Computational studies of polyurea coated steel plate under blast loads

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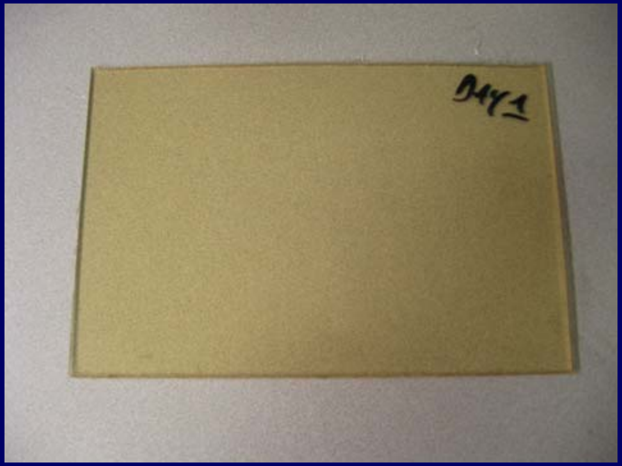
Background

- Lightweight material is sought for blast resistant application
- A new material – polyurea
  - Constituents
    - Isocyanate
    - Amine
  - Advantages
    - Fast, consistent reactivity and cure
    - Moisture insensitivity
    - Excellent physical properties
    - Low water absorption qualities
    - High Abrasion resistance



Source: PCI, http://www.pcimag.com/CDA/Archives/779f754db76a7010VgnVCM100000f932a8c0

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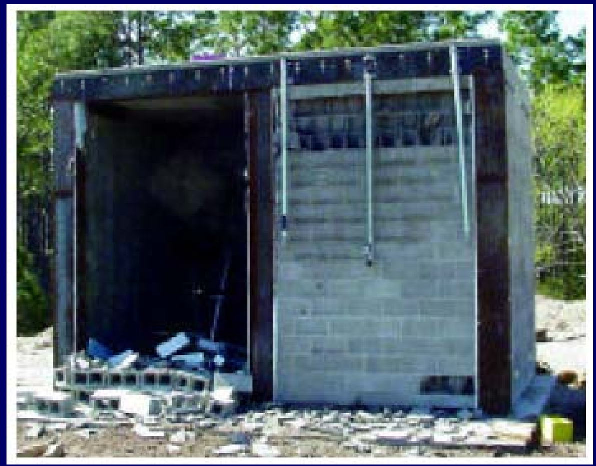
Background

- Application
  - Civil infrastructure
    - Timber framed structures (Knox et al.)
    - Concrete masonry walls (Davidson et al.)
  - DoD
    - Armor
    - Ship hull
  - Other
    - Water storage tank
    - Chemical plant infrastructure

Source: Polymer Materials for Structural Retrofit, Knox et al.
DefenseReview.com: http://www.defensereview.com/article502.html

Background

- Air Force Research Laboratory
  - Blast testing
  - Polyurea coated unreinforced masonry, timber stud walls
  - Promising results



Source: Polymer coatings increase blast resistance of existing and temporary structures, Porter et al., AFRL

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Motives of the study

- A lightweight material is sought for improving blast resistance
- Polyurea shows promising results from blast testing
- Lack of unclassified study on application of polyurea on steel components
- Blast testing is dangerous and costly

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Objectives

- Investigate effects of polyurea on steel members under blast loading
- Develop a numerical model using LS-DYNA to facilitate designing a blast-resistant steel component

Approach

- Utilizing a CFD code to perform blast simulation
- Using LS-Dyna to perform structural dynamics analysis

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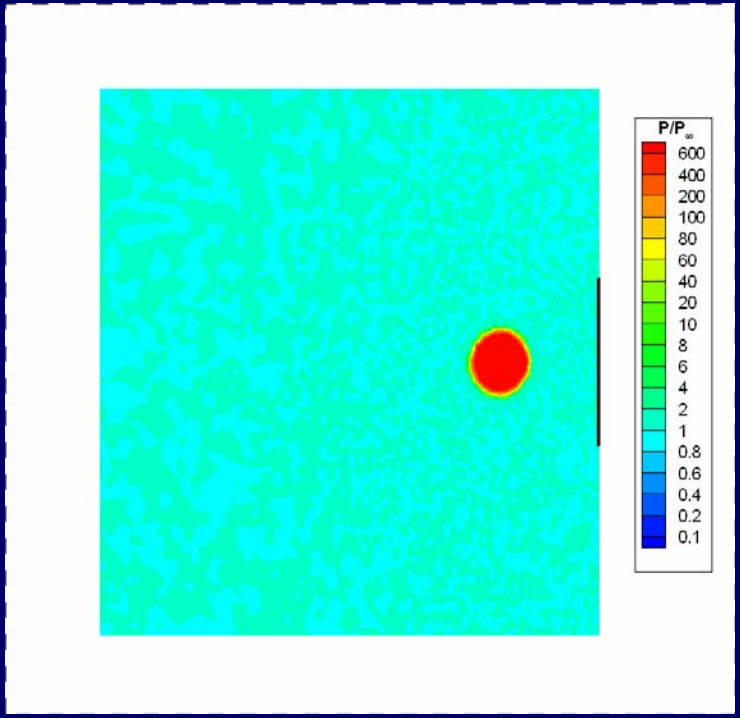
Blast simulation

- PUMA2, a computational fluid dynamics computer code developed at PSU
- Solve Euler equations
- Generate pressure and temperature time-histories



References: Parallelization of Euler Equations on Unstructured Grids, Bruner. 1996.
Parallel Unstructured Maritime Aerodynamics-2, Long et al.

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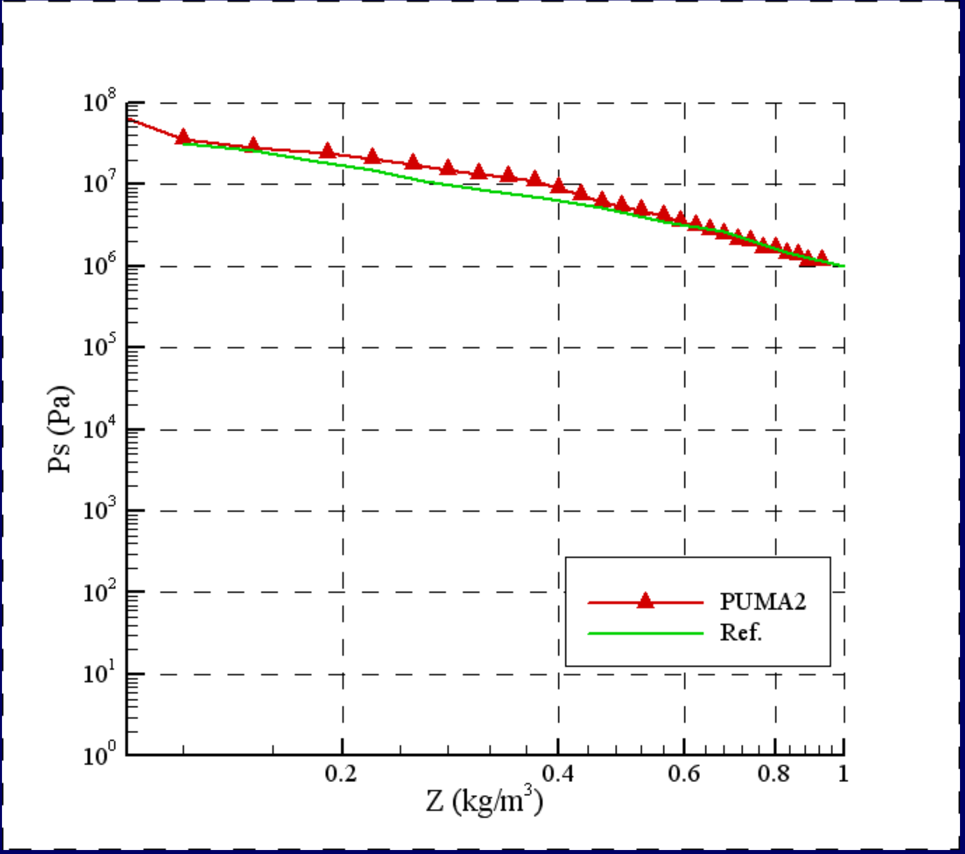
Validation of PUMA2 - Over-Pressure

- Predictions compared with the values presented in Reference.
- Good agreement despite the calorically perfect gas assumption.



Variation of Over-Pressure with Scaled Distance

Reference: Smith, P. D., Hetherington. J. D. "*Blast and Ballistic Loading of Structures*," Butterworth – Heinemann, 1994, pp.36.
Alpman E., Long L.N., Chen C., Linzell D.G. " Prediction of Blast Loads on a Deformable Steel Plate Using Euler Equations." 18th AIAA Computational Fluid Dynamics Conference. Jun 25-28, 2007.

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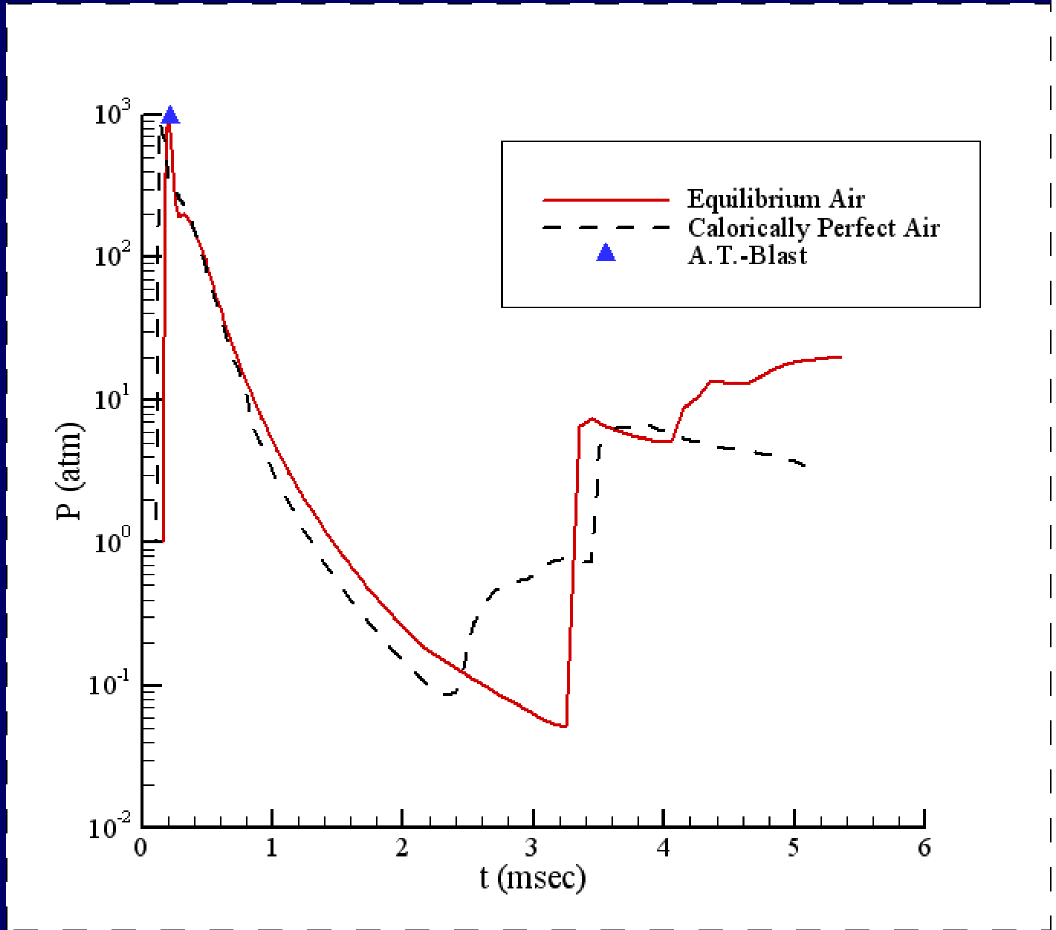
Pressure Loading at the Center of the Plate

- Results obtained using calorically perfect gas assumption were included for comparison.
  - Distance to the plate was measured from explosive center for the perfect air case.
- Blue triangle shows result from AT-Blast* program.
- Peak pressure predictions agree well with AT-Blast.
- Predictions do not differ from each other except in the vicinity of the secondary shock.
- High temperature effects had little impact on peak pressure.



*[AT-Blast 2.2, Applied Research Associates, Inc.]

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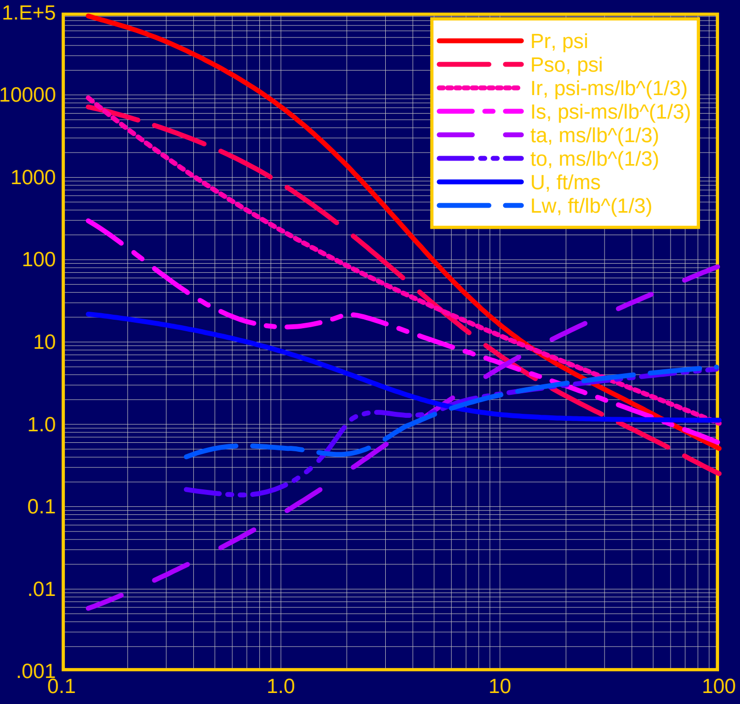
Comparison between PUMA2 and TM5-1300

- TM5-1300
  - A manual of Department of the army, the navy, and the air force

Table of scaled distances

W \ R	75 lb TNT
3.2 ft	0.76
6 ft	1.42

Figure 2-7. Positive phase shock wave parameters for a spherical TNT explosion in free air at sea level



Comparison of reflected pressures

	TM5-1300	PUMA2
Z = 0.8	10 ksi	14 ksi
Z = 1.4	4 ksi	4.8 ksi

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LS-DYNA model: Polyurea coated steel plate under blast loading (PUMA2)

- Dimensions of steel plate: 60”x60”x0.25”
- Thickness of coating (polyurea): 0”, 0.25”, 0.5”
- Material models from literatures
  - Steel (AISI 4340)
    - Johnson-Cook model
  - Polyurea (Air Products)
    - Finite elastic strain plasticity model
- Load: 75 lb TNT and 3 ft standoff distance
- Blast loads generated by PUMA2, a CFD code developed by Penn State

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Material model - Steel

- Steel (AISI 4340)
  - Johnson-Cook material model
  - A=66.7, B=100.4, n=0.26, C=0.014, and m=1.03

$$\sigma = \left[A + B\left(\varepsilon^{pl}\right)^{n}\right]\left[1 + C\ln\left(\dot{\varepsilon}^{*}\right)\right]\left[1 - T^{*m}\right]$$

ε^{pl} : equivalent plastic strain

$\dot{\varepsilon}^{*}$: normalized plastic strain rate

$$T^{*} = \frac{T - T_{room}}{T_{melt} - T_{room}}$$

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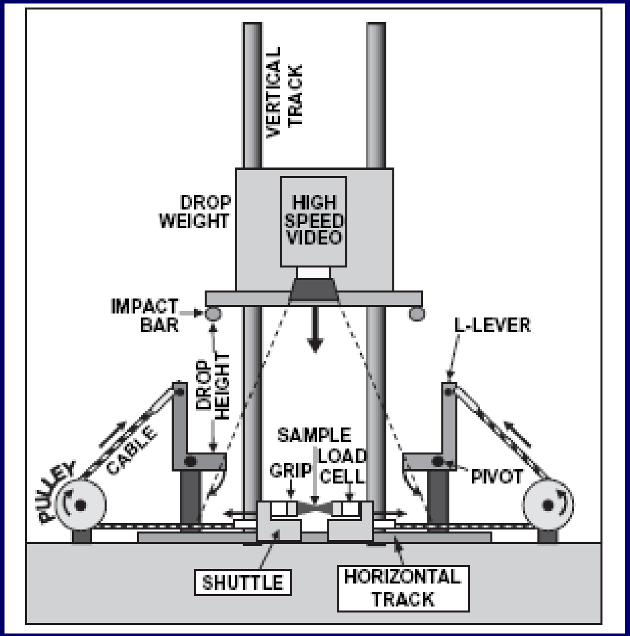
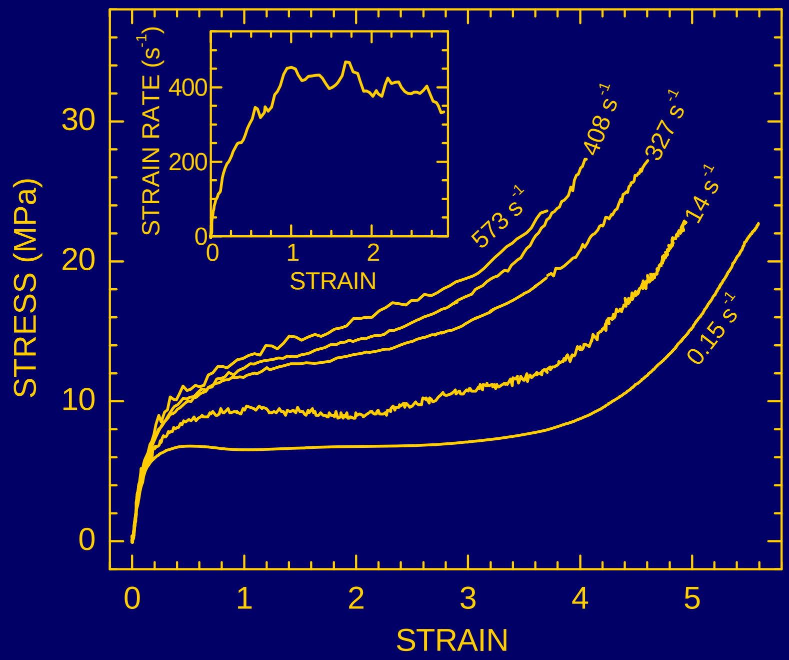
Material model - polyurea

- User-defined material properties
- Experimental data from NRL



A new drop weight test instrument



High strain rate tensile testing data

Reference: High strain rate mechanical behavior of polyurea, Roland et al., NRL. 2007.

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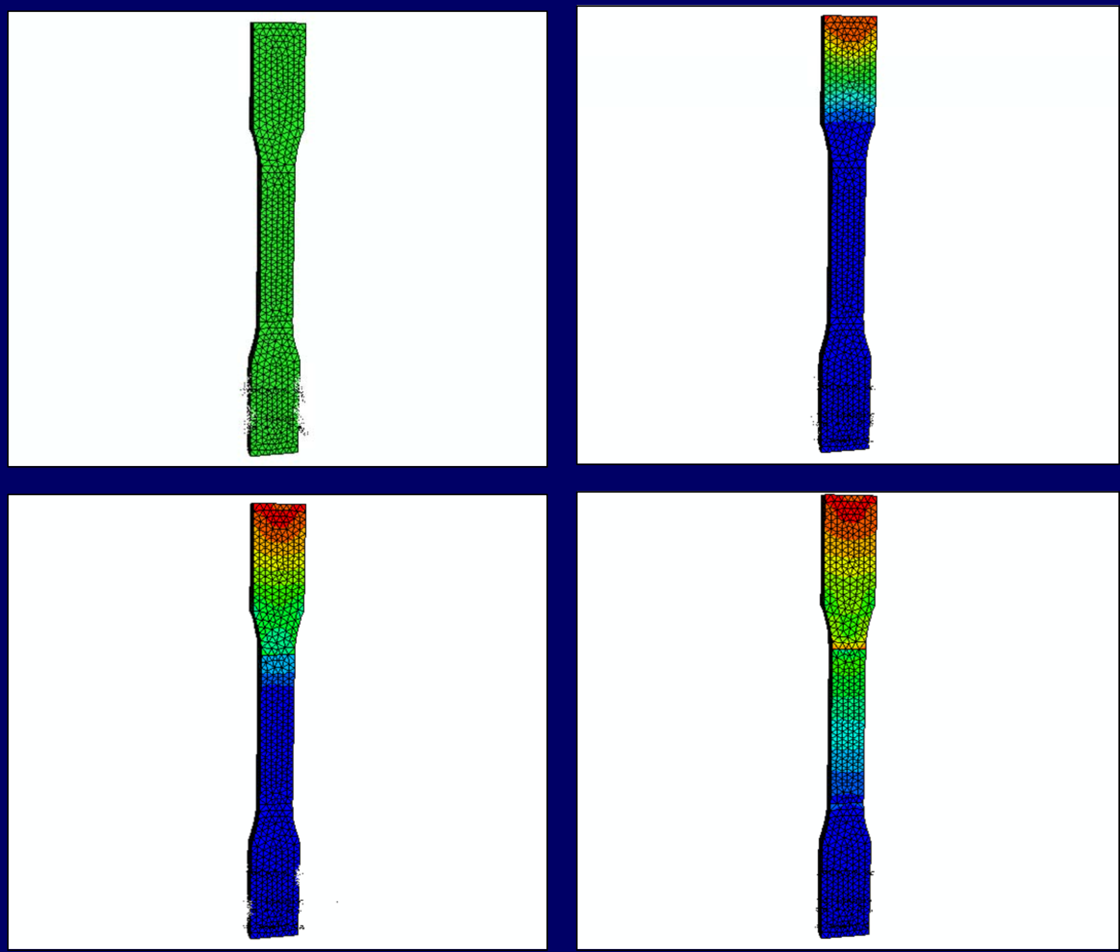
Validation of the material model for polyurea - Coupon model



Steel plate under blast loading

	Thickness of steel (in)	Thickness of polyurea (in)	Remark
Case 1	0.25	0	No coating
Case 2	0.25	0.25	
Case 3	0.25	0.5	
Case 4	0.25+0.068	0	No coating 0.068” steel = 0.5” polyurea

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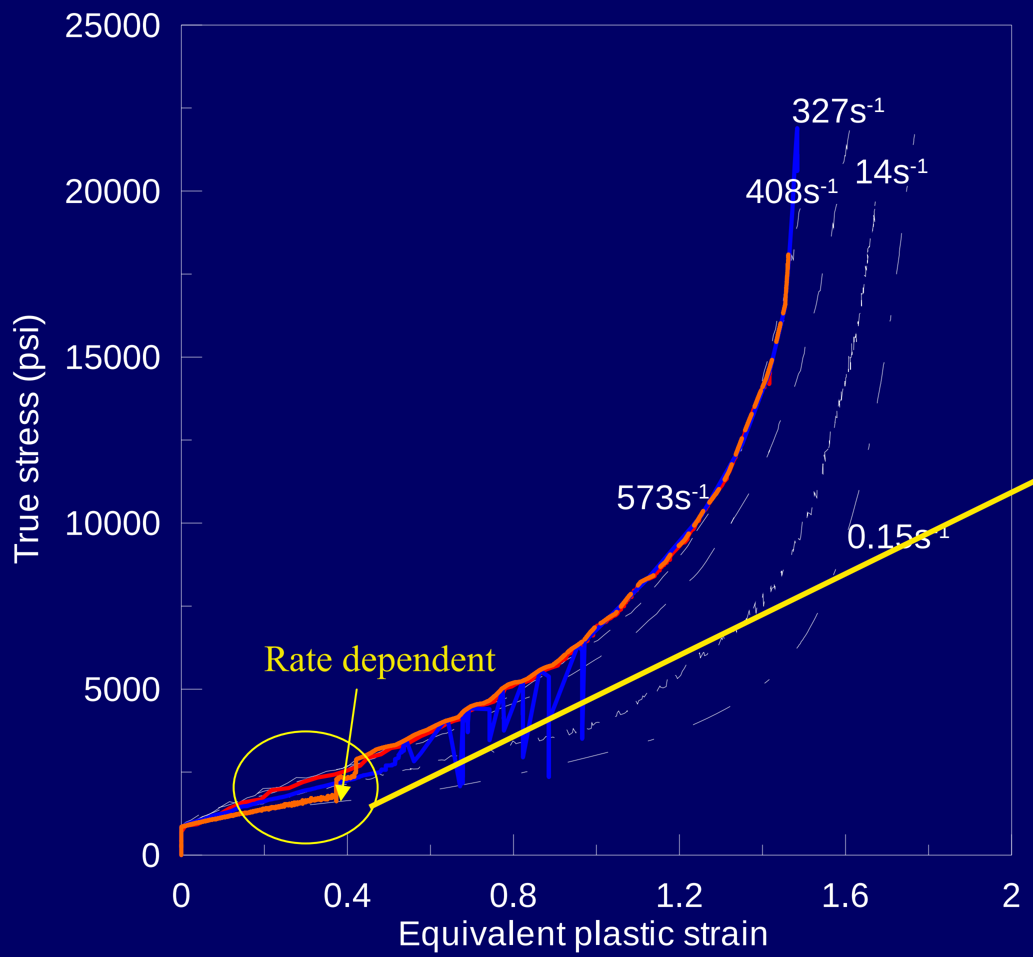
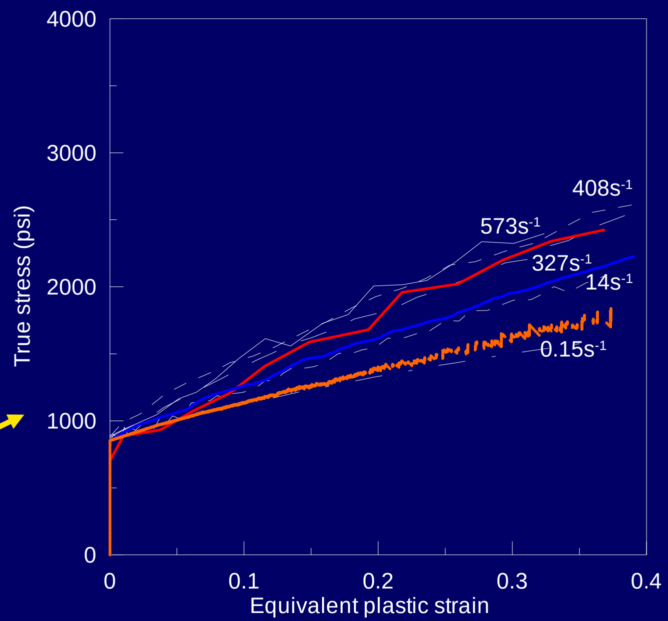
Comparison between the numerical and experimental results





Different loading rates were applied initially, but strain rates rose rapidly after necking which was the reason that it didn’t show rate dependence at the high end.

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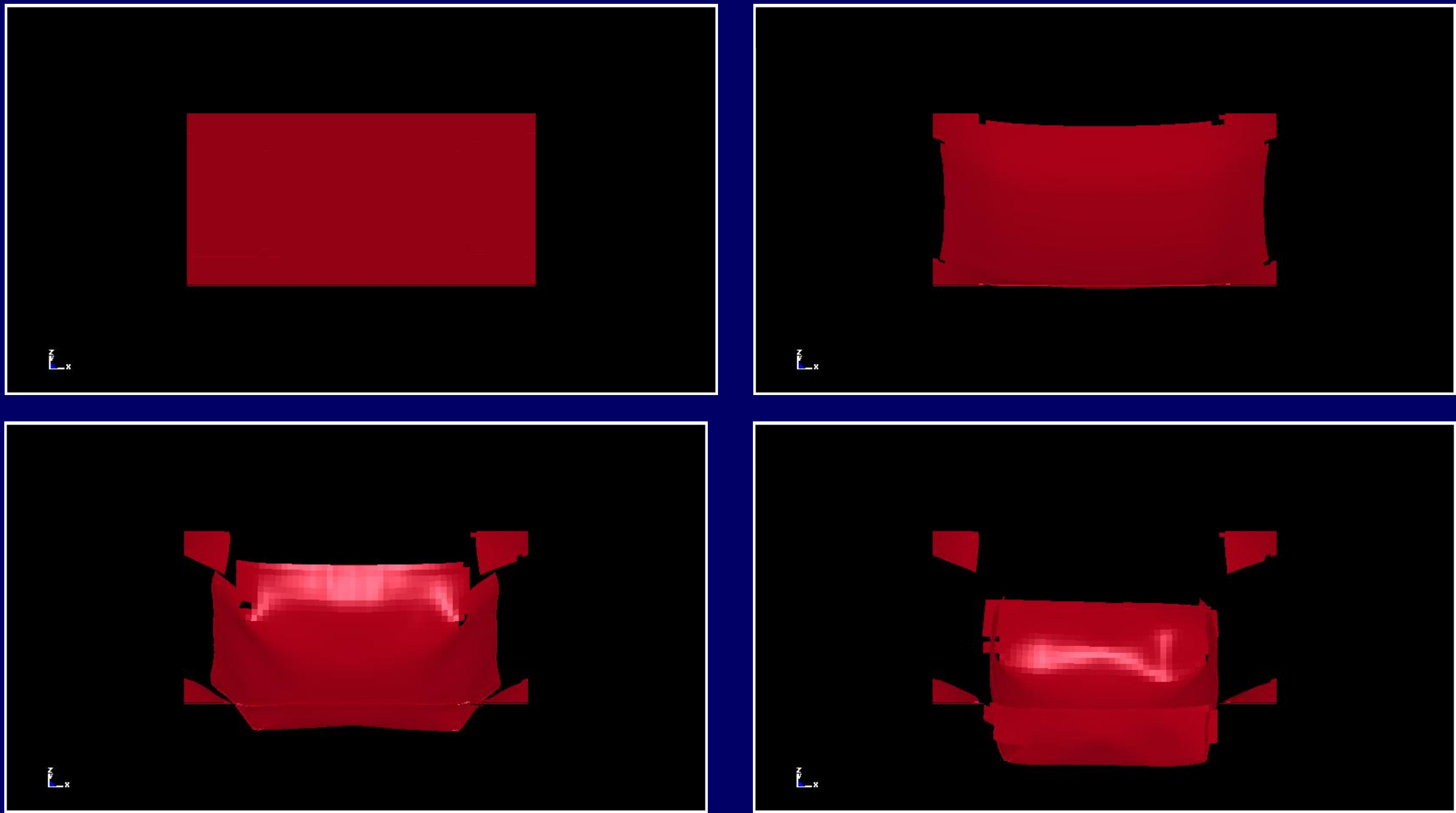
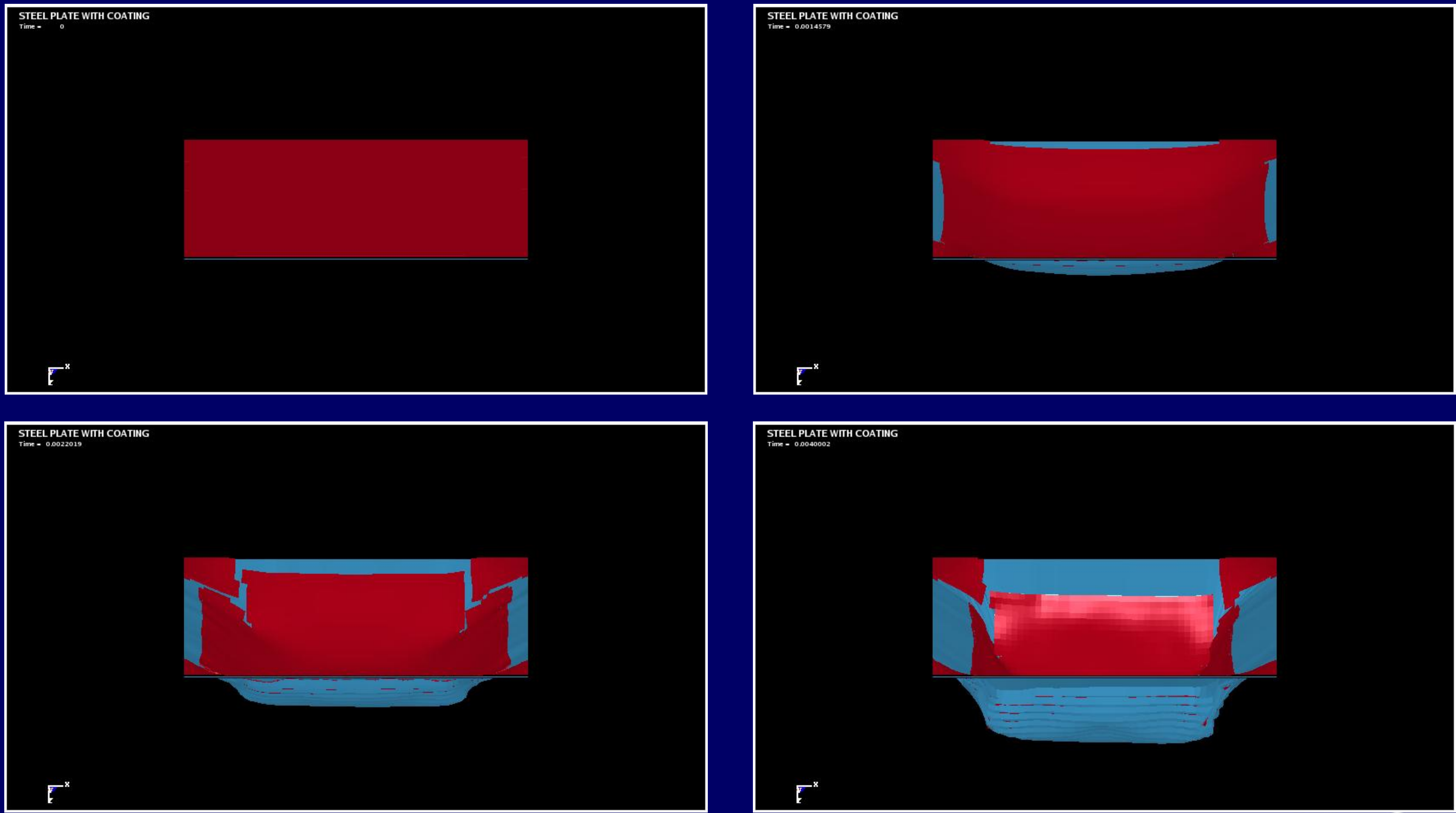
Case 1 – No coating



Case 2 – 0.25" thick coating



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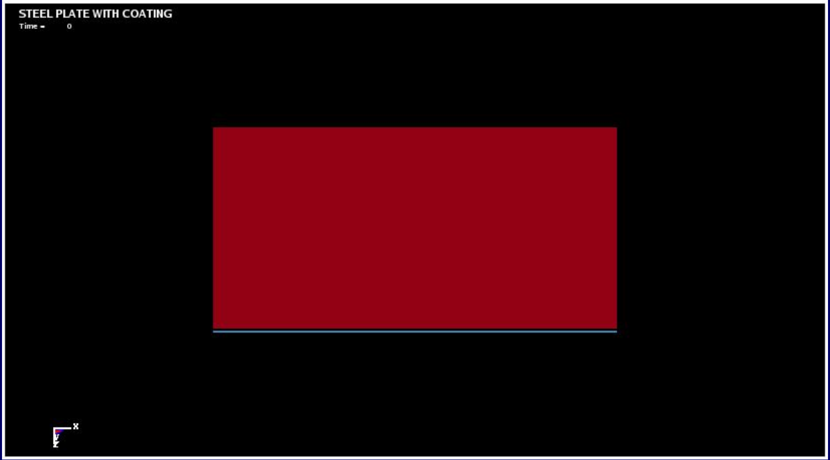
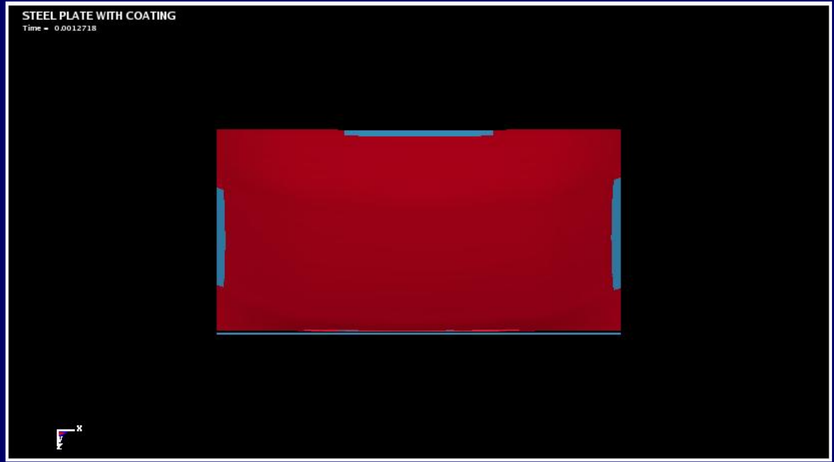
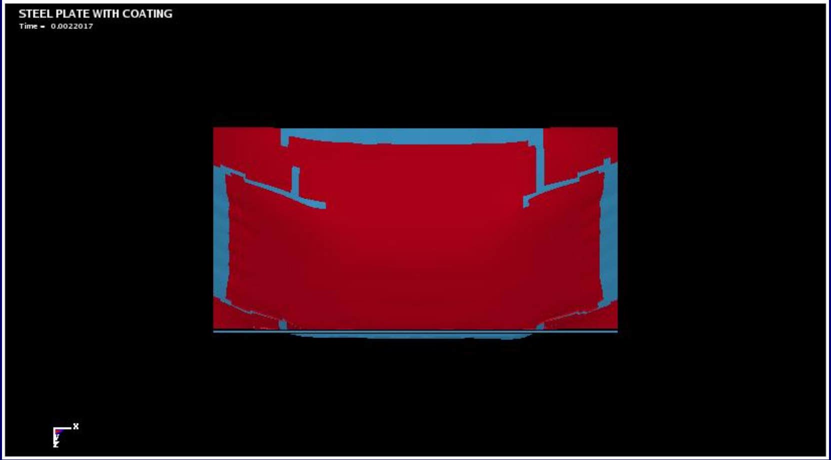
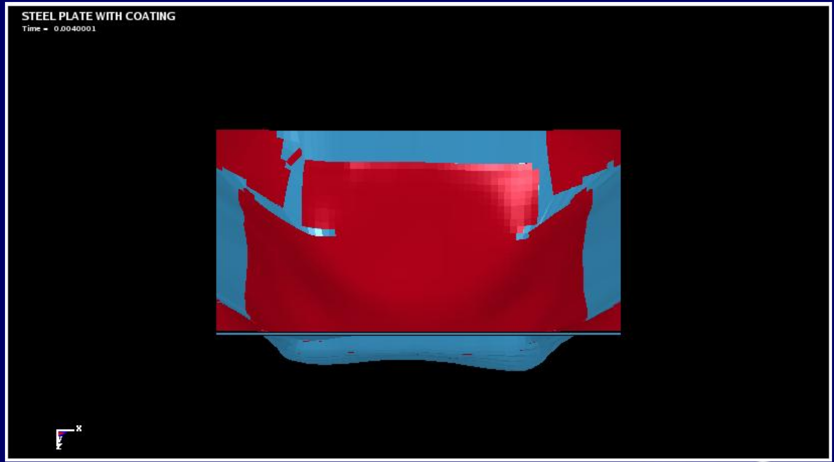
Case 3 – 0.5” thick coating

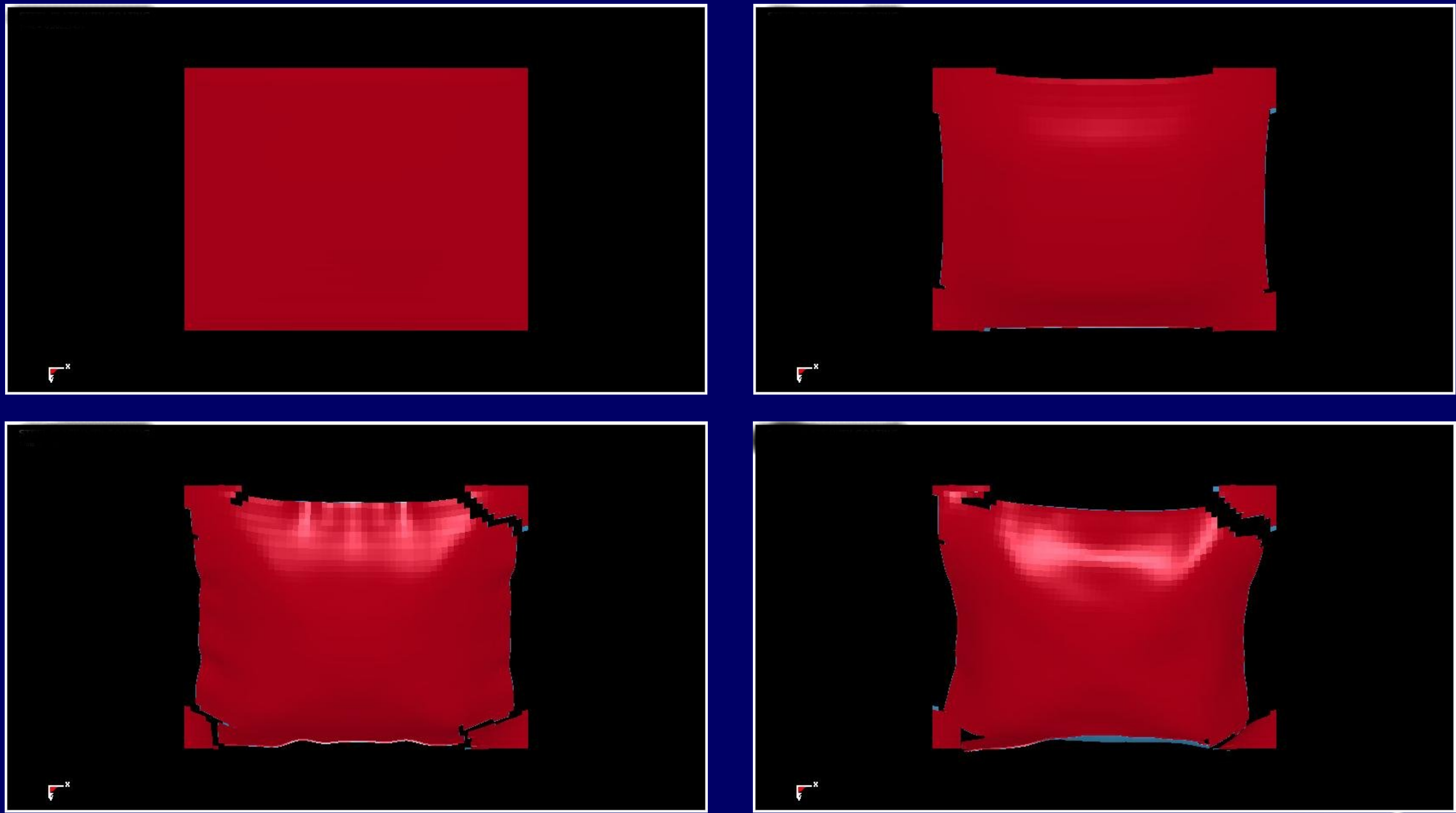




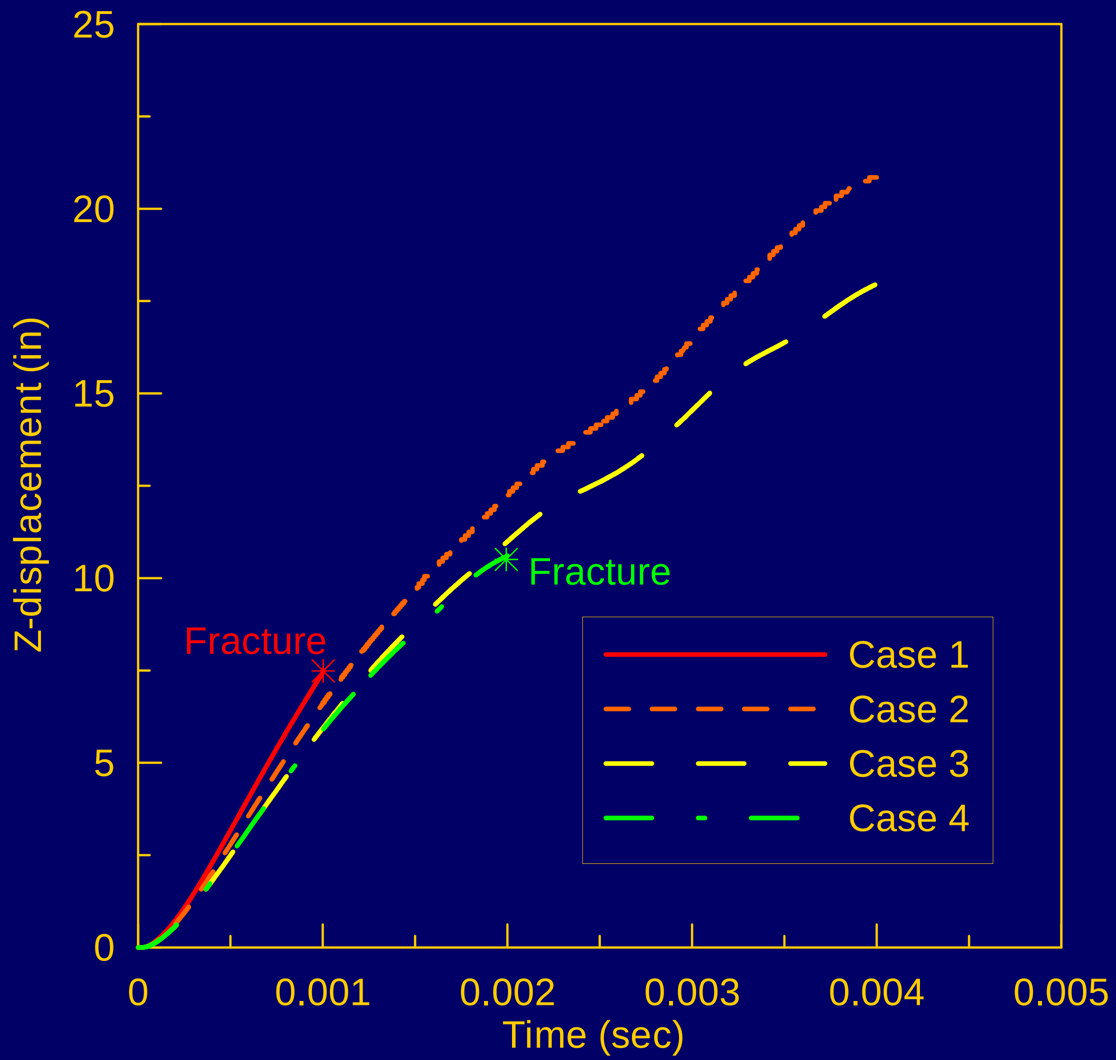




Case 4 – Additional 0.068” steel



Comparison of the displacements



Conclusion

- Apply polyurea to steel for blast mitigation
- Apply the CFD code for a more accurate blast simulation
- Apply the pressure histories generated by the CFD code to LS-Dyna as the blast loads
- Compare the blast loads from the CFD code with other references
- Successfully numerical model polyurea coated steel plate under blast loading

Conclusion

- Incorporate strain rate dependent material models for the steel and polyurea
- Validate the material model for polyurea
- Fracture observed at the corners of the steel plate under blast loading
- Polyurea is effective to prevent steel plate from fragmentation
- Benefit of excessive polyurea is not significant

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