

Corso di ADVANCED TECHNOLOGIES IN MANUFACTURING

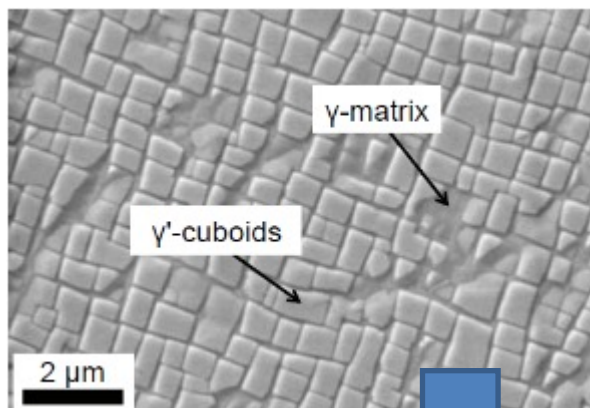
(ING/IND16) CF 9

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

The background of the slide features a 3D finite element (FE) model of a mechanical component, likely a turbine or compressor part. The model is rendered in blue, with various colored regions (red, yellow, green) indicating stress or temperature distributions. The component has a complex, curved shape with multiple internal features and a central shaft-like structure.

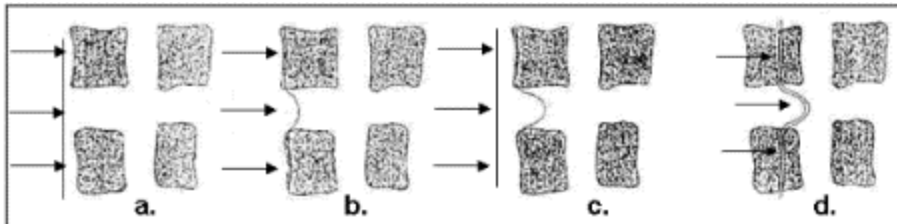
Summary

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



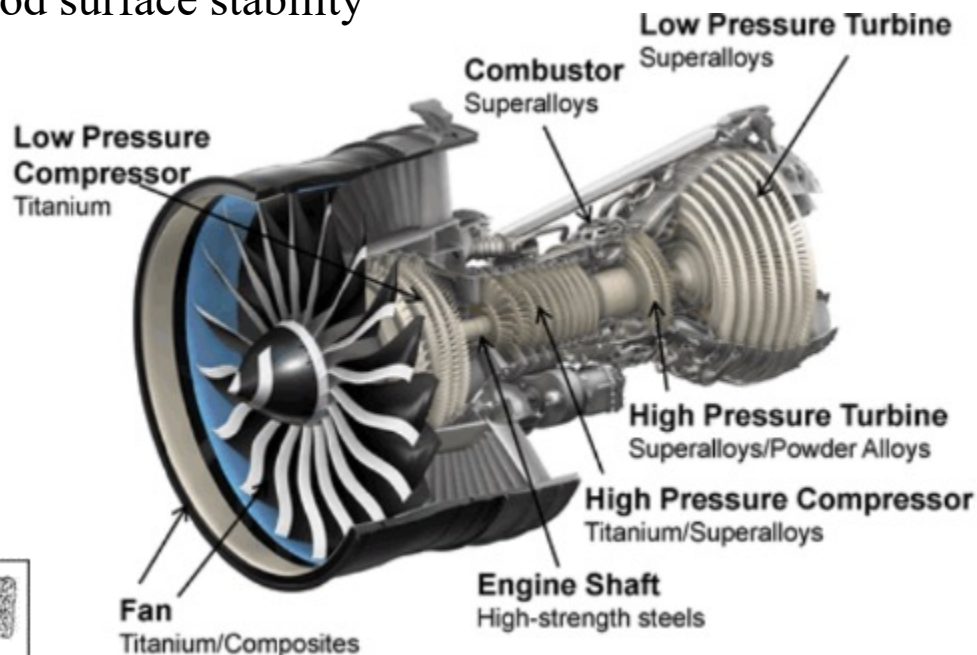
But also...

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



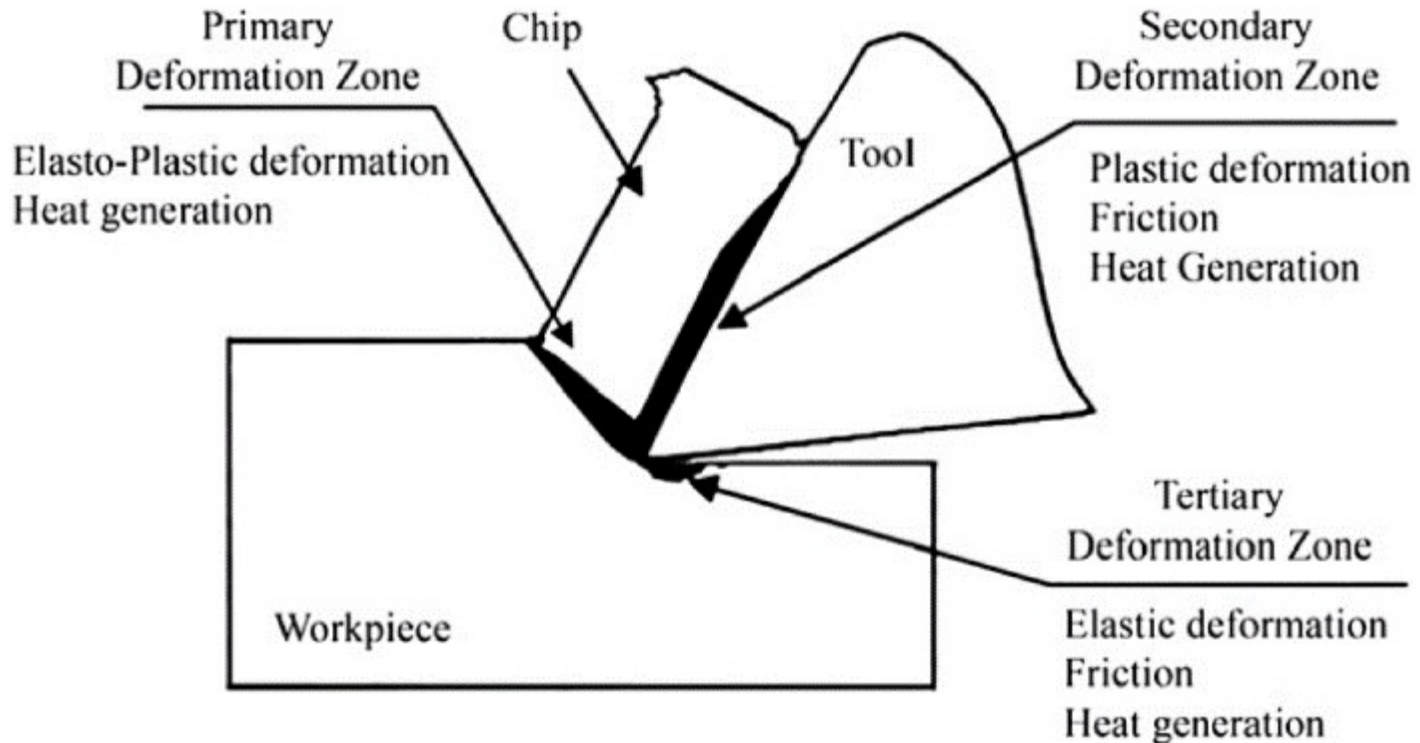
Nickel superalloys

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

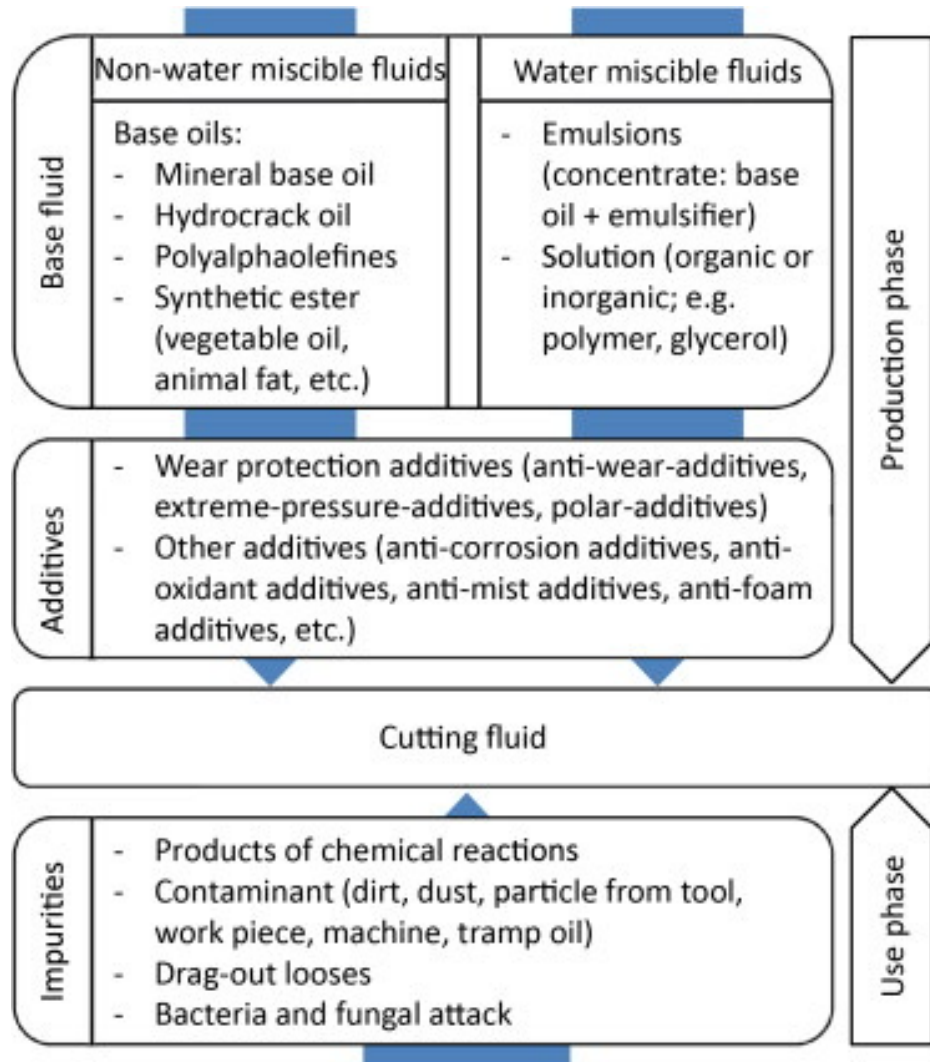


Surface integrity

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

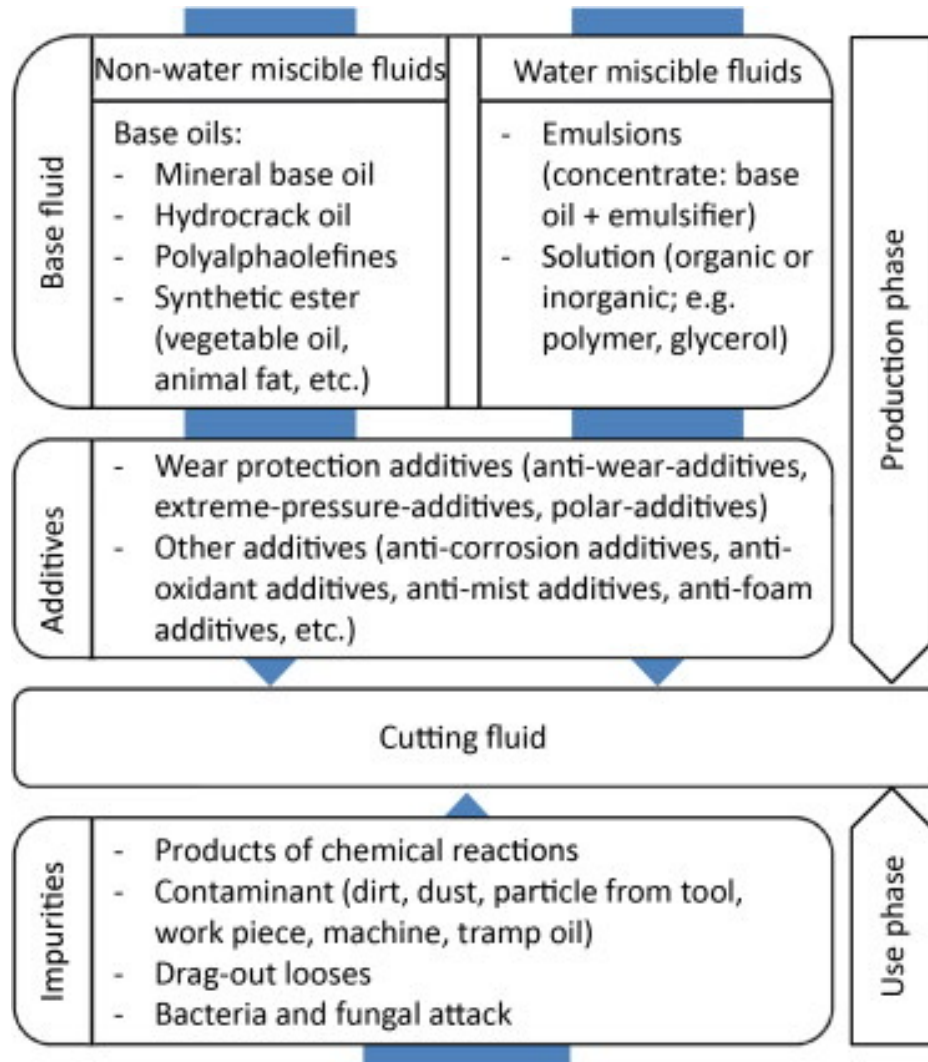


Coolant and Lubricants (CLs)



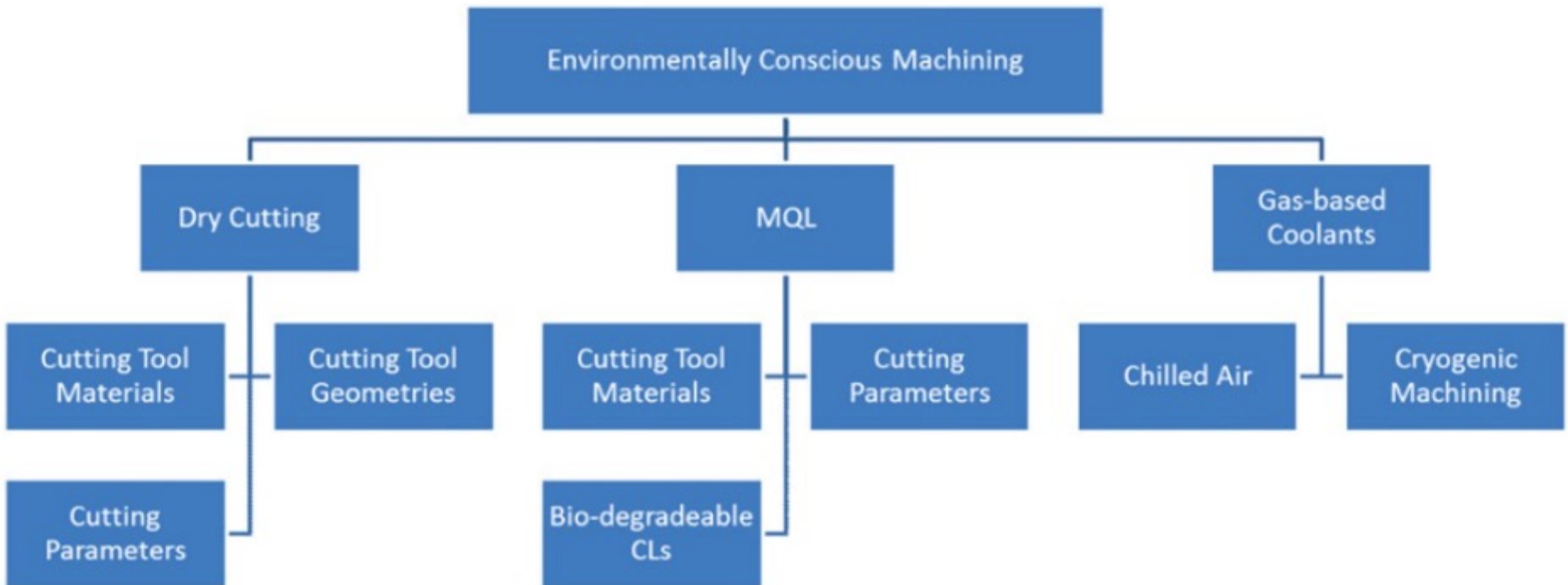
- ✓ Cool cutting area
- ✓ Reduce force
- ✓ Extend cutting edge life
- ✓ Transport the chips away from cutting area

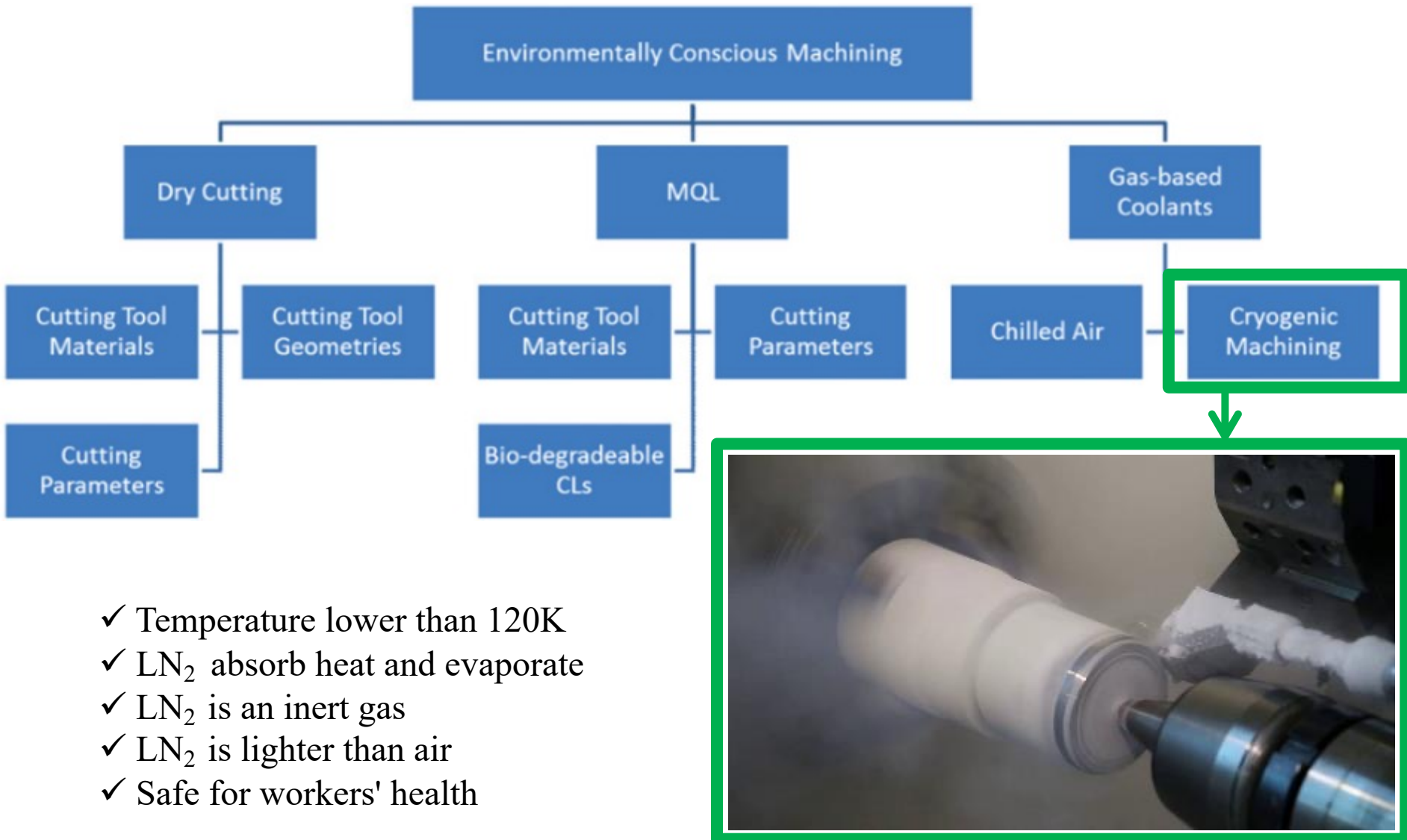
Coolant and Lubricants (CLs)



- ✓ Cool cutting area
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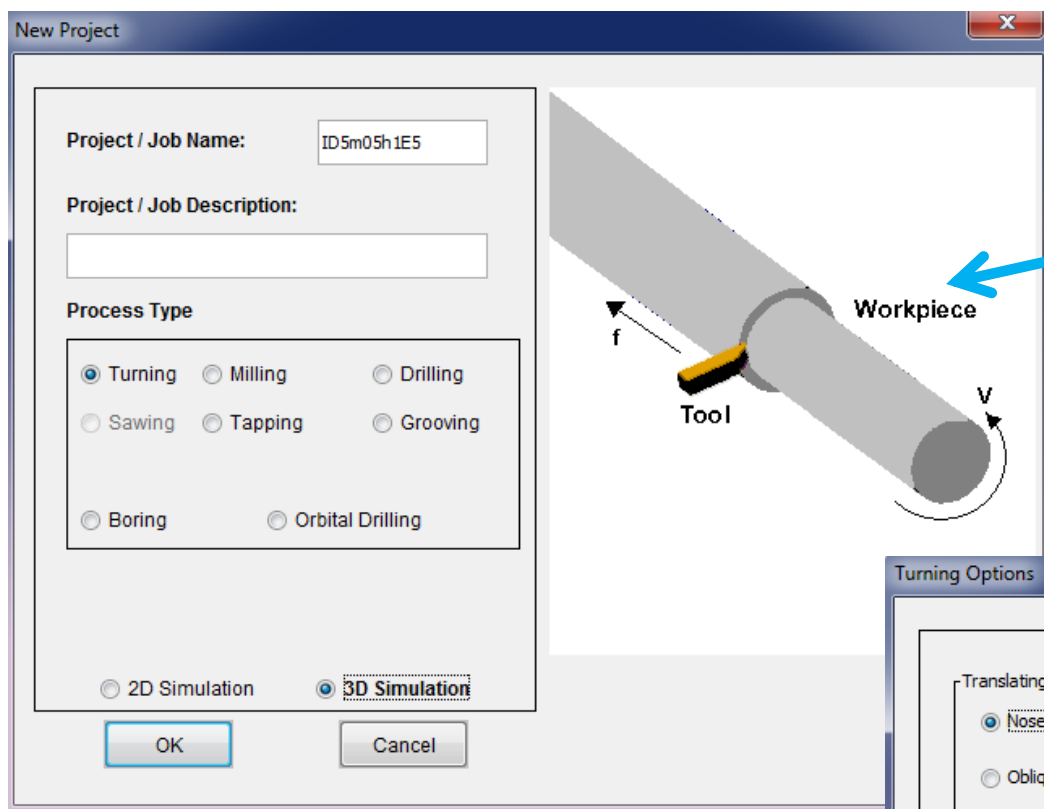






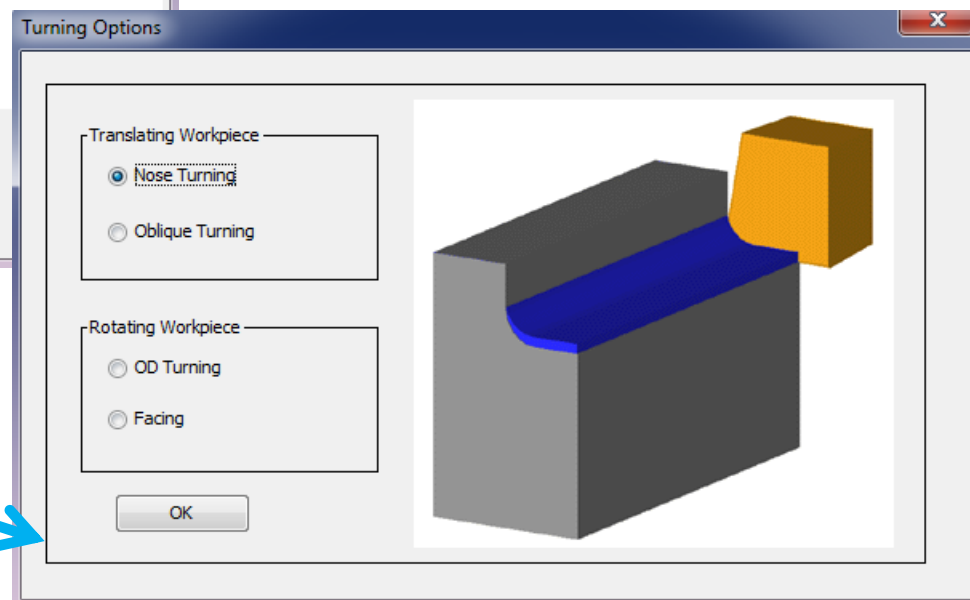
✓ Finite Element Model AdvantEdge (Third Wave Systems Inc.) is a commercial implementation of the finite element method designed to analyze the behavior of metals encountered during machining operations.

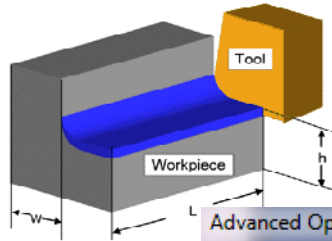
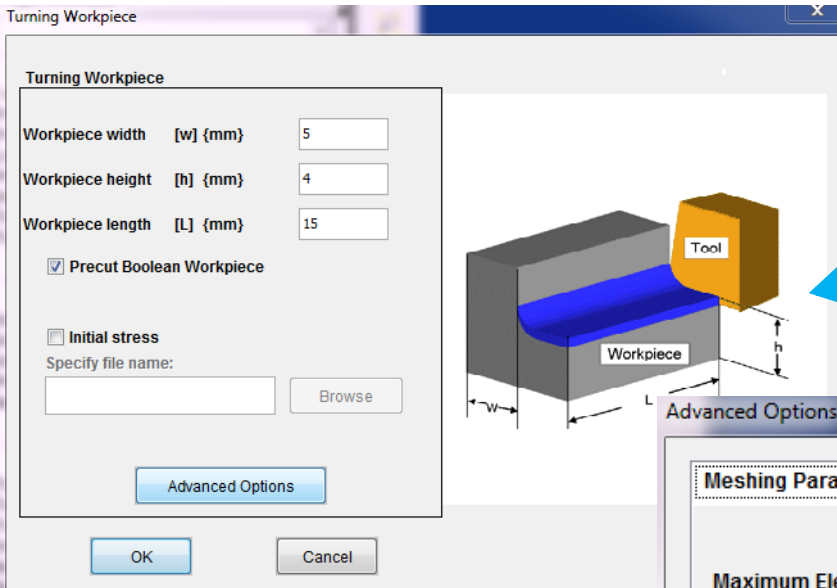
✓ The code embodies an explicit scheme capable of modeling coupled, non-linear thermo-mechanics at large strains and strain rates incorporating constitutive deformation behavior, contact, friction, fracture and adaptive meshing.



✓ New Project

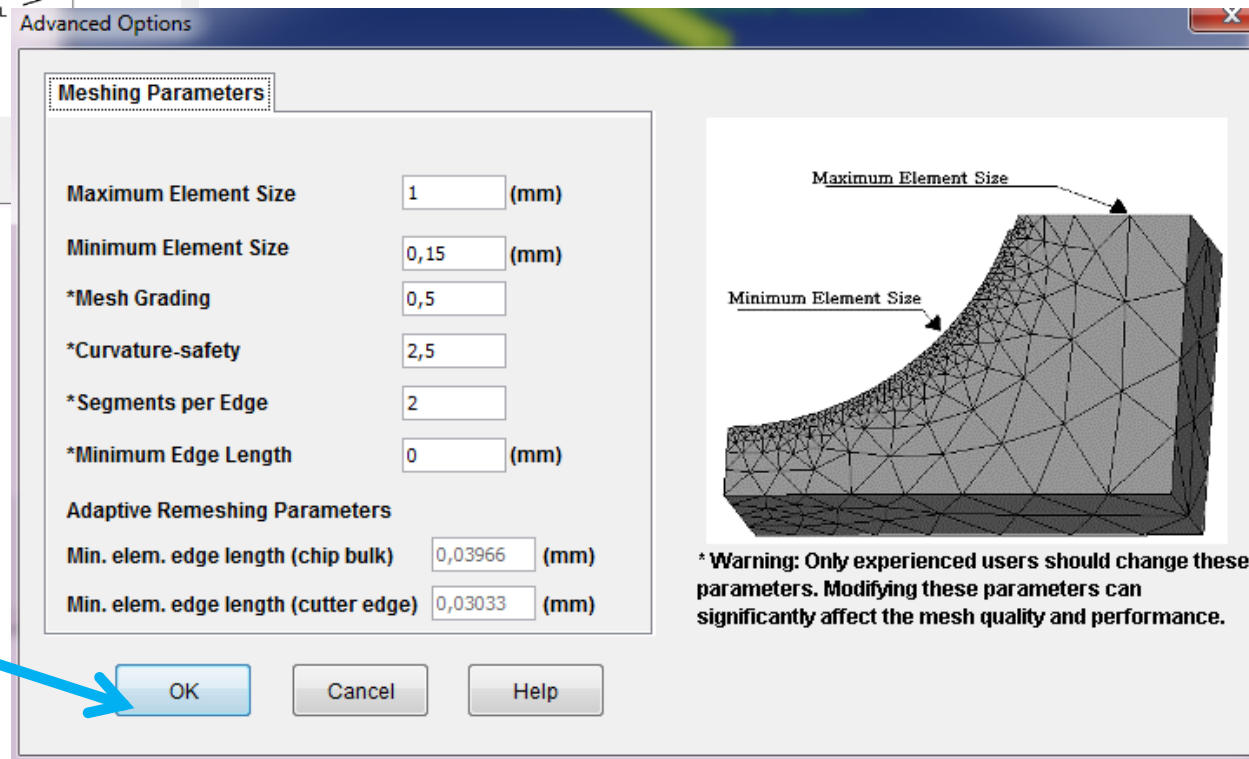
✓ Turning Options



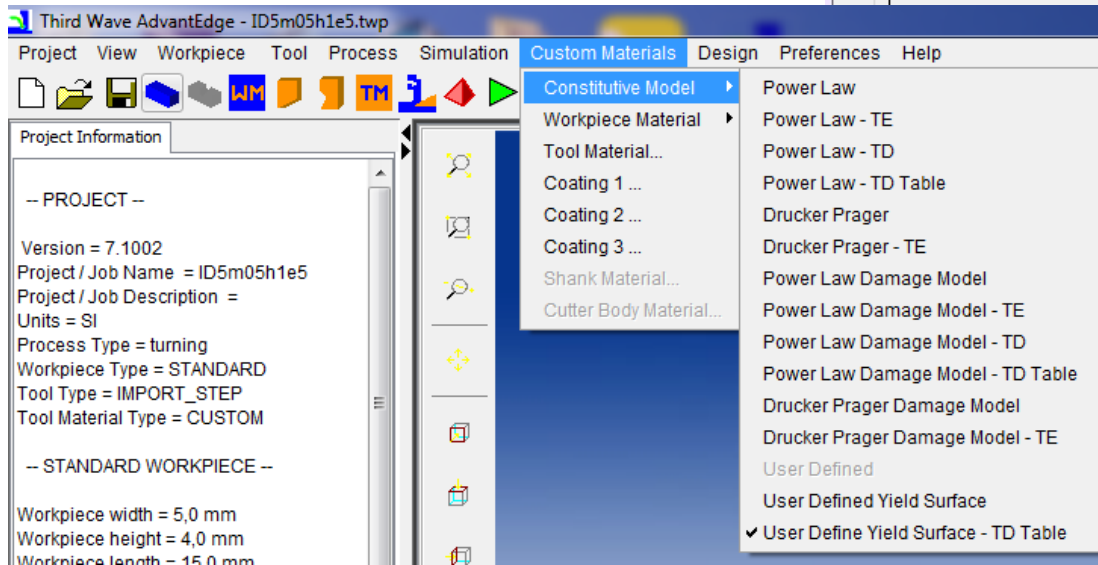
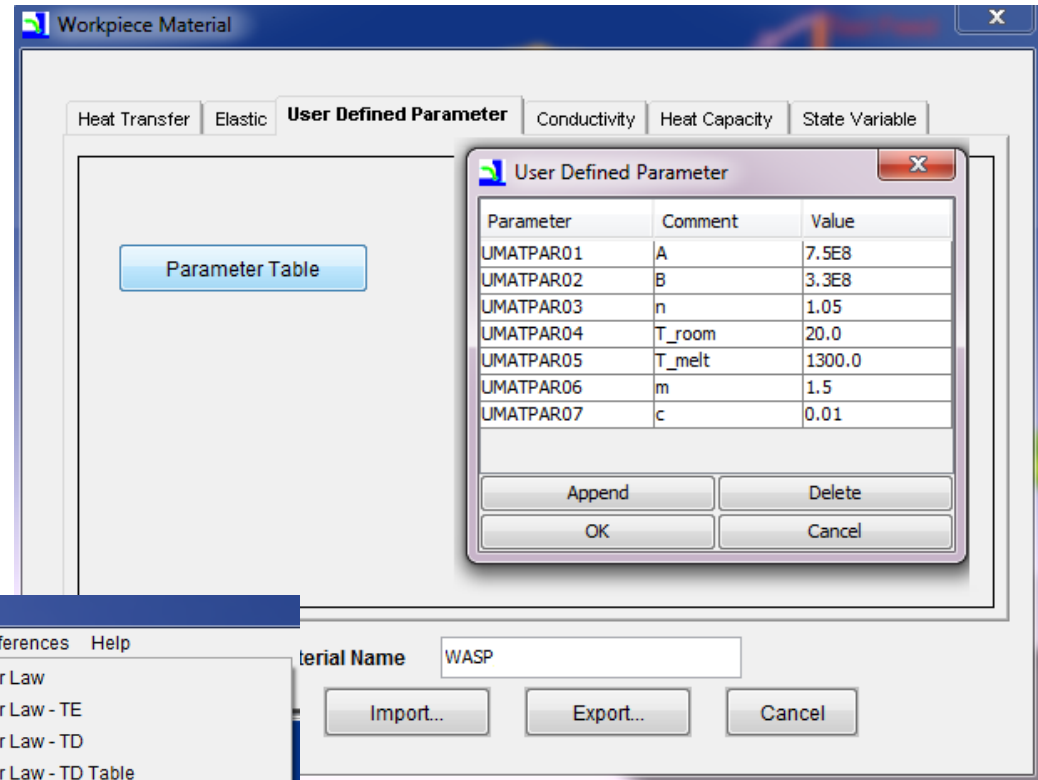
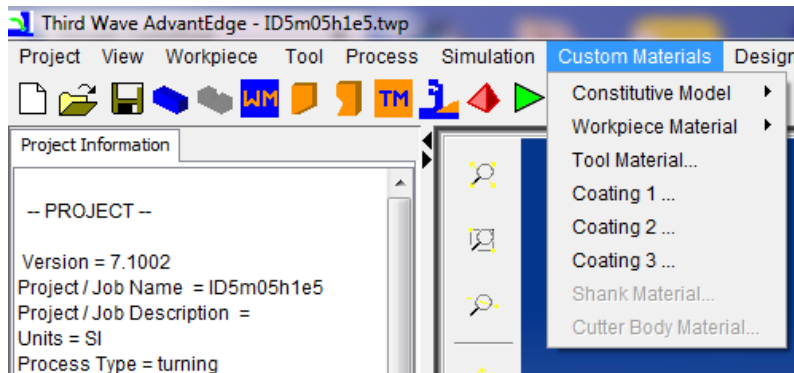


✓ Turning Workpiece

✓ Advanced Options



✓ Custom Materials



✓ Johnson-Cook model

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

STEP Tool Import

STEP Tool Import

Tool Only Import Tool-Workpiece Import

Side Tool Holder Angle 0 (deg)

Back Tool Holder Angle 0 (deg)

Lead Angle 0 (deg)

STEP Tool File ID5m05h1e5.stp

Check/Orient Tool Browse

☐ Heal STEP File

STEP Healing Tolerance (mm)

OK Cancel Advanced Options

✓ STEP Tool Import

Step Tool Import - Advanced Options

Tool Meshing

Maximum Tool Element Size 1 (mm)

Minimum Tool Element Size 0,1 (mm)

*Mesh Grading 0,5

*Curvature-safety 1,5

*Segments per Edge 0,5

*Minimum Edge Length 0 (mm)

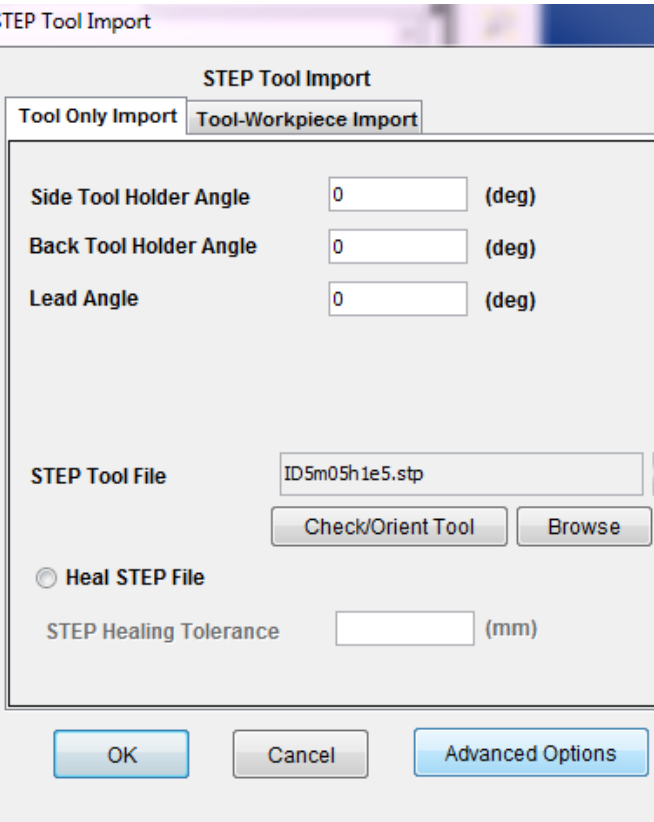
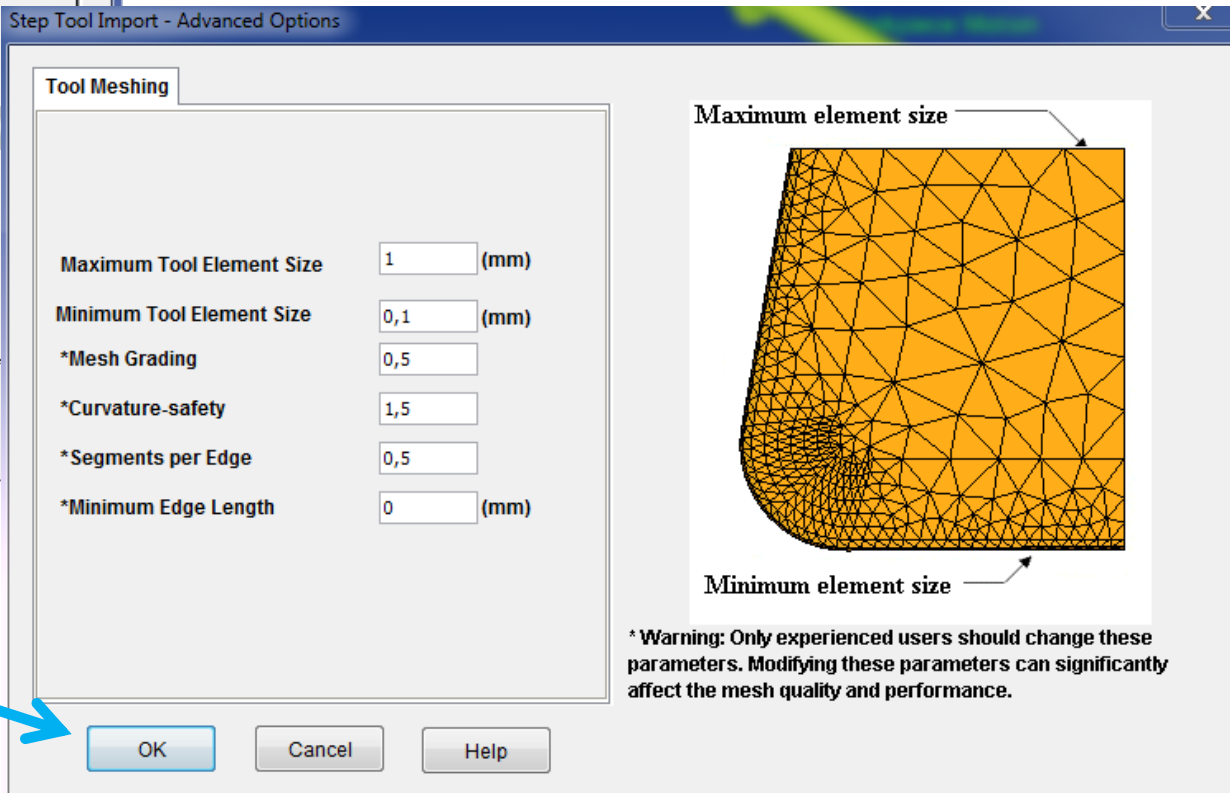
Maximum element size

Minimum element size

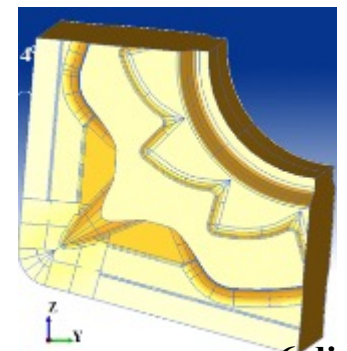
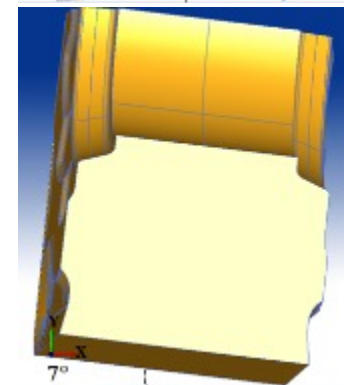
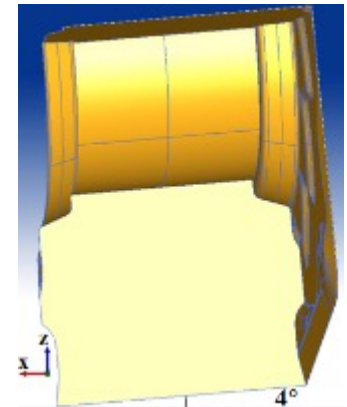
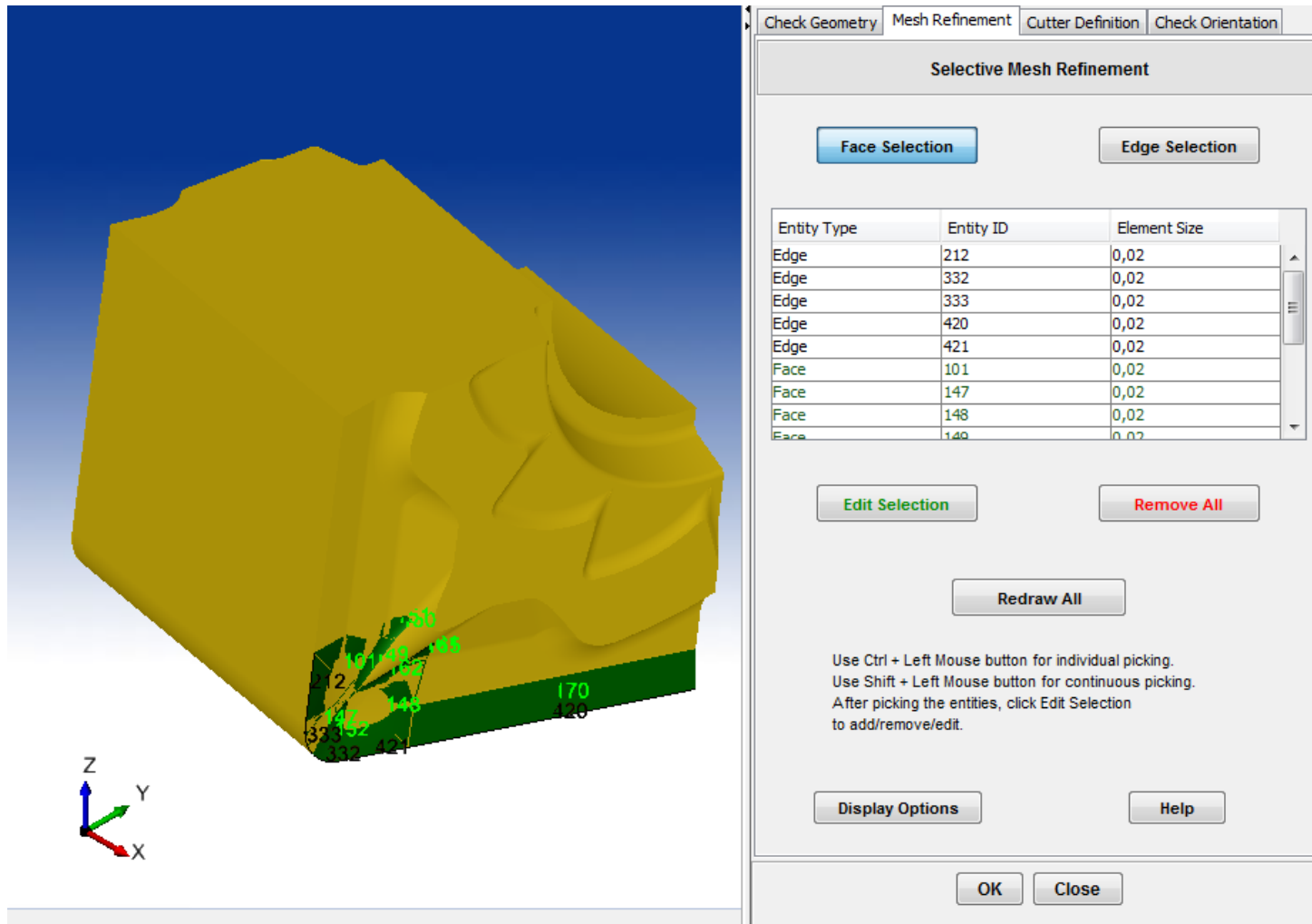
* Warning: Only experienced users should change these parameters. Modifying these parameters can significantly affect the mesh quality and performance.

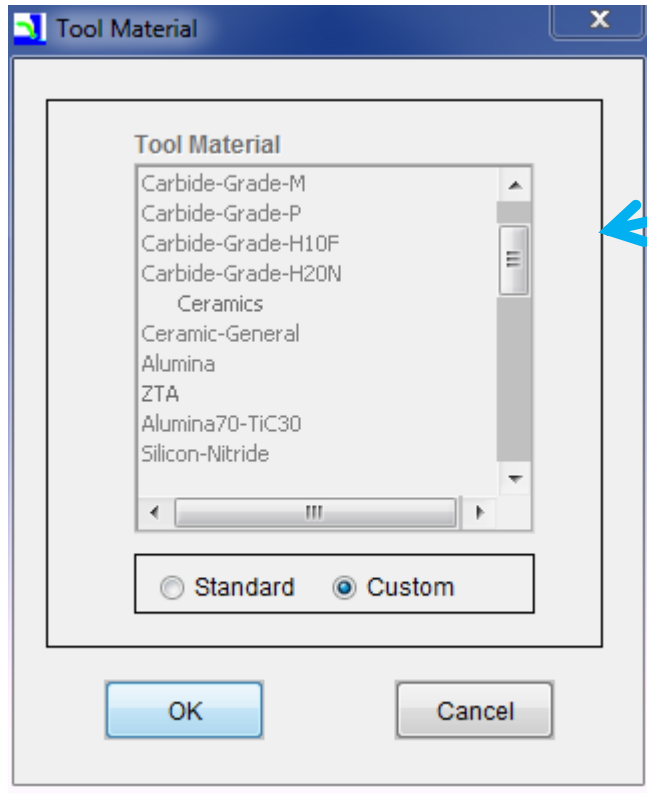
OK Cancel Help

✓ Advanced Options

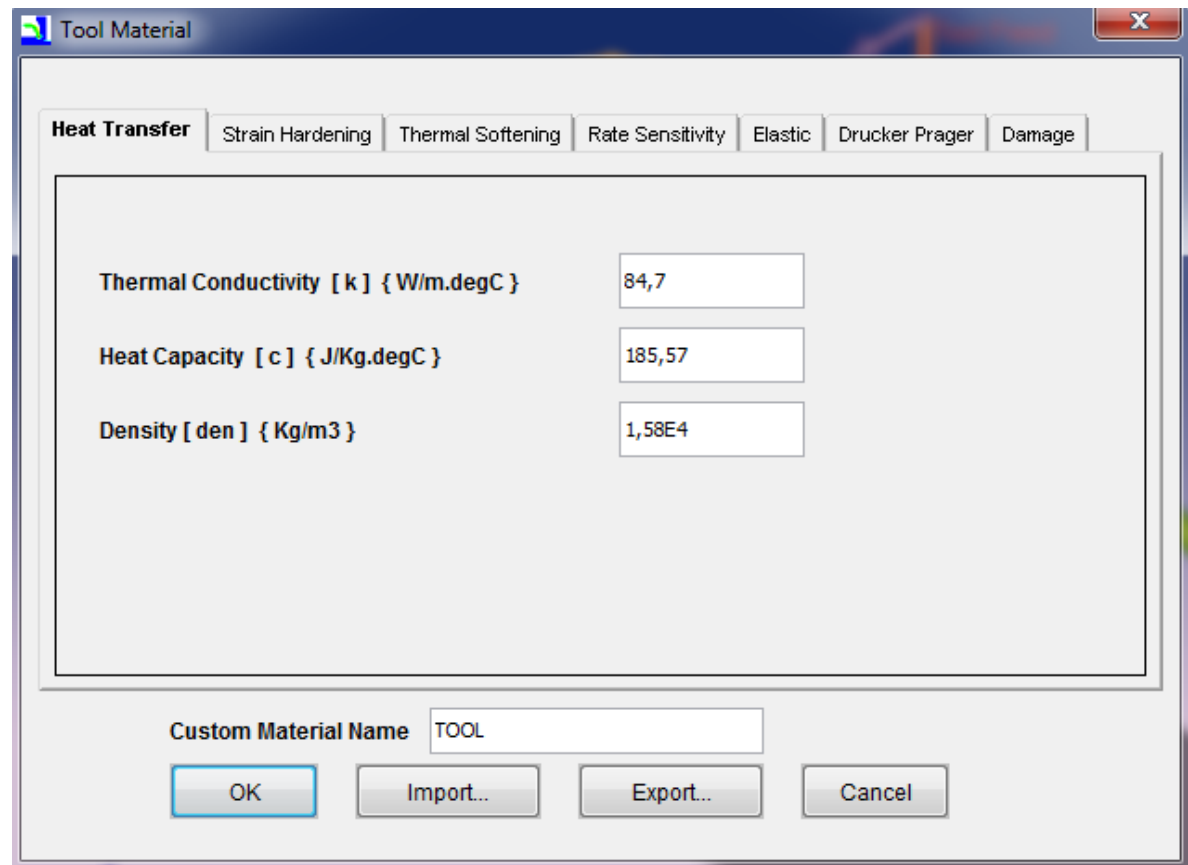



✓ Check/Orient Tool





✓ Tool Material



✓ Custom Material

Tool Coating Parameters

No. of coating layers: 3

Layer	Material	Thickness {mm}
1		5E-4
2		0,002
3		0,002

☐ Standard ☒ Custom

OK Cancel

✓ Tool Coating Parameters

Coating1 Material

Heat Transfer Strain Hardening Thermal Softening Rate Sensitivity Elastic Drucker Prager Damage

Thermal Conductivity [k] { W/m.degC } 25

Heat Capacity [c] { J/Kg.degC } 2290

Density [den] { Kg/m3 } 5240

Custom Material Name C1

OK Import... Export... Cancel

✓ Custom Coating Material

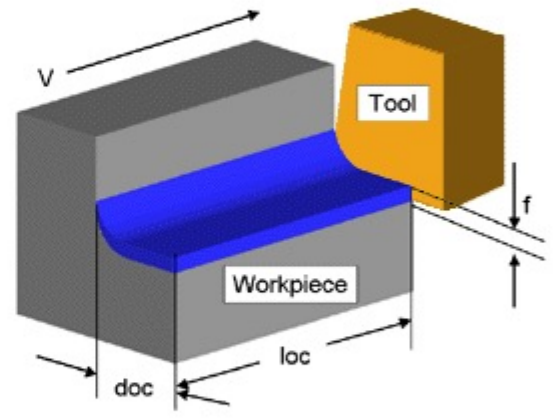
✓ Turning Process Parameters

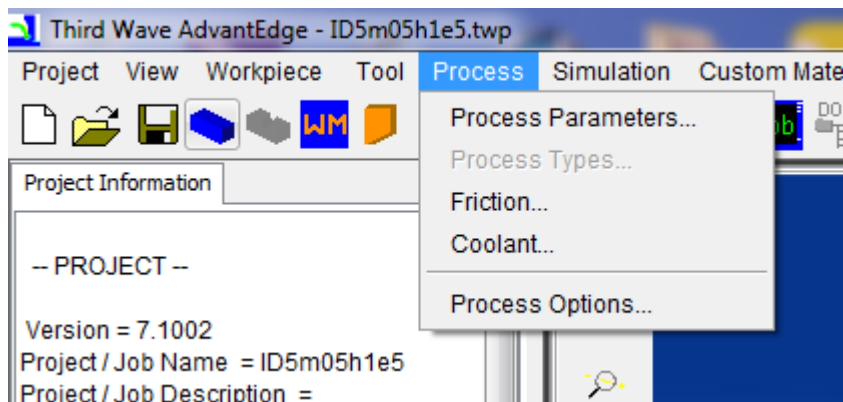
Turning Process Parameters

Parameter	Symbol	Unit	Value
Feed	[f]	{mm/rev}	0,1
Depth of cut	[doc]	{mm}	1
Length of cut	[loc]	{mm}	5
Cutting speed	[V]	{m/min}	80
Initial temperature	[To]	{degC}	20

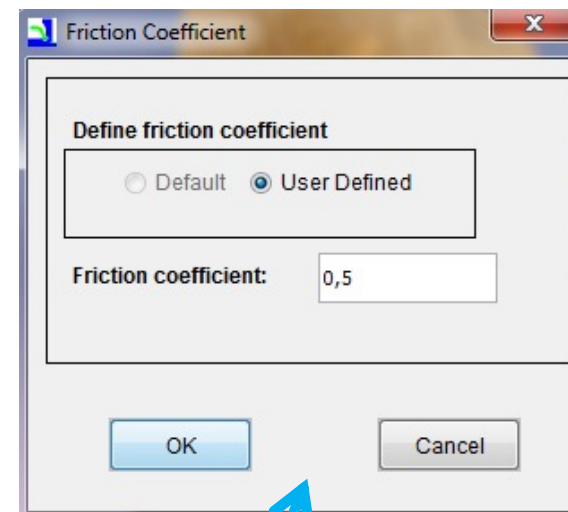
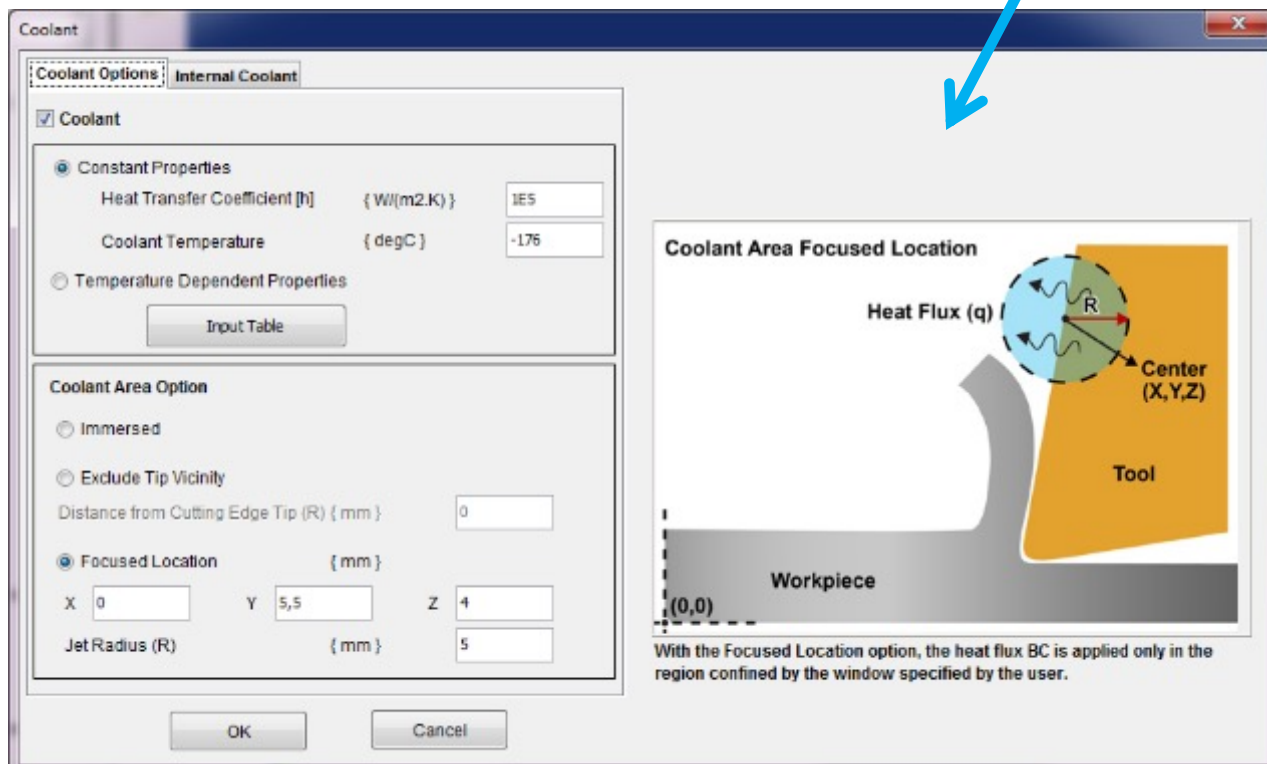
Note: Length of cut [loc] could be larger or smaller than workpiece length, but should not exceed twice the workpiece length.

OK Cancel





✓ Coolant



✓ Friction Coefficient

✓ Simulation Options

Simulation Options

General **Workpiece Meshing** Results Parallel

Caution Only experienced users should change the parameters below. Modifying these parameters can significantly affect performance and accuracy

Minimum / maximum element size

Min. elem. edge length (chip bulk)	{mm}	0,03966
Min. elem. edge length (cutter edge)	{mm}	0,03033
Radius of refined region (cutter edge)	{mm}	0,15

Adaptive remeshing

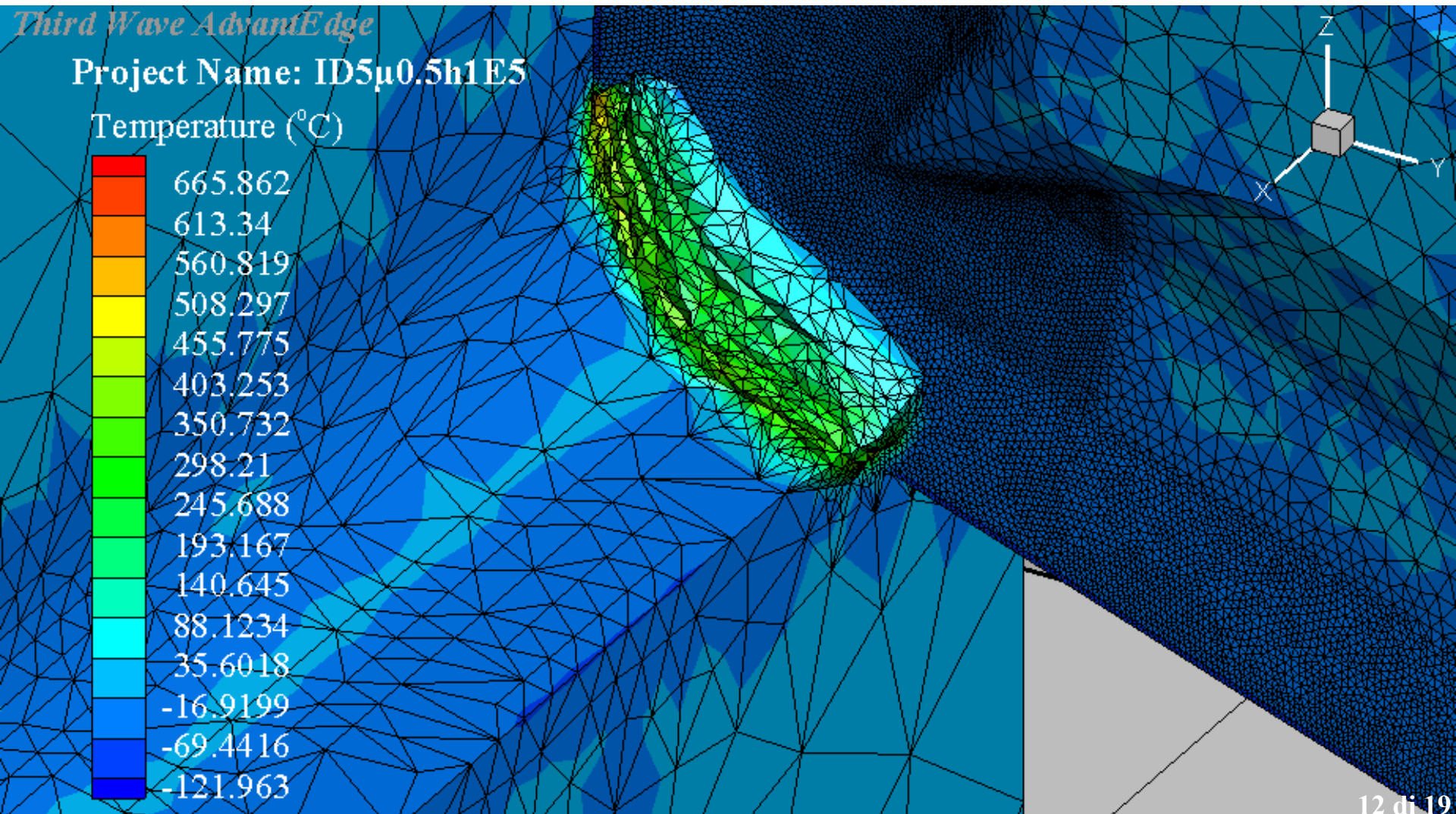
Mesh refinement factor	1	Coarse
Mesh coarsening factor	5	Default
Chip refinement factor	1	Coarse
Grading near cutting edge	6	
Grading radius factor	1	

Depth of mesh refinement for residual stress analysis

Depth in Y axis	{mm}	0,45
Depth in Z axis	{mm}	0,45

OK Cancel

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

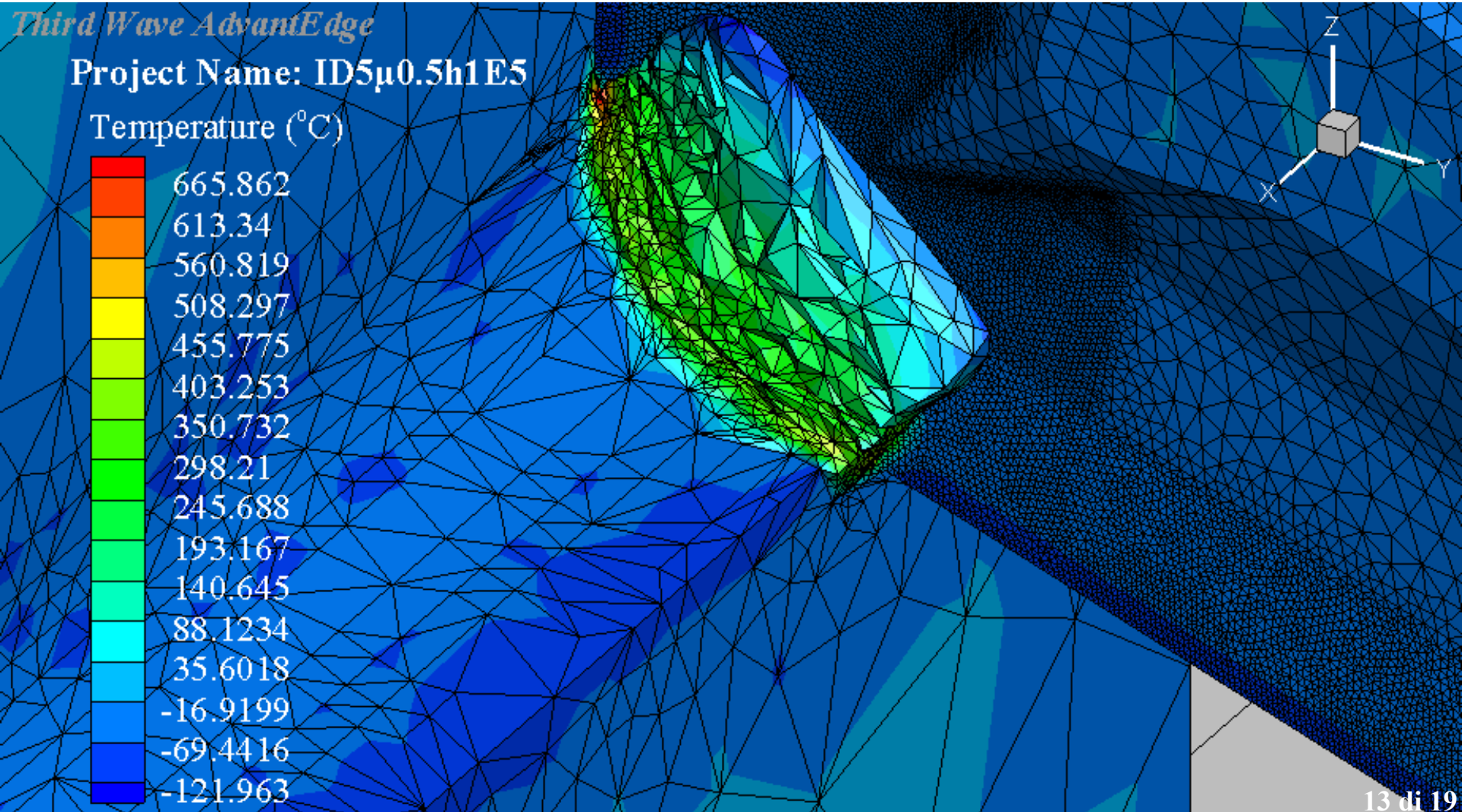
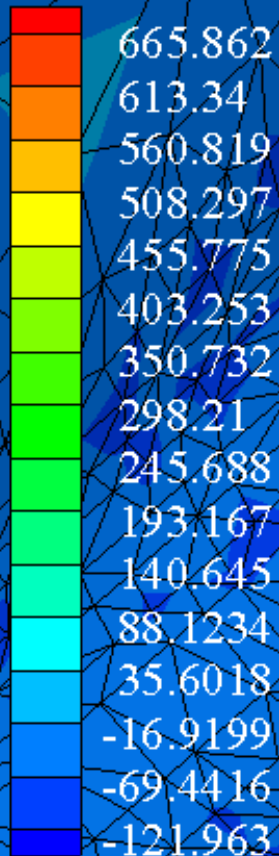


✓ $F=0.10$ [mm/rev] $S=80$ [m/min] - Length of cut = 2 mm

Third Wave AdvantEdge

Project Name: ID5 μ 0.5h1E5

Temperature ($^{\circ}\text{C}$)

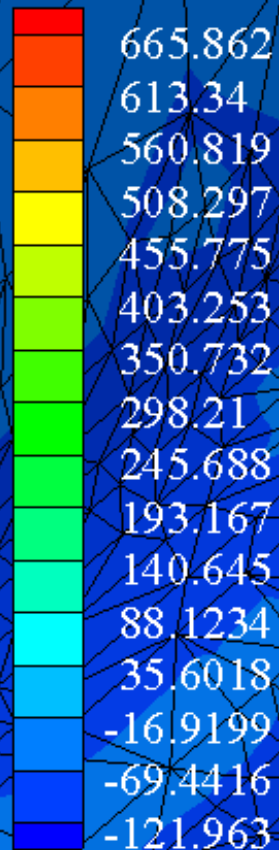


✓ $F=0.10$ [mm/rev] $S=80$ [m/min] - Length of cut = 3 mm

Third Wave AdvantEdge

Project Name: ID5 μ 0.5h1E5

Temperature (°C)

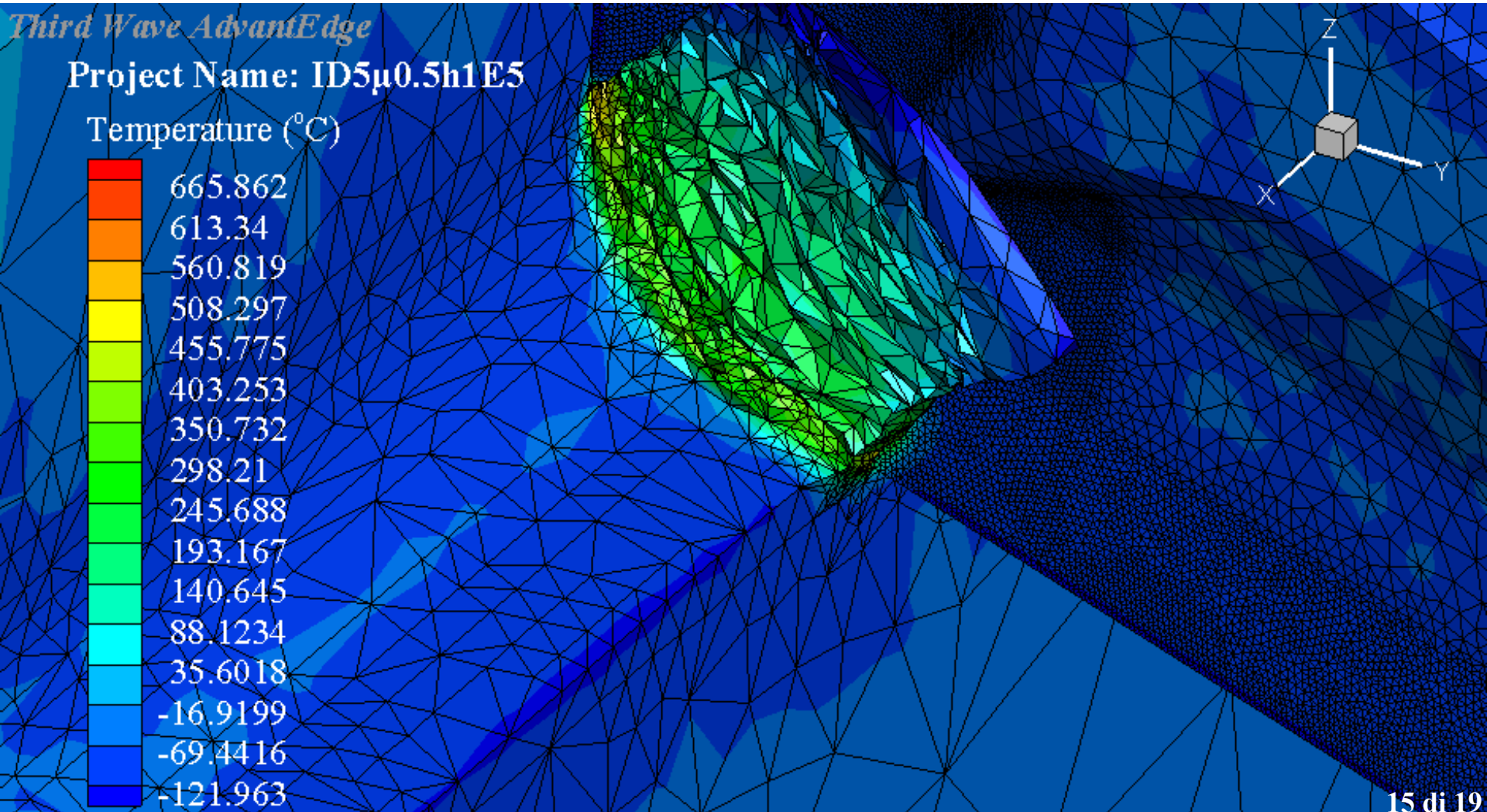
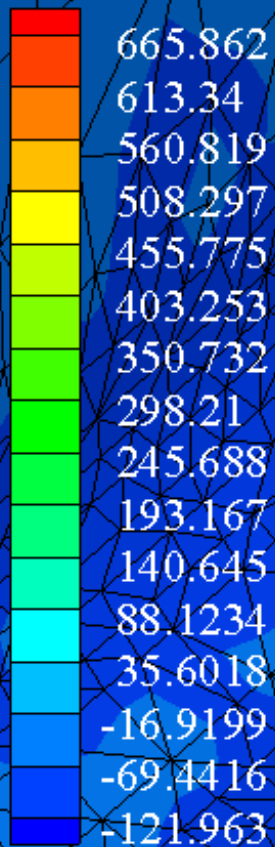


✓ $F=0.10$ [mm/rev] $S=80$ [m/min] - Length of cut = 4 mm

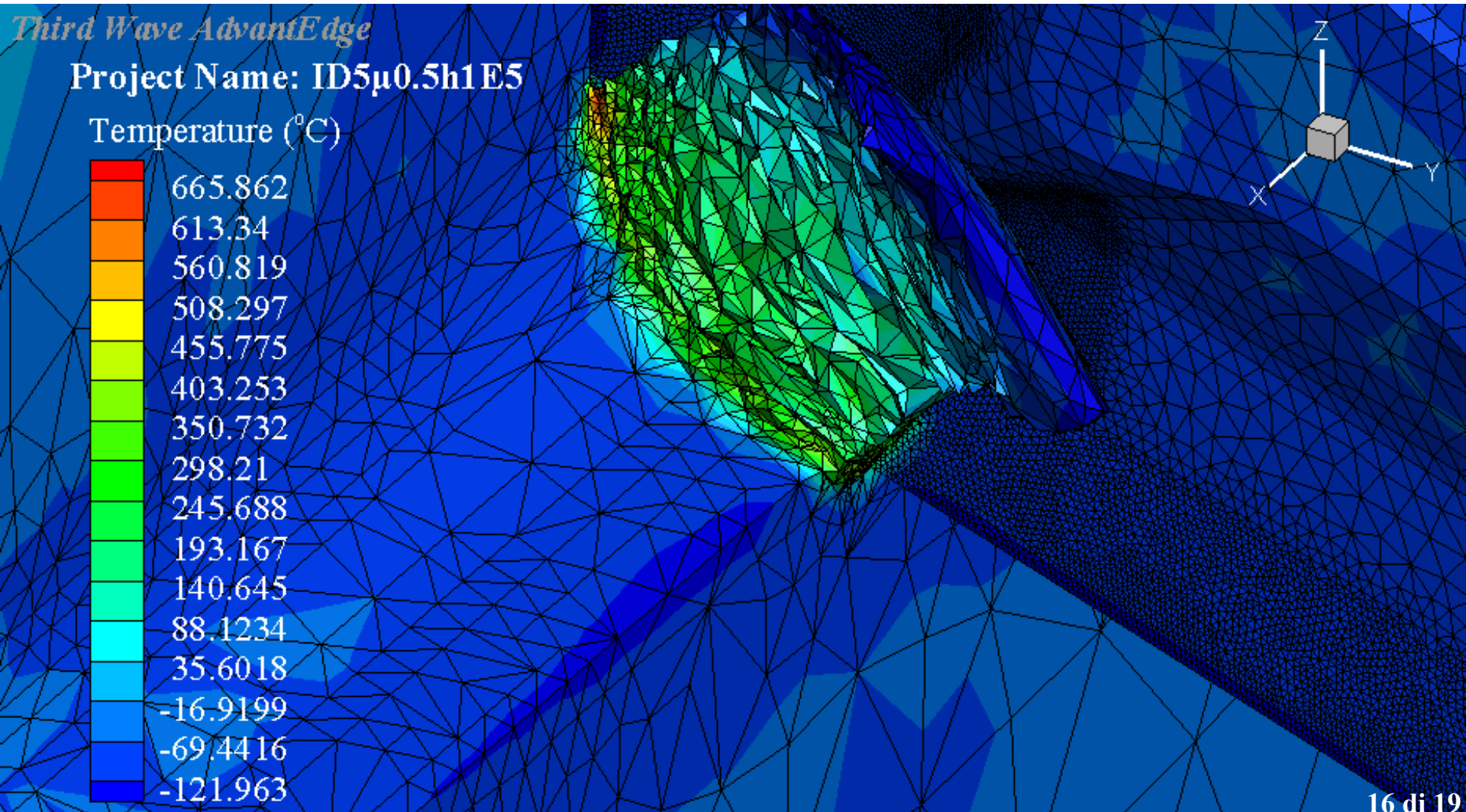
Third Wave AdvantEdge

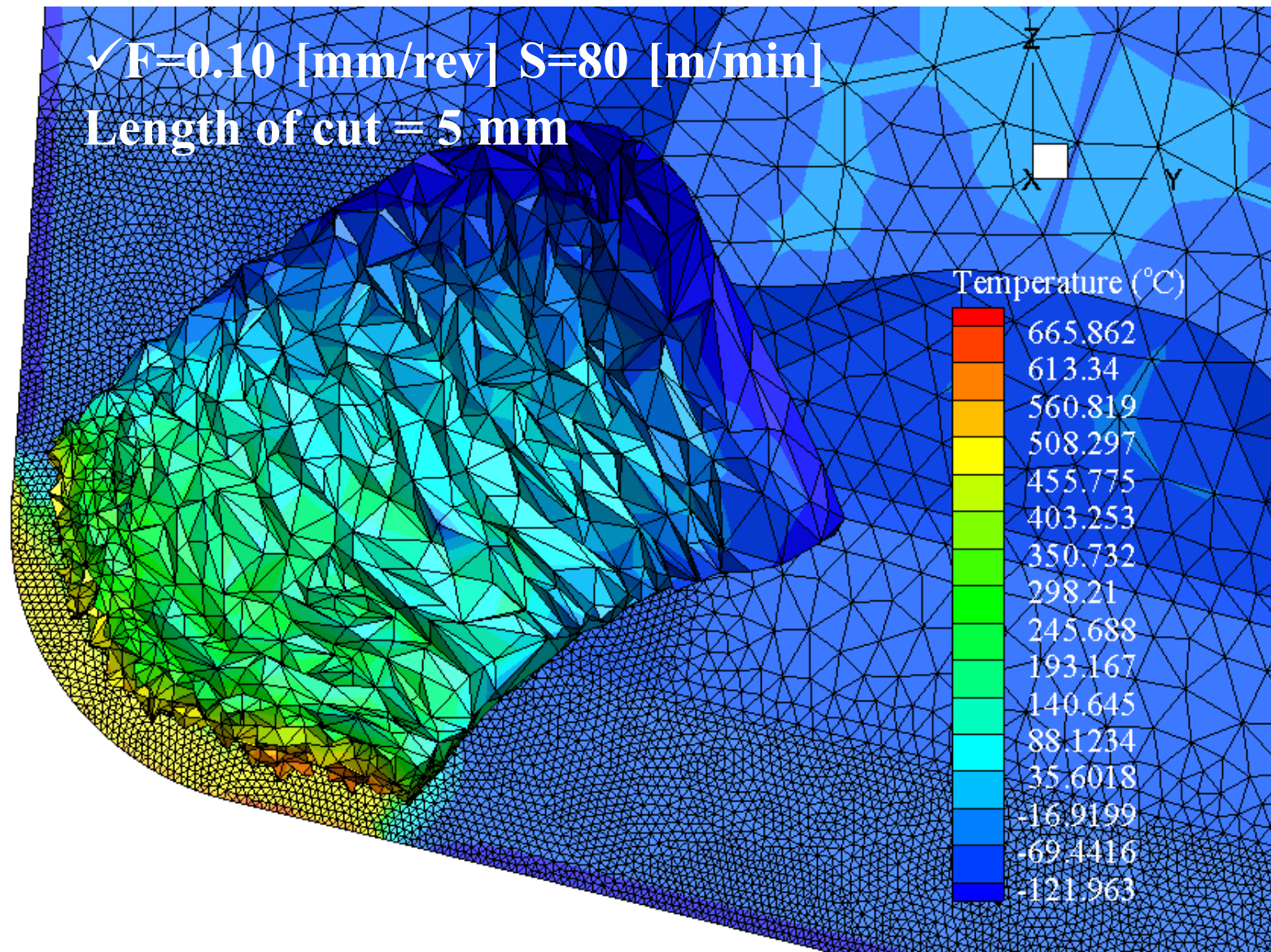
Project Name: ID5 μ 0.5h1E5

Temperature (°C)

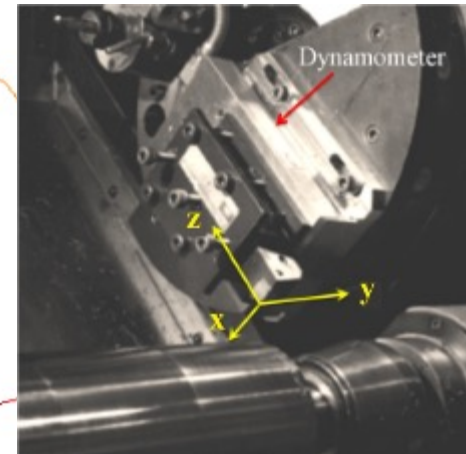
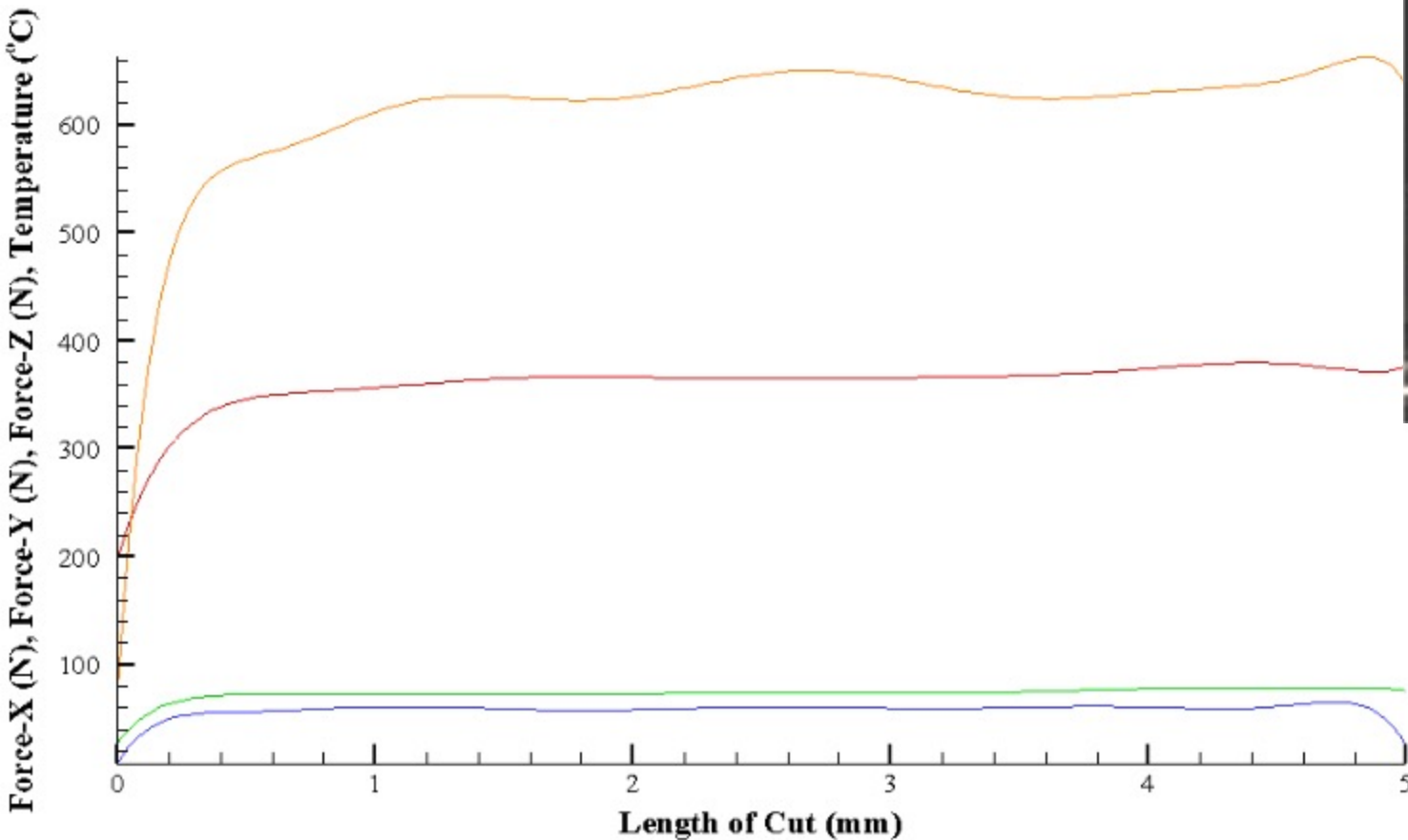


✓ $F=0.10$ [mm/rev] $S=80$ [m/min] - Length of cut = 5 mm



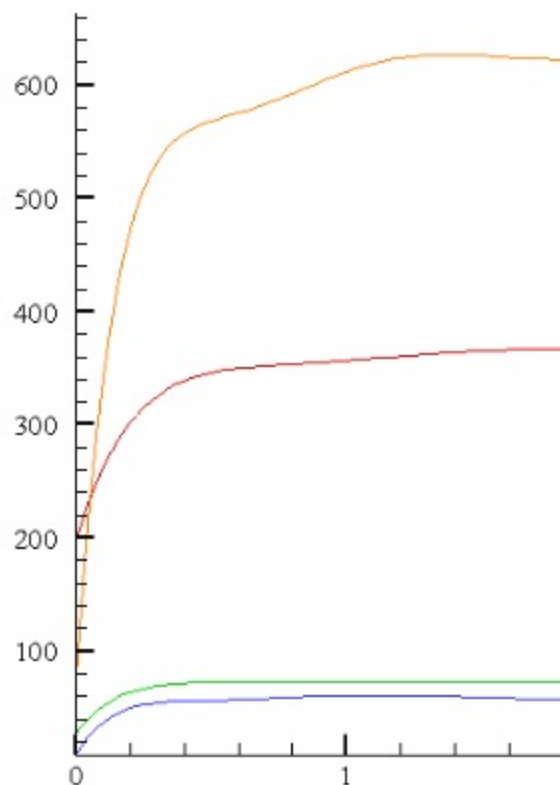


✓ Forces and max temperature



Force-X (N)
Force-Y (N)
Force-Z (N)
Temperature (°C)

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

Zone(s):

1 ZONE 001

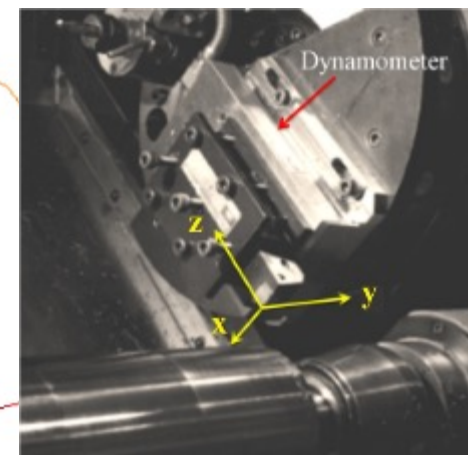
Variable(s):

- 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 (°C)

Layout Association

- ☐ Associate Layout with Newly Saved Data File

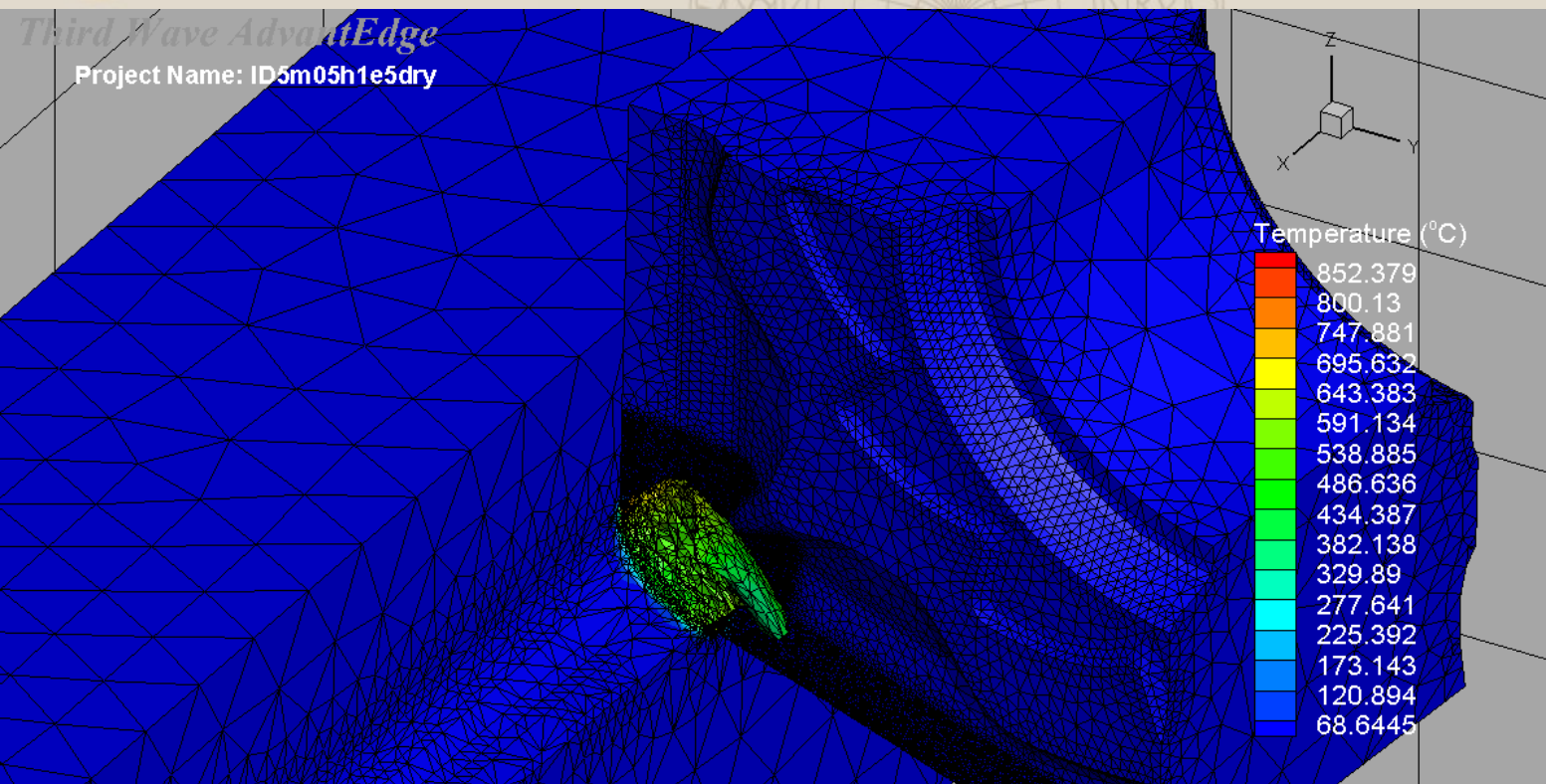
OK Cancel Help



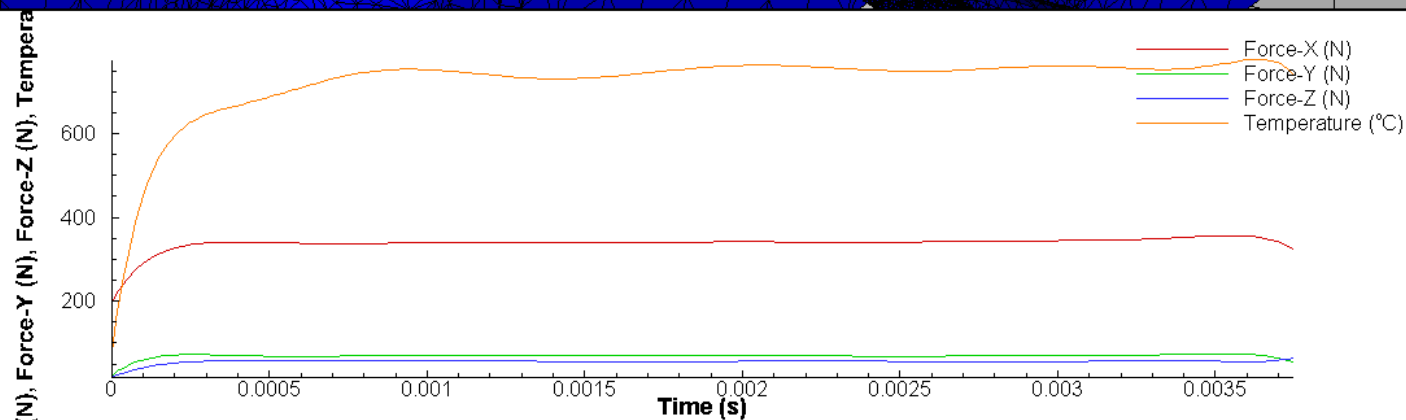
Force-X (N)
Force-Y (N)
Force-Z (N)
Temperature (°C)

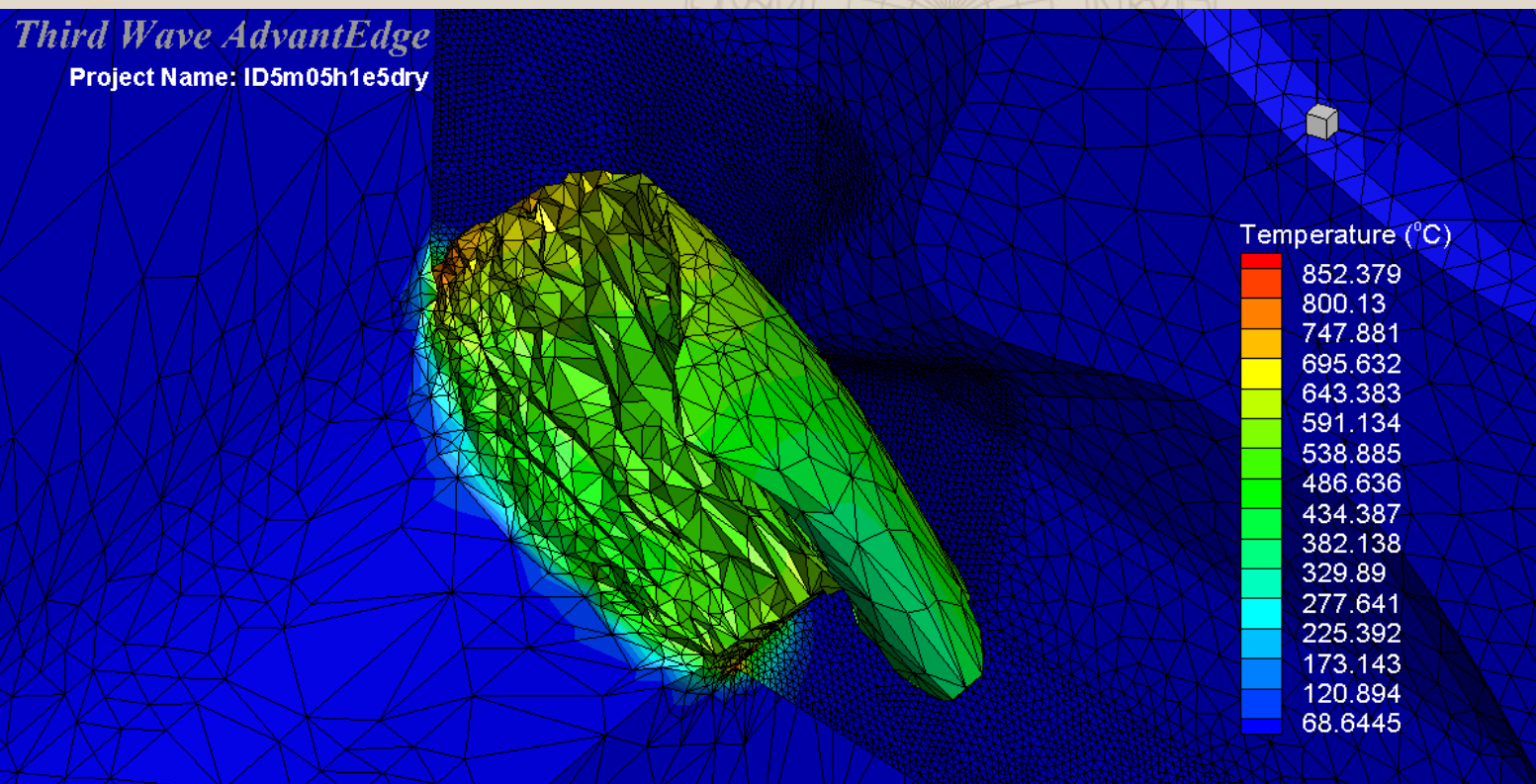
Third Wave AdvantEdge

Project Name: ID5m05h1e5dry

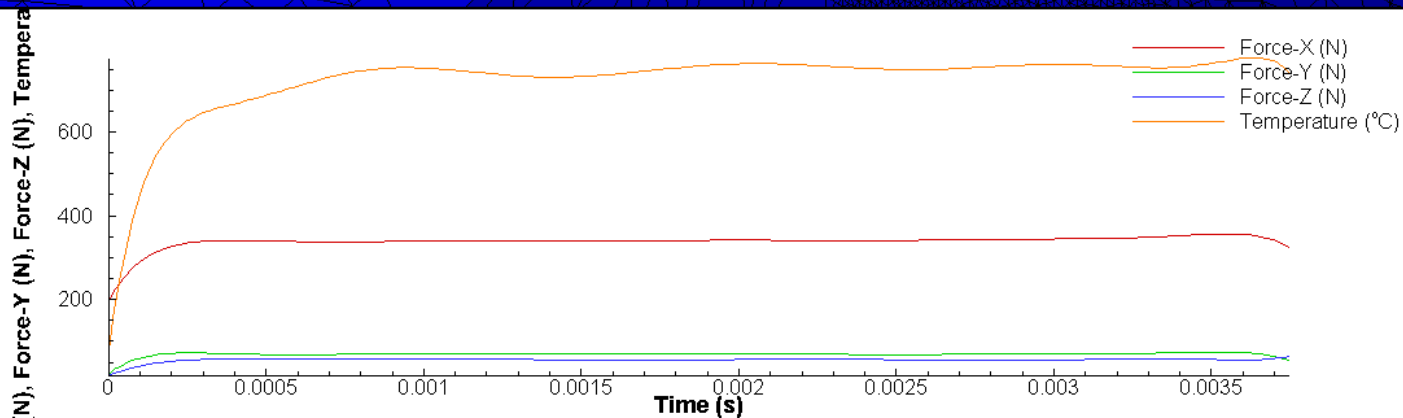


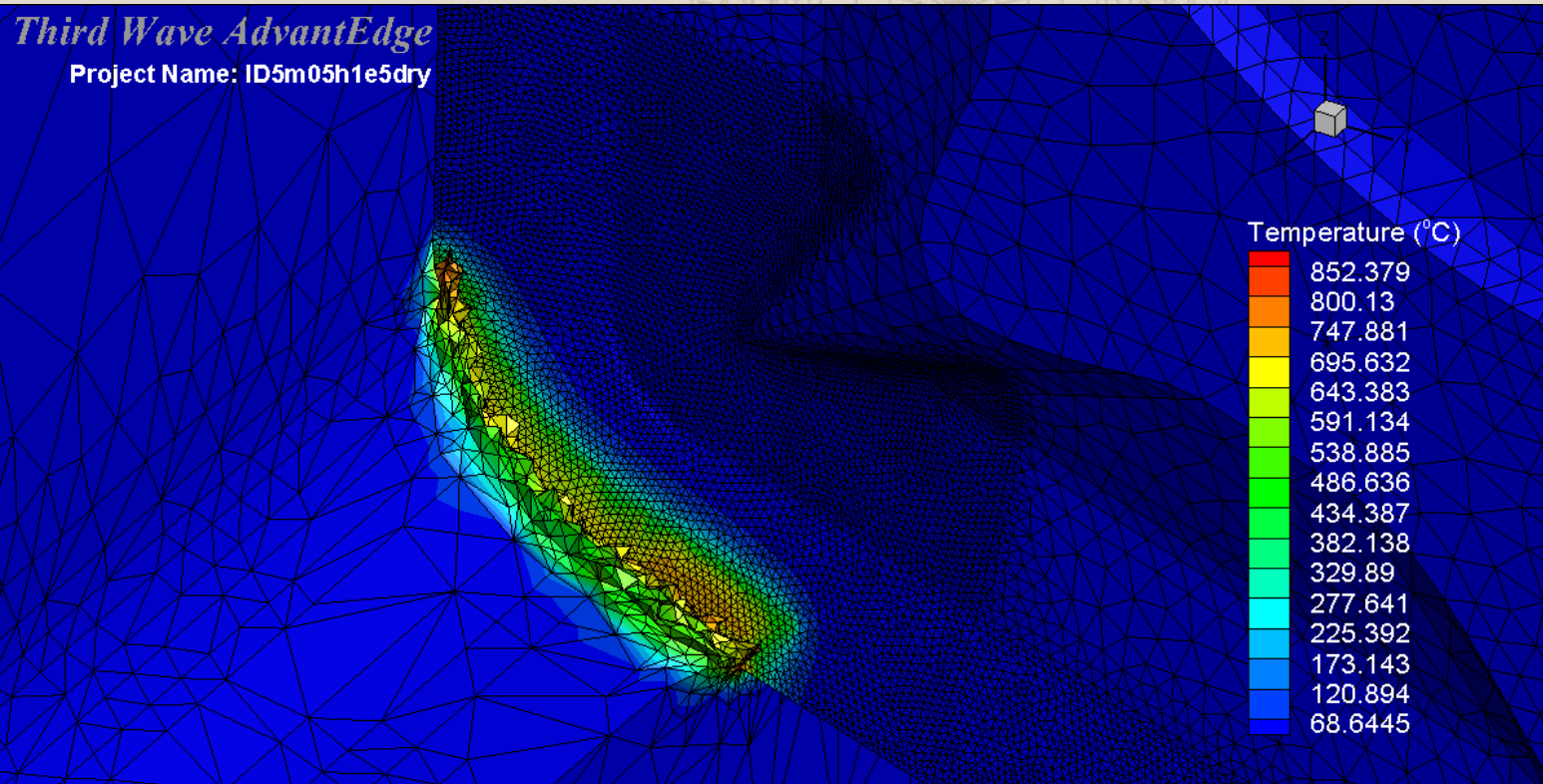
Dry machining



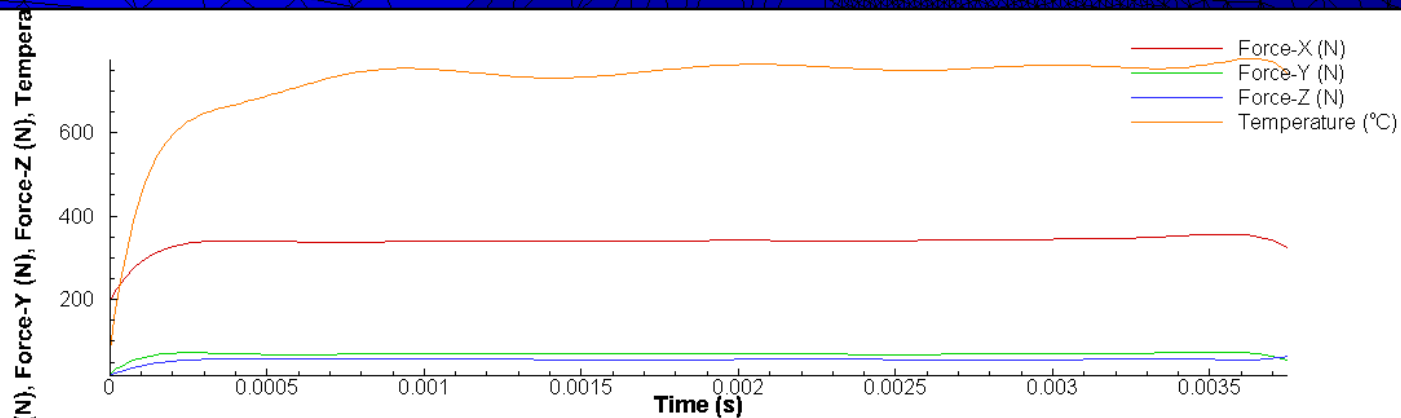


Dry machining





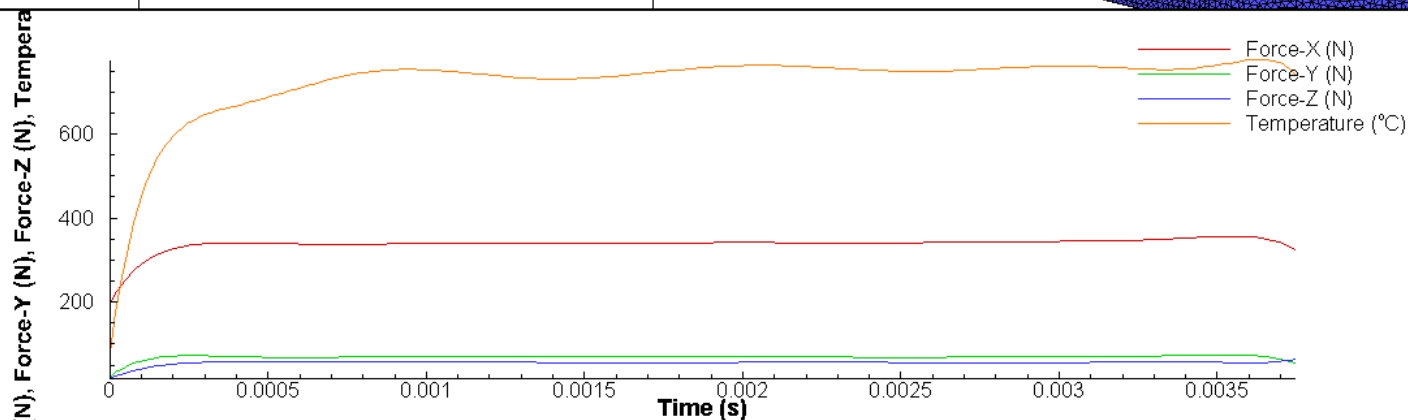
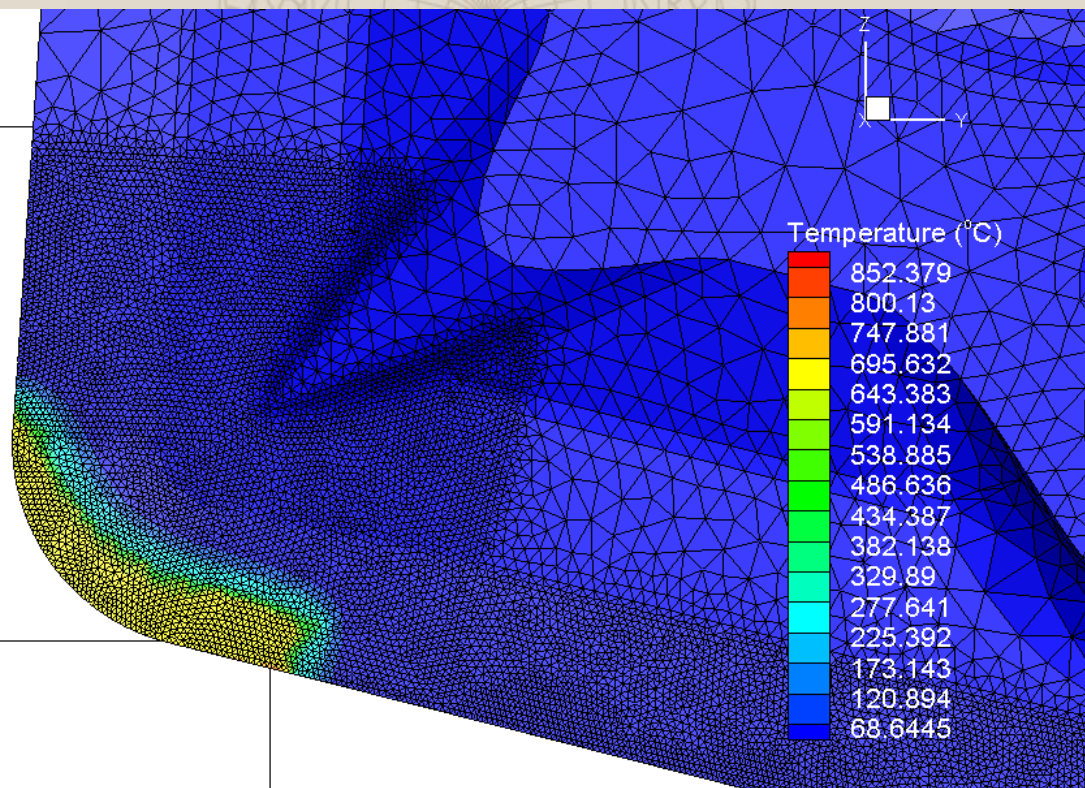
Dry machining



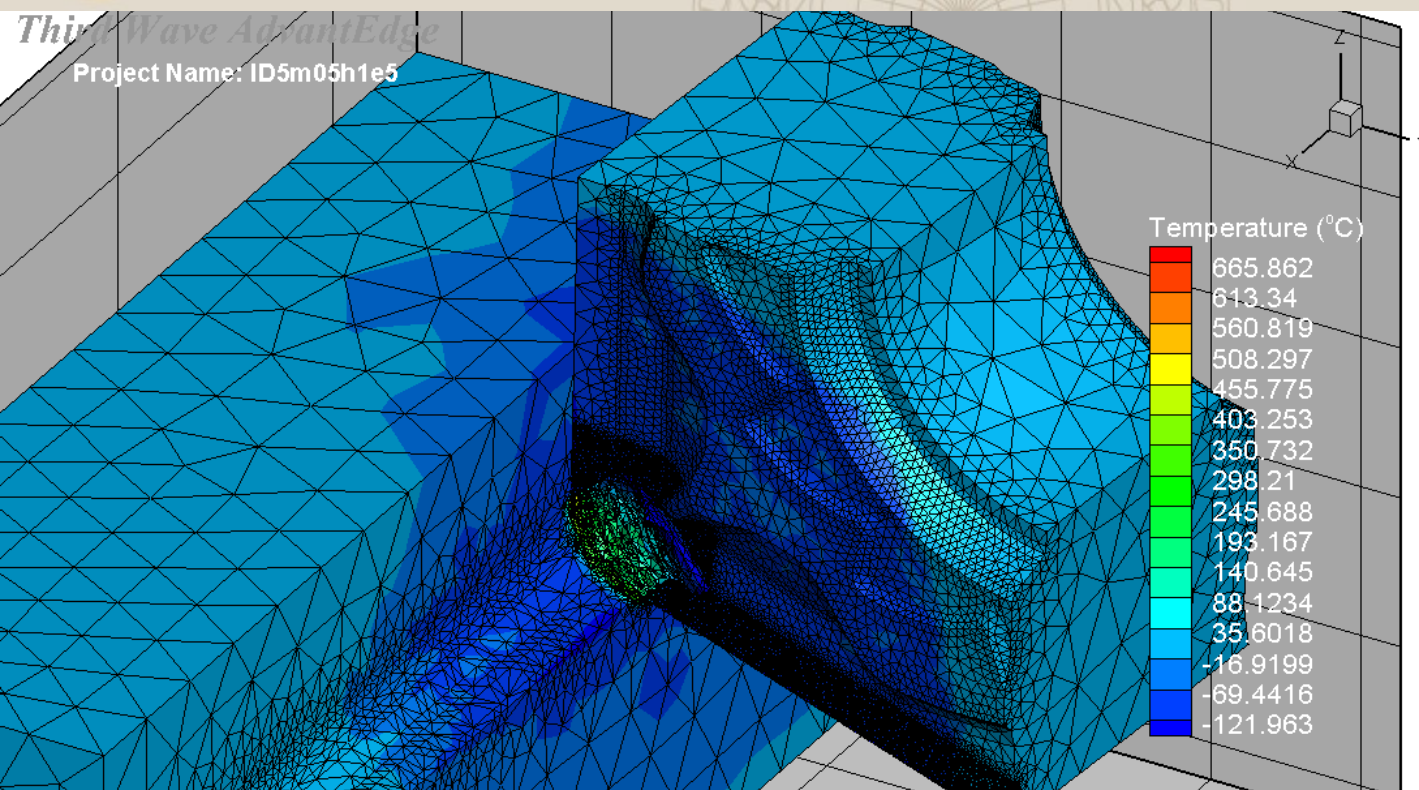
Third Wave AdvantEdge

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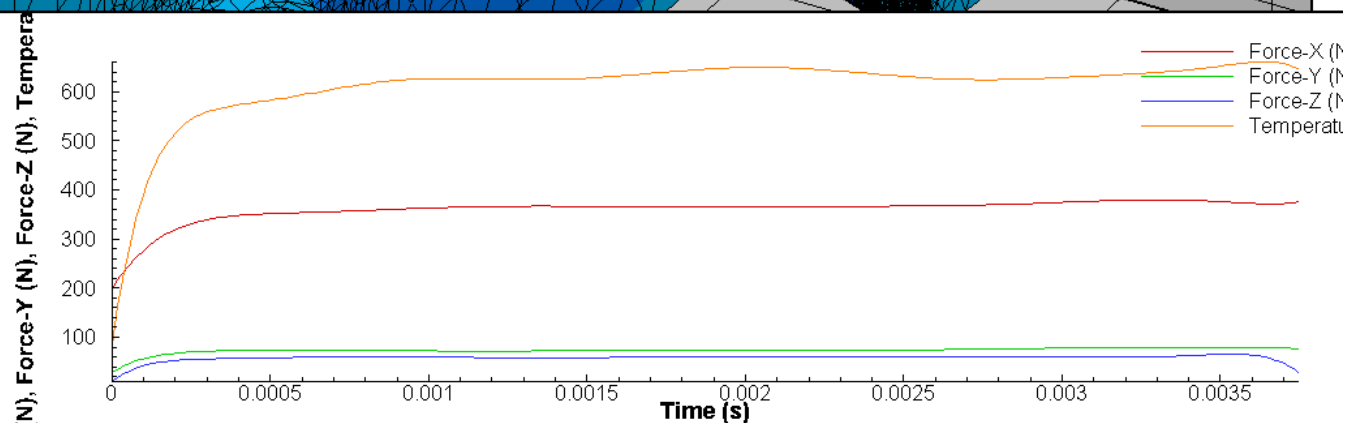
Dry machining



Thin Wave AdvantEdge
Project Name: ID5m05h1e5

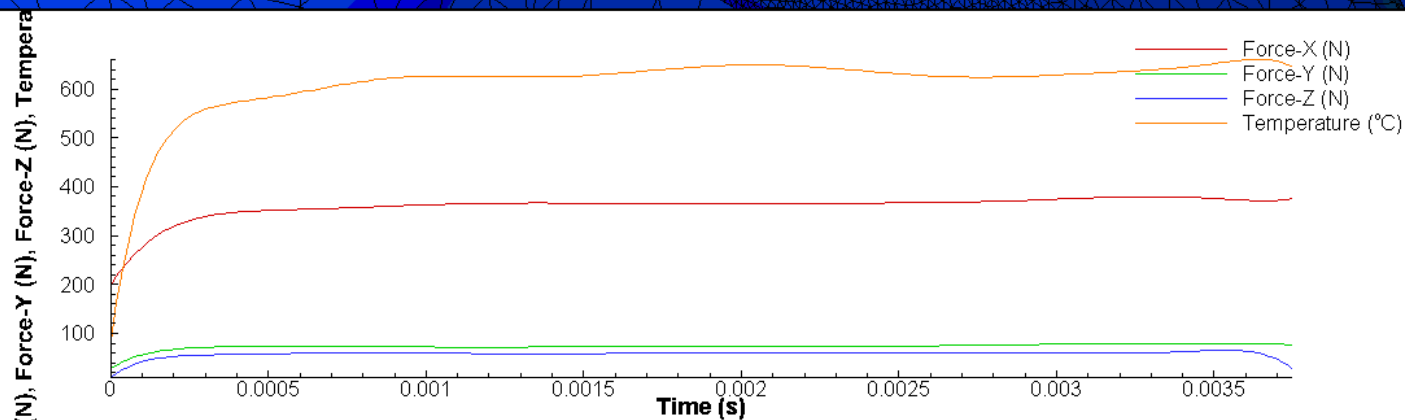
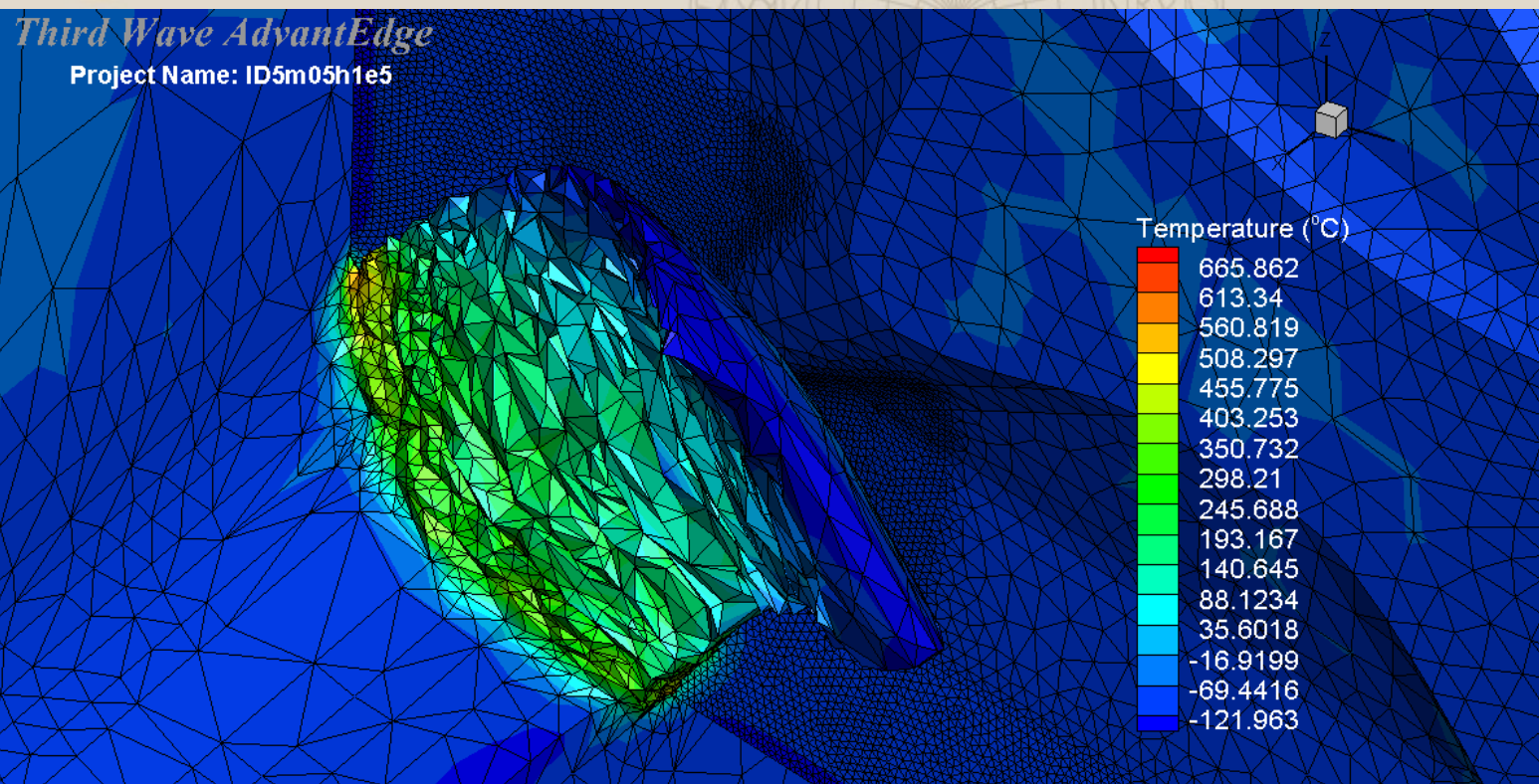


Cryogenic machining

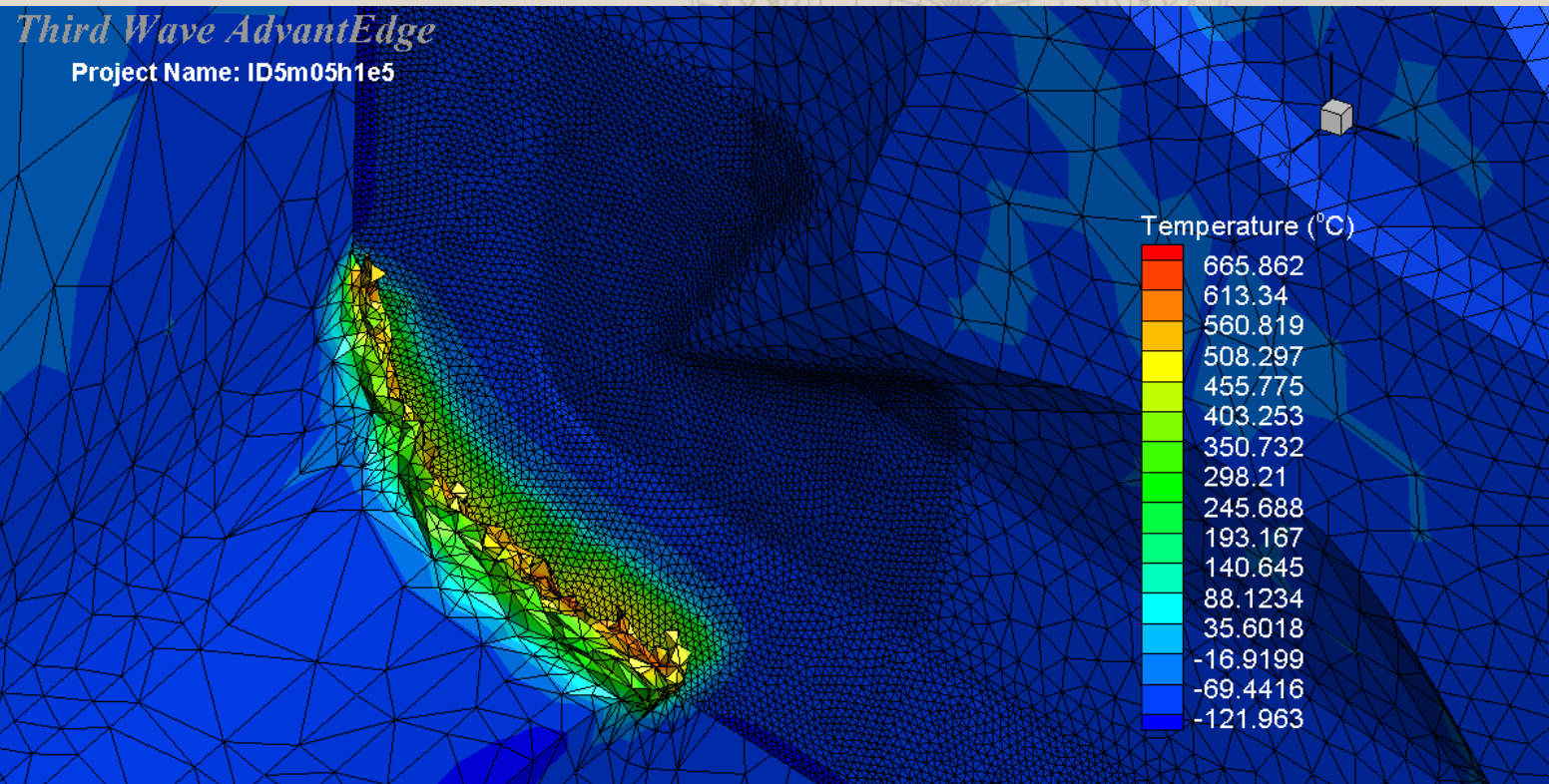


Third Wave AdvantEdge

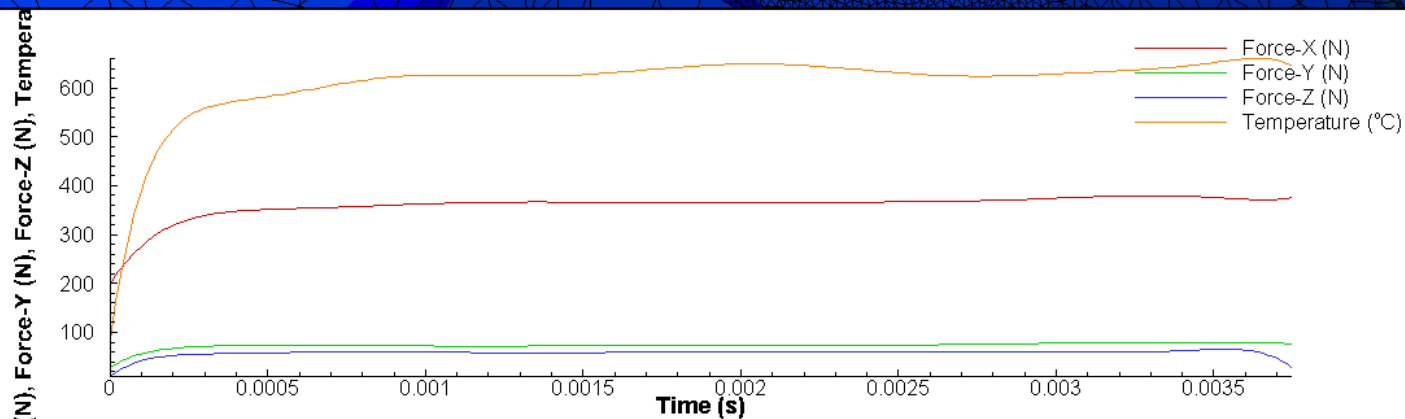
Project Name: ID5m05h1e5



Cryogenic machining



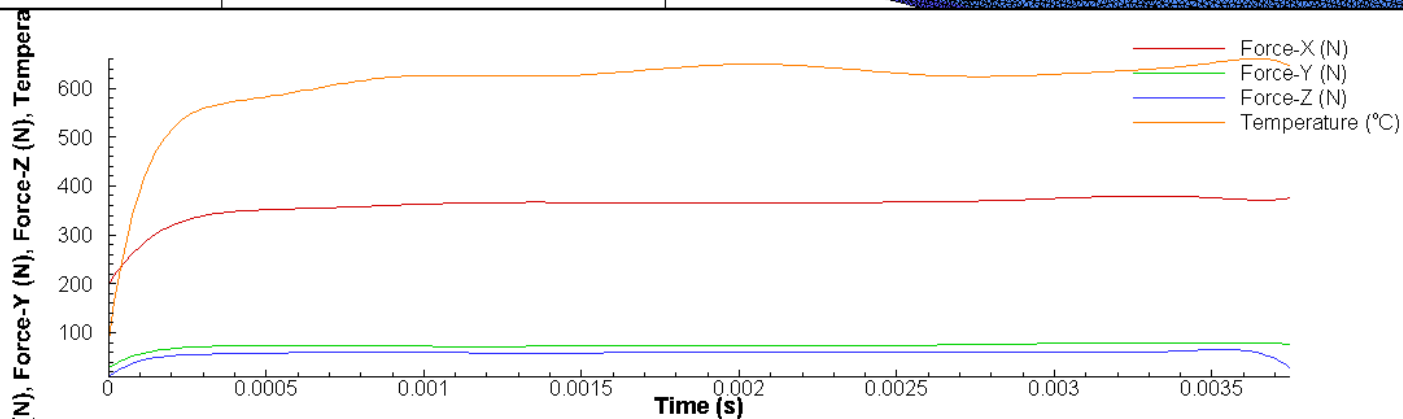
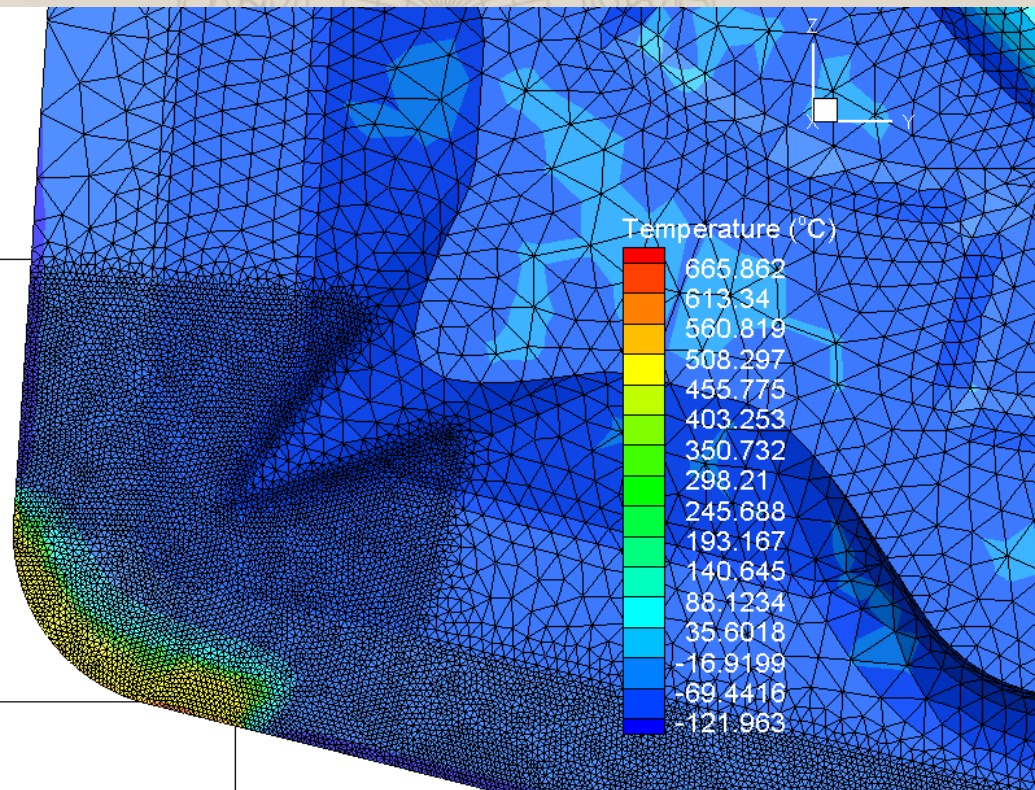
Cryogenic machining



Third Wave AdvantEdge

Project Name: ID5m05h1e5

Cryogenic machining



Conclusions...

- With LN₂: temperature lower than 120K;
- LN₂ absorb heat and evaporate;
- LN₂ is an inert gas;
- LN₂ 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.

