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Performance Characteristics of CVD Diamond Cutting Tools

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CVD diamond tools are becoming more widely used in industry as an economic alternative to polycrystalline diamond (PCD) for machining non-ferrous and non-metallic materials Although CVD diamond-sheet tools have been on the market for several years, diamond-coated carbide inserts have become available only recently, with the successful resolution of long-standing adhesion problems Diamond coating morphology on the rake surface of the tool affects chip formation favorably, whereas a microscopically rough, faceted morphology on the flank surface of the tool produces a rough workpiece finish. Workpiece finish can be improved by using a coated tool with a larger nose radius. The tool life provided by diamond-coated tools (~30 μm thick) can meet or exceed that of PCD tools, depending on the characteristics of the workpiece material. When using diamond-coated carbide tools in milling, a sharp-edged PCD tool should be used in the wiper position of the cutter to minimize workpiece roughness and burr formation.

Key words : CVD diamond tools, Diamond coated carbide, Cutting tools

I. Introduction

With the increased use of aluminum alloys in the automotive industry and of non-metallic materials in aerospace, conventional polycrystalline diamond (PCD) tools are one of the fastest growing products in the cutting tool industry. High pressure/high temperature techniques are employed to produce PCD discs, which are composed of a layer of diamond grit containing a metallic cobalt catalyst metallurgically bonded to a WC-Co layer. The surface of the disc is usually lapped to a mirror finish and then electrical-discharge machined into small blanks, which are then brazed into a pocket ground in a cemented carbide cutting tool. The periphery of the tool is then finish ground to the final specified dimensions. Most PCD tools have only one cutting edge and are limited to simple geometries because of the difficulty in shaping PCD.

There are three grades of PCD readily available in the market, and these grades are based on the average diamond particle size, which are classed as fine (~2 μm), medium (~10 μm), and coarse (~25 μm). In general, the wear resistance of PCD is directly proportional to particle size, with 25 μm grades providing the best wear resistance, and hence longer tool life. Conversely, the workpiece surface finish provided by the tool is inversely related to diamond particle size, with the 2 μm PCD grade providing the best surface finish. For metalcutting applications, the 10 and 25 μm grades are most widely used, whereas the 2 μm grade is most popular in the woodworking industry. Coarsergrained PCD grades can also be obtained, but they are not widely used because of their tendency to chip. Natural and synthetic diamond, single crystal tools are also employed in special applications on high-precision components requiring ultrasmooth workpiece finishes.

Recently, CVD diamond tools have been introduced to the marketplace in two basic types: CVD diamond sheet toos, and thin-film diamond coated carbide tools. This paper will review the critical steps in manufacturing CVD diamond tools, report on their performance characteristics in the metalcutting environment, and discuss several successful commercial applications of thin-film diamond coated carbide tools.

II. CVD Diamond Tool Manufacturing

1. Sheet Tools

The first commercially successful CVD diamond tools were fabricated from diamond sheet,[1,2] about 300-to-500 μm thick over an area of about 80-to-100 cm^2. The hot filament, microwave plasma, and plasma torch methods are most commonly used to grow sheet on refractory metal substrates such as tungsten, molybdenum, or silicon. The deposition rate provided by the torch method is typically much greater than that provided by the other techniques. Regardless of the deposition process, however, the purity, microstructure and internal stress of the diamond can be altered by manipulation of the deposition variables.

After removing the diamond from the substrate, typically by chemical dissolution in acid, the freestanding sheet is polished and lapped to produce planar surfaces. The blanks that will be brazed to the tips of carbide cutting tools are then cut by a laser from the diamond sheet. Care must be taken in brazing the diamond-sheet blank directly to the carbide tool. Special braze alloys, compatible with the diamond and the carbide, must be used, and the brazing process is usually performed under an inert atmosphere or vacuum. Recently, diamond-sheet blank,[3] have become available that are already pre-brazed to a thin carbide planchet, and these blanks can be used to fabricate tools in a manner quite similar to conventional PCD. A periphery grinding operation to finish the tool to final dimensions is the last step in sheet-tool fabrication.

The wear resistance and workpiece surface finish provided by sheet tools can be superb, but these tools still suffer the same limitations as conventional PCD, i.e., single cutting edge, lack of chipbreaker geometries, depth-of-cut limitations, and high cost. Because the cutting edge is essentially pure diamond, the fracture toughness is inferior to that of PCD. Accordingly, sheet tools are best suited to light, finishing cuts with few interruptions.

2. *This-Film Coated Tools*

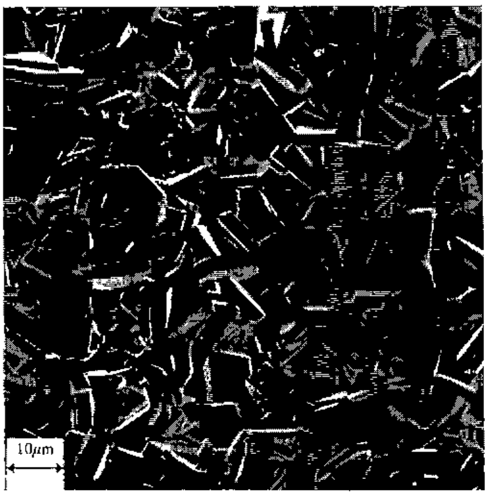
The successful development of a reliable thin-film diamond-coated carbide tool, possessed of high and uniform performance in metalcutting, overcomes the technical and economic limitations of PCD and sheet tools listed above. Early thin-film tools typically employed silicon nitride[2,4] or silicon carbide[5] as substrates for the diamond coating. The chemical and thermal expansion characteristics of these materials are much more compatible with diamond than are the cemented carbides, leading to a moderate degree of coating adhesion. However, these tools were found to be limited in use to non-metallic workpiece materials (graphite, carbon-carbon composites, etc.) where cutting forces are low. In general, these tools failed unpredictably by flaking when used in metalcutting; in particular by chipping and breaking in interrupted cutting due to their comparatively low fracture toughness.

The key to producing an adherent diamond coating on a cemented carbide tool is to minimize the diamond-cobalt interaction. Most carbide metalcutting grades contain 5-to-6 weight percent cobalt, which is actually in the form of a tungsten, carbon, and cobalt alloy. The interaction of cobalt and carbon at CVD temperatures has been well documented[6-11] and results from the solubility of carbon in cobalt in this thermal regime. The presence of cobalt on the tool surface retards nucleation of the diamond coating and leads to the precipitation of graphite at the interface, promoting the formation of a discontinuous "parting layer" that is a clear impediment to adhesion. It has been shown[12,13] that the accumulated graphite is directly proportional to the cobalt content of the cemented carbide, weakens the bond strength of the coating, and degrades diamond quality. Therefore, cemented carbides with lower bulk cobalt contents are favored as substrates for diamond, so long as the tool possesses sufficient toughness to withstand interrupted cutting operations.

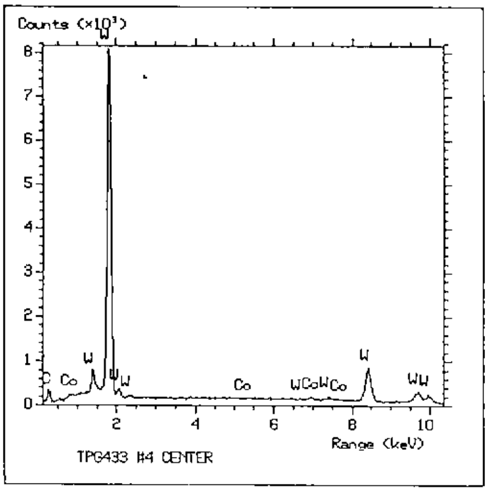
A low-cobalt grade alone will not improve diamond adhesion, because cobalt is still present on the surface from sintering or grinding operations used in tool manufacturing. Several methods to remove surface cobalt have been investigated and they include: (1) chemical etching, (2) intermediate or composite bonding layers, and (3) heat treating. Although etching techniques[12,14-17] are very effective in eliminating cobalt from the surface, they often remove sub-surface cobalt, leaving a porous, weakened WC network upon which the diamond coating is deposited. Post-coating adhesion may be satisfactory and the coated tool may sometimes perform well in continuous cutting operations where the cutting edge is in compression. However, the cyclic stresses of interrupted cutting usually lead to exfoliation of the coating and unpredictable tool failure.

The use of intermediate layers[16,18-22] has also proved beneficial to improving diamond adhesion to cemented carbides by promoting a high nucleation density, by serving as barriers to cobalt diffusion at coating temperatures, and by accommodating the interfacial stresses that result from the coating process. In general, intermediate layers are most effective in improving the adhesion of thin diamond coating;[23] at thicknesses greater than about 15 μm, the coatings tend to flake, leading to unpredictable cutting performance. It has been shown[13,24-26] that the diamond coating thickness should be about 25 μm to provide the same tool life as a 25 μm-particle size PCD grade in cutting an 18 percent silicon-aluminum alloy.

Heat treatment of WC-Co tools prior to coating[13,27] has shown considerable promise for improving diamond adhesion in metalcutting applications. Selection of the temperature, time, and protective atmosphere for the treatment is tailored to the composition of the cemented carbide and designed to promote evaporation of the cobalt and WC grain growth at the surface of the tool As the cobalt evaporates, the tungsten and carbon in the binder alloy precipitate on existing WC grains at the surface causing growth; the bulk microstructure of the carbide remains nearly unchanged. The heat treated surface, Fig. 1, is essentially cobalt-free with no subsurface porosity and is roughened to > 0.6 μm R_a. Regardless of the coating process, the diamond readily nucleates on the clean WC grains; and because of the roughened surface, mechanical interlocking of the coating and substrate occurs, playing a vital role in the adhesion mechanism. The temperature of the coating process, however, should be low enough[28,29] to minimize diffusion of cobalt from the bulk of the tool to the coating/substrate interface, which could lead to graphitization of the diamond and degradation of adhesion. Similarly, use of a higher deposition-rate process will lower the thermal load on the coating/substrate system and promote good adhesion.[27] Inserts prepared in



(a) Surface morphology showing large WC grains



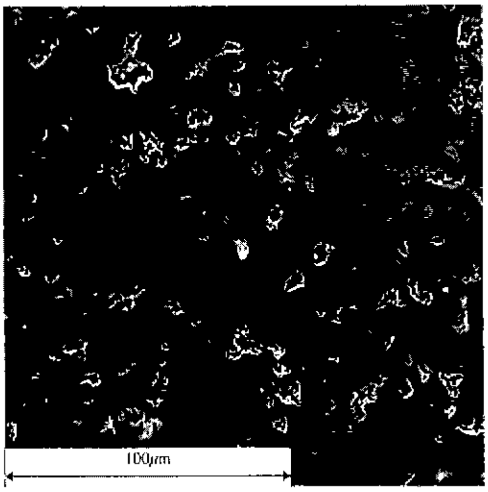
(b) EDX Spectra showing cobalt-free surface

Fig. 1. SEM Micrograph and EDX Spectra of a cemented carbide surface prepared for diamond coating.

this manner[13] were dimond coated (~30 µm) using hot filament, microwave plasma, and plasma torch techniques and evaluated in turning an 18 percent silicon-aluminum alloy. Regardless of coating method, metalcutting performance was equivalent with no evidence of flaking in the wear zone of the tool.

The surface morphology of the diamond coating has a significant influence on the performance of the tool.[27,30] In the as-deposited condition, the coating on both rake (top) and flank (side clearance) surfaces of the tool is usually highly faceted on the microscopic scale, which is in sharp contrast to the smooth surface morphology of PCD, Fig. 2. The faceted coating on the rake has a favorable influence on workpiece chip formation in that smaller, more manageable chips are formed during the cutting process. Conversely, the faceted coating on the flank surface causes the generation of rougher workpiece surface finishes. For this reason, the final step in diamond-coated tool production may involve smoothening the flank surfaces by a buffing or polishing operation.

(a) Thin-Film Diamond Coated Carbide



(b) 25 µm PCD Tool

Fig. 2. Rake surface morphology of diamond tools outside of cutting zone.

III. Metalcutting Performance Characteristics

For this work, the cemented carbide tools were heat treated to remove surface cobalt and roughen the surface in preparation for diamond coating. After scratching the tool surface with diamond grit to promote uniform nucleation, tools were coated in a hot filament reactor to a nominal thickness of 30 µm. A post-coating buffing operation, using a diamond-impregnated nylon brush, was performed on flank surfaces of the tools to smoothen the coating and to provide the best possible workpiece surface finish. The chemical composition of workpiece materials is listed in Table 1.

1. Tool life

PCD is the tool material of choice in machining hy-

Table 1. Chemical Composition of Aluminum Alloy Workpiece Materials

Alloy	Composition,[a] Weight Percent					Comments
	Silicon	Copper	Iron	Nickel	Magnesium	
Mahle 138	17.8	0.97	0.43	0.93	1.02	Uniform Microstructure
Reynolds A390	17.8	5.12	0.39	< 01	0.72	Non-uniform Microstructure
Reynolds 383.2	11.0	2.60	0.76	<.01	<.01	-
Duralcan A359/SiC/20p-T6*	9.3	0.01	0.07	<.01	0.61	Metal Matrix Composite

[a] Aluminum Balance.
*SiC present at 20 volume %.

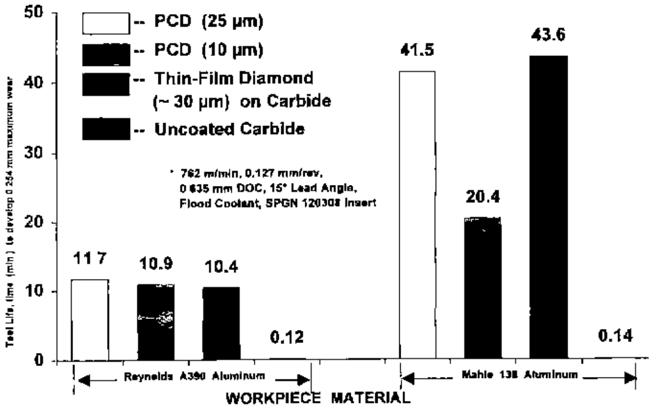


Fig. 3. Metalcutting performance in turning* hypereutectic (~18% Silicon) aluminum alloys.

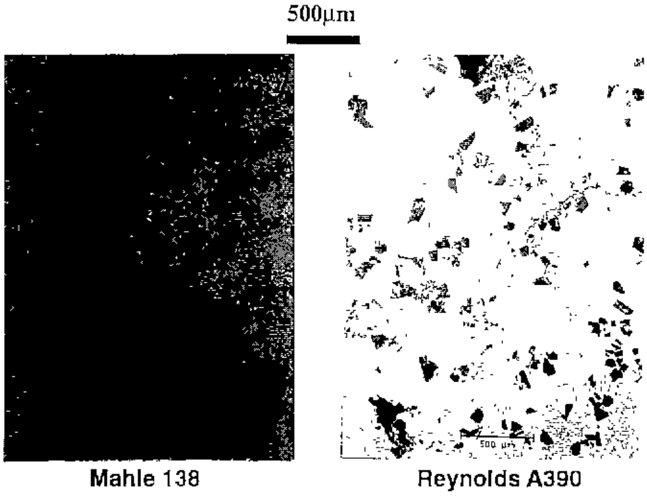


Fig. 4. Microstructure of hypereutectic aluminum alloys with similar (18%) silicon content.

pereutectic aluminum alloys (> 12.2% silicon) because of the extremely abrasive nature of the primary silicon particles in the microstructure of these materials. The results of turning tests on two hypereutectic alloys (Reynolds A390 and Mahle 138), each containing nominally 18% silicon, are shown graphically in Fig. 3. The tests included a 10 µm PCD grade, a 25-µm PCD grade, a diamond-coated carbide tool, and the uncoated carbide substrate in the as-ground condition. New PCD tools were used for the test on Mahle 138, whereas the diamond-coated tool was merely indexed to the next corner.

The uncoated-carbide tool reached the failure criterion in seconds for both alloys, as expected. On the A390, the 25-µm PCD provided 11.7 and 10.9 minutes of tool life, respectively; whereas, the diamond-coated carbide tool lasted 10.4 minutes and failed by abrasive wear with no evidence of flaking. The metalcutting data were quite different for the Mahle 138 alloy in that tool lives increased significantly for all the diamond tools. The tool life of the diamond-coated insert exceeded that of the 25-µm PCD by a small margin, but was double the life of the 10-µm PCD. The significant difference in the machinability of these alloys, even though they are identical in silicon content, can be explained on the basis of their microstructural features, Fig. 4. The primary silicon particles in a390 are larger, more irregularly shaped, and non-uniform in distribution compared to those in the 138 alloy, which are smaller, spheroidal in shape, and more uniformly distributed in the matrix. Consequently, the silicon particles in A390 will cause more impact damage at the cutting edge under these machining conditions. It has been reported[25] that the tool life of some diamondcoated tools in machining other types of A390 has exceeded that of PCD under similar conditions.

To simulate the manner in which cutting tools are used in production, a cyclic turning test was designed wherein the tools were cycled through 30 passes, each 3.93 cm long, to turn the A390-bar diameter from 12.55 to 8.13 cm, which took a total of 5 minutes. The inserts, which included a 25-µm PCD tool and four new diamond-coated carbide tools, were tested in a random sequence; and after 120 passes had been completed, the insert was soaked in a hot NaOH solution to remove the aluminum smear in the wear zone of the tool, which enabled an accurate wear-land measurement and examination for flaking. A tool was removed from the test when the cutting zone developed a maximum wear land of 0.254 mm or after a total cutting time of 100 minutes (600 passes) had elapsed.

Results are listed in Table 2 and show that the diamond-coated tools performed equal to or better than the PCD insert under these cutting conditions. Although the cutting speed is lower than used in the previous test (457 versus 762 m/min), the metal removal rate is significantly higher (133 versus 62 cm^3/min). Moreover, the life of all tools were improved by a factor of ~10 in this test on A390, demonstrating that cutting speed has the most significant effect of tool wear. Therefore, both PCD and diamond-coated carbide tools can be used more effectively at moderate cutting speeds and somewhat higher feed rates and depths of cut, remembering that one of the heuristics in using PCD tools is that the depth of cut should not exceed 60 percent of the cutting length of the blank. A diamond-coated tool is not subject to this limitation.

Table 2. Performance of PCD (25 μm) and THIN-FILM (~30 μm-thick) CVD Diamond Tools in Cyclic Turning* A390 (~18% Silicon) Aluminum

Tool Material	Measured Wear (mm) After Indicated Time					Performance Relative TOPCD
	20 min	40 min	60 min	80 min	100 min	
PCD (25 μm)	0.097	0.130	0.173	0.224	0.254	1.00
Thin Film No. 1	0.104	0.132	0.142	0.208 (S)[a]	0.262	0.97
Thin Film No. 2	0.086	0.104	0.127	0.140	0.165	1.54
Thin Film No. 3	0.091	0.104	0.137	0.155	0.221 (S)	1.15
Thin Film No. 4	0.099	0.185	0.216	0.226	0.239	1.06

*457 m $(min)^{-1}$, 0.381 mm $(rev)^{-1}$, 0.762 mm DOC, Flood Coolant, 15° Lead Angle, SPGN120308 Insert. Each twenty-minute increment represents 120 passes.

[a] S-Substrate Exposed.

Earlier work[27] has shown that diamond-coated carbide tools offer tool life advantages over 25 μm PCD tools in machining aluminum-based metal matrix composites (MMCs). The aluminum MMCs are essentially hypoeutectic alloys reinforced with either Al_2O_3 or SiC in the form of particles or whiskers; and because of the hardness and abrasive nature of the reinforcing phase, diamond is the only viable tool material.[31,32] Inasmuch as the performance of PCD tools is a function of diamond particle size, 10, 25, 45 and 75 μm PCD grades were tested along with diamond sheet, thin-film diamond-coated carbide, and synthetic single-crystal diamond tools in turning Duralcan (A359/SiC/20p-T6) under a variety of cutting conditions.

Results of the MMC turning test are summarized in Table 3 and show clearly that use of higher cutting speeds and feeds shorten tool life. The best overall machining efficiency, defined as the total volume of material removed until tool failure at all conditions, was exhibited by the thin-film coated carbide tools at 12.4 k cm^3 of MMC, 45 percent greater than the second-best tool, 25 μm PCD. At the higher speed and feeds, the diamond sheet tools showed the best performance, followed by the thin-film tool, 3839 versus 3122 cm^3 of MMC, respectively. It is noteworthy that the single-crystal tools failed by chipping at all conditions; these tools are generally used at much lower feed rates and depths of cut, and the high tool pressures under the conditions of this test led to the chipping. Further, at the low speed and high feed condition, the diamond sheet tool and the coarser-grained PCD tools also failed by chipping, probably for the same reason.

SEM micrographs of the wear zone on several of these tools are shown in Fig. 5. With exception of the chipping

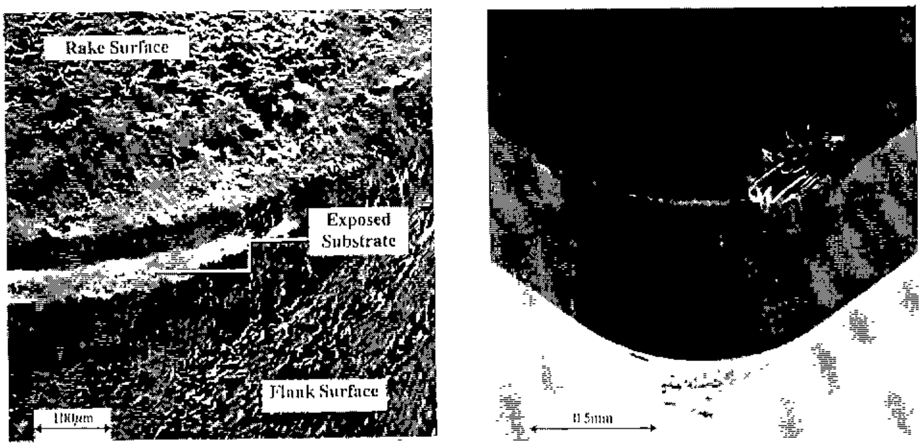
Table 3. Tool Life and Mode of Failure of Diamond Cutting Tools in Turning[a] Duralcan MMC

Tool Material	Speed, 305 m/min				Speed, 762 m/min				Machining Efficiency
	Feed, mm/rev				Feed, mm/rev				Total MMC Removed, cm^3 (Ranking)
	0.127		0.381		0.127		0.381		
	Tool Life[b], minutes	Mode of[c] Failure	Tool Life, minutes	Mode of Failure	Tool Life, minutes	Mode of Failure	Tool Life, minutes	Mode of Failure	
PCD - 10 μm	59.8	AW	96.0	AW	3.7	AW	1.1	AW	7,188 (#4)
PCD - 25 μm	68.4	AW	111.8	AW	7.5	AW	1.9	AW	8,595 (#2)
PCD - 45 μm	87.4	AW	31.1	CH	12.0	AW	7.4	AW	5,916 (#6)
PCD - 75 μm	149.2	AW	60.1	CH	13.0	AW	1.5	AW	7,344 (#3)
Thin-Film (~30 μm)	129.6	AW	114.5	AW	21.8	AW	13.9	AW	12,431 (#1)
Sheet	99.1	AW	5.9	CH	25.6	AW	17.5	AW	6,137 (#5)
Synthetic Single Crystal	76.1	CH	0.7	CH	9.0	CH	5.3	CH	2,763 (#7)

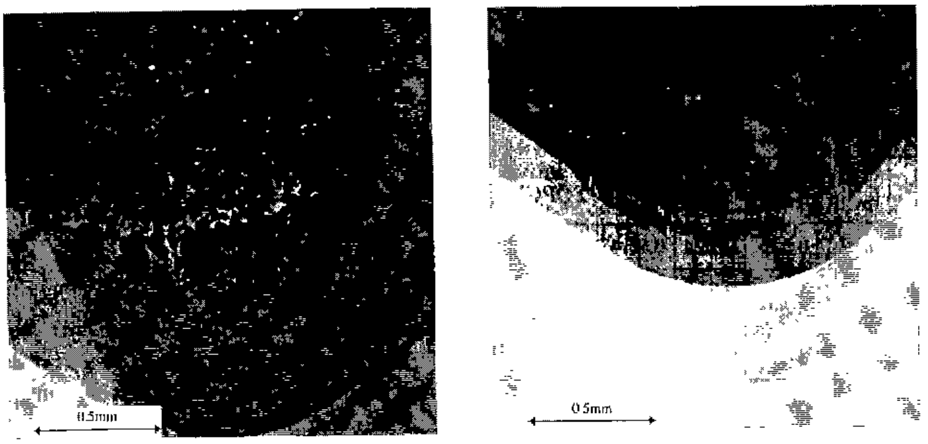
[a] Speeds and Feeds as indicated, 0.508 mm Depth-of-Cut, Flood Coolant, SPGN 120308 Insert Style, 15 Degree Lead Angle.

[b] Time to develop 0.254 mm Maximum Wear, Chipping or Flaking.

[c] Abrasive Wear - AW, Chipping - CH, Flaking - FL.



(a) Thin-Film Coated Carbide Tool (b) Synthetic Single Crystal Tool



(c) 75 μm PCD Tool (d) Diamond Sheet Tool

Fig. 5. SEM micrograph of the wear zone developed on diamond tools in turning MMC at 762 m/min., 0.013 mm/rev., and 0.51 mm/doc.

that occurred on the single-crystal tool, the wear zones on the "pure" diamond cutting tools were much smoother than that on the 75 μm PCD tools, which is typical for all PCD tools. Cobalt at the interstices of the diamond particles in the PCD tools is rapidly worn by the SiC in the MMC, leading to premature microfracture and pullout of the diamond particles. Note that there is no evidence of flaking on the thin-film tool even though the coating has been worn through to the substrate. Moreover, the surface of the diamond coating has been smoothened in the wear zone by chip flow on the rake surface and by attritive wear on the flank surface.

2. *Chip formation*

The chip formation characteristics of diamond tools used in turning Duralcan MMC are illustrated in Fig. 6. Only chips formed by the thin-film and 25 μm PCD tools are shown, because chips formed by the latter tool are typical of those produced by the other diamond tools with polished rake surfaces. Confirming results of earlier work on aluminum-silicon alloys,[27] it is clear that chips produced with thin-film coated carbide tools are much smaller and more manageable than those produced by polished-rake tools under all MMC cutting conditions. In general, chips produced at the lower feed rate were smaller than those produced at the higher rate; and chips produced at the higher cutting speed are smaller than those produced at the lower speed. The microscopically rough, faceted diamond coating in the wear zone affects chip flow early in the cutting process, inducing frictional turbulence and stresses in the chip that cause it to rapidly deflect and break more easily. Because polished rake surfaces lack obstructions to chip flow, the chips are larger and more continuous and may be objectionable under some cuting conditions, such as at 305 m/min and 0.381 mm/rev.

3. *Workpiece surface finish*

The workpiece finish provided by a cutting tool is a key element of tool-performance evaluation and is a function of several metalcutting variables including cutting speed and feed, nose radius of the tool, surface characteristics in the wear zone of the tool, metallurgical quality of the workpiece material, lead angle, coolant utilization, and machine-tool condition. Workpiece surface roughnesses generated by the diamond tools in turning Duralcan MMC are listed in Table 4. As expected, feed rate had the most significant influence on surface finish, with the lower feed producing roughnesses betwen 1.5 and 2.8 μm R_a versus 5.8 and 7.7 μm R_a at the higher feed rate. In this test, cutting speed did not have a significant effect on finish, however, higher cutting speeds generally provide smoother finishes at a given feed rate. The best overall surface finishes were produced by the single-crystal tool and the 45 μm PCD tool. Both flank and rake surfaces of the single-crystal tool were highly polished, and the polished flank led to the superior finishes, even though this tool was prone to chipping.

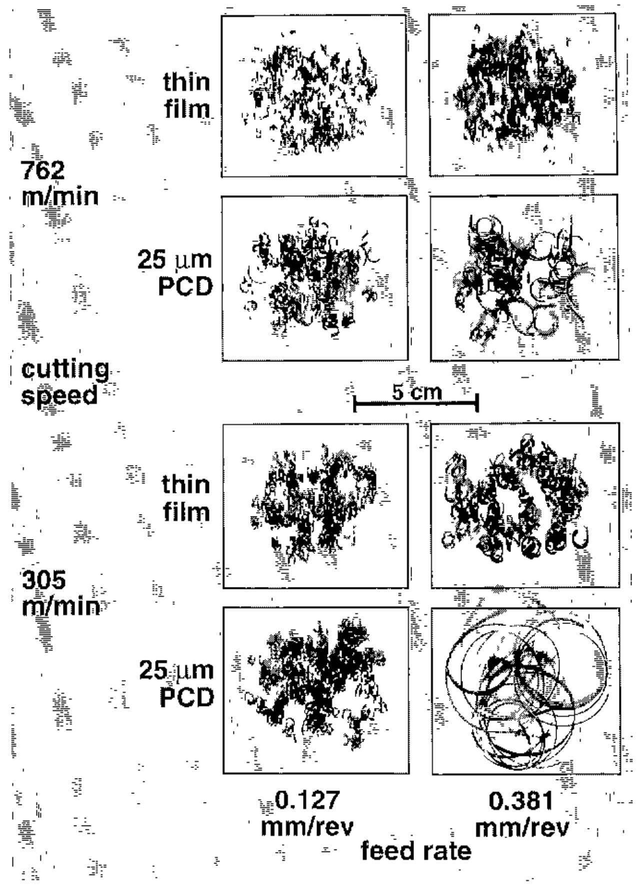


Fig. 6. Chip formation characteristics of diamond tools used in turning Duralcan® MMC.

To demonstrate the effect of cutting tool nose radius on workpiece surface finish, thin-film, diamond-coated carbide tools with nose radii of 0.2, 0.8, 1.2 and 1.6 mm were used to turn A390 and A383.2 aluminum alloys at the same conditions. For comparison, a 25 μm PCD tool with an 0.8 mm nose radius was also tested. Each tool was used to make ten 2-minute cuts in random sequence on each alloy; and the surface roughness was measured at the beginning, mid-point, and end of each cut.

The surface roughness data are shown graphically in Fig 7, with each bar representing the range of surface roughness generated by a tool. As expected, workpiece

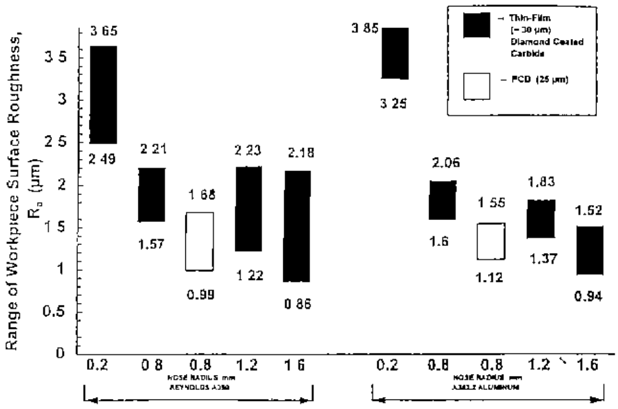


Fig. 7. Effect of tool nose radius (SPGN 1203XY insert) and workpiece material on surface finish when turning at 762 m/min, 0.13 mm/rev, 0.635 mm DOC, 15 degree lead angle and flood coolant.

Table 4. Workpiece Surface Roughnesses Generated by Diamond Tools in Turning[a] Duralcan MMC

Tool Material	Speed, 305 m/min		Speed, 762 m/min	
	Feed, mm/rev		Feed, mm/rev	
	0.127	0.381	0.127	0.381
PCD - 10 μm	2.06±0.61[b]	6.80±0.63	2.84±0.68	6.47±0.71
PCD - 25 μm	1.57±0.51	7.03±0.41	2.39±0.58	6.17±0.15
PCD - 45 μm	1.62±0.28	6.19±0.99	2.59±0.91	5.91±0.84
PCD - 75 μm	1.62±0.30	6.62±0.69	2.66±0.94	7.66±0.96
Thin - Film (~30 μm)	1.65±0.20	6.85±0.66	2.28±0.38	6.80±0.48
Diamond Sheet	2.34±0.53	7.03±0.23	2.36±0.33	6.45±0.36
Synthetic Single Crystal	1.55±0.25	7.51±0.48	1.52±0.38	5.81±0.36

[a] Speed and Feeds as indicated, 0.508 mm Depth-of-Cut, Flood Coolant, SPGN 120308 Insert Style, 15 Degree Lead Angle.
[b] Mean and Standard Deviation of Roughness Measurements, R_a in μm

roughness decreases with an increase in tool nose radius. Regardless of workpiece material, for a given nose radius (0.8 mm), the PCD tool provided a smoother finish than the thin-film tool because the flank surface of the PCD cutting edge is much smoother than that of the diamond-coated tool. The data also indicate that if the desired workpiece geometry permits, a thin-film tool with a 1.6 mm nose radius will provide nearly the same finish as a PCD tool with 0.8 mm radius.

IV. Applications

1. Aluminum pistons

Thin-film, diamond-coated carbide inserts in style CPGH09T308K have been used successfully in roughing and semifinishing the skirt portion of aluminum-12% silicon pistons at speeds ranging from 840 to 880 m/min, feeds from 0.4 to 0.5 mm/rev and DOC from 0.4 to 1.0 mm. Tool life on a per edge basis has been excellent, ranging from 1.5 to 3.0 times that of the 25 µm PCD tool it replaced. Moreover, the improved chip forming characteristics of the thin-film tool reduced machine-tool downtime for chip disposal by one hour per week.

2. Bi-Metallic milling

The production of aluminum engine blocks with cast iron linera has been increasing in recent years. Presently, 25 µm PCD tools are typically used in milling these parts; however, thin-film, diamond-coated carbide tools have recently proven to be a very cost effective alternative. In one application (aluminum-11% silicon block/ cast iron liners), a 15-degree lead angle, double-positive, face-mill cutter (20.32 cm diameter) loaded with ten thin-film inserts in style SPGN120308 were used at 1067 m/min, 0.20 mm/tooth, and 1.78 mm depth of cut at a cross-head speed of 51 cm/min. Initially, the thin-film tools produced a surface finish of 2.34 µm R_a ($\leq$1.52 µm R_a was specified for this part) with some objectionable burr formation. At this point one-thin-film tool was replaced with a 25 µm PCD tool in style SPGN120412 which was set at 0.018 mm above the plane defined by the other inserts in the cutter to ensure a good wiping action on the workpiece. Installation of the sharp-edged wiper tool lowered the surface roughness to 0.95 µm R_a and completely eliminated burr formation. The tool life of the thin-film tools in this milling application has equaled that of PCD on a per edge basis.

3. Carbon-Carbon composite

Thin-film tools have also been used successfully in dry profiling tapered tubes fabricated from a very abrasive carbon-carbon composite material. Single-point, 25 µm PCD tools typically yield 200 parts per tool at speeds ranging between 133 and 360 m/min, feeds between 0.10 and 0.24 mm/rev and a depth of cut of 0.8 mm. Thin-film tools in style DNGP150408DK have provided 390 parts per tool on average under the same cutting conditions; workpiece finish was equivalent to that provided by PCD.

4. Aluminum motor caps

Thin-film tools in style TD6P05 were used to turn motor end caps, cast from an aluminum-8.5% silicon alloy, at 300 m/min, 0.1 mm/rev and 1.00 mm depth of cut. The diamond-coated tools provided nearly four times the tool life of PCD on a per-edge basis and workpiece roughnesses < 0.6 µm R_a. The PCD tools typically fail by chipping in this application, whereas the thin-film tools failed by uniform abrasive wear.

V. Summary

Key to the successful commercialization of diamond-coated cemented carbide cutting tools is the development of reliable adhesion technology. It has been found that heat treating the carbide insert produces an essentially cobalt-free, roughened surface, which is an excellent substrate for diamond. Use of lower coating temperatures and higher deposition-rate processes also promote adhesion. The morphology of the coating on the rake surface of the tool influences chip formation and on the flank surface it affects workpiece finish.

The tool life provided by diamond-coated carbide tools (~30 µm thick) can equal or better that of PCD tools, depending on the composition and microstructure of the workpiece material. However, because of the microscopically faceted flank surface of the thin-film tool, it usually generates a somewhat rougher workpiece finish than PCD. If the workpiece geometry permits, this limitation can be overcome by using a coated tool with a larger nose radius. In milling operations requiring a low workpiece roughness, diamond-coated tools should be used along with sharpedged PCD wiper tools in the cutter to insure the best possible surface finish and freedom from burr formation. With multiple cutting edges (lower cost per edge), superior chip formation characteristics, elimination of depth-of-cut limitations, and improved performance reliability, diamond-coated carbide tools will find increasing use for machining of non-ferrous and nonmetallic materials.

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