Cutting Performance Evaluation of Helical Milling Specialized Tool for CFRP/Titanium Alloy

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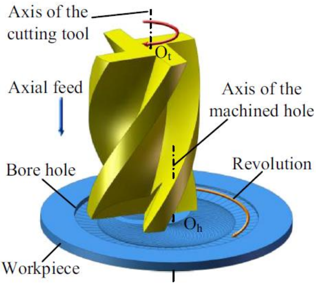
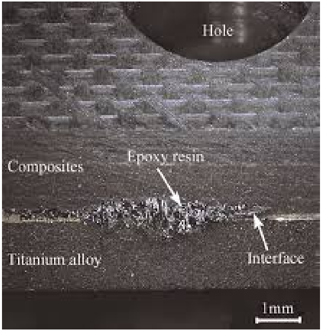
Outline

Introduction

1. What is helical milling: simultaneously of a peripheral cut on the peripheral cutting edge with a discontinuous cut, and a frontal cut on the axial cutting edge with a continuous cut
2. What is CFRP/Titanium Alloy: Dissimilar material stack-ups of CFRP and titanium are used for high performance structural components





Merits of helical milling for CFRP/Titanium alloy holemaking

Low burr formation, low process forces as well as good chip transportation

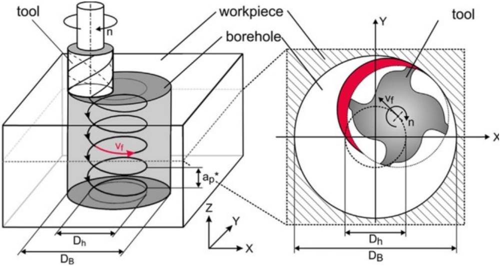
Research motivation

Tool wear in helical milling							
Paper	Work material/ Tool material/ Coating	Wear monitoring technique	Cutting edge of wear investigation	Wear type	Wear mechanisms	Tool life criteria	Number of holes machined
Qin et al.	Ti−6Al-4V/ Tungsten carbide/ TiAlN; Diamond	Scanning electron microscope, digital microscope and energy dispersive X-ray	--	Flank wear	Adhesive wear, oxidation wear, coating flaking and chipping	VB = 0.2 mm	88 holes (TiAlN-cooted tool); 70 holes (diamond-cooted tool)
Voss et al.	CFRP/ Cemented carbide end mill/ Diamond	3D microscopy	Frontal and peripheral cutting edges	Flank wear	Diamond coating flanking at peripheral cutting edges	--	1000 holes
Surface roughness levels in helical milling studies							
Paper	Measurement system			Work material		Roughness [µm]	
Sultana et al.	Form Talysurf profilometer			CFRP		13-16.6 (super abrasive diamond tool)	
Qin et al.	Surface roughness & contour machine			Cr12 die steel (35 HRC)		0.40–1.56	
Machine, tool, alloy and lubrication in helical milling of CFRP-Ti stacks							
Paper	Machine tool	Tool material/type		CFRP/Ti alloy		Lubrication condition	
Wang et al.	DMC75V linear 5-axis high speed machining centre	TiAlN-coated carbide tool		CFRP/Ti6Al4V stacks		Dry	
Zhou et al.	Orbital drilling unit fixed to KUKA360-1 robot	TiAlN-coated solid hard alloy (YG8) tool designed by the authors for CFRP/Ti orbital drilling		CFRP/Ti alloy (TC4-DT) stacks		Blowing air through tool cooling holes for Ti chips removal and vacuum dust removal system for CFRP chips	

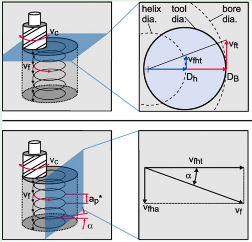
Current problems:

1. There is no in-depth and systematic research on the specialized tool, and the traditional end mills are still used mainly.
2. Problems such as large exit burrs, poor hole wall quality, and short tool life in the hole machining of aerospace dfficult-to-machine materials are prone to occur, which cannot meet the Processing requirements.

Kinematics of helical milling



Kinematic parameters:



feed velocity, tooth, axial:
$v_{fha} = f_{za} \cdot z \cdot n$

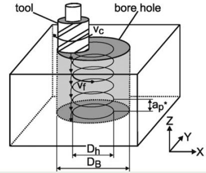
feed velocity, tooth, tangential:
$v_{ft} = f_{zt} \cdot z \cdot n$

feed velocity, helix, tangential:
$v_{fht} = v_{ft} \cdot \frac{D_h}{D_B}$

feed velocity of the TCP:
$v_f = \sqrt{(v_{fha}^2 + v_{fht}^2)}$

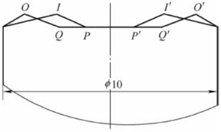
helix angle:
$\alpha = \arctan\left(\frac{v_{fha}}{v_{fht}}\right)$

depth setting per helical rotation:
$a_p^* = \tan(\alpha) \cdot \pi \cdot D_h$

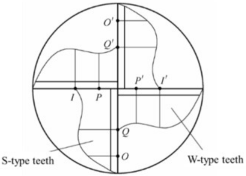


v_c	=	cutting speed
v_f	=	feed velocity
D_B	=	bore diameter
D_h	=	diameter of helical path
a_p^*	=	depth setting per helical rotation

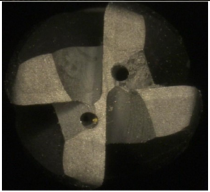
Distributed multi-point front cutting edge design



(a)→Multi-point·front·cutting·edge·(front·view)



(b)→Multi-point·front·cutting·edge·(top·view)



Anaiysis:

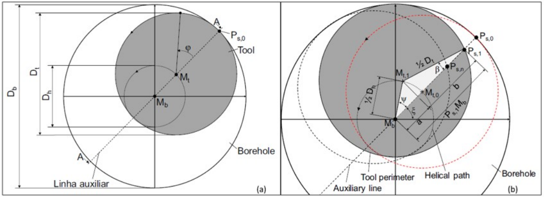
1. The chip size can be reduced, the cutting force can be effectively reduced, and the smoothness of the chip removal can be effectively improved.
2. The cutting ratio of the periphery cutting edges can be reduced, and the service life of the periphery cutting edges can be fully improved.

Simulation of chip segmentation at the front cutting edge

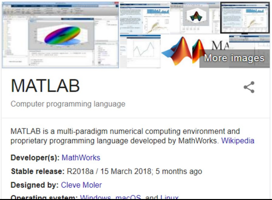
Process:

Establish the trajectory equation of the point motion of the tool cutting edges and simulate it with Matlab

- Geometrical relations to define the trajectory in helical milling

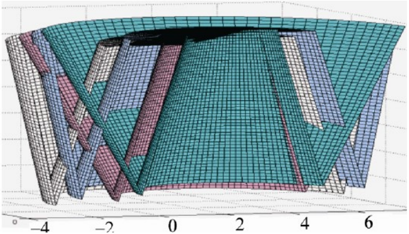


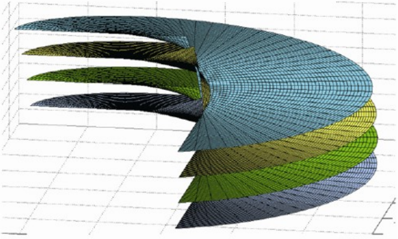
- Numerical simulation software



Simulation of chip segmentation at the front cutting edge

- Comparsion of specialized tool and end mill's cutting edges trajectory (each color represents the front cutting edge of single tooth)



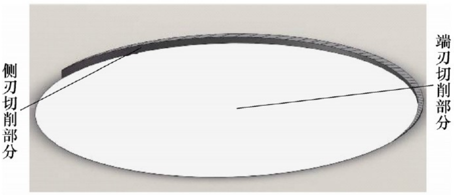


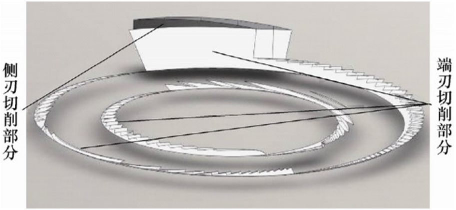
Conclusion:

It can be seen that the trajectory of the specialized tool cutting edges is superimposed, while the end cutting edge of the end mill has a parallel relationship, and there is no help to chip segamentation.

Chip shape simulation and cutting ratio analysis

1. Through the chip shape simulation, the different functions of the end and side edges are obvious.
2. The respective machining ratios during the helical milling process can be analyzed.
3. The simulation of the chip shape is obtained by performing a Boolean operation.



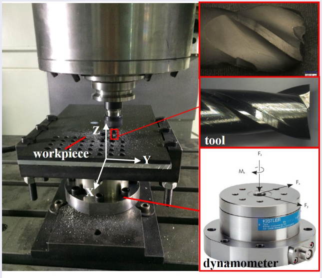


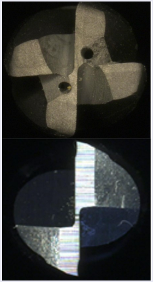
Conclusion:

- The undeformed chip of the end mill is like a disc, and the undeformed chip obtained by the specialized tool is two rings.
- The two rings are composed of two half rings, the joint is weak. It is easy to separate during processing, so the final chip size is small and the chip segmentation is good.

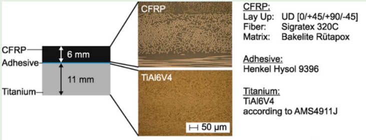
Experimental setup details

Experimental setups and helical milling cutters used in the experiment





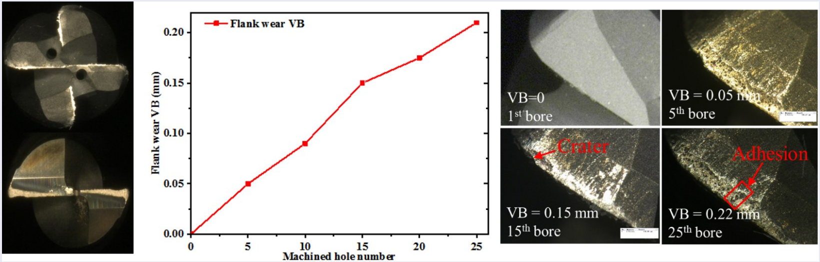
Build-up of the CFRP-Ti layer compound and cutting parameters



material	spindle rotation speed (rpm)	Tangential feed (mm/tooth)	Axial feed (mm/re)
CFRP	3000	0.06	0.4
TiAl6V4	1000	0.06	0.6

Tool wear

Comparison of wear at front cutting edge zone

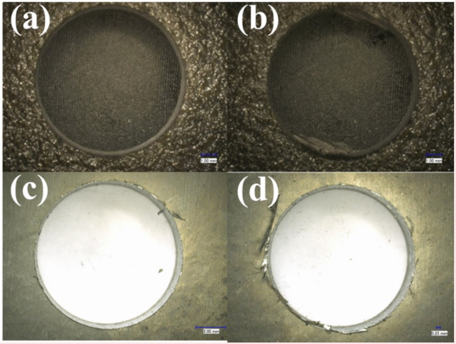


Conclusion:

1. The two-edge end mill's maximum wear amount reaches 0.4 mm. While the maximum wear of the specialized tool is only 0.1 mm, and the wear is even, but it is worth noting that there is a micro-disintegration phenomenon at the edge
2. The front cutting edge of the helical milling cutter encountered crater, adhesion, and chipping.

Burrs at borehole entrance of CFRP and exit of Ti alloy

Comparesion of the machining quality of the specialized tool and the end mill



Conclusion:

1. The entrance burr of the end mill machining hole is large, and the outlet tears.
2. The specialized tool machining quality is superior to the end mill

Conclusion

1. Helical milling cutters based on the principle of chip separation enable effective chip separation by means of distributed multi-point front cutting edges. The chip size is smaller than the end mill.
2. The tool life of the helical milling cutter is much longer than that of the drill cutter under the same cutting conditions in hole-making of CFRP-Ti stacks.
3. The multi-point design of the specialized tool front cutting edge can realize the burr-free processing of titanium alloy under dry cutting conditions. The composite material hole has no delamination and the machining quality meets the engineering application requirements.

Thank You