GRINDING GUIDELINES for Superior Surfaces

By Steve Kendjelic
During the past year the gear industry has seen growth in hard machining, a trend which is expected to continue to progress, possibly passing the levels of 2000. Gear grinding has extended the life cycle of many high-performance gears by assisting manufacturers in accurately predicting end of life cycles as well as predictive maintenance requirements.

Many commodity gears, which have minimal load and accuracy requirements, have moved to manufacturing using powdered metals. The markets serviced by this portion of the industry tend to be lawn and garden power hand tools, which generally utilize smaller gears. As hard machining or grinding technologies are not employed in their manufacture, this type of gear will be omitted from this discussion.

Automotive gears, motorcycle gears, and helicopter rotor drives are but a few of the systems that require precision gears to handle high load, reduce transmission noise, and minimize gear backlash. Typical initial manufacturing steps to process gears include hobbing, planing, and shaving. Following this rough machining, the gears are sent to heat-treat for hardening. Grinding is then employed to correct distortion and profile in precision gears post heat-treat.

**Honing Skills**

During the grinding process, “grind lines” are generated on the gear face. Grind lines that run transverse to the flank are unacceptable in many applications as they create noise during operation. Gear honing is a process used to remove surface damage and burrs from tooth flanks, improve concentricity and correction of pitch error, correct distortion after the hardening process, and for flank correction. For surface improvement the parameters to adjust are the oversize stock allowance of the surfaces to be honed, honing rpm, dwell time, and table speed. As in any abrasive process grain size, porosity, hardness, and dressing technology are the driving parameters to process stability. Gear honing, like any honing process, permits parts to be finished with the highest accuracy.

Gear honing can consist of both resin bond and vitrified bonded honing rings. Honing rings are unique in their makeup as they allow the option to employ vitrified bonded aluminum oxide conglomerates mixed with...
aluminum oxide or silicon carbide in the resinoid matrix. This provides excellent stock removal, making the most of the dampening characteristics of the resin bond.

**Abrasive Types**

A discussion of abrasive machining would be incomplete without including wheel technology. Extensive developmental work has taken place in the past decade with both conventional and superabrasive wheels. Superabrasive is the nomenclature applied to diamond and cubic boron nitride (CBN) abrasives. Diamond is the hardest known abrasive (7000-9000 Knoop hardness), followed by cubic boron nitride (4700 Knoop hardness) and conventional fused aluminum oxide Al2O3 (2100 Knoop hardness). In comparison, high carbon steel is rated at approximately 800 Knoop. Due to the process used in manufacturing plated and vitrified grinding wheels, increased wheel speed is possible before reaching a burst or separation of bond layer. Because of its cost, CBN is not the norm in gear grinding as the development of conventional blended abrasives and new bonds that are being developed under continuous improvement policies.

The grinding process provides a superior surface finish when compared to conventional machined surfaces. While initial inspection for surface finish, or Ra (average of the height of peaks and depth of valleys from the mean line), might meet the print requirements, additional inspection is also needed for work hardening or micro cracks at the subsurface processed. Better understanding and control of process parameters serves to eliminate micro cracks and poor surface finishes.

The two major world suppliers of CBN and diamond are Diamond Innovations—previously GE Superabrasives—and Element Six, formally known as the DeBeers Company. Washington Mills, Norton (Saint-Gobain), and European suppliers such as General Abrasive/Treibacher are sources for conventional abrasives. The 3M Company supplies ceramic grain under the trade name 321 Cubitron™, the Norton company markets their ceramic under the trade names of SG™ (seeded gel) and Targa™. The third supplier of ceramic grain is Hermes Abrasives, which markets their ceramic grain under the trade name of Sapphire Blue™.

Conventional abrasives utilize various types of friable fused aluminum oxide grains as well as blends of grains and grain treatments in grinding (2100-2500 Knoop hardness). The abrasive structure used in grinding applications allows the wheel density to be modified by artificial inducement of pore forming agents. Many manufacturers use aluminum oxide bubbles and/or naphthalene to
provide the mechanism for induced porosity. The distribution of the pore formers is an important issue in direct relation to pore former volume. The bonds used in the manufacture of grinding wheels, when fired, control the wheel hardness. Grinding wheel bonds are engineered specific to their application, such as low temperature and high temperature bonds to provide form retention. Materials below 38 Rc (Rockwell hardness) require increased bond volume and grain volume for use.

Volumetric Percentages

The three component diagram (Figure 5), which includes the volumetric percentages of grain, bond, and pores, can be used to show a wide range of formulation variations (Figure 6). As an example, increased bond content is used to achieve form-retaining characteristics in parallel axis gear generating grinding.

![Generating honing](image)

Figure 4 — Typical OD honing using ID and OD honing rings

Burka-Kosmos has been manufacturing grinding wheels since 1890. They have specialized in grinding wheels for gear grinding since 1980 and now over 95% of their production is for gear grinding applications. They manufacture wheels for profile grinding, generative grinding and thread grinding. They offer both aluminum oxide and ceramic. JRM International, Inc. is the exclusive North American partner of Burka-Kosmos. We stock wheels for all applications in a variety of sizes. We are also available to assist you in optimizing your grinding process.

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In this type of grinding the single grain force is high, in which the increased bond content (variant B) facilitates increased form retention. The increased bond content also requires higher force to break down the grain from the bond.

To high a bond content with insufficient porosity creates an increase in heat during the grinding operation. Grain selection in any abrasive is important, because if the grain cannot penetrate the material wear is caused by thermal stress, resulting in a plowing of material. The desired result is mechanical stress, which fractures the grain particles, exposing new cutting edges (self-sharpening). Typically, the grain is pulled or sheared from the wheel face during grinding when it becomes dull.

**Abrasive Blends**

Conventional abrasive wheel grains can be regular, friable, modified friable, microcrystalline, and macrocrystalline. The cutting action of the grain is broken down into two basic grades; grains that are very tough, and grains that are friable.

Tough grains such as ruby, with approximately 3 percent chromium oxide, are used for rough grinding and high material removal rates (MRR). Ruby is manufactured by fusing pure alumina and
chromium oxide. Ruby is also known to be tougher than white aluminum oxide, and for its form holding and corner holding abilities. The friable grains provide a self-sharpening action by grain fracture, thus exposing new cutting edges. This self-sharpening of the abrasives is accomplished by the fracturing process of the grain. If the grain did not fracture, larger wear flats would develop, which would cause an increase in motor amperage from the electric spindle drive, most likely causing thermal damage to the work piece. White aluminum oxide is considered a cool cutting friable grain. When a small (.5 percent) amount of chromium oxide is added the grain becomes pink, and it is used for its form holding characteristics. Sulfur is added by some manufacturers to aid in lubricity. Other manufacturers use cobalt and titanium treatments to increase the durability of the grain.

Ceramic Grains

Ceramic grains bridge the gap between regular aluminum oxide and superabrasive CBN grains. Ceramic grain is a microcrystalline aluminum oxide (Al2O3) that, with sufficient grinding pressure, becomes dull and fractures along microcrystalline structure, exposing multiple new cutting edges. Figure 5

![Figure 5](image-url)
edges. With material removal rates above standard Al2O3, but below the superabrasive grain, they are appropriate for specific operations. This type of grain is commonly mixed with standard abrasives to reduce costs and reduce grinding pressure in surface, profile, cylindrical, and creep-feed applications. The use of ceramic grains in profile surface grinding offers significant improvement in wheel wear because the single grain forces are high and permit the fracture of the fine grain microstructure of the ceramic grains. In many creep-feed applications the use of ceramic is typically 20 to 30 percent of the wheel content due to the lower single grain force. Increased ceramic content would not permit the grain to achieve the desired effect of self-sharpening (see Ref. 1 for more information).

**Bonding**

The bond is the glue that links all the components of the manufacturing
process together. The bonding agents contain clay, glass frits of various sizes, and other proprietary elements that make up the grinding wheel. The green wheel is then formed and pressed to a predetermined density. The firing of the wheel permits the bond bridges to be formed as the elements flow from a solid to a liquid state. Most manufacturing problems occur in the cooling phase of firing cycle.

The various temperatures used range from low temperature bonds and high temperature bonds, which vary according to wheel manufacturer, but typically range from 900 to 1200 C. These sintered or glassy bonds form the bond posts and can have multiple smaller contact areas between the grain in a less porous wheel to distribute the stress. They can also have large bond bridges in an induced porosity wheel to provide swarf and coolant cavities. The important aspect is that bond bridges coat the grain and evenly distribute the stress during grinding. The majority of the mechanical aspects of the wheel are attributed to the bond and grain used. Earlier in this article ceramic was discussed, with its ability to micro fracture and expose new cutting edges. The requirement of the bond is to retain these grain particles with the increased unit pressure in order to permit ceramic grain to fracture with overall grain particle retention. This factor for bond strength is the key today, as well as the future of gear grinding and the entire grinding industry.

The desired effect of any grinding process is achieving dimensional accuracy, part geometry, and surface quality—all at an economical cost. To optimize an existing process the engineer must evaluate existing operating characteristics, determine known wheel operating characteristics, and unique part grinding requirements to optimize grinding parameters. These building blocks are the necessary data collected for interpretation of the various phases of a design of experiments.

**ABOUT THE AUTHOR:**
Steve Kandjelic is a senior product engineer with Hermes Abrasives and has more than 25 years of experience in grinding machine tools and applications engineering. During his career he has held positions in management and worked in applications engineering for the aerospace, power generation, and medical-device industries. He can be reached by sending e-mail to cncgrind@earthlink.net. The author would like to thank United Grinding Technologies and Hermes Abrasives Ltd for the artwork used in this article.

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