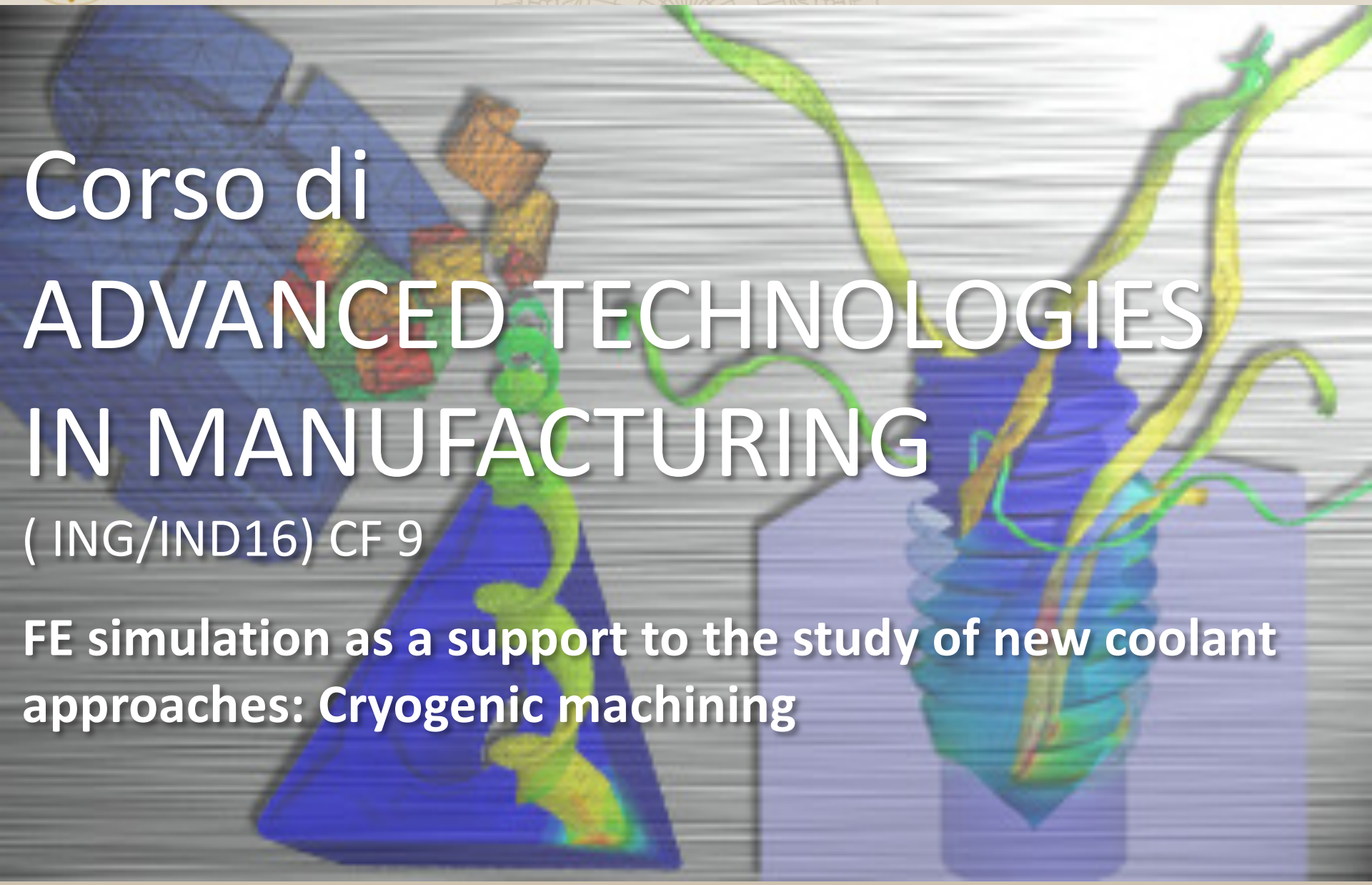
UNIVERSITÀ DEL SALENTO

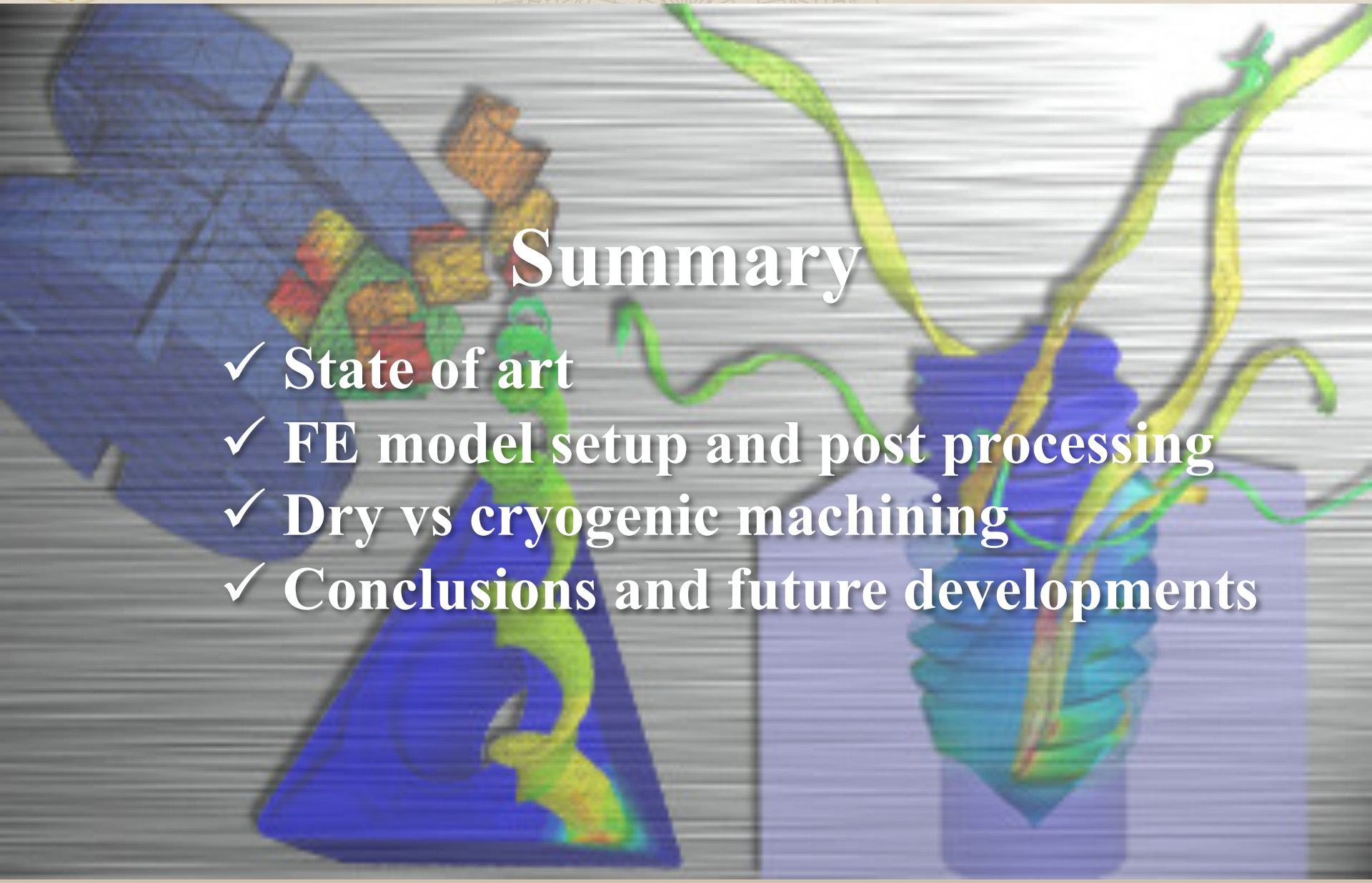


Corso di ADVANCED TECHNOLOGIES IN MANUFACTURING

(ING/IND16) CF 9

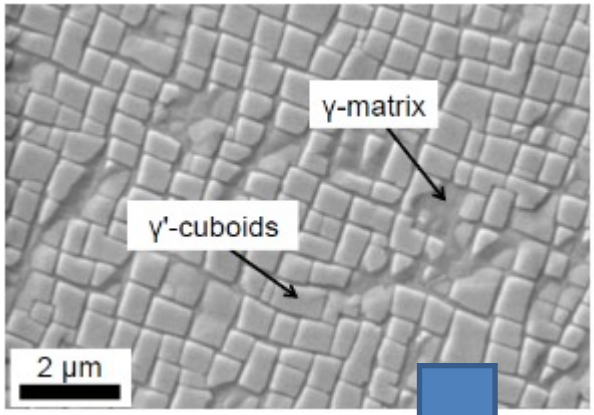
FE simulation as a support to the study of new coolant approaches: Cryogenic machining

Department of Engineering for Innovation – TSL Group



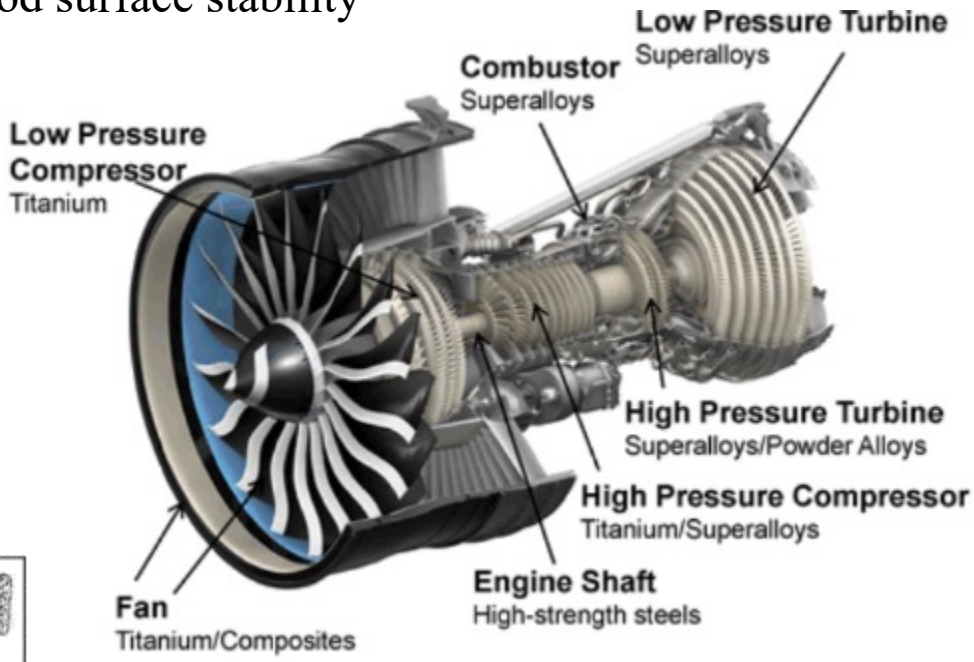
Summary

- ✓ State of art
- ✓ FE model setup and post processing
- ✓ Dry vs cryogenic machining
- ✓ Conclusions and future developments



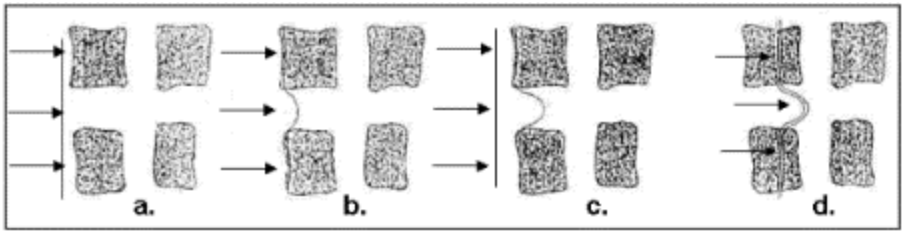
Nickel superalloys

- ✓ High creep resistance
- ✓ High corrosion resistance
- ✓ High oxidation resistance
- ✓ High mechanical strength
- ✓ Good surface stability



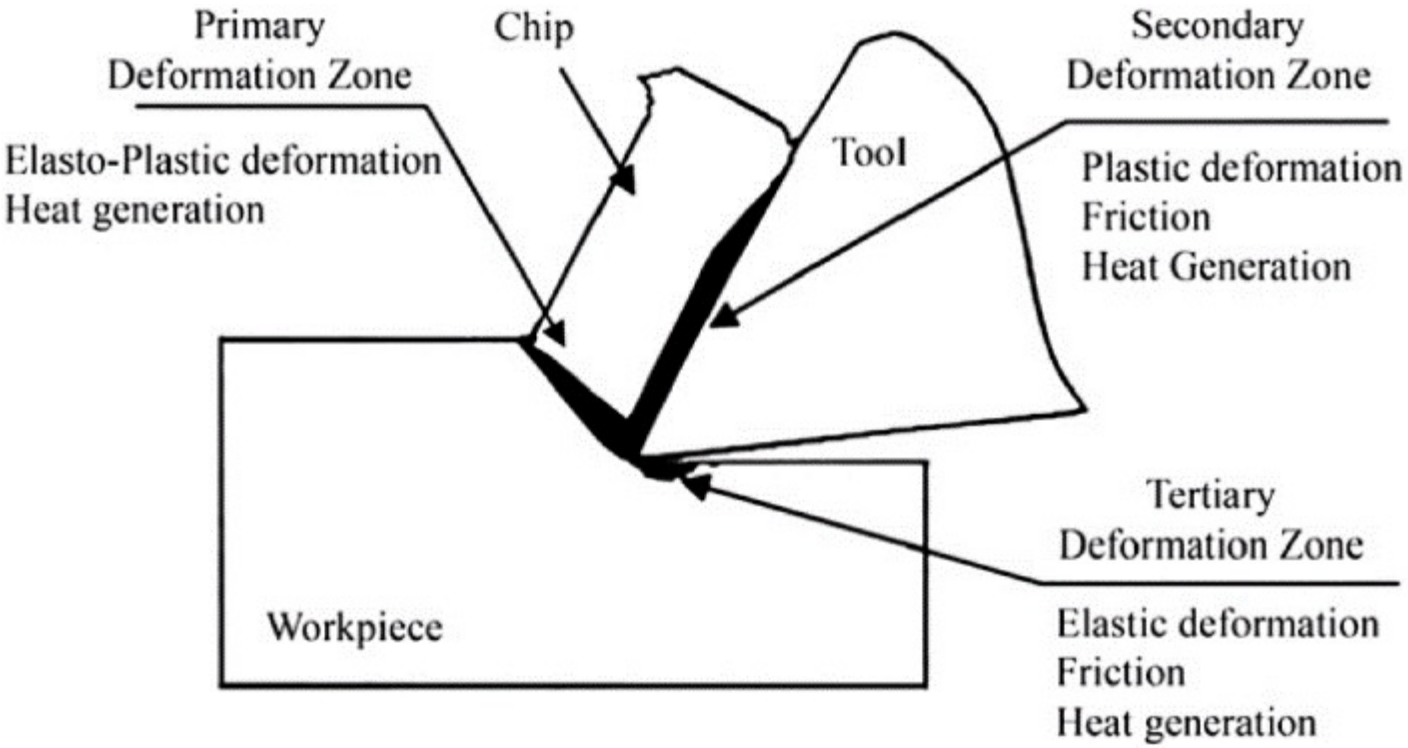
But also…

- ✓ Low productivity
- ✓ Poor surface quality
- ✓ Short tool life
- ✓ High cost

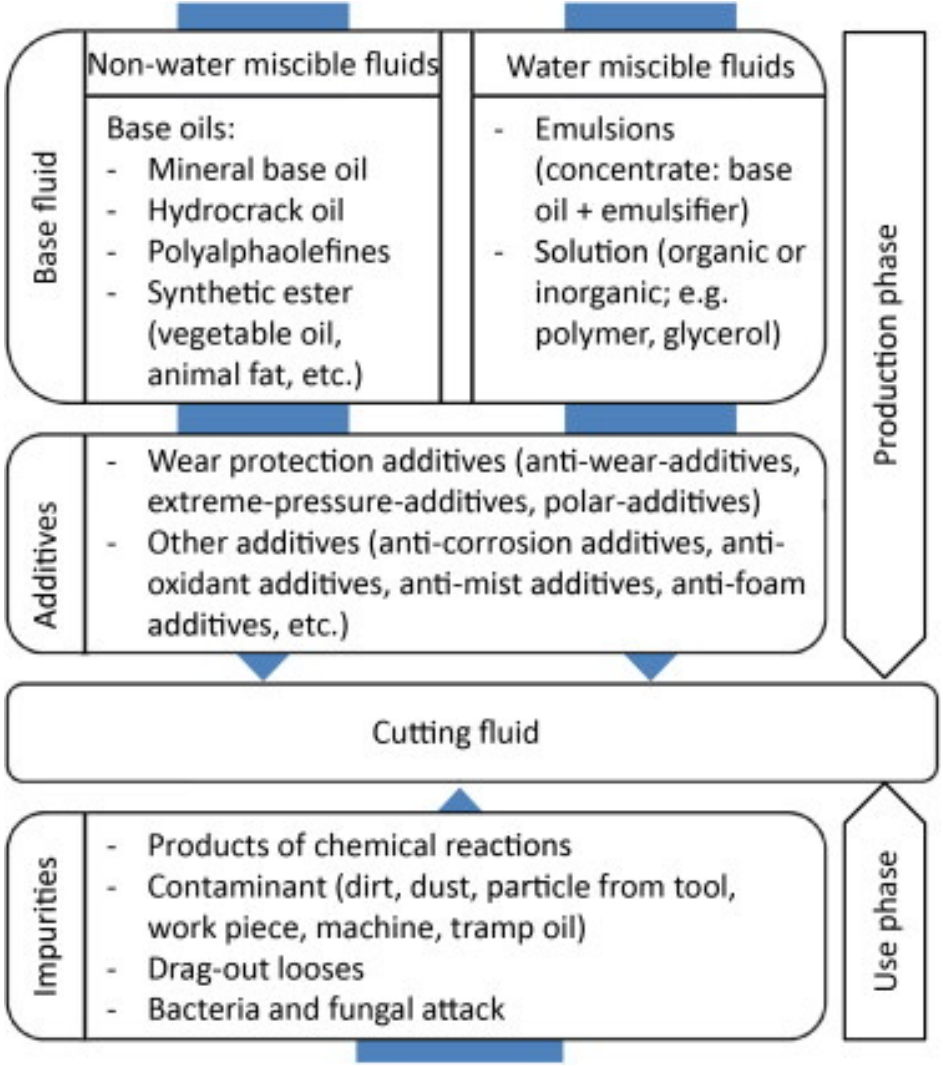


Surface integrity

- ✓ Surface topography
- ✓ Surface metallurgy
- ✓ Mechanical characteristic

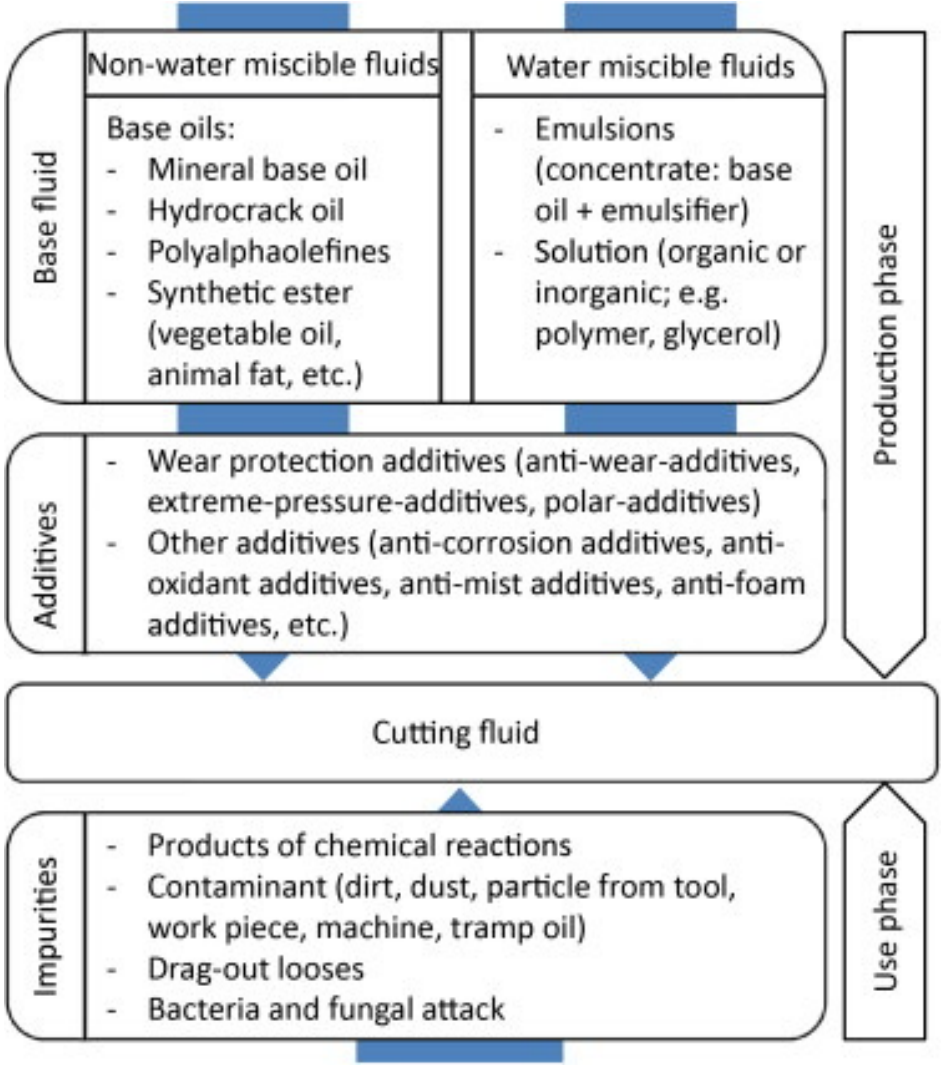


Coolant and Lubricants (CLs)



- ✓ Cool cutting area
- ✓ Reduce force
- ✓ Extend cutting edge life
- ✓ Transport the chips away from cutting area

Coolant and Lubricants (CLs)



- ✓ Cool cutting area
- ✓ Reduce force
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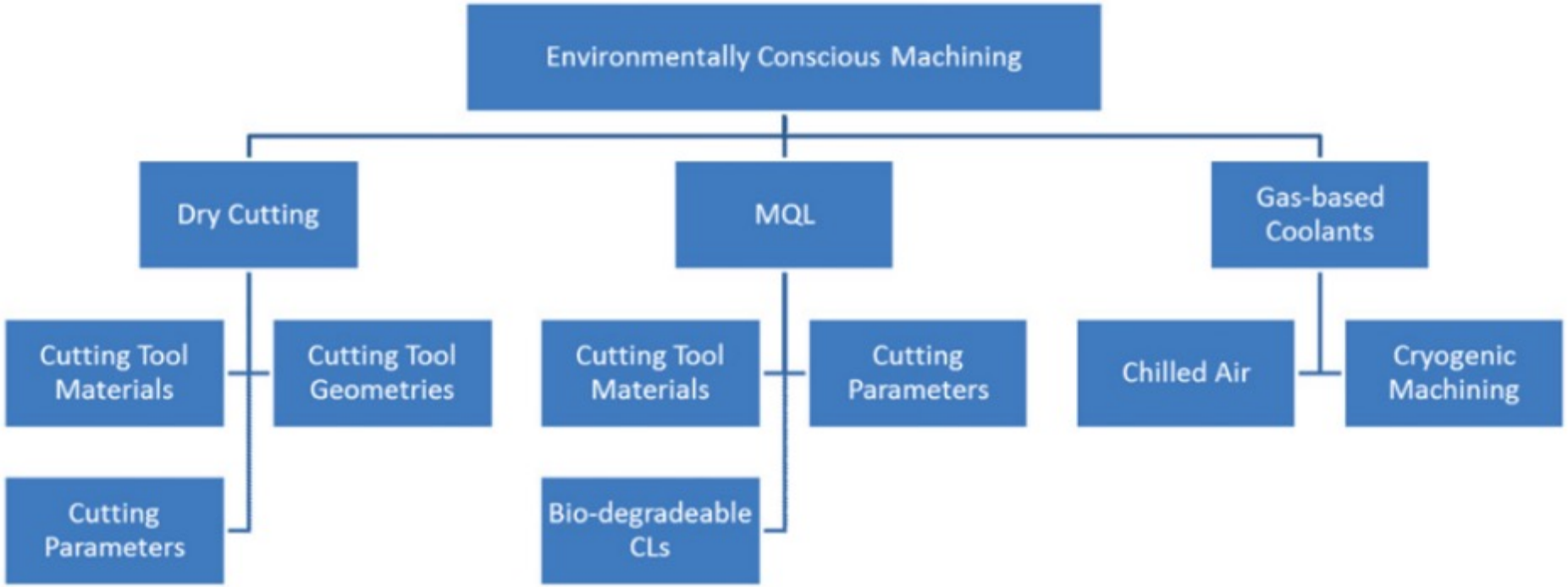
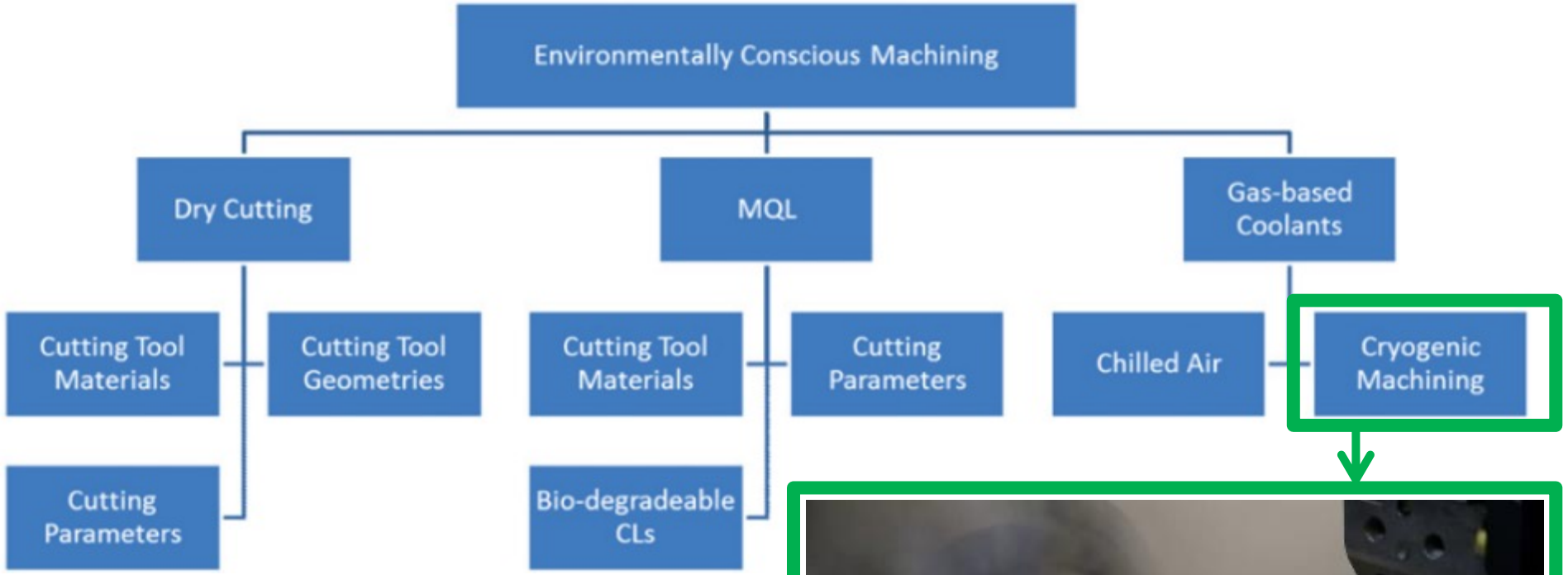
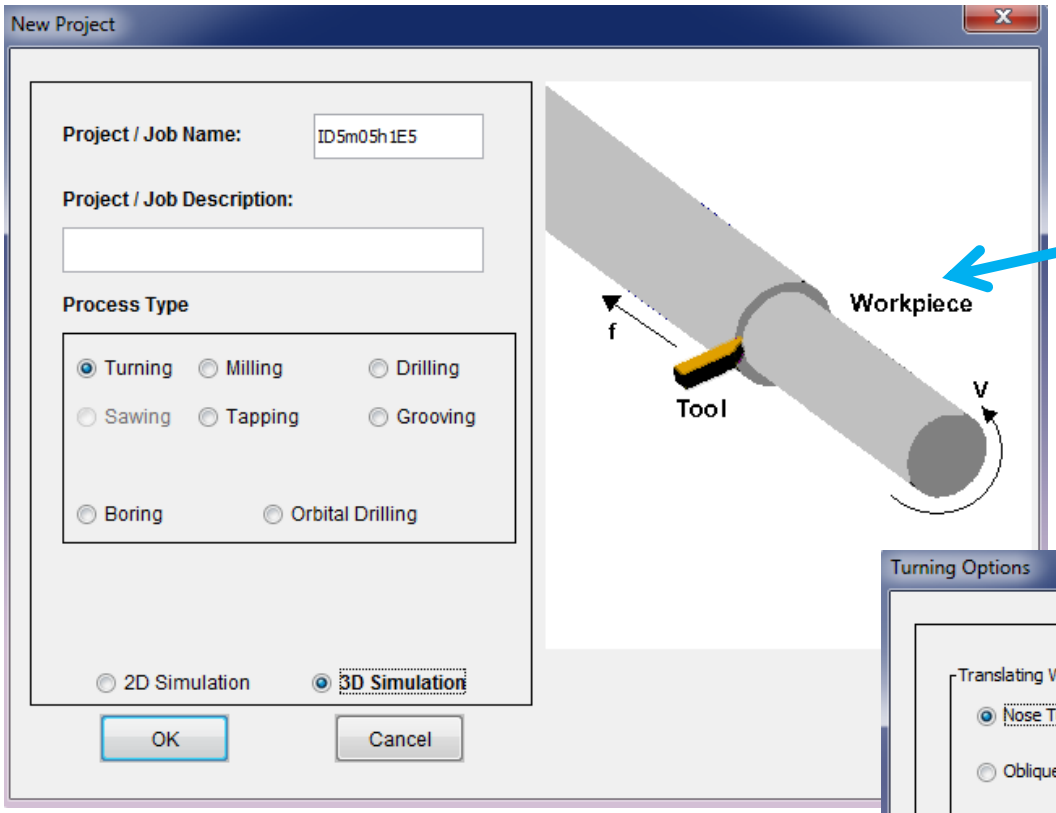

Environmentally Conscious Machining
Dry Cutting
MQL
Gas-based Coolants
Cutting Tool Materials
Cutting Tool Geometries
Cutting Parameters
Cutting Tool Materials
Cutting Parameters
Bio-degradeable CLs
Chilled Air
Cryogenic Machining



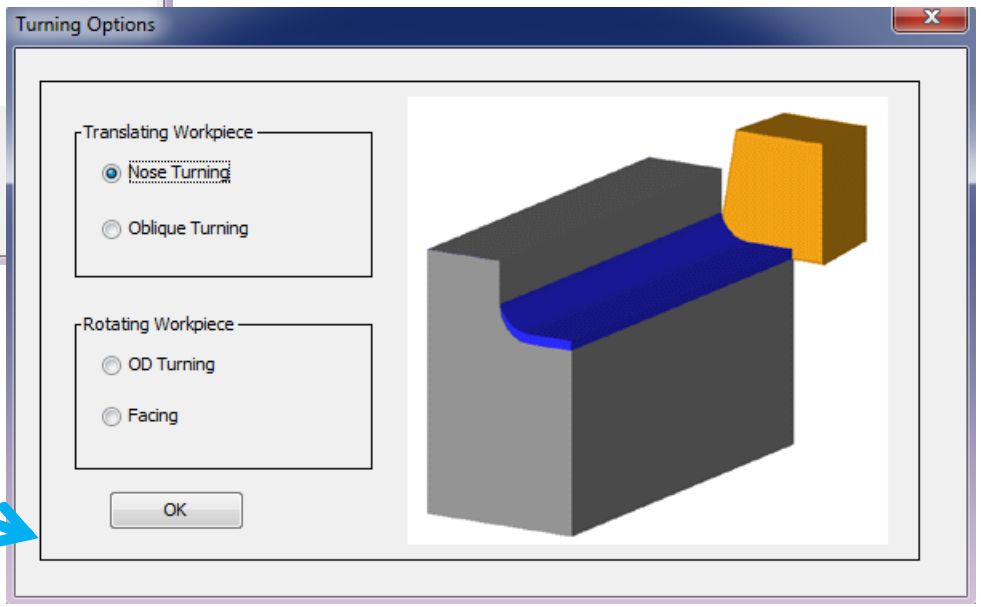
- ✓ Temperature lower than 120K
- ✓ LN_2 absorb heat and evaporate
- ✓ LN_2 is an inert gas
- ✓ LN_2 is lighter than air
- ✓ Safe for workers' health

✓Finite Element Model AdvantEdge (Third Wave Systems Inc.) is a commercial implementation of the finite element method designed to analyze the behavior of metals encountered during machining operations.

✓The code embodies an explicit scheme capable of modeling coupled, non-linear thermo-mechanics at large strains and strain rates incorporating constitutive deformation behavior, contact, friction, fracture and adaptive meshing.

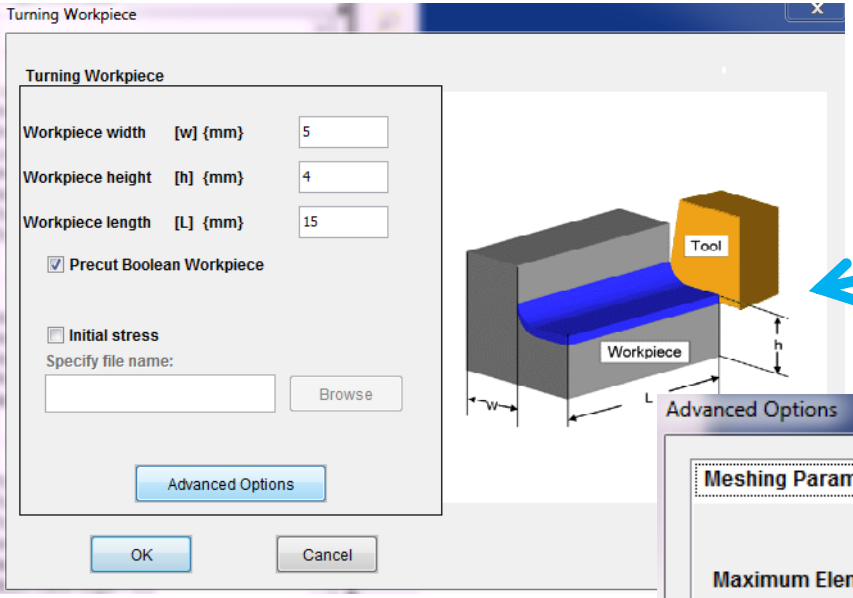


✓ New Project

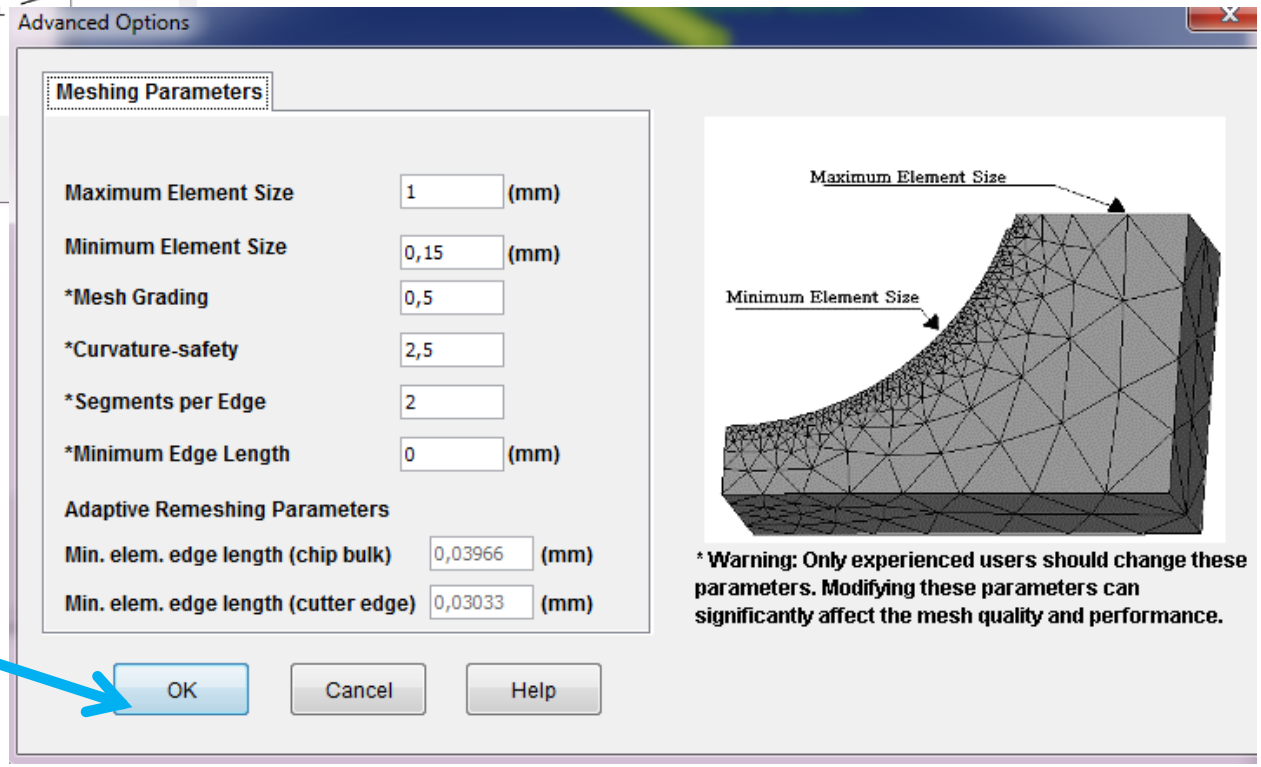


✓ Turning Options

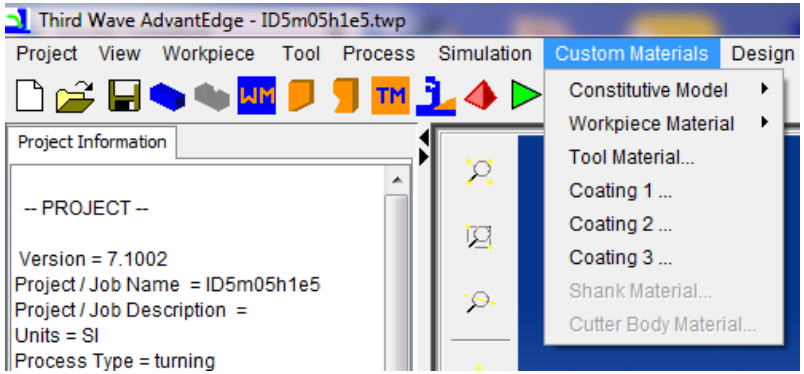
✓ Turning Workpiece

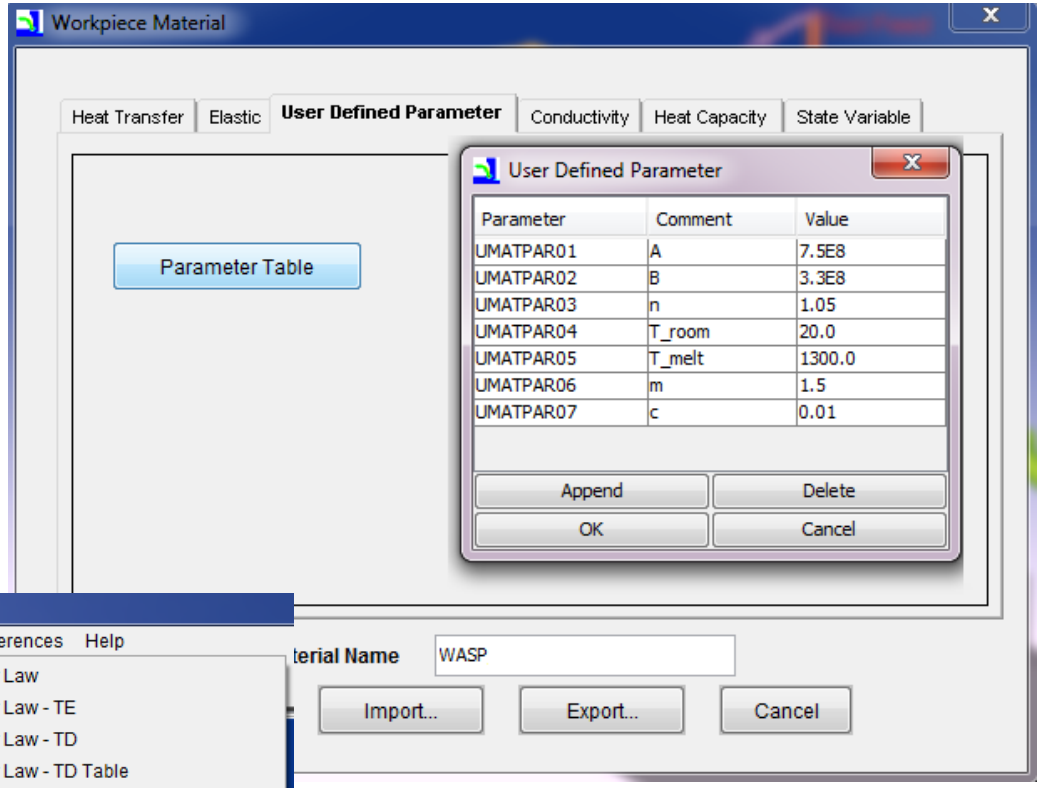


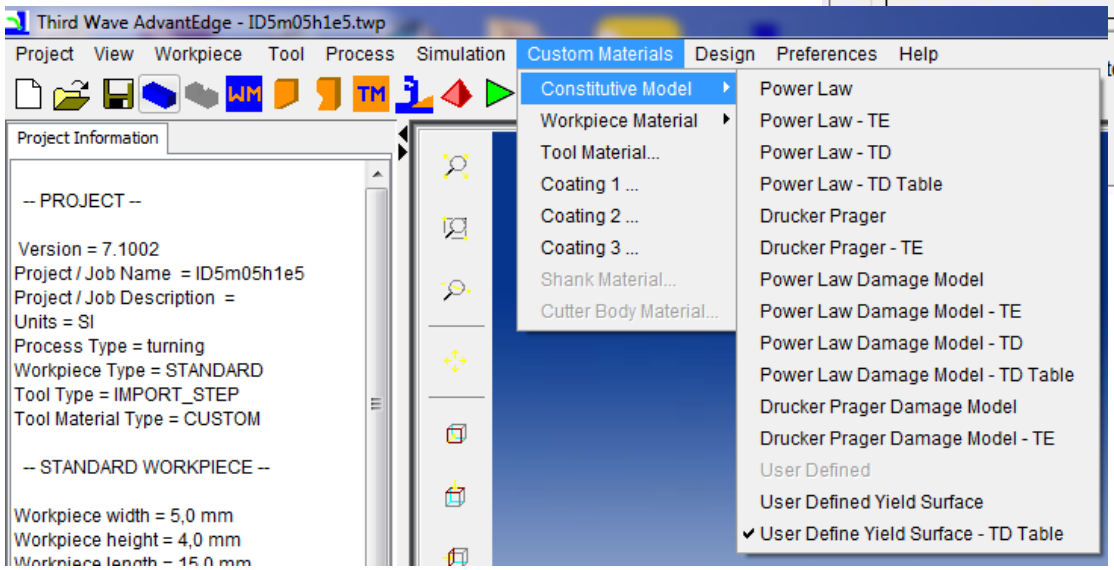
✓ Advanced Options



✓ Custom Materials

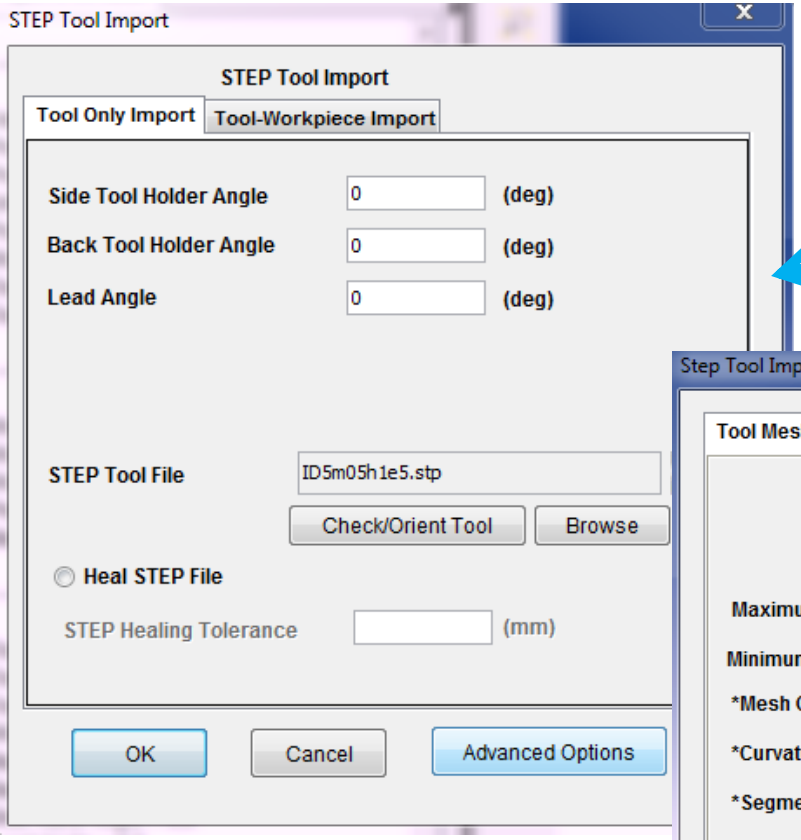




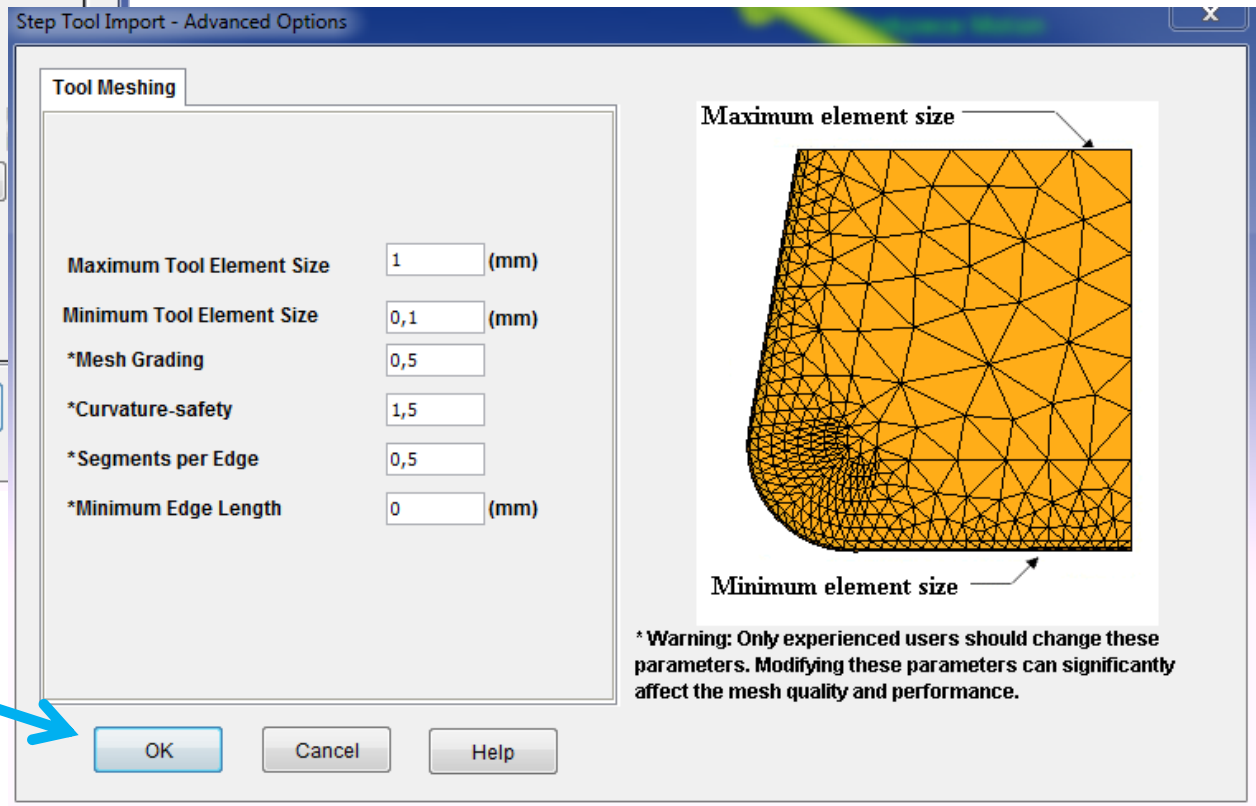


✓ Johnson-Cook model

$$\sigma = \underbrace{(A + B\varepsilon^{n})}_{\text{Elasto-Plastic term}} \underbrace{\left[1 + C\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right]}_{\text{Viscosity term}} \underbrace{\left[1 - \left(\frac{T - T_{room}}{T_{melt} - T_{room}}\right)^{m}\right]}_{\text{Thermal softening term}}$$

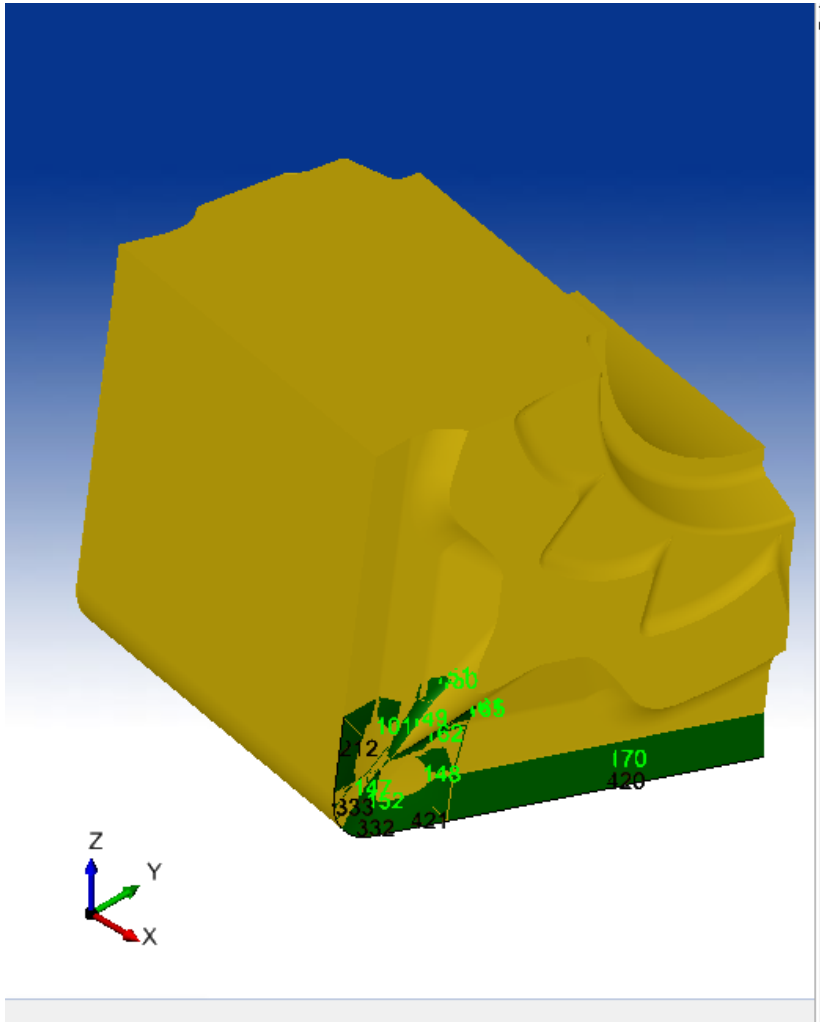


✓ STEP Tool Import



✓ Advanced Options

✓ Check/Orient Tool



Check Geometry | Mesh Refinement | Cutter Definition | Check Orientation

Selective Mesh Refinement

Face Selection | Edge Selection

Entity Type	Entity ID	Element Size
Edge	212	0,02
Edge	332	0,02
Edge	333	0,02
Edge	420	0,02
Edge	421	0,02
Face	101	0,02
Face	147	0,02
Face	148	0,02
Face	149	0,02

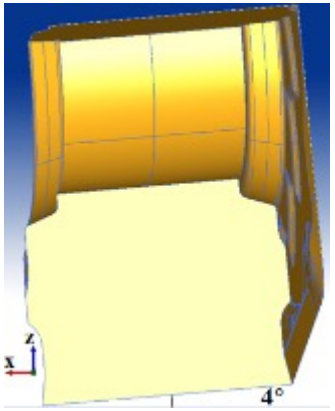
Edit Selection | Remove All

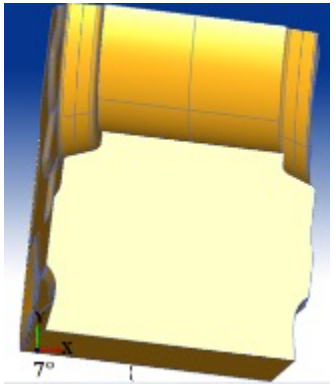
Redraw All

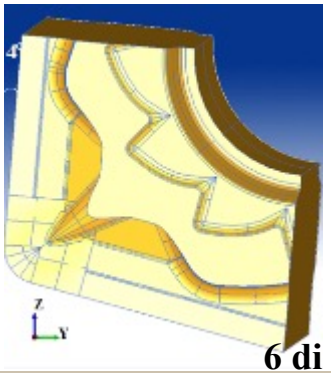
Use Ctrl + Left Mouse button for individual picking.
Use Shift + Left Mouse button for continuous picking.
After picking the entities, click Edit Selection
to add/remove/edit.

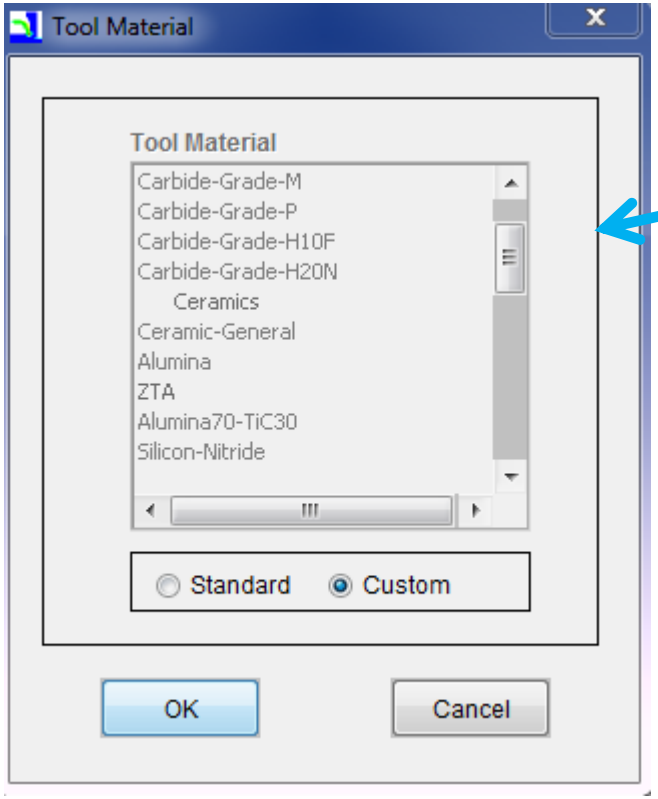
Display Options | Help

OK | Close



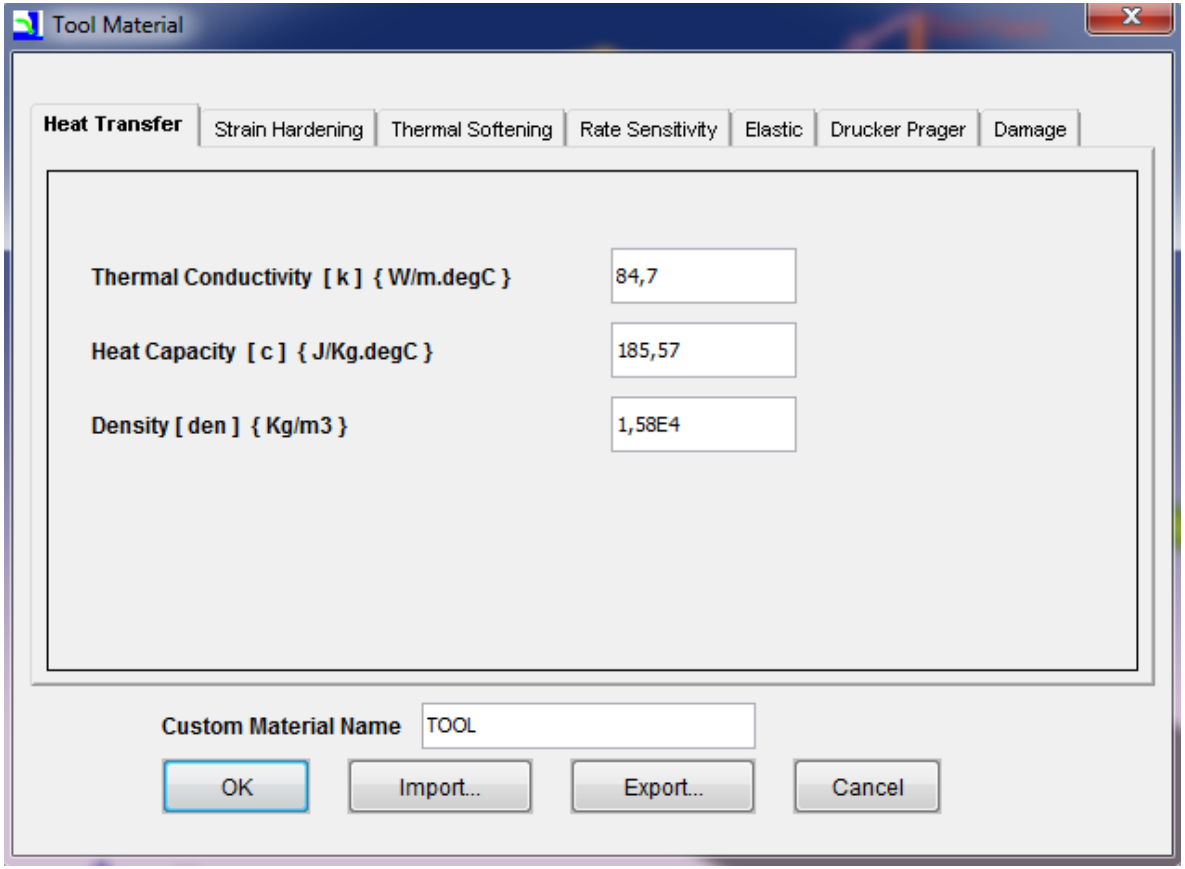




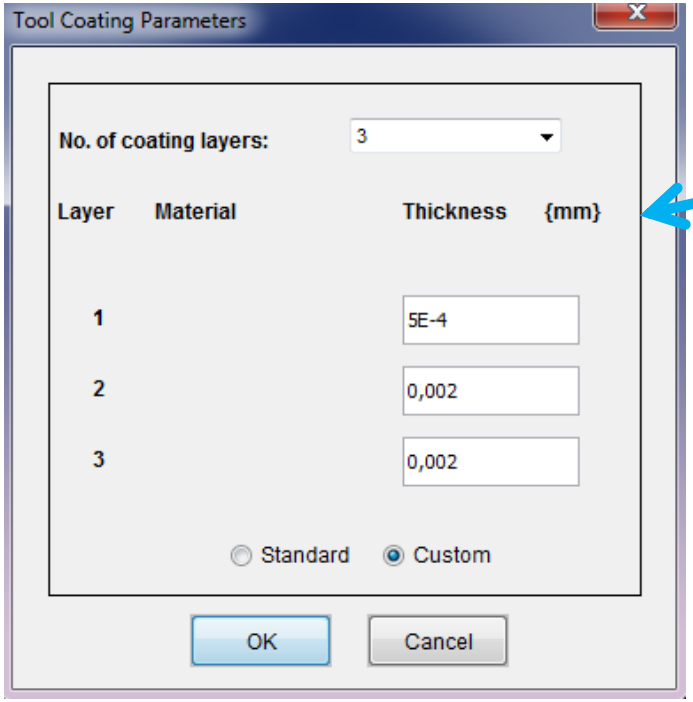


✓ Tool Material

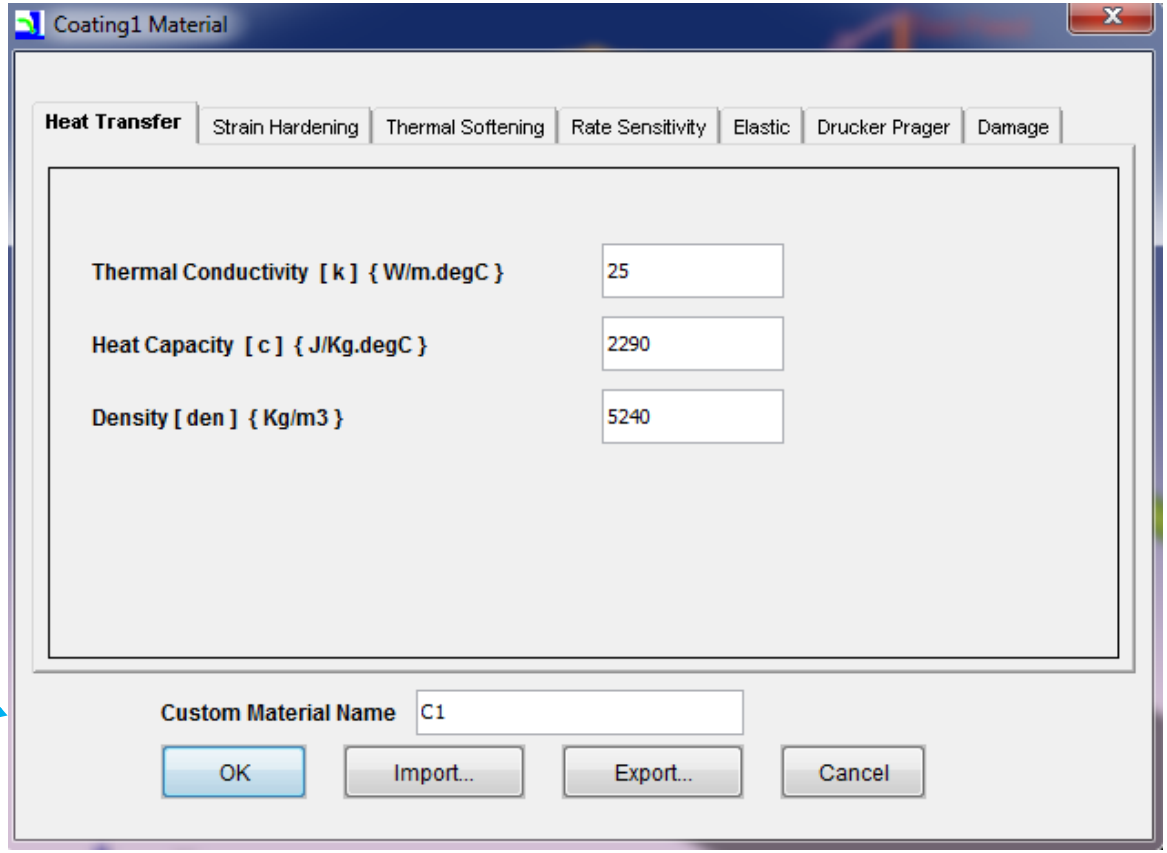
✓ Custom Material



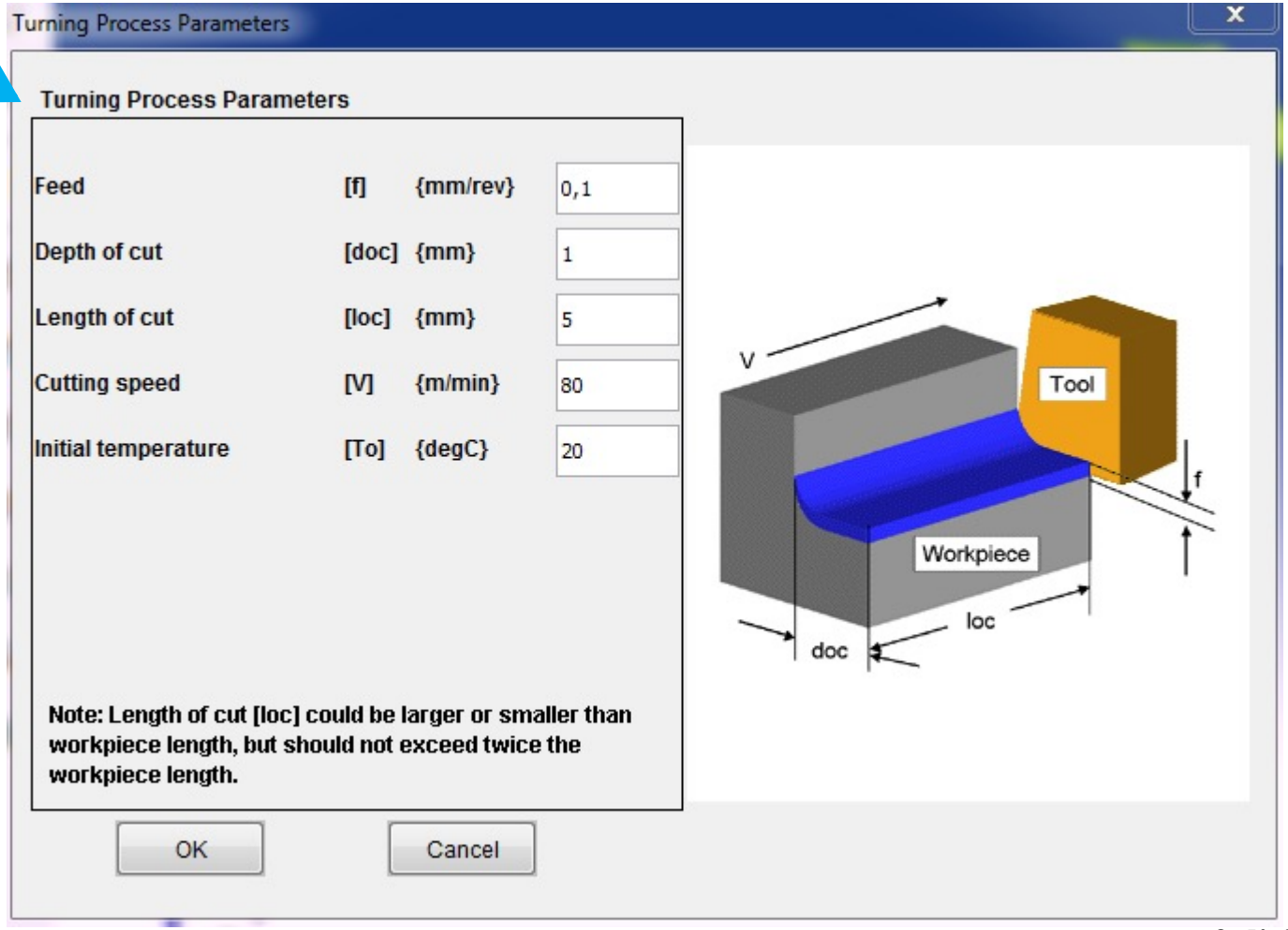
✓ Tool Coating Parameters

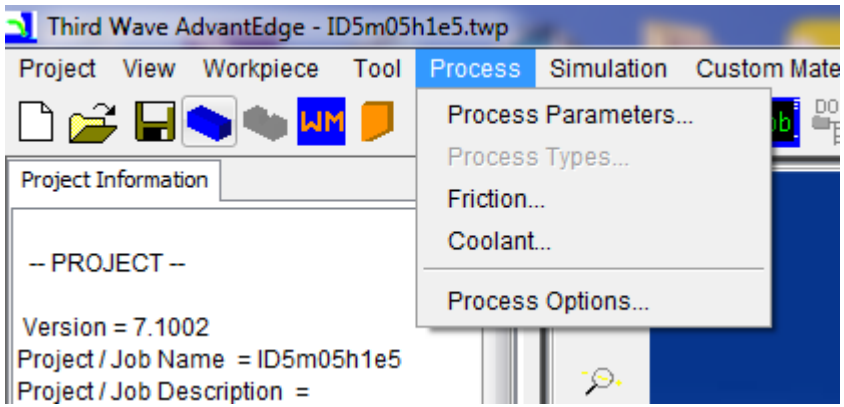


✓ Custom Coating Material

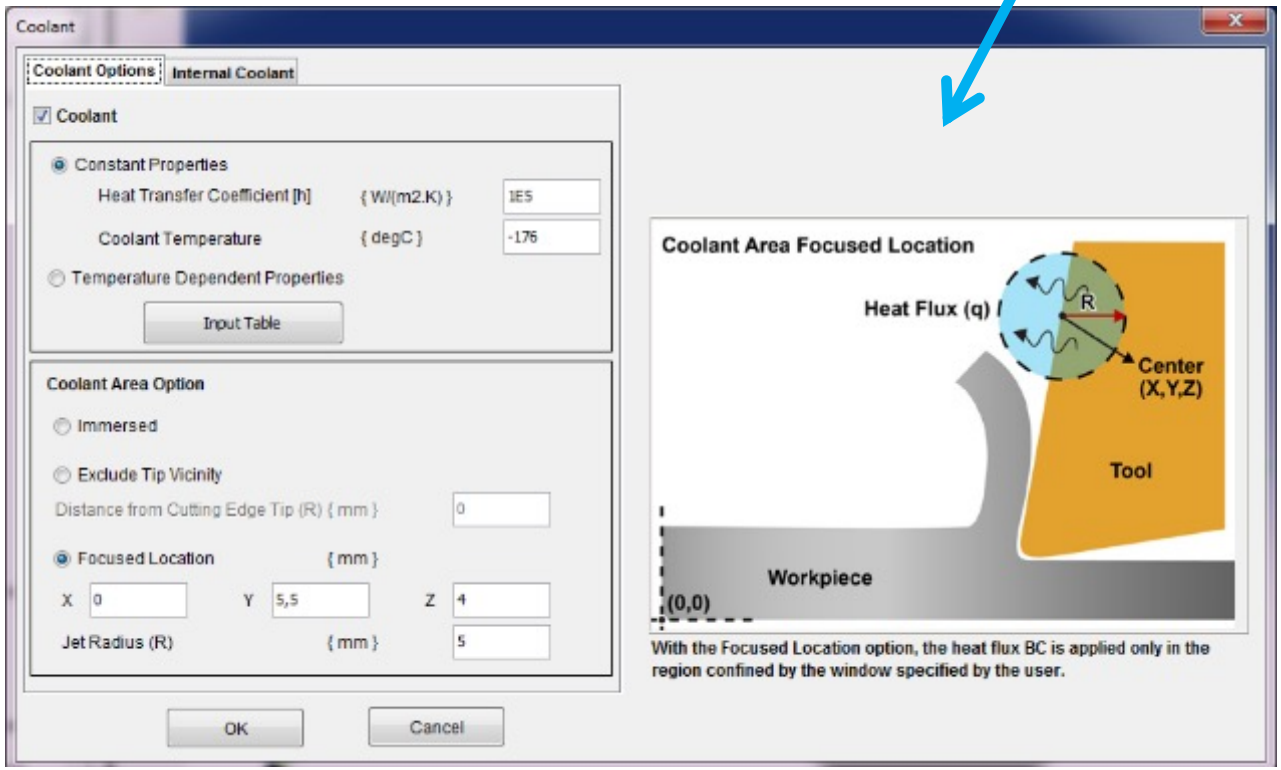


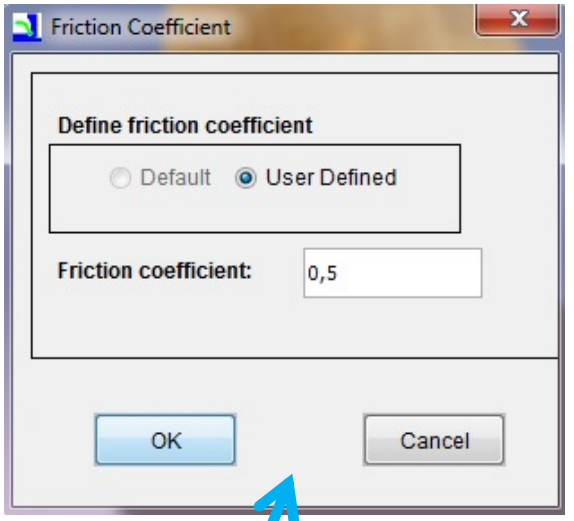
✓ Turning Process Parameters





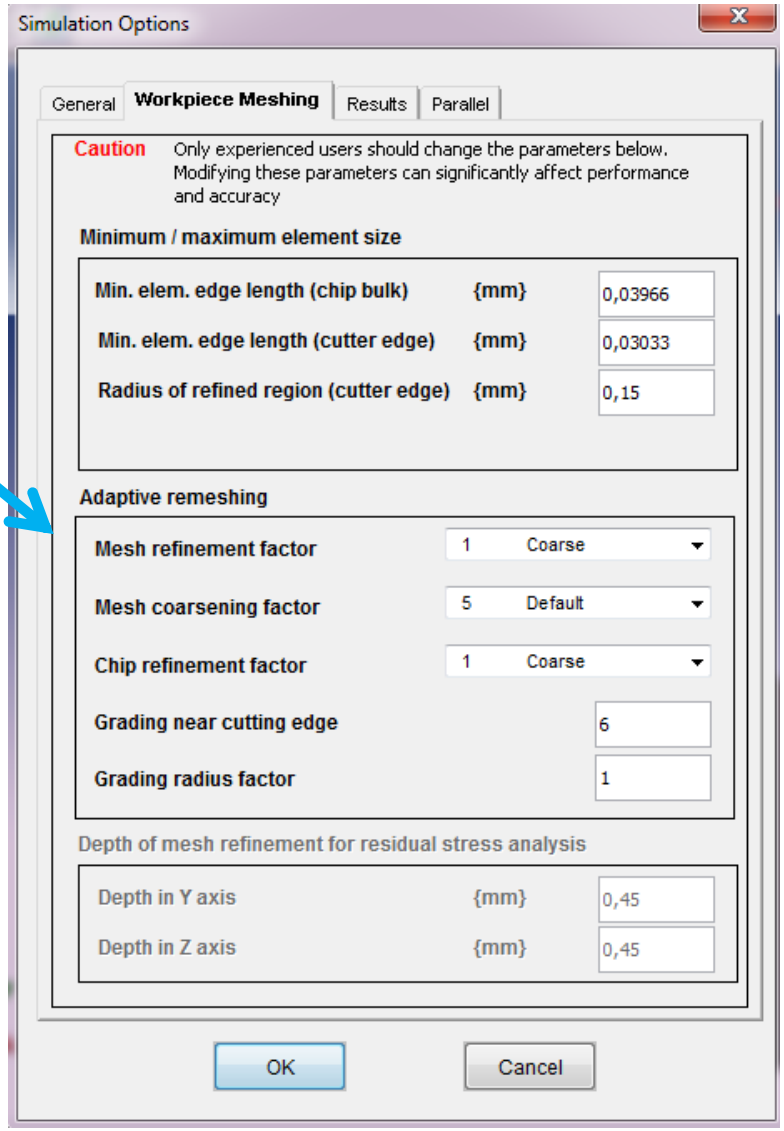
✓ Coolant



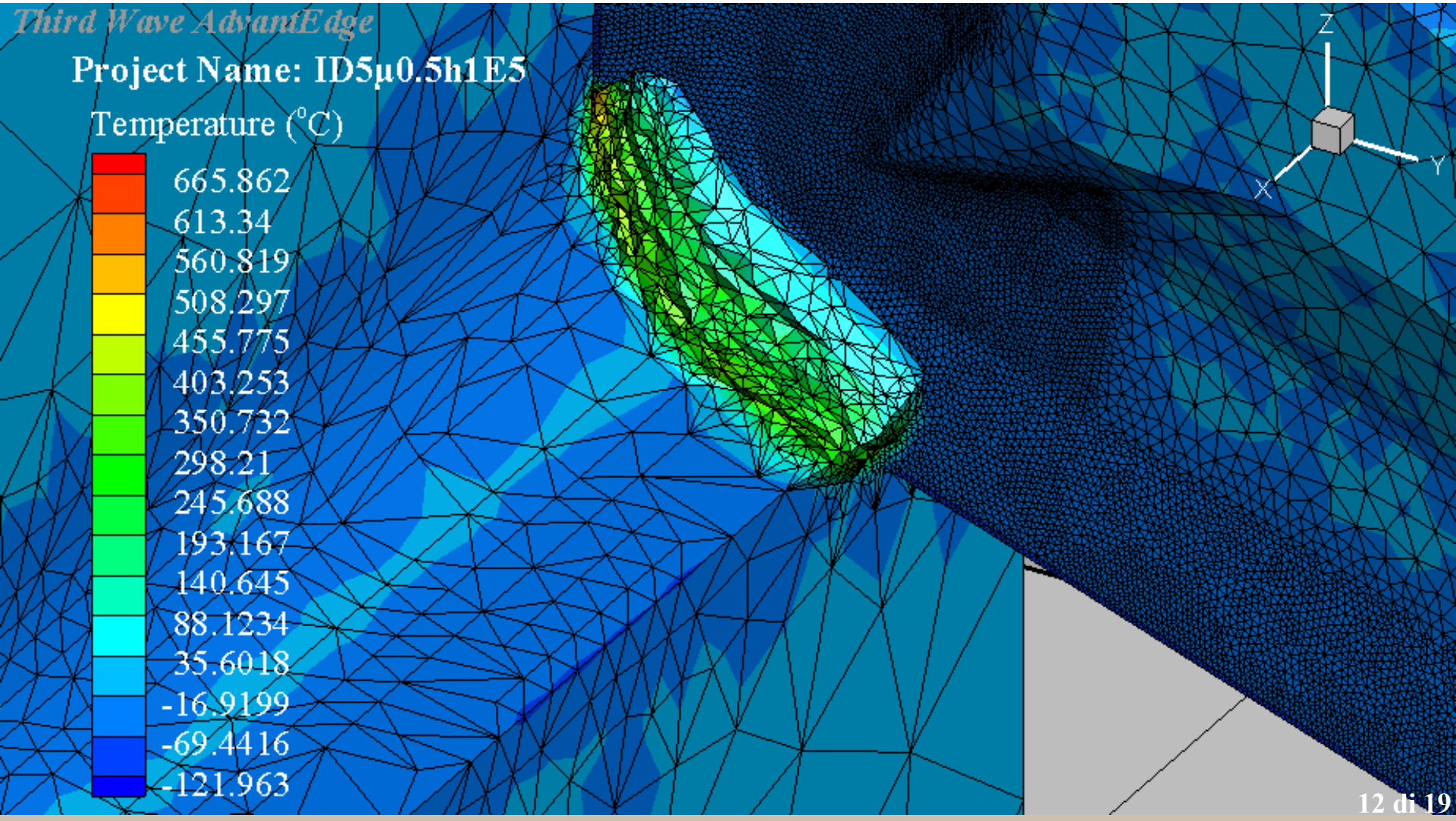


✓ Friction Coefficient

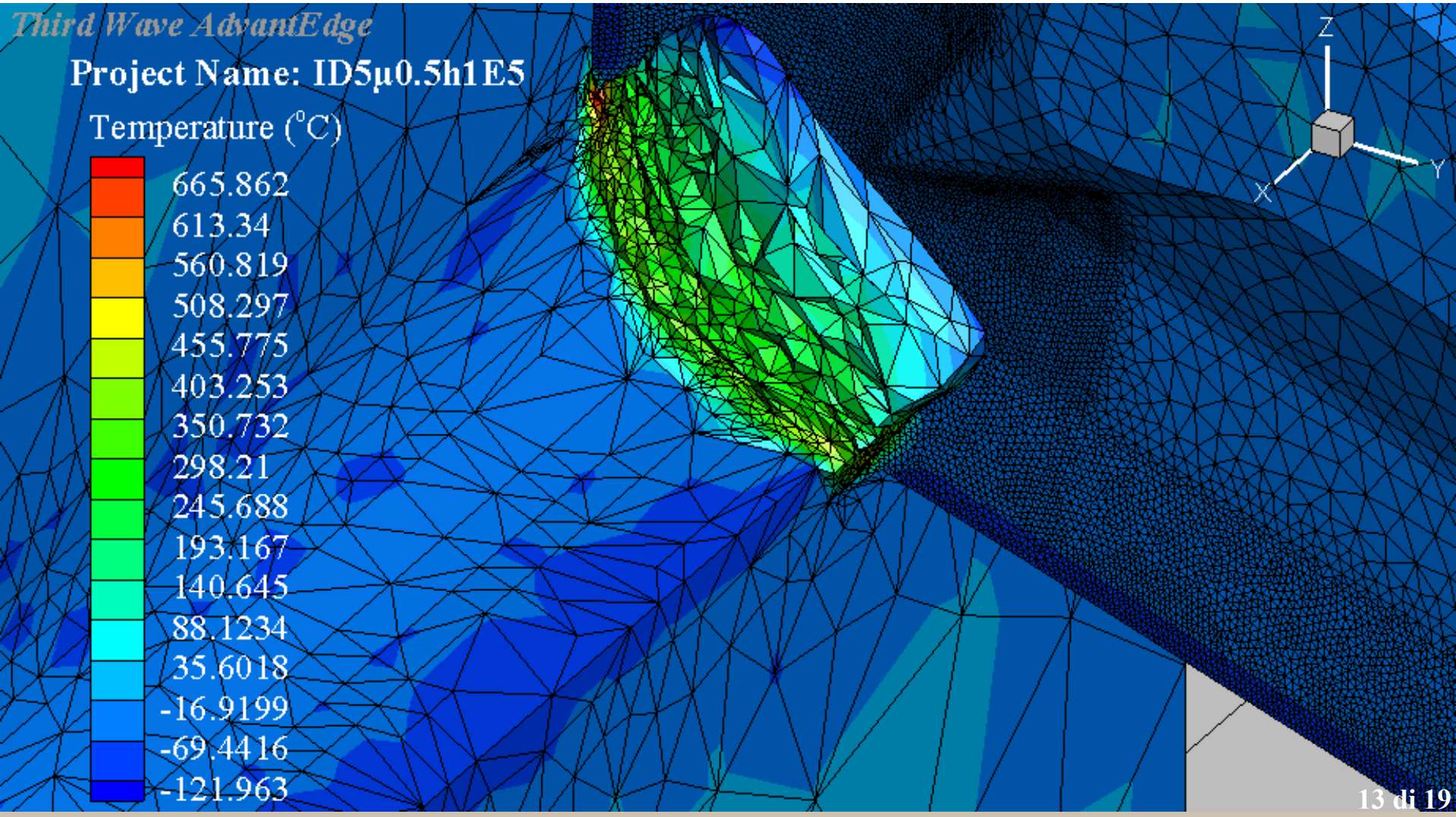
✓ Simulation Options



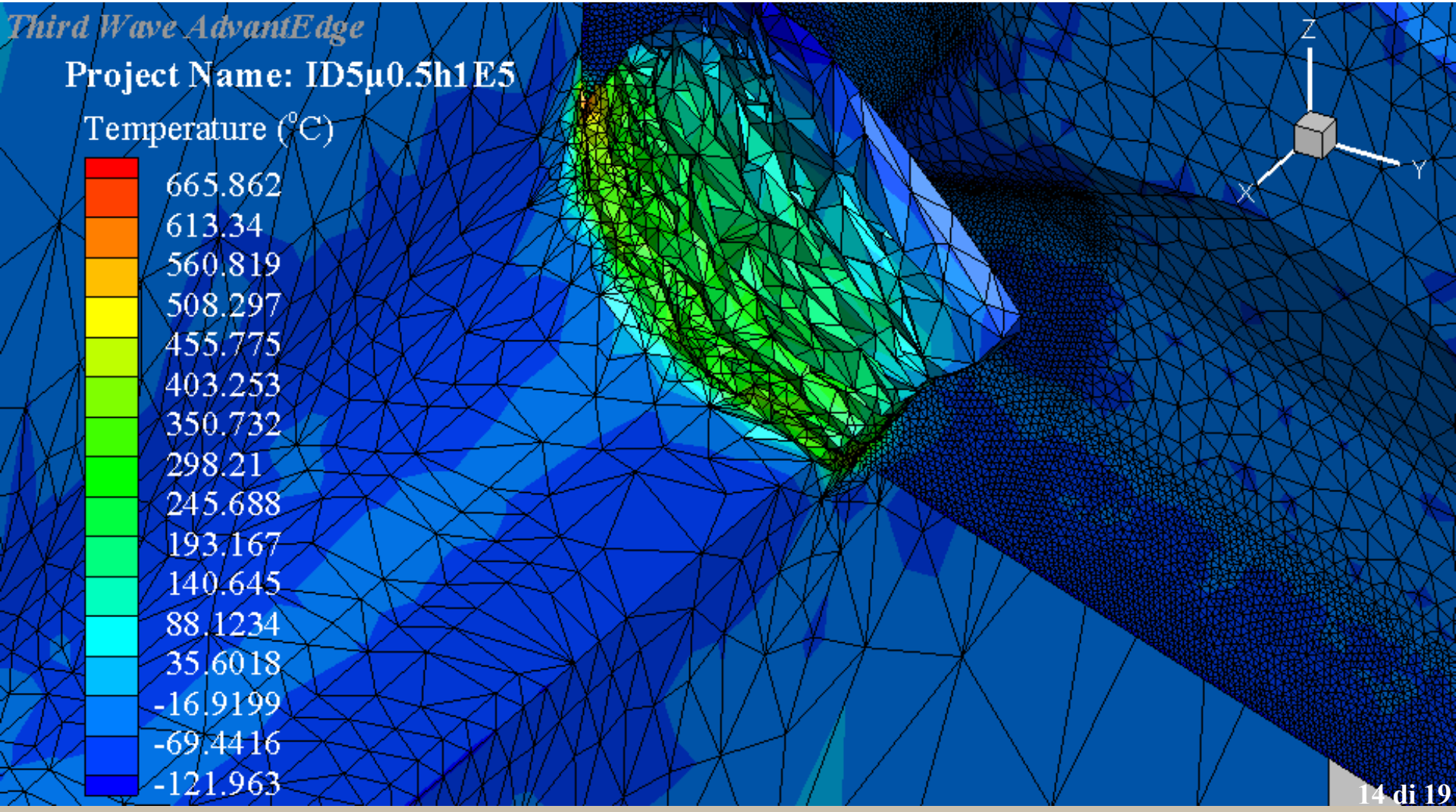
✓F=0.10 [mm/rev] S=80 [m/min] - Length of cut = 1 mm



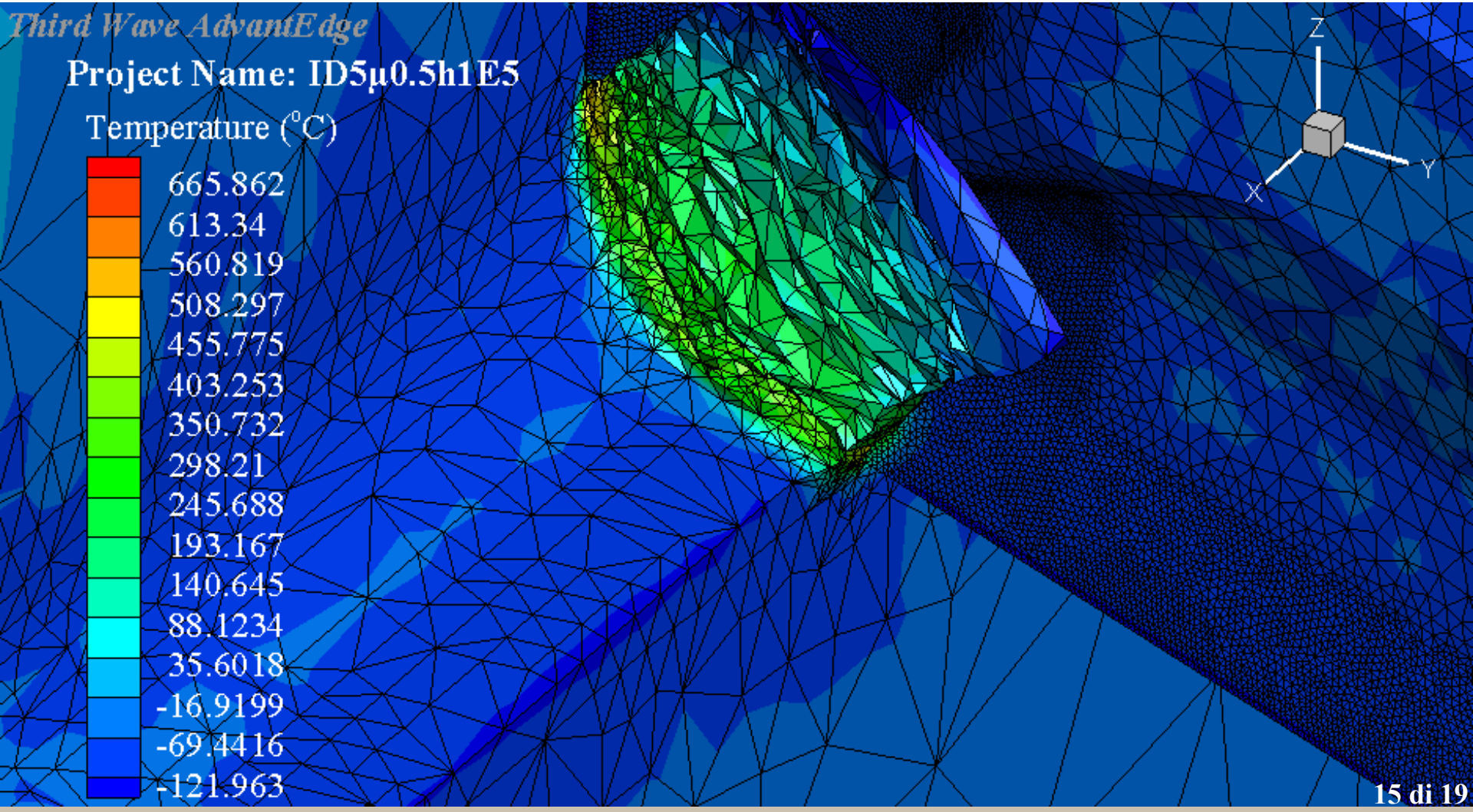
✓F=0.10 [mm/rev] S=80 [m/min] - Length of cut = 2 mm



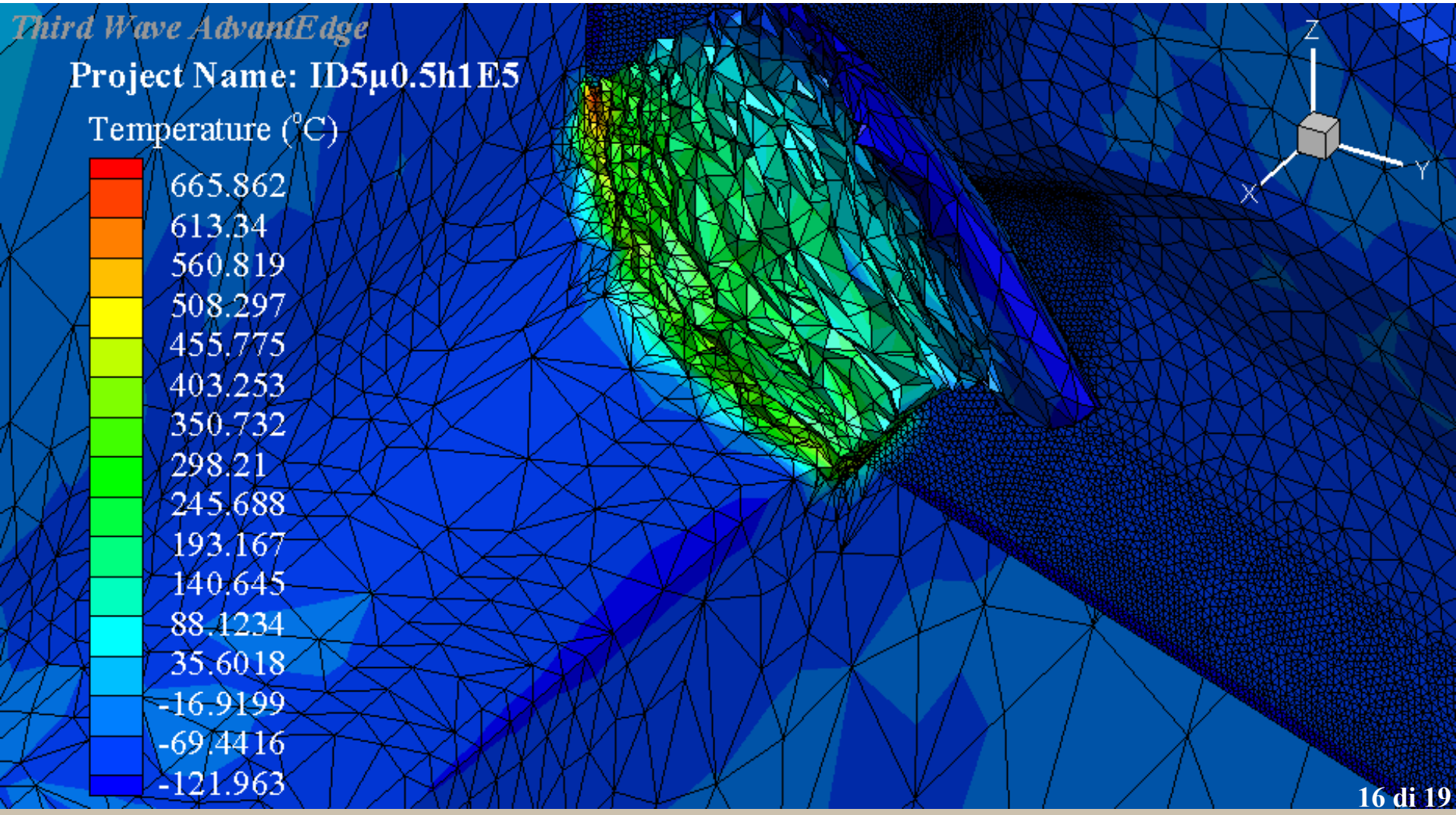
✓F=0.10 [mm/rev] S=80 [m/min] - Length of cut = 3 mm

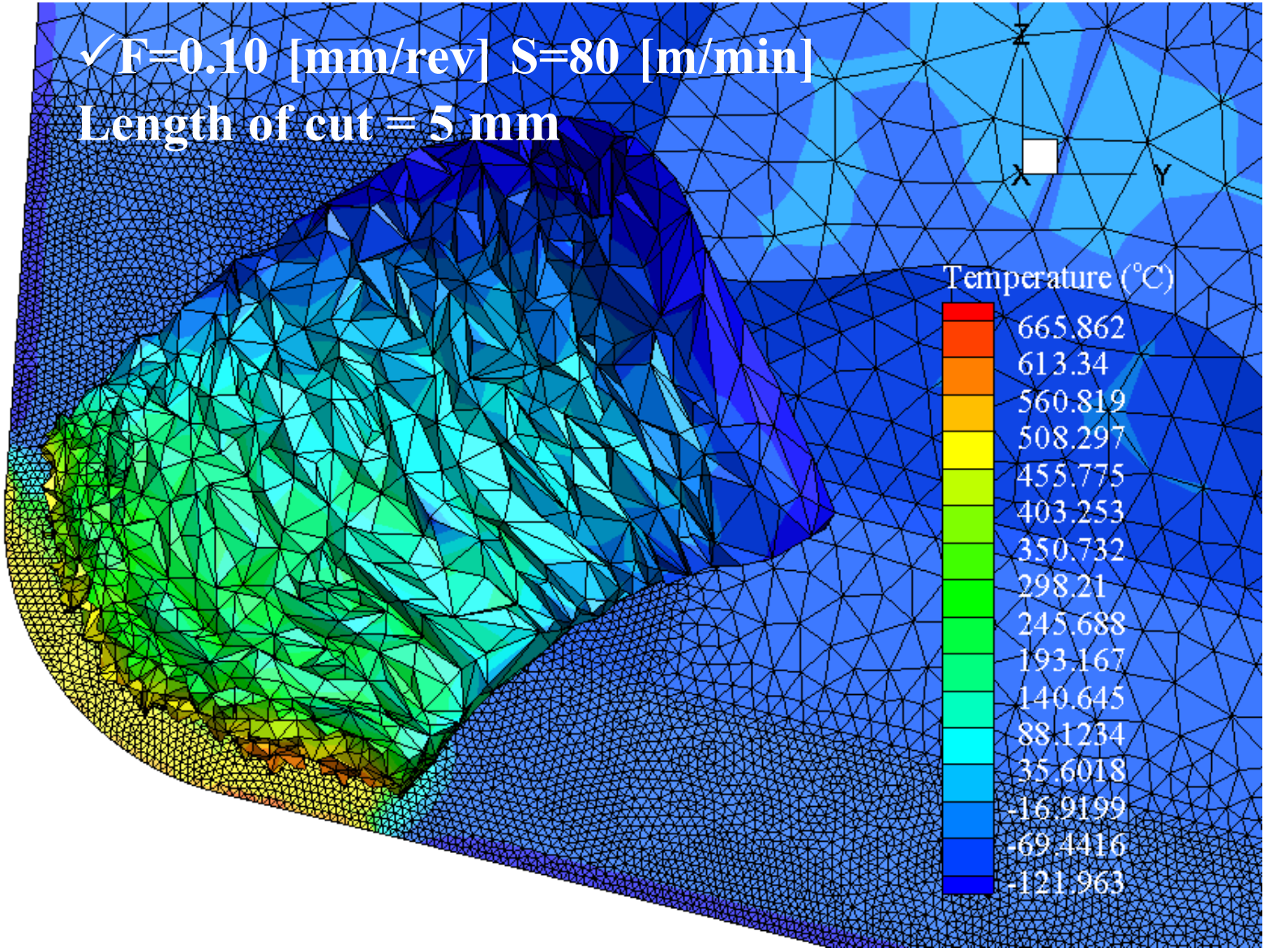


✓F=0.10 [mm/rev] S=80 [m/min] - Length of cut = 4 mm

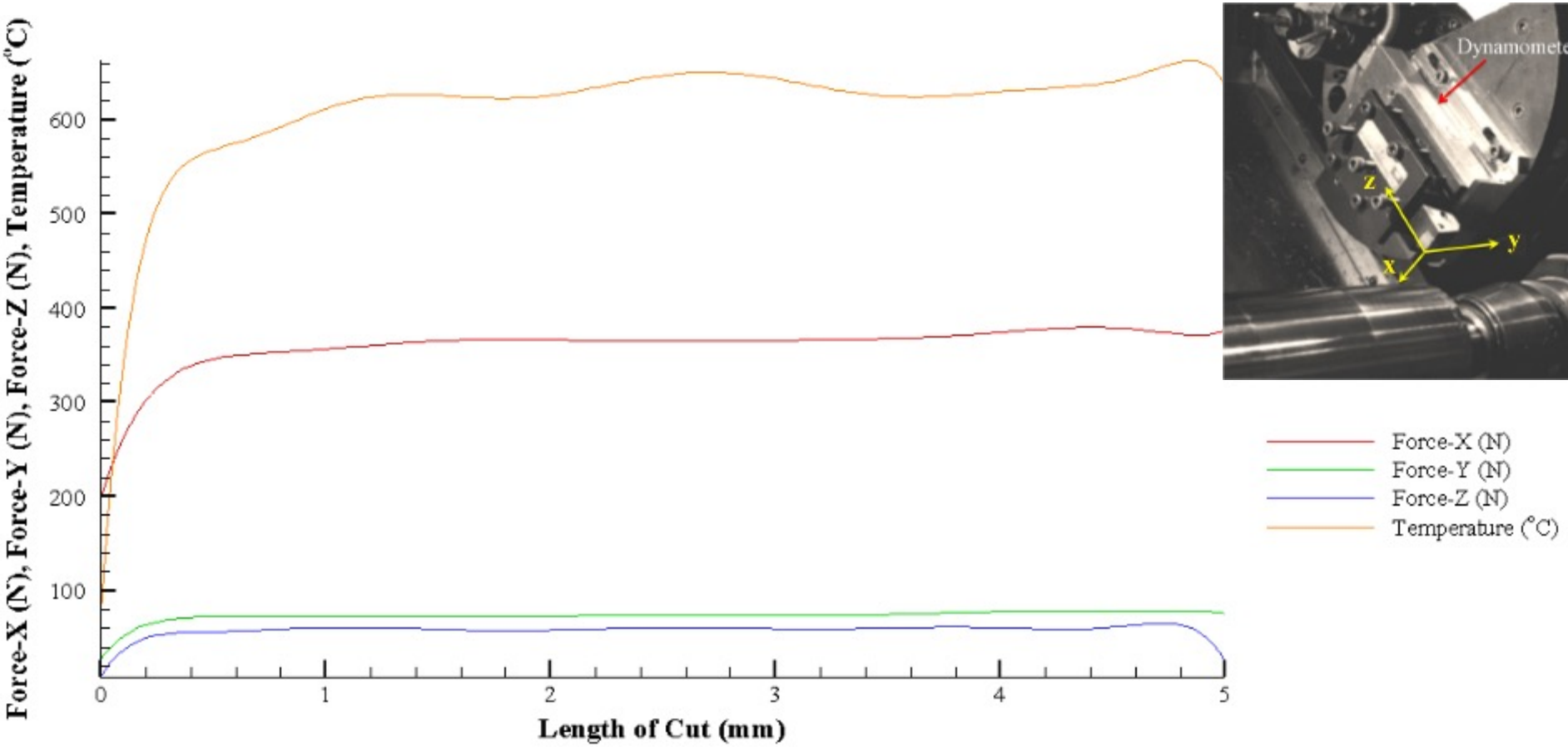


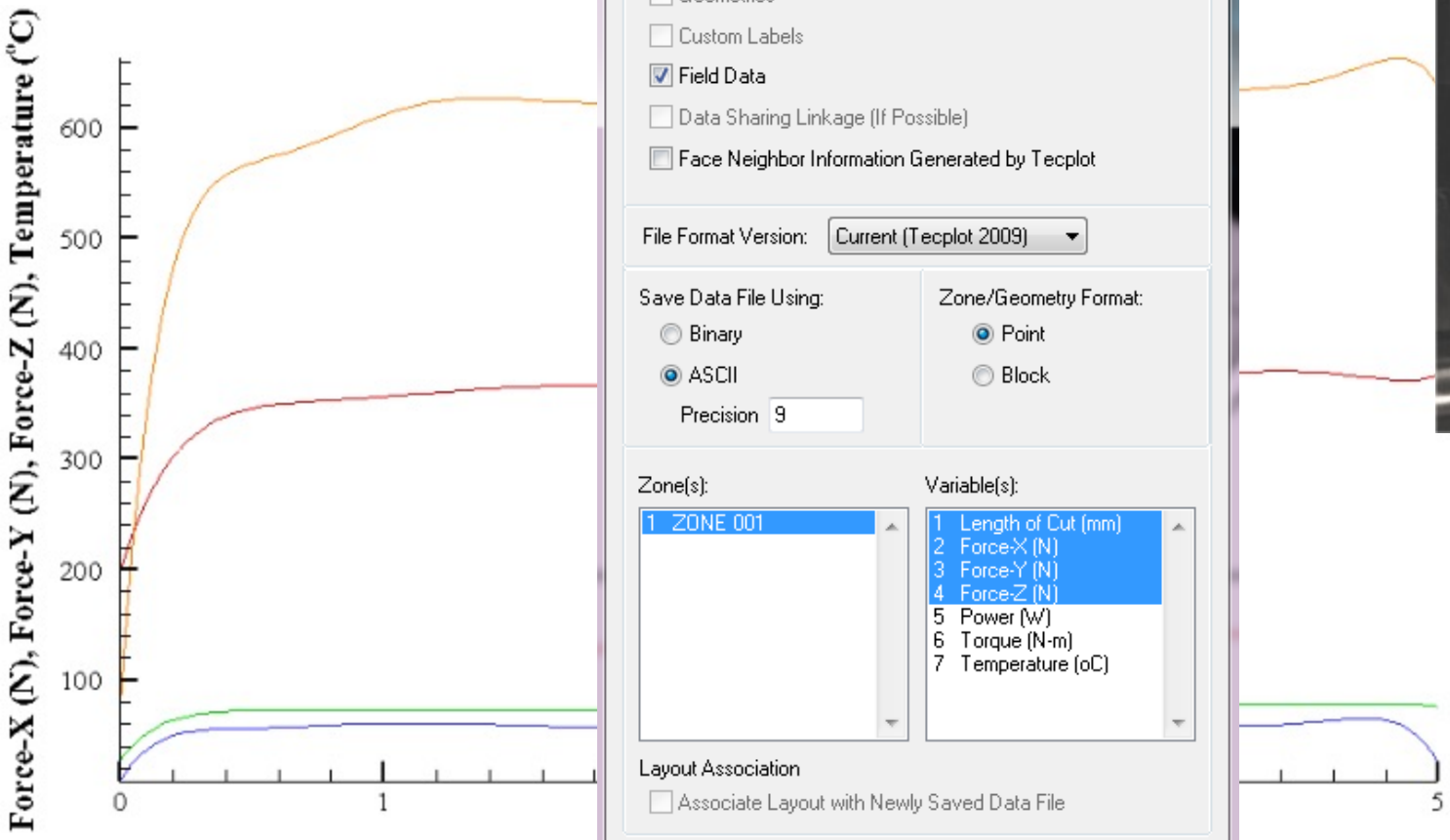
✓F=0.10 [mm/rev] S=80 [m/min] - Length of cut = 5 mm




✓F=0.10 [mm/rev] S=80 [m/min]
Length of cut = 5 mm
Z
X
Y
Temperature (°C)
665.862
613.34
560.819
508.297
455.775
403.253
350.732
298.21
245.688
193.167
140.645
88.1234
35.6018
-16.9199
-69.4416
-121.963

✓ Forces and max temperature




Force-X (N), Force-Y (N), Force-Z (N), Temperature (°C)
600
500
400
300
200
100
0
1
5
Force-X (N)
Force-Y (N)
Force-Z (N)
Temperature (°C)

Write Data File Options
Details to Save
Text
Geometries
Custom Labels
Field Data
Data Sharing Linkage (If Possible)
Face Neighbor Information Generated by Tecplot
File Format Version:
Current (Tecplot 2009)
Save Data File Using:
Binary
ASCII
Precision 9
Zone/Geometry Format:
Point
Block
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1 ZONE 001
Variable(s):
1 Length of Cut (mm)
2 Force-X (N)
3 Force-Y (N)
4 Force-Z (N)
5 Power (W)
6 Torque (N-m)
7 Temperature (oC)
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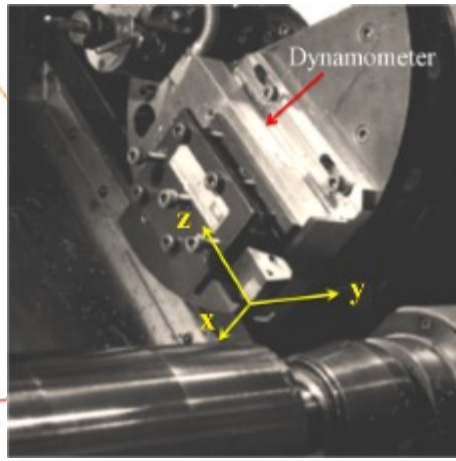
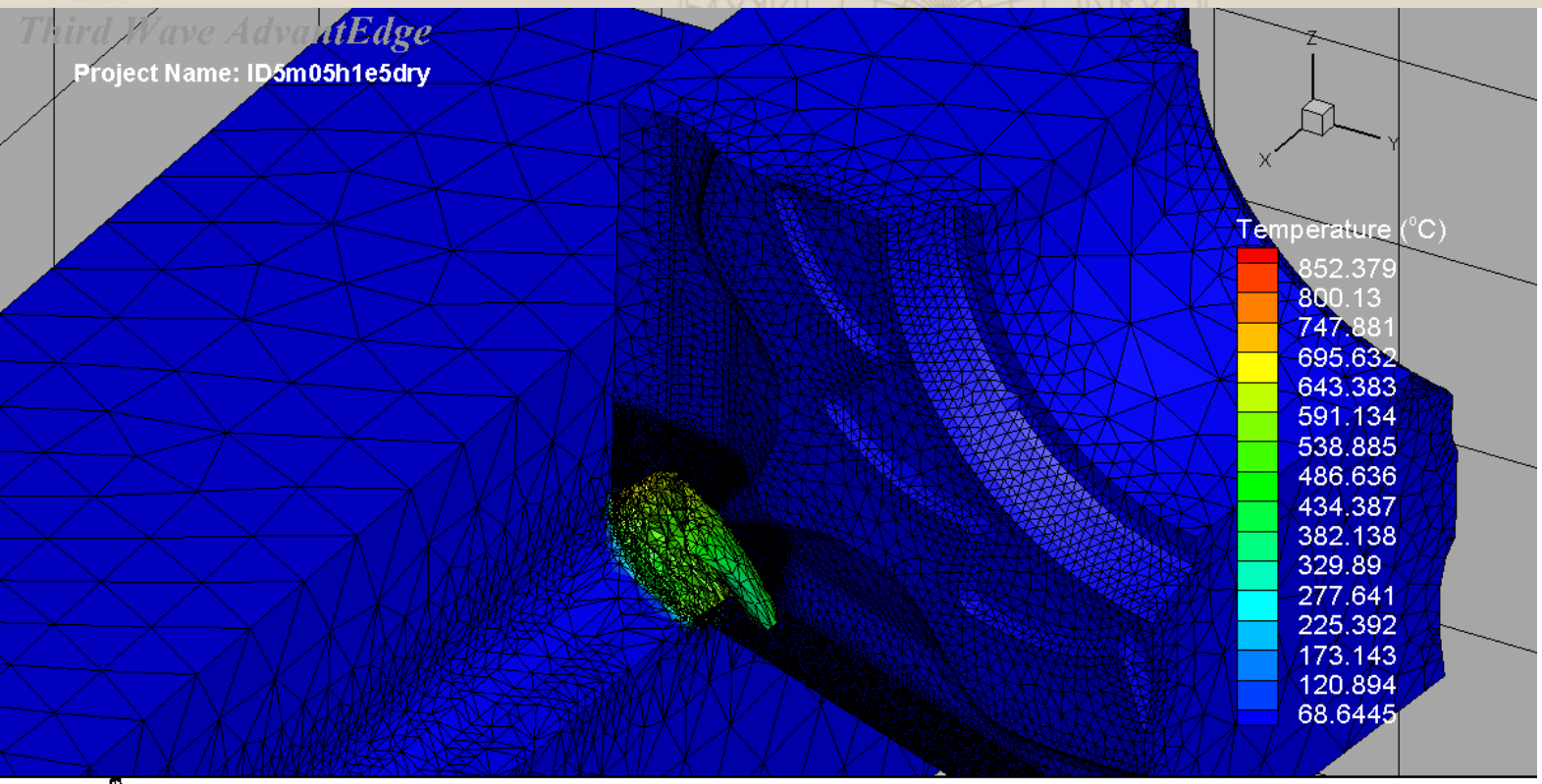
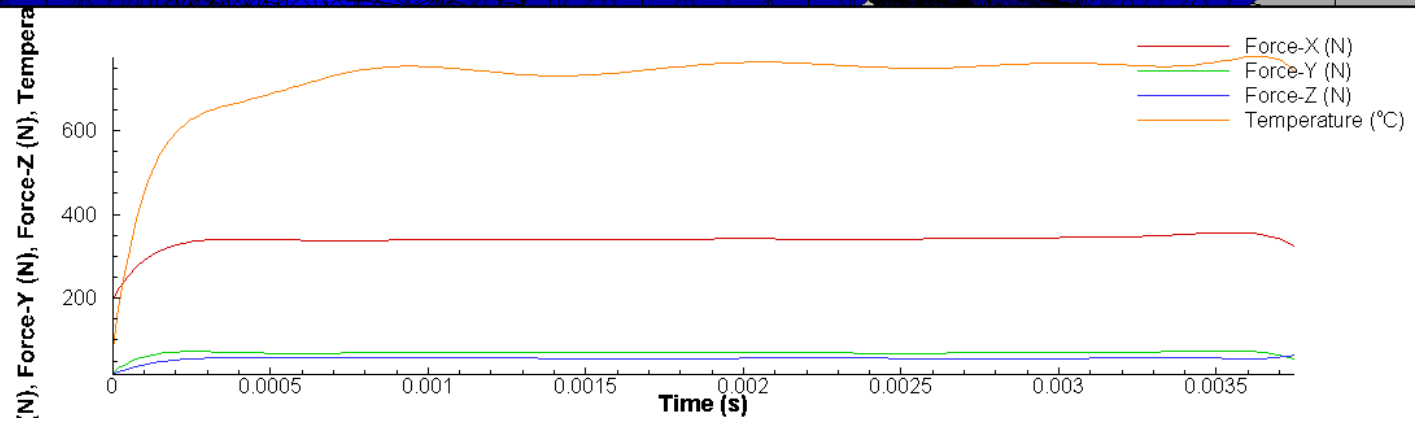
Associate Layout with Newly Saved Data File
OK
Cancel
Help

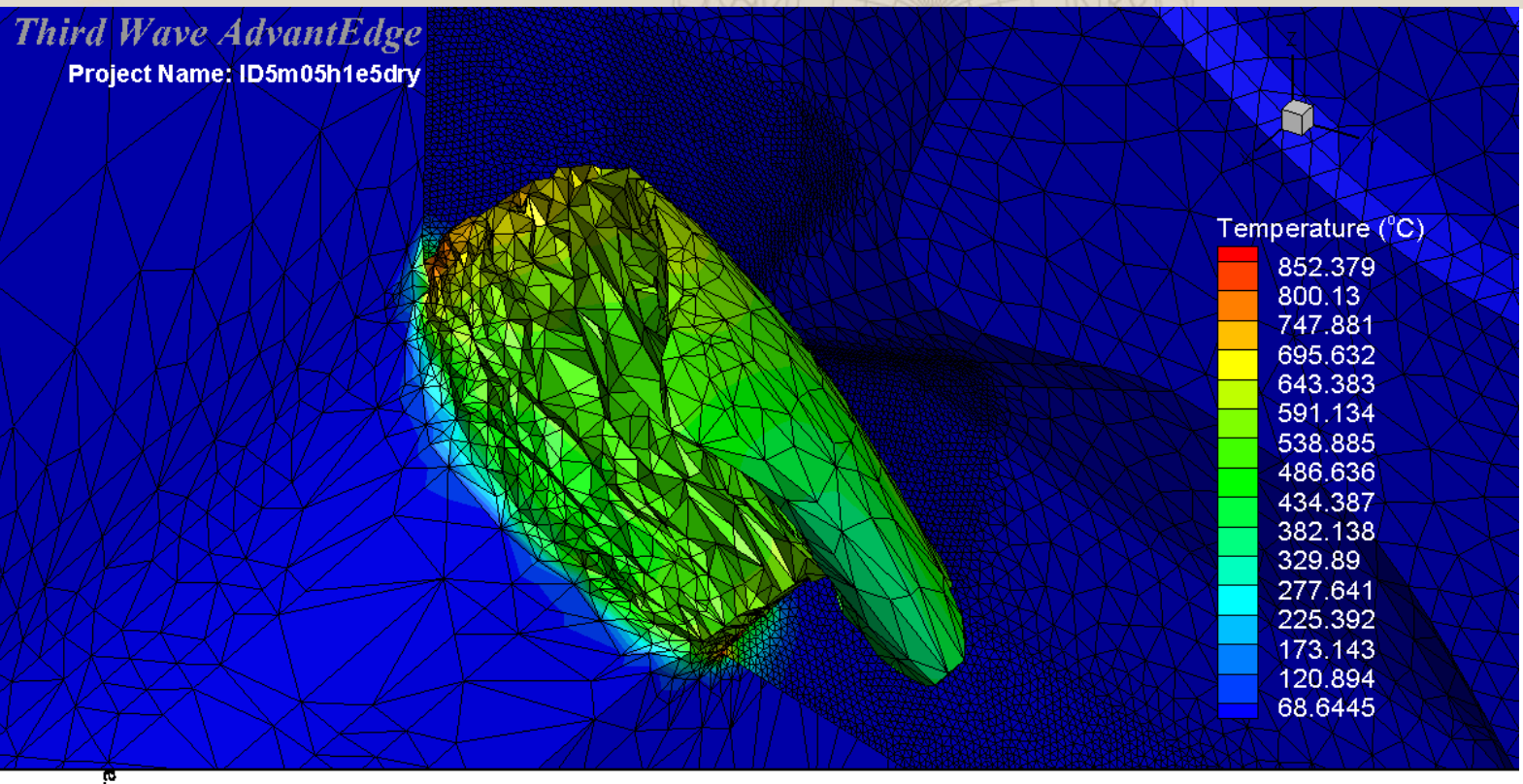

Dynamometer
z
y
x

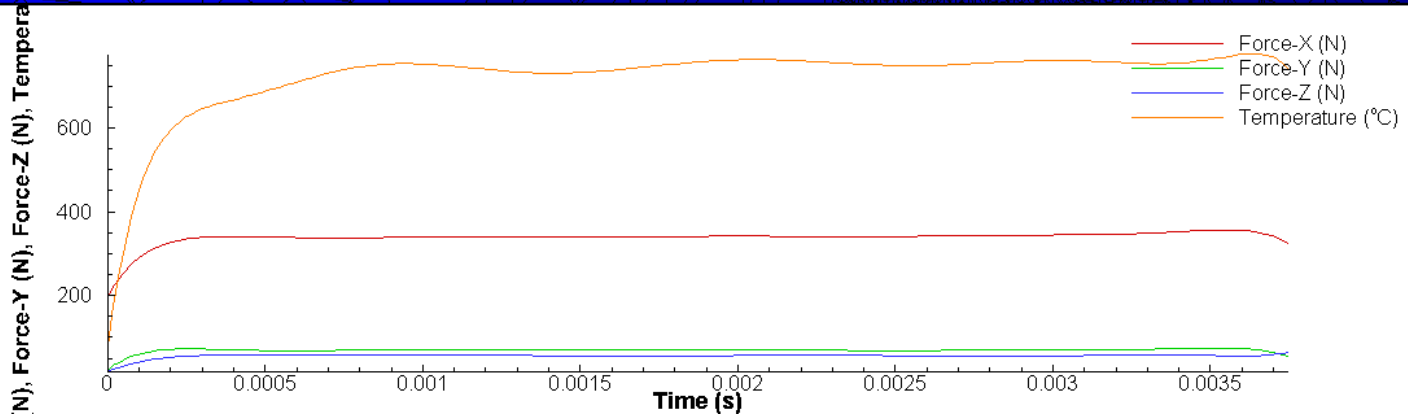
Dry machining



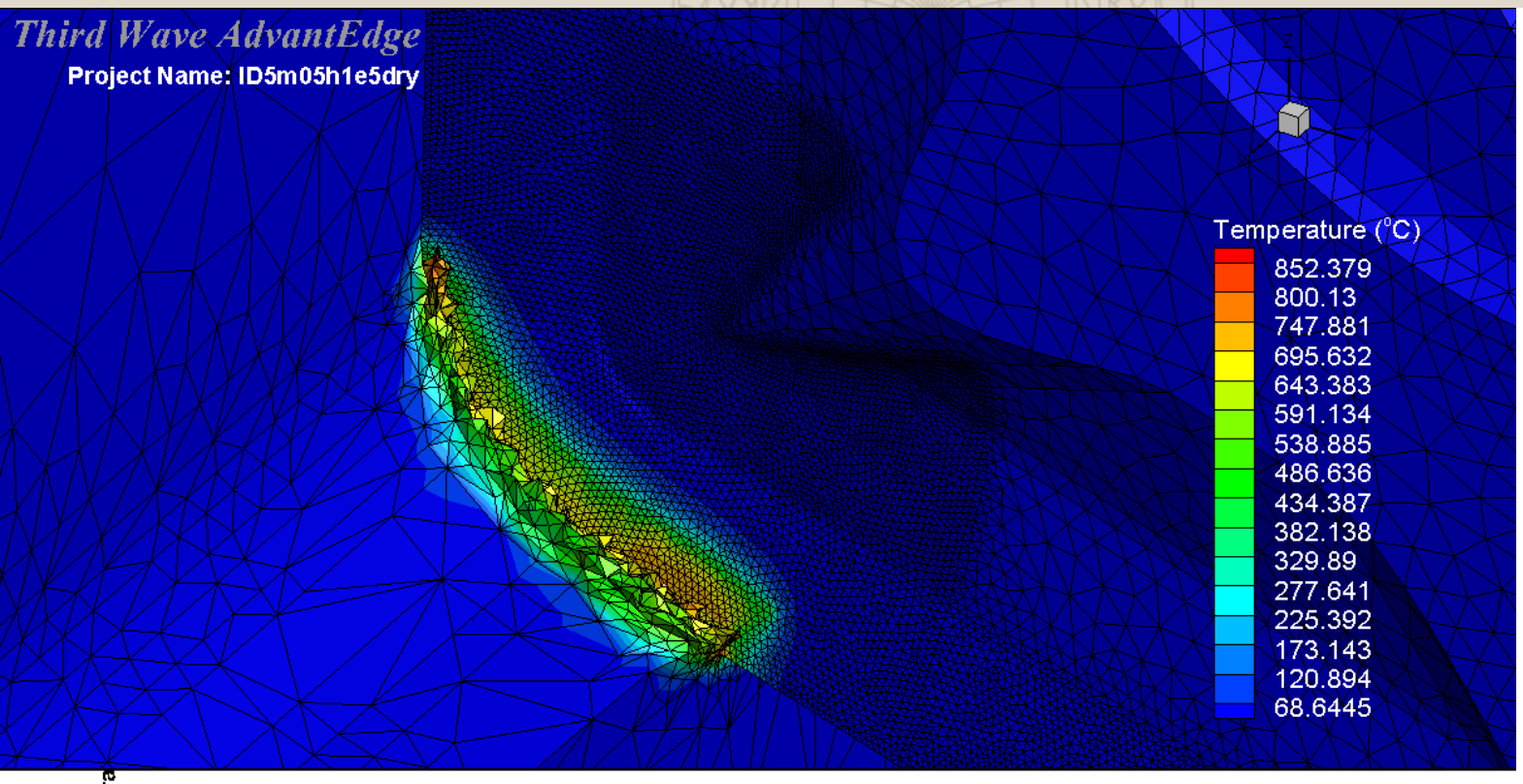


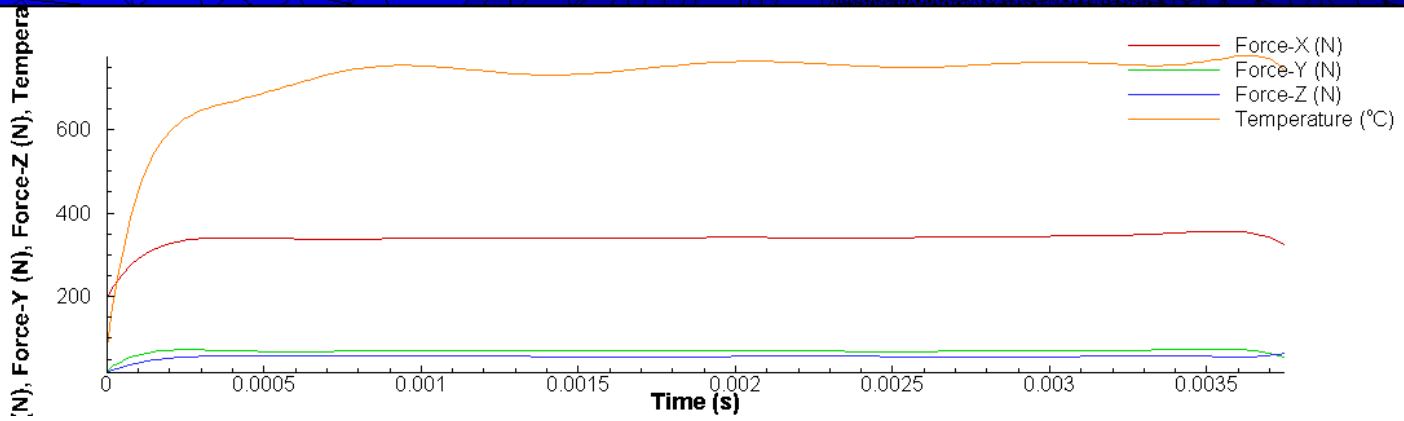
Dry machining



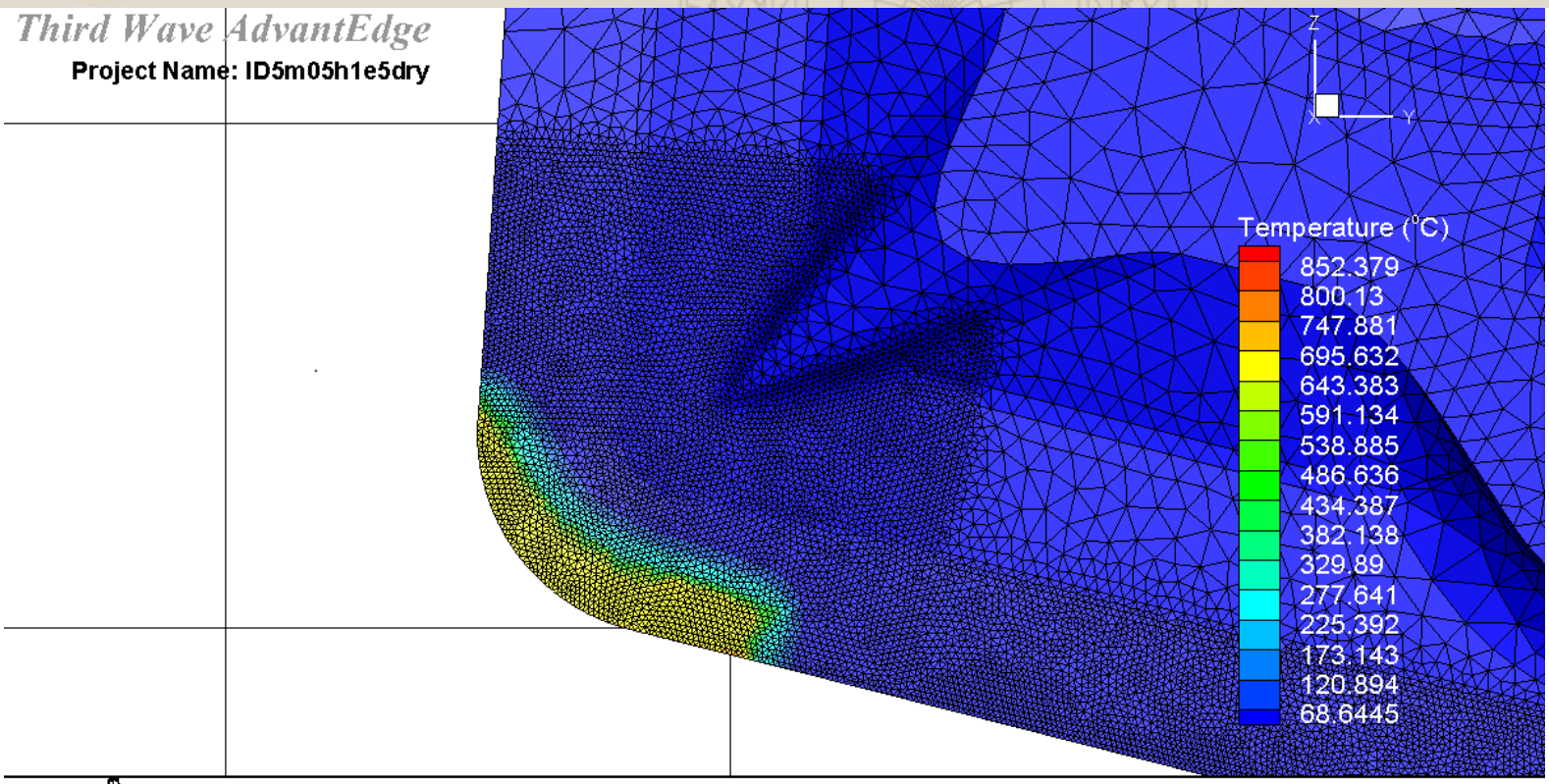


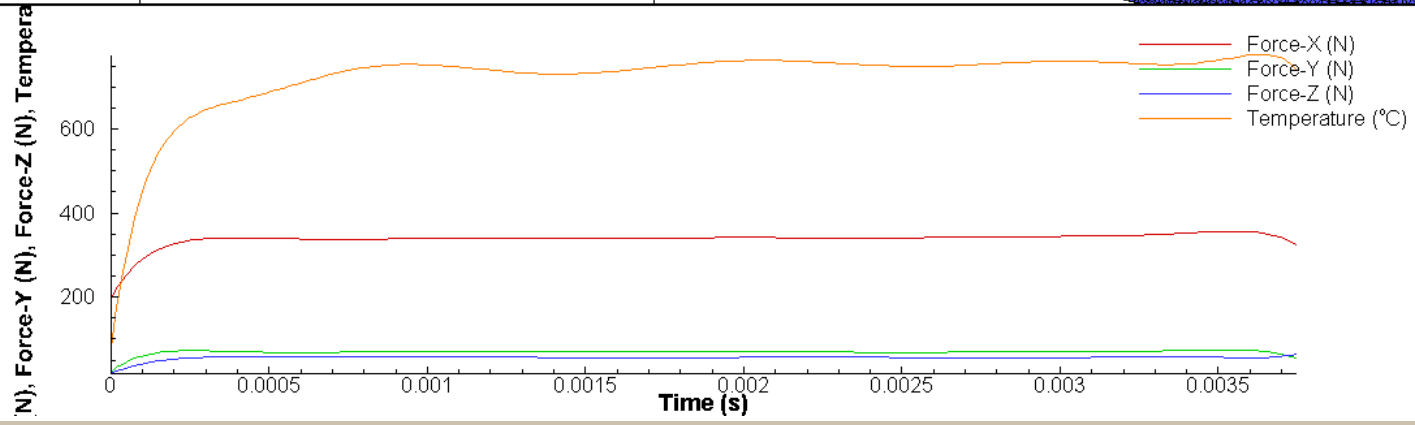
Dry machining



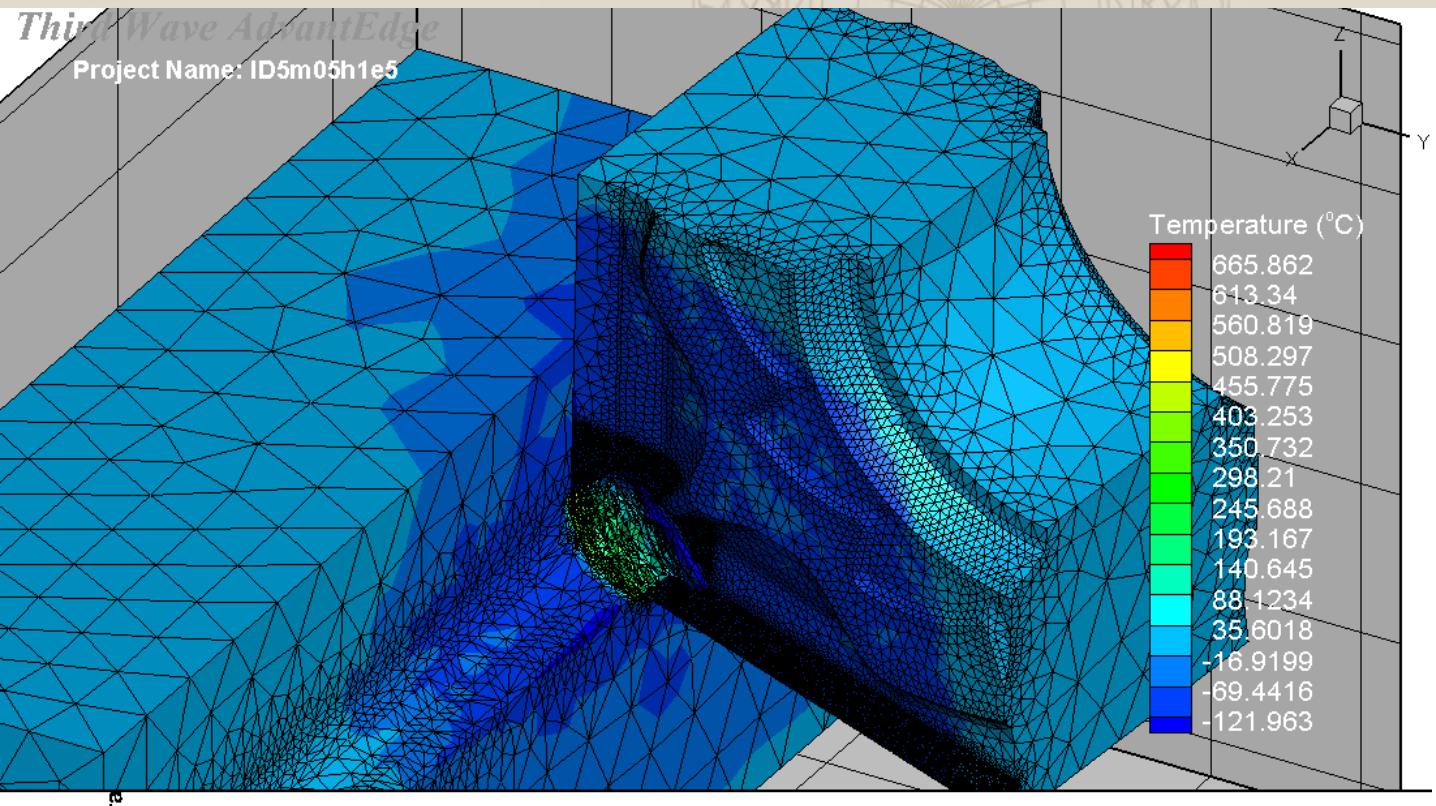


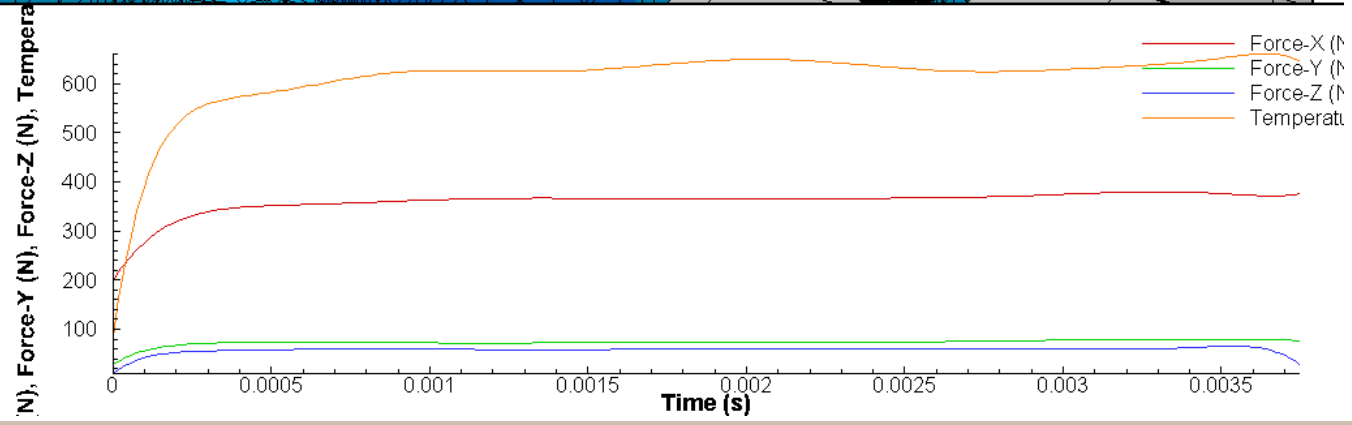
Dry machining



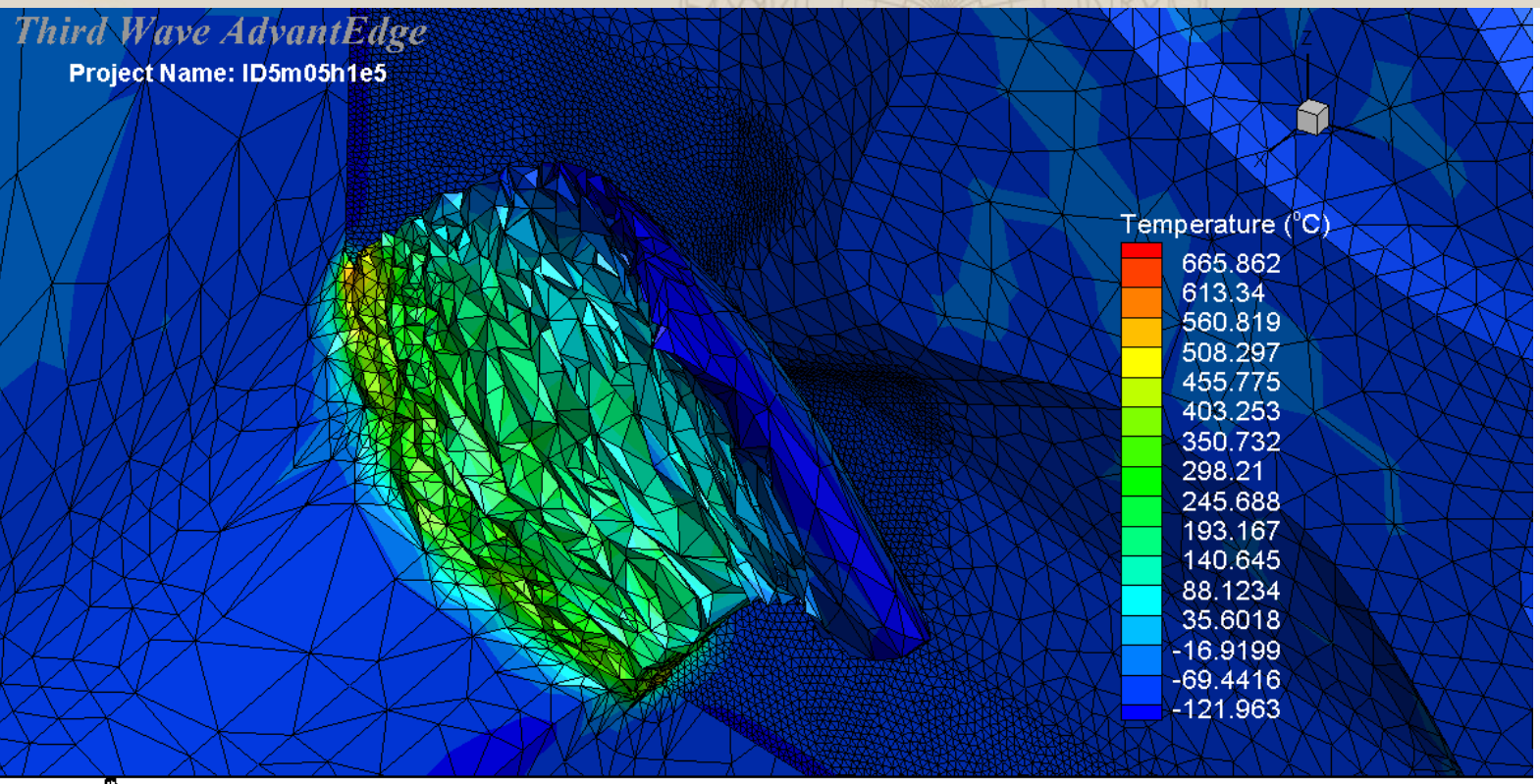


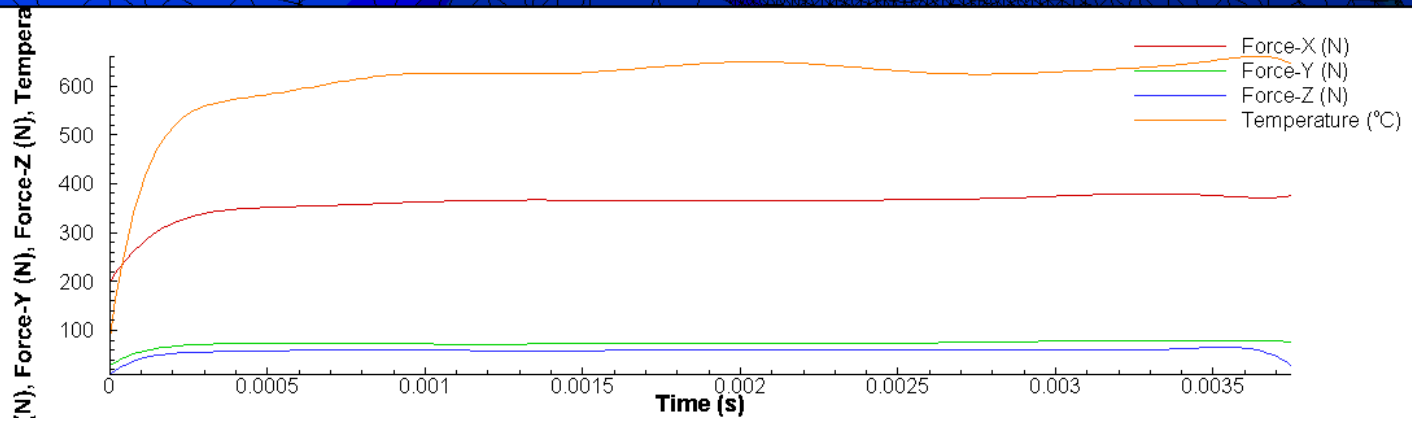
Cryogenic machining





Cryogenic machining





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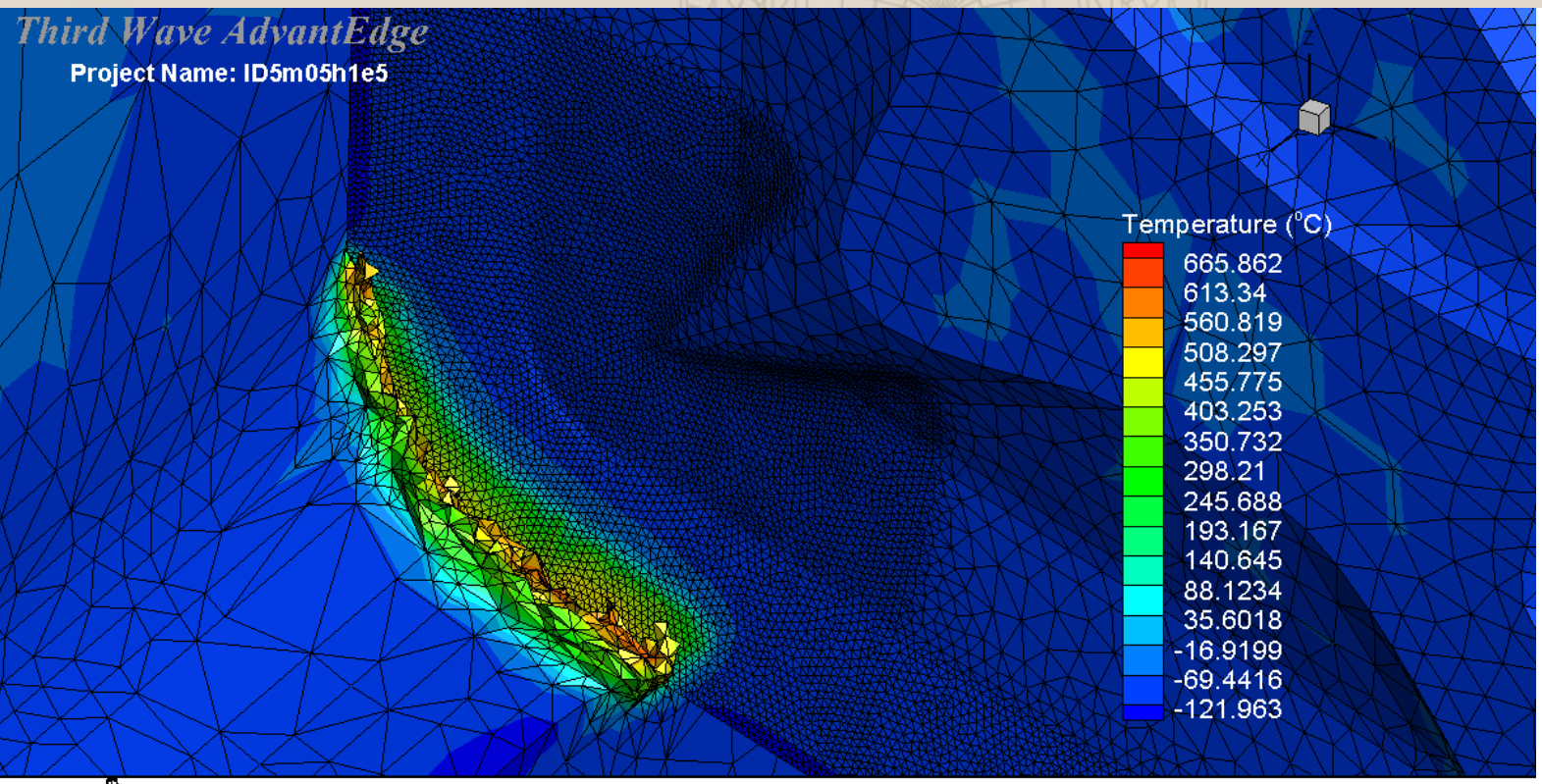
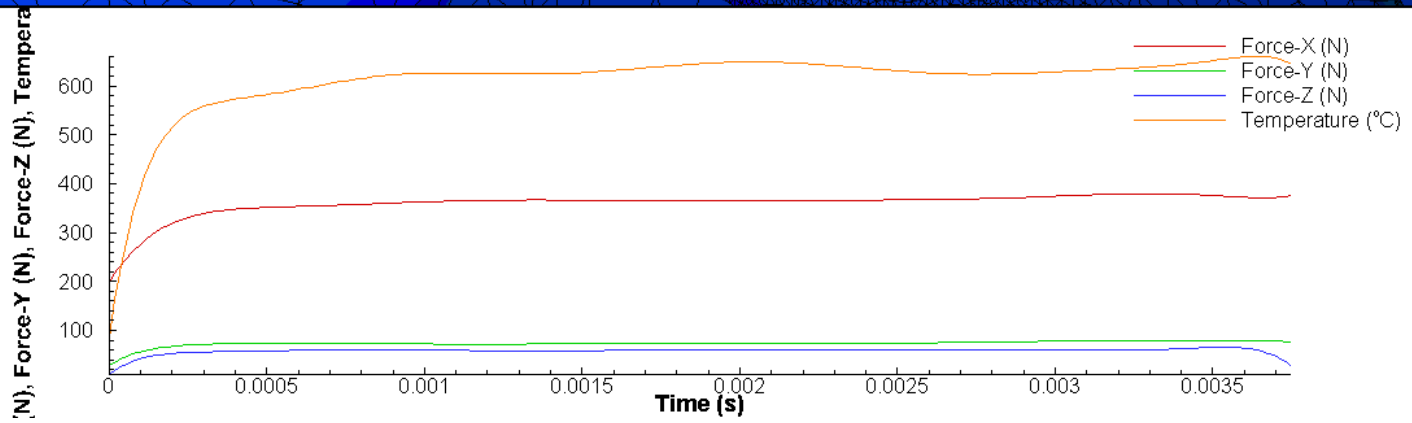
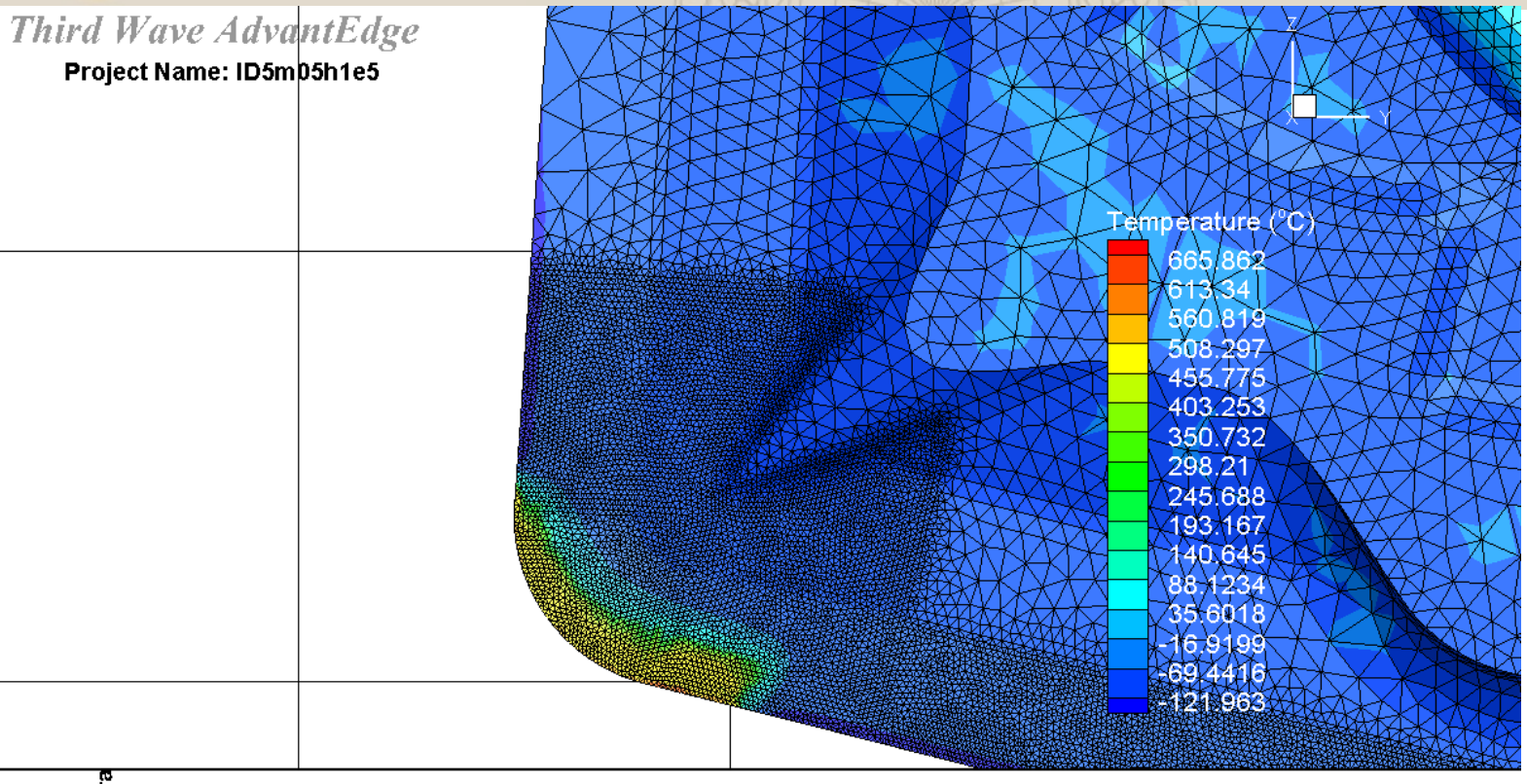
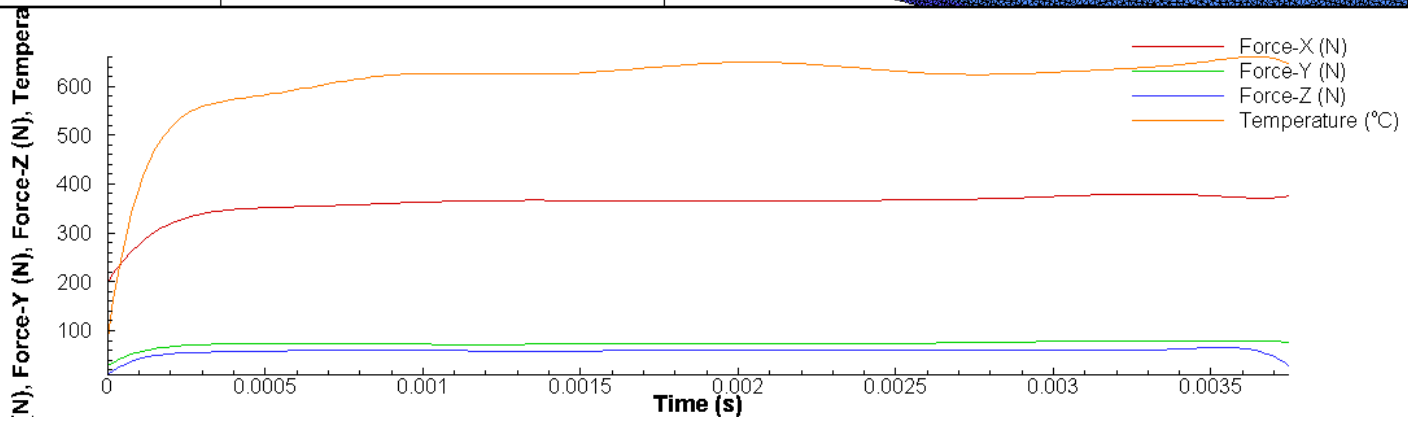




Cryogenic machining





Conclusions…

- With LN_2: temperature lower than 120K;
- LN_2 absorb heat and evaporate;
- LN_2 is an inert gas;
- LN_2 is lighter than air Safe for workers' health;

- Numerical/experimental errors on the main cutting force below 10% can be obtained. The main cutting force trend can be correctly predicted;

- Numerical/experimental errors on the feed/radial force obtained vary in a range of 50-80%;

- Numerical/experimental errors on the temperature below 10% can be obtained. Numerical temperatures that differ from experimental ones by about 10 °C, in the case of thermocouples, is widely acceptable;

…and future developments

- Cryogenic fluid affects material thermomechanical behavior (few studies explore this aspect);
- The cooling approach for effectively using cryogenic machining and dispensing method shall be identified: FE simulation can be a valid support tool for the process understanding;
- In order to improve the prediction of the FE model the research lines suggested include: Friction and Rheological models
- Experimental characterization of the cryogenic machining of Waspaloy, is still at an early stage.