Francois.Ducobu@umons.ac.be

Experimental contribution to the study of the Ti6Al4V chip formation in orthogonal cutting on a milling machine

1st Research Day of the Materials Research Institute

Context

Ti6Al4V = hard-to-machine material

✧ Understanding of chip formation mechanisms (particularly when saw-toothed) needs to be improved ⇨ Ongoing research topic

✧ Numerical and experimental investigations

- ➨ Modeling must be validated by experiments but there is a lack of experimental data for strictly orthogonal cutting of Ti6Al4V
- ➨ Novel setup to perform orthogonal cutting on a milling machine without modifications, at cutting speeds up to 30 m/min

✧ Basis of a benchmark for numerical orthogonal cutting validation based on :

- ✦ Chip morphology (without chip distortion due to unrolling)
- ✦ Mechanism of chip formation
- ✦ Cutting forces
- ✦ Teeth formation frequency

Experimental setup

Configuration

✦ Machined material = annealed Ti6Al4V according to AMS 4928

✦ Sample = cylinder + tenons of 1 mm width > 280 µm ➨ plane strain conditions

✦ Tool : tungsten carbide, r = 20 µm, $\gamma = 15°$ and $\alpha = 2°$

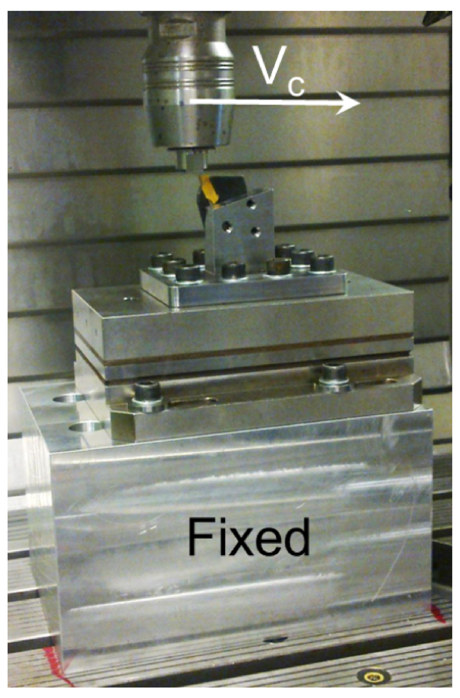
✦ Cutting forces measured with 9257B Kistler dynamometer

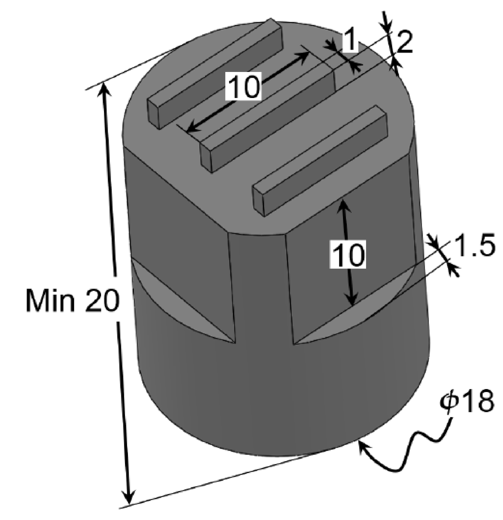
Cutting conditions

✦ v_c = 30 m/min and h = 40 µm, 60 µm, 100 µm and 280 µm

✦ Sample horizontal displacement with respect to the stationary tool

✦ Chips were collected to be observed on optical and numerical microscopes

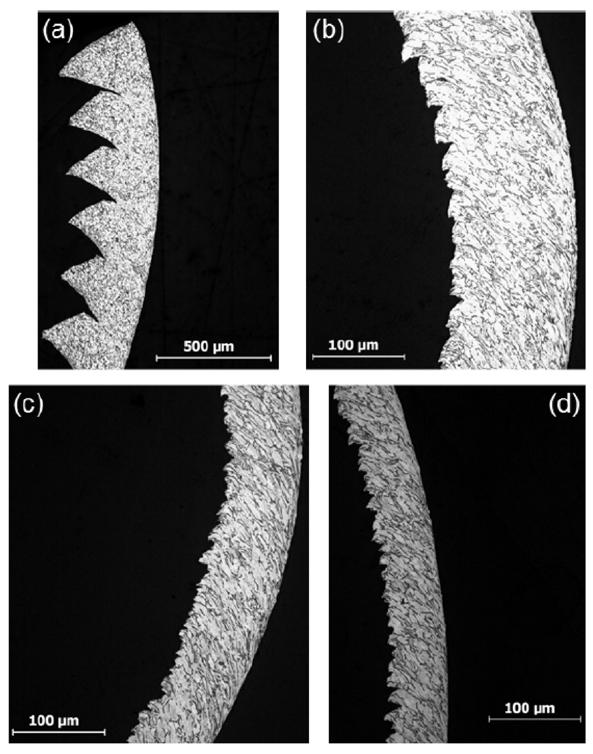




Results

Chips morphology – Optical and numerical microscopes

✦ From saw-toothed to continuous chip morphology (from a to d)



Saw-toothed chip – Optical microscope

✦ Highly deformed grains in primary shear zone (PSZ)

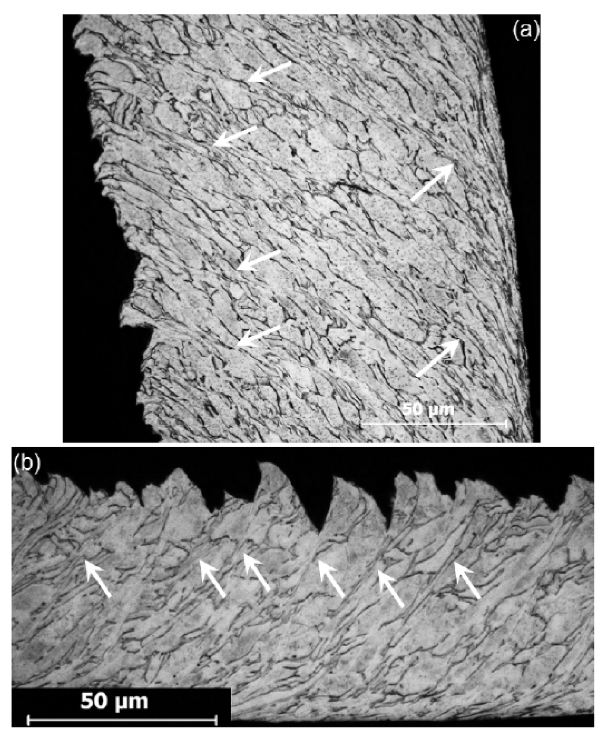
✦ Deformed grains on the continuous surface of the chip :

- ♦ Contact with tool
- ♦ Zone where chip comes off the workpiece

✦ Deformed grains on the free surface of the chip : workpiece preparation or previous tool passage during experiments

✦ On teeth sides : almost not deformed grains + irregular surfaces ➨ crack propagation characteristics

✦ Crack propagation inside PSZ, from the free chip surface to the tool



Saw-toothed chip – Numerical microscope

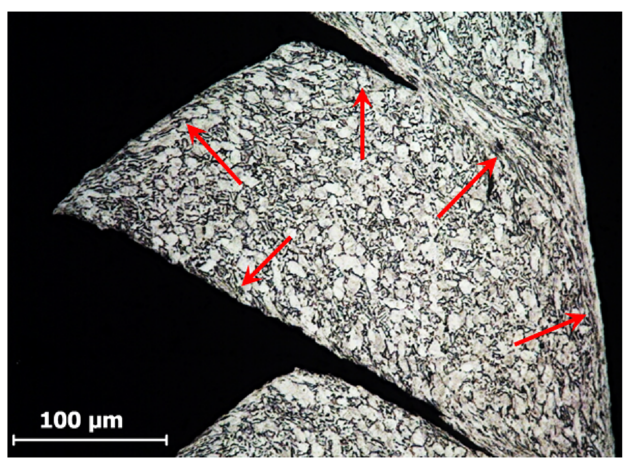
✦ Chip observation : embedding + polishing

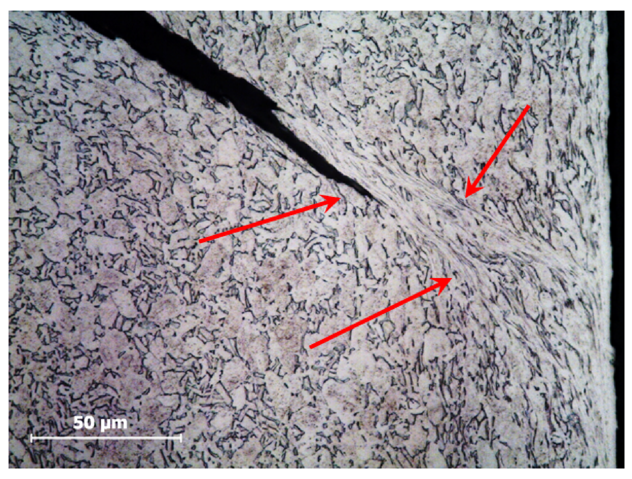
✦ Lateral chip faces ≠ central part (obtained after polishing)

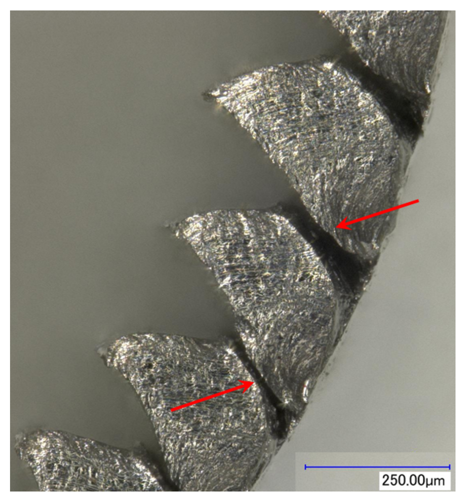
✦ No material between teeth in PSZ

➨ Not observable with an optical microscope and disappear with polishing

➨ **Characteristic of Ti6Al4V saw-toothed chip not mentionned in literature**







Cutting forces

✦ Cyclic cutting force evolution for saw-toothed chip morphology

✦ Nearly constant force value for continuous chip morphology

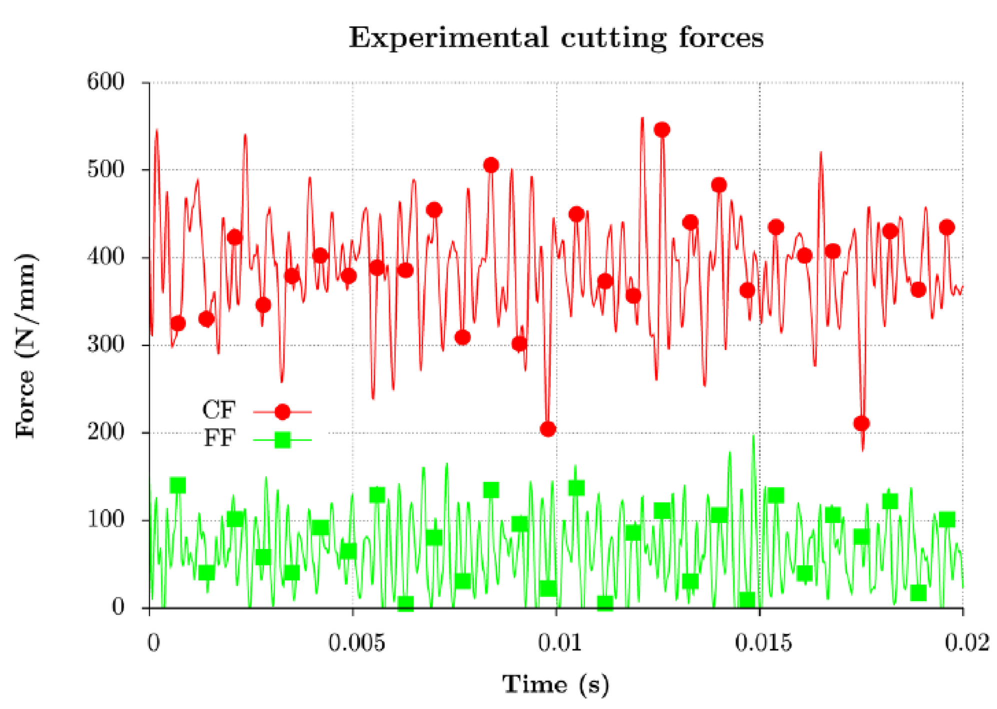
✦ RMS value decreases with the depth of cut

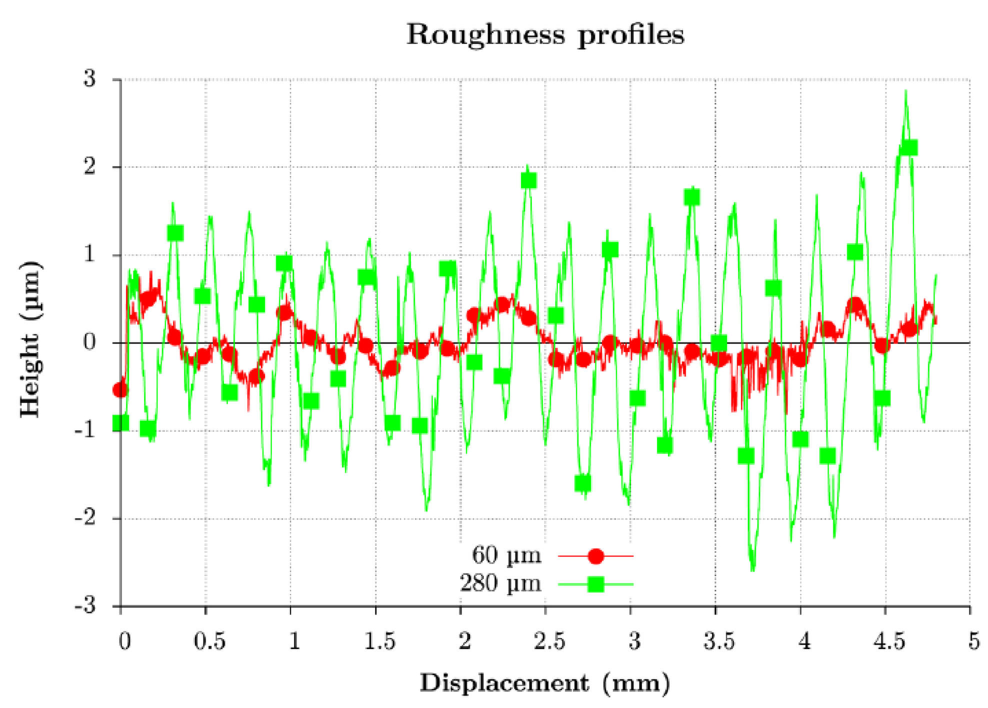
Surface roughness

✦ Cyclic evolution for saw-toothed chip morphology

➨ **Estimation of the teeth formation frequency**

h	RMS CF (N/mm)	RMS FF (N/mm)	$\frac{FF}{CF}$
280 (µm)	387±2	77±4	0.20
100 (µm)	173±2	51±1	0.29
60 (µm)	112±2	45±1	0.40
40 (µm)	86±2	41±1	0.48





Conclusions and perspectives

✧ For these cutting conditions, Ti6Al4V saw-toothed chip formation mechanism = adiabatic shear band + crack propagation inside PSZ

✧ No material between the teeth on lateral faces of the chip

✧ FFT of the roughness of the machine surface is a good estimator of the teeth formation frequency

✧ From saw-toothed to continuous chip when the depth of cut is reduced

✧ Decrease of the cutting forces with the depth of cut

✦ Perform this benchmark for other cutting conditions and for other materials, as long as the cutting speed is compatible with the feed rate of the machine

Université de Mons
Dr F. Ducobu, Prof. E. Rivière, Prof. E. Filippi | Machine Design and Production Engineering Department