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High-performance milling of Ti-6Al-4V through rotary ultrasonic elliptical milling with anticlockwise elliptical vibration

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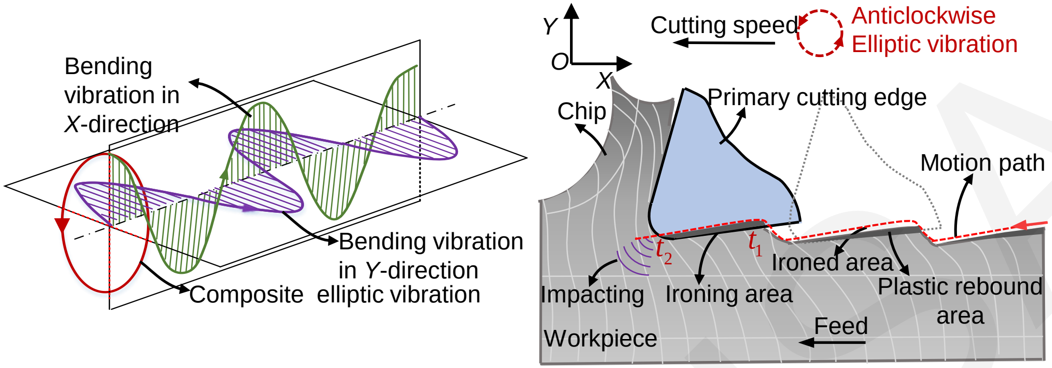
Surface formation mechanism



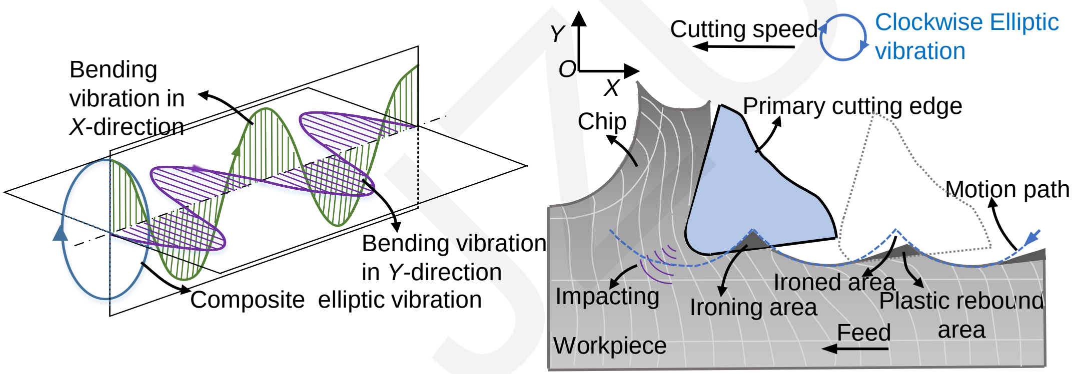
Direction of vibration and surface topography in anticlockwise rotary ultrasonic elliptical machining (ARUEM)

The theoretical trajectory of one tool tip in ARUEM:

$$\begin{cases} x_{\text{ARUEM}} = -\dfrac{2\pi nr}{60}t - A\sin(2\pi ft) \\ y_{\text{ARUEM}} = A\cos(2\pi ft) \end{cases}$$

The theoretical trajectory of one tool tip in CRUEM:

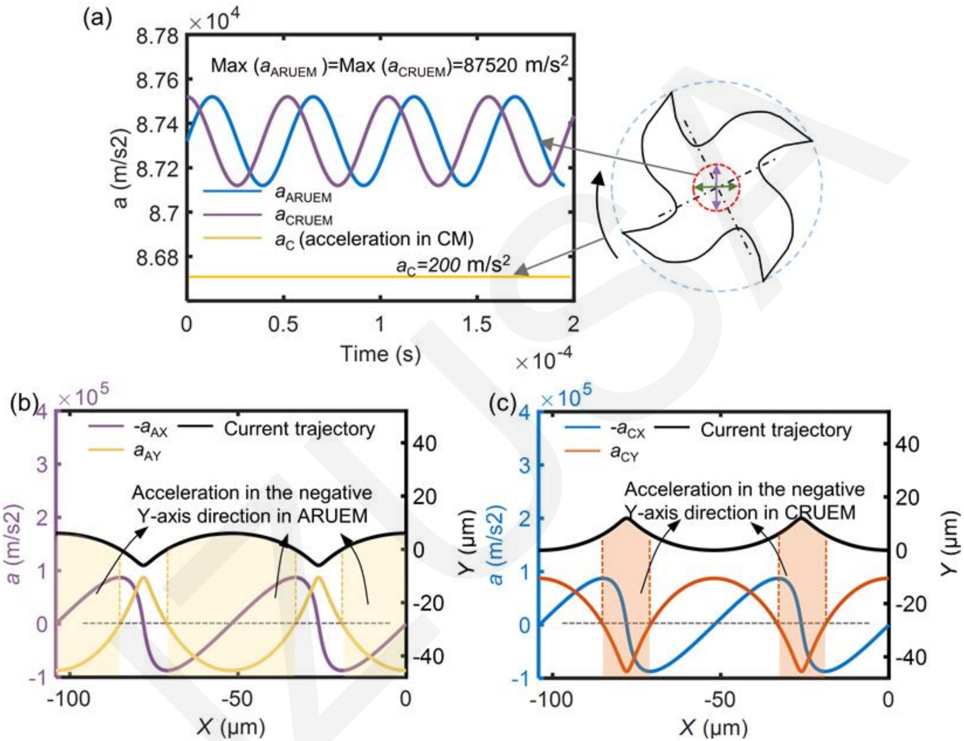
$$\begin{cases} x_{\text{CRUEM}} = -\dfrac{2\pi nr}{60}t + A\sin(2\pi ft) \\ y_{\text{CRUEM}} = A\cos(2\pi ft) \end{cases}$$



Direction of vibration and surface topography in clockwise rotary ultrasonic elliptical machining (CRUEM)

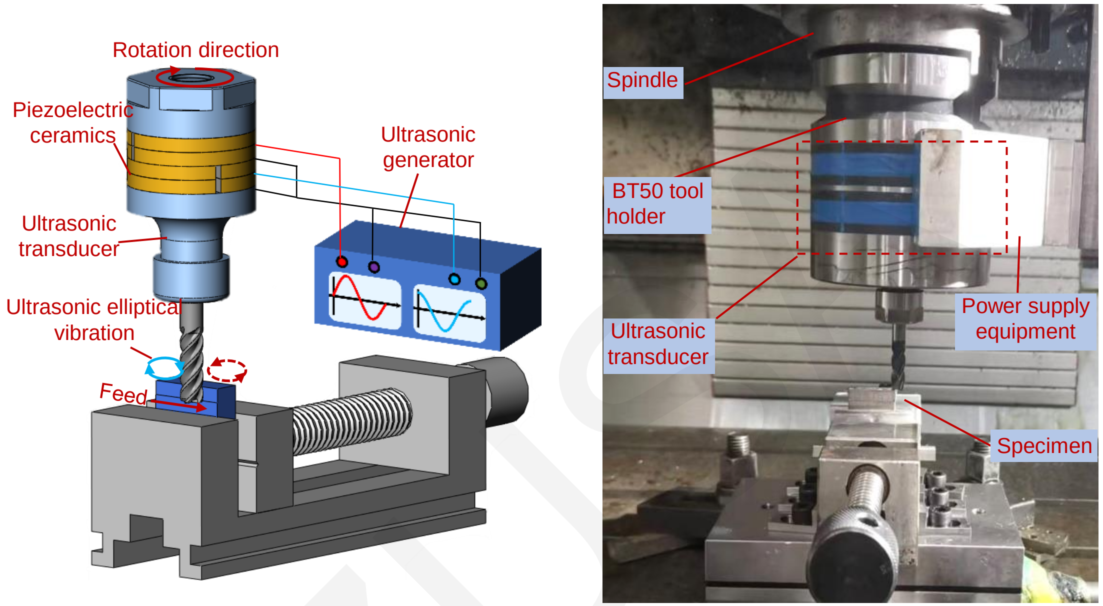
The surface formation mechanism in ARUEM was revealed based on a corrected motion trajectory for the cutting edge. Moreover, it was found that a lower residual height of the machined surface could be obtained in ARUEM as compared to CRUEM.

Variable acceleration cutting effect



Cutting speed v_c (a) varied with time, and varied with *X* position in (b) ARUEM and (c) CRUEM

In ARUEM, the proportion of trajectory points where the *Y* direction acceleration is directed toward the negative *Y* axis is significantly higher than in CRUEM, suggesting a stronger cutting ability in this direction.

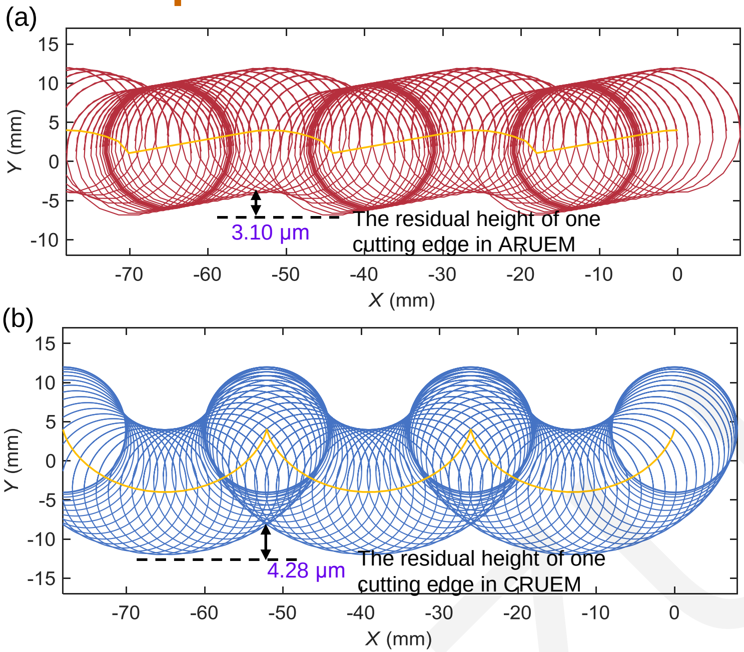


Experimental setup

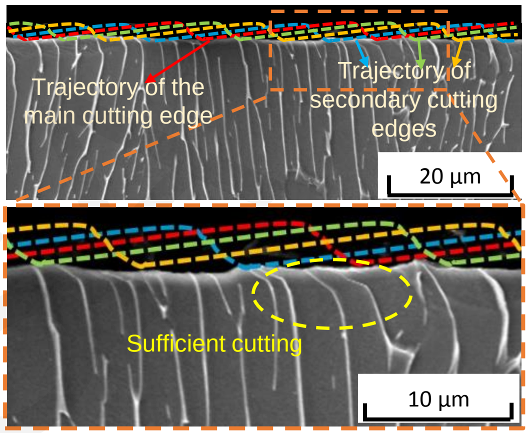
Cutting parameters

Milling condition	Description
Milling speed, v_c (m/min)	30, 60, 90
Feed rate per tooth, f_z (mm)	0.015
Radial depth of cut, a_e (mm)	0.2
Axial depth of cut, a_p (mm)	5
Vibration amplitude, A (μm)	0, 4, 6, 8
Milling method	CM, ARUEM, CRUEM

Optimization effect of surface morphology in ARUEM

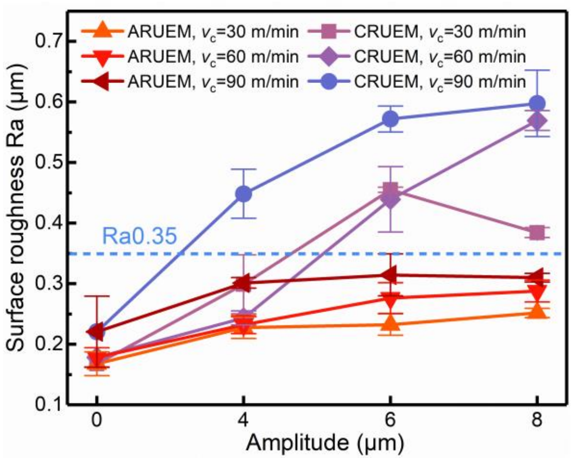


Envelope curves of actual motion trajectory in: (a) ARUEM and (b) CRUEM considering rounded cutting edge



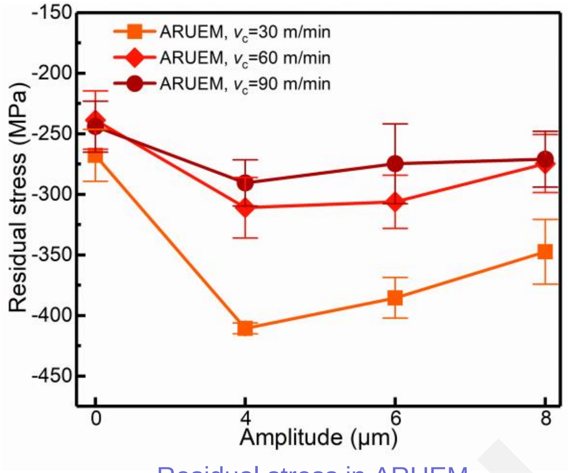
Fitting diagram of the envelope locus and metallographic cross-section topography in ARUEM

The surface roughness Ra in ARUEM was up to 50% lower rela-tive to CRUEM, and was accompanied by reduced ridge heights and undulations. This was primarily due to the lower residual height of ARUEM.

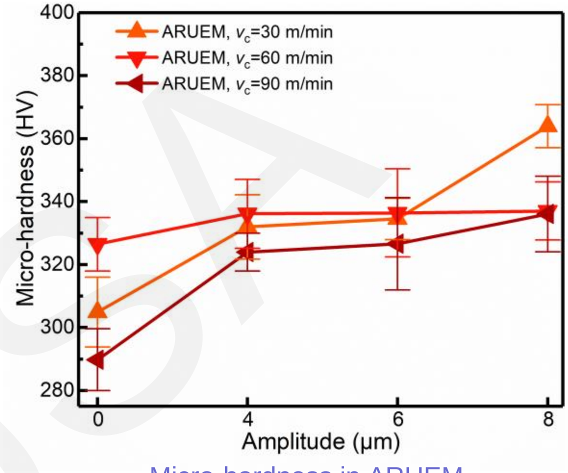


Surface roughness Ra

Strengthen effect in ARUEM

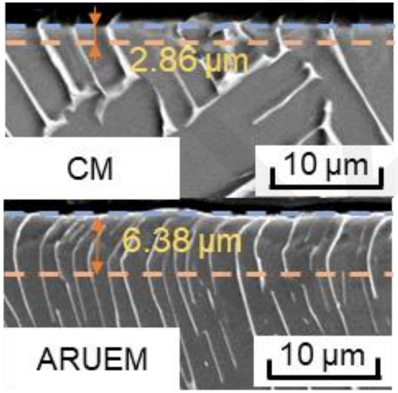


Residual stress in ARUEM



Micro-hardness in ARUEM

subsurface microstructure in ARUEM



Both ARUEM and CRUEM showcased notable strengthening effects compared to CM. For ARUEM, the maximum increases in plastic deformation layer thickness, surface residual compressive stress, and surface micro-hardness were 122.6%, 53.4%, and 19.3.