PCD engineered for the demands of high-speed milling

High-speed milling practices are becoming more prevalent in today's manufacturing industry. Although PCD material technology in general is reaching maturity, the demands of high-speed milling impart a challenge for improvements from PCD suppliers. Medium grain size PCD materials are generally used for their ability to strike a balance between good abrasion resistance (tool life) and maintaining good workpiece surface finish. Typical failure mode for milling inserts is loss of cutting edge sharpness resulting in burr formation on the workpiece. The challenge is to minimise this burr formation while improving surface finish. Specific material properties such as flexural strength and toughness can be improved through an engineered diamond grain size distribution and advanced processing techniques to accomplish this. The result is a PCD material with improved cutting edge retention, better workpiece surface finish without sacrificing wear resistance; thus, delivering ultimate performance gains in high-speed milling applications. Report by **J. W. Peterson**. **P. R. Davis** and **H. Hack**.

PCD is a composite material manufactured by sintering together a mass of diamond grains under ultra-high pressure and high temperature (HP/HT) conditions. At the same time that the PCD layer is fused together it is integrally bonded to a tungsten carbide substrate. The sintering of diamond particles relies on diffusion of cobalt metal, in this case coming from the carbide substrate, to facilitate diamond grain growth between crystals, forming strong diamond-to-diamond bonding. The residual pore spaces between the diamond crystals are filled with Co metal, forming metallic pools throughout the diamond matrix. The resultant product combines the extreme hardness, high thermal conductivity, and abrasion resistance of diamond with the toughness properties approaching that of tungsten carbide.

Traditional PCD grade classifications

PCD products for the metal cutting industry have traditionally been classified into four general categories. The main controlling factor determining PCD grade is the relative diamond particle size. Consequently, we use this relative grain size as a reference to categorise Extra Fine, Fine, Medium and Coarse grade PCD products. It is generally accepted that abrasion resistance increases with increased grain size. While simply increasing the grain size does provide better abrasive wear resistance, several other desirable properties such as tool edge quality, edge toughness, and work piece surface finish are diminished.

A new approach to high-speed milling

The milling and turning of automotive materials such as Al-Si alloys typically require a medium grade PCD for an optimum combination of tool life and component surface finish. However, as current working practices demand increasingly faster machining operations, current tool performance has been reduced due to the loss of cutting edge sharpness resulting in burr formation on the work piece. To overcome this some tool manufactures have attempted to introduce coarse grade PCD to maintain an acceptable tool life. Unfortunately, the increase in grain size has lead to reduced surface finish on the component, typically deemed unacceptable in providing satisfactory performance in these more aggressive applications. In response to this increased demand on medium grade PCD cutting tool products MegaDiamond has developed a new, technically advanced type of medium grade PCD called AMX. Using a select blend of diamond particles coupled with proprietary methods of powder preparation and the addition of toughening agents, the durability of diamond is substantially increased. These techniques, in combination with a unique sintering technology, produces a material with dramatically improved diamond-to-diamond bonding and a more uniform polycrystalline microstructure. This advanced PCD structure not only improves wear resistance, but also enhances other essential cutting tool properties such as wire-EDM cuttability, edge quality and edge toughness.

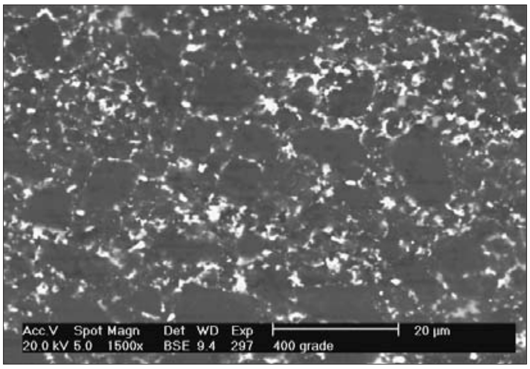

Fig 1 Typical medium grade PCD 1500X

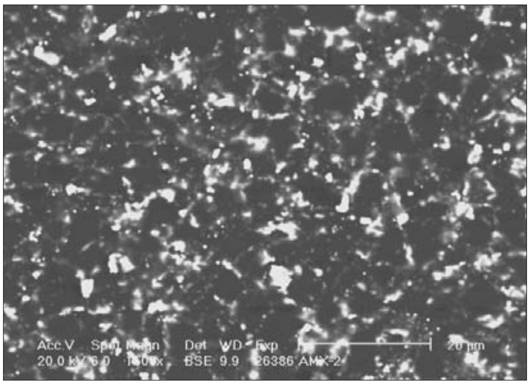

Fig 2 The effect of applying the HSC technology – note the more uniform particle size distribution, and improved inter-granular bonding

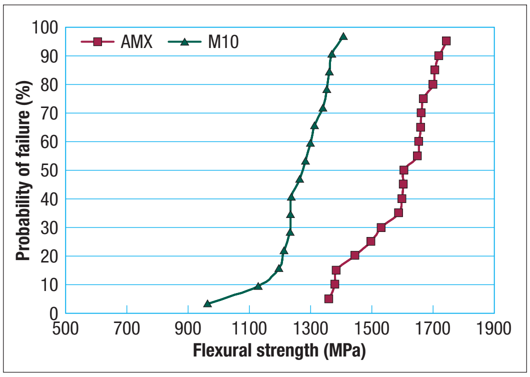

Fig 3 TRS values of typical medium grain PCD and AMX grade PCD

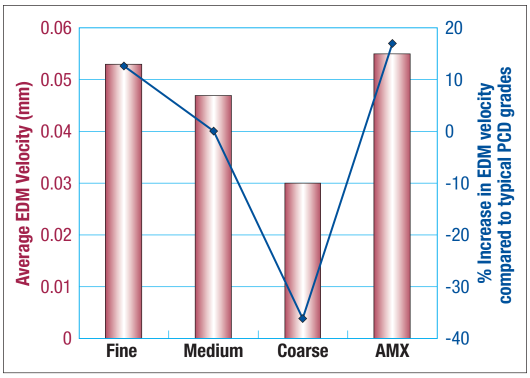

Fig 4 Comparison of wire-EDM cuttability of various grades of PCD

A materials engineering approach

In order to produce a material that exhibits improved edge toughness combined with similar if not improved wear resistance, several modifications to the polycrystalline microstructure were necessary. This is achieved by two approaches. First the feedstock diamond powders are carefully selected and blended. The largest grains, which provide the superior abrasion resistance, yet detract from the edge quality of the tool, were removed resulting in an overall reduction of average grain size of the material. Secondly, a new process of powder preparation increases the packing density and surface activity of the diamond grains prior to sintering. This facilitates and maximises diamond-to-diamond bonding of the diamond grains, the resulting polycrystalline microstructure exhibits minimised interstitial gaps compared to traditional medium grade PCD products. The metallic second phase provides a toughening effect, but must be dispersed evenly to provide uniform and consistent properties. If excessive interstitial metallic pools or gaps exist between diamond crystals, a weakness becomes inherent by degrading the desired properties of the cutting tool such as, abrasion resistance, chemical and thermal stability.

This unique and proprietary manufacturing process has brought about significant breakthroughs in the ability to provide a highly dense structure of diamond crystals adjacent to other diamond crystals. These diamond crystals are closely packed maximising the surface contact between each other through this patented high shear compaction (HSC) technology. This enables superior material transfer between diamond crystals during the sintering process, minimising the amount of metal pools that form. The result is a uniform and evenly dispersed metal diffusion allowing a high degree of bonding between diamond crystals, providing both superior abrasion resistance and edge toughness. This also enhances thermal and chemical properties of the cutting tool, which are also key to overall performance.

To illustrate the degree of improvement in the PCD microstructure and the uniform dispersion of the metallic second phase, side-by-side micrographs of typical medium grade PCD and AMX grade PCD structures are provided (Figs 1 and 2). As previously discussed, the target is to achieve a uniform microstructure, with smaller and better dispersed metallic pools. This results in a minimised but desired level of second phase and optimised diamond-to-diamond bonding.

The general failure mode of medium grade PCD in typical abrasive, non-ferrous metal cutting and milling applications is a dulling or breakdown of the cutting edge through attrition. This means the boundaries between two adjacent diamond particles, normally filled with a second phase binder material are weakened during the cutting application, eventually causing diamond grain pull-out leading to edge chipping and burr formation on the component. By employing the use of this new manufacturing method, the inter-granular bonding is greatly increased, effectively minimising these defined grain boundaries, which become weakened during the cutting application. The result is more effective edge retention of the PCD cutting tool, which translates into substantial improvements in tool life.

TRS values of typical medium grain PCD and AMX grade PCD are shown in Fig 3. It is evident that the flexural strength of the material has been significantly increased, which leads to reduced incidence of tool edge chipping in application. The optimal life of the tool is thereby extended.

Benefits

Today all medium grades of PCD are typically cut with wire-EDM with varying degrees of success. Cuttability by wire-EDM is a function of how uniformly the conductive metallic phase is dispersed throughout the diamond matrix. Controlled cutting tests show that the AMX grade cuts more efficiently than other medium grade products. AMX has shown an increase in EDM cuttability of up to 15% over typical medium grade PCD (Fig 4).

As previously discussed, the quality of the ground edge that can be produced using typical medium grade PCD products is crucial for achieving an optimum tool life performance and work piece surface finish. By tailoring the diamond particle distribution and improving the packing density of the diamond grains, it has been shown that the edge quality achievable with AMX is notably improved compared with traditional medium grade PCD. The magnified edge of finish-ground PCD inserts, one fabricated with grade AMX and the other with a competitive medium grade show a distinct improvement in edge sharpness using AMX grade (Figs 5-6).

Likewise, Figs 7 and 8 show highly magnified edge of a rotary tool finished with a wire EDM, one fabricated with AMX and the other with a competitive medium grade PCD.

Controlled field test applications have indicated up to a 100% increase in tool life in high speed automotive machining applications. Two examples are provided in Table 1.

Additional independent field tests have been carried out in aluminum wheel turning and engine block milling applications, which have shown performance increases of up to 3 times compared to typical medium grade PCD grades.

Through blending of diamond powders of tightly controlled particle size distributions and the use of propriety powder preparation techniques which maximise diamond packing density, it has been possible to produce a material with superior physical and mechanical properties compared to standard medium grade PCD. The result is a new generation medium grade PCD that not only provided superior wear resistance, but also provides better tool edge quality, edge toughness, and fabrication properties. ◆

	Milling	
Component	10% Si-Al road car cylinder head	7-9% Si-Al V6 sports car cylinder head
Operation	Milling	Milling
Diameter	315 mm	200 mm
No of teeth	28	20
Speed	2000 m/min	3800 m/min at 6000 RPM (Competitive medium grade ran at 2500 m/min)
Advance	-	2000 mm/min
Feed per tooth	0.07 mm/tooth	0.1 mm/tooth
Depth of cut	0.5 mm	0.5 mm
	Results	
AMX	12000 components	2000 parts per edge
Competitive medium grade	5000 components	1300 parts per edge AMX reduced burr compared to competitive medium grade due to better tool edge quality

Table 1 Field test comparisons for milling with AMX

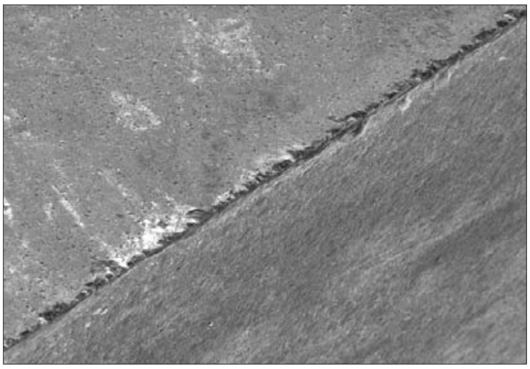

Fig 5 Typical ground edge of AMX 500X

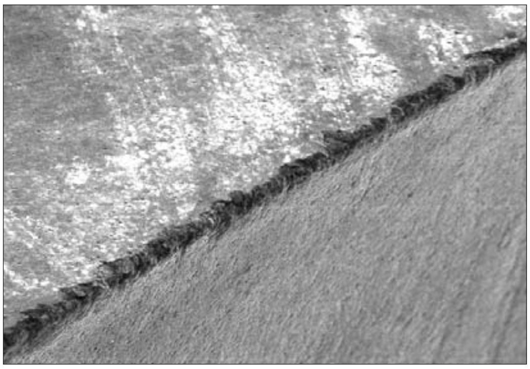

Fig 6 Typical ground edge of medium grain PCD grade 500X

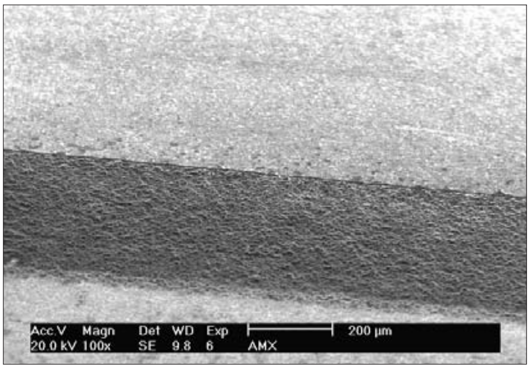

Fig 7 Typical EDM edge of AMX

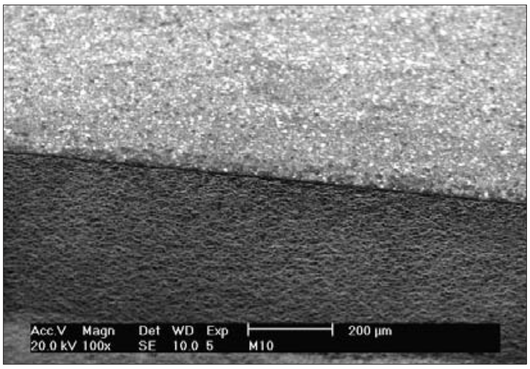

Fig 8 Typical EDM edge of medium grain PCD

Authors

J. W. Peterson is a Technical Services Specialist and
P. R. Davis is Global Sales Manager for MegaDiamond Inc.

Main Office

Sii MegaDiamond, Inc., 275 West 2230 North, Provo, Utah 84604
Telephone: 801.377.3474 Toll-Free: 800.453.1370 Fax: 801.818.4550
megadiamondcs@smith.com

Outside the US

Smith International Italia, S.p.A., 38050 Scurelle (TN) Italy, Località Asola.
Telephone: +39 0461 781.063 Toll-Free: +00 800 26 032.003 Fax: +39 0461 763.776

H. Hack is Manager of Technical Sales and Marketing at
Hollfelder-Gühring GmbH, Wertachstraße 27, D-90451 Nürnberg, Germany.