COATINGS FOR CFRP MILLING

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Introduction

CFRP are widely used in the airframe of commercial airplanes, examples are the Airbus 380 (25%), the A350 (52%) and the B787 Dreamliner (50%). Structural parts (wings, cowlings, J-nose, etc.) are mainly made in multilayer composite sheets. The components are conformed to the final shape, but after the composite construction all parts must be trimmed to the right dimensions and shape, using milling (routing) as the main process. Milling tools for this operation is a specialized product to be optimized in geometry, material substrate and coating [1-3].

Coatings provide a hard, chemical stable and thermal protection to cutting tools, improving their performance during cutting. PVD (physical vapor deposition) coatings are ceramic materials usually applied in 1 to 15 micron thicknesses on tools made of steel or sintered carbide. In this work the tool substrate was submicron tungsten carbide, optimized after a testing procedure [1].

Coatings based in physical vapor deposition (PVD) technology are performed at much lower temperatures than CVD coatings, 400 - 500 ºC against 900 - 1000 ºC, which decreases the risk of damage on carbide tools. There was also a great difference which helped promote the use of PVD coatings: the ability to control thicknesses on the edges accurately. In the late 90s a mayor change arrived in coating technology with the production of TiAlN coatings. The addition of aluminum to the TiN base composition provided not only a higher hardness such as 3300 HV but a remarkable improvement which was enhanced high temperature behavior. The effect of the aluminum alloying resulted not only in a higher temperature hardness resistance of up to 900 ºC, but also it provided a much better oxidation resistance up to that temperature. Table 1 summarizes some of the coatings offered by current Platit's technology.

However, a new trend for high temperature nanostructure control was opened when endmills coated with TiAlN-TiSiN coatings were developed, and soon after Platit® did so with AlTiSiN coatings with the nACo™ trademark. It's remarkable the step increase in wear resistance from an AlTiN coating to a nACo™ AlTiSiN coating. It is also shown the result for higher Si content nACo™ coated endmills. Silicon containing coatings have been adopted by tool manufacturers and end users for improving more hard machining conditions. The success of employing silicon alloying ensures that a fine nanostructure is maintained up to 1200 ºC, therefore, the hardness loss at high temperature is minimized thanks to silicon in the coating, which is surrounding TiAlN crystallites as a silicon nitride binder.

After AlTiSiN a new coating was AlCrN, it intended for expanding the capabilities of TiAlN coatings especially where high oxidation resistance is required. The hardness of AlCrN coating is similar to that of TiAlN, but what makes this coating outstanding is its high oxidation resistance, up to 1200 ºC. That is thanks to the growth of a stable $(Al,Cr)_2O_3$ oxide during cutting instead of the $TiO_2 + Al_2O_3$ oxides which growth in TiAlN coatings.

Table 1 Current tool coatings, by Platit®

Coat	Color	Nano hardness (GPa)	Thickness (µm)	Friction (fretting) coefficient	Max. temperature (ºC)
TiN	gold	24	1 - 7	0.55	600
TiCN	blue-grey	37	1 - 4	0.20	400
AlTiN	black	38	1 - 4	0.70	900
µAlTiN	black	38	1 - 4	0.30	900
TiAlCN	burgundy-violet	33	1 - 4	0.30	500
AlCrN	blue - grey	32	1 - 4	0.60	900
nACo	violet - blue	45	1 - 4	0.45	1200
nACRo	blue - grey	40	1 - 7	0.35	1100

From the material point of view alloying of TiAlN coatings with different alloying elements opens an endless way: TiAlCrN, TiAlCrSiN and TiAlCrYSiN compositions are developed recently. The coating surface can also be improved for better edge stability. Industrial PVD coatings are produced by arc technology, more economical and more suitable for providing stable quality to coatings. However its main drawback is the presence of droplets in the coating surface, which are originated from the target melting during the arc burning. Coating roughness on the edge creates a deleterious effect in the lifetime stability therefore droplet removal processes are usually performed for high-end tools. Fir these reasons the tested tools describe in the above section were all polished after coating, increasing tool life in a 20% with respect to unpolished ones.

2. Milling test in CFRP

In the tests, the features of machined composite was:

- Matrix Epoxy phenol (10 % - 30 %)
- Carbon fibres 7782-42-5
- Glass fibres and Kevlar fibres 26125-61-1
- Acetone (<2 %), Aniline 5026-74-4 (10 % - 30 %)
- Tensile strength: 2690 MPa
- Tensile modulus: 165 Gpa

Fig. 1 Geometry of ∅8mm milling tools

Tool was a multiedge router shown in Fig.1. The multitooth solution eliminates the cutting force along the Z-axis are easy to be manufactured using the usual tool grinders in toolmaker's workshops. Controlling the grinding wheels by CNC the grinding machines produce the tool edges on carbide rods by the crossing of several helices right-hand and several others left-hand. The final aspect of tool side surface is a multipyramidal-like surface (knurling-like).Tool wear was measured by means of the area of the worn surface:

Worn surface = (a b) / 2* (1)

Where *a* and *b* are the diagonals of the wear surface, as shown in Fig. 2. The percentage of the worn area with respect to the area of the pyramid base is

*%Wear = (Worn surface/Area of the base) * 100* (2)

The machining operation was slotting, where the contact area of tool with material along the Z axis, the a_p, matched with the composite thickness (approx. 20 mm). High speed milling (15,000 rpm) machine was used with feed of 0.04 mm/rev.

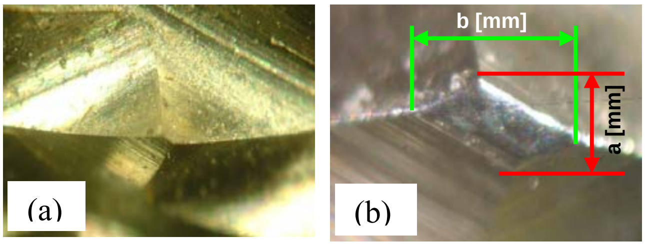

Fig. 2. (a) Pyramidal edge at the initial state. (b) Worn surface atop the pyramid due to the abrasion of the cutting process.

A testing procedure was performed to define the best TiAlN, AlCrN or naCo coatings. However the naCo showed no a very good performance in the prospective tests and therefore it was rejected. The reason perhaps was the excessive brittleness of this coating. In Table 2 tested tools are shown, in this case 8 mm diameter, made with micrograin substrate.

The best results were found with a thicker layer of AlTiN (4.5 microns), due to the longer protective effect of layer against abrasion (see Fig.3). AlCrN and normal thick (3 microns) AlTiN achieved the similar tool life.

Table 2. Tools tested to define the best coating

Coating and layer thickness
No coating
ALCRN 2.5 ± 0.5 µm
ALTIN 2.5 ± 0.5 µm
ALTIN+ 4 ± 0.5 µm

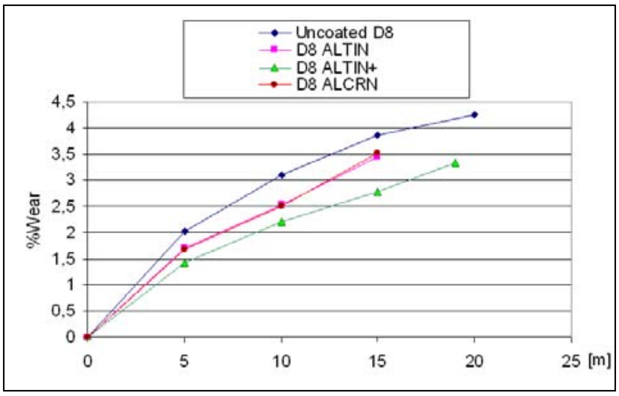

Fig. 3 Wear of coated tools

Fig. 4. Burnt of the CFRP epoxy matrix, due to the bad cutting of worn tools, after 42 mm of the slotting operation.

Fig. 5: Final design of tool edges with TiAlN+ coating

Special care was the detection of damage on CFRP [3], due to delamination or burnt parts when tool was much worn (see Fig.4). Tool final geometry is shown in Fig. 5, the final pyramidal height was increased along test.

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