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High-efficiency ultrasonic assisted drilling of CFRP/Ti stacks under non-separation type and dry conditions

Key words:

Carbon fiber reinforced plastic and titanium alloy (CFRP/Ti) stacks; Ultrasonic-assisted drilling (UAD); Cutting force; Surface integrity; Tool wear

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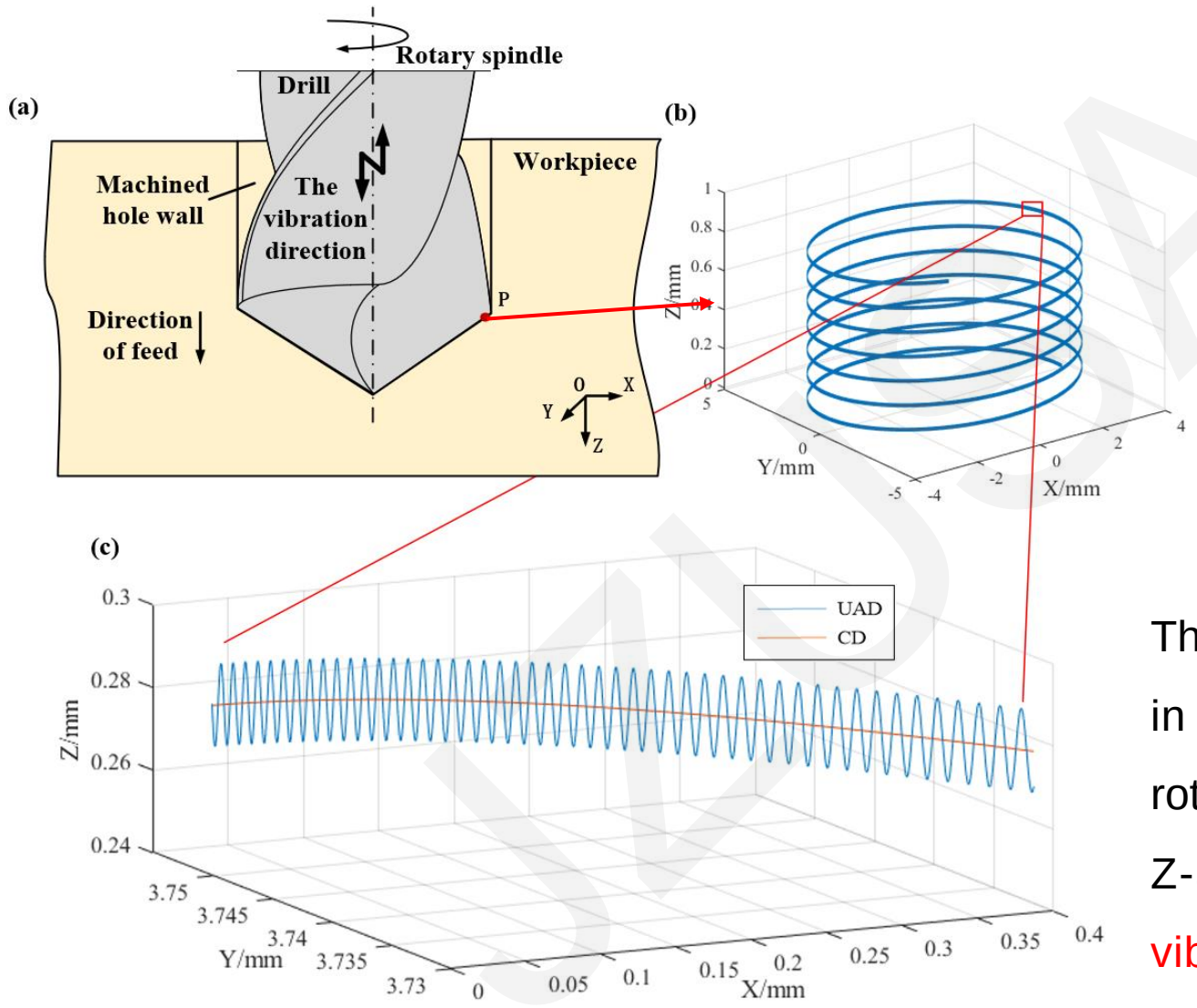
Mechanism of the UAD method



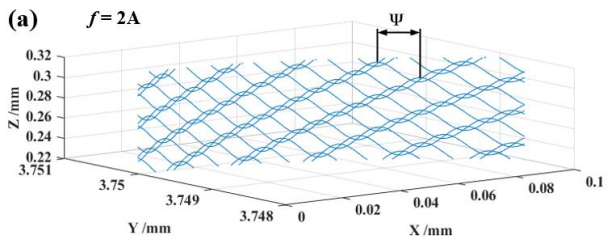
macroscopic motion trajectory of the cutting edge

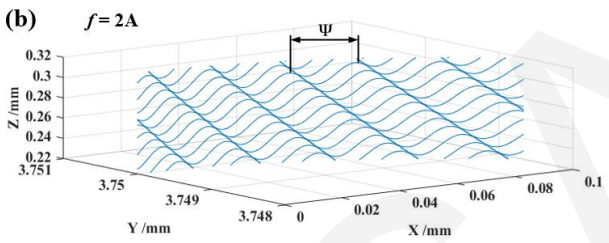
the equation for the motion trajectory of the cutting edge:

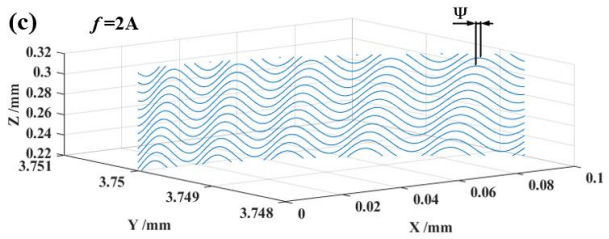
$$\begin{cases} x(t) = d\cos\dfrac{2\pi n}{60}t \\ y(t) = d\sin\dfrac{2\pi n}{60}t \\ z(t) = V_f t + A\,sin(2\pi F t) \end{cases}$$

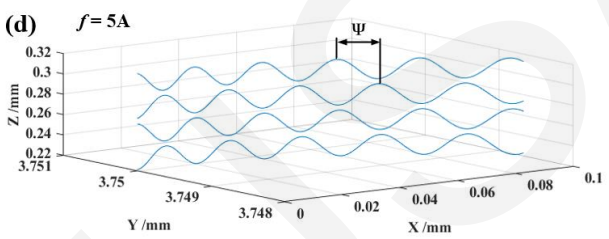
The cutting-edge movement in UAD is coupled by the rotation of the tool along the Z-axis and the ultrasonic vibration is applied to the tool feed direction

Mechanism of non-separation type UAD

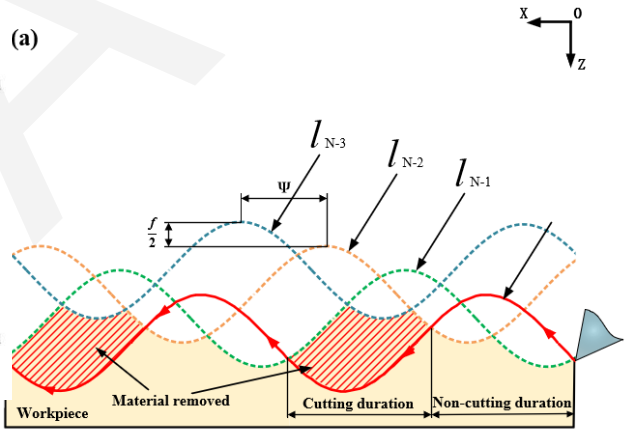








Schematic diagram of material removal in UAD



separation cutting mode

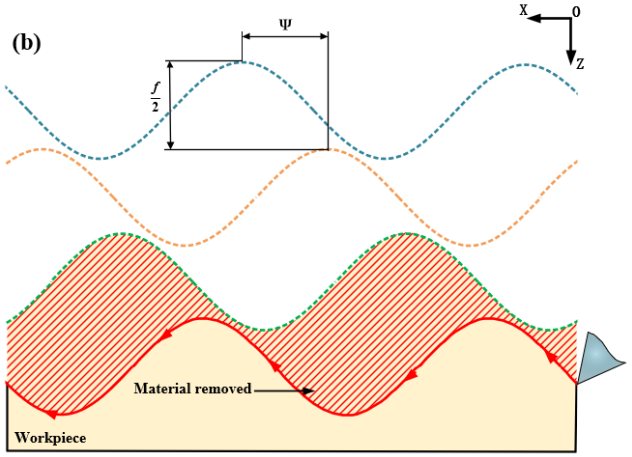
Effect of feed rate and phase difference on cutting-edge trajectory

The separation condition: $\begin{cases} f \le 4A \\ 2\,arcsin\dfrac{f}{4A} \le \Psi \le 2\pi - 2\,arcsin\dfrac{f}{4A} \end{cases}$

f : the feed rate; A : the vibration amplitude; Ψ : the phase difference

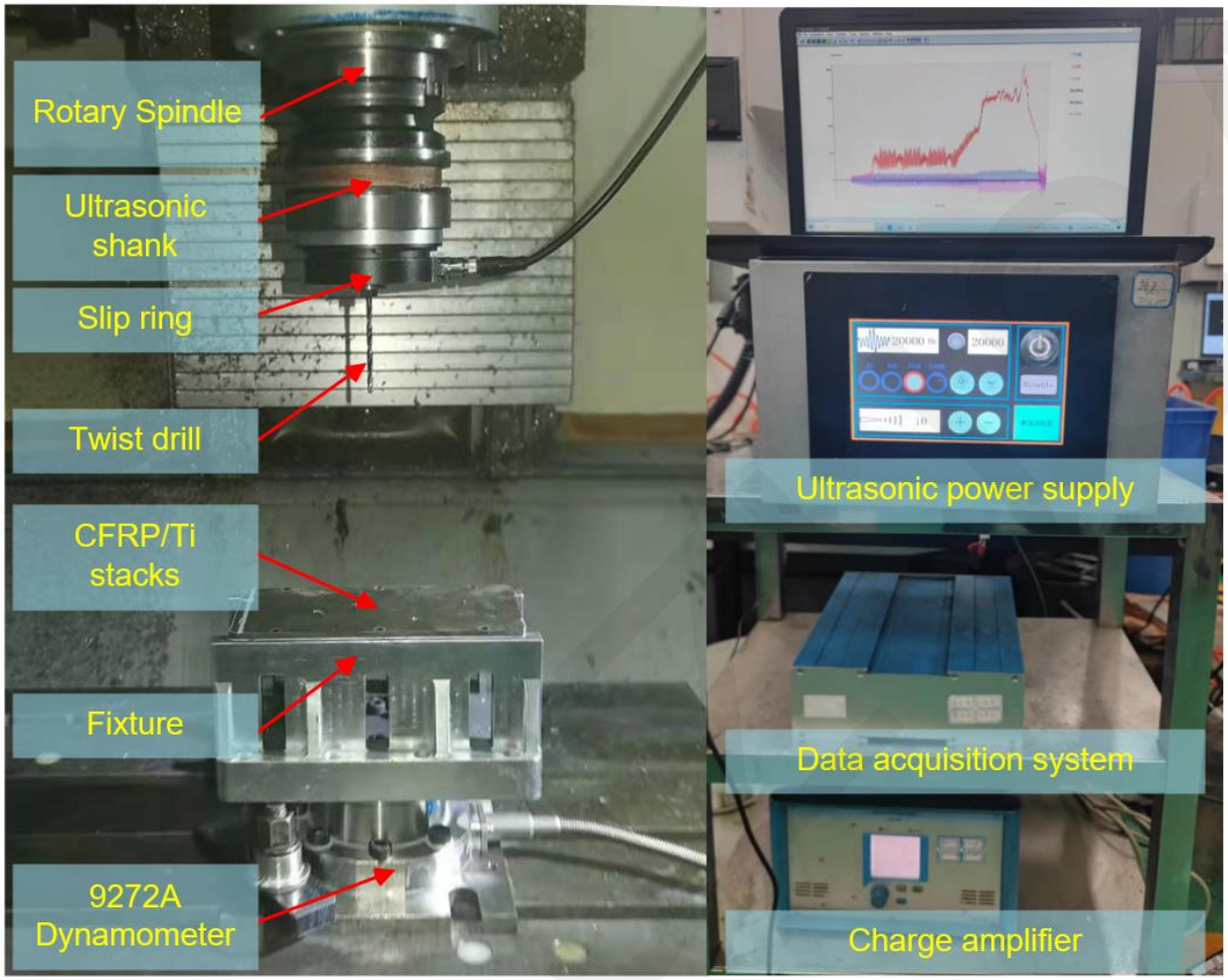
Satisfy the separation condition ➡ separation cutting mode

$f > 4A$ ➡ non-separation cutting mode



separation cutting mode

UAD experiment of CFRP/Ti stacks under dry conditions

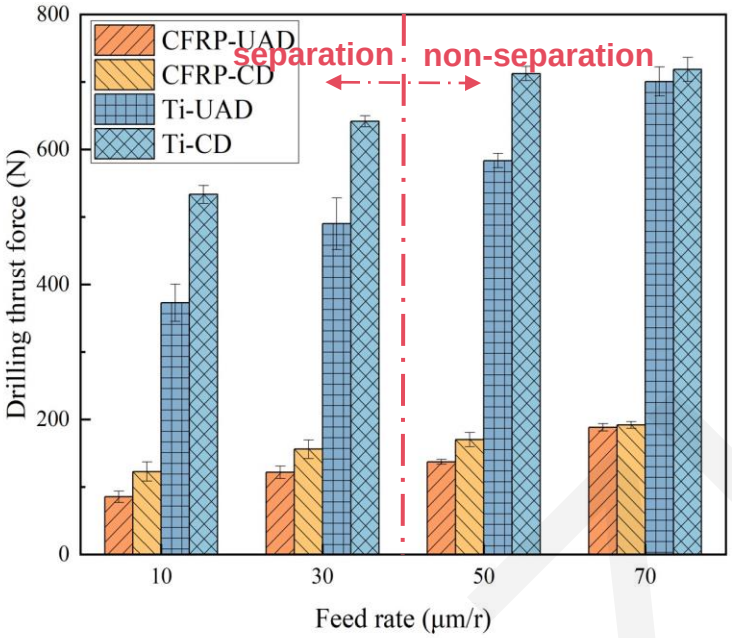


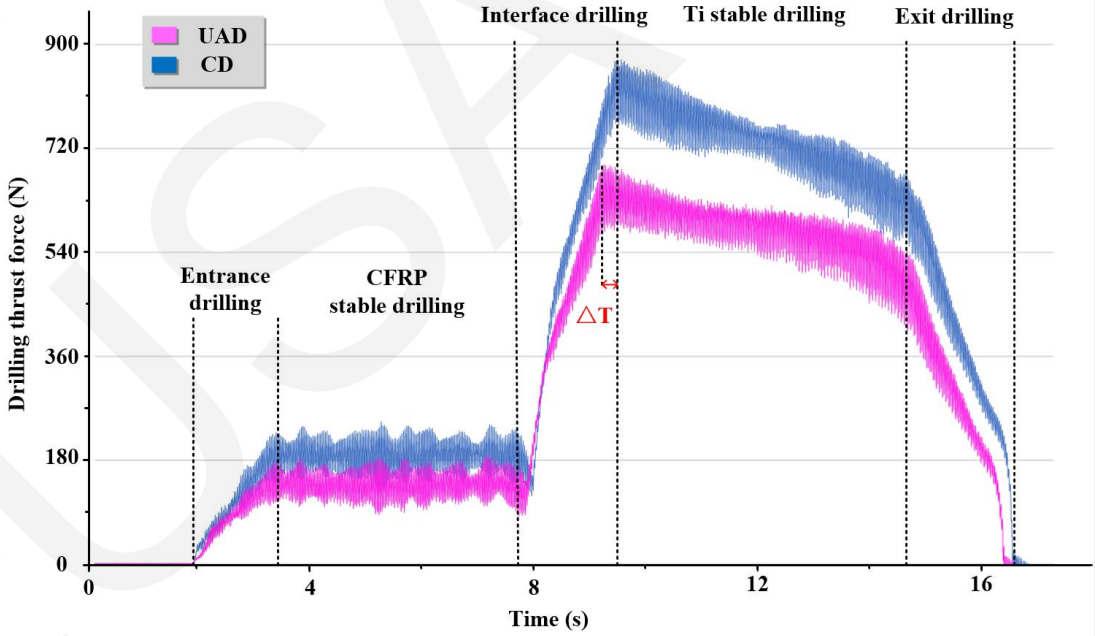
Experimental setup

parameters	CD	UAD
Cooling condition	无	无
Drilling diameter(mm)	7.5	7.5
Drilling depth (mm)	10	10
Vibrational frequency(Hz)	0	20020
Amplitude (μm)	0	10
Cutting speed (m/min)	15,25,35	15,25,35
Feed rate (μm/r)	10,30,50,70	10,30,50,70

Experimental conditions

Cutting force comparison

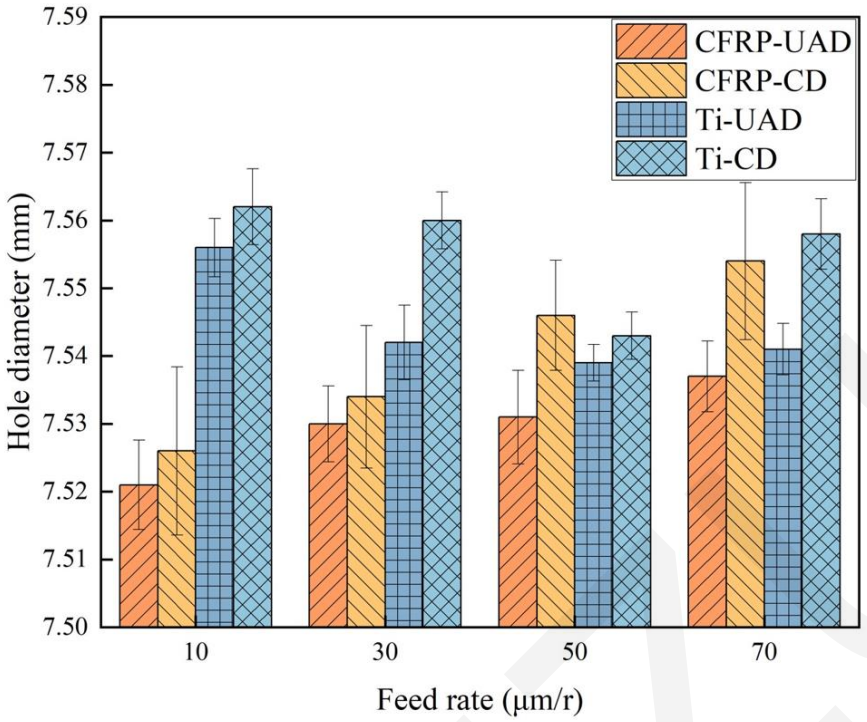




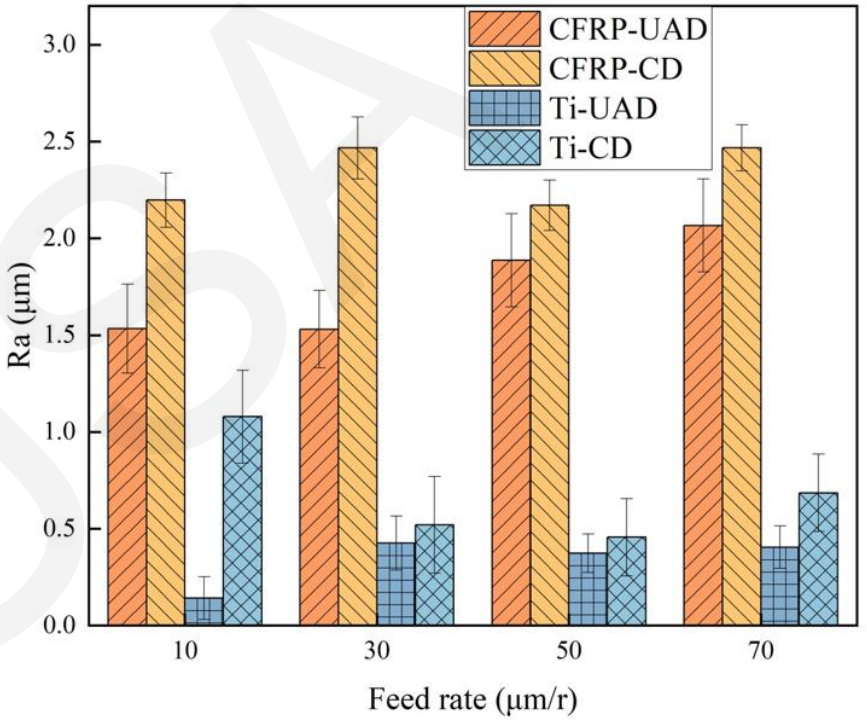
Thrust cutting forces with different feed rates **Typical cutting force curve**

Compared to conventional separation UAD, the non-separation UAD still effectively reduces the cutting forces by 24.2% and 1.9% for CFRP stage and 22.1% and 2.6% for the Ti stage at the feed rates of 50 and 70 μm/r, respectively.

Hole diameter accuracy and Hole surface roughness



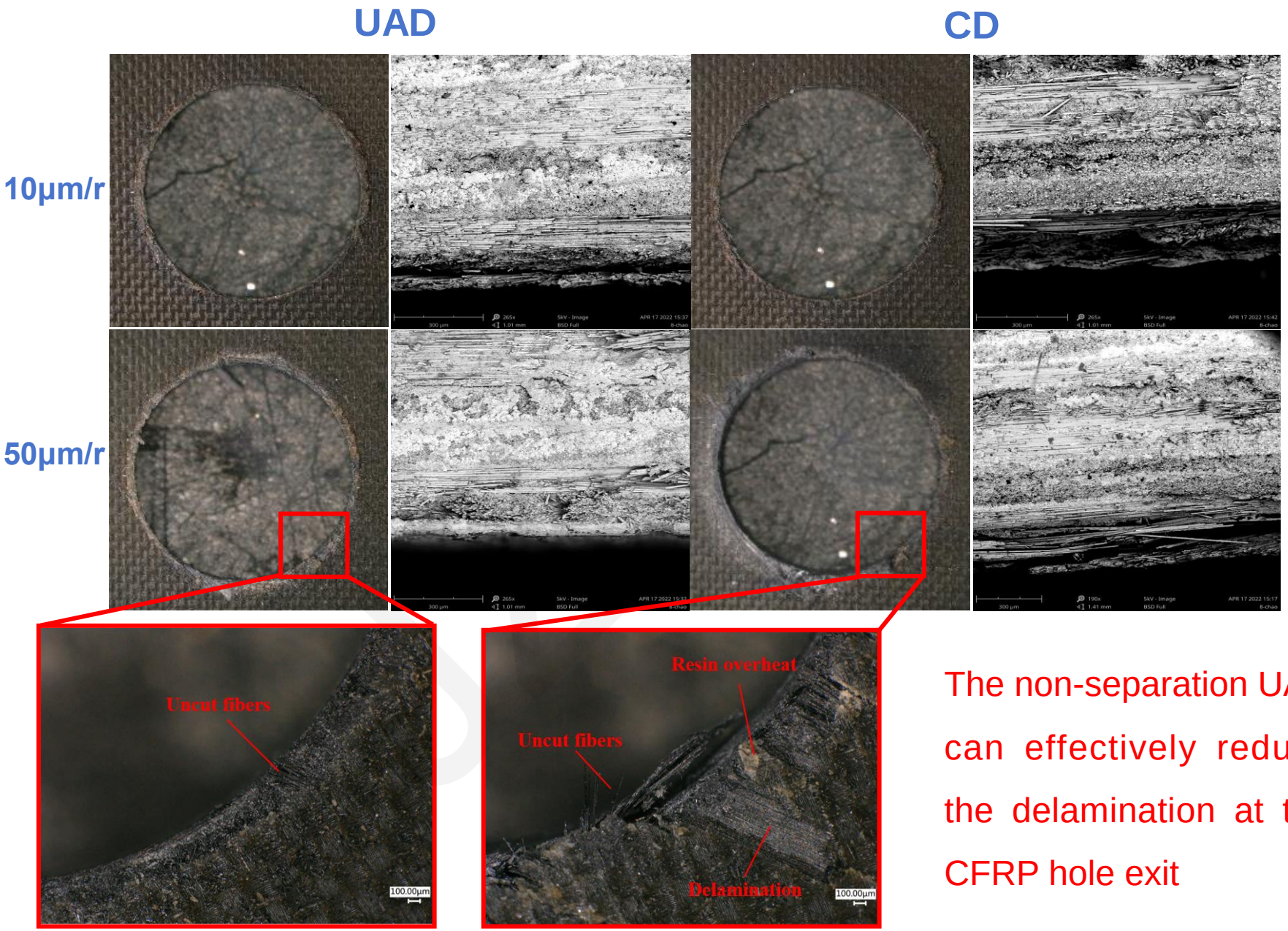
Hole diameter with different feed rates



Roughness with different feed rates

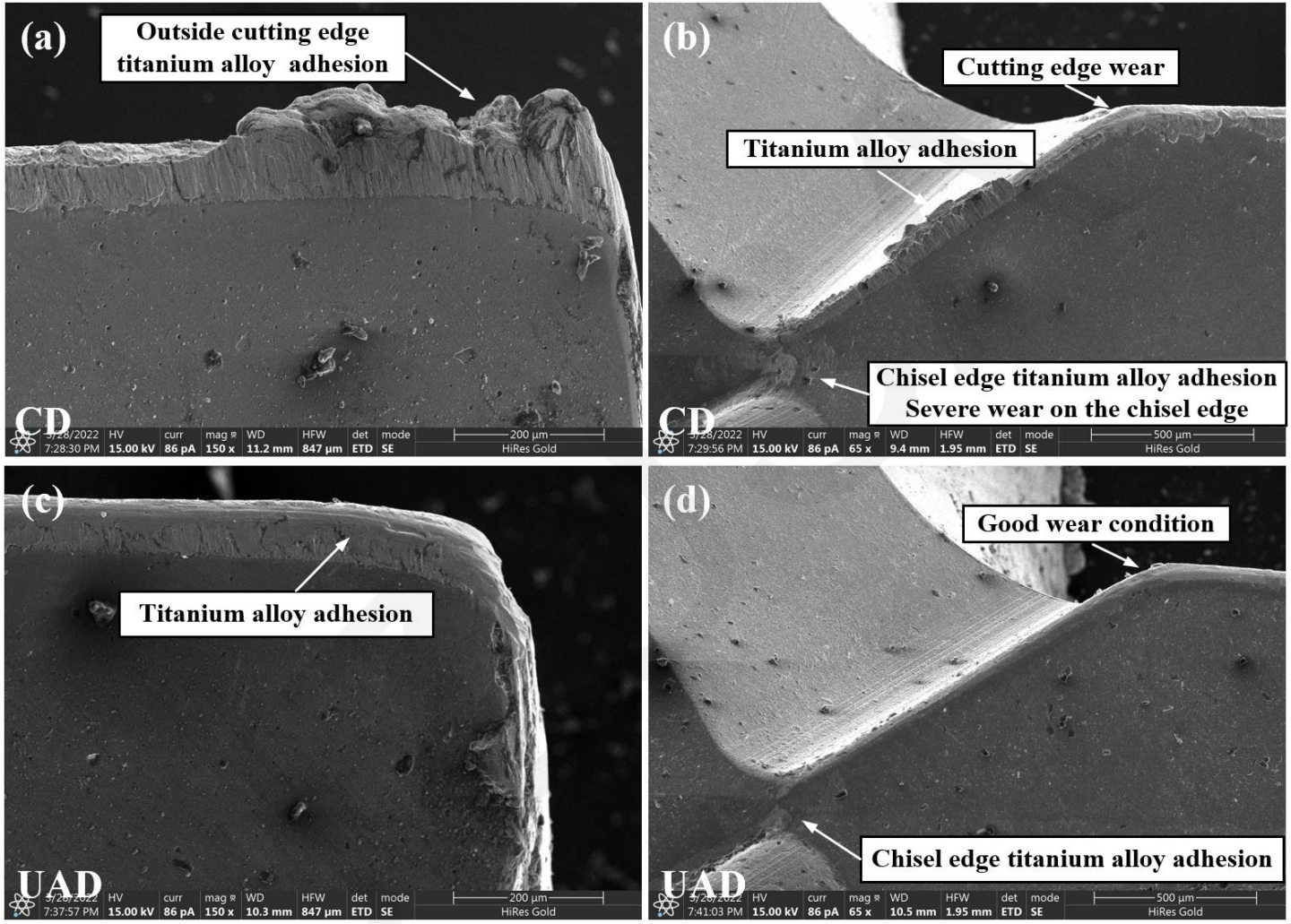
The non-separation UAD can significantly improve the hole diameter accuracy (11.8%–32.6% for CFRP and 9.3%–32.1% for Ti) and reduce the surface roughness (14.8%–19.3% for CFRP and 22.0%–40.1% for Ti).

Hole drilling damage



The non-separation UAD can effectively reduce the delamination at the CFRP hole exit

Tool wear comparison



Tool wear after drilling 60 holes

The non-separation type UAD can reduce the adhesion of titanium alloy to the cutting tool due to its adhesion reduction characteristics.