Estimation of the Influence of Tool Wear on Force Signals

A Finite Element Approach in AISI 1045 Orthogonal Cutting

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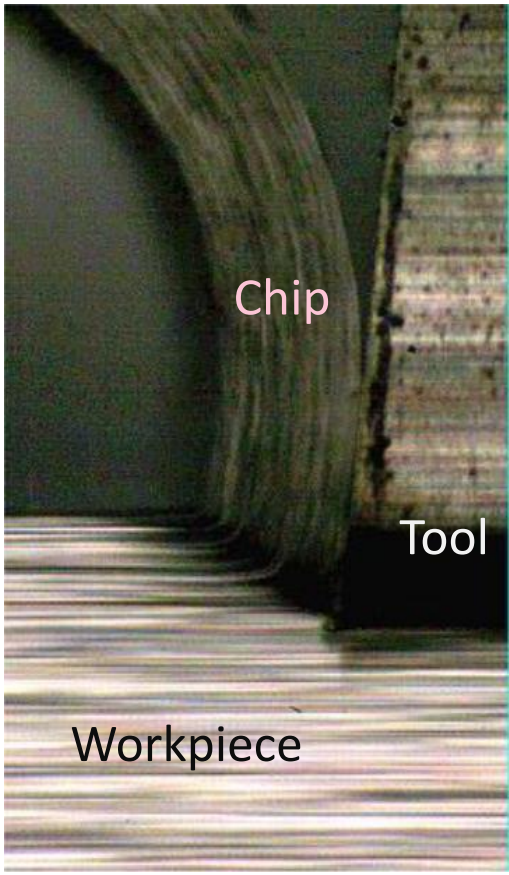
Context

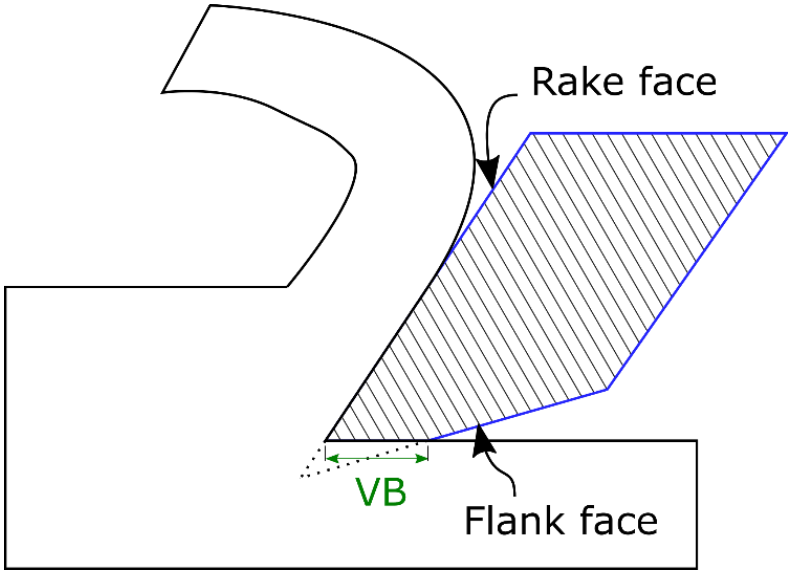


- Ortogonal cutting
- Worn tools (flank wear)
  - Poor roughness
  - Incorrect dimensions
- High costs caused by improper tool management (up to 40% of machining costs[1,2])

[1]Li, B. *Int. J. Refract. Met. Hard Mater.* **35**, 143-151 (2012)
[2]Denkena et al. *Int. J. Adv. Manuf. Technol.* **74**, 471-480 (2014)

Flank wear and tool end of life

- Mainly abrasive wear
- Nominal type of wear[1]
- Most predictable[1]



- Tool end of life:
  - ISO 3685[2]: VB = 0.3 mm
  - Various industrial practice (optical measurement, indirect measurement, statistical approach)

[1]SECO TOOLS AB. Turning catalog and technical guide, 2015
[2]ISO 3685:1993, Tool-life testing with single-point turning tools

Indicators of flank wear and factors of influence

- Flank wear can be linked to cutting forces[1]
- Other parameters[2] include:
  - Vibrations,
  - Acoustic emission, etc.

- Cutting parameters influence the evolution of flank wear[3] (for a given material and cutting tool)

[1]Ducobu et al. *Procedia CIRP.* **31**, 124-129 (2015)
[2]Siddhpura and Paurobally *Int. J. Adv. Manuf. Technol.* **65**, 371-393 (2013)
[2]Aramesh et al. *CIRP J. Manuf. Sci. Technol.* **12**, 35-43 (2015)

Finite element of cut and force signals

- Similar studies in Ti6Al4V[1] and Inconel 718[2]
- Revert problem can be studied[3]
  (estimate of wear evolution given the cutting conditions)
- Influence of tool shape on wear evolution and cutting stresses[4]

[1]Ducobu et al. *Procedia CIRP.* **31**, 124-129 (2015)
[2]Arrazola et al. *Int. J. Mach. Mach. Mater.* **15**, 84-100 (2014)
[3]Attanasio et al. *Wear*. **269**, 344-350 (2010)
[4]Senthilkumar and Tamizharasan. *Arab. J. Sci. Eng*. **39**, 4963-4975 (2014)

Objectives and methodology

- Influence of tool flank wear on force signals in AISI 1045 orthogonal cutting

1. Finite element model of the cut
2. Computing of forces signals
3. Assessment of model for fresh tool by comparison with experimental data
4. Hypothesis: increase in cutting forces as wear increases (as observed in other studies with Ti6Al4V and Inconel 718)[1,2]

[1]Ducobu et al. *Procedia CIRP.* **31**, 124-129 (2015)
[2]Arrazola et al. *Int. J. Mach. Mach. Mater.* **15**, 84-100 (2014))

Finite element model - mesh

- Coupled Eulerian and Lagrangian (CEL) approach in ABAQUS v6.14
  - Usually for fluid-structure interaction
  - Can model large deformations
- Fixed Lagrangian tool (1080 4-nodes elements)
- Eulerian region in which the workpiece flows (40175 4-nodes elements – structured mesh)
- Mesh refined around the cutting edge

Finite element model
Materials and interaction

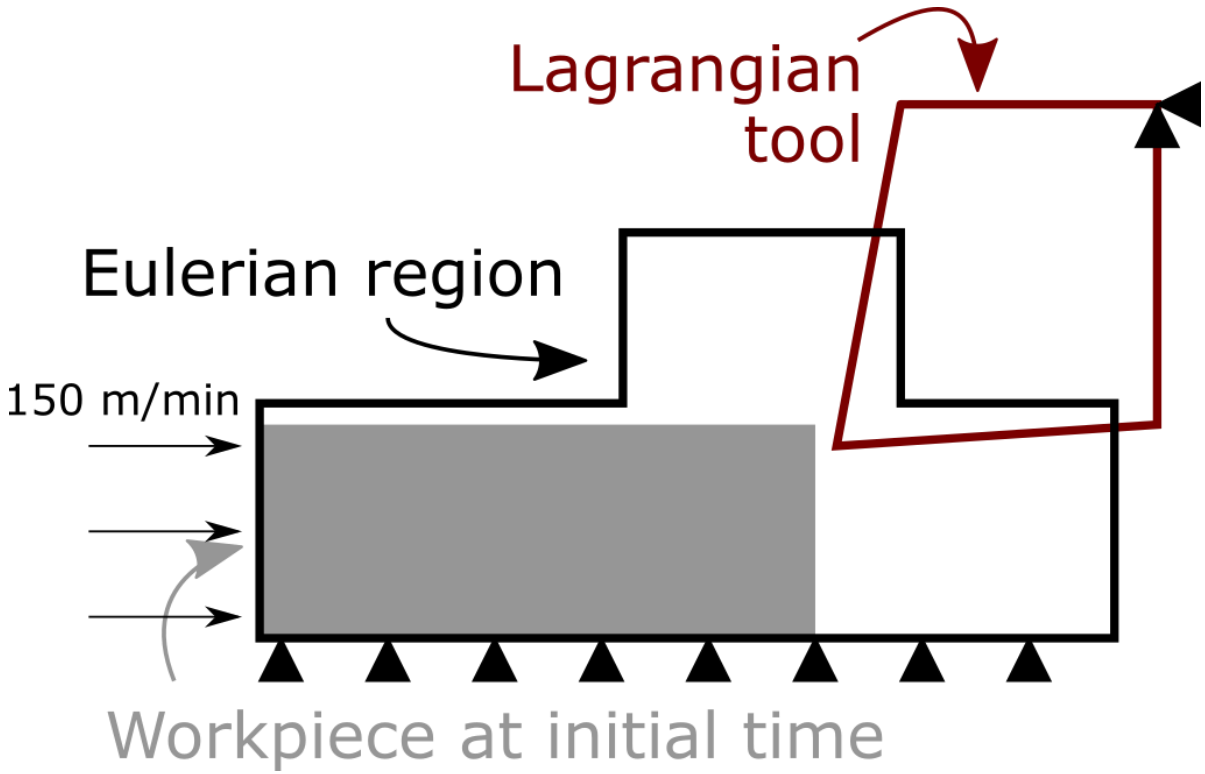
- AISI 1045 (normalized) - Johnson-Cook law
- Uncoated tool – elastic body
- Coulomb friction law
  - Sticking in the contact zone because of uncoated tool:

$$\mu = \frac{\tau_{friction}}{\sigma_{yield}} = \frac{\sigma_{yield}/\sqrt{3}}{\sigma_{yield}} = \frac{1}{\sqrt{3}} = 0.577$$

- Equal dissipation of heat (tool and chip)

General geometry of the model

- Elastic, fixed tool
- Eulerian regions with entry and exit borders



Tool geometry and cutting conditions

- Chosen geometry and cutting conditions matches previous experiments
  - Cutting edge radius 5 µm (conservated when worn)
  - Depth of cut h=0.1 and 0.2 mm
  - Cutting speed v_c=150 m/min
  - Worn tool flank wear VB=0.1, 0.2 and 0.3 mm

Assessment of the model

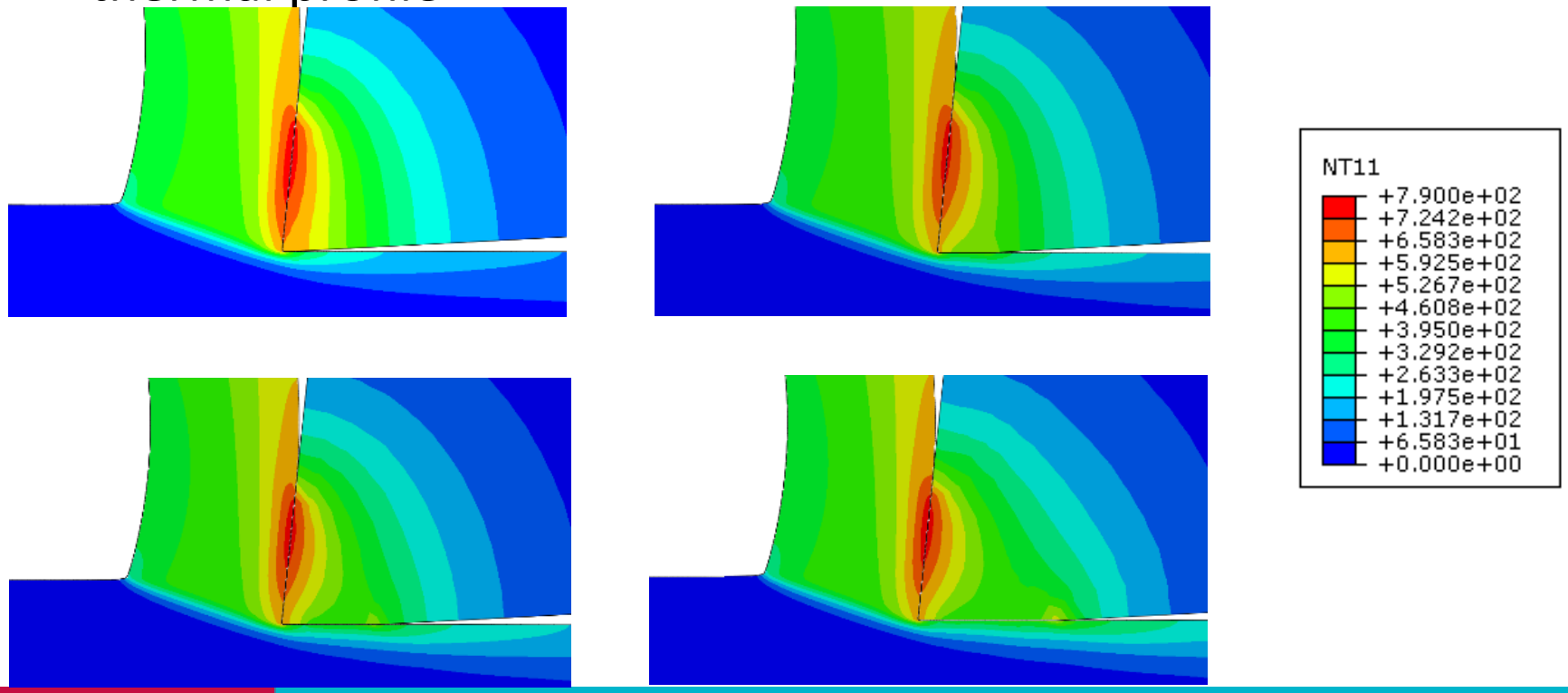
- Assessment by comparison with experimental tests

	h = 0.1 mm, experimental	h = 0.1 mm, numerical	h = 0.2 mm, experimental	h = 0.2 mm, numerical
Cutting force (N/mm)	285.7	285	428.6	520
Feed force (N/mm)	214.3	137	228.6	230
Cutting force/feed force	1.34	2.08	1.88	2.26

- Overestimation of the ratio by 35 and 20%
- Either correct cutting force or feed force
- Better results concerning the cutting forces at h=0.1 mm

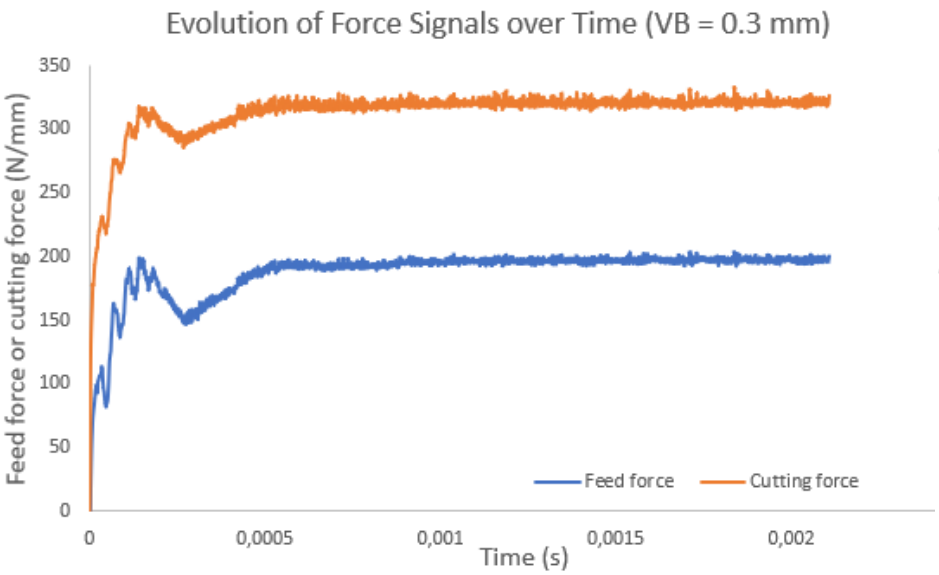
Influence of flank wear

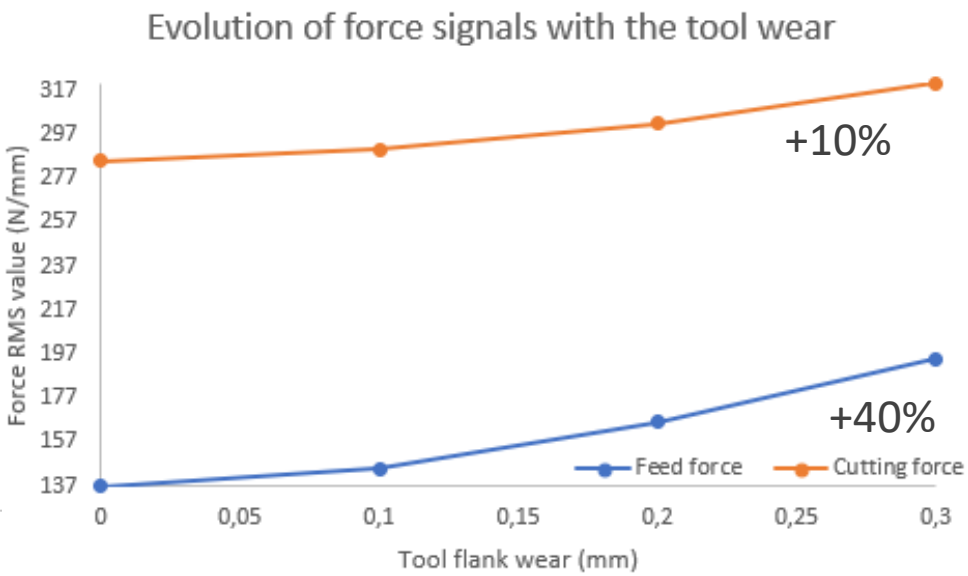
- Thermal effects of flank wear (VB=0, 0.1, 0.2, 0.3 mm)
  - Heat generation on the flank face, change in the tool thermal profile



Force signals

- Satisfactory convergence of the computed force signals
- Increase of cutting **and** feed forces
  (feed forces increase more in proportion and in value)
- Consistant with similar work in other materials





Influence of flank wear

- Acceptable assessment of the model
- Production of qualitatively similar results to previous studies in other materials[1,2]
- Clear incremential influence of wear
- Most important increase in feed force rather than cutting force (+40%)
- Thermal effects on the tool and on the workpiece

[1]Ducobu et al. *Procedia CIRP.* **31**, 124-129 (2015)
[2]Arrazola et al. *Int. J. Mach. Mach. Mater.* **15**, 84-100 (2014)

Conclusions and perspectives

- Reproduction of qualitatively similar results in different materials
- Highlight of important rise in feed force rather than cutting force
- Thermal effects both on the workpiece and the tool

- Further tests with different materials
- Use of the computed as condition monitoring indicator for tool end of life

Thank you for your attention!