

Diamond Dynamics

Nanotechnology is creating better diamond abrasives.

Synthetic monocrystalline diamond (SMD) is currently used to machine and finish a wide variety of surfaces including ceramics, optics, semiconductor materials, and media storage components. In most cases, SMD is more than adequate to meet customer specifications for surface roughness and removal rate. However, the inherent crystal structure of SMD will eventually limit its use for next generation finishing.

Recently, abrasive manufacturers have made some fascinating morphology refinements to the base crystalline structure of sub-micron sized diamond.

Conventional monocrystalline

To understand the advantages offered by the newest generations of diamond abrasives, it is helpful to review the features of conventional monocrystalline diamond.

Monocrystalline diamond is a highly ordered crystalline solid. The carbon atoms are linked together in a regular structure; each atom shares one of its outer shell electrons with four other carbon atoms.

To meet industry volume demands and emulate the production conditions of diamonds found in nature, artificial synthesis requires the use of high temperatures and pressures—typically around 2,000 K and 60 kilobars (kbar) using modern diamond presses and nickel catalysts. SMD production factories often use hundreds of presses since the reaction chamber is quite small; one synthesis might produce fewer than 100 carats to specification per run. The raw diamond must then be crushed, milled, cleaned, and graded.

For most finishing processes, SMD provides a good material removal rate (MRR), which increases with particle size distribution. SMD cutting edges are large in comparison to the total crystal size, sharp, and not friable. It is this toughness that enables micron and submicron SMD to retain some of the shape characteristics (such as pyramids and trigons) of the parent crystals after the crushing and milling process.

Heat-treated SMD

For its part, heat-treated synthetic monocrystalline diamond (HTSMD) is manufactured by heating well-graded and cleaned SMD in an inert atmosphere to about 1200°C. Under these conditions, the powder darkens from light gray to black, which represents a reorganization of the surface into a more disordered, graphite-like layer.

The graphite sheets provide a lubricating region between a sharp diamond edge and the workpiece. This shell coating lowers the scratch and defect rate compared to SMD. Elongated

pieces in SMD are very difficult to remove completely from a batch since they are hydrodynamically equivalent to well-shaped pieces. However, since the entire batch of HTSMD feed is engulfed in a high-temperature oven during processing, all elongated pieces that would otherwise scratch or damage a surface are now shaped and lubricated.

The particle size distribution of HTSMD is often tighter than SMD, since unwanted pieces on the fine end tend to fuse into larger clusters or disappear completely in the heat-treating process. This property gives HTSMD a distinct advantage in the TMR (tunneling magnetoresistive) head lapping industry.

Polycrystalline Diamond

Unlike SMD, synthetic polycrystalline diamond (SPD) is produced through shock synthesis. High energy explosives are used to generate

about 250 kbar of pressure on the graphite feed. Each SPD piece contains smaller diamond "microcrystallites."

The microcrystallites are oriented in different crystallo-

graphic directions every 10-50 nm, regardless of the particle size distribution of the parent pieces. The hardness of an individual microcrystallite is comparable to that of SMD. While the difference between SPD and SMD is discernable through scanning electron microscopy (SEM), the transmission electron microscope (TEM) is required to visualize the microcrystal structure.

SPD also costs an average of 10 times more than SMD. However, the upfront costs can be easily recovered in the finishing operation because less diamond is required to achieve equivalent or better results, and less labor is needed.

Ultra Dispersed Diamond

In recent years, the functional utility trend of diamond is increasing with decreasing particle size. Nanodiamond (defined as diamond having an average dia. of 0.100 µm or less) has more pieces per carat than traditional micron diamond used in finishing. In fact, just one carat (200 mg) of 100 nm diamond abrasive contains slightly more than 100 trillion pieces.

The newest type of nanodiamond, ultra-dispersed diamond (UDD), contains about 100,000 trillion primary particles per carat. If we compare this number to 300-µm Bermuda beach sand at 4,000 pieces per 200 mg, the equivalent mass now becomes 22 million tons—

enough to fill a 50-yard beach 1-ft deep with dry-packed sand, 550 miles long.

—Nicholas Tumavitch, Manufacturing and Development Chemist, Warren/Amplex Superabrasives

Nanodiamond vs. traditional micron diamond

	One Carat 100 nm Diamond	One Carat UDD
Pieces per Carat	1.1×10^{14}	5×10^{17}
Equivalent pieces		
3.0 micron diamond	44 lbs	22 tons
30 micron diamond	22 tons	22,000 tons
Bermuda Beach Sand	5000 tons	22,000,000 tons

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