SAND2011-3631C

Axial Crushing of Aluminum Tubes

Experimental Results and Finite Element Modeling

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Sandia National Laboratories
Albuquerque, NM

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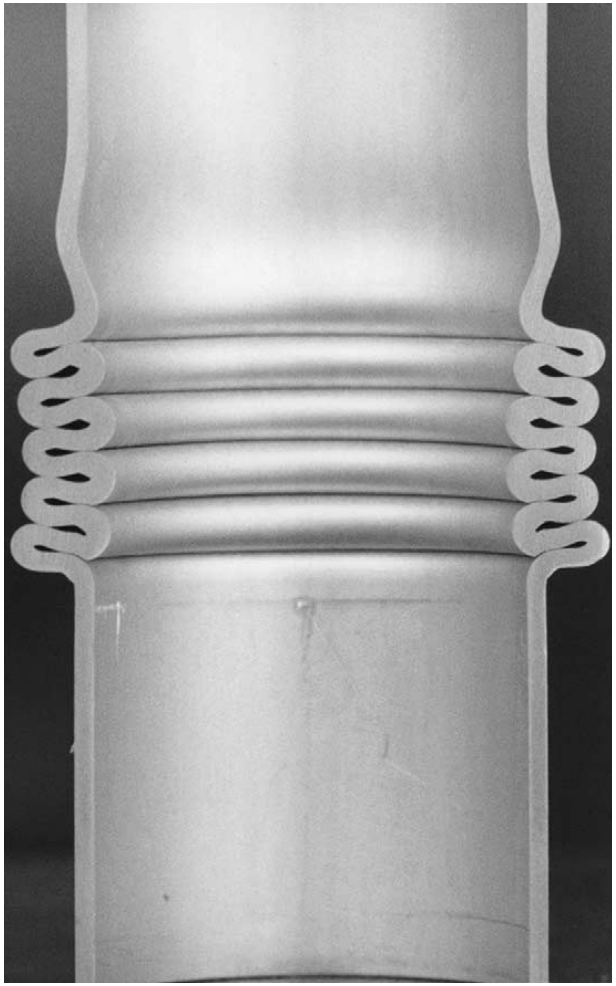
Introduction

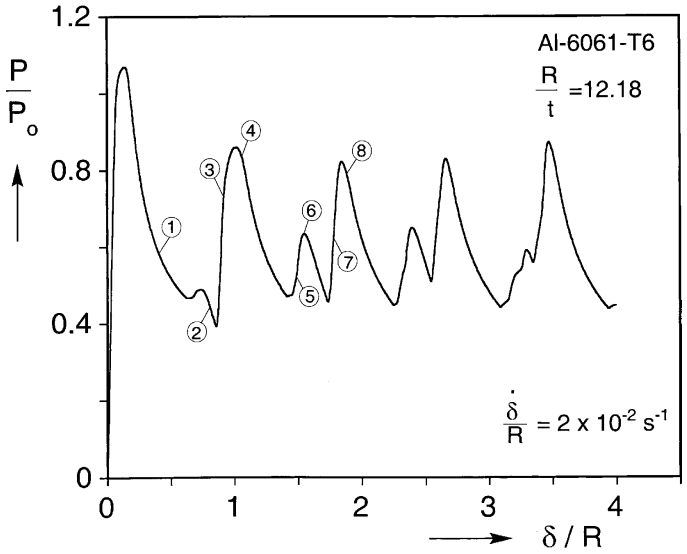
- Many Sandia-designed systems may be subjected to severe mechanical environments. Safety and security issues require analysis of system response under these conditions.
- System and component level finite element models are widely used to perform a substantial part of the analysis and to guide testing.
- Validation of FE modeling capabilities, by comparison to experiment is an essential part of the process.

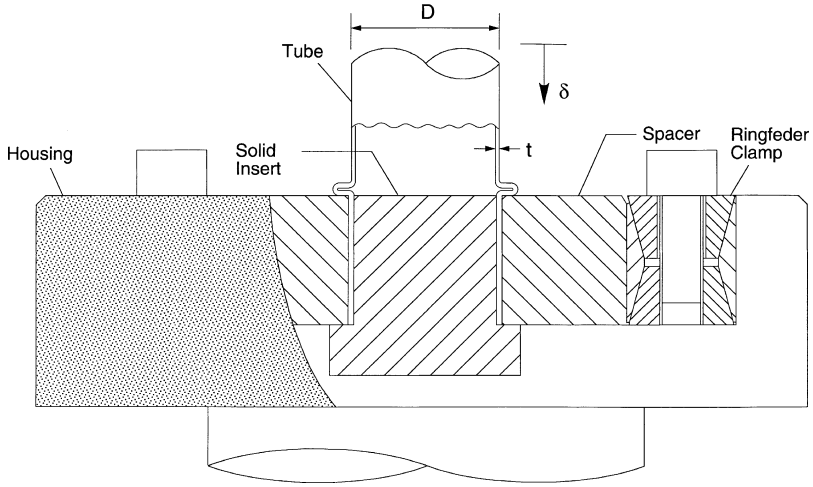
Objectives

- Demonstrate the performance of FE nonlinear structural models to simulate crushing and other large-deflection scenarios.
- Examples:
  - Axial and lateral crushing of tubular structures
  - Hydraulic collapse
  - Puncturing
  - Etc.
- This presentation addresses aluminum tubes crushed by quasi-static axial compression.

Axisymmetric Collapse (Bardi et al, 2003)







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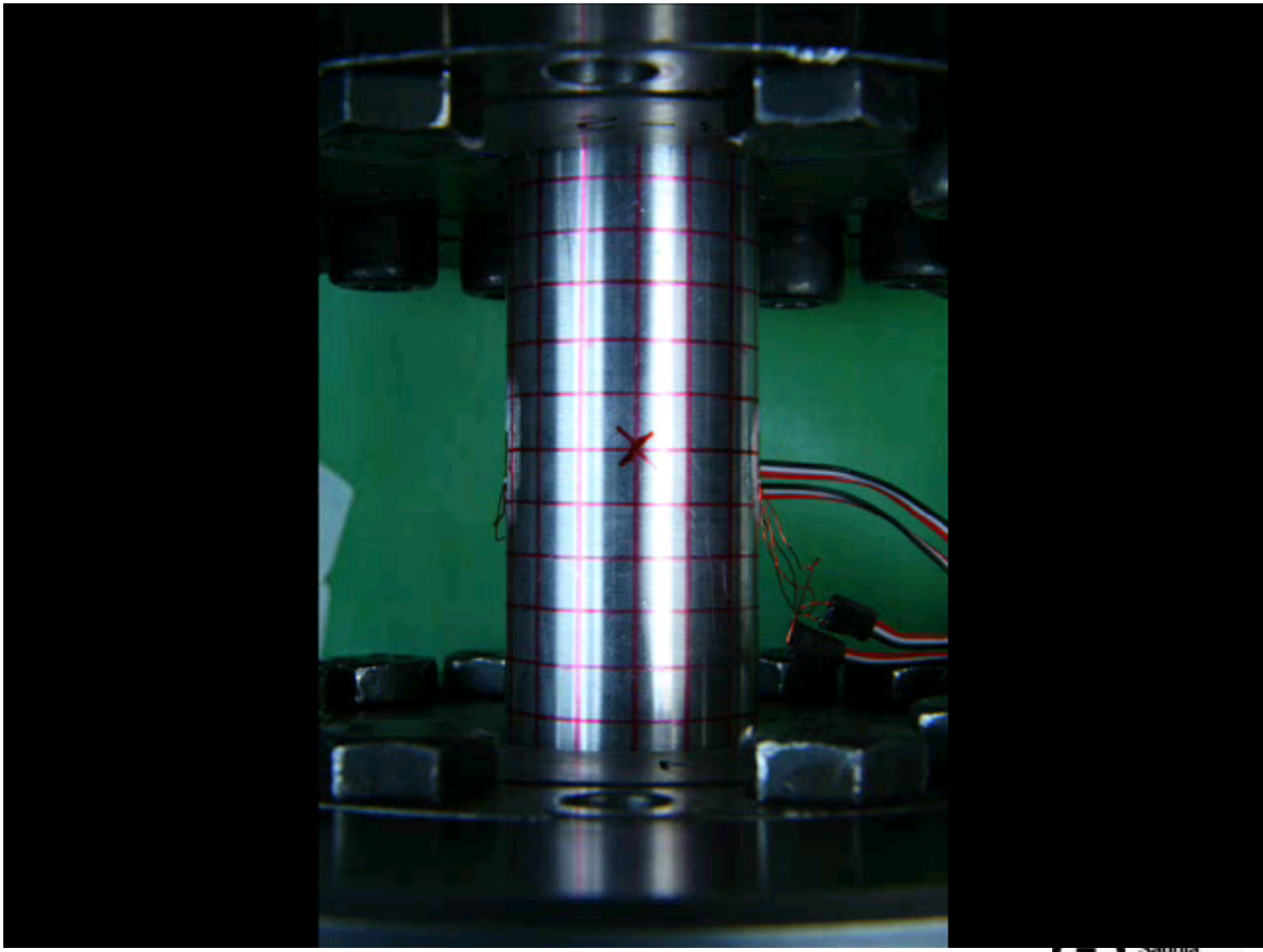
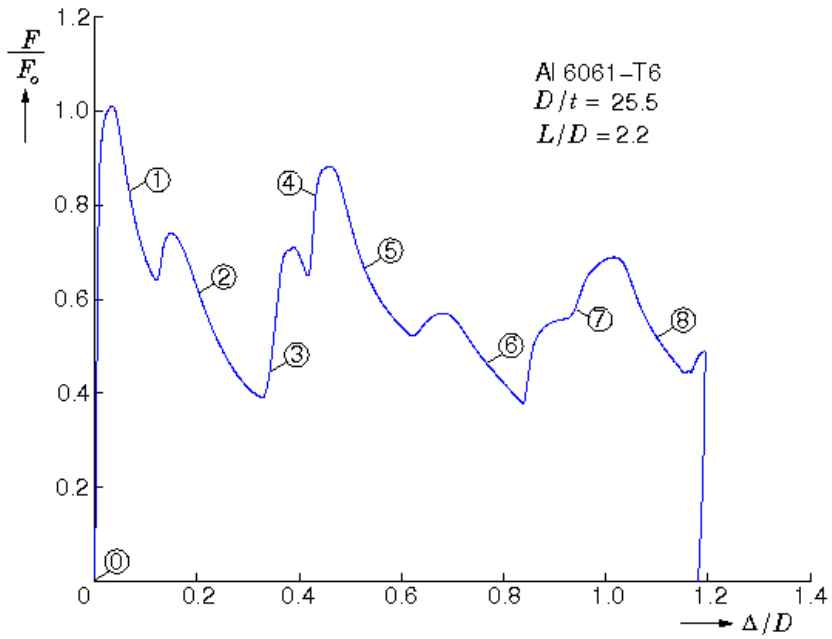
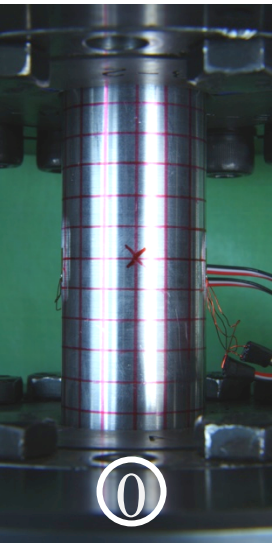
L/D = 2.2

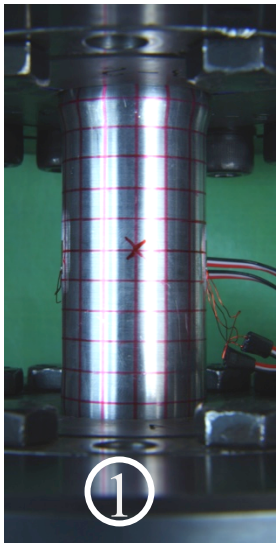


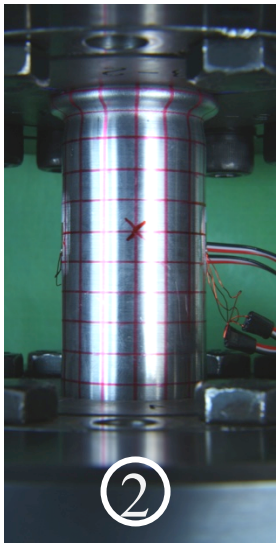
Al 6061-T6
D/t = 25.5
L/D = 2.2

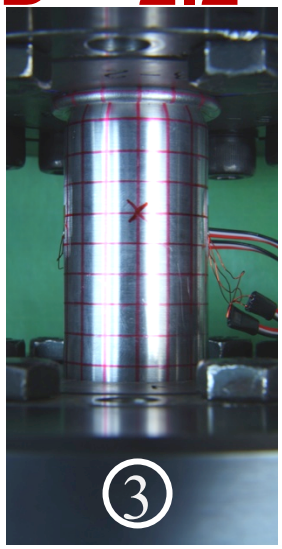
L/D = 2.2

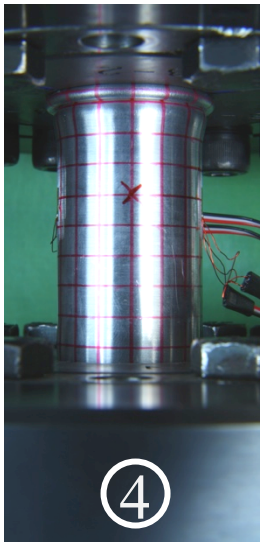


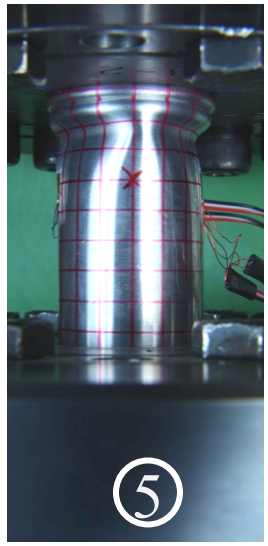


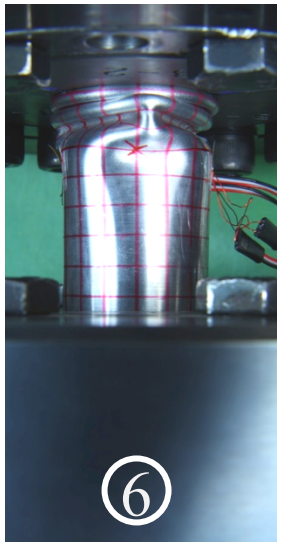












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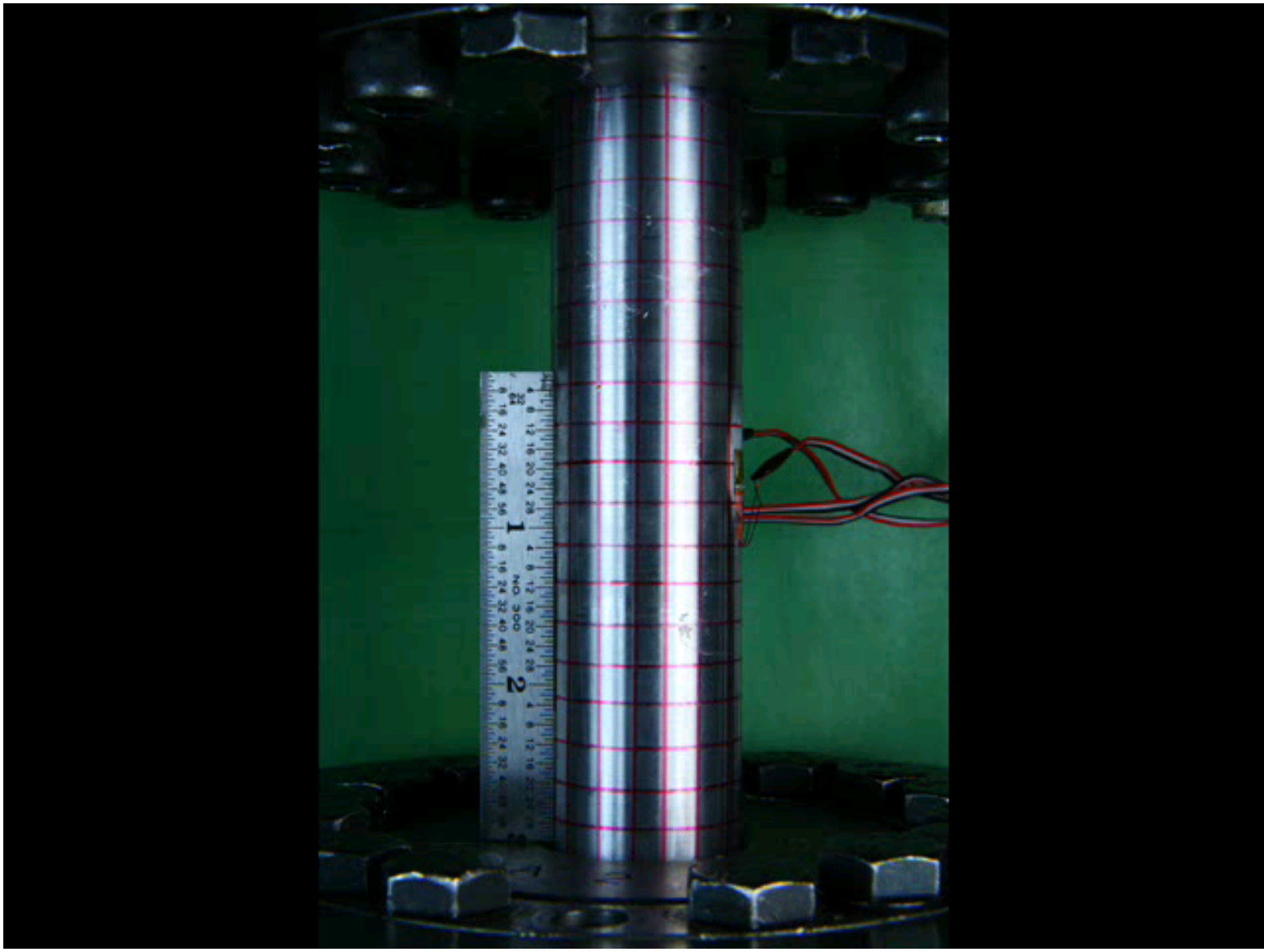
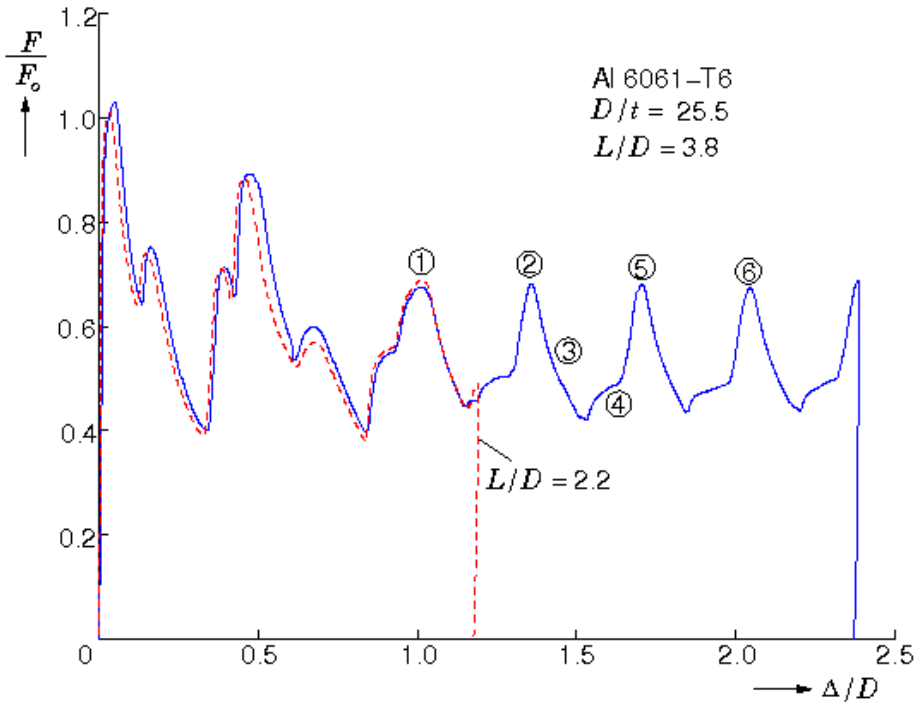
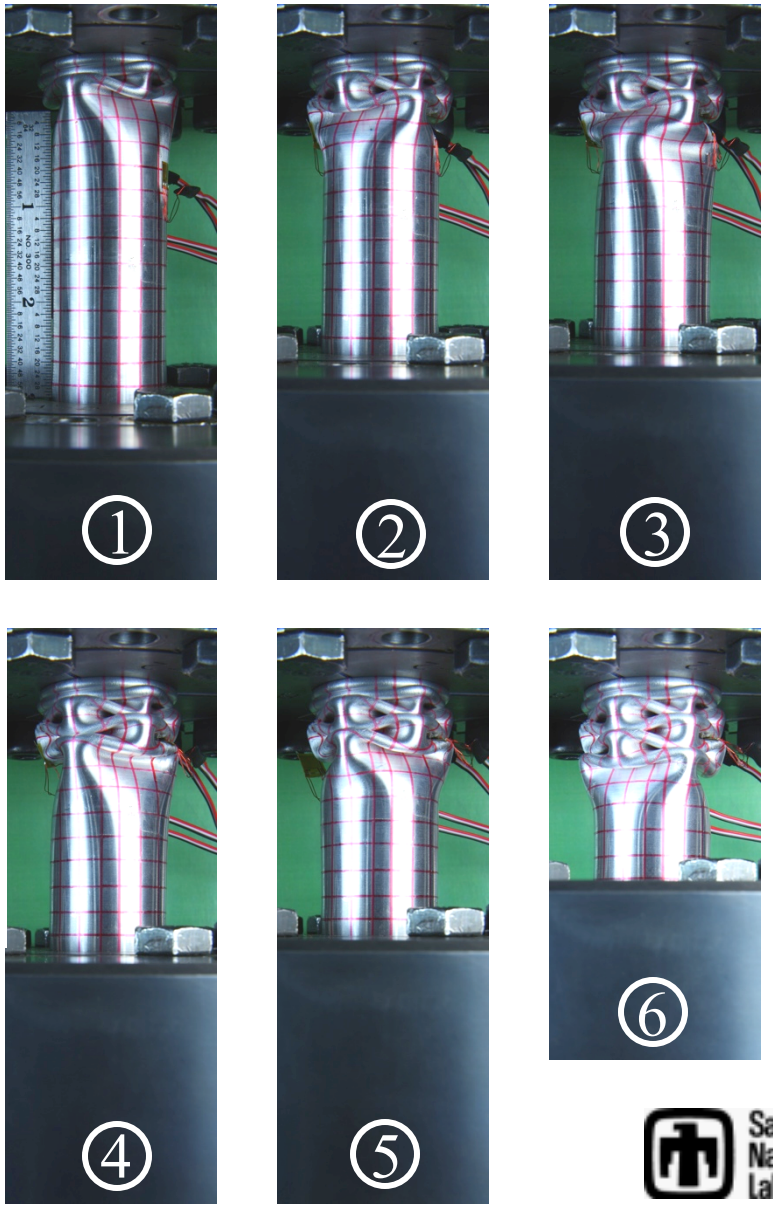
L/D = 3.8



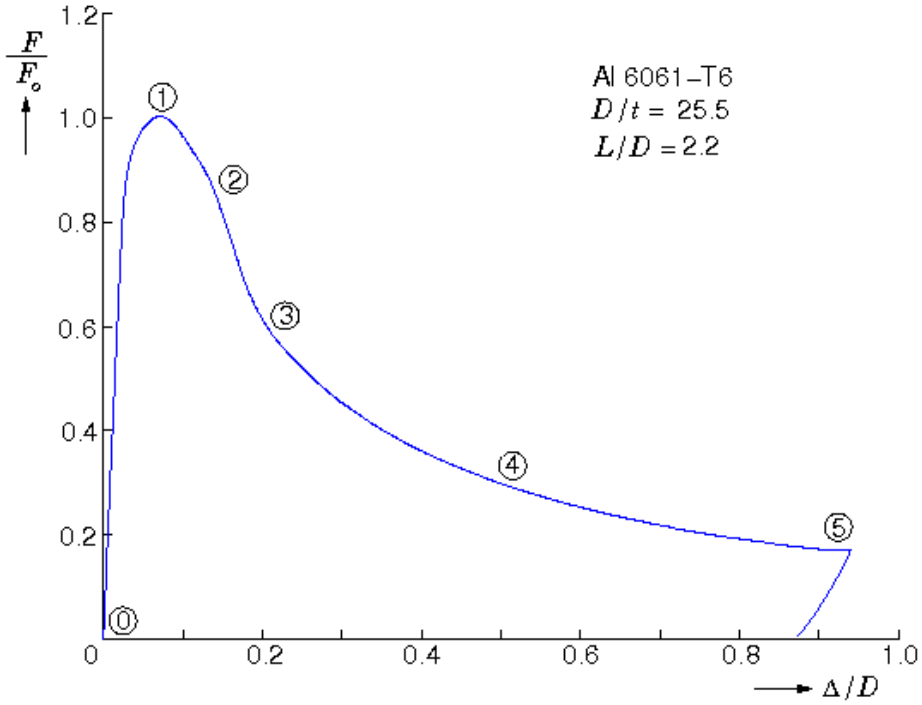
Al 6061-T6
D/t = 25.5
L/D = 3.8

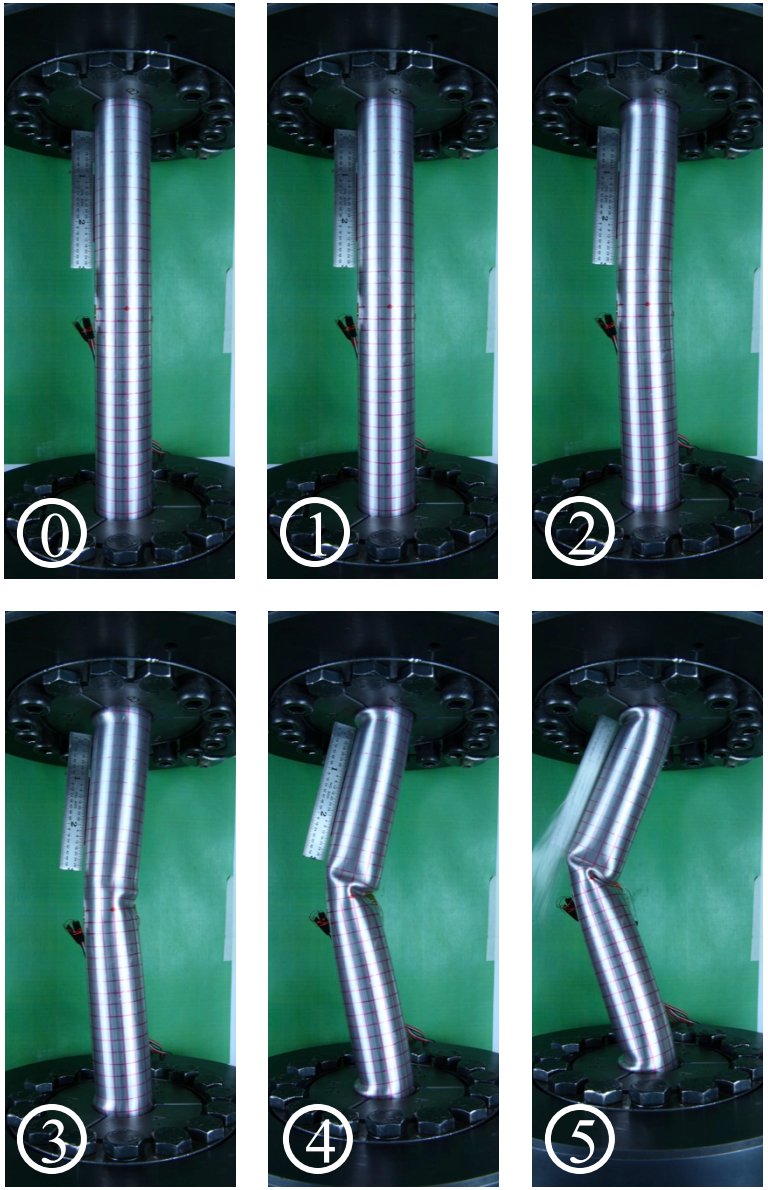
L/D = 3.8


F/F_o
1.2
1.0
0.8
0.6
0.4
0.2
0
0.5
1.0
1.5
2.0
2.5
Δ/D
Al 6061–T6
D/t = 25.5
L/D = 3.8
L/D = 2.2
①
②
③
④
⑤
⑥


①
②
③
④
⑤
⑥

L/D = 7.0





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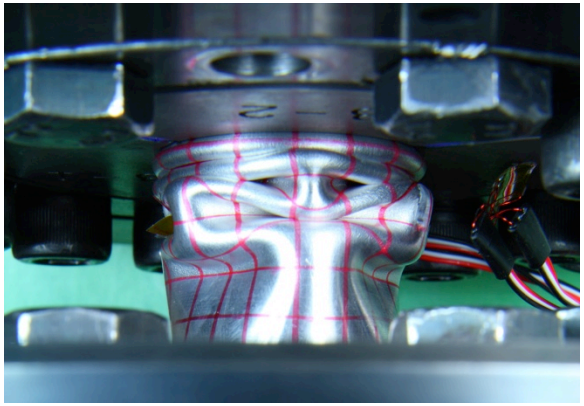
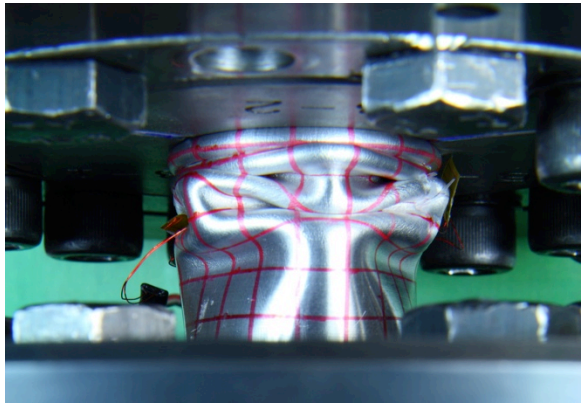
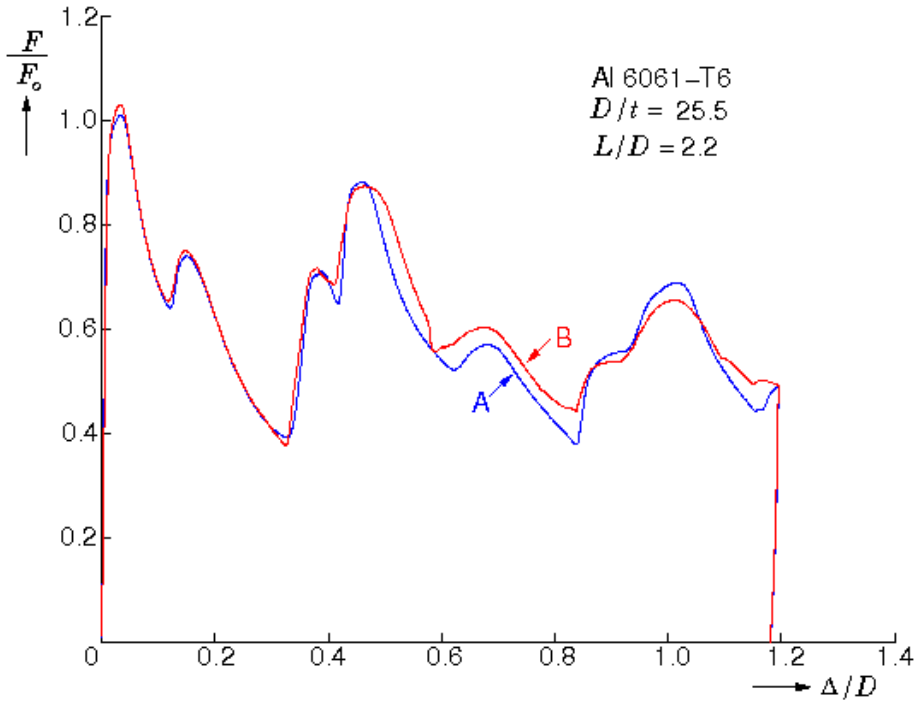
L/D = 2.2





A

B



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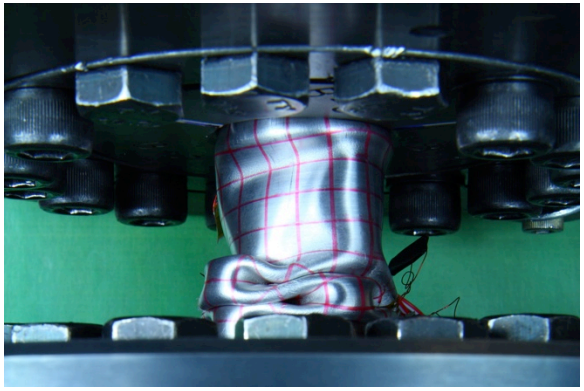
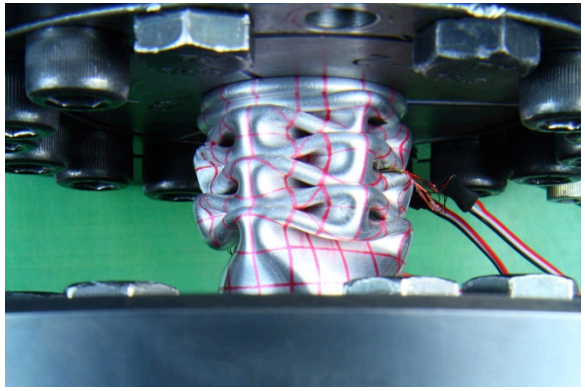
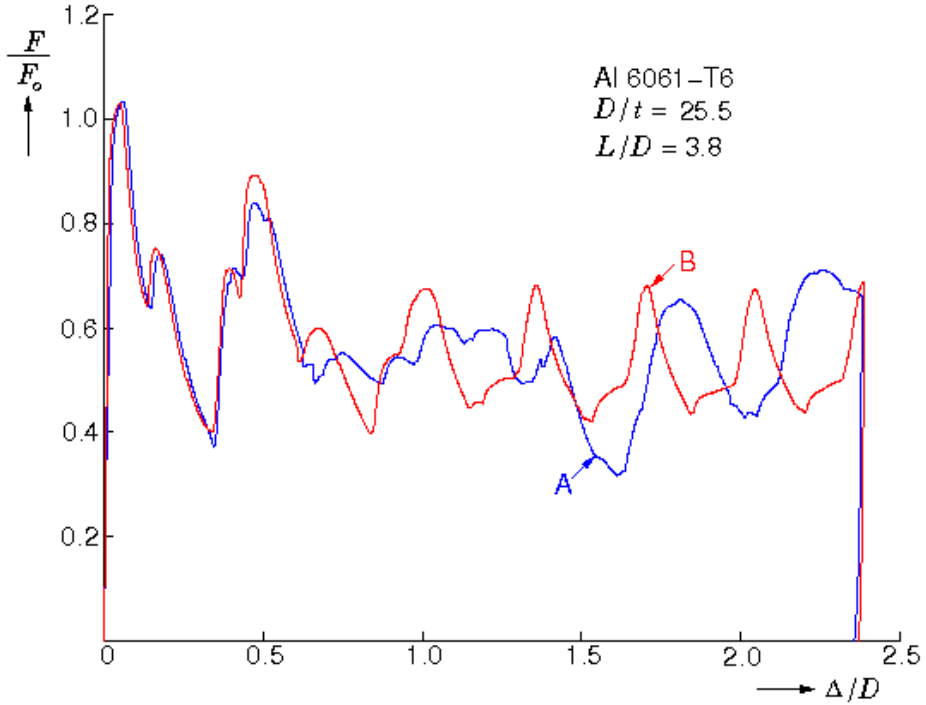
L/D = 3.8





A

B



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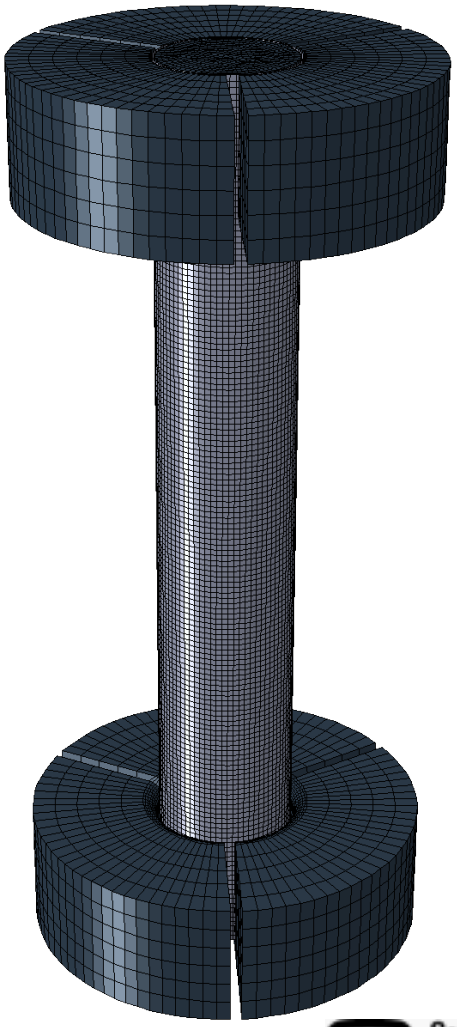
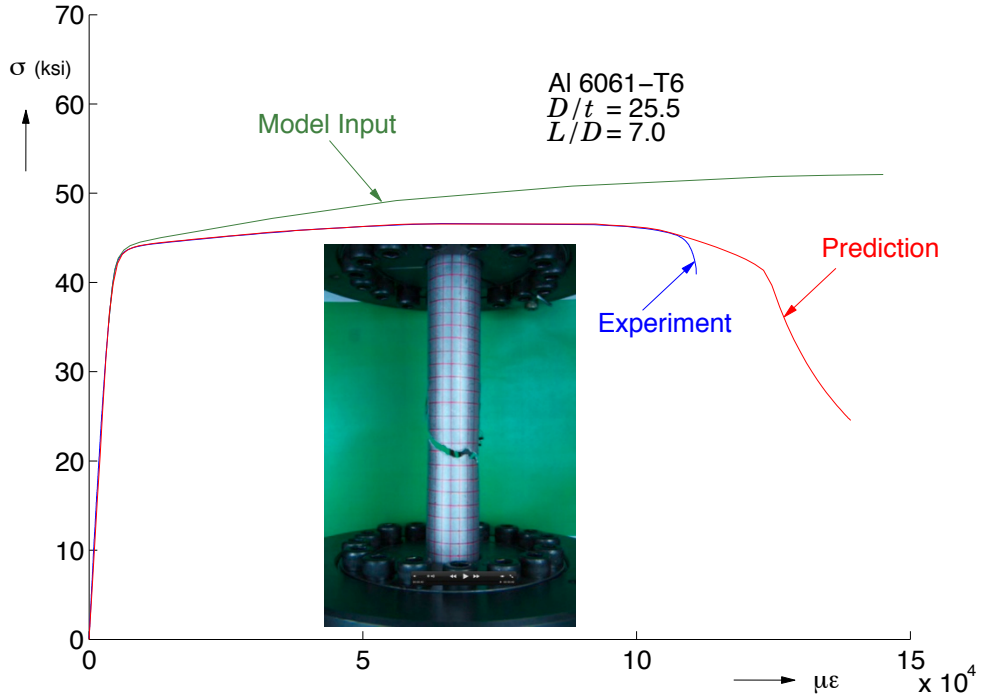
Modeling Overview

- Abaqus/Explict
- Shell Elements on Tube
  - Reduced Integration (S4R)
  - Relax Stiffness Hourglass Control
- Rigid Fixtures
- Two Step Procedure
  - Clamping Pressure on Fixtures
  - Displacement on End
- Shell Contact Thickness
  - Set by Contact Algorithm
  - <= 42% of Element Edge Length



Material Properties

- **Tensile Test of Tube**
  - **Pulled a Section from Same Tube**
- **Material Model Input**
  - **Up to UTS from Test**
  - **Iteratively Determined from UTS till Near Failure**



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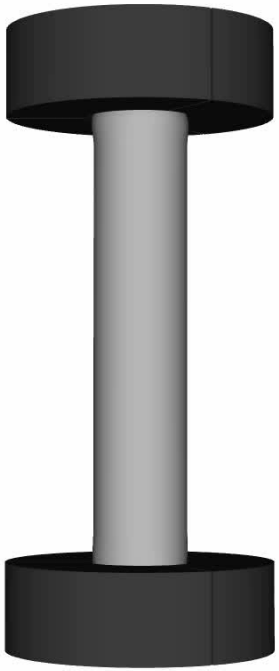
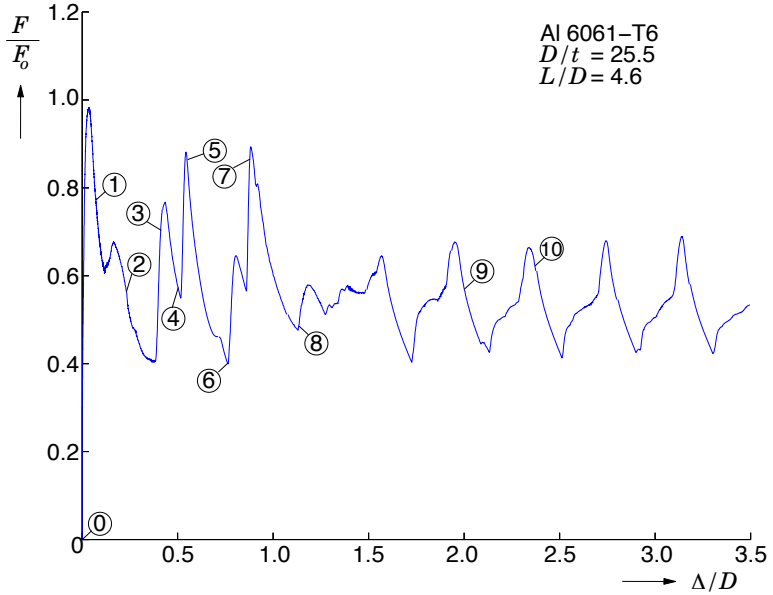
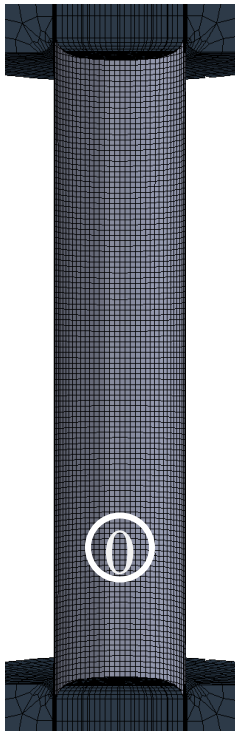
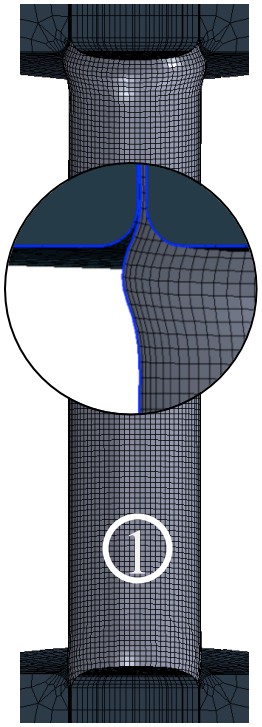
Crushing Prediction L/D=4.6

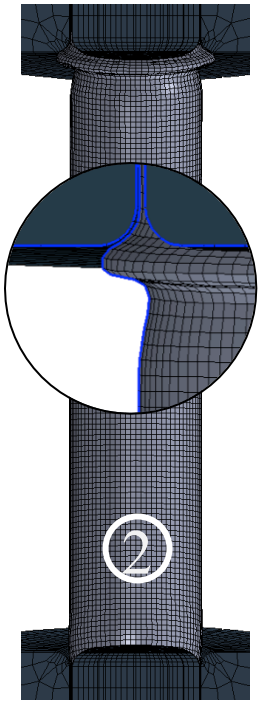


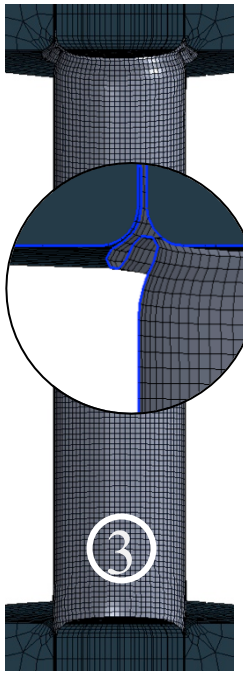
L/D = 4.6

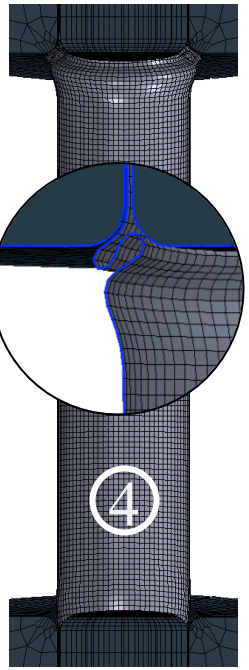


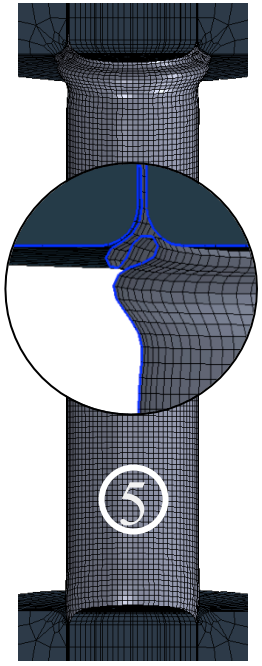


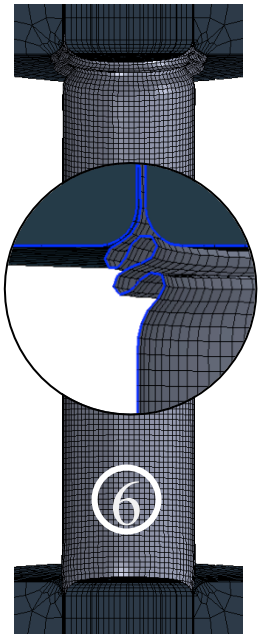


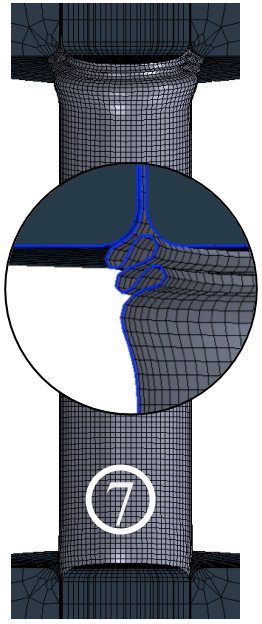












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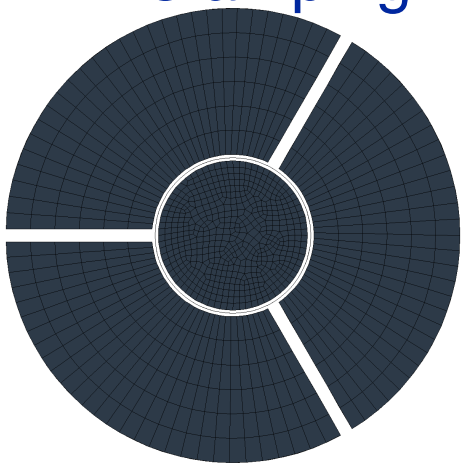
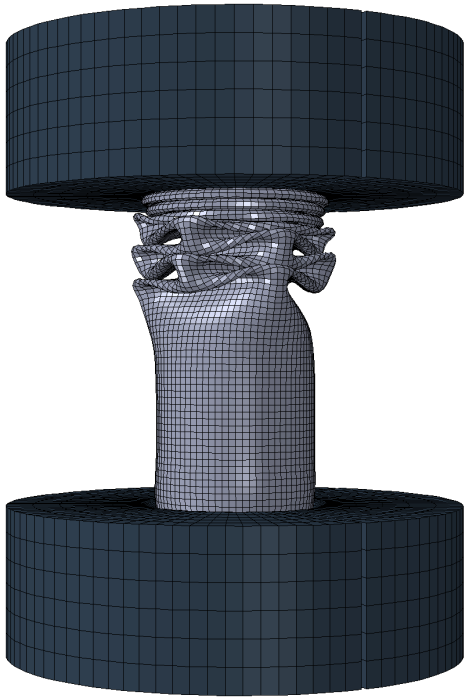
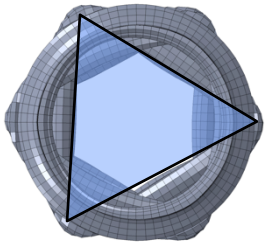
Crushing Pattern

3 Piece Fixture
w/ Clamping

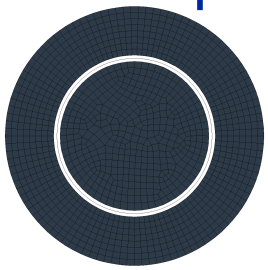


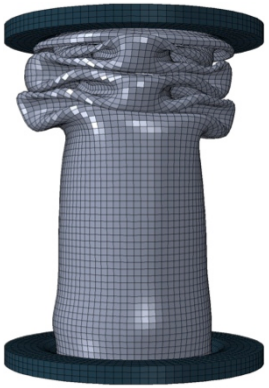


N=3

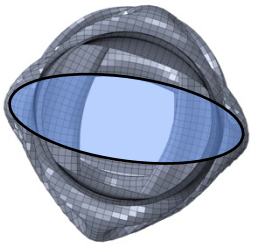


Continuous Fixture
No Clamping



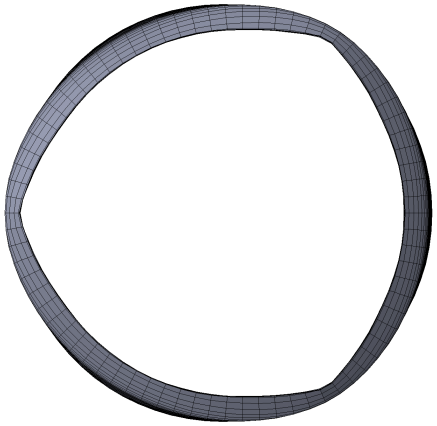


N=2

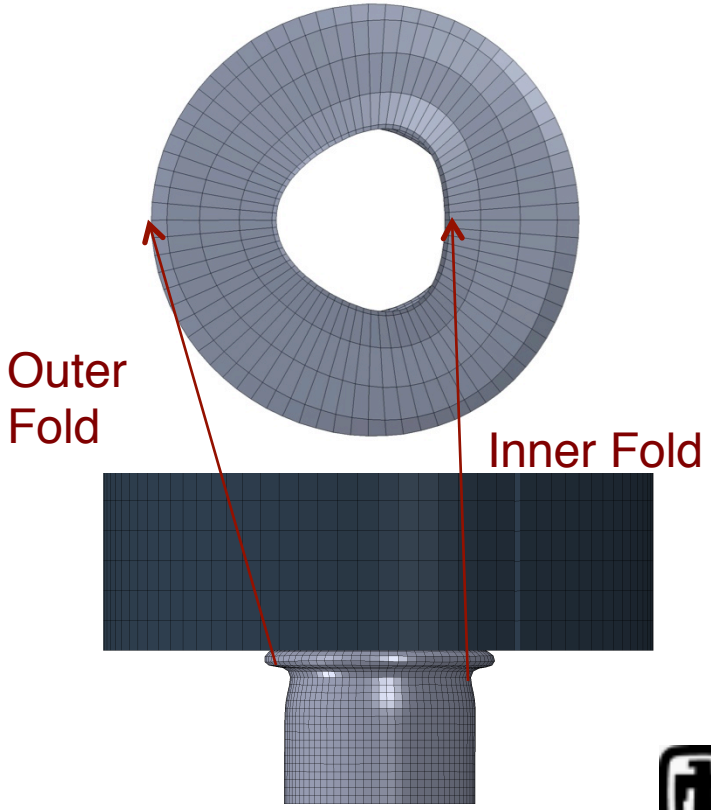


N = 3 Pattern

Tube End After Clamping
(5x Displacement)

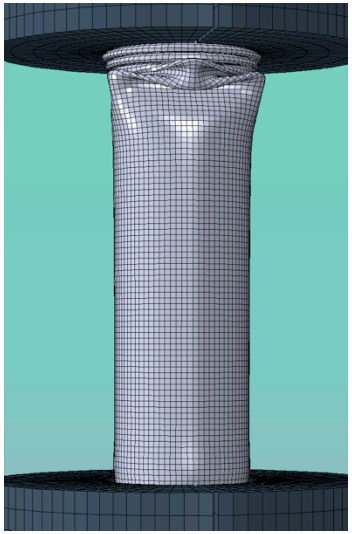


X-Section at First Neck
(5x Displacement)

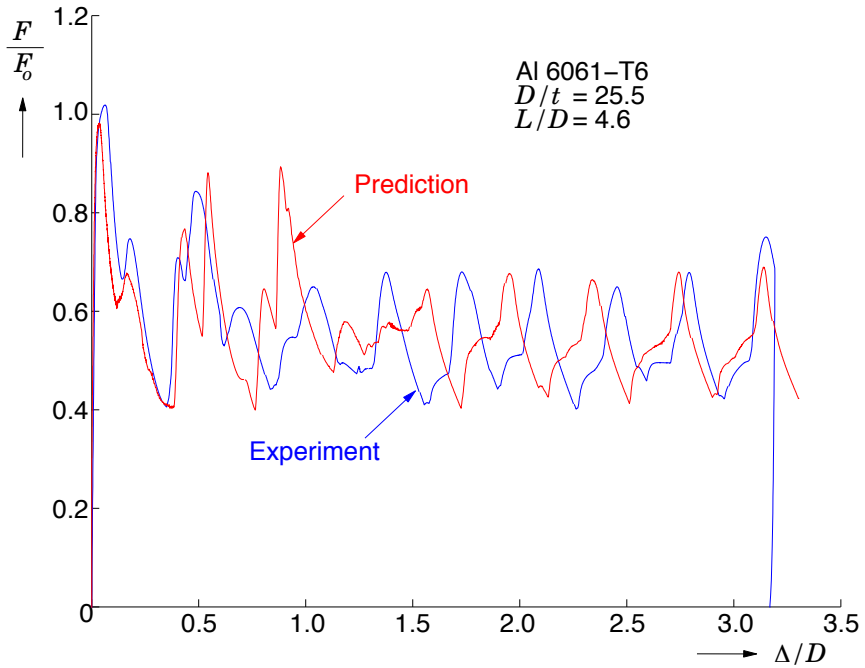


L/D = 4.6

Experiment



Prediction



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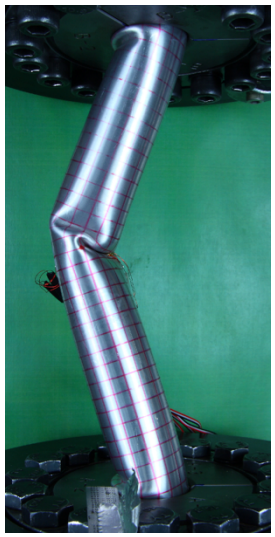
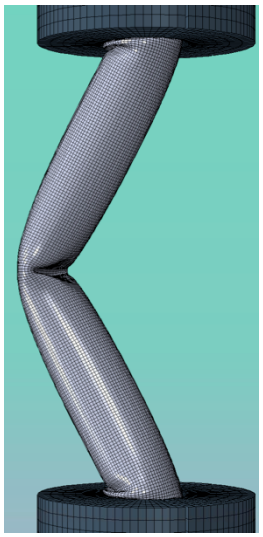
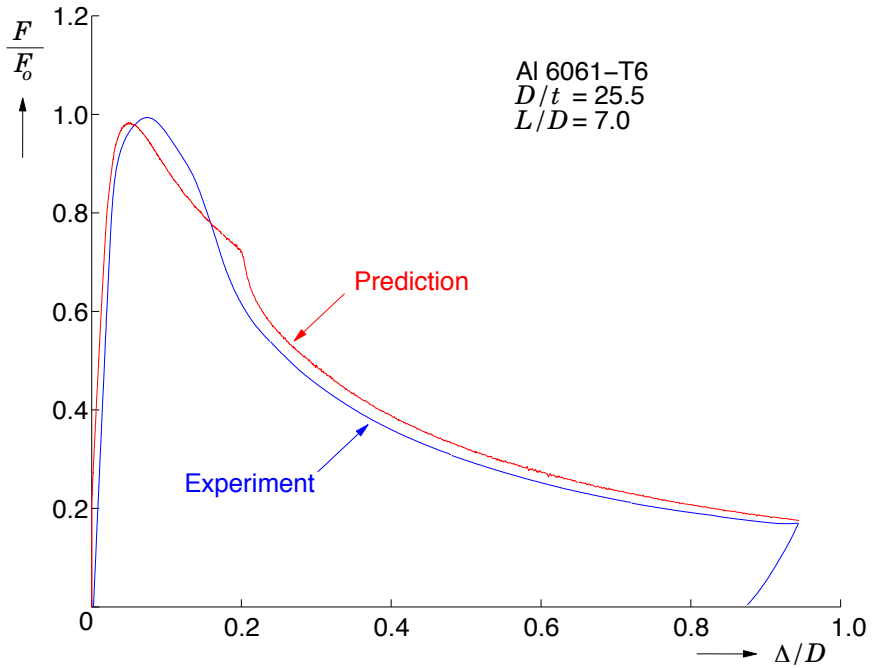
L/D = 7



Experiment



Prediction



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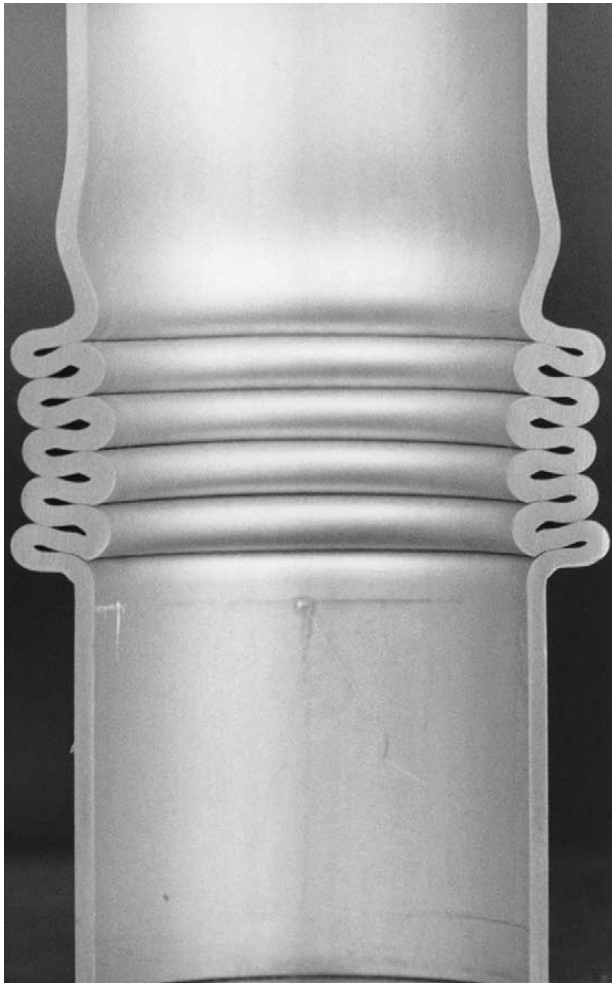
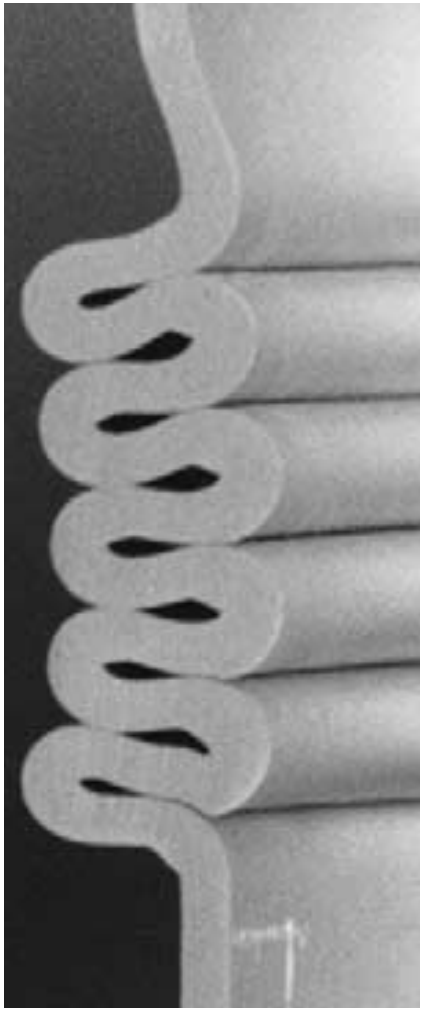
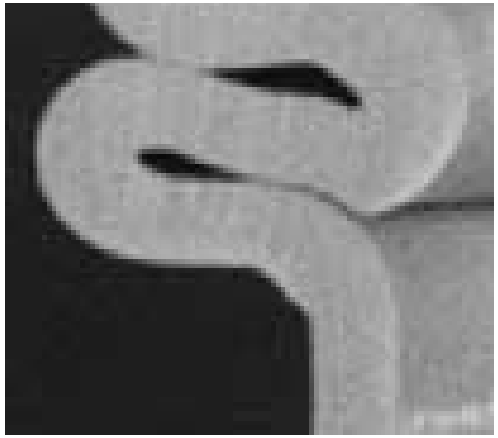
Summary of Results

L/D	Mode Experiment	Mode Prediction	λ (Δ/D) Experiment	λ (Δ/D) Prediction
2.2	N=3 / N=3	N=3	-	-
3.8	N=3 / N=3	N=3	0.352	0.388
4.6	N=3 / N=2-3	N=3	0.354	0.394
5.4	N=3 / Lateral	N=3	-	0.395
7.0	Lateral / Lateral	Lateral	-	-

Axisymmetry?
Bardi et al







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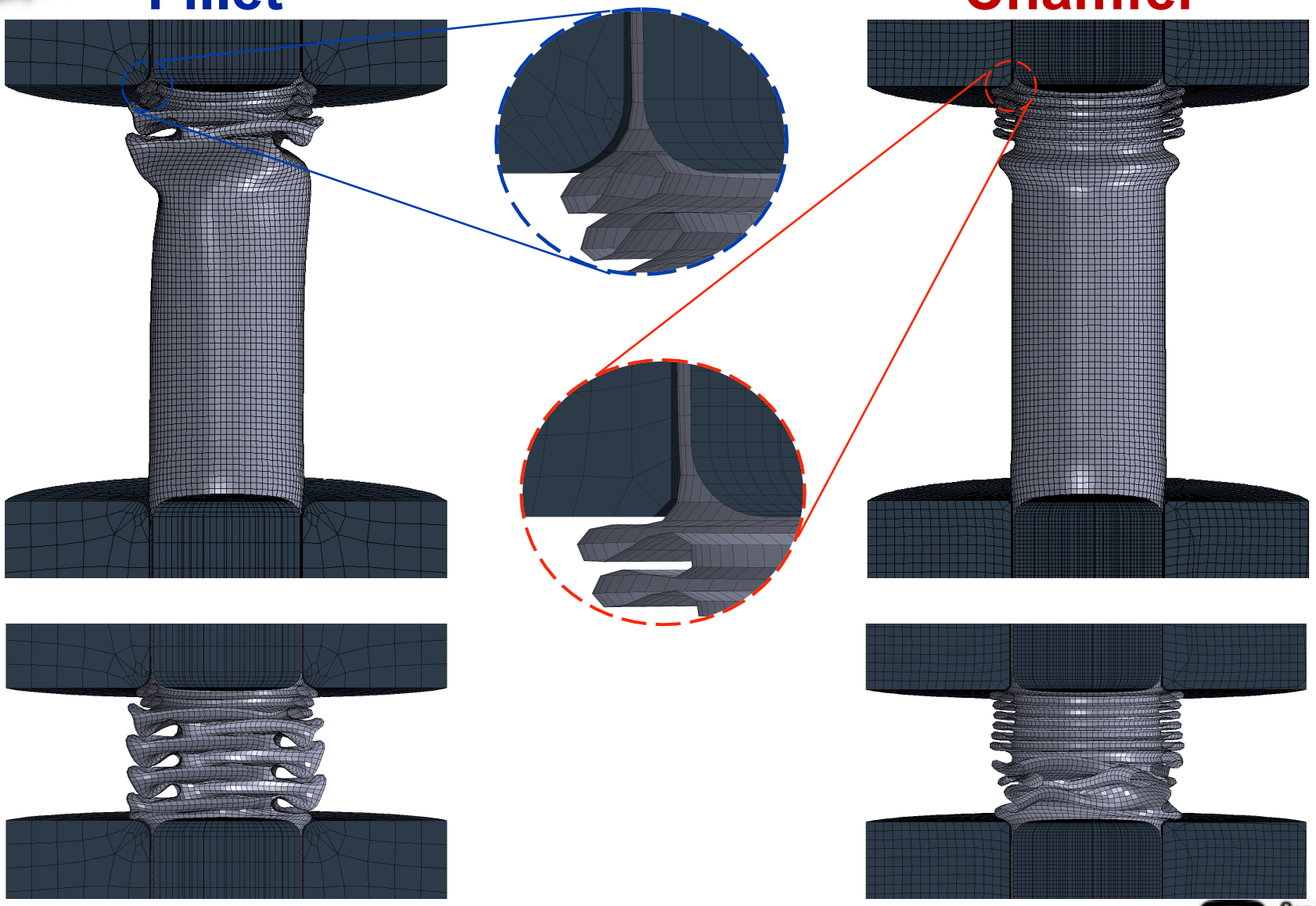
Boundary Effects



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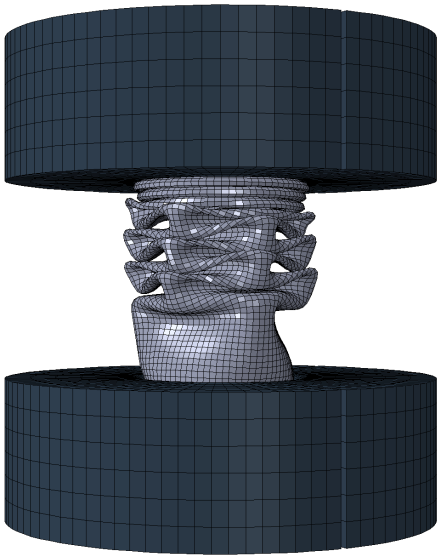
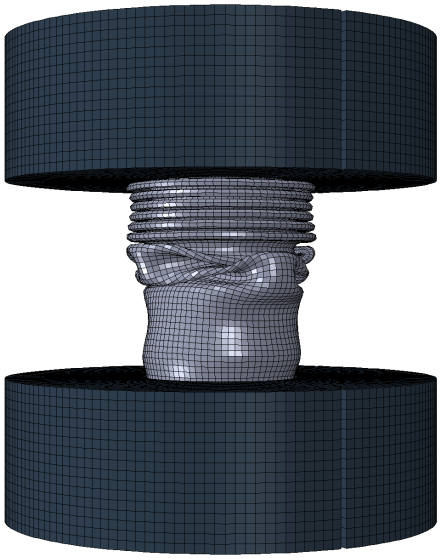
Boundary Effects



Fillet



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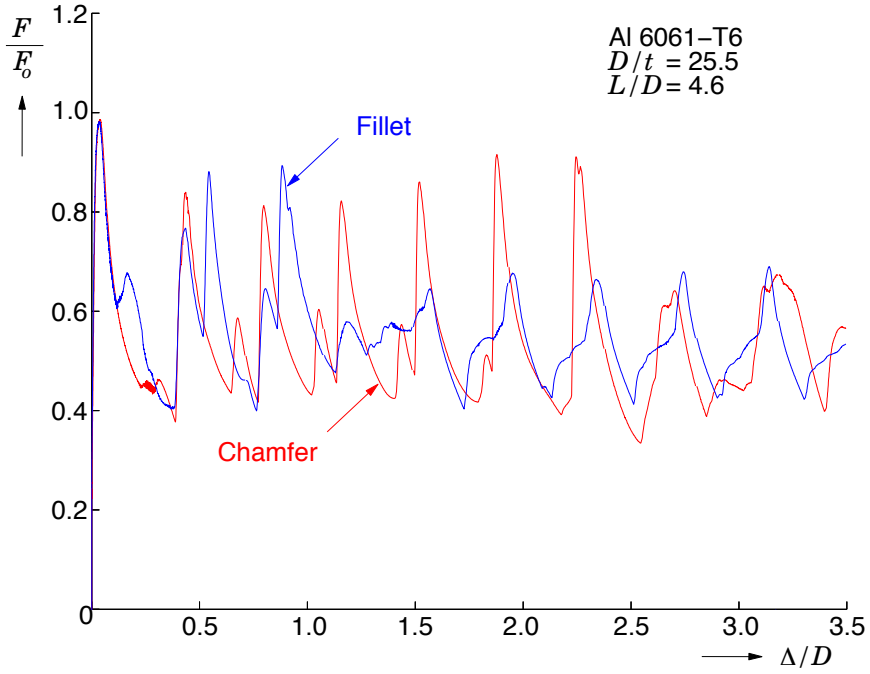
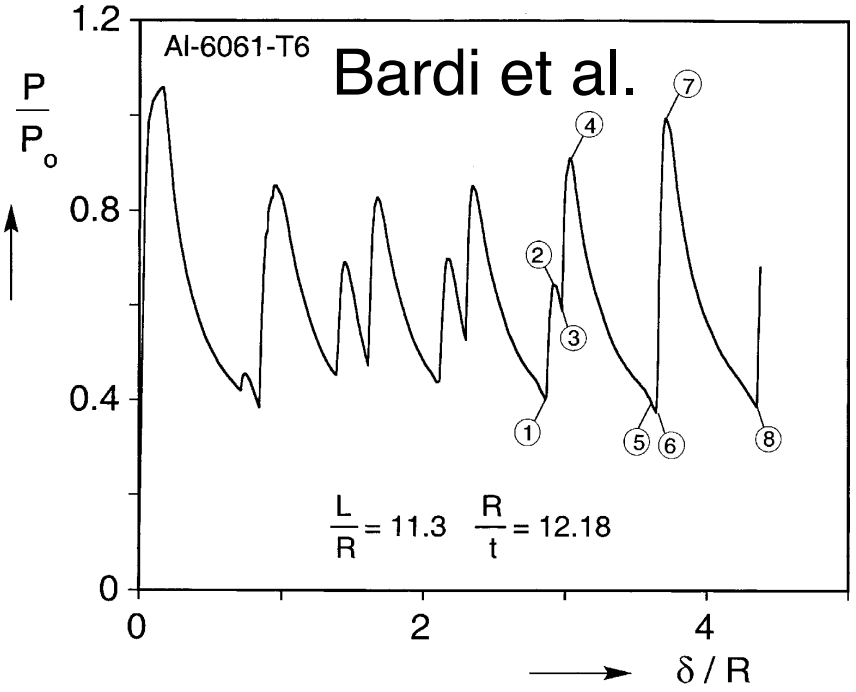
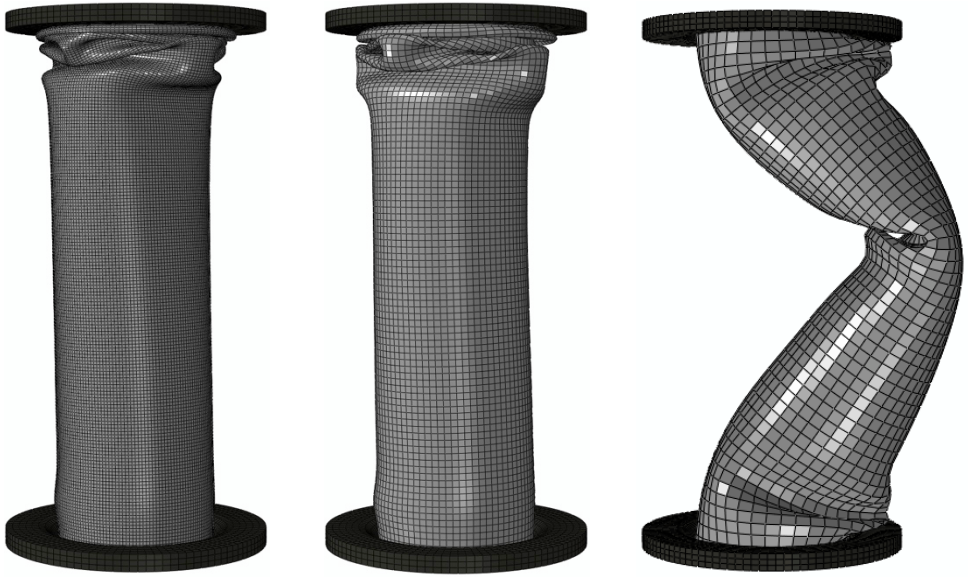




Sensitivity Investigations

- **Mesh Sensitivity**
  - 0.025, 0.05, 0.1 inch squares studied
- **Other Studies**
  - Clamping Pressure
  - Fixture Dimensions
- **Future Studies**
  - Hex-Based Meshes
  - Anisotropic Material



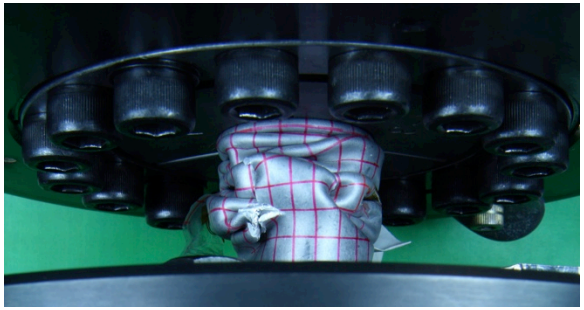
0.025” 0.05” 0.1”

Conclusions

- Shell model does a reasonable job in predicting the crushing response of the tubes.
- N=3 crushing mode seems to be a consequence of the three-segmented clamping fixture and of the applied clamping pressure.
- Shell contact thickness is a model feature that probably affects the numerical results.
- Crushing mode is influenced by the geometric details of the clamping fixture. Perhaps more generally, by the geometry of preceding folds.

Backup Slides Below

L/D = 4.6



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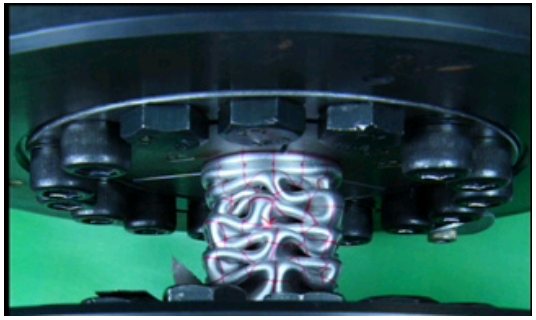

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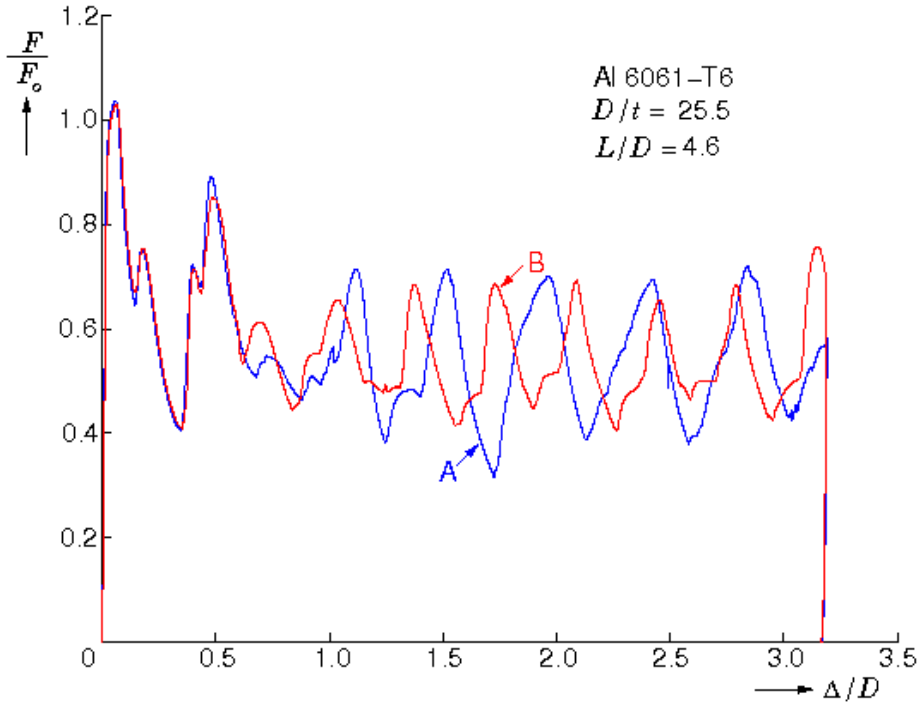

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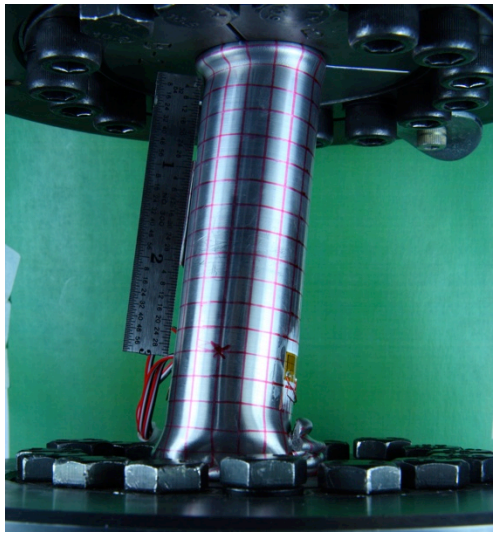

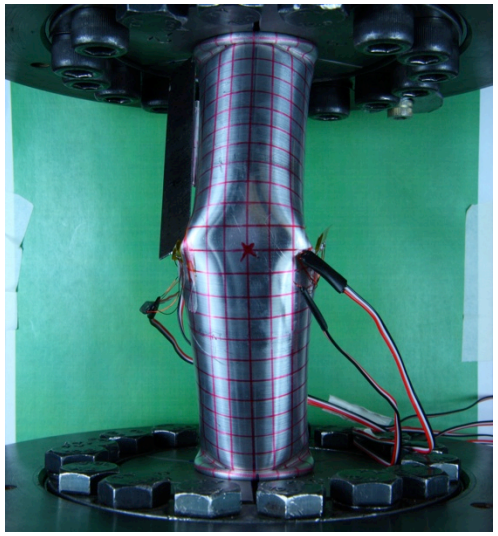

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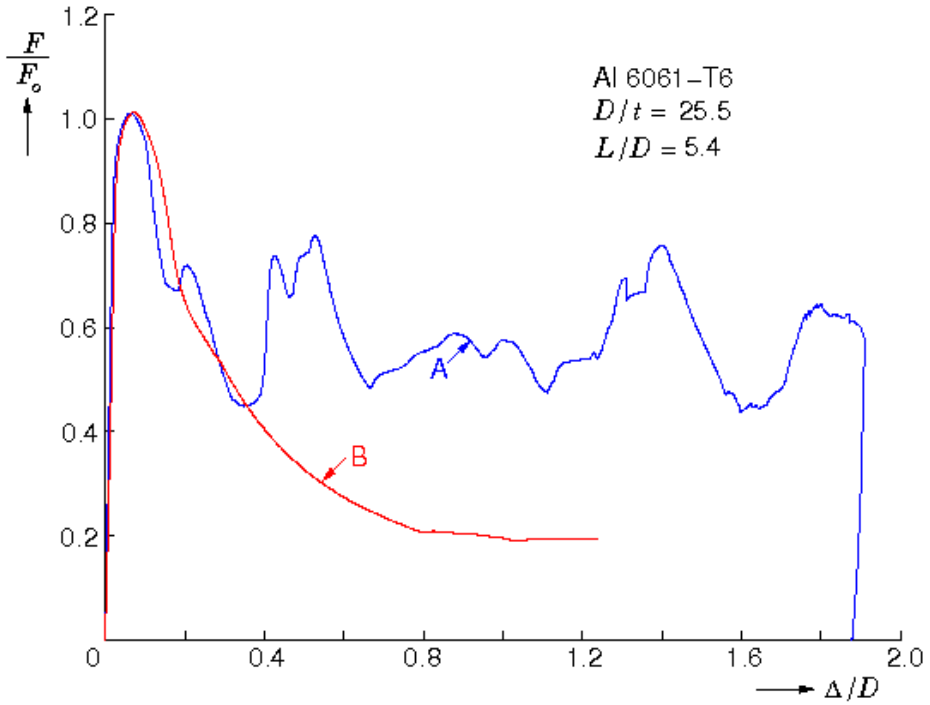

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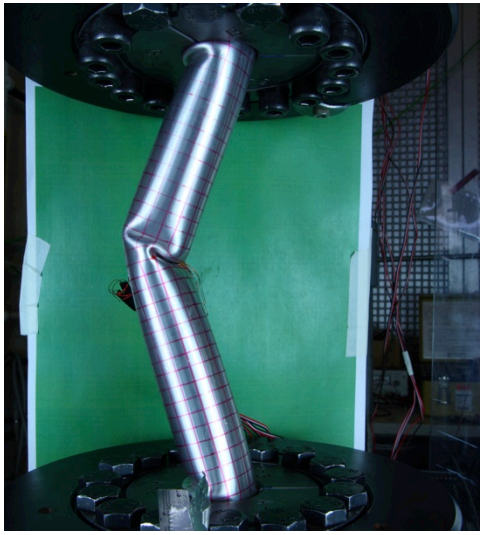
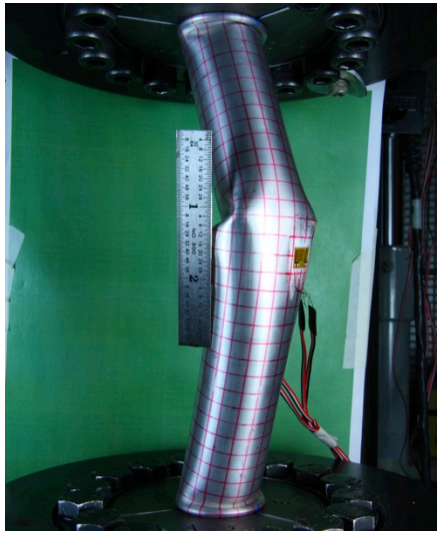
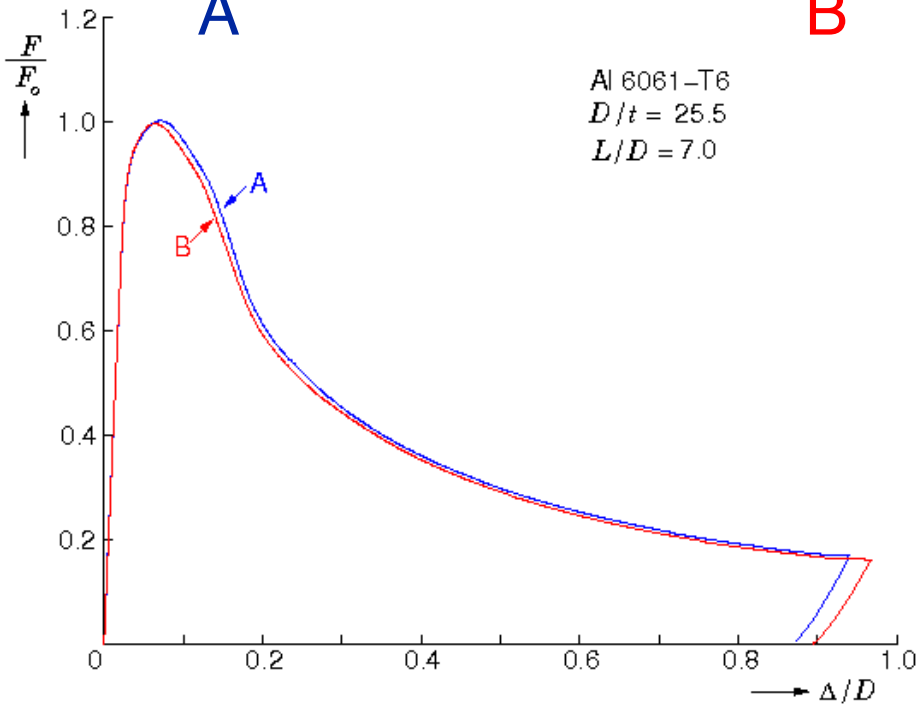




A

B



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Parametric Study

Clamping Pressure (PSI)	Plug Size (inches)	Mesh (inches)	Result
1250	1.15	0.05	N=3
1250	1.147	0.05	N=2
1250	1.15	0.025	N=2
2500	1.15	0.05	N=3
2500	1.147	0.05	N=3
12500	1.15	0.05	N=3
12500	1.15	0.025	N=3
12500	1.147	0.05	N=3
6250	1.15	0.025	N=3