Composite Machining

For decades, the aircraft industry has utilized composite materials in multiple applications, including flight surfaces and some internal cabin parts. Unfortunately, these materials are unique to each design in their fiber layering techniques, resins, and curing processes, which creates great challenges to consistency in manufacturing and assembly.

Composite materials are bonded together to form complex structural sub-assemblies that must be either assembled together or attached to other structural components, such as aluminum or titanium. This presents a unique set of challenges that requires radical new technologies.

One of the newest materials using carbon fiber and resins is called CFRP (Carbon-Fiber Reinforced Polymer). Due to attractive properties, such as weight-to-strength ratio, durability, and extreme corrosion resistance, CFRP is used mostly in primary structure applications like aircraft hull and wings.

Kennametal has years of experience working with material suppliers, machine tool providers, aircraft OEMs, and parts manufacturers. We have invested substantially to better understand how to machine CFRP/CFRP and CFRP/metals combinations. Our research has led us to become a leader in this field and has resulted in many exciting innovations, like our diamond-coated drills and orbital holemaking solutions.

We would like to share some of this knowledge and are pleased to present the following guide to machining composite materials — from understanding their properties to selecting the best technologies.

Characteristics of Composite Materials

Composite materials are generally composed of soft, tough matrix with strong, stiff reinforcements. Fiber-reinforced polymers are the broad class of composites usually targeted.

Fiber Reinforcements

— Carbon fiber/Graphite fiber (high strength or high modulus)
— Glass fibers
— Ceramic fibers
— Polymer fibers (Kevlar, Polyethylene)
— Tungsten fibers

Polymer Matrix

— Epoxy
— Phenolic
— Polyimide
— Polyetheretherketone (PEEK)

- CFRP/carbon-fiber reinforced polymers (particularly epoxy) have gained tremendous importance due to their high strength-to-weight ratio.

Properties Compared to Common Engineering Materials

Material	Tensile Strength (MPa)	Density (g/cm³)
Carbon-fiber epoxy	1,500–3,000	1,5–2,0
Aluminum	600	2,7
Steel	600–1,500	8,0

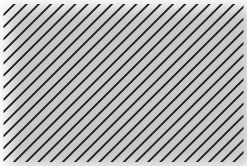
- High strength-to-weight ratio leads to widespread acceptance in structural aerospace components.
- Corrosion resistance and radiolucent properties have made CFRP/carbon-fiber attractive in the medical industry.

Overview • Effect of Attributes on Mechanical and Machining Properties

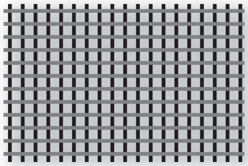
Attribute	Properties	Comments on Machining
Fiber	High strength, high modulus	Abrasiveness of fiber increases with strength
Fiber length	—	Small pieces of fiber delaminate easier and present machining difficulties
Fiber diameter	Increasing diameter decreases tensile strength	While tensile strength reduces with diameter, cutting forces are expected to increase
Matrix	Toughness	—
% Volume of fibers	Improves mechanical properties	Adversely affects machinability
Fiber layout: Unidirectional or fabric weave	Affects the degree of anisotropy of properties	Delamination is usually severe in unidirectional tapes

Types of Fiber Layout

Fiber can be laid in the matrix in several different configurations. Two common examples are:



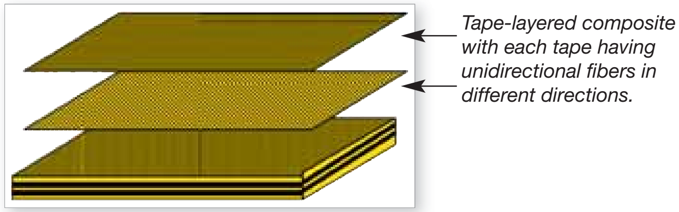
Unidirectional tape



Fabric weave

Methods of Fabrication

- Most common method: Fiber-resin “prepregs” (tape), with one laid over top of another (each tape laid in one or several directions) and one bag/vacuum molded to form a laminate.
- Other methods include bulk resin impregnation, compression molding, filament winding, pultrusion, etc.



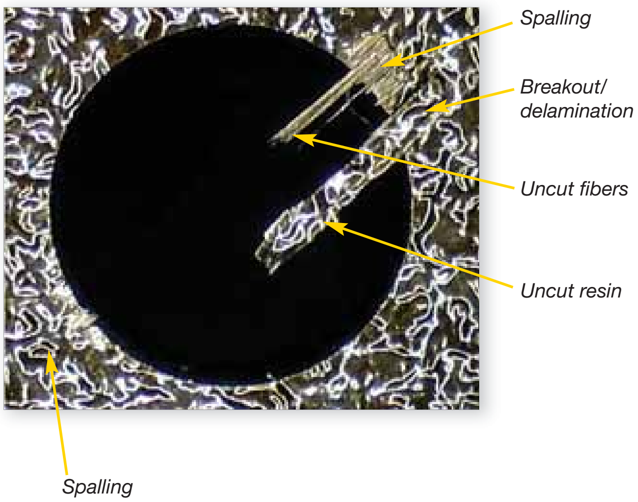
Machining Challenges

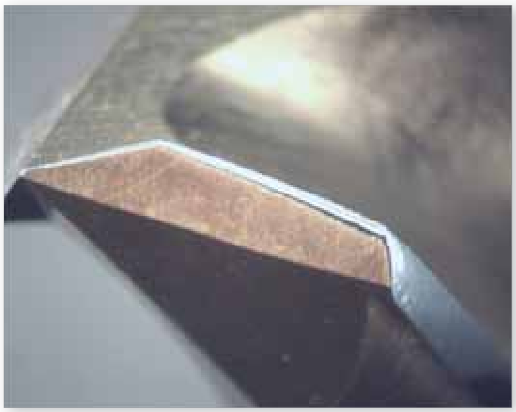
Surface Quality

— Delamination (separation of layers)
— Fiber pullout
— Uncut fibers
— Breakout

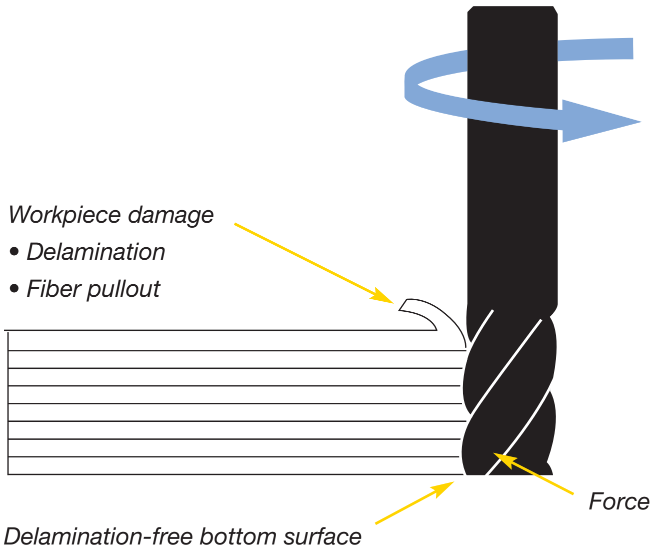
Rapid Tool Wear

Very rapid flank wear due to the abrasive nature of composites.





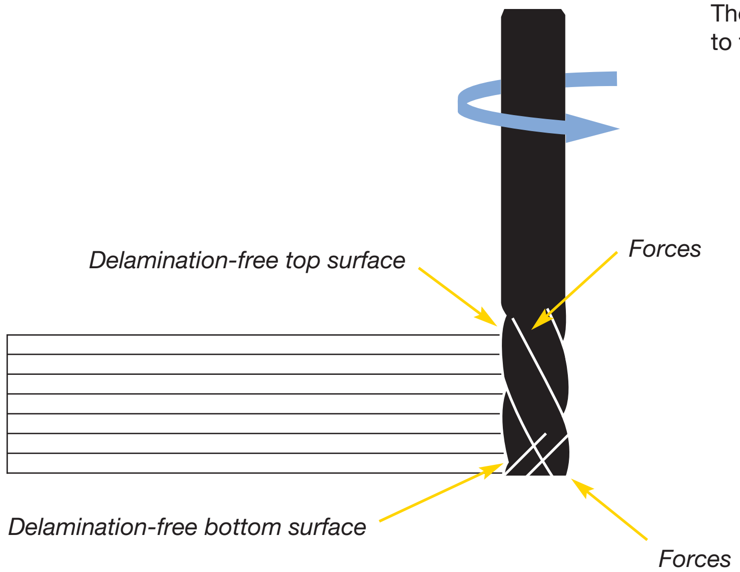
Standard End Milling



Tool Design for Composite Routing

The standard style end mills generate cutting forces in only one direction. With a positive helix cutter, this will have the tendency to lift the workpiece while causing damage to the top edge.

Compression End Milling



The compression-style router generates cutting forces into the top and bottom surfaces of the workpiece. These forces stabilize the cut while eliminating damage to the workpiece edges.

End or Face Milling Mill 1–10™

The Kennametal Mill 1-10 Indexable Milling Series — Face Milling, up to 100% Engagement with PCD Inserts

Ideal for applications utilizing Carbon-Fiber Reinforced Polymer (CFRP).

- Aggressive ramping rates, high RPM capabilities, and a superior surface finish — time after time.
- Varying axial depth of cut, meeting the challenges of a wide range of applications.
- No material breakout or burr formation upon entry or exit of the workpiece.

Choose the Mill 1-10 to mill 90° walls.

Visit **www.kennametal.com** or contact your local Authorized Kennametal Distributor.

www.kennametal.com

KENNAMETAL®

Composite Milling Solutions

Kennametal has the right milling solutions designed for machining difficult CFRP (Carbon-Fiber Reinforced Plastic) and non-ferrous components. Our diamond-coated (Grade KCN05™) products provide excellent tool life while producing smooth finishes with improved edge quality. Our unique geometries are free cutting, reducing heat generation and providing high quality machined surfaces.

Compression-Style Router • Helix 25°

Cutters are designed for high feed rates and producing excellent quality edges on both sides of the material. This up-cut down-cut geometry generates the forces into the workpiece, providing stable cutting conditions.

Burr-Style Routers • Helix 15°

Cutters were originally designed for trimming fiberglass, but also are found to work in CFRP. Excellent temperature control while producing good surface quality.

Down-Cut-Style Router • Helix 25°

Cutters are designed for surface work having great ramping capabilities for producing pockets. Geometry designed to produce down forces to eliminate surface delamination.

Ball-End-Style Routers • Helix 30°

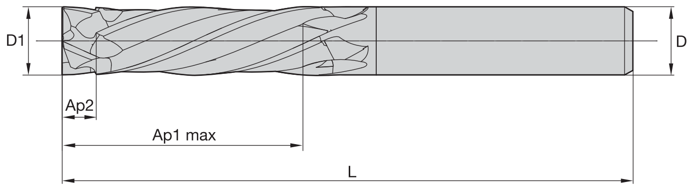
Cutters are designed for slotting and profiling while providing excellent tool life.

Features

- Kennametal standard
- Through hole capability
- Plain shank
- Through coolant
- Helix angle 25°

Application

- Slotting and side milling
- Ramping capabilities
- Aerospace composites and fiberglass



Compression-Style • KCN05 • Inch

order number	catalog number	D1	D	L	Ap1 max	Ap2	Z
4137446	CCNC0250J3AH	.250	.250	2.500	0.750	.125	3
4137447	CCNC0250J3BH	.250	.250	4.000	1.500	.125	3
4137448	CCNC0375A4AH*	.375	.375	3.250	0.750	.125	4
4137449	CCNC0375A4BH*	.375	.375	4.000	1.500	.125	4
4137279	CCNC0500A4AH*	.500	.500	3.250	0.750	.125	4
4137280	CCNC0500A4BH*	.500	.500	4.000	1.500	.125	4

Compression-Style • KCN05 • Metric

order number	catalog number	D1	D	L	Ap1 max	Ap2	Z
4137452	CCNC0600A3AH	6,00	6,00	63	18	3,2	3
4137453	CCNC0600A3BH	6,00	6,00	100	36	3,2	3
4137281	CCNC1000A4AH*	10,00	10,00	83	18	3,2	4
4137282	CCNC1000A4BH*	10,00	10,00	100	36	3,2	4
4137443	CCNC1200A4AH*	12,00	12,00	83	18	3,2	4
4137444	CCNC1200A4BH*	12,00	12,00	100	36	3,2	4

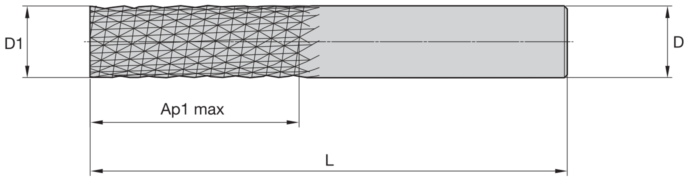
* *Through coolant available on 4-flute styles only.*

Features

- Kennametal standard
- Plain shank
- Helix angle 15°

Application

- Slotting and side milling
- Ramping capabilities
- Aerospace composites and fiberglass



Burr-Style • KCN05 • Inch

order number	catalog number	D1	D	L	Ap1 max
4137459	CBDB0250JXAS	.250	.250	2.500	.750
4137460	CBDB0250JXBS	.250	.250	4.000	1.500
4137461	CBDB0375JXAS	.375	.375	3.250	.750
4137462	CBDB0375JXBS	.375	.375	4.000	1.500
4137473	CBDB0500JXAS	.500	.500	3.250	.750
4137474	CBDB0500JXBS	.500	.500	4.000	1.500

Burr-Style • K600 • Inch

order number	catalog number	D1	D	L	Ap1 max
4137493	CBDB0250JXAS	.250	.250	2.500	.750
4137481	CBDB0250JXBS	.250	.250	4.000	1.500
4137482	CBDB0375JXAS	.375	.375	3.250	.750
4137483	CBDB0375JXBS	.375	.375	4.000	1.500
4137484	CBDB0500JXAS	.500	.500	3.250	.750
4137485	CBDB0500JXBS	.500	.500	4.000	1.500

Burr-Style • KCN05 • Metric

order number	catalog number	D1	D	L	Ap1 max
4137475	CBDB0600AXAS	6,00	6,00	63	18
4137476	CBDB0600AXBS	6,00	6,00	100	36
4137477	CBDB1000AXAS	10,00	10,00	83	18
4137478	CBDB1000AXBS	10,00	10,00	100	36
4137479	CBDB1200AXAS	12,00	12,00	83	18
4137480	CBDB1200AXBS	12,00	12,00	100	36

Burr-Style • K600 • Metric

order number	catalog number	D1	D	L	Ap1 max
4137486	CBDB0600AXAS	6,00	6,00	63	18
4137487	CBDB0600AXBS	6,00	6,00	100	36
4137488	CBDB1000AXAS	10,00	10,00	83	18
4137489	CBDB1000AXBS	10,00	10,00	100	36
4137490	CBDB1200AXAS	12,00	12,00	83	18
4137491	CBDB1200AXBS	12,00	12,00	100	36

(continued)

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Additional Burr-styles point styles available upon request:

Non-End Cutting

Drill Point Cutting

End Mill End Cutting

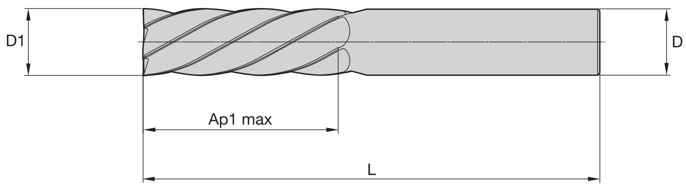
Down-Cut-Style Routers • KCN05

Features

- Kennametal standard
- Plain shank
- Helix angle 25°

Application

- Slotting and side milling
- Ramping capabilities
- Aerospace composites and fiberglass



Down-Cut-Style • KCN05 • Inch

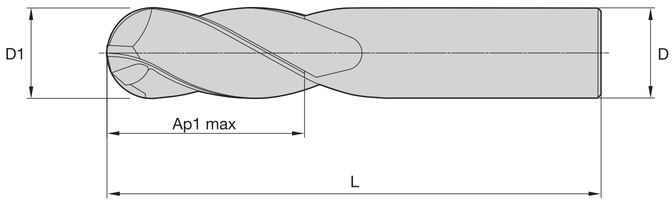
order number	catalog number	D1	D	L	Ap1 max	Z
4137719	CDDC0250J6AH	.250	.250	2.500	.750	6
4137720	CDDC0250J6BH	.250	.250	4.000	1.500	6
4137721	CDDC0375J6AH	.375	.375	3.250	.750	6
4137722	CDDC0375J6BH	.375	.375	4.000	1.500	6
4137733	CDDC0500J6AH	.500	.500	3.250	.750	6
4137734	CDDC0500J6BH	.500	.500	4.000	1.500	6

Down-Cut-Style • KCN05 • Metric

order number	catalog number	D1	D	L	Ap1 max	Z
4137735	CCNC0600A3AH	6,00	6,00	63	18	6
4137736	CDDC0600A6BH	6,00	6,00	100	36	6
4137737	CDDC0375J6AH	10,00	10,00	83	18	6
4137738	CDDC0375J6BH	10,00	10,00	100	36	6
4137739	CDDC0500J6AH	12,00	12,00	83	18	6
4137740	CDDC0500J6BH	12,00	12,00	100	36	6

Features
- Kennametal standard
- Plain shank
- Helix angle 30°

Application
- Slotting and side milling
- Aerospace composites and fiberglass



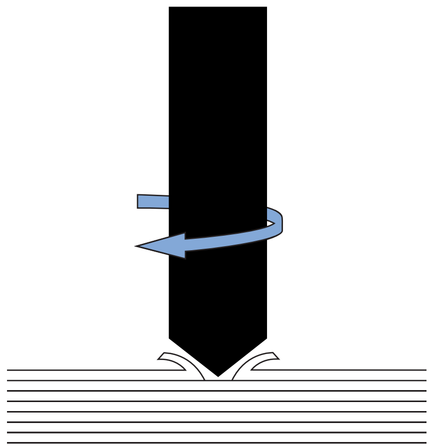
Ball-End-Style • KCN05 • Inch

order number	catalog number	D1	D	L	Ap1 max	Z
4152648	CRBD0375J4AR	.375	.375	3.250	.750	4
4152649	CRBD0500J4AR	.500	.500	3.250	.750	4

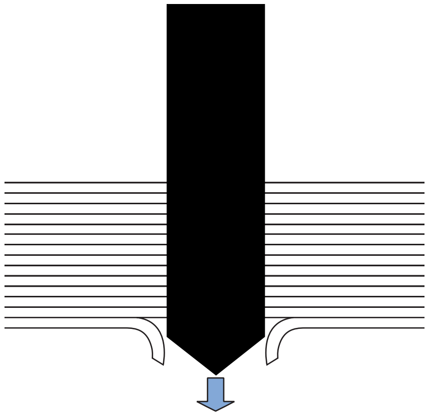
Ball-End-Style • KCN05 • Metric

order number	catalog number	D1	D	L	Ap1 max	Z
4152650	CRBD1000A4AR	10,00	10,00	83	18	4
4152651	CRBD1200A4AR	12,00	12,00	83	18	4

Mechanism of Damage During Drilling



Torque twisting action causing peel-in effect on entry.



Thrust action of the drill causing breakout and delamination.

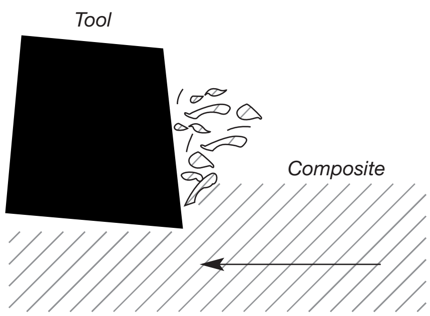
High-speed camera capture of breakout/delamination when hand-drilling in CFRP. Look closely for the extent of delamination prior to drill exit.

Tool Design for Composite Machining

Tool design should be developed with regard to the failure modes observed. Development can be divided into two streams:

1. Geometry
   - Positive geometry to minimize stresses that can cause delamination.
   - Sharp geometry to cut fibers with localized, induced strain.
   - Chip evacuation not essential, but dust needs to be evacuated.
2. Material
   - Sufficient hardness to resist abrasion wear.
   - Strength to support sharp geometries.

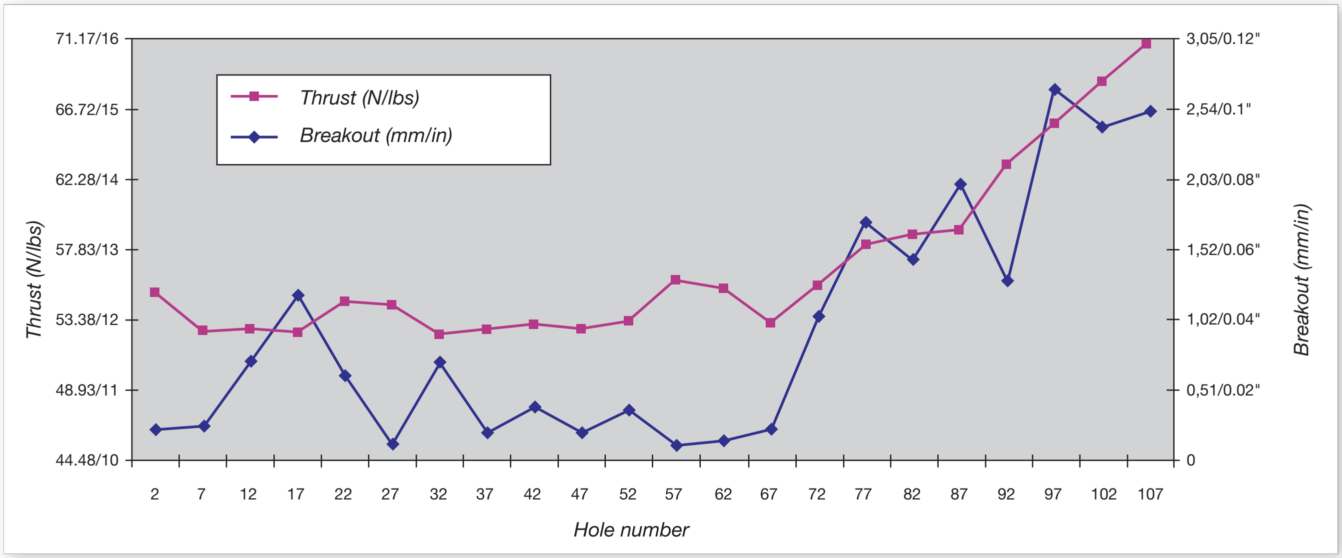
Mechanism of Composite Machining



While the machining of ductile metals is based on shearing, the machining of composites involves several mechanisms:

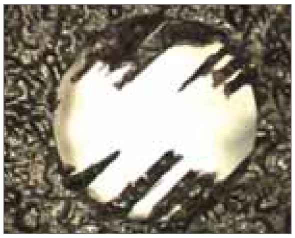
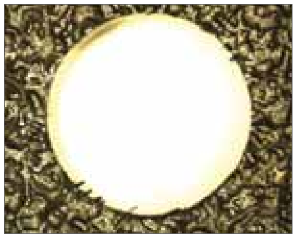
- Compression-induced fracture of fiber (buckling).
- Bending-induced fracture of fiber.
- Shearing, yielding, and cracking of the matrix.
- Interfacial debonding.
- Sub-surface damage.

Thrust versus Delamination



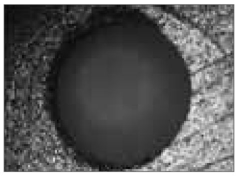
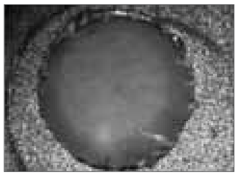
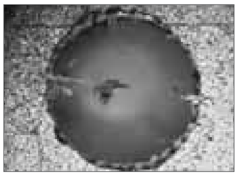
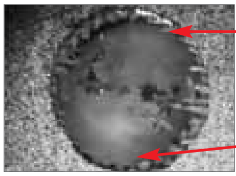
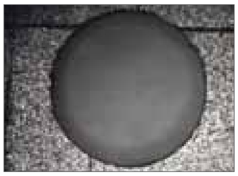
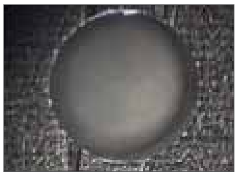
While breakout/delamination and thrust are strongly correlated, there seems to be a high degree of variation in delamination due to other factors, such as fiber position, voids, material effects, etc.

Effect of Geometry on Breakout

Drill Configuration Parameters	Hole Quality Criteria	Incorrect Drill Configuration	KMT SPF Drill Configured Specifically for CFRP
Helix angle, clearance gash, rake	Fiber pull out, delamination, uncut fibers		

SPF Drills • The Kennametal Diamond-Coated Drill

for Excellent Exit Surface Quality in Composite Materials

	Hole #1	Hole #30	Hole #60	Hole #150	Hole #300
PCD					Burr Delamination
Kennametal					

Drills Tested: Kennametal (diamond-coated drill)
Competitive PCD veined drill

Diameter: 0.25" (6,35mm)

Speed: 400 SFM (121 m/min)

Feed: 0.0015 IPR (0,04 mm/r)

Thickness of Plate: ~0.3" (7,62mm) through hole

Material: CFRP (carbon-fiber reinforced polymer)

Coolant: Dry

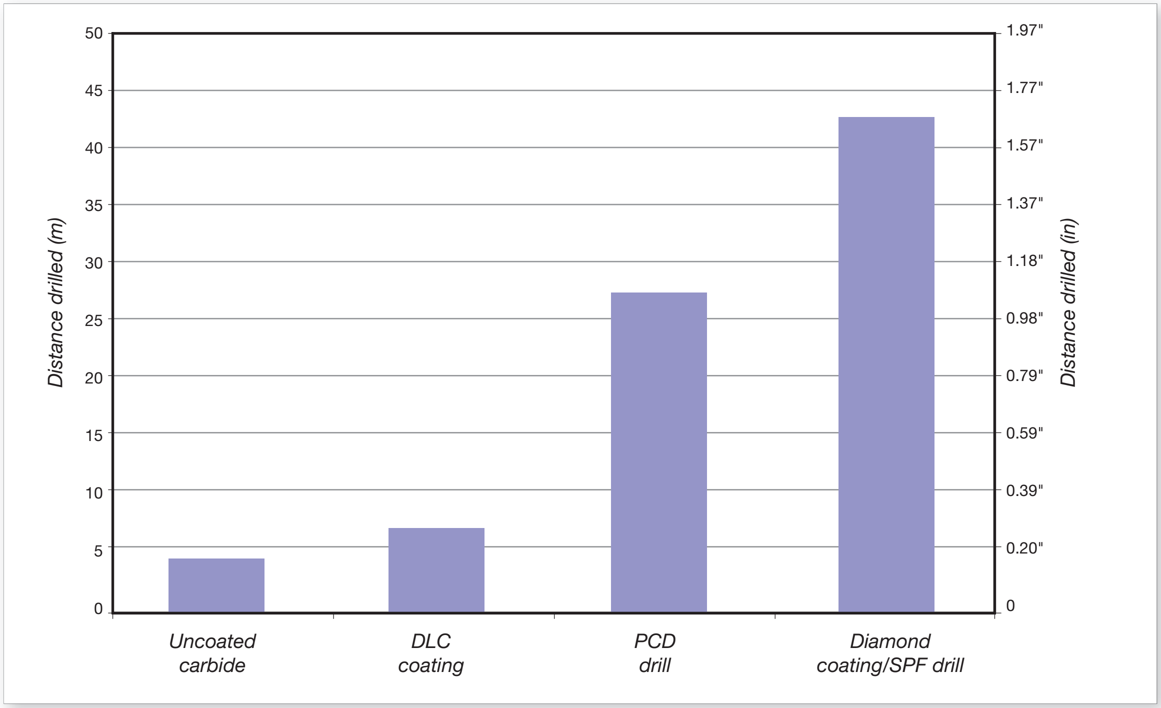
Machine: Makino A55 HMC

NOTE: Testing performed for illustration purposes only; your results may vary.

Effect of Tooling Material

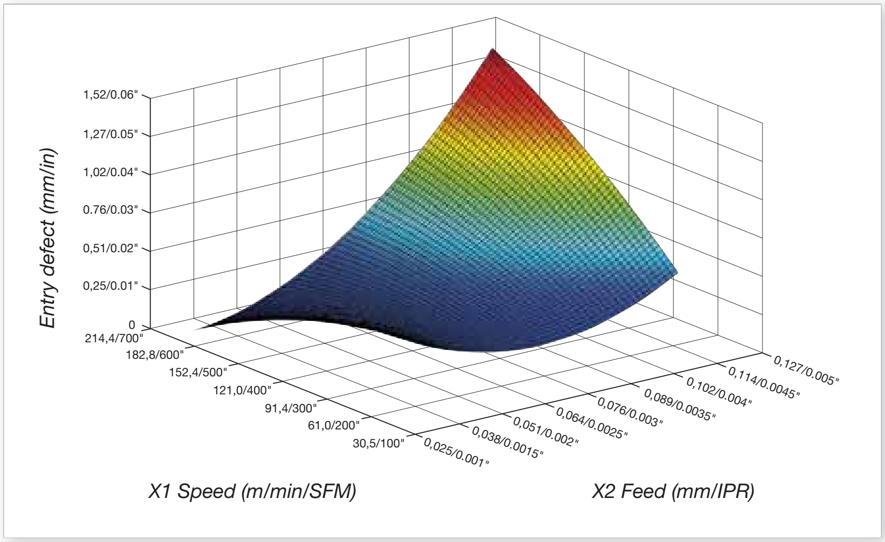
Diamond coating shows a tool life improvement of nearly 10x that of an uncoated solid carbide drill.

Diamond coatings require specific carbide substrates (low Co, coarse grain structure) for best adhesion. Such substrates sometimes lack the toughness required for heavy-duty applications.



Effect of Process Parameters

- Response surface plotted for a variety of speeds and feeds.
- Based on hole entry, exit defects, and productivity — 400 SFM (121 m/min) and 0.0015 IPR (0,04 mm/r) chosen.



Practical Tooling Solutions

Currently, only three types of conventional tools in the market can address both geometry and material design:

Veined PCD Drills

- Drills with PCD sintered directly onto carbide.
- Enable complex shaping of geometry.

Diamond-Coated Drills

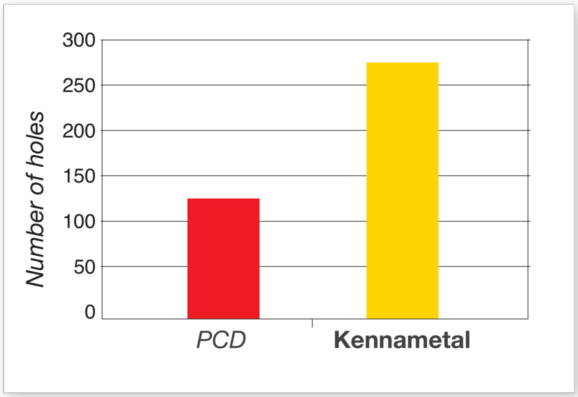
- CVD diamond coating with higher hardness than PCD.
- Any geometry is possible.

Orbital Drills

- Helical milling of hole reduces thrust and therefore breakout/delamination.

Tool Wear

After 300 holes



Kennametal SPF Drills Reduce Per-Hole Costs in CFRP Applications

As the industry explores new ways to reduce structural weight to increase fuel efficiency, studies predict that the use of composite materials will increase to more than 40%.

Kennametal is helping aerospace manufacturers prepare for these future changes. Our new SPF drills are specifically engineered to outperform higher cost PCD drills in applications involving carbon fiber-reinforced polymer (CFRP) composite materials by minimizing delamination and increasing tool life.

Kennametal SPF Drills

Features:

- Specifically engineered for CFRP materials.
- Special 90° point angle increases centering capability to reduce thrust and improve hole quality.
- Smooth CVD multi-layer diamond coating resists wear to provide longer tool life.
- More cost-effective than PCD drills, with better quality holes.
- Available in standard 3xD and 5xD lengths and common aerospace manufacturing diameters.

State-of-the-Art Technology Maximizes Productivity

Technical Specifications

Product: Kennametal SPF K531A Drill, 3xD, without coolant
Material: Diamond-coated 6% straight cobalt
Speed: 400 SFM (120m/min)
Feed rate: .0015 IPR (0.04mm/rev)

Solution At-A-Glance

Operation: Holemaking
Customer: Aerospace Manufacturer
Workpiece: Aircraft component – 0.300" (7,62mm) thickness
Material: CFRP (carbon fiber-reinforced polymer)
Machine Tool: Makino A55 HMC
Solution: Kennametal SPF K531A 0.250" (6,35mm) Drill with grade KDF400
Results:
- **Doubled output from 150 to 300 holes**
- Fewer burrs and less delamination

Savings: Reduced application costs by 68% per hole!

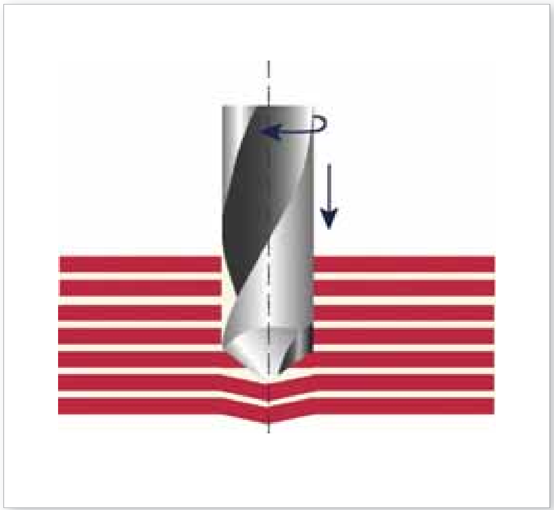
Conventional Push Drilling versus Orbital Drilling

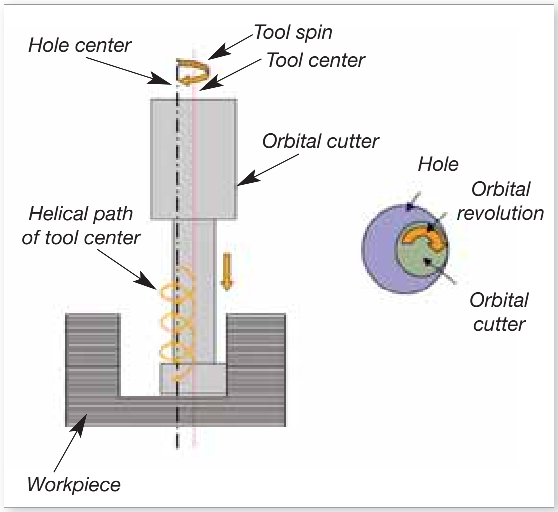
Conventional Push Drilling

- Rotating the tool around its own axis.
- Zero cutting speed at cutter center.
- Continuous contact with hole edge.
- Cutter diameter same as hole diameter.
- Continuous chips.

Orbital Drilling

- Rotating the tool around its own axis.
- Revolving (orbiting) the tool around hole center.
- Cutting edge intermittently in contact with hole edge.
- Cutter diameter less than hole diameter.





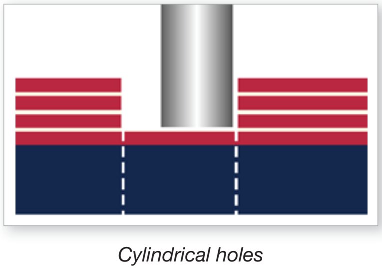
Advantages of Orbital Drilling

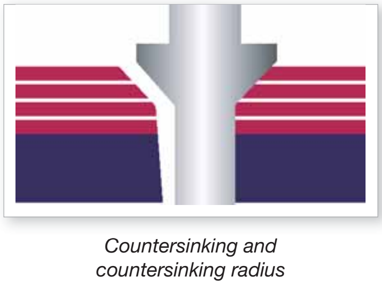
Characteristics	Advantages
Reduced thrust force	• Burrless hole in metal. • Delamination-free hole in CFRP.
Intermittent cutting and cutting edge partially engaged	• Lower cutting temperature. • Reduced risk of matrix melting in CFRP. • Efficient cooling of cutter and hole surface.
Small chip formation	• Easy chip evacuation and heat extraction. • Drilling in closed structure is possible. • Machining in clean environment is possible.
Tool diameter smaller than hole diameter	• One tool for different diameter holes. • Reduce tool inventory. • Easy chip evacuation. • Reduced chip damage.
Others	• Countersink capable. • Capable of repairing misaligned holes. • Adjustable feed, orbital speed in each layer. • Capable of drilling into inclined or curved surfaces.

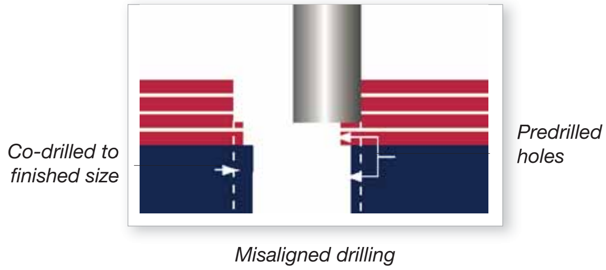
Reduce Manufacturing Steps/Cycle Time

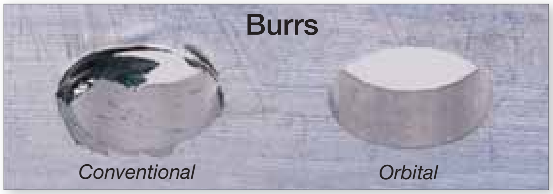
Due to the high-quality holes generated by orbital drilling, the following manufacturing steps might be eliminated:

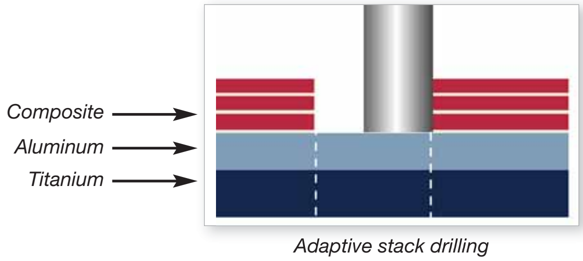
- Disassembly
- Deburring
- Cleaning
- Reassembly
- Repair











Orbital Drilling • Applications and Cutter Grades

Aerospace Aluminum

- Diamond-Like Carbon (DLC) (Grade — KCN15™).
- Medium-grain carbide topped with a hard DLC. This smooth coating is excellent for aerospace aluminum applications.

Titanium and High-Temp Alloys

- AlTiN (Grade — KCS20™).
- Medium-grain carbide topped with state-of-the-art AlTiN coating. This grade is excellent for titanium and high-temp applications.

CFRP

- Diamond-Coated (Grade — KCN05™).
- Fine-grain carbide topped with a smooth CVD, multi-layered diamond coating. Specifically engineered for withstanding the abrasion machining of CFRP materials.

CFRP and CFRP/Aluminum

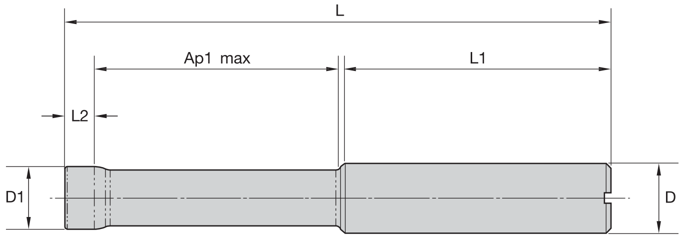
- Brazed PCD (Grade — KDN20™).
- Multi-modal coarse grain PCD specially engineered for machining highly abrasive materials, such as CFRP, while providing exceptional toughness of the cutting edge.

CFRP, CFRP/Aluminum, and CFRP/Titanium

- Veined PCD (Grade — KDNS15™).
- Medium-grain PCD engineered with multi-modal grain size and state-of-the-art sintering processes to provide superior performance in CFRP and CFRP stacked with aluminum and titanium.

Features

- High-performance, quality grades.
- Latest in coating technologies.
- Test cutters for cylindrical holes.
- Straight shank.
- Best performance when used with Shrink Fit toolholders.

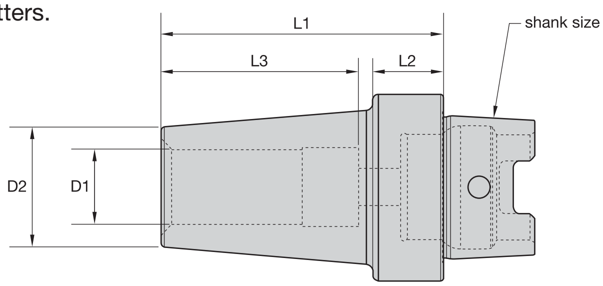


General-Purpose Cutters

application	cutter grade	order number	D1	D	L	L1	L2	Ap1 max	drawing number
Aluminum	KCN15	3964891	10	10	71	40	2.10	28	1886194
Titanium	KCS20	3400773	7	10	61	30	2.20	28	1884807
		3376783	10	10	66	30	2.00	33	1700443
		3964892	10	10	76	40	2.00	33	1884801
CFRP	KCN05	3558611	7	10	61	30	2.80	28	1720890
		3588295	10	10	75	30	4.00	40	1754695
		3964923	10	10	85	40	4.00	40	1882173
CFRP/Al	KDN20	3966866	10	10	80	40	4.00	35	1886193
CFRP CFRP/Al CFRP/Ti	KDNS15	3884120	10	10	80	40	2.50	36	1866477

Features

- Balanced by design.
- Runout ≤0,003mm (.0001").
- Through-the-toolholder coolant capability.
- Suitable for carbide and HSS cutters.

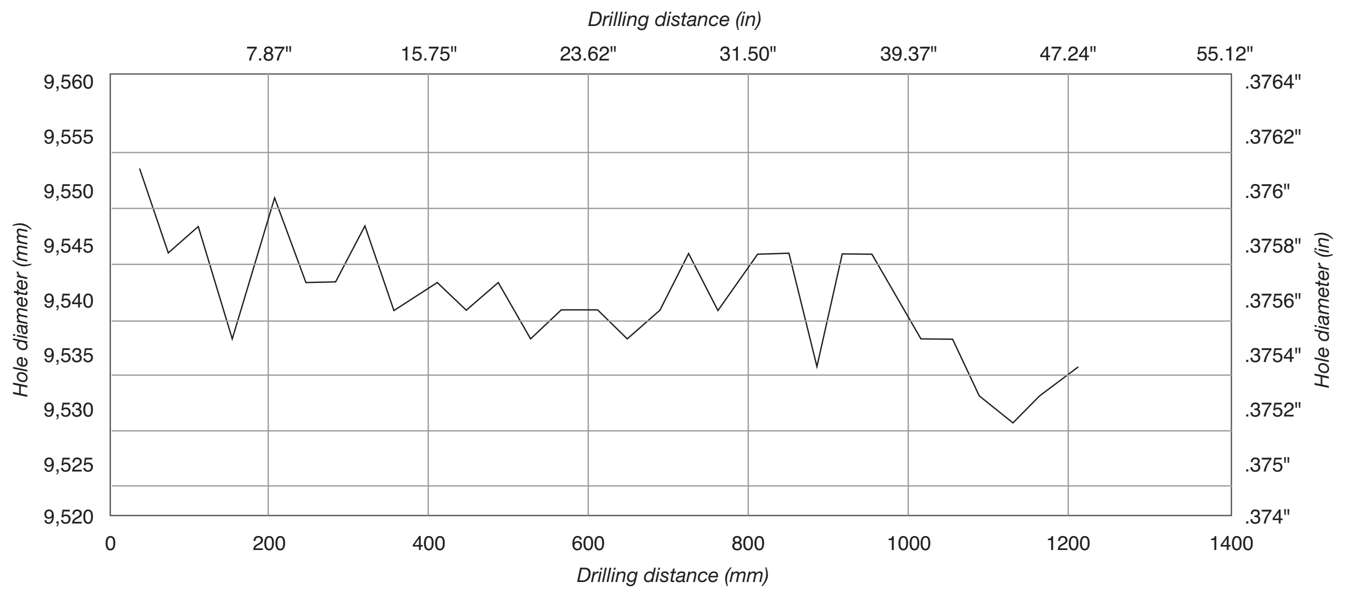


Shrink-Fit Toolholders

shank size	order number	D1	D2	L1	L2	L3	drawing number
HSK25C	3047331*	8	16	40	10	30	1648725
	3047334	10	16	40	10	30	1648725
	3657616*	12	20	40	10	30	1790926
HSK32C	3885411*	10	25	80	27	40	1848692
	3885423	12	25	80	27	57	1797415

**Non-stock standard.*
NOTE: Additional sizes of HSK adapters can be manufactured per request.

Hole Diameter Produced by Orbital Drills



Cutting Parameter and Cutting Forces

	orbital speed ⬆	axial feed	offset ⬆
fz Force	⬇	⬆	⬇
fz Force	mixed	⬆	mixed