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**Understanding the fundamentals and possibilities of grinding.**

# Abrasive Lessons

## PART 1

Today's manufacturing industry is desperately searching for alternatives to grinding. Among the "new" processes being tried to speed the production of parts are hard turning; dry machining; the use of coated, wear-resistant cutting tools; and high-speed machining.

It should be noted, though, that "high speed" isn't foreign to grinding. An abrasive wheel typically runs at a peripheral speed of around 6,000 sfm. High-speed superabrasive grinding wheels are used in production operations at speeds of 15,000 sfm to 35,000 sfm. And, laboratory testing has been carried out on grinding rigs running in excess of 60,000 sfm—just shy of the speed of sound.

The industry's dislike of grinding is due, in part, to a lack of understanding about the process. Superabrasive and creep-feed (CF) grinding competes, technically as well as economically, with milling, broaching, planing and, in some cases, turning. There are plenty of naysayers at manufacturing engineering companies who keep grinding from competing with those processes, particularly when their expertise lies in traditional machining. But when new materials come along—like ceramics, whisker-reinforced metals and polymers, and multilayer metals with nonmetallic laminates—grinding is often the only process able to do the job.

Abrasive grains—in suitable bonds—break down or resharpen in a controlled manner while in process. If the grinding wheel becomes too dull or loaded with debris, then it can be dressed or resharpened on the machine. No other mechanical machining process resharpens its tools on the machine.

A grinding wheel also can machine surfaces to tolerances on the order of tens of thousandths of an inch, while producing a surface with the finest possible finish and the highest level of integrity.

Unfortunately, grinding has long been regarded as an art. Over the past 40 to 50 years, however, grinding researchers worldwide have studied abrasive machining and gained a comprehensive understanding of the process. They have developed new and improved abrasives, bonding systems and grinding fluids, all of which bring grinding into the realm of science.

| | Hardened Steels | Nickel-Based Superalloys | Gummy Stainless Steels | High-Temperature Alloys | Tungsten Carbide | Aluminum, Titanium | Rubbers, Polymers | Copper Alloys | Plastics | Ferrous Metals | Ceramics, Cermets |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Aluminum Oxide ($Al_2O_3$) | ● | ● | | ● | | | | | | ● | |
| Ceramic $Al_2O_3$ | ● | ● | ● | ● | | | | | | | |
| Silicon Carbide | | | | | ● | ● | ● | ● | ● | | |
| Diamond | | | | | ● | ● | | ● | | | ● |
| Cubic Boron Nitride | ● | ● | | | | | | | | ● | |

**The types of materials that are suitable for grinding with conventional abrasives and superabrasives.**

To promote a better understanding of grinding, this article will examine some of the fundamentals of the process. Part 1 covers abrasives and abrasive bonds, while wheel preparation and grinding fluids and their application will be covered next month in Part 2.

## Types of Abrasives

Abrasives fall into two basic groups: conventional (such as aluminum oxide and silicon carbide) and superabrasive (diamond and cubic boron nitride).

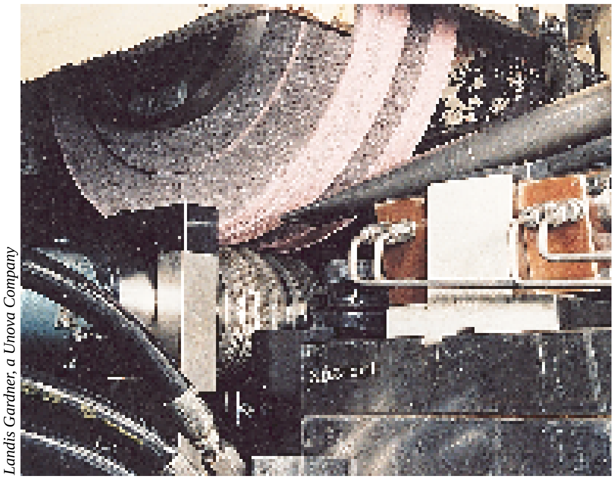
CBN and diamond are harder and more wear-resistant than conventional abrasives, but they cost significantly more. An important additional difference is that superabrasives are excellent conductors of heat (diamond conducts heat six times better than copper), whereas conventional abrasives are ceramics. Therefore, they are insulators and do not conduct heat.

Superabrasives also have high thermal diffusivity, which is the ability to quickly shed heat. This makes superabrasives inherently "cool cutting." The abrasion resistance of superabrasives is vastly superior to conventional abrasives, but the properties of superabrasives do not necessarily make them candidates for every grinding operation.

Every abrasive has its niche, so it is important to fully understand the properties of each. For example, $Al_2O_3$ ceramic abrasive—sometimes called "seeded-gel" (SG) or "ceramic abrasive"—generally exhibits better wear resistance and better form-holding capability than fused (conventional) $Al_2O_3$, but not always. Again, ceramic abrasive has its niche.

**Aluminum Oxide**. $Al_2O_3$ is the least expensive abrasive. It is good for grinding hardened steels. $Al_2O_3$ also can grind nickel-based superalloys when continuously dressed. $Al_2O_3$ is versatile in that it can successfully grind soft and hard materials at light-to-heavy stock-removal rates and imparts a superior surface finish.

**Ceramic Aluminum Oxide**. Ceramic $Al_2O_3$ is very tough and best used where the force on each grain in the arc of cut is high. Ceramic $Al_2O_3$ is good for grinding hardened steel when cylindrical grinding or reciprocal grinding large surfaces. It is not suited for grinding operations where the arc of cut is long and the force on individual grains is very low, such as ID and CF grinding.



*Landis Gardner, a Unova Company*

**Creep-feed grinding competes, technically as well as economically, with milling, broaching, planing and, in some cases, turning.**

However, a modified ceramic grain that is "extruded" is nicely suited to grinding gummy stainless steels and high-temperature alloys, even when the arc of cut is long. The aspect (length-to-width) ratio of these grains is around 5.

The properties of the SG grain may be complemented by the friability of the fused $Al_2O_3$ when they are mixed together to form a composite fused/ceramic abrasive wheel. It is, therefore, necessary to know the length of the arc of cut between the grinding wheel and the workpiece to better specify the grinding wheel for the job.

**Silicon Carbide**. A SiC grain has a naturally sharp and aggressive shape. It is best for grinding hard materials, like tungsten carbide. Because of its sharpness, it also is well-suited to machining very soft materials, like aluminum, polymers and rubbers, as well as softer materials, such as low-tensile-strength steels, copper alloys and plastics.

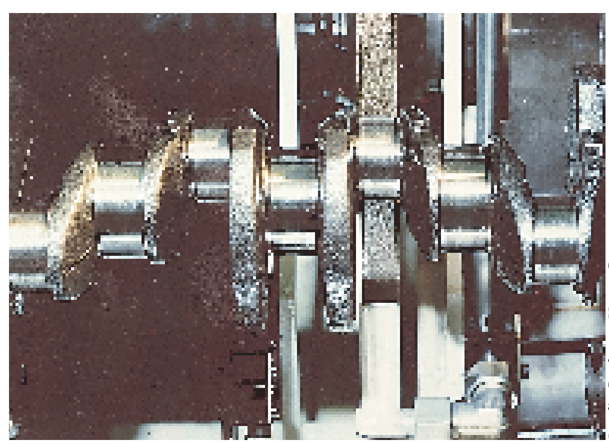
**Diamond**. Both natural and synthetic diamonds are used for grinding. Diamond is not a good candidate for grinding ferrous materials. Being an extremely hard form of carbon, it has an affinity for the iron (steel being an iron and carbon alloy) and will wear rapidly. However, diamond is a good candidate for grinding nonferrous materials, titanium and, particularly, ceramics and cermets.

**Cubic boron nitride**. CBN, like diamond, is an expensive abrasive. The price of a superabrasive wheel may be 50, or more, times higher than a conventional abrasive wheel. But the superabrasive wheel might grind more than 100 times the number of parts. It can grind the hardest of steels while exhibiting very little wear.

CBN is ideally suited for grinding hard, ferrous materials and jobs such as grinding ID bearing races, especially when the form will remain on the grinding wheel for long runs. CBN also is well-suited to operations where the wheel is changed infrequently. Small batches and wheel changes require dressing and redressing during setup—a major expense. Because CBN reacts with water at high temperatures and wears rapidly, it grinds best with glycols and straight oils.

## Bonds

Conventional-abrasive wheels may be made with vitrified bonds, resin bonds or plastic bonds. In addition, superabrasives can be bonded in a sintered metal matrix or plated to a wheel hub with a layer of nickel. Such wheels



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**A plated CBN wheel "green-grinds" a crankshaft. CBN is ideally suited for grinding hard, ferrous materials when the form will remain on the wheel for long part runs.**

## Glossary of Grinding Terms

**Arc of Cut:** The part of the wheel that contacts the workpiece.

**Aspect Ratio:** The ratio of an abrasive's grain length to its width.

**Cermet:** A heat-resistant alloy formed by compacting and sintering together a metal and a ceramic material.

**Continuous Dressing:** A process where a diamond dressing roll sharpens the grinding wheel by removing dull grits all the time the wheel is machining the workpiece.

**Creep-Feed Grinding:** A process where a very soft and porous grinding wheel takes a deep cut in one slow pass. Well-suited for difficult-to-machine materials, the process offer a high stock-removal rate with accurate form retention.

**Cylindrical Grinding:** A process for machining round components.

**Dressing:** Removal of undesirable material from a "loaded" grinding wheel by using a diamond tool.

**Dry Machining:** A metal-removal operation where coolant is not applied to the cutting tool/workpiece interface.

**Friability:** The ability of an abrasive to fracture.

**Hard Turning:** Turning hardened metal on a lathe to eliminate grinding it.

**ID Grinding:** A process that removes metal from the inside diameter of holes or profiles by applying a very small, high-rpm grinding wheel.

**Reciprocal Grinding:** A process where the workpiece is mounted on a table that moves back and forth beneath the grinding wheel.

**Swarf:** The mass of chips and debris remaining after grinding.

**Truing:** Application of a diamond tool to a grinding wheel to ensure roundness and concentricity.

are impervious and have no porosity.

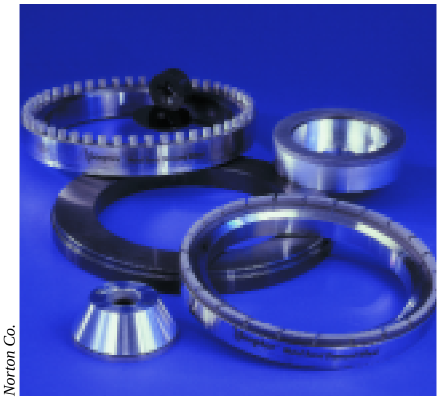
Care must be taken to apply the grinding fluid properly to plated and metal bond grinding wheels to prevent them from hydroplaning. Significant hydrodynamic pressures in the arc of cut can lift the wheel from the workpiece surface, resulting in poor surface finish and high wheel wear.

The choice of bond and abrasive go hand in hand. For example, CBN might be the abrasive of choice if the wheel form is to remain exactly the same over the life of the wheel and it will stay on the machine spindle until spent. Since CBN conducts heat so well, a metal bond is advantageous. This combination provides a cool-cutting wheel, since the heat flows into the grain and wheel and away with the coolant rather than into the workpiece.

There are two types of metal bond: plated and sintered. Plated wheels are never dressed; they are made to the exact form and grind until spent. Sintered wheels are generally dressed by the electrical discharge machining process while off the grinder, and then are mounted like a plated wheel.

Both sintered and plated wheels need to be set up to minimize spindle runout: 0.0005" or less. Minimal spindle runout is especially important for metal bond wheels. Because the grains protrude a short distance above the bond, runout of 0.001" might cause excessive wear to one portion of the wheel while another section's grains remain sharp.

Some plated applications can form very tight radii (0.005" or so), but this




**Pictured are various metal-bonded diamond wheels for ceramic OD and ID cylindrical grinding.**

bond is generally reserved for more open forms with radii greater than 0.020". Often, plated wheels are applied in high-speed grinding applications and sintered wheels are used on ceramics.

Solid metal wheels have little forgiveness for vibration, runout and fluid flow. If the grinding machine, part and/or fixture lack rigidity and/or the machine is old with less-than-perfect bearings and without an on-machine balancer, then the unforgiving plated wheel may cause wheel-life, surface-finish and surface-integrity problems. A resin bond would be a better choice, based on the condition of the machine tool and vibrational instability. Resin bonds have excellent vibration-damping capabilities. However, the wheel would need to be trued and dressed, and there are costs associated with dressing devices and dressing time.

Vitrified bonds are the most popular bond, as they make for a porous wheel. Vitrified bonds allow effective application of the grinding fluid to the arc of cut and provide ample chip clearance for the grinding swarf. Vitrified bonds are easily dressed to shape and sharpness with diamond dressing tools.

*This concludes the first part of "Abrasive Lessons." The second installment will appear in the April edition.*

### About the Author

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