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Experimental contribution to the comprehension of Ti6Al4V saw-toothed chip formation mechanisms in orthogonal cutting

Context

✧ Mechanisms of Ti6Al4V saw-toothed chip formation = question still opens in literature
✧ 3 theories are found in literature
⇨ Goal : make a breakthrough in this problem

Literature background

Formation by adiabatic shear band

✦ Large shear in PSZ ➨ large shear strains in very thin bands
✦ Localization ➨ very large local temperature increase ➨ thermal (and strain) material softening
✦ Thermoplastic instability
✦ Competition between hardening and strain softening
✦ $v_c \nearrow$: deformed band ➨ transformed band (β phase $\Rightarrow$ α phase + micro-hardness $\neq$)

Formation by crack propagation

✦ Large shear ➨ continuous crack initiation at free chip surface
✦ Propagation in PSZ towards tool
✦ At about 1/2 chip width : localized and disconnected cracks = 'micro-cracks'

Formation by adiabatic shear band and crack propagation

✦ Combination of the two previous theories
✦ Bai and Dodd [1] : adiabatic shear band = precursor of failure ?

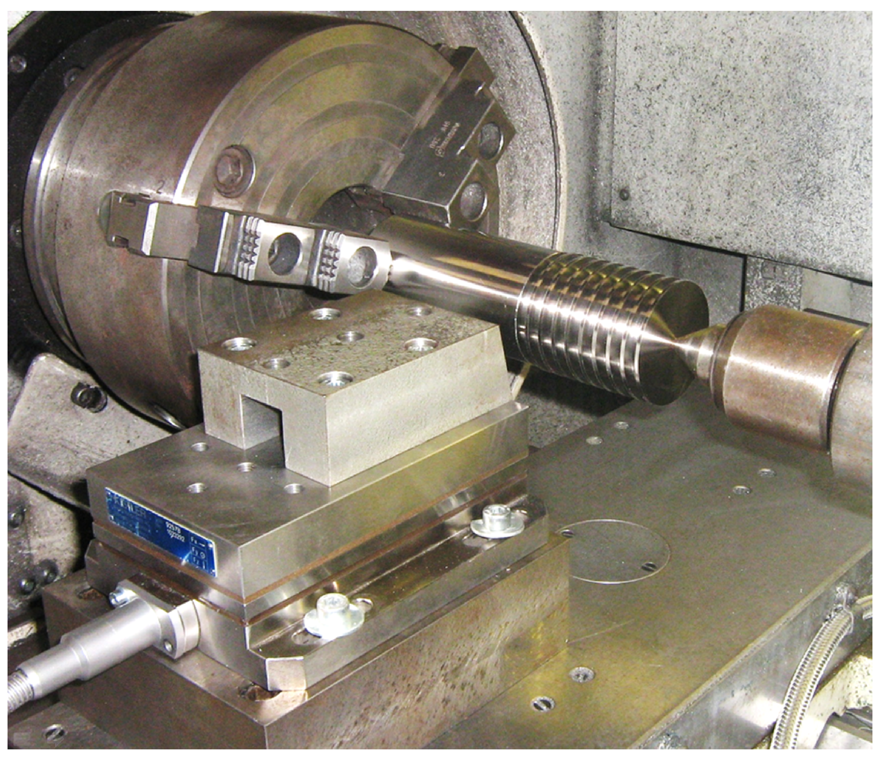
Conclusions

✦ Recent literature : adiabatic shear band = most likely theory
✦ Our opinion : Ti6Al4V saw-toothed chip formation mechanism = combination
- with preponderance depending on the cutting conditions (+ Ti6Al4V state)
- in very variable proportions

Experimental setup

Configuration

✦ Machined material = annealed Ti6Al4V according to AMS 4928 [2]
✦ Workpiece = shaft + flanges : successive slices (ϕ 60 mm) of equal thickness
✦ Tool : tungsten carbide, r = 10 µm, γ = 15° and α = 2°
✦ Tailstock to avoid workpiece displacements and vibrations



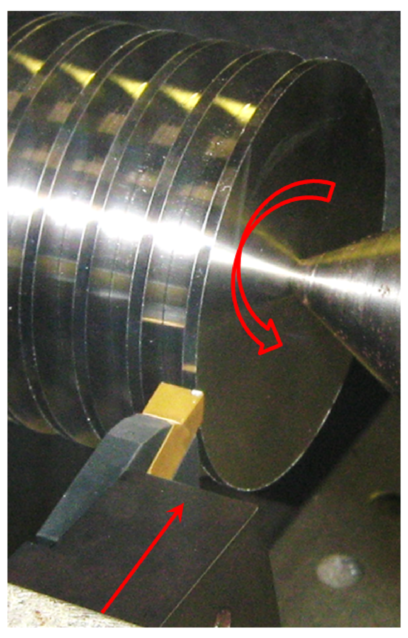
Cutting conditions

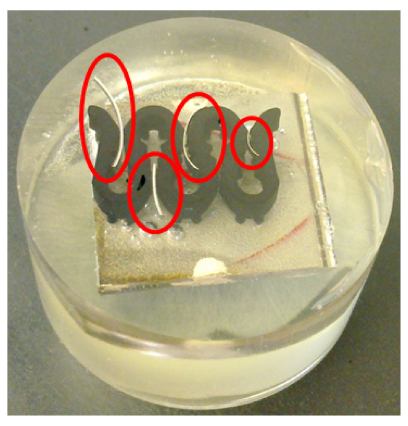
v_c = 75 m/min and h = 0.28 mm/rev

Orthogonal cutting

✦ Plunge cutting on each slice + dry cutting conditions
✦ Tool width (6 mm) > disks width (2 mm) ➨ plane strain conditions

Chips were collected to be observed on optical and numerical microscopes





Results

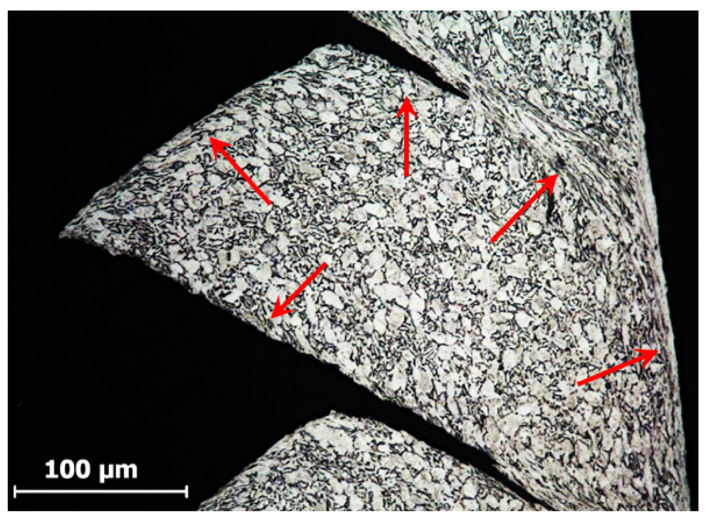
Microstructure revelation

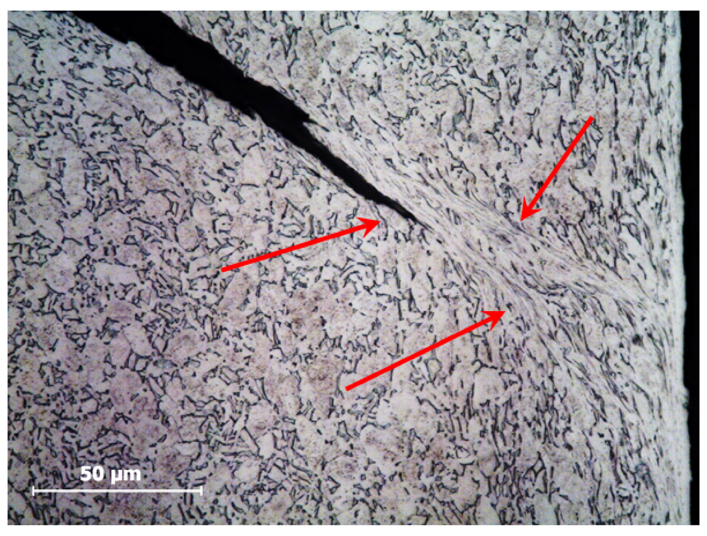
1. Embedding into epoxy resin
2. Polishing
3. Etching with Kroll's reagent during 45 s

Optical microscope

✦ Highly deformed grains in 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
✦ Split shear band as in [3]





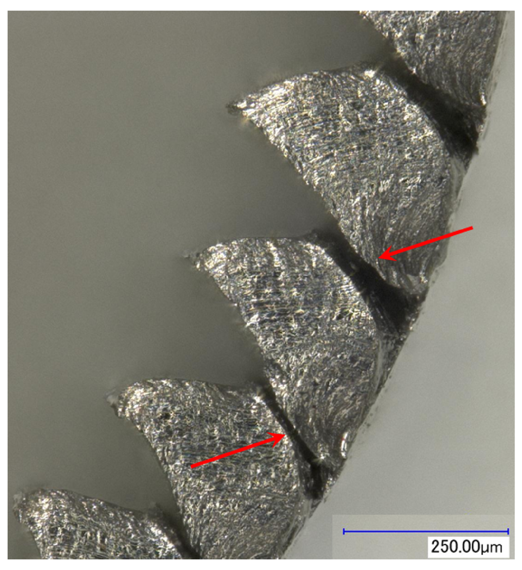
Microstrucure analysis

➨ Chip formation = large deformation + crack propagation inside PSZ

Numerical microscope

✦ Chip observation : embedding + polishing
✦ Lateral chip faces ≠ central part (obtained after polishing)
✦ No material between teeth in PSZ
✦ Width varies depending on the tooth
✦ High surface roughness

➨ Not observable with an optical microscope and disappear with polishing
➨ **Characteristic of Ti6Al4V saw-toothed chip not mentionned in literature**



Conclusions and perspectives

✧ For these cutting conditions, Ti6Al4V saw-toothed chip formation mechanism = adiabatic shear band + crack propagation inside PSZ
✧ Measure chip micro-hardness to study its evolution when crossing PSZ
⇒ phase transformation ?
✧ Compare these experimental results to these of the finite element model we have developed [4]

References

[1] Y. Bai and B. Dodd : Adiabatic Shear Localisation : Occurrence, Theories and Applications. Pergamon Press, 1992
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[4] F. Ducobu, E. Rivière-Lorphèvre and E. Filippi : A Lagrangian FEM Model to Produce Saw-toothed Macro-chip and to Study the Depth of Cut Influence on its Formation in Orthogonal Cutting of Ti6Al4V. Advanced Materials Research, 223 : 3-11, 2011

Acknowledgements

The authors gratefully acknowledge the FEDER financial support (SINUS project) allowing to carry out the experimental tests.