

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

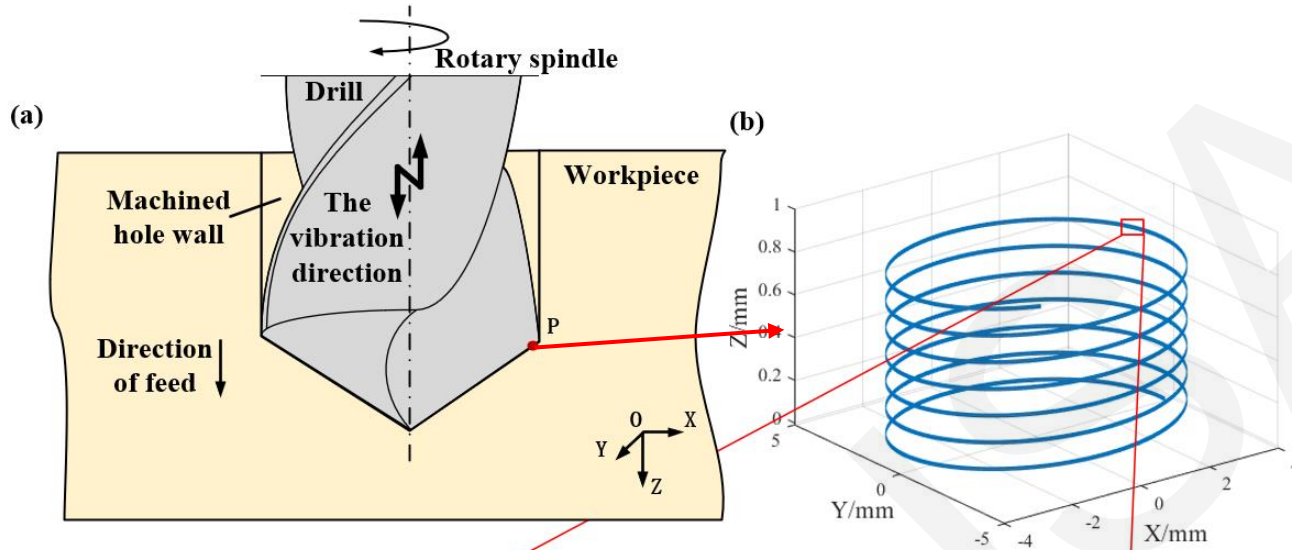
Key words:

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

Cite this as: Enze YING, Zehua ZHOU, Daxi GENG, Zhenyu SHAO, Zhefei SUN, Yihang LIU, Lianxing LIU, Xinggong JIANG, Deyuan ZHANG, 2024. High-efficiency ultrasonic assisted drilling of CFRP/Ti stacks under non-separation type and dry conditions. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 25(4):275-291.

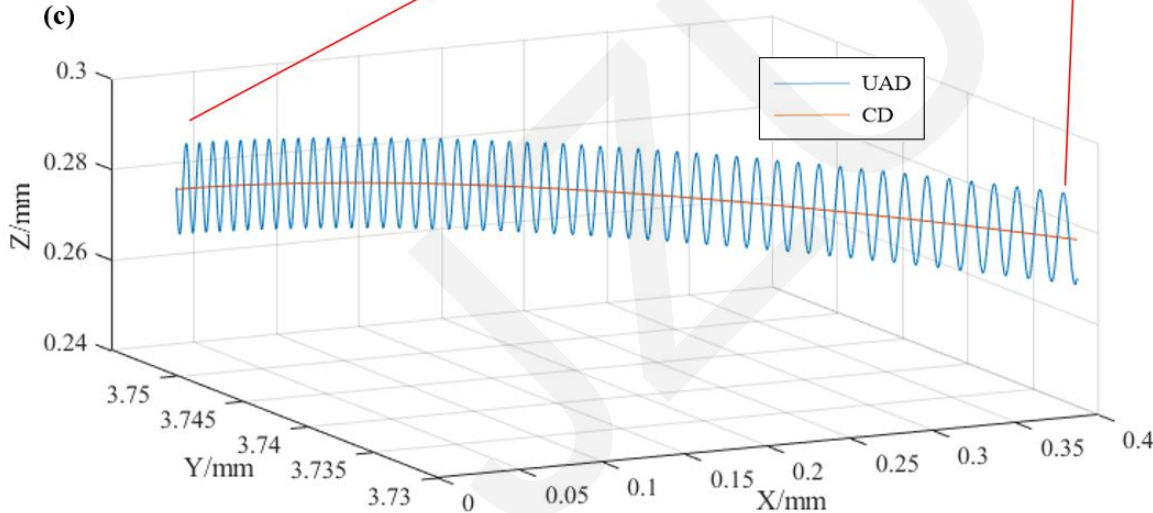
<https://doi.org/10.1631/jzus.A2300227>

Mechanism of the UAD method



the equation for the motion trajectory of the cutting edge:

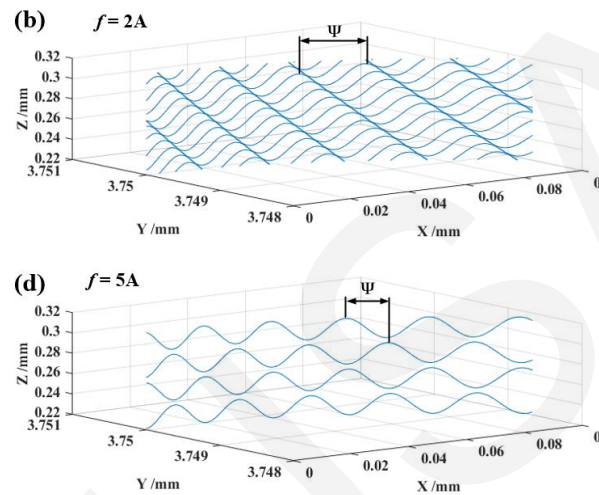
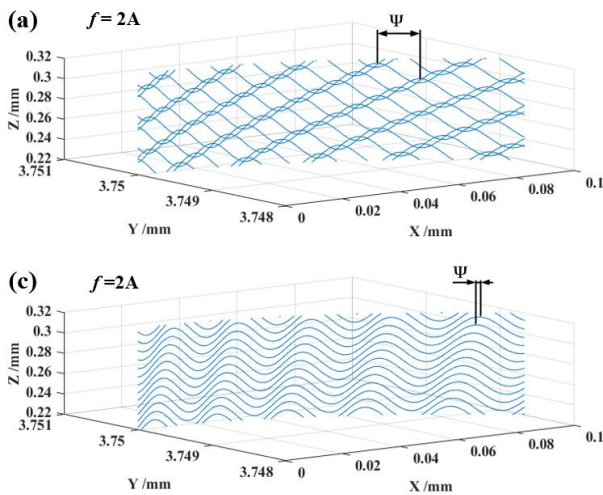
$$\begin{cases} x(t) = d \cos \frac{2\pi n}{60} t \\ y(t) = d \sin \frac{2\pi n}{60} t \\ z(t) = V_f t + A \sin(2\pi F t) \end{cases}$$



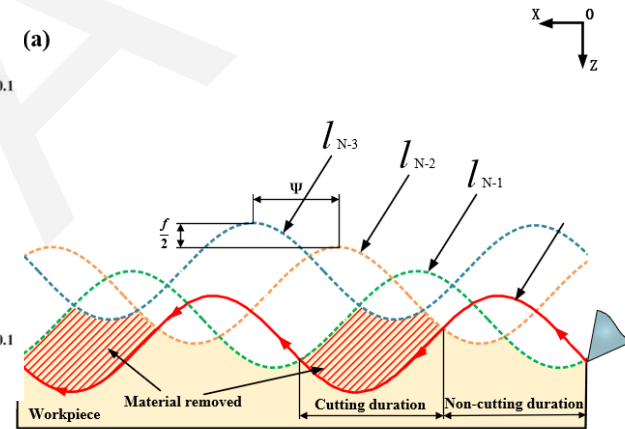
The cutting-edge movement in UAD is coupled by the rotation of the tool along the Z-axis and **the ultrasonic vibration is applied to the tool feed direction**

macroscopic motion trajectory of the cutting edge

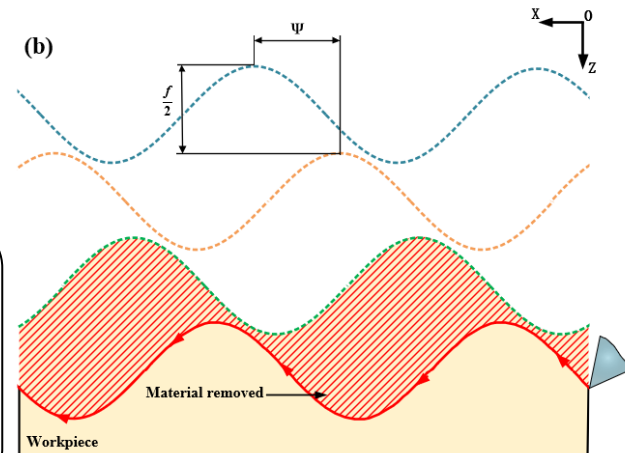
Mechanism of non-separation type UAD



Schematic diagram of material removal in UAD



separation cutting mode



separation cutting mode

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

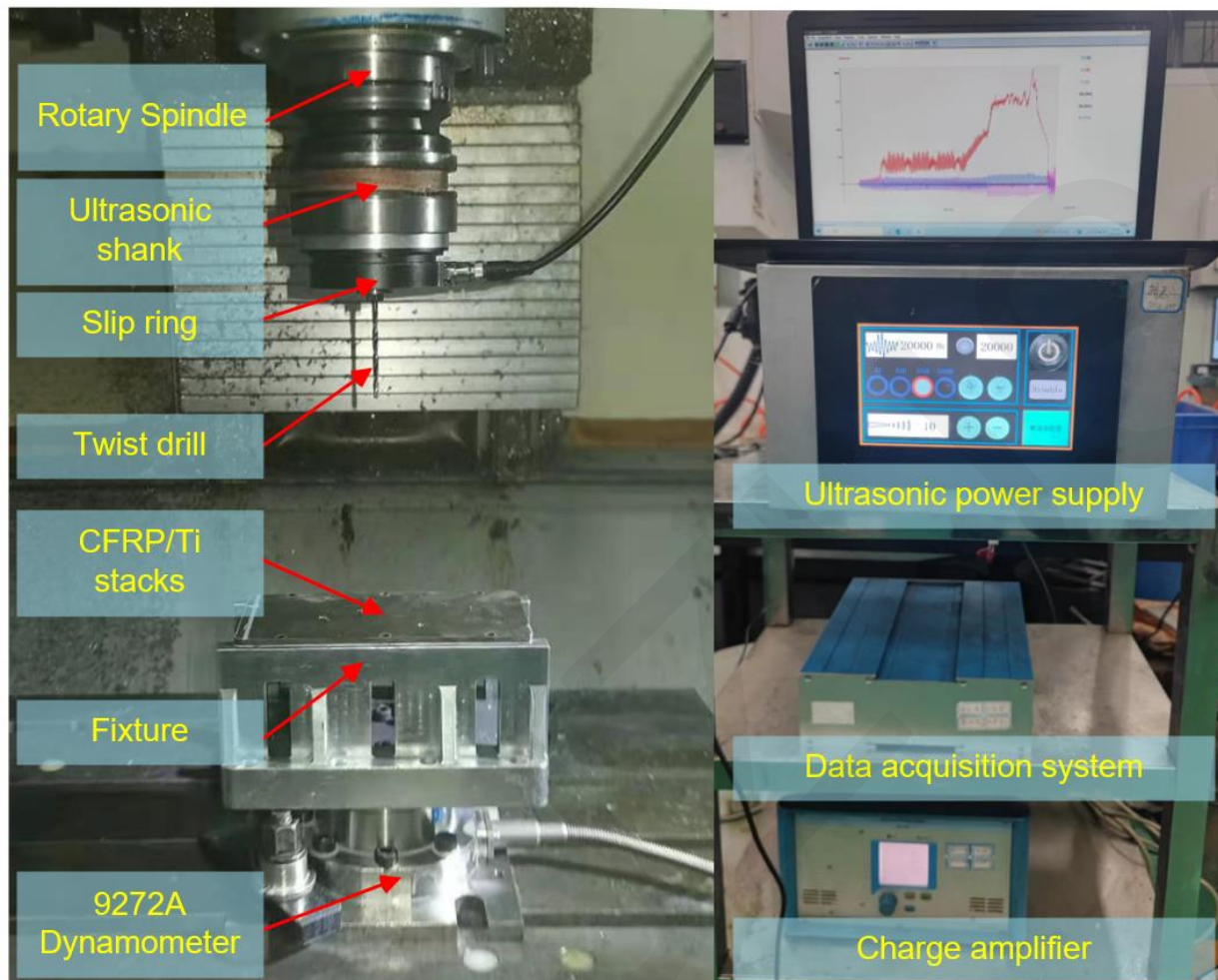
The separation condition:
$$\begin{cases} f \leq 4A \\ 2 \arcsin \frac{f}{4A} \leq \Psi \leq 2\pi - 2 \arcsin \frac{f}{4A} \end{cases}$$

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

Satisfy the separation condition $\rightarrow$ separation cutting mode

$f > 4A$ $\rightarrow$ non-separation cutting mode

UAD experiment of CFRP/Ti stacks under dry conditions

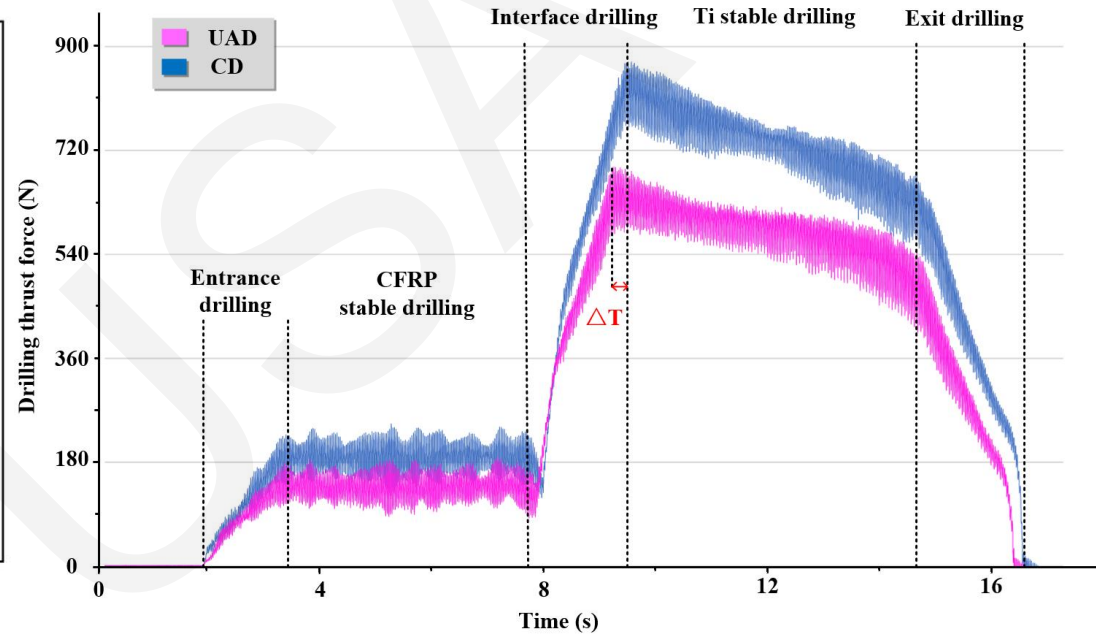
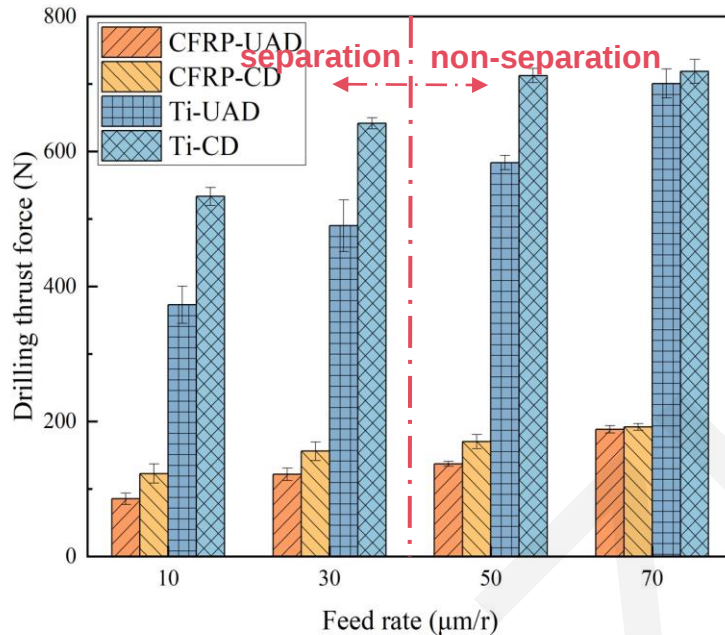


Experimental setup

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 ($\mu\text{m/r}$)	10,30,50,70	10,30,50,70

Experimental conditions

Cutting force comparison

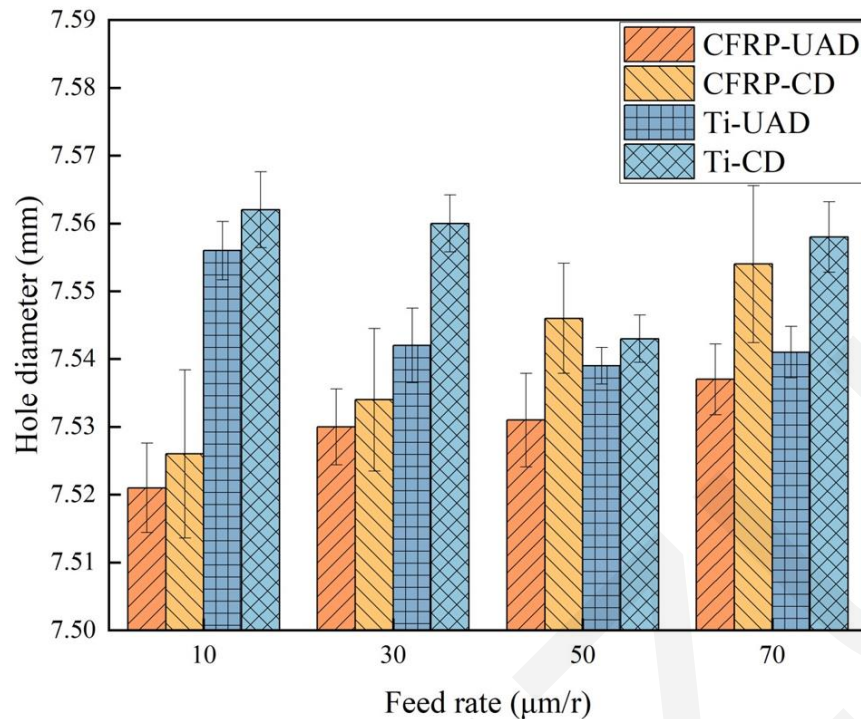


Thrust cutting forces with different feed rates

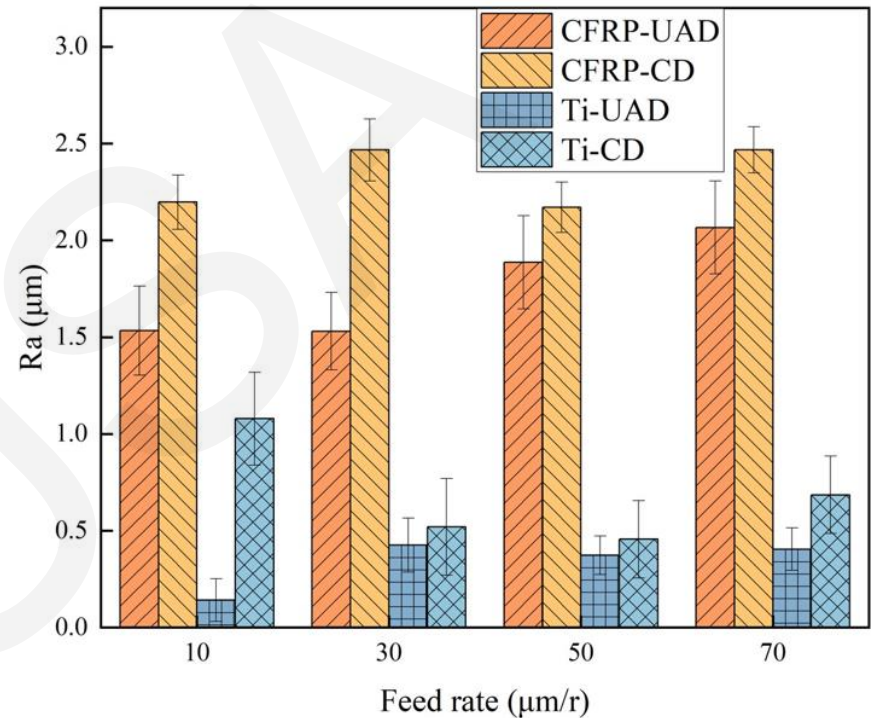
Typical cutting force curve

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 $\mu\text{m/r}$, respectively.

Hole diameter accuracy and Hole surface roughness



Hole diameter with different feed rates



Roughness with different feed rates

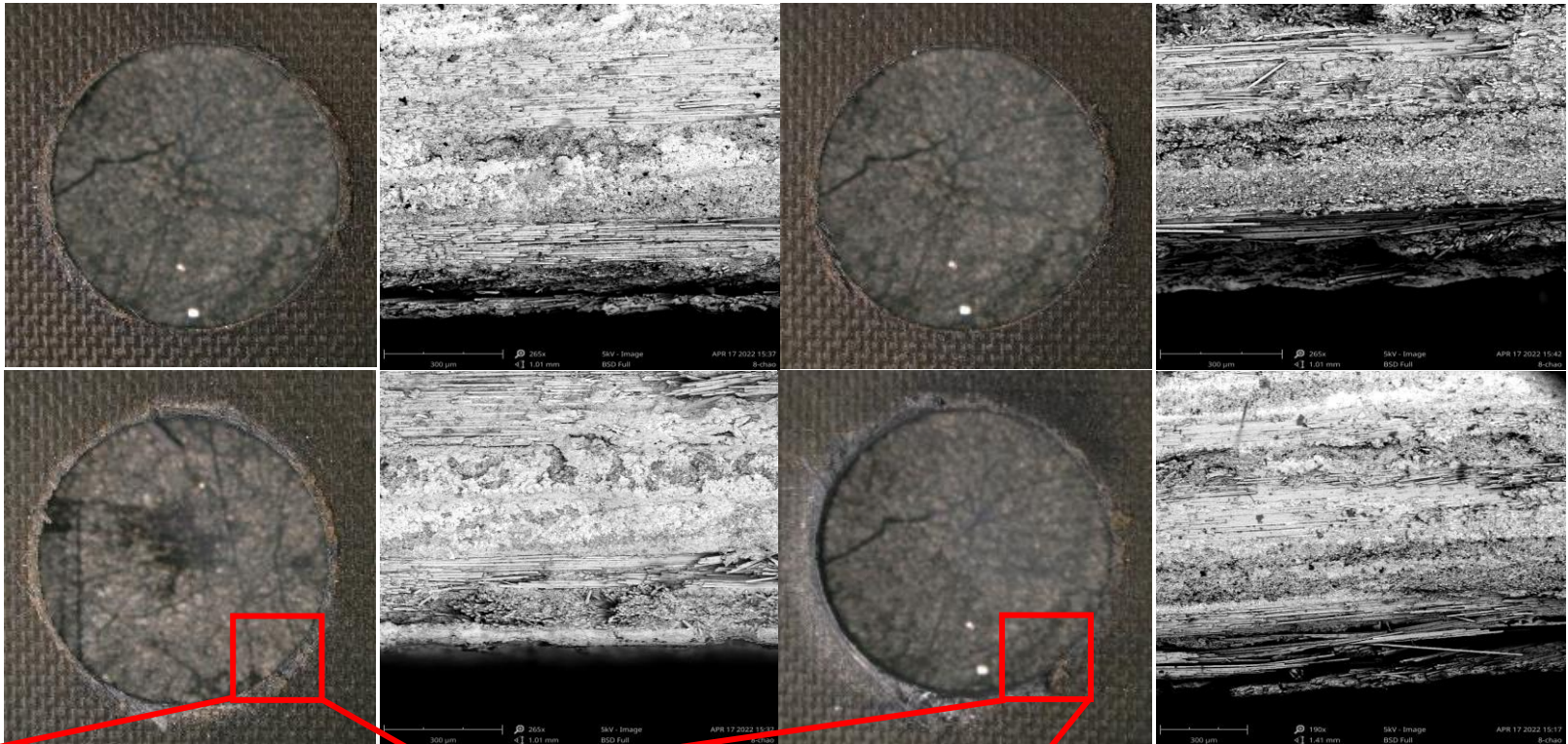
The non-separation UAD can significantly improve the hole diameter accuracy (11.8%–32.6% for CFRP and 9.3%–32.1% for Ti) and reduce the surface roughness (14.8%–19.3% for CFRP and 22.0%–40.1% for Ti).

Hole drilling damage

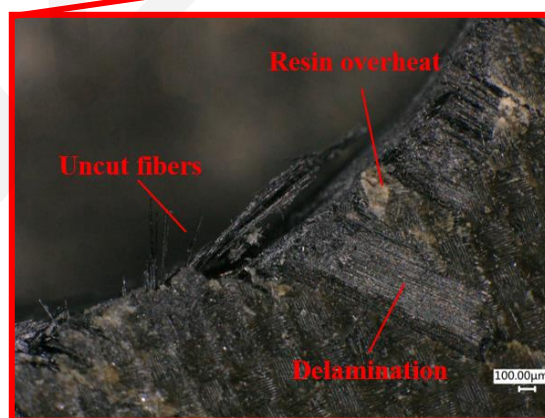
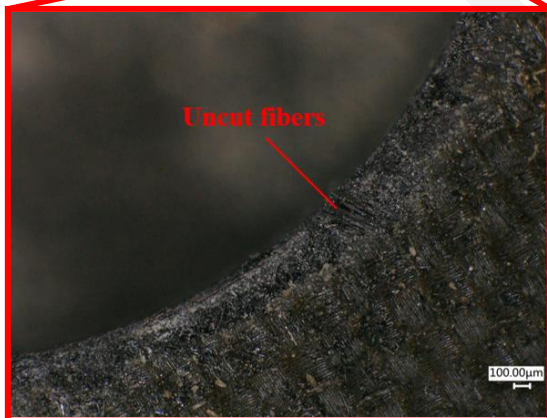
UAD

CD

10 μ m/r

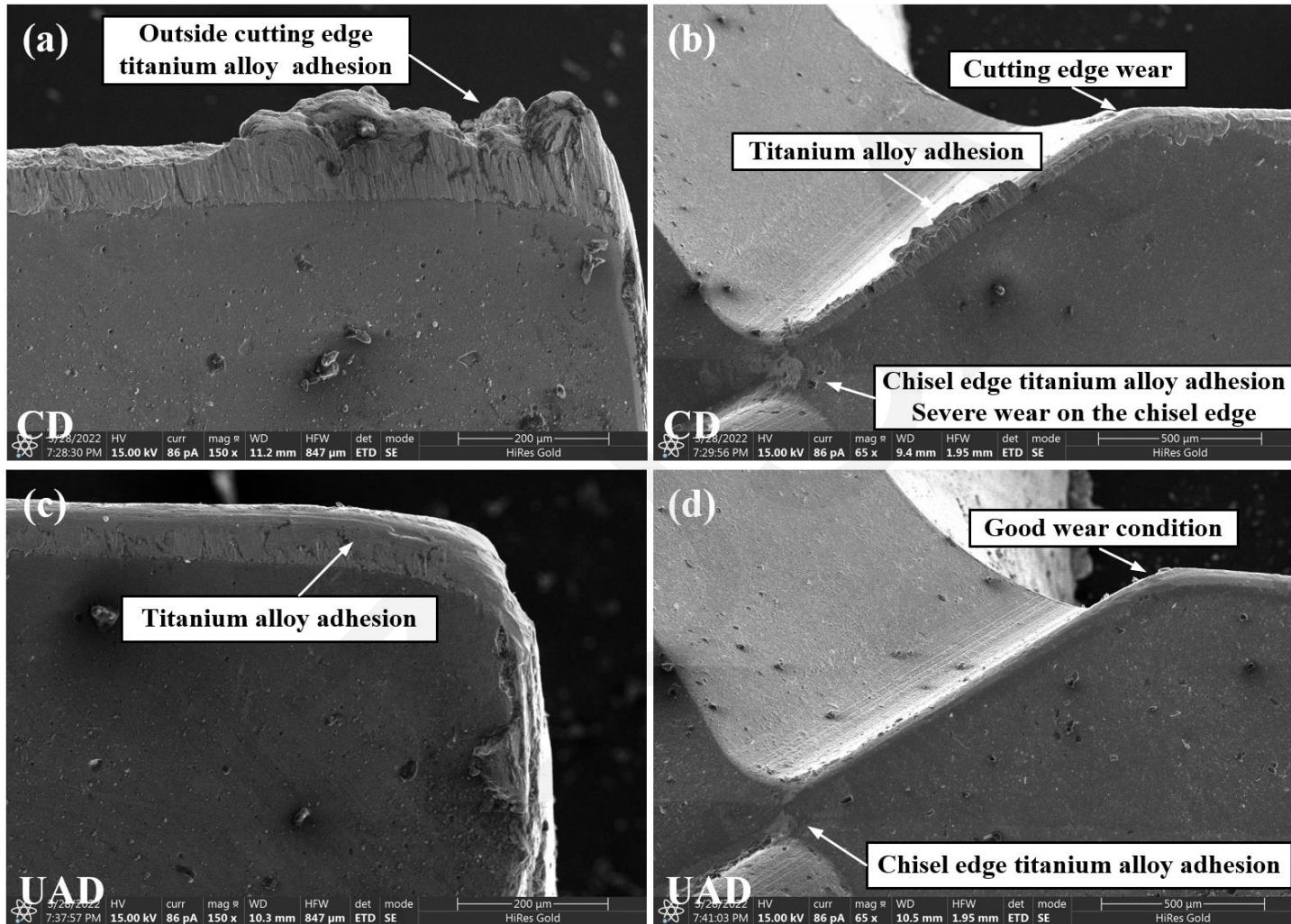


50 μ m/r



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.