

ISMCME 2010
COMPOSITE MACHINING

复合材料加工

focus on machining Carbon Fibre Reinforced Plastics (CFRP)

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苏国江

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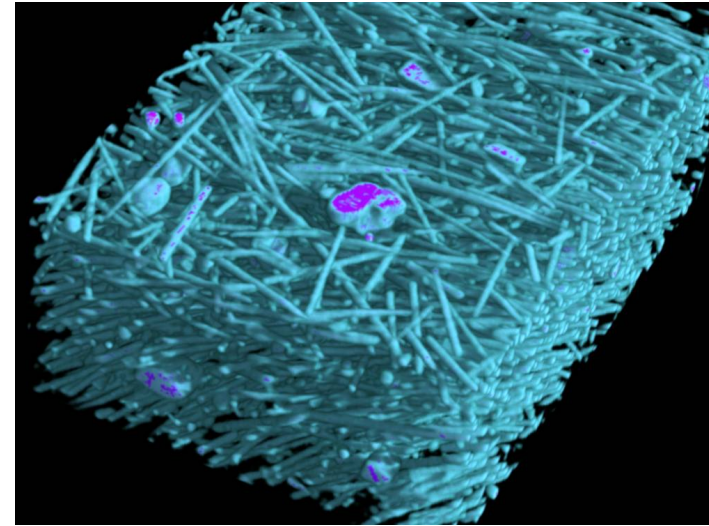
Dec 11th, 2010
Beijing

Content 议题

- **Composite materials 复合材料**
- **Carbon Fibre Reinforced Plastics (CFRP) – cutting process
碳纤维增强塑料（碳纤维）-加工工艺**
- **Jabro™ Composite tooling standard tool range
Jabro™加工复合材料标准产品系列**
- **Milling CFRP-application examples 铣削碳纤维-应用举例**
- **Composite tooling drilling solution 复合材料孔加工解决方案**
- **PCD tools for composite 复合材料PCD刀具加工**

Composite materials – Definition 定义

在复合材料中，纤维、晶须、颗粒或织物被分散在基体内，使用一种聚酯基树脂作为基体，而各种不同的纤维材料（如玻璃纤维、碳纤维和芳纶纤维）用作增强剂。



复合材料结构上是由分层或夹层构成，并能包含钛合金和铝合金叠层材料。填充材料可以是分层的、蜂窝状、铁基或非铁基的。

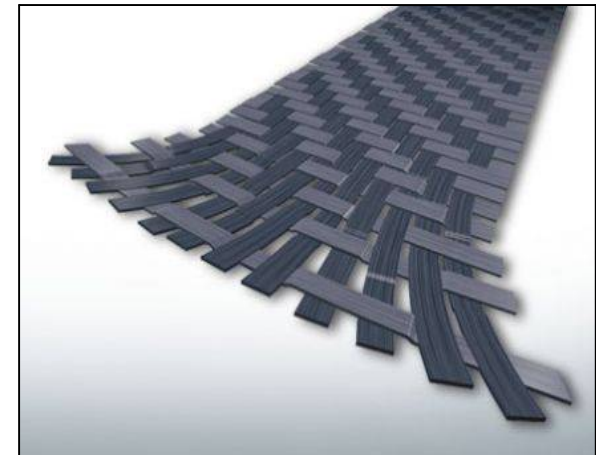


Composite materials – History 历史



'Fibreglass', as we know it today was invented in 1938 by Russell Games Slayter and it is now marketed as Fibreglass, ® the trademark.
玻璃纤维（玻璃钢），于1938年由Russel Games Slayter发明，现在使用Fibreglass, ® 作为商标

Carbon fibre was invented in the early 1960s at the Royal Aircraft Establishment at Farnborough, Hampshire (England).
碳纤维，1960年代初在英国的Farnborough, Hampshire 皇家航空发明

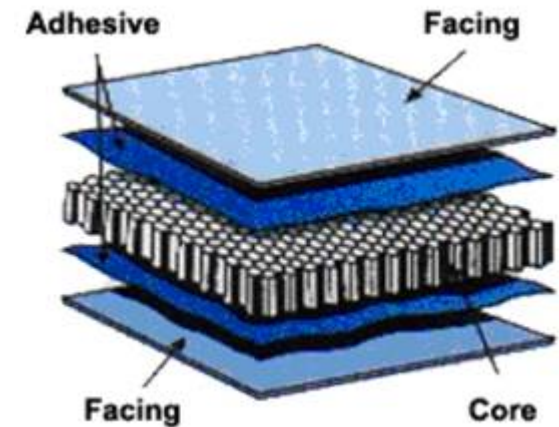
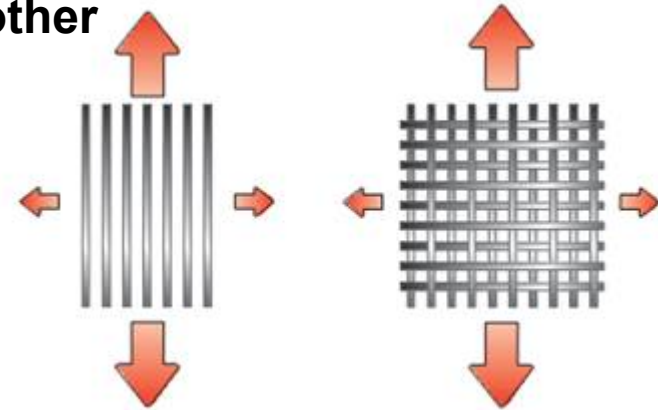


Composite materials – benefits 优点

Composite material benefits compared with other materials:

复合材料与其他材料相比优点

- Reduced weight 减轻重量
- Corrosion-resistant 耐腐蚀性
- Recyclable material 可循环利用
- Very high tensile strength 非常高的抗拉强度
- Very low thermal expansion rate 非常低的热膨胀系数



Composite materials - industry trends 行业趋势

Composite industry trends / demands 复合材料行业趋势/需求:

- Reduced material and manufacturing costs 降低材料和生产成本
- Larger commercial usage 扩大商业应用
- Improve repair and maintenance 改进维修与维护
- Adaptation to automation 采用自动化生产
- Components with more complex structure 更复杂结构工件



SECO 

Global Composites Markets 全球复合材料市场



Medical
医疗



Aerospace
航空



F1



Sport运动



Marine
游艇



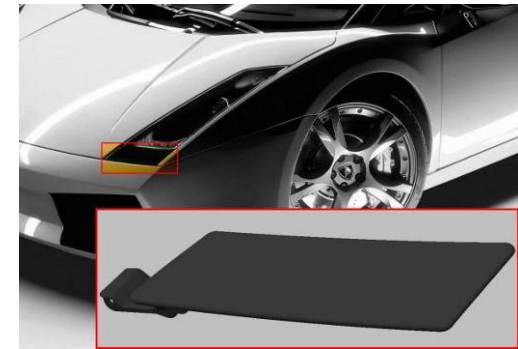
Leisure
休闲



Transport运输



Components
零部件

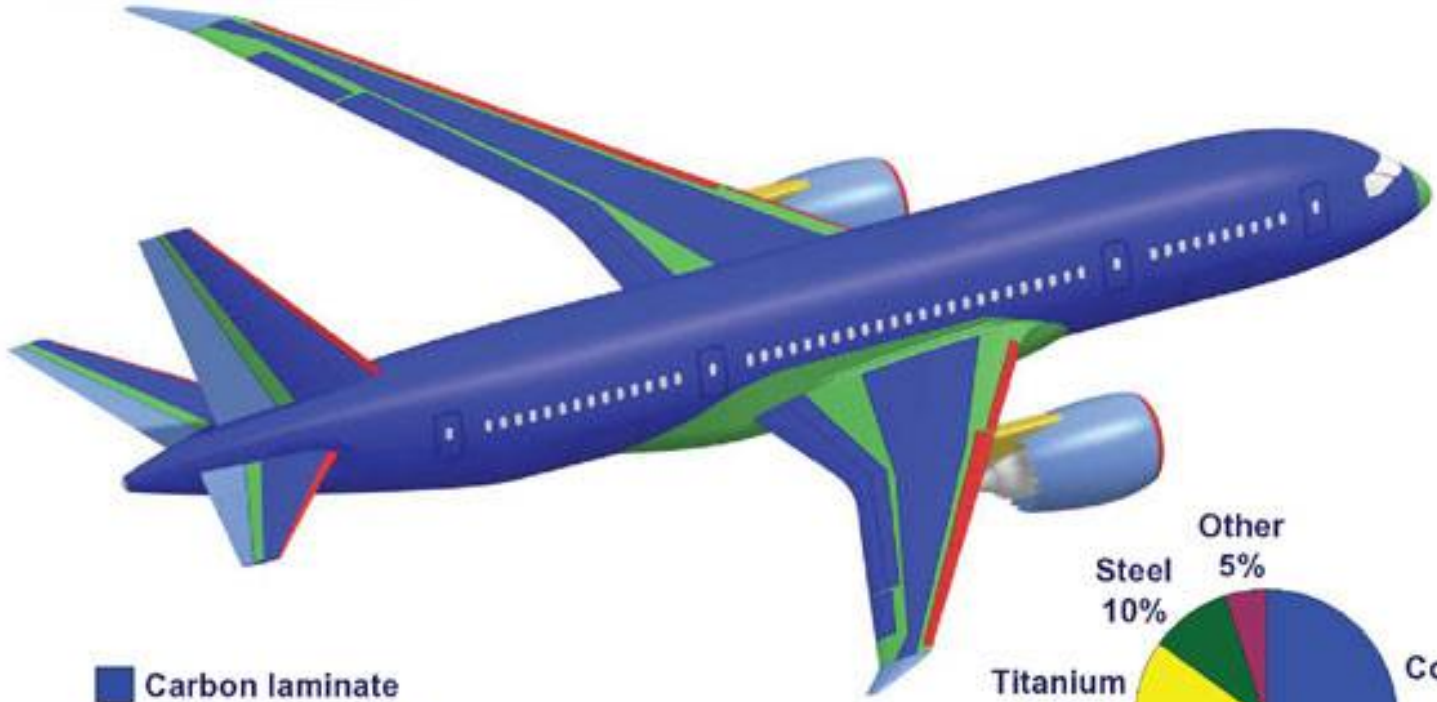


Automotive汽车

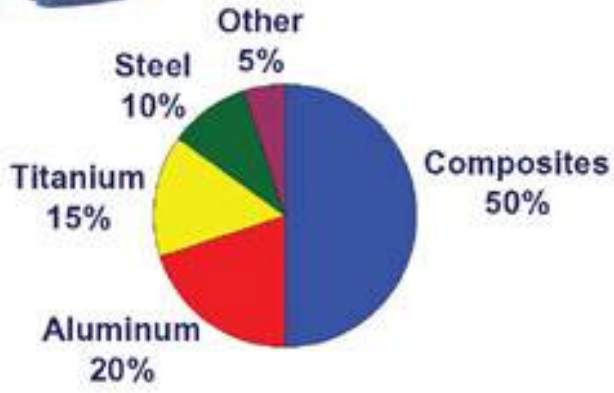




Composite Solutions Applied Throughout the 787



- Carbon laminate
- Carbon sandwich
- Fiberglass
- Aluminum
- Aluminum/steel/titanium pylons

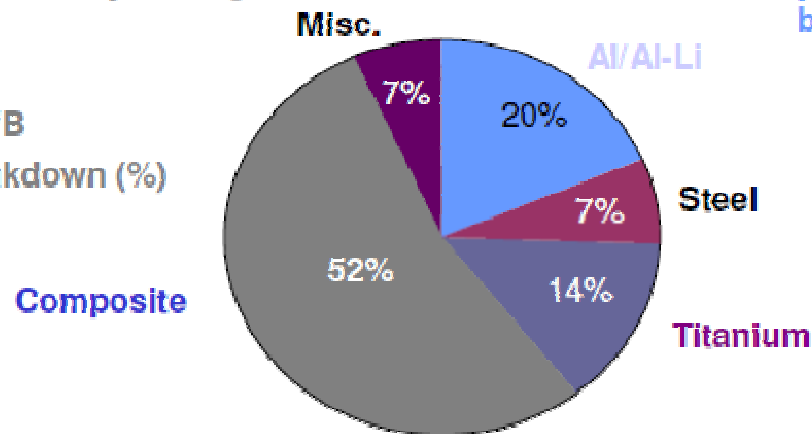




A350 – Material Breakdown



A350-900 XWB
Material Breakdown (%)
Including Landing Gear



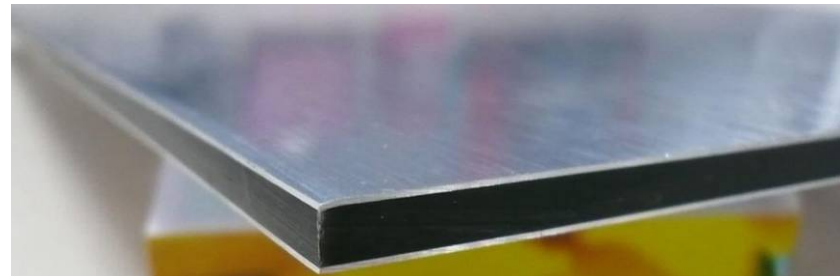
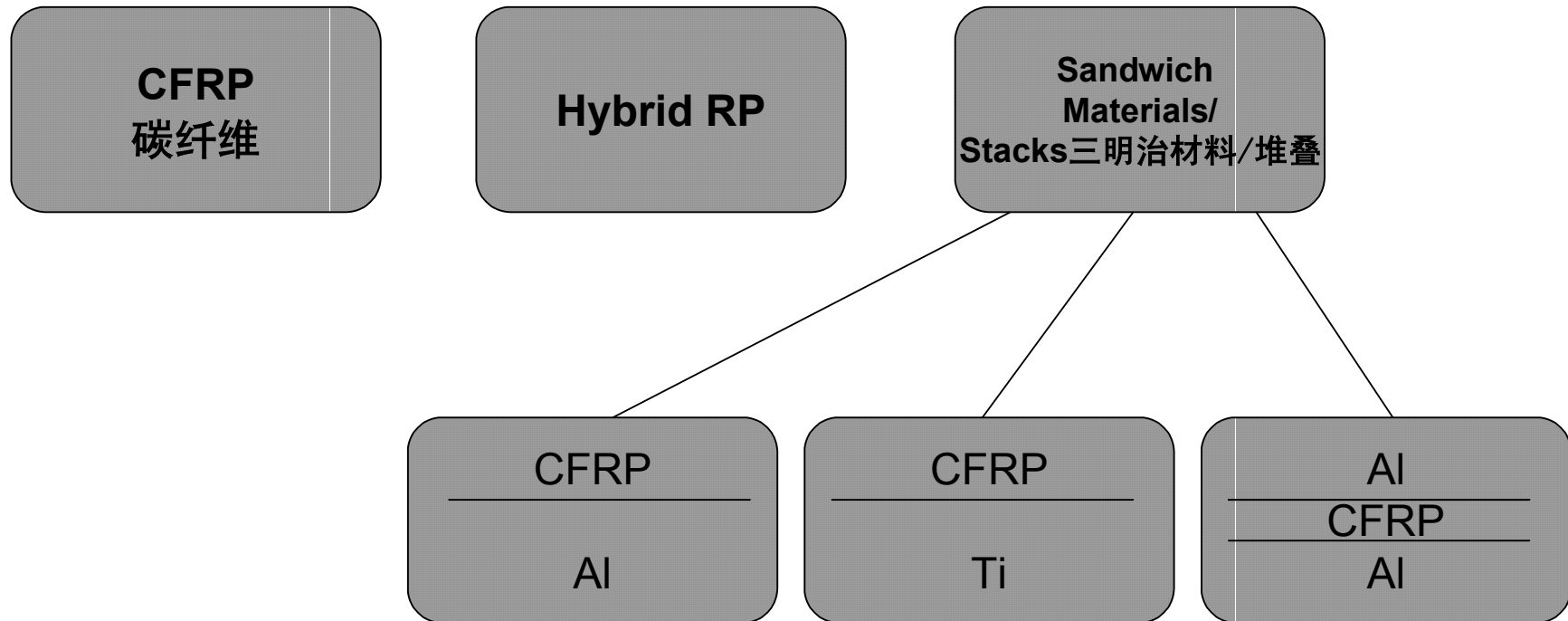
A350 XWB puts the right material in the right place





CFRP
material identification
and cutting process 材料定义与切削工艺

CFRP – material identification 材料定义



CFRP – work piece quality demands 工件质量要求

Quality demands on CFRP parts to determine machining operation strategies – methods

碳纤维工件的质量要求决定了加工工艺-方法

- Breakout & de-lamination of composite when machining

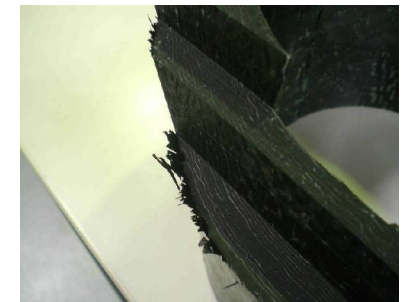
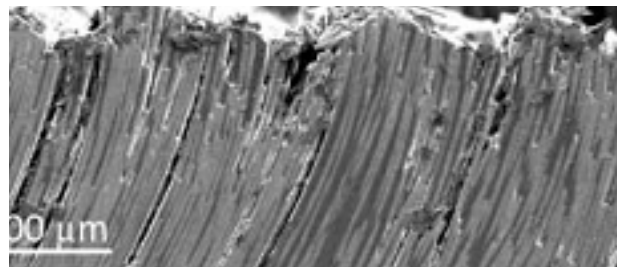
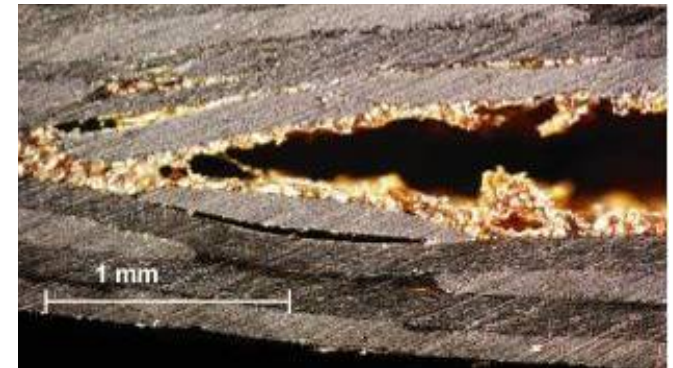
加工过程中材料断裂或分层

- Splintering 碎片

- Part crumbling or flaking 工件崩碎或脱落

- Melting 融化

- Sub surface damage 次表面损伤



CFRP – operations 加工工艺

Besides drilling (50%), milling represents an estimated (40%) of the operations on CFRP components; 除了孔加工（50%），铣削大约在碳纤维工件加工的40%

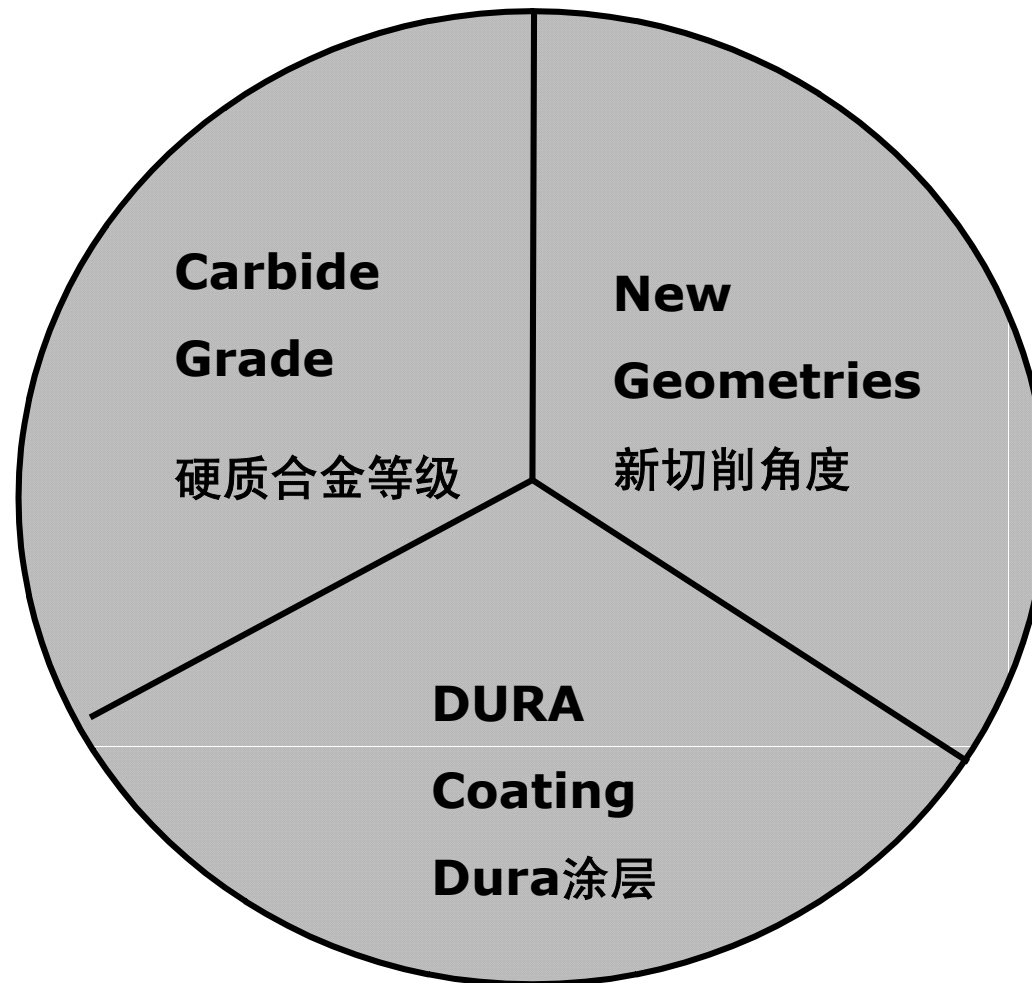
- Drilling 钻孔
- Milling 铣削
 - Side milling, or trimming flash, remove excess material (after moulding)
侧铣，修整飞边，去除多余材料（成模后）
 - Face milling 平面铣削
 - Edge routing 周边铣削
- Turning 车削
- Orbital drilling 铆钉钻
- Reaming 绞削



Milling CFRP, the SECO offer 铣削复合材料，山高提供



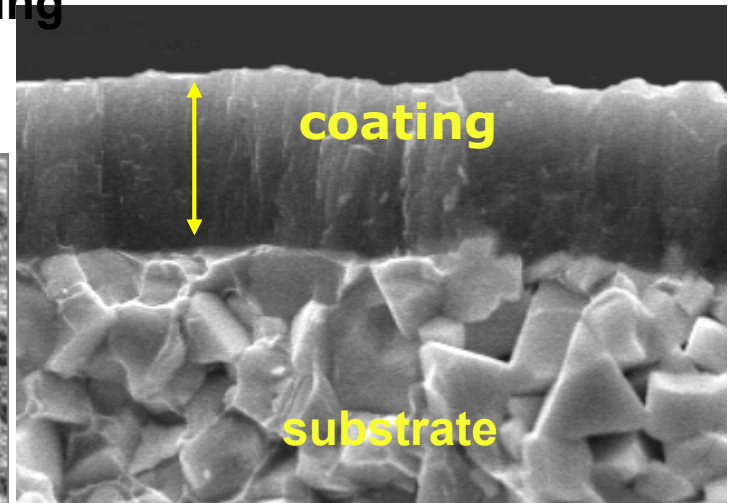
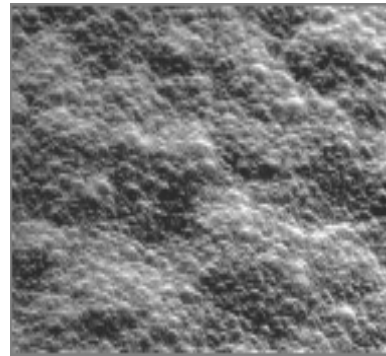
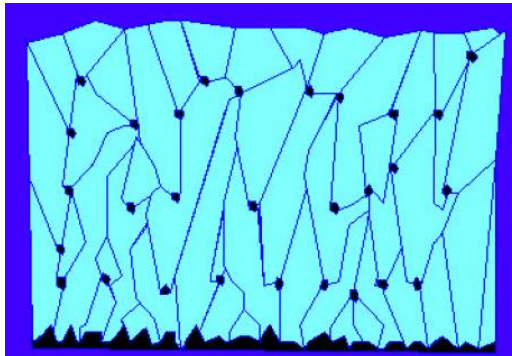
The SECO offer – grade 山高提供-设计



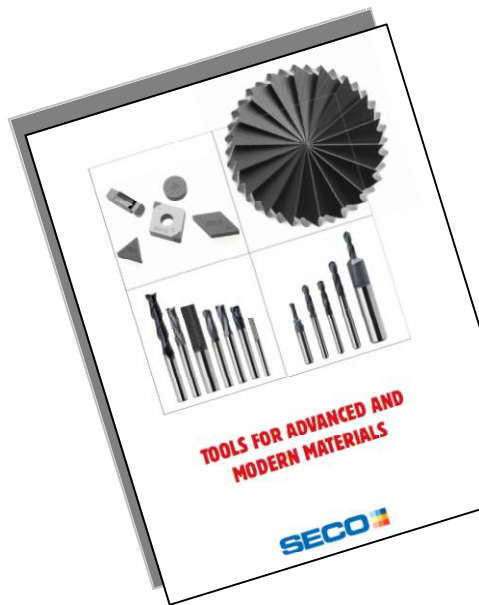
The SECO offer – DURA coating 山高提供-设计 Dura 涂层

The Jabro SECO carbide grade provides an excellent bonding for the DURA coating (CVD process) 山高Jabro硬质合金提供优异的与DURA涂层接合性能 (CVD工艺)

- DURA coating is a high wear-resistant diamond coating for extended tool life
DURA 涂层是高耐磨性的金刚石涂层，具有优异的刀具寿命
- DURA has a relatively low friction coefficient DURA 涂层具有相对较低摩擦系数
- DURA is not as thick as normal Diamond coating
DURA涂层比普通金刚石涂层更薄



The SECO offer – JC800 series 山高提供-JC800系列



Tool selection based on workpiece materials SECO

	JC840	JC850	JC860	JC870	JC871	JC870	JC871	JC880																																																																																																
Name	JC840	JC850	JC860	JC870	JC871	JC870	JC871	JC880																																																																																																
Type of cutter																																																																																																								
Coating	dura	dura	dura	dura	dura	uncoated	uncoated	dura																																																																																																
Shank	Cylindrical	■	■	■	■	■	■	■																																																																																																
Weldon																																																																																																								
Number of flutes	4-9	4	5-11					4																																																																																																
Diameter range	Metric	6-12	3-12	6-16	3-12	3-12	3-12	6-20																																																																																																
Inch	1/4-1/2			1/4-1/2	1/4-1/2	1/4-1/2	1/4-1/2																																																																																																	
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Operation																																																																																																								
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● Preferred choice
 ○ Alternative
 *Al and Ti top/bottom layers max. 1mm thickness.

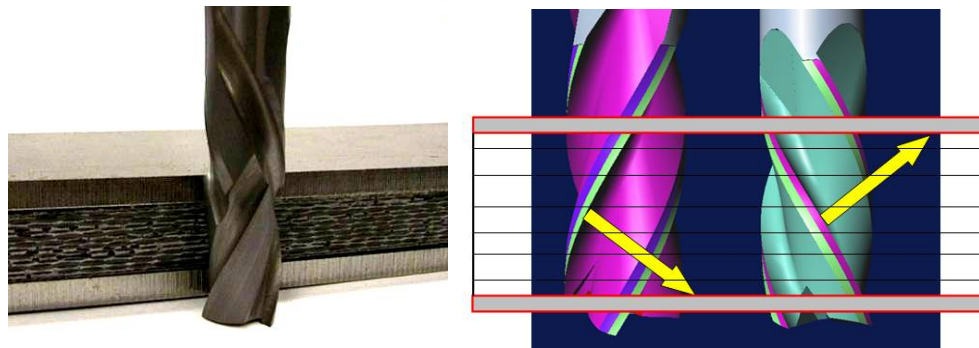
Seco material group		
PMG	GRP	CFRP
		CFRP Stacked(Al)*
		CFRP Stacked(Ti)*
		Honeycomb (non ferrous)
	GRP	GRP
		GRP Stacked(Al)*
		GRP Stacked(Ti)*
		Honeycomb (non ferrous)

The SECO offer – JC840 geometry 山高提供- JC840

This double helix cutter is initially designed to machine stacked (sandwich) materials.

双螺旋角原始设计为加工叠层（三明治）材料

- Standard available with cylindrical shanks in both METRIC (6mm-12mm) and INCH sizes ($\frac{1}{4}$ ", $\frac{3}{8}$ ", $\frac{1}{2}$ "). 标准产品提供直柄公制尺寸(6mm-12mm)和英制尺寸($\frac{1}{4}$ ", $\frac{3}{8}$ ", $\frac{1}{2}$ ").
- Stable machining in unstable conditions (clamping, feed machines) 在不稳定条件下实现稳定切削（装夹，机床等）
- Very good surface finish in (stacked) CFRP, no finishing or rework needed
- Split line = $a_p = \frac{1}{2} \cdot d_c$ 在叠层材料加工中实现非常好的表面质量，无需精加工或人工处理，分界点为 $\frac{1}{2}d_c$



The SECO offer – JC850&880 geometry山高提供–JC850&JC880

These general use cutters are designed for a variety of applications.

这两款通用刀具设计用来加工各种应用。

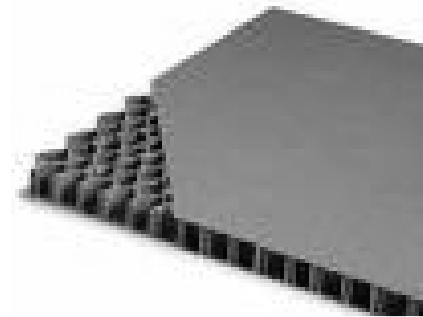
- JC850 Standard available in metric (3mm-6mm) with ap 3 x Dc
JC850标准尺寸为公制(3mm-6mm)，切削刃长3 x Dc
- JC880 Standard available in metric sizes (6mm-20mm) with ap 3 x Dc and corner radius. JC880标准尺寸为公制(6mm-20mm)，切削刃长3 x Dc
- Low axial forces generated due to flat 20° helix angle, ideal when vacuum clamped. 20度螺旋角产生较低轴向切削力，当真空夹紧时更加理想
- Capable to do all machining methods in CFRP 可以加工各种复合材料



The SECO offer – JC860 geometry 山高提供-JC860

This cutter was specifically designed for side milling and slotting in honeycomb sandwich materials 本刀具专门设计为侧铣和槽铣蜂窝材料夹层板

- JC860 Standard available EX stock in metric with cylindrical shank in diameters (Dc): 6mm-16mm with cutting lengths (ap) 3 x Dc
JC860标准型号库存为公制尺寸直柄6mm-16mm，切削刃长(ap) 3 x Dc
- LH helix to create downward axial cutting forces.
左旋产生向下的轴向切削力
- Chip splitter to break the honeycomb material into smaller piece
断屑槽将蜂窝材料切为更小碎屑



The SECO offer – JC870 & 871 geometry山高提供-JC870

These routers are multi-purpose cutters which operate in a variety of materials and applications.

这些菠萝铣刀为多功能铣刀，可以适用于多种材料和应用

- **JC870 & JC871 Standard available with cylindrical shank in METRIC (3-12mm) and INCH (1/4", 3/8", 1/2"). sizes. Also available as a uncoated version.**

More than a normal router;

JC870 & JC871 标准系列产品为直柄公制尺寸(3-12mm) 和英制尺寸 (1/4-1/2)

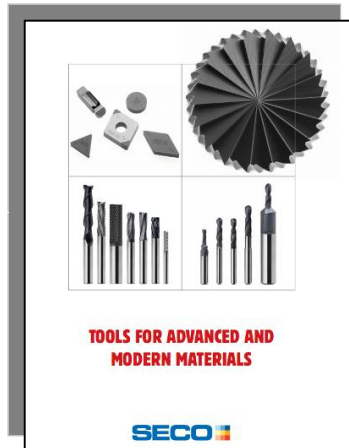
，并且提供涂层系列和非涂层系列。性能远超普通菠萝铣刀。



Milling CFRP, the SECO offer 铣削复合材料, 山高提供

A full range of solid carbide end mills with specific geometries to machine composite materials of all kinds. 完整系列整体硬质合金铣刀, 专用角度设计加工各种复合材料

- On stock 库存产品
- Catalogue available 样本提供
- Cutting data in catalogue 切削参数提供





MILLING CFRP

铣削复合材料

Application example

应用举例

Milling CFRP - application examples – 1 应用举例-1

Customer 客户	German (Aero-) space centre 德国航空中心
Part 工件	Diverse 多样
Machine 机床	3-axis HSK 32A Spindle 3轴 HSK32A 主轴
Operations 操作	Drilling, slotting, side milling, facing 孔, 槽, 侧铣, 面铣
Materials 材料	(Stacked) CFRP's 叠层复合材料
Coolant 冷却	Air 空气
Tool 刀具	Flat helix solid carbide end mill JC880060R020Z4.0-DURA
Goal 目标	Find a versatile cutter for roughing and finishing (Stacked) CFRP找到一款粗加工和精加工叠层复合材料刀具

Current tool in use is a ø6mm pcd tool. 现用刀具为 6 mm PCD刀具

Milling CFRP - application examples - 1a 应用举例-1a

Aerospace CFRP, 60 vol. %. prepreg. Plunging and full slotting form.

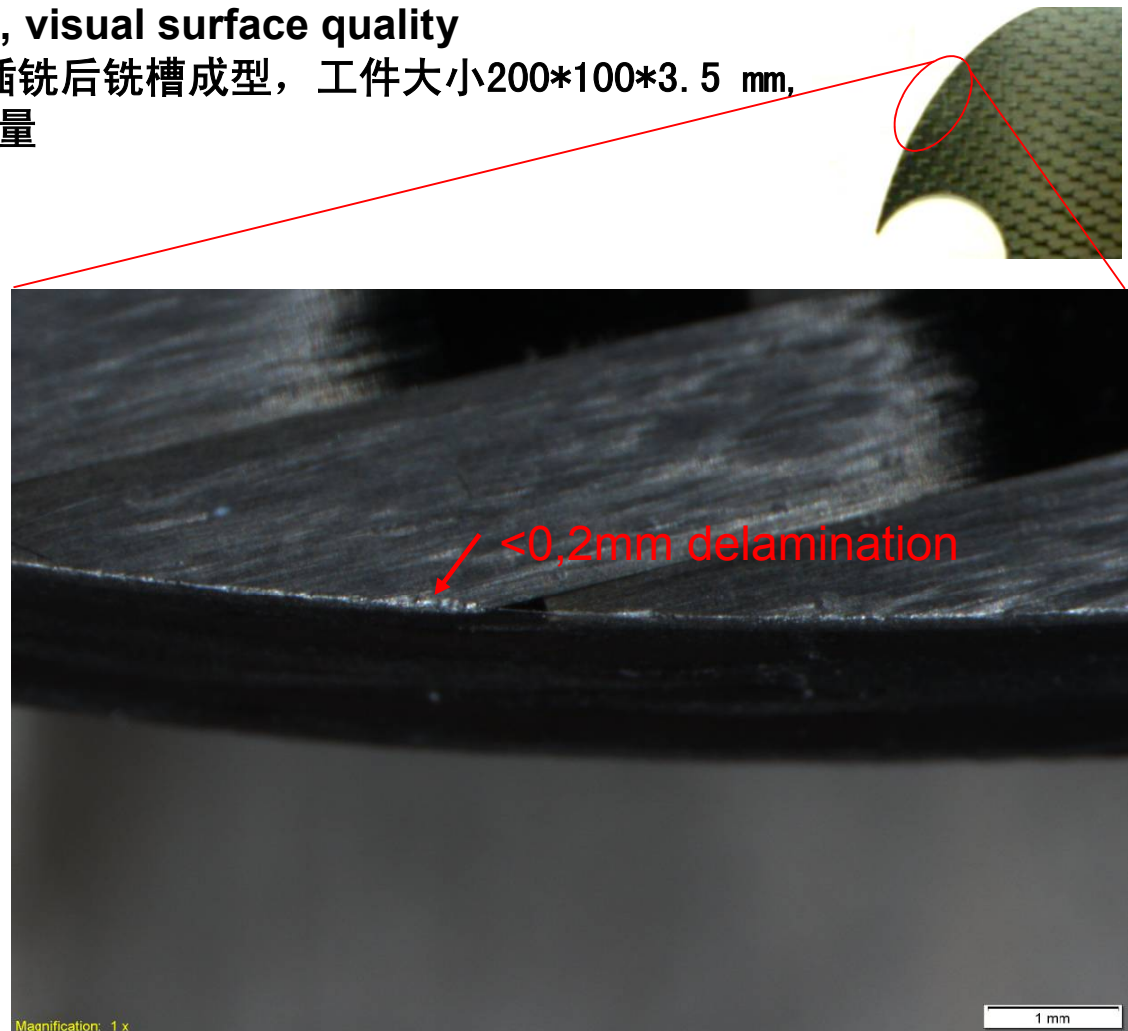
Part dimensions est.: 200*100*3.5mm

Criterion: de-lamination <1.0mm, visual surface quality

航空复合材料，碳纤维含量60%，插铣后铣槽成型，工件大小200*100*3.5 mm，

标准：材料分层<1 mm，目视表面质量

JC880060Z4.0-DURA	
D_c [mm]	6
Zn eff	4
a_p [mm]	0.25
a_e [mm]	6
v_c [m/min]	200
n [1/min]	10800
f_z [mm]	0.018
v_f [mm/min]	760
Q [cm ³ /min]	1.14



Milling CFRP - application examples – 1b 应用举例-1b

Aerospace Stack CFRP-UD dry+ 1.4301 Plunging and full slotting form.

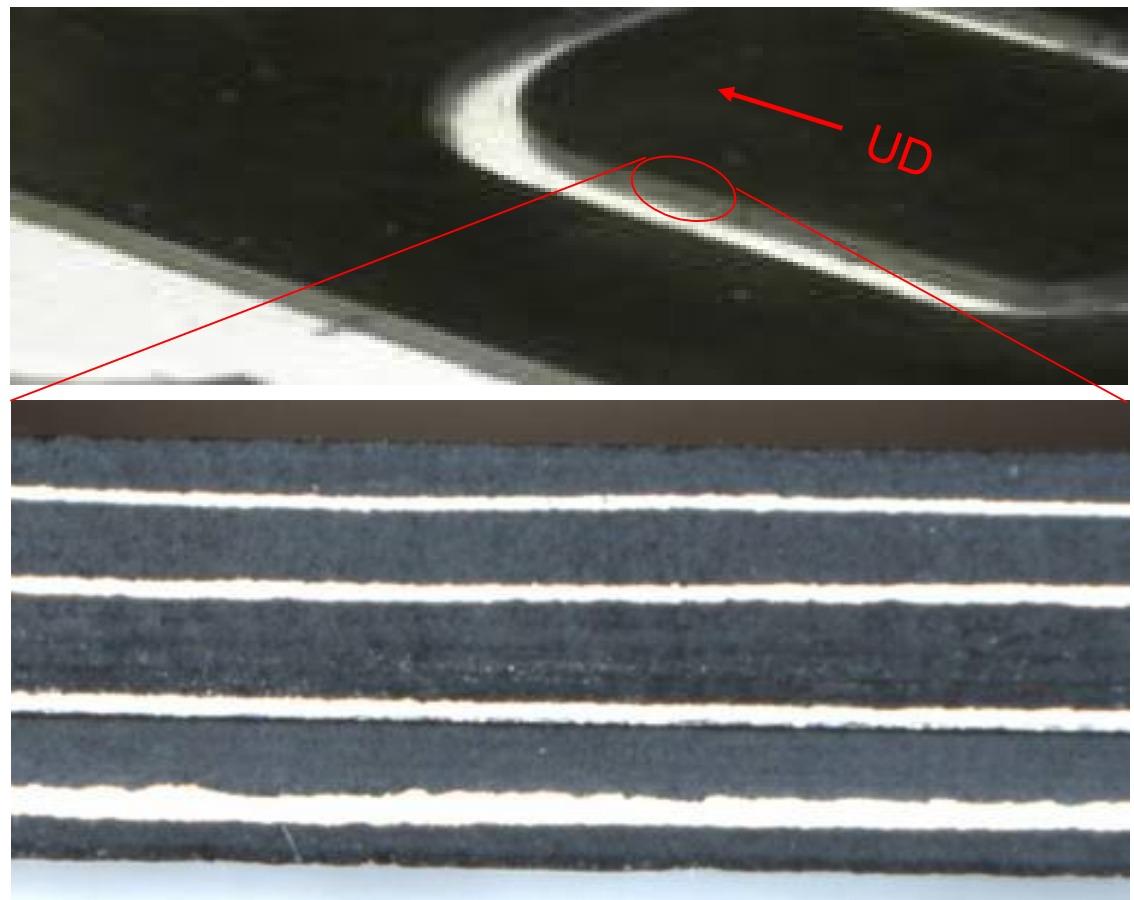
Part dimensions est.: 400*200*4mm

Criterion: de-lamination <0.5mm + Minimum spreading of steel layer

航空叠层材料碳纤维+304不锈钢，插铣后槽铣成型。工件尺寸400*200*4 mm，

标准：材料分层<0.5mm，最小不锈钢层分离

JC880060Z4.0-DURA	
D_c [mm]	6
Zn eff	4
a_p [mm]	1.4
a_e [mm]	6
v_c [m/min]	200
n [1/min]	10800
f_z [mm]	0.04
v_f [mm/min]	1400
Q [cm ³ /min]	11.8



Milling CFRP - application examples – 1c 应用举例-1c

Aerospace Hybrid 'CFRP prepreg + AFRP' Plunging and full slotting form.

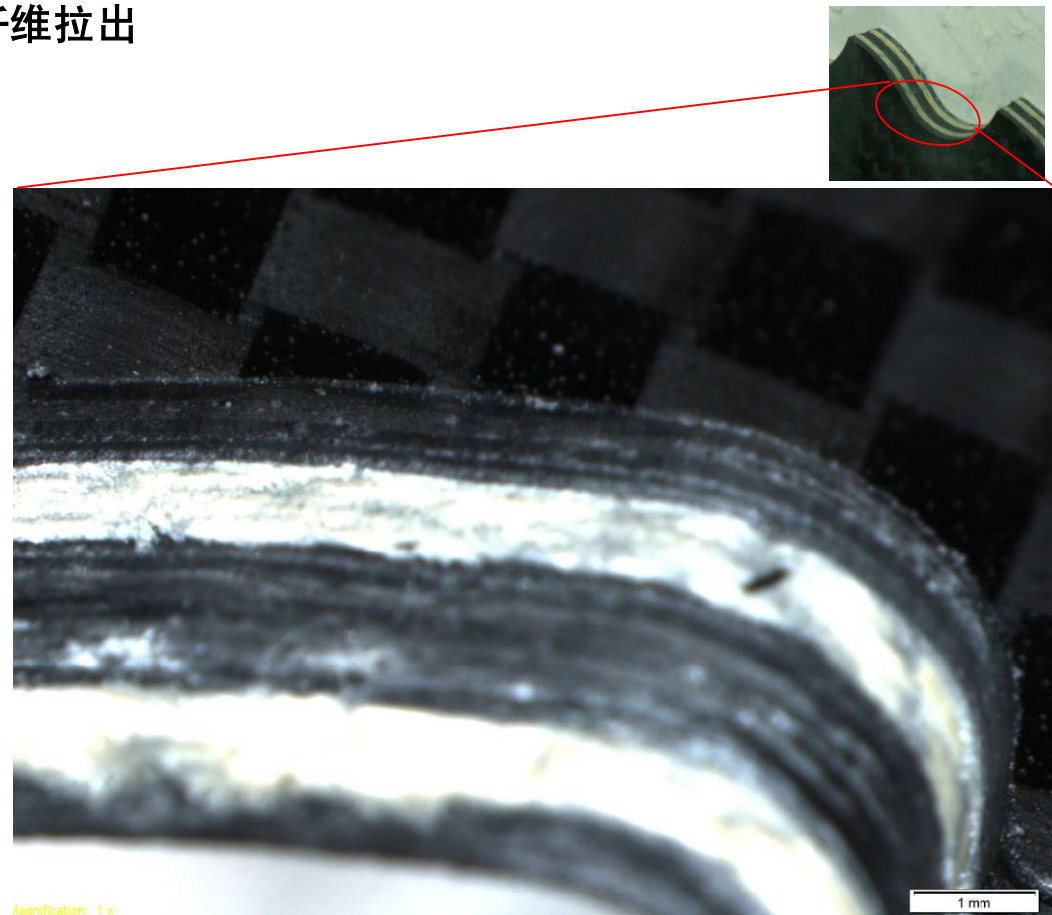
Part dimensions est.: 400*100*7.5mm

Criterion: de-lamination top layers <0.5mm + Minimum AF pull out

航空复合材料叠层“碳纤维+纺纶纤维”插铣后槽铣成型，工件 尺寸400*100*7.5

标准：上层分层<0.5mm+最小的纺纶纤维拉出

JC880060Z4.0-DURA	
D_c [mm]	6
Zn eff	4
a_p [mm]	2.5
a_e [mm]	6
v_c [m/min]	200
n [1/min]	10800
f_z [mm]	0.018
v_f [mm/min]	760
Q [cm ³ /min]	11.4

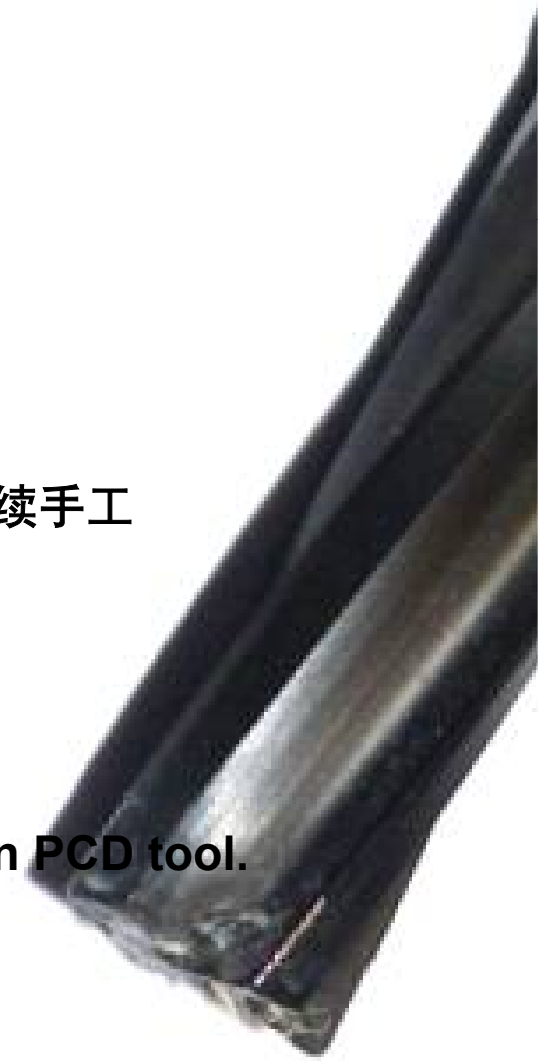


Milling CFRP - application examples – 1应用举例1

Observations and findings during machining with the flat helix cutter JC880060Z4.0-DURA:

使用小螺旋角铣刀JC880060Z4.0-DURA: 实际加工效果

- **Efficiency increase in all materials compared with PCD**
与PCD刀具相比，加工各种材料，效率均得到提升
- **no finish pass or manual re-work required** 加工后无需后续手工
- **Reliable process** 工艺可靠
- **No or light de-lamination and or splintering (<0.5mm)**
无材料或纤维分层(<0.5 mm)
- **Smooth machining, no high vibrations. Much better than PCD tool.**
切削平稳，无振动，比PCD加工效果提高明显
- **Tool wear stabilizes at 0.08mm (measured on relief)**
刀具磨损稳定于0.08 mm (检测后刀面)
- **Tool still not worn out, more tool life to go** 刀具没有严重磨损，仍可继续测试



Milling CFRP - application examples – 2 应用举例2

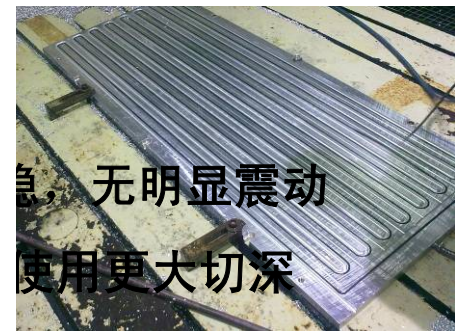
Customer客户	1st tier aerospace supplier, Belgium 第一迪尔航空, 比利时
Part工件	Test part试验件
Machine机床	5-axis Jomack 156 HSK 63A Spindle 5轴Jomack 156 HSK63A 主轴
Operation操作	Slotting 铣槽
Material材料	CFRP 60% CF content, prepreg, aerospace 60%碳纤维含量复材
Coolant冷却	Air + additional water flow to prevent debris becoming airborne
Tool刀具	Solid carbide router SECO Jabro JC870 ø20mm
Remark备注	Test was part of manufacturing process optimisation测试优化工艺

Cutter was challenged to side-rough for at least 15 metres to be competitive with pcd
与PCD刀具对比，刀具必须能够在保证侧面质量情况下切削15m

Milling CFRP - application examples – 2 应用举例-2

Findings during side milling roughing with the JC870 router:
采用JC870菠萝铣刀实际加工效果:

- Feed increase compared with PCD 进给相对PCD得到提高
- Reliable process 工艺稳定
- No or light de-lamination and or splintering (<0.8mm 无或轻微材料和纤维分层 (<0.8mm)
- Smooth machining, no heavy or high vibrations 切削平稳, 无明显震动
- Possible usage of multiple ap-zones (ap tool=55mm 使用更大切深)
- Tool wear stabilizes at 0.25mm 刀具磨损0.25mm (测量后刀面)
- Tool life exceeding expectation 刀具寿命超过预期



Milling CFRP - application examples – 2 应用举例2

PCD Tool	
D_c [mm]	20
Zn eff	-
a_p [mm]	10
a_e [mm]	10
v_c [m/min]	150
n [1/min]	4774
f_z [mm]	-
v_f [mm/min]	800
Q [cm ³ /min]	80
Toollife [M]	27

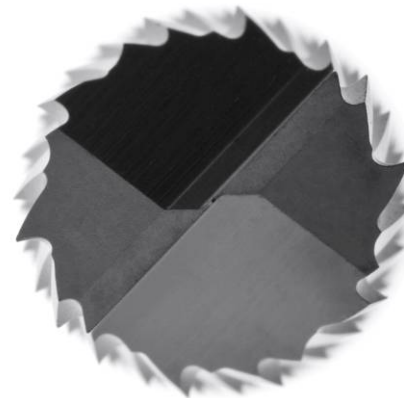
JC870 router	
D_c [mm]	20
Zn eff	13
a_p [mm]	10
a_e [mm]	10
v_c [m/min]	150
n [1/min]	4774
f_z [mm]	0,019
v_f [mm/min]	1500
Q [cm ³ /min]	150
Toollife [M]	27



Milling CFRP - application examples – 2 应用举例-2

Instant benefits when side milling roughing with the JC870 router compared with PCD: 采用JC870菠萝铣刀加工时相对PCD刀具优势

- Increased feed, higher efficiency 提高进给，更高效率
- Reliable process 可靠的加工工艺
- Possible usage of multiple ap-zones (ap tool=50mm) 可以采用不同切深区域 (切削刃长-50 MM)
- Lower price level compared with PCD 与PCD刀具相比更低价格水平



Milling CFRP - application examples – 3 应用举例-3

RUSAVIAINTER



Stringer
机身桁条

Milling CFRP - application examples – 3 应用举例-3

RUSAVIAINTER



JC840; D=12 mm; Z=9

Contouring 轮廓铣削

Ae=5 mm

Ap= part thickness = 8 mm

V=180 m/min

n = 4777 rpm

Fz=0.02 mm

F= 860 mm/min

Climb milling 顺铣

Smoothly cutting 切削平稳

Drilling CFRP 复合材料孔加工

Drilling composites (CFRP)
复合材料孔加工



Drilling CFRP Range 孔加工刀具范围

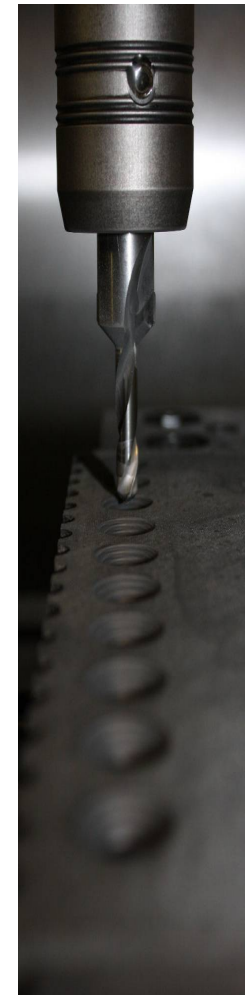
Seco Feedmax range 整体硬质合金钻头系列



Single diameter drill
单直径钻头

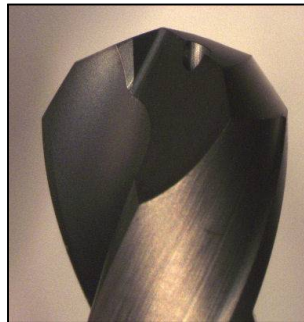


**Chamfer drill
(one shot drill)**
带倒角钻头



Drilling CFRP Geometry 孔加工刀具结构设计

Geometry 刀具设计	Operation 操作	Application / Material 应用/材料
<p>C1 geometry C1设计</p>	<p>Drilling 钻孔</p>	<p>C1 geometry to be used when drilling in plain composite material. It should also be used when drilling stack which ends in composite material. C1设计主要用于加工复合材料板材。也可以用于叠层材料中出口材料为复材情形。</p>
<p>C2 geometry C2设计</p>	<p>Stack drilling 叠层材料钻孔</p>	<p>Stacked applications, composite and aluminum/titanium, exiting in the metal material. Improved chip breaking will give good chip evacuation and secure surface quality of the composite material. 叠层材料，复材和铝合金/钛合金叠层，出口为金属材料情形。改进断屑将得到更好排屑并保证复合材料部分表面质量。</p>

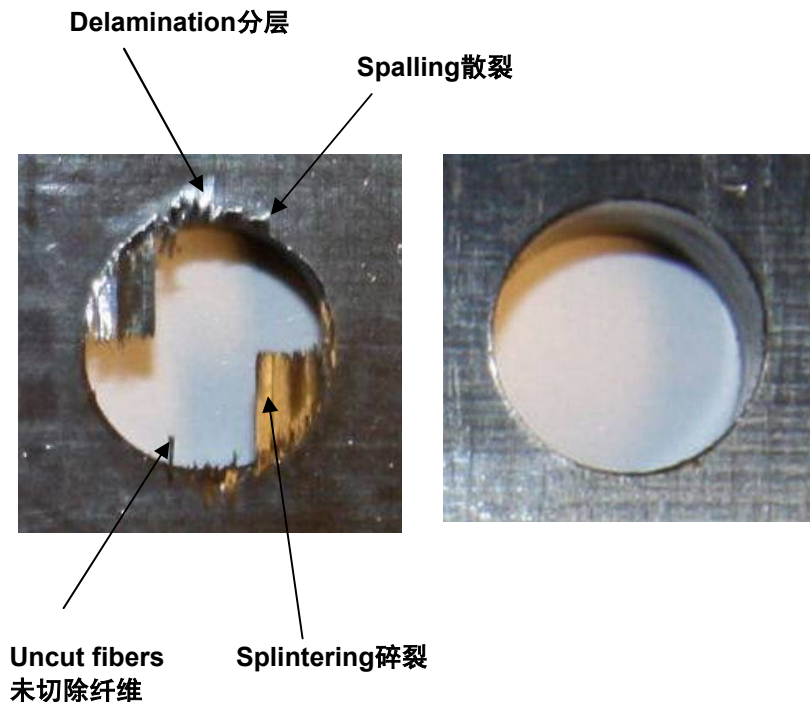
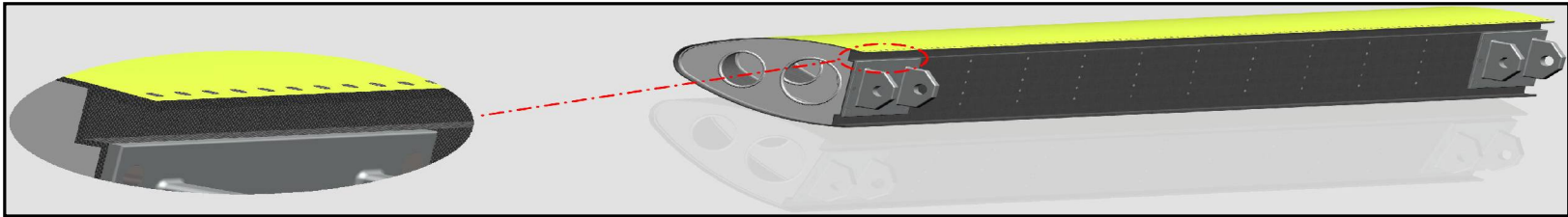


C1-geometry C1设计



C2-geometry C2设计

Drilling CFRP Hole Quality 钻孔质量



Hole quality 钻孔质量

- ❑ Different parameters compare to metal 与金属加工相比区别
 - ❑ Delamination 分层
 - ❑ Peel-up delamination (entrance) 材料上翘 (入口)
 - ❑ Push-down delamination (exit) 材料下翘 (出口)
 - ❑ Splintering 碎裂
 - ❑ Spalling 散裂
 - ❑ Uncut fibres and resin 未切除纤维和基体
- ❑ Surface finish 表面质量
 - ❑ Marks from metal chips (stacked material) 金属表面痕迹 (叠层材料)
 - ❑ Melted resin 基体熔化

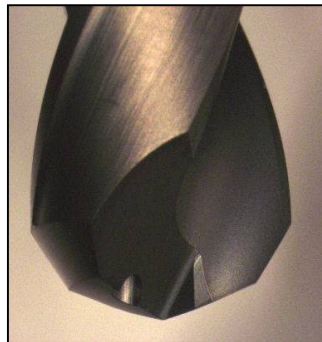
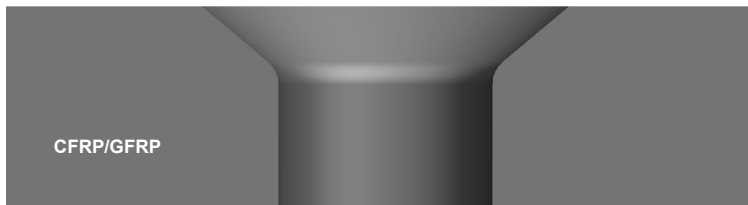
Drilling CFRP C1 geometry 孔加工C1设计

Application example: exit in composite

应用：出口为复合材料

Plain CFRP/GFRP (exit in composite material)

碳纤维/玻璃纤维板（出口为复合材料）

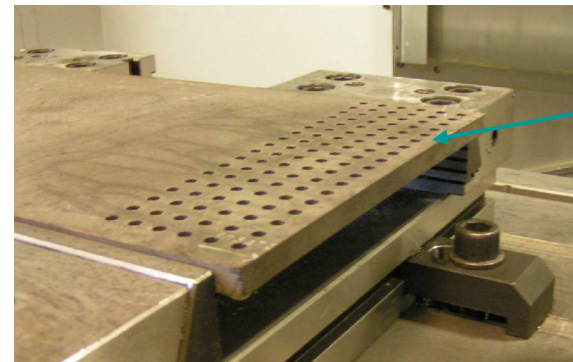


Tool 刀具

- Double angle point geometry 双顶点角设计
 - Reduce axial forces 减少轴向力
 - Delamination free drilling 减少分层
- Dura diamond coating Dura 金刚石涂层
 - Long tool life 长刀具寿命

Application 应用

- Exit in composite material 出口为复合材料
 - Plain composite 复合材料板
 - Stacks with composite as last layer 叠层复材为最底层



CFRP

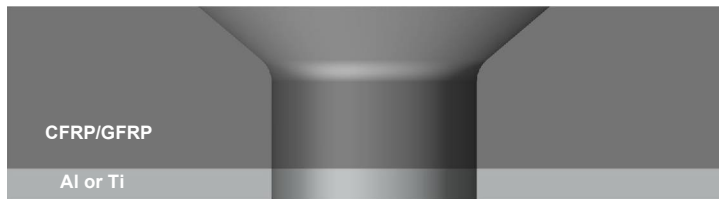
Drilling CFRP C2 geometry 孔加工C2设计

Application example: stacked material

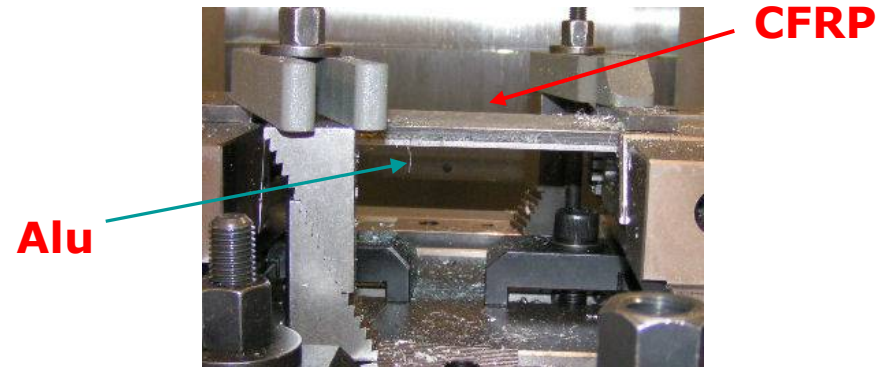
应用举例：叠层材料

Sandwich material (exit in Al/Ti)

三明治材料（出口为Al/Ti）



C2 geometry



Tool 刀具

- ❑ **Straight cutting edge (180° angle) 平面顶尖角 (180度)**
 - ❑ **Good chip breaking and evacuation 好的断屑和排屑**
 - ❑ **Secure good hole quality 保证孔的质量**
 - ❑ **Surface finish of the composite intact, not damaged by the metal chips. 安全接触复合材料表面，无金属屑接触**
- ❑ **Dura diamond coating Dura 金刚石涂层**
 - ❑ **Long tool life 更长刀具寿命**

Application 应用

- ❑ **Stacks with exit in metal material material 叠层材料金属出口**
 - ❑ **Aluminum 铝合金**
 - ❑ **Titanium 钛合金**

Drilling CFRP Success Story 孔加工应用举例

Tests – Medical 测试-医疗行业

Competitor竞争对手: TiCN SC drill. TiCN涂层钻头

Tools刀具: **Diamond coated solid carbide drill with CFRP geometry, internal coolant**
金刚石涂层硬质合金钻头C1设计, 内冷

Machine机床: **Hermle C30U**

80 bar internal coolant pressure 80 巴内冷却压力

EPB shrink fit 5803 EPB热胀刀柄

Part工件: **Bracket for head fixation**头部支撑托架

Material材料: **Medical CFRP** 医疗碳纤维

Results效果: - **surface quality outstanding;** 表面质量优秀

the roughness made with the Ref. tool could not even be measured.

表面粗糙度几乎不能用仪表检测出来

- **size & shape of the hole outstanding** 尺寸和孔形状优异

- **Vc 600 m/min**

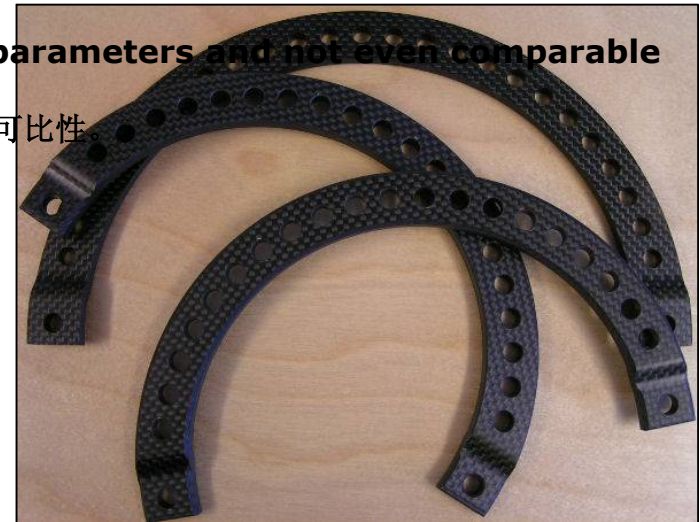
- **feed**进给 **1600 mm/min**

- **2800 holes without size degradation (within 0.025 mm tolerance)**

2800个孔后尺寸无变小 (在0.025内)

against 800 holes of the Ref. tool with far lower parameters and not even comparable hole tolerances.

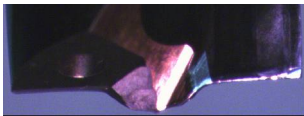
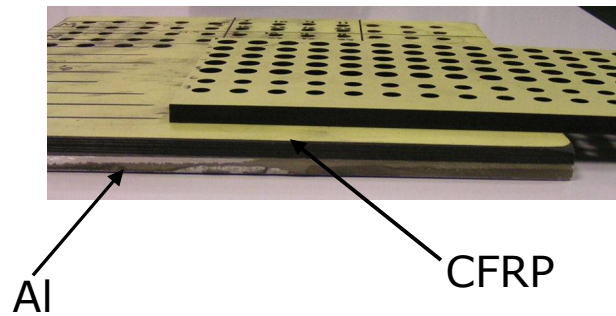
金竞争对手刀具寿命**800**孔, 非常低切削参数, 孔的尺寸公差也无可比性。



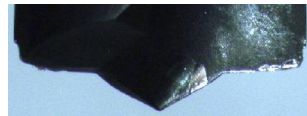
Drilling CFRP Success Story 孔加工应用举例

Test drilling specifications – Aerospace

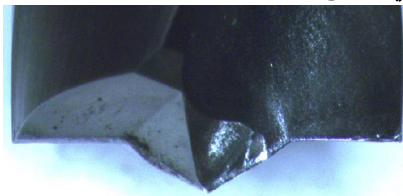
钻孔测试-航空



DLC coated Solid carbide drill (210 holes) DLC涂层刀具

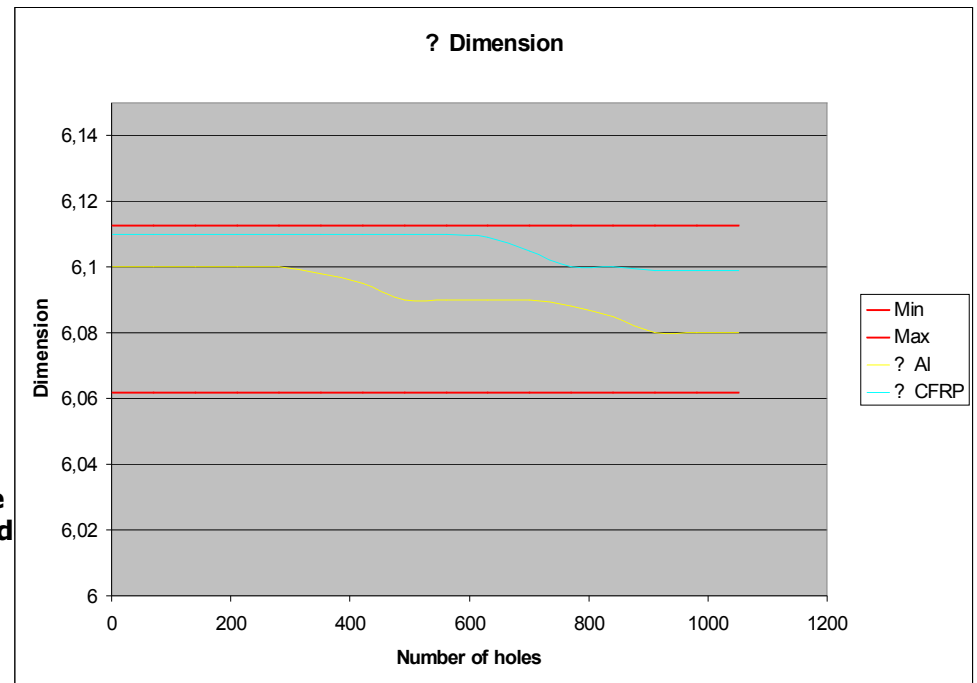


Dura coated solid carbide drill (910 holes) (std grad) DURA 涂层刀具



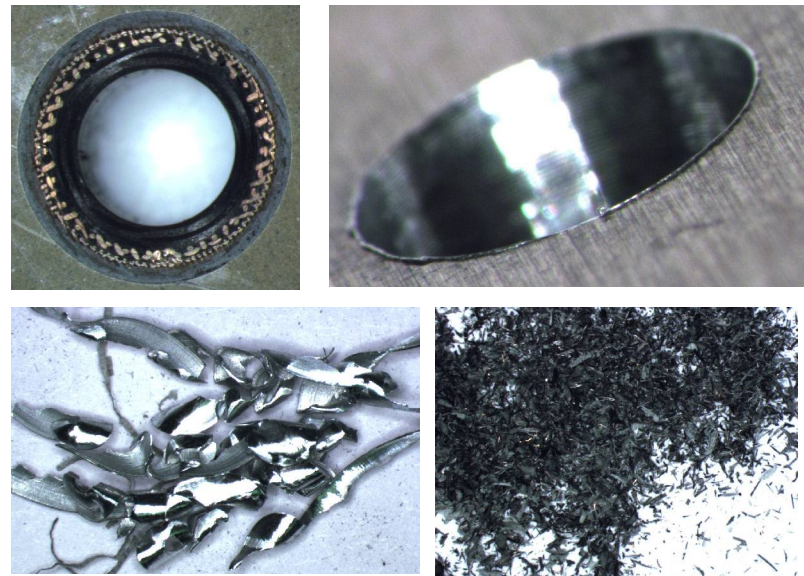
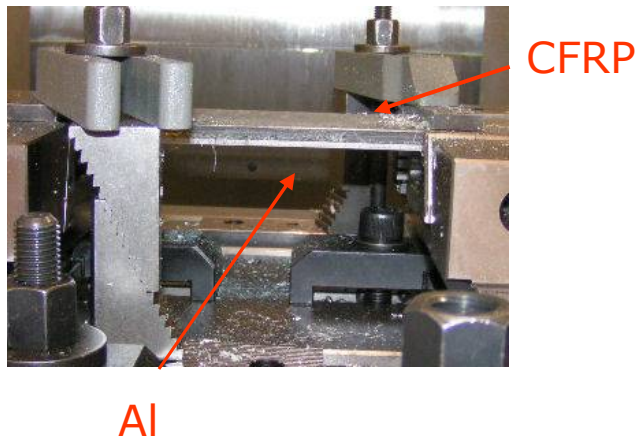
Dura coated solid carbide drill, optimized grade and coating (+1200 holes, still working) Dura涂层刀具优化材质和涂层 (加工1200孔后仍然可以使用)

Hole dimensions 孔直径



Drilling CFRP Success Story 孔加工应用举例

Stacked material CFRP/Alu 叠层材料CFRP/Alu



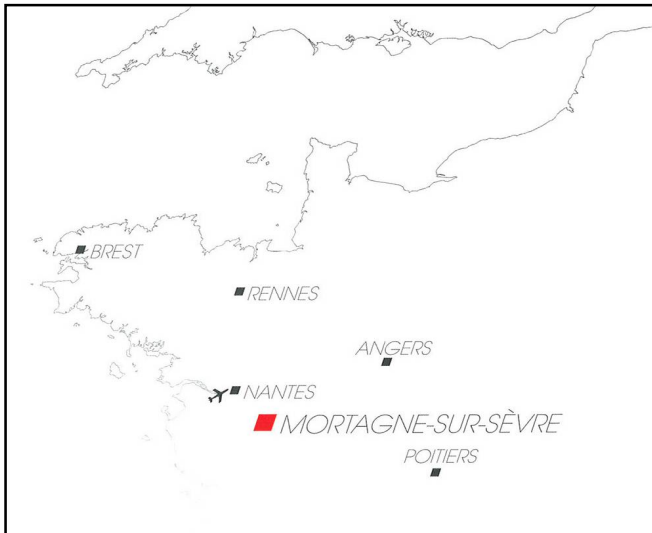
Achieved results 获得效果:

- ❑ Surface finish Al $Ra < 1,0$ 铝表面质量 $Ra < 1$
- ❑ Small exit burrs (much smaller than the maximum of 0,2mm in standard) 微小出口毛刺 (比0.2mm的标准要求小很多)
- ❑ no visually detected chipping/splintering in CFRP 无可视崩齿/碳纤维碎裂

Dura coated solid carbide drill
Dura 涂层整体硬质合金钻头
Test done in
测试
CFRP+Al
CFRP+Ti



Composite Machining AOB 复合材料加工AOB



Centre for Composite machining

复合材料加工中心

- ❑ **AoB, France should become a Competence center for round PCD tools for composite machining**
AOB将成为整体PCD刀具加工复合材料的竞争中心
- ❑ **With AoB, Seco will aim for becoming a leading, global supplier of PCD round tools for future**
通过AOB，山高将成为全球整体PCD的全球领先提供商。
- ❑ **With the R&D and manufacturing competence of AoB and Seco being a certified supplier with existing relations to several key aerospace customers globally Seco will aim to become a total solutions provider for the Aerospace industry**
通过研发和生产竞争中心，AOB和山高将成为现有的大型航空客户的认证提供商，山高将成为航空行业完整解决方案提供商。

Composite Machining AOB Products AOB 产品

Wood working
木工加工



Automotive
汽车行业



Aerospace
航空行业

AOB Offering AOB 产品提供



PCD sandwich drills
PCD三明治钻头

PCD offering PCD产品

- Drills 钻头
 - Optimized geometries 优化角度
 - Configuration 形状
 - Chamfer drills 倒角钻
 - Step drills 阶梯钻
- End mills 立铣刀
 - Routing cutters 菠萝铣刀
 - Double helix cutters 双螺旋角铣刀



Step drill
阶梯钻



Chamfer drills
倒角钻



CFRP end mills
复合材料立铣刀

Composite materials here today.

Edward Su
苏国江

Seco Jabro Product Manager JABRO™

