productivity can be realized by clamping multiple workpieces in one setup to reduce the indexing time required per part. Workpieces can be rough and finish ground in one setup (Fig. 1). Machines with multiple spindles are able to grind dissimilar gear members on cluster gears in one setup (Fig. 2).

The roughing wheel is generally designed using coarse CBN grains for aggressive grinding. The finishing wheel is designed to meet engineering specifications. Cycle times can be improved in certain applications by using a specially designed multiple wheel set which rough and finish grinds the workpiece at the same time. An additional advantage of using this wheel set is in the predetermined control of the stock removal condition between the roughing and finishing operations. The design and manufacture of high-quality CBN wheels capable of meeting or

Paul Brazda
is Product Engineering Manager of Kapp Tech, Boulder, CO, manufacturer of grinding systems and wheels. He has a master's degree from CVUT, Prague, in the Czech Republic and 20 years' experience in power transmission systems, including gear form grinding wheel design and development.

Fig. 4 — A variety of CBN grinding wheels.

exceeding AGMA class 13 profile tolerance requires a high level of engineering and manufacturing expertise.

Coroning®*

Coroning is a newly developed gear finishing process that uses the same principle as traditional gear honing, but has some special features. The tool used in this operation is an internal gear with a hardened body, electroplated with a single layer of diamond. Coroning is a two-step process where roughing and finishing tools are used. Its cutting ability arises from the crossed axes of the tool and workpiece rolling with each other (Fig. 3). This process creates a superb surface finish structure with the grinding traces parallel to the rolling direction of the gear, which improves its performance. (Note that traditional form grinding creates grinding traces which are perpendicular to the rolling direction of the gear.) Another characteristic of this process is a relatively low cutting speed, which minimizes the thermal effect of generation of residual stresses.

Coroning is a highly productive, continuous grinding process which distributes the load of material grinding over a larger area of grains. This process has particular advantages for high volume transmission gears and for producing parts with large numbers of teeth. Noncontinuous form grinding cannot achieve the short cycle times of Coroning. Some gears which normally cannot be form ground due to limitations caused by adjacent shoulders or related design restrictions can be produced by the Coroning process.

Metallurgical Considerations

Certain measures must be taken in order to ensure optimum grinding results with respect to the structural condition of the workpiece. If the grinding process uses incorrect machining parameters, there is a danger that a thermally induced modification of the workpiece surface can take place locally. This is called "grinding burn." If the heating process exceeds the tempering temperature, a "tempered zone" is produced. If it exceeds the austenitizing temperature, a "rehardened zone" is produced.

Parameters that may lead to a thermally induced modification of a workpiece include:

1. Excessive feed rate during the grinding process;

2. Excessive infeed (or grinding depth) as a result of

- Errors in the preliminary machining of the workpiece, causing uneven distribution of the grinding allowance;
- Hardening distortions resulting from the heat treatment process;
- Positioning errors of the ground profile with respect to the workpiece clamping device;
- Alignment errors of the ground profile relative to the position of the grinding wheel.

The excellent heat conductivity of CBN produces a cool grinding action, thus reducing the danger of thermally induced part modifications. In spite of this, grinding burns can occur when the parameters of the grinding process are exaggerated or when the CBN grains are significantly worn out. To prevent this, some notion of just how aggressively one can grind in a particular situation needs to be arrived at.

Normalized Removal Rate Per Unit of Time—Q_w

This parameter is a function of the machine, the wheel, the grit size, and the feeds and speeds used. The grinding must take place at a reasonable depth and speed that at the same time will not produce thermal changes; i.e., grinding burns. Kapp uses the term Q_w to express this limit. This value refers to the volume of material removed (mm^3) per unit of time (seconds), based on the grinding wheel width in millimeters. The dimension is, therefore, expressed as mm^3/sec/mm.

Q_w can be obtained by calculating the product of feed rate and infeed. As the number of workpieces ground with an electroplated CBN grinding wheel increases, the abrasive grains (CBN crystals) become dull, whereupon the permissible values for Q_w decrease as well.

Other grinding wheel manufacturers may use other terms to describe this parameter. If this information is unavailable from the grinding wheel provider, the user has to arrive at some notion of what these grinding limits are on his own.

Grinding Fluids

The grinding fluid is probably the most overlooked factor in optimizing a grinding wheel's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IF THE GRINDING PROCESS USES INCORRECT PARAMETERS, A THERMALLY INDUCED MODIFICATION OF THE SURFACE — GRINDING BURN — CAN TAKE PLACE.

performance. The type of fluid and its application are very important for the success of a grinding wheel's performance. Most production operations use some type of grinding fluid in order to increase the grinding wheel life and improve the quality of the ground part. These fluids contain a blend of ingredients which inhibit corrosion and extend fluid life despite very adverse conditions. Some of the grinding fluid functions are to

- Lubricate the grinding zone;
- Reduce the frictional heat;
- Cool the grinding wheel and workpiece to eliminate the danger of a grinding burn;
- Remove the chips from the grinding zone;
- Clean the grinding wheel surface to allow higher material removal rates.

CBN grinding wheels provide the most outstanding performance when used with waterless lubricating fluids. Such fluids reduce the chemical decomposition associated with CBN and high temperature steam. The formation of an oxide (B_2O_3) on the surface of a CBN particle creates a protective layer to deter further oxidation. However, this oxide layer is soluble in high temperature water and can allow further oxidation of the CBN particles. These reactions can cause accelerated breakdown of the CBN abrasive particles and shorten the grinding wheel life. The use of oil-based grinding fluids minimizes this effect.

Generation of Residual Stresses

While the grinding grains are applying pressure on the surface of the workpiece during its movement, tensile stresses are introduced under the surface. Chips are literally pulled away from the surface of the gear. When the tensile stress reaches the yielding point, plastic deformation will develop, reducing the level of tensile stress. After rapid unloading, plastic deformation turns into compressive stress in the direction of grinding and also perpendicular to it. The surface "snaps back." Simultaneously with this mechanical generation of stress, a thermal generation takes place that produces tensile stress. Whenever residual stresses are discussed, the term includes the sum of the two generating mechanisms and their impact on the ground surface. In order to improve the properties of the gear, these stresses should be of a compressive nature.

CBN as a cutting material produces higher residual stresses at the surface than aluminum oxide. The reason for this phenomenon is the thermal conductivity of CBN, which is approximately 40 times higher than that of aluminum oxide. This reduces the thermal load of the ground zone because a bigger portion of heat can be transferred out through the wheel body and particles of removed material. An additional effect arises from the greater protrusion of electroplated grain particles, which supports the free cutting ability of CBN and allows more coolant to be transported through the contact zone. The result of grinding wheel wear of both CBN and aluminum oxide is the loss of sharpness or cutting ability of the individual grain particles. Therefore, a greater amount of heat is generated in the process. However, the electroplated CBN wheels at the end of their useful lives still produce higher compressive residual stresses than a newly dressed aluminum oxide wheel. The CBN wheel can be economically replated many times, providing consistent and repeatable form.

Conclusion

Current trends and future demands for grinding technology are to produce power transmissions that have

- Improved energy efficiency,
- Higher power capacity,
- Lower weight and volume,
- Lower noise levels generated by gear mesh,
- Lower cost,
- Extended life.

Such goals can be achieved only through the higher overall system accuracy and improved quality of material. Research and development of grinding technology have to address these demands. CBN electroplated grinding tools have the best potential to reach these demands.

Gear designers are developing sophisticated and complex modifications of profile and lead in order to eliminate the vibrations and noise generated by the gear train. In addition to the geometrical requirements, it is necessary to develop the shortest possible grinding times for economic reasons. Close coorperation between gear designers and grinding process designers is therefore essential to the successful production of CBN-ground gears. ✪

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