

Diamond

Lapping and Polishing

► **Flat lapping is often the process of choice when finishing a ceramic surface to precise dimensions.**

by Mark Irvin, Hyprez® Product Manager, Engis Corp.

As advanced ceramics evolve and ever harder and more stable materials are introduced into the market, the challenge to finish parts to precise dimensions grows. Flat lapping is often the process of choice when it is necessary to achieve dimensional flatness and finish requirements.

Unless the proper tools are applied, however, flat lapping can be a time-consuming process. Lapping with diamond can pay off in lower cycle times and lower slurry consumption. Lapping with diamond also results in lower slurry cost per hour, lower sludge generation, lower reject rates and fewer process steps.

What is Lapping?

Free abrasive lapping is a four-body process that involves an abrasive, a carrier (paste or liquid) to be applied between the workpiece surface, and a lapping plate. While some of the diamond particles in the carrier can become embedded in the lapping plate to perform a fine grinding action, abrasive particles in lapping may also be continuously loose and rolling (see Figure 1).

The lapping process, which is well-suited to brittle materials like hard ceramics, works by pushing the points of the diamond grains into the work surface to abrade microchips of workpiece material. As a result, lapped surfaces do not have directional marks. This kneading or abrading action on the work surface is repeated millions of times in order to effectively remove material while simultaneously providing a polishing action (especially when using very fine micron and sub-micron sized abrasive particles).

Applications and Advantages

Diamond lapping is most appropriate for ceramic machining or finishing projects that require any of the following:

- Working with non-oxide advanced ceramics or dense, high-purity oxide ceramics; these materials are “super-hard,” but they are not harder than diamond, which can offer more economical processing.

- Greater planar, spherical or conical surface requirements
- Improved sealing
- Improved cosmetic surfaces
- Planarizing joined dissimilar materials (e.g., laminates, composites)
- Surface deburring, removal of “gummy” materials
- Thinning/finishing parts with poor aspect ratios

Common applications for the flat lapping of precision ceramics include mechanical seals, seal rings, pump parts, vacuum chucks, fixture components, wafers for microelectromechanical devices (MEMs), and flat glass or mirror substrates. Almost any application of engineered ceramics with high flatness and/or surface finish requirements may benefit from the diamond lapping process.

Compared to lapping with conventional abrasives (e.g., silicon carbide), diamond lapping offers the following benefits:

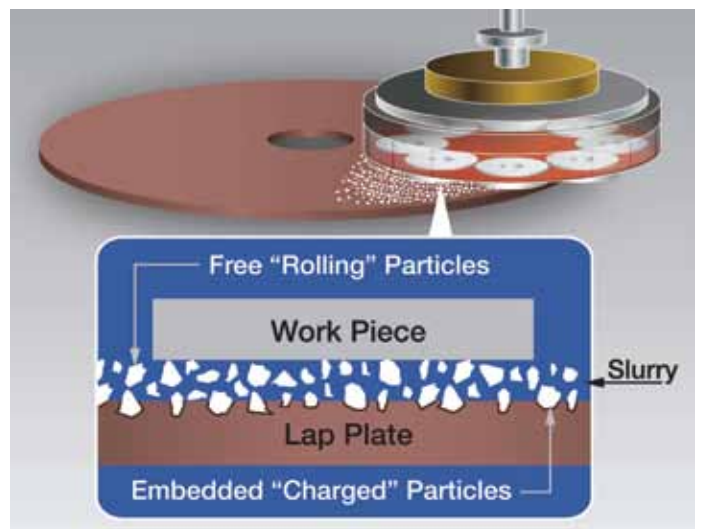


Figure 1. Lapping uses a combination of embedded and free diamond abrasive particles.

Table 1. Diamond lapping vs. conventional silicon carbide for an alumina wafer.

	Silicon Carbide	Diamond
Number of process steps	2	1
Removal rate/cycle time	.0013 in./hr, 45 min cycle	.004 in./hr, 15 min cycle
Slurry consumption	.5 gal/hr	1 pint/8 hr
Sludge generation	4 gal/8 hr	.125 gal/8 hr
Part finish	Matte finish	Reflective
Part cleanliness	Dark, dirty; two cleaning steps	Relatively clean; one-step light cleaning
Slurry cost/8-hr shift	\$166	\$47

Table 2. Diamond lapping examples.

	Seal Ring	Pump Slider	Hot Water Seal	Chuck
Ceramic material	99.7% alumina	Alumina	Alumina	Alumina nitride
Surface area	49 in ²	0.35 in ²	1.5 in ²	104 in ²
Removal rate	.0018 in./hr	.0024 in./hr	.0038 in./min	.0005 in./hr
Diamond size	6 micron	3 micron	15 micron	3 micron
Slurry type	Water-based	Water-based	Water-based	Water-based
Plate type	HY iron composite	HY copper	HY copper	HY ceramic
Surface finish	5.7 μin	1.7 μin	6.5 μin	6 μin

- Aggressive material removal for equal or better productivity
- Uniform edge-to-edge flatness; sub-light band (11 millionths of an inch) results are routine, and up to 1/20 wavelength is achievable under specific conditions
- Better than sub-micron surface finish (< 0.5 Ra) is routine; sub-nanometer surface finishes are achievable
- High potential to develop a one-step lapping and polishing solution for reduced cycle times
- Reduced waste supports green initiatives

A Case Study

As shown in Table 1, diamond provided a more effective lapping solution than conventional abrasives for an alumina wafer. In this instance, diamond eliminated the hand-polishing step, reduced the cycle time by 30 min, saved \$14.87 per hour in slurry costs, reduced waste and associated disposal costs, and reduced cleaning time and the use of cleaning solutions. In addition, diamond minimized the messy appearance that is often associated with conventional abrasive lapping. Diamond's lower slurry volume requirements also reduced shipping and inventory costs.

The removal rates and slurry consumption in this study are fairly typical

for lapping alumina. However, every case is a bit different since removal rate is a function of pressure, speed, and a lapping constant that accounts for material and abrasive efficiency (as explained by Preston's Equation*).

In some cases, part geometry or equipment constraints limit the pressure that can be applied, so removal rates vary accordingly. Table 2 shows the results achieved with diamond in four different ceramic lapping applications. In applications where surface finish requirements are particularly demanding, parts typically undergo a polishing step after lapping. For example, with the alumina nitride chuck, the part was brought to a 6 μin² reflective finish using 1 micron diamond slurry on a fine-nap pad.

A "Systems Approach"

When it comes to the fine grinding and lapping of ceramics, the best results occur through a "systems approach" that examines abrasive powders, slurries, plates/pads, machine tools and accessory options, and matches them against specifications for consistent part quality, processing time, environmental requirements and overall costs. Following are guidelines for each of these system components:

Abrasive Powder and Slurry

Achieving super-fine finishes requires rigid control over diamond particle size. For this reason, high-quality slurry always has at its core a carefully graded abrasive with a consistent, predictable mean particle size and tight standard deviation. High-quality slurry is also free of oversize particles at the high end of the distribution. Diamond can be paired with a specially engineered slurry vehicle that promotes diamond dispersion, wets the plate, keeps debris formation to a minimum and lubricates to enhance the cutting action.

"Ceramics are typically processed with water-based slurries containing mono-crystalline diamond for greatest economy," says Rich Pacyna, manager of Engis' Process Development Lab. "These are easy to use and clean up well. A diamond size should be selected based on the target finish and material removal rate. If everything else is equal, denser ceramics will yield smoother finishes."

Machines

To gain the full benefit of the inherent strength of diamond on ceramic, the ideal lapping machine design features high down-pressure/down-force (5 psi and up), a robust drive system to tolerate the high down-pressure, and a variable speed drive with high top-end RPM capability.

Plates and Accessories

Proper plate selection is vital. The plate must be of optimal hardness and malleability to maintain flatness, accept a diamond charge, and accelerate the rolling abrasive action. Lapping ceramics with diamond typically requires a lapping plate made from composite metal iron (X-08) or cast iron for roughing operations; composite metal copper (HY Cu) is needed for general purpose and finishing operations. The use of a composite ceramic plate (HY Ce) can eliminate concerns regarding potential metal contamination, when needed.

After a certain period of use, the lapping plate will become worn and require

* $R=KPV$, where R is removal rate, K is Preston's Coefficient (process dependent), P is pressure (load/area) and v is relative lapping velocity.

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Reprinted from Ceramic Industry Magazine

reconditioning to re-establish plate flatness and meet end-part flatness tolerance and surface finish requirements. When plates become “glazed,” they no longer remove material at a consistent rate, which, in turn, introduces undesired production variables. Reconditioning a diamond lapping plate requires cutting away the top surface to restore flatness (facing) and retexturing the plate so that it

can be “charged.” Charging is the process of embedding the diamond abrasive into the plate.

A facing device can be considered as an alternative to traditional conditioning rings. Facing devices provide superior control over the groove pattern (macro texture) and land shape (micro texture) of the plate surface, which allows for greater consistency in removal rates and surface finishes.

The lapping force applied is actually load per unit contact area, so controlling the contact area (or bearing ratio) is vital to consistent performance. A consistent bearing ratio results in repeatable removal rates and excellent batch-to-batch consistency. As a corollary, the reduced contact area provided by a grooved plate increases the load per unit area, therefore increasing removal rates. An added benefit is that the groove also aids in clearing away swarf.

Note that the development of facing devices was driven by the need to increase first-pass quality and reduce scrap costs. If a manufacturer determines that diamond would add benefit to its operations, a facing device eliminates concerns about finding an operator with the skills to maintain a plate using traditional ring-conditioning techniques, thus simplifying the integration of a diamond lapping system.

Consistency is Key

The advanced ceramics industry is facing an ever-increasing demand to process harder and more stable materials. It is important to remember that consistency is key, and successful manufacturers make every effort to implement a “systems approach” that controls the bearing area, pressure, plate speed, charging process, slurry dispensing and—most importantly—the quality of the diamond slurry. Controlling equipment, consumables, and process variables ensures that the desired stock removal, flatness, and surface finish tolerances are achieved while the amount of waste and rejected parts is reduced. 🌐

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