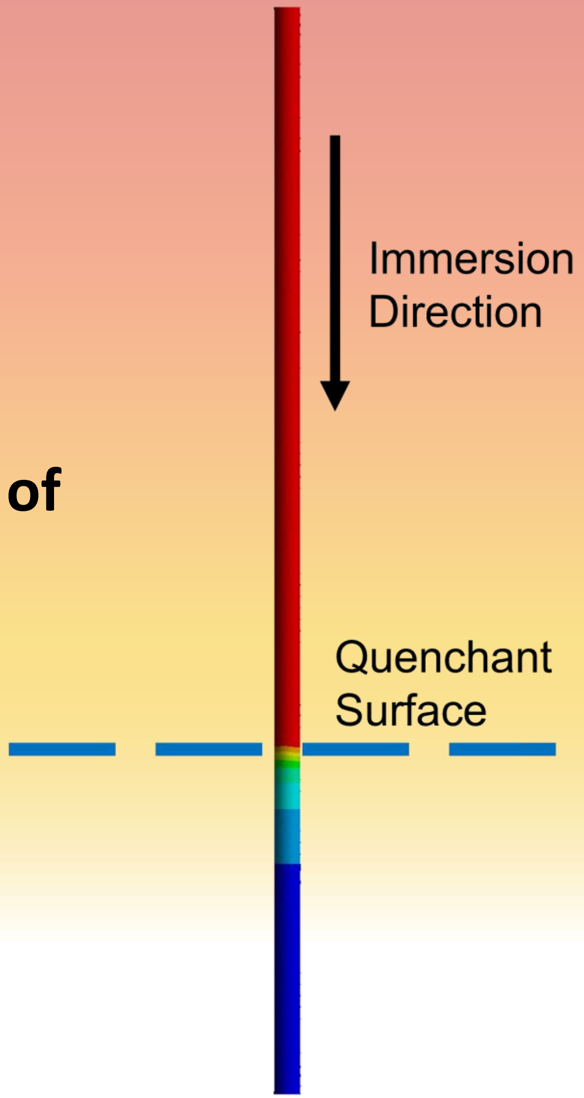
Immersion Quenching of Long Components

Using DANTE and ANSYS to evaluate the effects of simulating the immersion process for long components



Introduction

Liquid quenching of long steel components can introduce significant distortion if the component is not lowered into the liquid quench bath properly. Whether the liquid quenchant is oil, water, or a polymer solution, the angle and rate of immersion can have a significant effect on the final distortion. Heat-treatment simulation software can provide insight into how a long component will behave during heat-treatment, but only if the immersion process is simulated. The simulation of relatively small steel components assumes that the entire part enters the quench bath simultaneously. This assumption is valid for most bearing rings, gears, etc., since the entire part is submerged within the quenchant in a fraction of a second. However, the assumption begins to lose its validity when applied to relatively long parts.

To show the significance of simulating the immersion process during quench hardening of relatively long steel components, a 500 mm long, 12 mm diameter steel bar made of AISI 9310 was constructed and meshed in Ansys and the heat-treatment process was modeled using the heat-treatment simulation software DANTE. Several immersion rates were compared to a bar that was instantly lowered into the quenchant as well as a comparison between gradually lowering the bar into the quenchant vertically and horizontally.

Model and Process Description

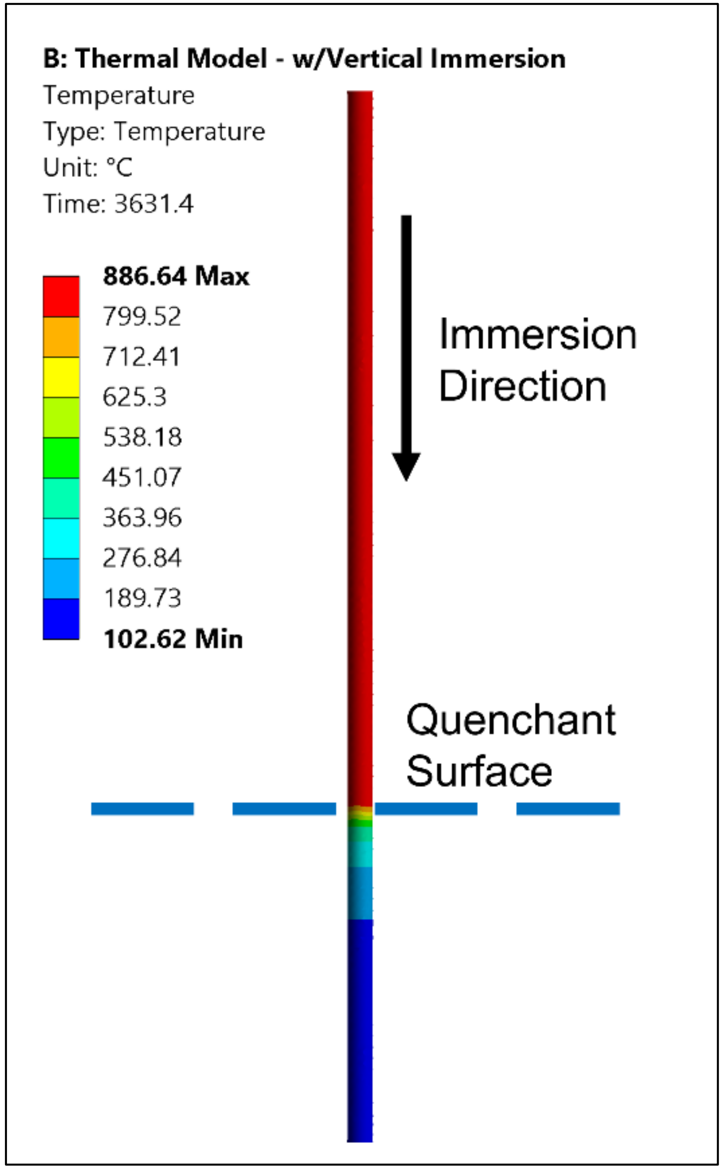
Model Description:

- Material: AISI 9310
- Bar length: 500 mm
- Bar diameter: 12 mm

Process Description:

- Several scenarios were investigated to evaluate the effects of immersion parameters on the bow distortion of the bar
  - Instantly immersed
  - Vertical immersion rate of 2.5 mm/s
  - Vertical immersion rate of 5.0 mm/s
  - Vertical immersion rate of 10.0 mm/s
  - Horizontal immersion rate of 1.0 mm/s

An algorithm in DANTE determines the location of the component relative to the quenchant surface and applies a defined air heat transfer coefficient (HTC) to the part surface above the quenchant surface and a defined liquid HTC to the part surface below the quenchant surface.

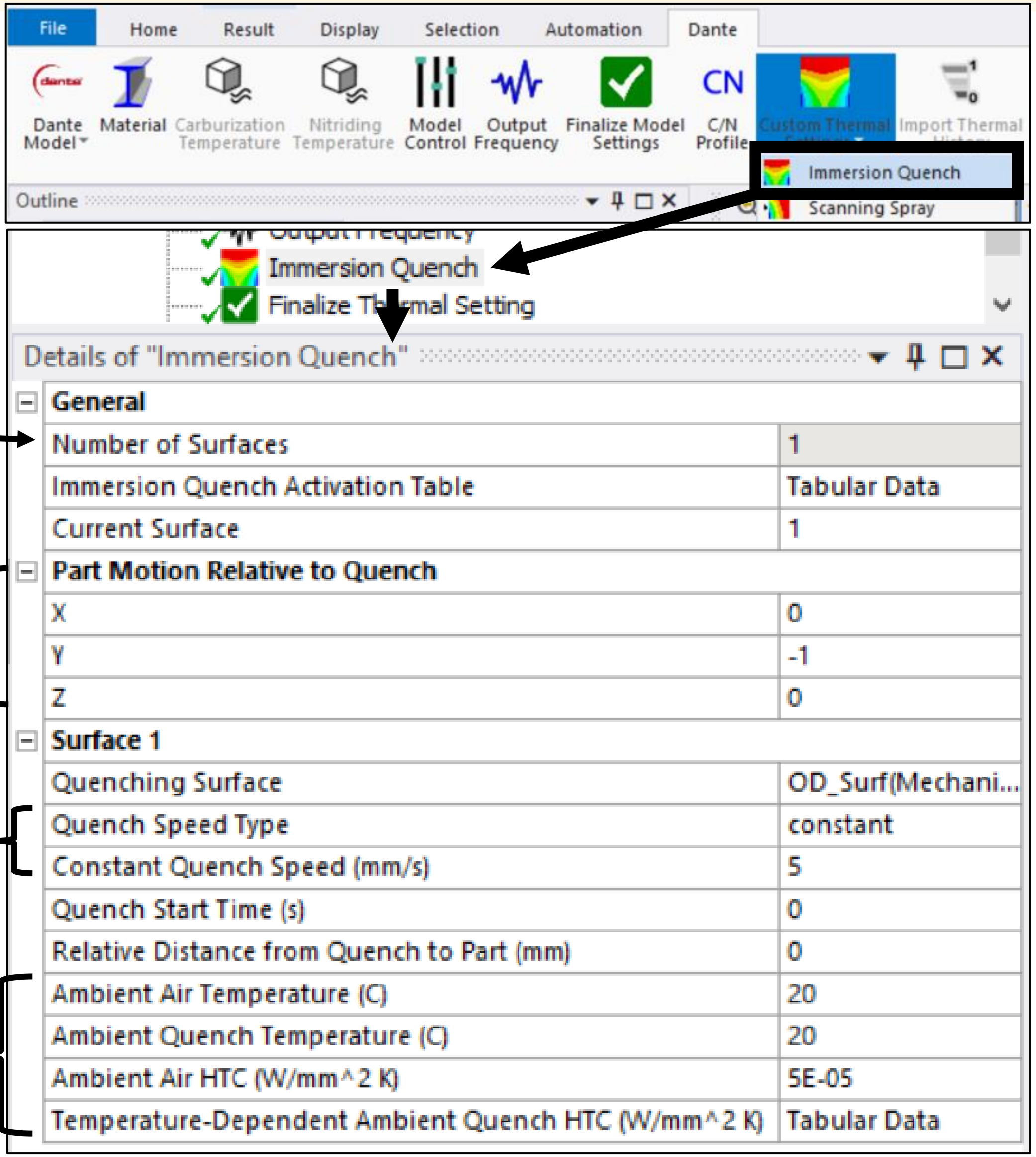


Immersion Input Parameters

DANTE makes setting up an immersion process simple by adding a Custom Thermal Setting-Immersion Quench object from the DANTE ACT and entering the process specific parameters.

<u>Modifiable immersion parameters in DANTE include:</u>

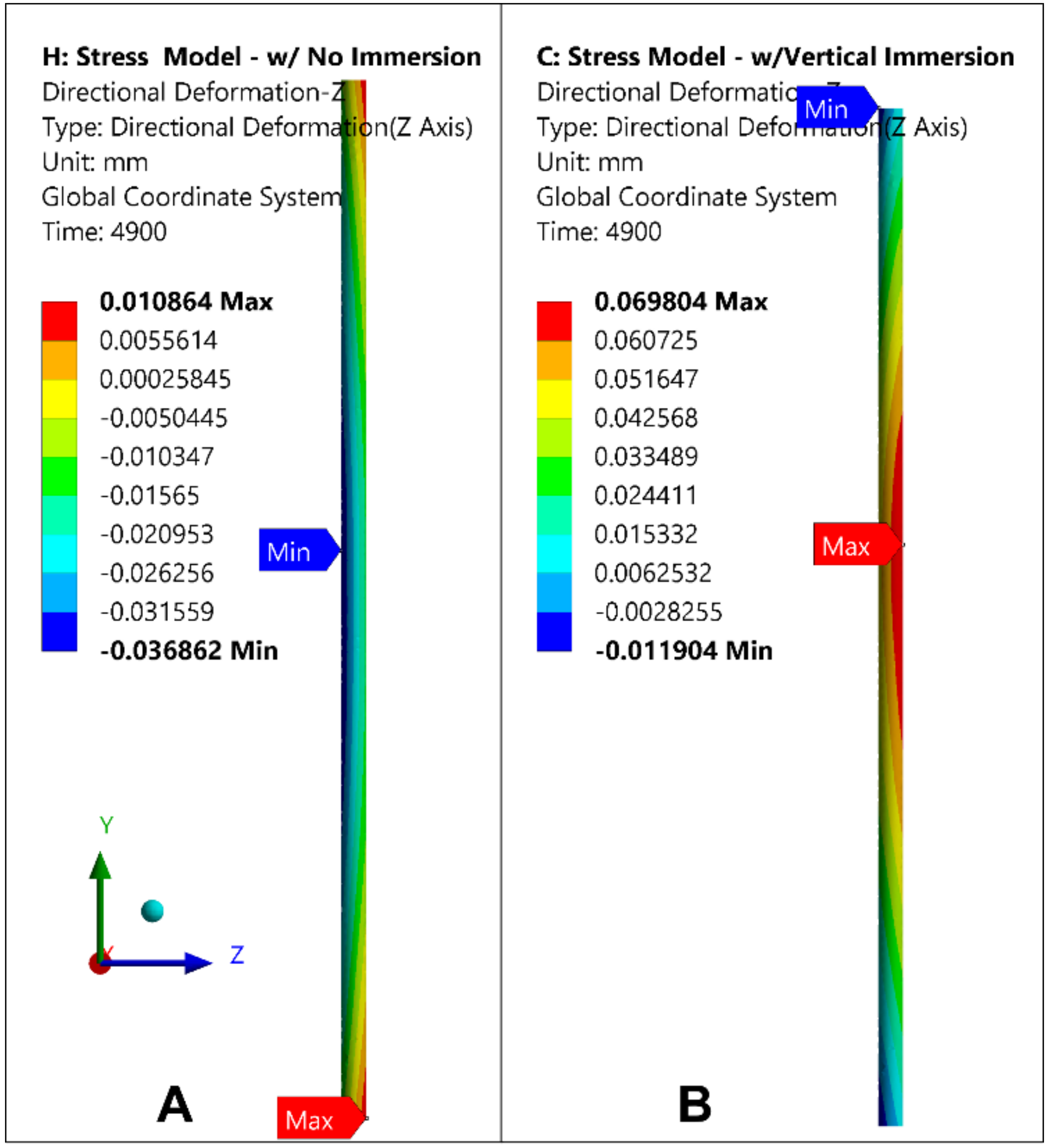
- Number of surfaces subjected to different parameters; this is useful if blind holes or other geometric features influence the flow of quenchant around the part
- Immersion direction; the immersion direction can be any angle, regardless of model orientation, with respect to the global coordinate system
- Immersion rate; the rate can be defined as a constant or as a function of time
- Heat transfer coefficient and ambient temperature of the air above the quenchant (both are constant) and the quenchant (ambient is constant, HTC is a function of part surface temperature)



Bow Distortion Comparison

No Immersion (A) vs. Immersion (B)

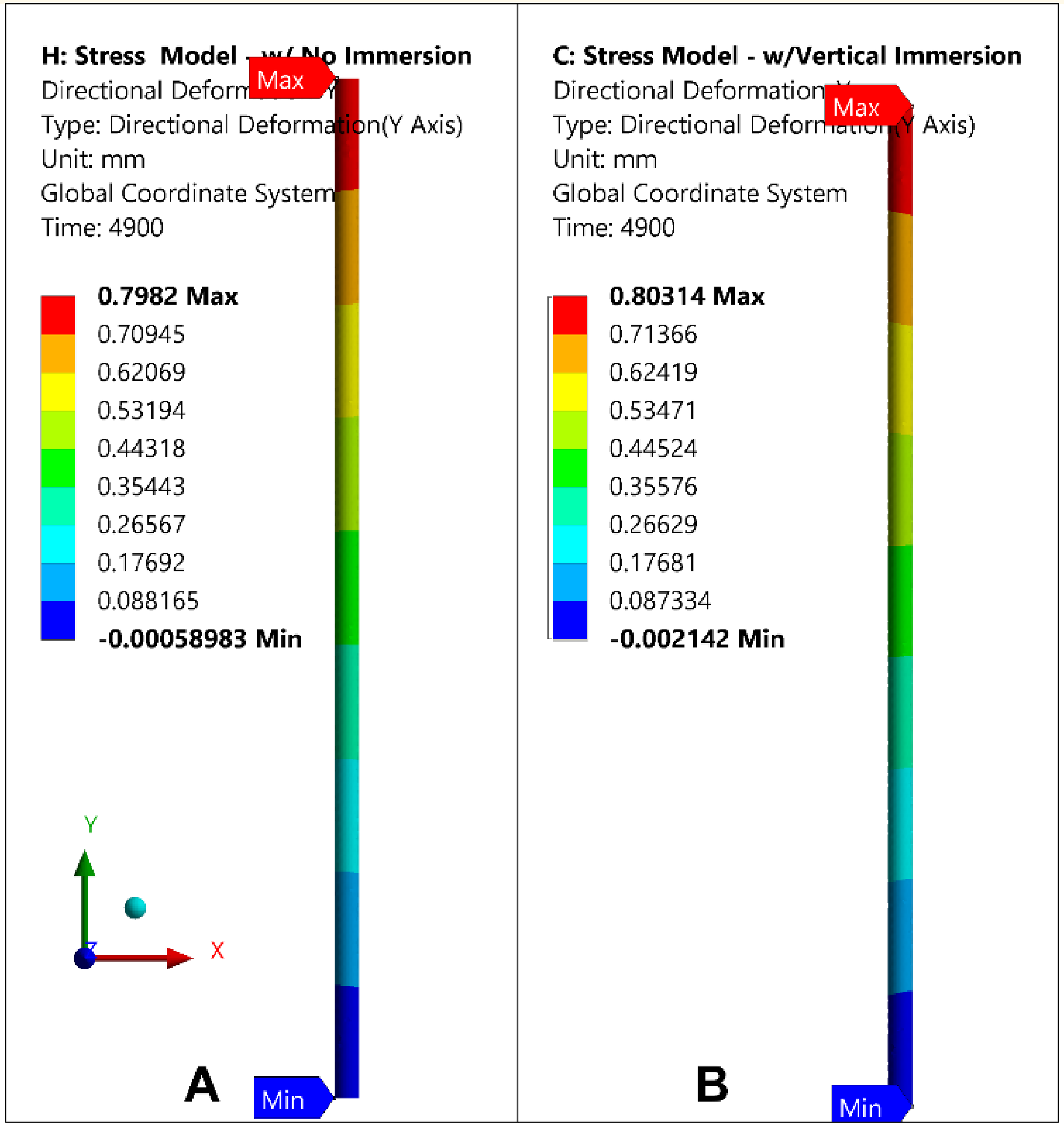
- Predicted bow distortion shown for a simulation **NOT** considering immersion (A) and a case which **DOES** consider immersion (B)
  - Without considering immersion, the part is considered to be instantaneously submerged below the quenchant surface
  - The immersion rate used in this example was 5 mm/s; meaning the 500 mm long component is fully immersed in 100 seconds
- The bow magnitude is twice as much when immersion is considered
  - Bow distortion exists in the No Immersion case due to the ends' effect on cooling uniformity
- The bow direction between the two cases is opposite
  - If immersion is ignored for this component and process, not only is the magnitude significantly underpredicted, but the direction of bow is incorrect



Axial Distortion Comparison

No Immersion (A) vs. Immersion (B)

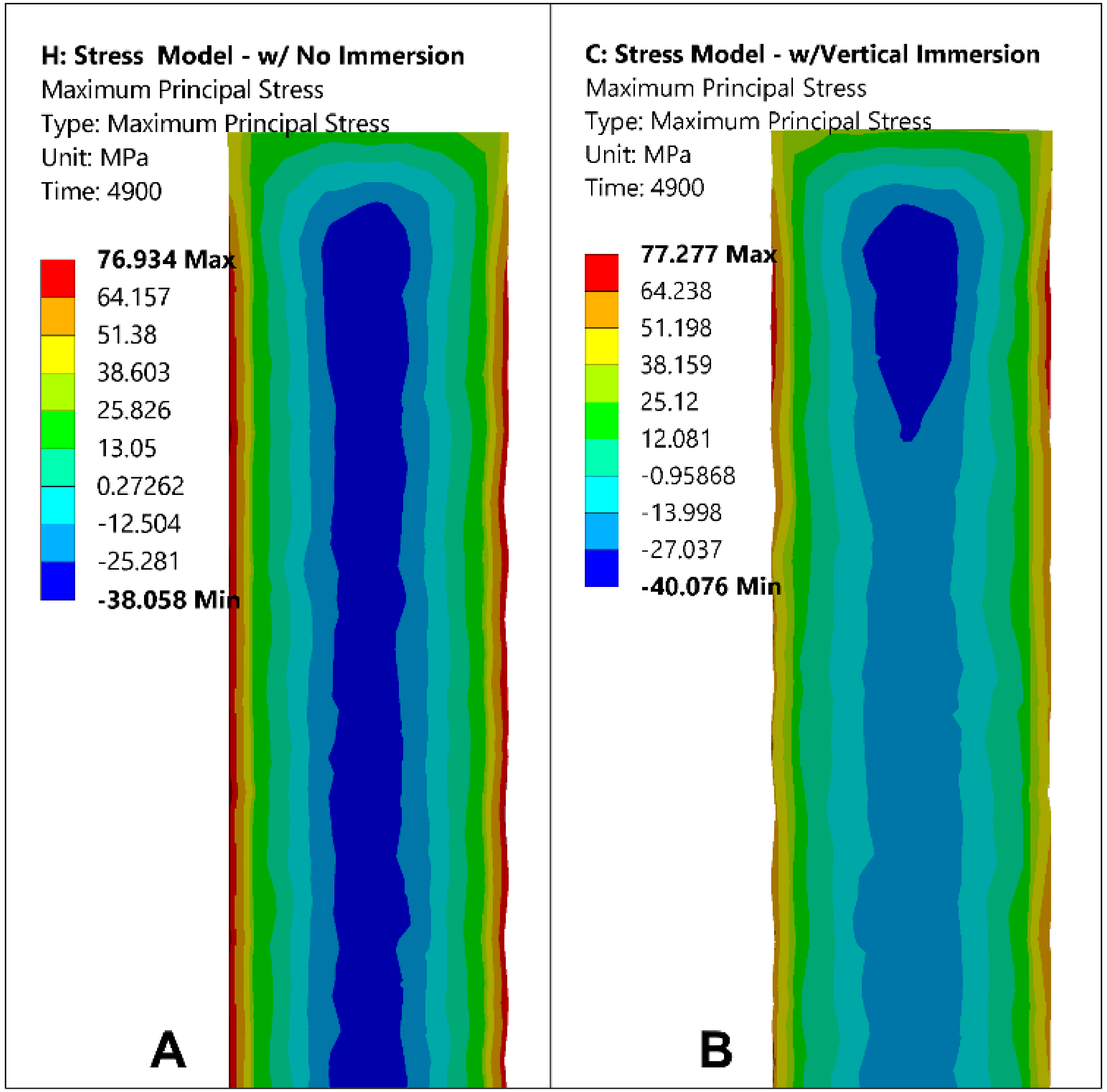
- Predicted axial distortion shown for a simulation **NOT** considering immersion (A) and a case which **DOES** consider immersion (B)
    - Without considering immersion, the part is considered to be instantaneously submerged below the quenchant surface
    - The immersion rate used in this example was 5 mm/s; meaning the 500 mm long component is fully immersed in 100 seconds
- The axial distortion magnitude is equivalent between the two cases
    - This will generally be true when the bow distortion is a full magnitude or more less than the axial distortion, as it is with this case
    - Axial dimensional change is generally determined by the volumetric difference between the initial and final microstructure
    - Whereas bow distortion is generally determined by nonuniform heating/cooling conditions, which can be a result of processing conditions or geometry



Residual Stress Comparison

No Immersion (A) vs. Immersion (B)

- Predicted residual maximum principal stress shown for a simulation **NOT** considering immersion (A) and a case which **DOES** consider immersion (B)
  - Without considering immersion, the part is considered to be instantaneously submerged below the quenchant surface
  - The immersion rate used in this example was 5 mm/s; meaning the 500 mm long component is fully immersed in 100 seconds
- The residual stress magnitude and distribution is equivalent between the two cases
  - This will generally be true if the final phase distribution is equivalent between the two processes being evaluated
  - Residual stress is mainly determined by the volumetric difference between the initial and final microstructure



Immersion Rate Definition

- DANTE has the capability to model different immersion rates
- Constant or Time-Dependent immersion rates can be applied to the model
- An example of both cases are shown below

Immersion Quench

Details of "Immersion Quench"

General	
Number of Surfaces	1
Immersion Quench Activation Table	Tabular Data
Current Surface	1
Part Motion Relative to Quench	
X	0
Y	-1
Z	0
Surface 1	
Quenching Surface	OD_Surf(Mechani...
Quench Speed Type	constant
Constant Quench Speed (mm/s)	5
Quench Start Time (s)	0
Relative Distance from Quench to Part (mm)	0
Ambient Air Temperature (C)	20
Ambient Quench Temperature (C)	20
Ambient Air HTC (W/mm^2 K)	5E-05
Temperature-Dependent Ambient Quench HTC (W/mm^2 K)	Tabular Data

Constant Immersion Rate

Immersion Quench

Details of "Immersion Quench"

General	
Number of Surfaces	1
Immersion Quench Activation Table	Tabular Data
Current Surface	1
Part Motion Relative to Quench	
X	0
Y	-1
Z	0
Surface 1	
Quenching Surface	OD_Surf(Mechani...
Quench Speed Type	time-dependent
Time-Dependent Quench Speed (mm/s)	Apply / Cancel
Quench Start Time (s)	0
Relative Distance from Quench to Part (mm)	0
Ambient Air Temperature (C)	20
Ambient Quench Temperature (C)	20
Ambient Air HTC (W/mm^2 K)	5E-05
Temperature-Dependent Ambient Quench HTC (W/mm^2 K)	Tabular Data

Time-Dependent Quench Speed (mm/s)

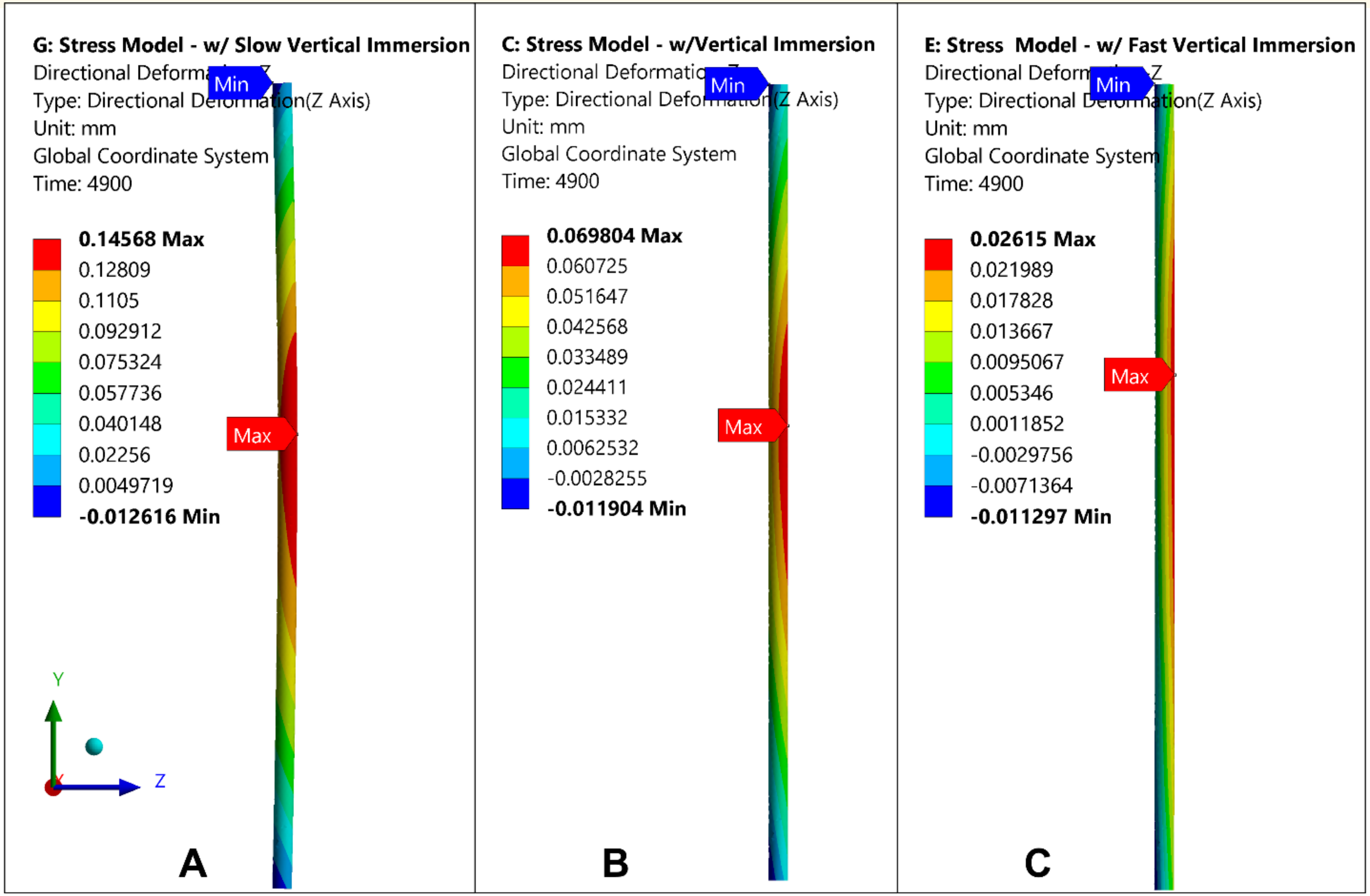
Time (s)	Quench Speed (mm/s)
0	1
1	1
1.5	5
5	5

Time Dependent Immersion Rate

Bow Distortion Comparison

Immersion Rate Effects (2.5 mm/s (A), 5 mm/s (B), 10 mm/s (C))

- Three immersion rates were modeled to show the effect of the immersion rate on distortion
- For this geometry and material, the faster the immersion rate, the smaller the bow distortion
  - For the fast case, 10 mm/s immersion rate, the bow distortion begins to approach the instantly immersed case
- Generally, the faster the immersion rate or the thicker the component cross-section, the less distortion that results



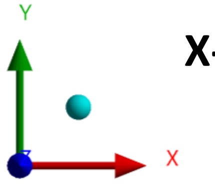
Immersion Orientation Definition

- DANTE has the capability to model different immersion orientations without modifying the CAD geometry
- Relative part motion definitions in the negative Y and negative X-Directions are shown below

Immersion Quench

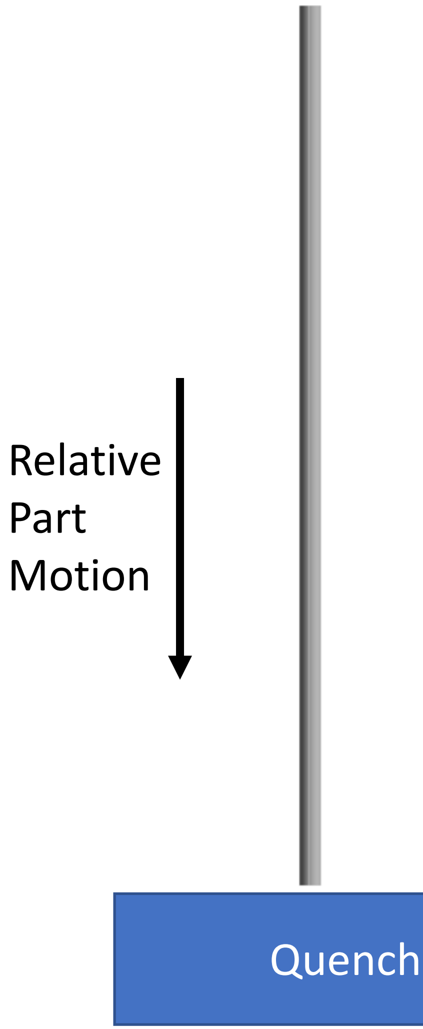
Details of "Immersion Quench"

General	
Number of Surfaces	1
Immersion Quench Activation Table	Tabular Data
Current Surface	1
Part Motion Relative to Quench	
X	-1
Y	0
Z	0
Surface 1	
Quenching Surface	OD_Surf(Mechani...
Quench Speed Type	constant
Constant Quench Speed (mm/s)	5
Quench Start Time (s)	0
Relative Distance from Quench to Part (mm)	0
Ambient Air Temperature (C)	20
Ambient Quench Temperature (C)	20
Ambient Air HTC (W/mm^2 K)	5E-05
Temperature-Dependent Ambient Quench HTC (W/mm^2 K)	Tabular Data



X-Direction Motion

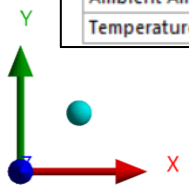
Relative Part Motion



Immersion Quench

Details of "Immersion Quench"

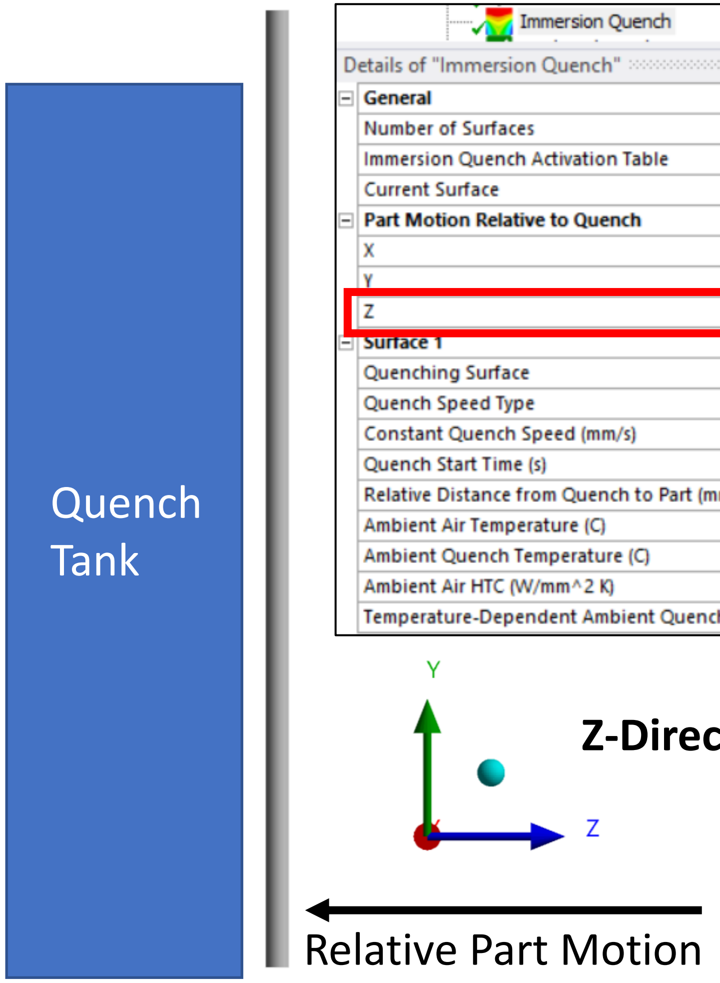
General	
Number of Surfaces	1
Immersion Quench Activation Table	Tabular Data
Current Surface	1
Part Motion Relative to Quench	
X	0
Y	-1
Z	0
Surface 1	
Quenching Surface	OD_Surf(Mechani...
Quench Speed Type	constant
Constant Quench Speed (mm/s)	5
Quench Start Time (s)	0
Relative Distance from Quench to Part (mm)	0
Ambient Air Temperature (C)	20
Ambient Quench Temperature (C)	20
Ambient Air HTC (W/mm^2 K)	5E-05
Temperature-Dependent Ambient Quench HTC (W/mm^2 K)	Tabular Data



Y-Direction Motion

Immersion Orientation Definition, cont'd

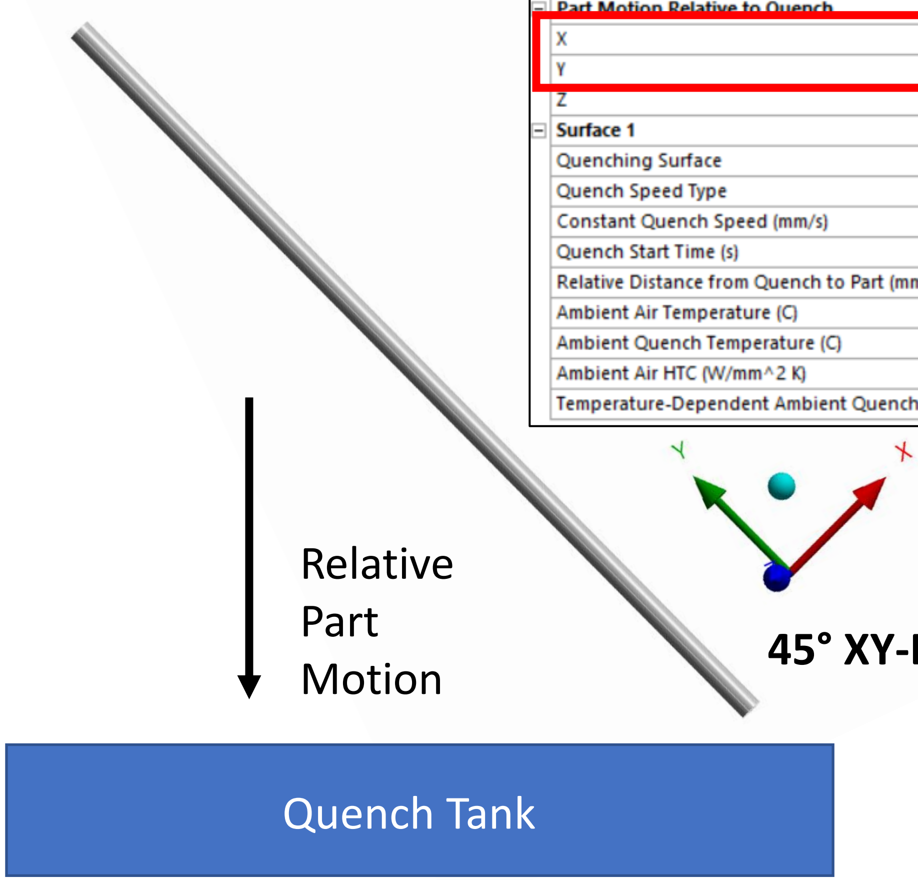
- Relative part motion definitions in the negative Z and 45° negative XY-Directions are shown below



Immersion Quench	
Details of "Immersion Quench"	
General	
Number of Surfaces	1
Immersion Quench Activation Table	Tabular Data
Current Surface	1
Part Motion Relative to Quench	
X	0
Y	0
Z	-1
Surface 1	
Quenching Surface	OD_Surf(Mechani...
Quench Speed Type	constant
Constant Quench Speed (mm/s)	5
Quench Start Time (s)	0
Relative Distance from Quench to Part (mm)	0
Ambient Air Temperature (C)	20
Ambient Quench Temperature (C)	20
Ambient Air HTC (W/mm^2 K)	5E-05
Temperature-Dependent Ambient Quench HTC (W/mm^2 K)	Tabular Data

Z-Direction Motion

Immersion Quench	
Details of "Immersion Quench"	
General	
Number of Surfaces	1
Immersion Quench Activation Table	Tabular Data
Current Surface	1
Part Motion Relative to Quench	
X	-1
Y	-1
Z	0
Surface 1	
Quenching Surface	OD_Surf(Mechani...
Quench Speed Type	constant
Constant Quench Speed (mm/s)	5
Quench Start Time (s)	0
Relative Distance from Quench to Part (mm)	0
Ambient Air Temperature (C)	20
Ambient Quench Temperature (C)	20
Ambient Air HTC (W/mm^2 K)	5E-05
Temperature-Dependent Ambient Quench HTC (W/mm^2 K)	Tabular Data

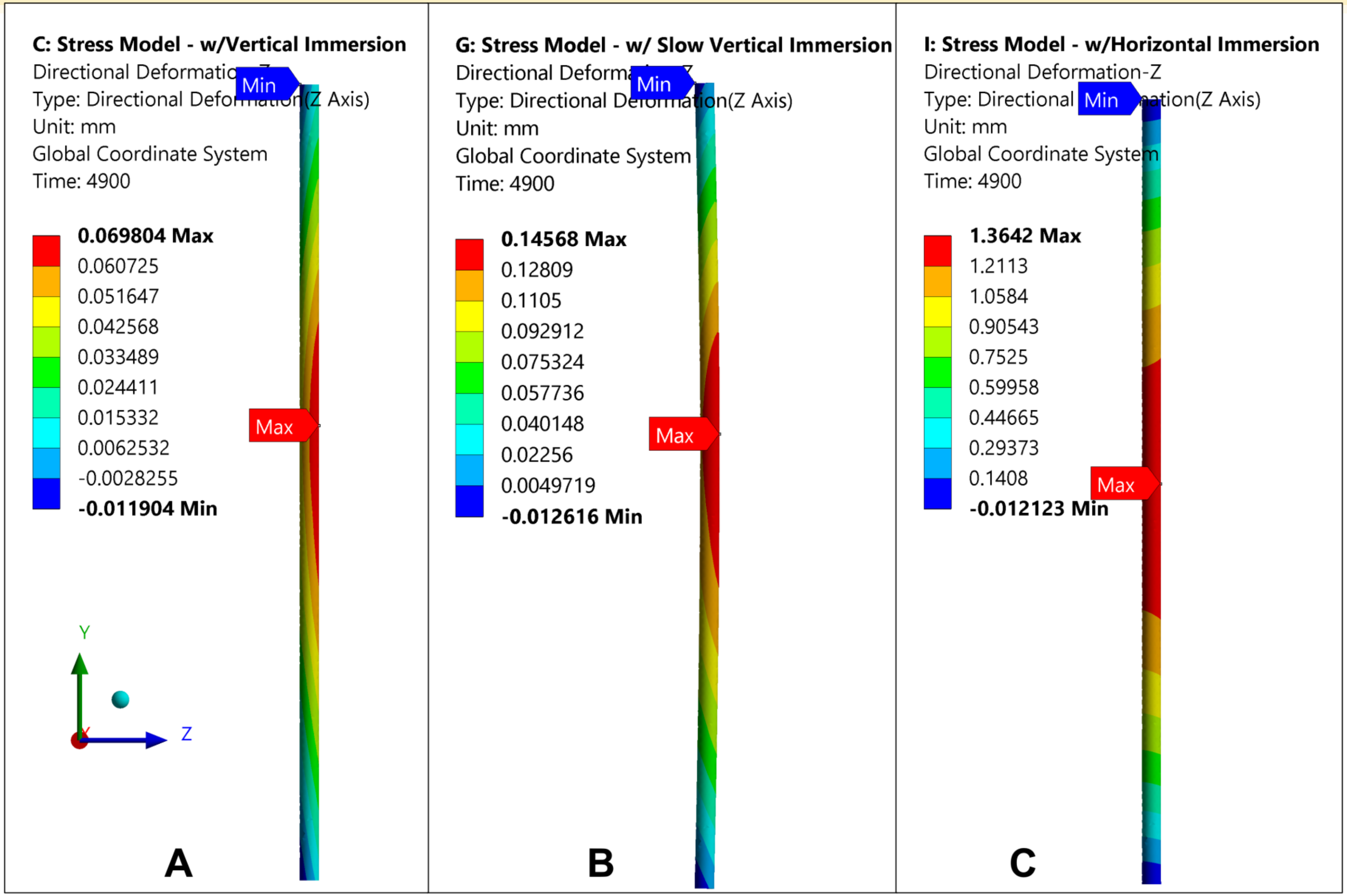


45° XY-Direction Motion

Bow Distortion Comparison

Immersion Orientation Effects (vertical 5mm/s (A), vertical 2.5 mm/s (B), horizontal 1 mm/s (C))

- Two immersion directions were modeled to show the effects on distortion
- Generally, long components are immersed vertically (long axis normal to the quench tank) and not horizontally
  - The modeling results for two vertical immersion cases (5 mm/s (A) and 2.5 mm/s (B)) are compared to a horizontally immersed component (1 mm/s) (C)
- The horizontally immersed bar has a full magnitude greater bow distortion than the vertically immersed bar with the slowest immersion rate



Summary

- Simulating the immersion process of long steel components being quench hardened is now easily handled by DANTE linking with ANSYS
  - Immersion parameters can be easily modified, including the immersion rate (constant or time dependent), any delays before immersion begins (time or distance), ambient temperatures for the air above the quenchant and the quenchant (constant only), and HTCs for the air above the quenchant (constant) and the quenchant (function of part surface temperature)
- The effect of immersion on bow distortion was shown to be significant, when compared to not considering the immersion process in the simulation
- The effect of immersion on the axial distortion and residual stress was shown to be equivalent to a case not considering immersion
  - The equivalency of axial distortion and residual stress is not guaranteed, as it is dependent on the steel grade, processing conditions, and geometry
- The effect of the immersion rate on bow distortion was shown to be significant for the component and conditions modeled
- The effect of the immersion direction on bow distortion was shown to be significant for the component and conditions modeled

Links to Relevant Case Study Material

Additional DANTE Aerospace Case Studies

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