Experimental Study and Numerical Simulation of Electromagnetic Tube Expansion

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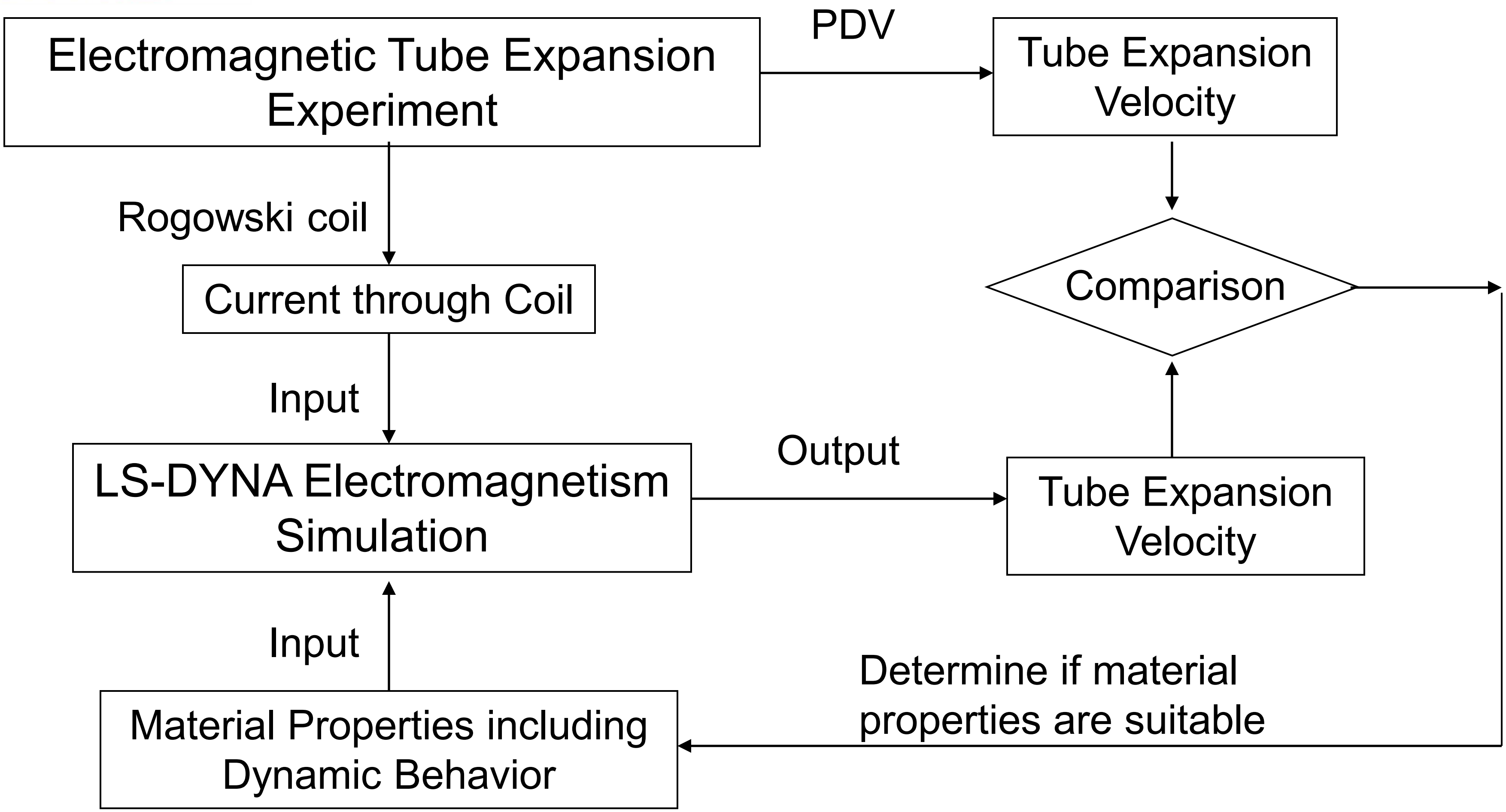
**Thank Professor Glenn Daehn and Mr. Geoffrey Taber of the Ohio State University for the velocity measurement using PDV, and Pierre L'eplattenier of Livermore Software Technology Corporation for LS-DYNA software support*

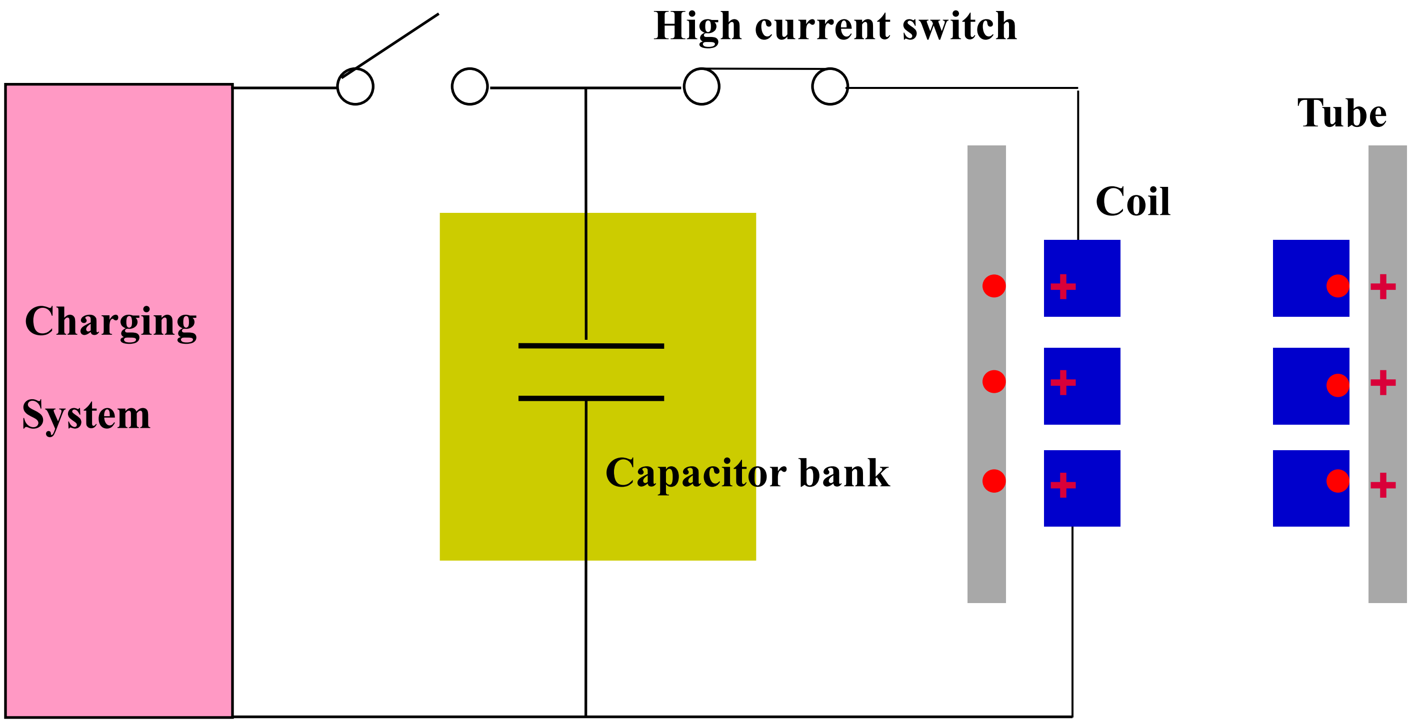
Motivation

1. Electromagnetic forming involves large deformation, high velocity and high strain rate.
2. Tube expansion is a simple 2D axisymmetric forming process.
3. Photon Doppler Velocimeter (PDV) enables the reliable measurement of high velocity.
4. Electromagnetism module of LS-DYNA allows the simulation of electromagnetic forming.
5. Combination of PDV and LS-DYNA can help the study of the dynamic behavior of aluminum alloys at high strain rate and high velocity.

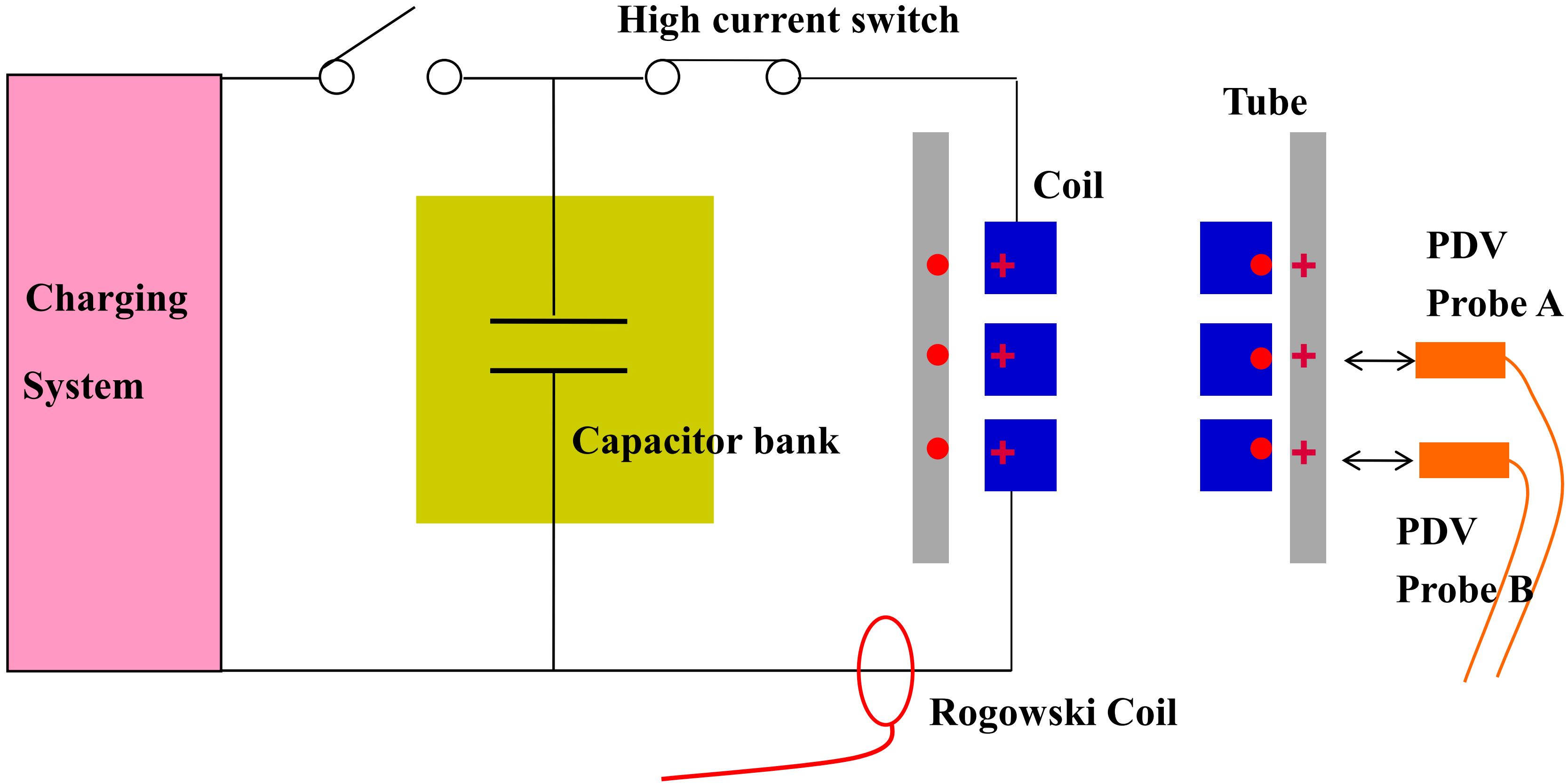
Procedure


Electromagnetic Tube Expansion Experiment
PDV
Tube Expansion Velocity
Rogowski coil
Current through Coil
Comparison
Input
LS-DYNA Electromagnetism Simulation
Output
Tube Expansion Velocity
Input
Determine if material properties are suitable
Material Properties including Dynamic Behavior

Basic Layout of Electromagnetic Forming

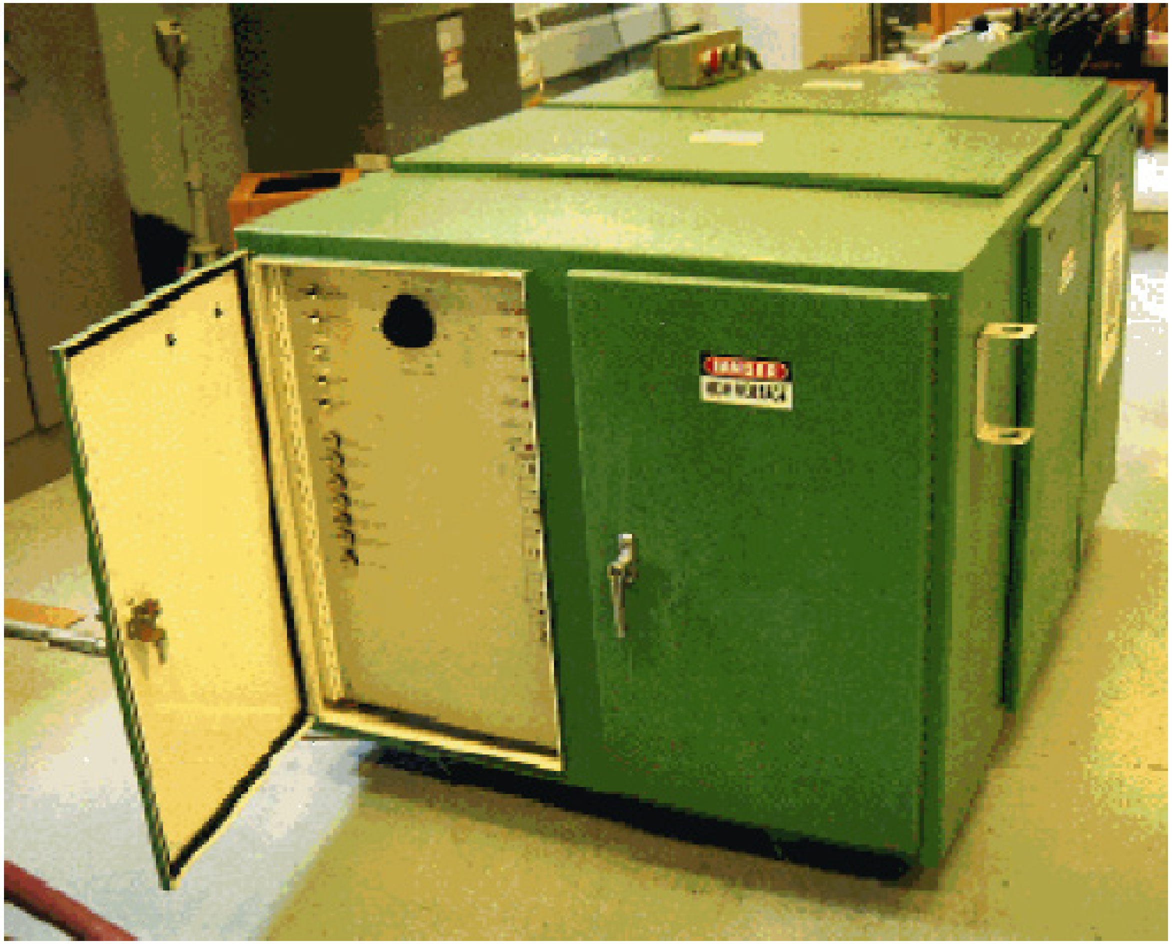


Experimental Set-up



Rogowski coil measures current; PDV measures expansion velocity.

Capacitor Bank Used



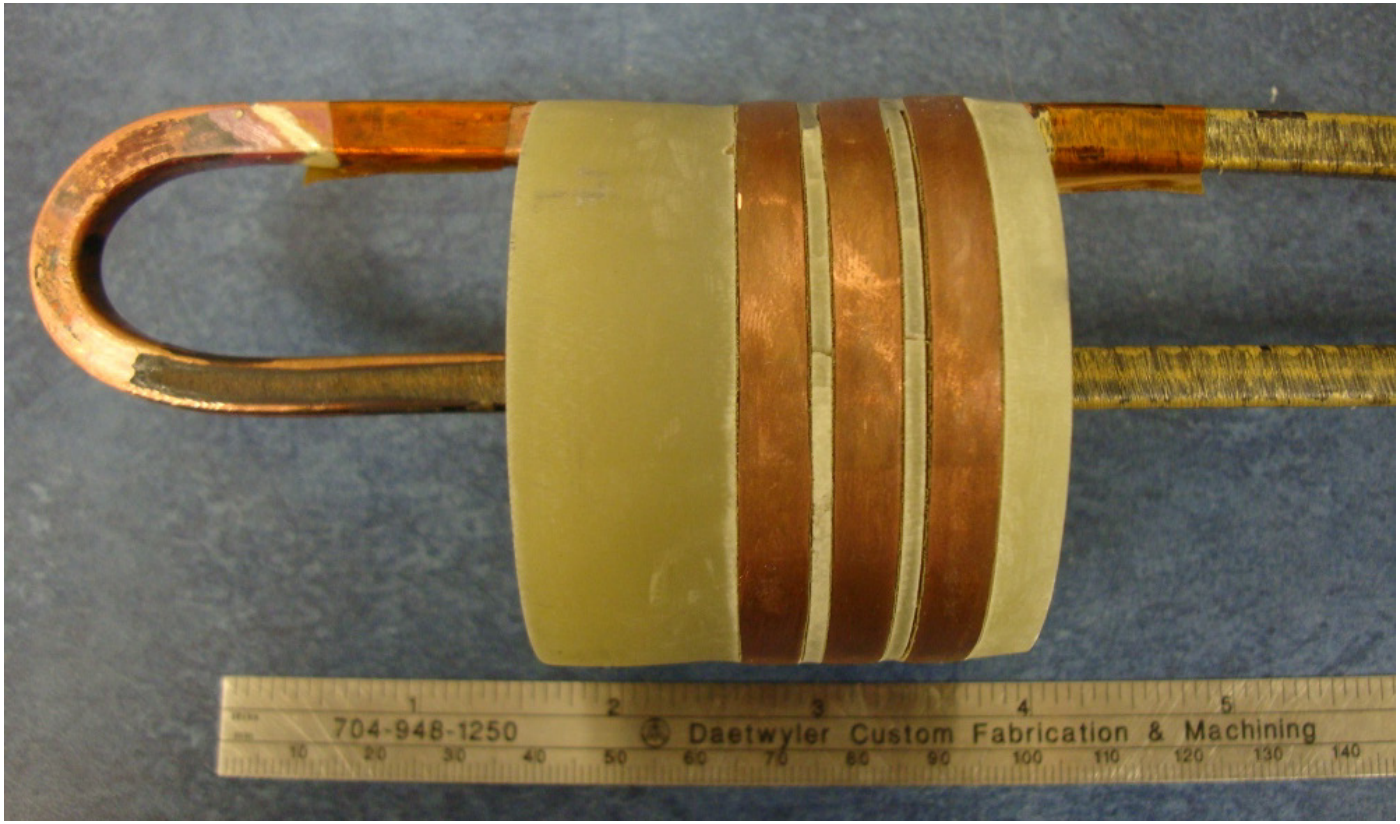
A 16kJ Magneform machine in OSU

(1) Maximum charging voltage is 8.66kV;

(2) Total capacitance is 426μF;

(3) Internal inductance is around 100nH;

Three-turn Coil



OD: 61mm; Gap between turns: 1.8mm; 6.3mm x 6.3mm cross section

Al6061-T6 Tube

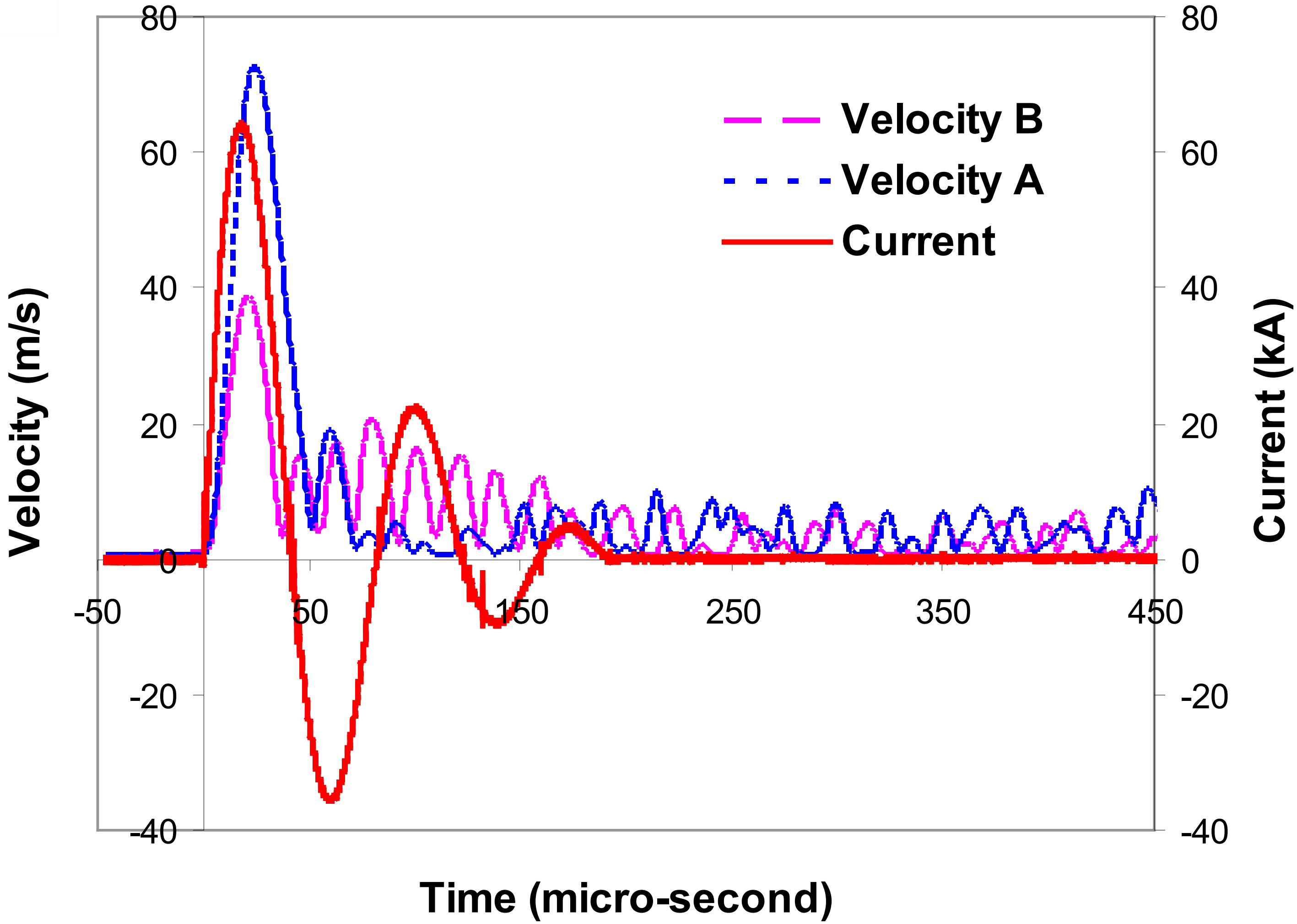
PDV probe B
(10mm away from
Probe A)

PDV probe A

(Middle of 3-turn coil)

OD of Al tube: 63.5 mm; Wall thickness: 0.89mm; Length: 45mm

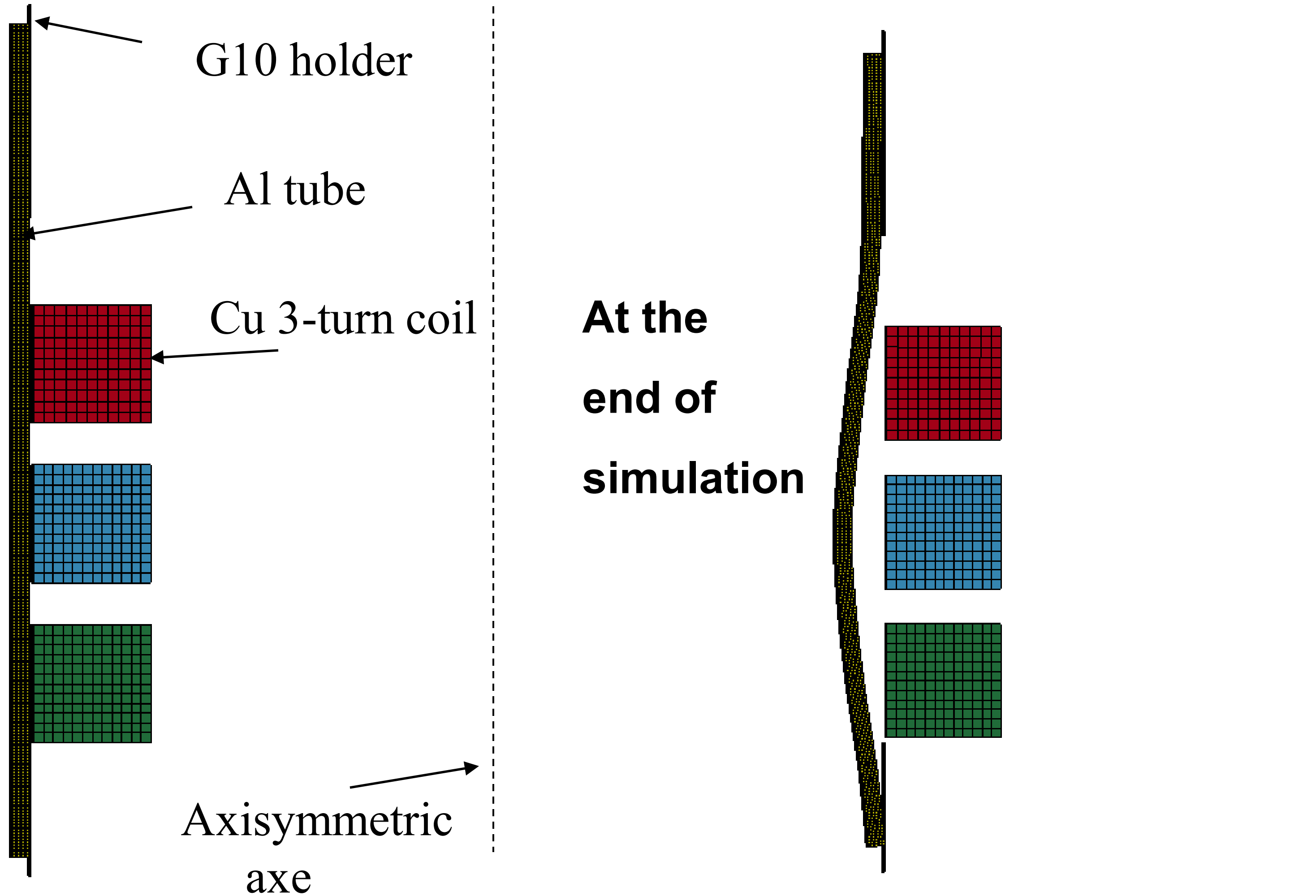
Velocity and Current Measurements (0.8 kJ)



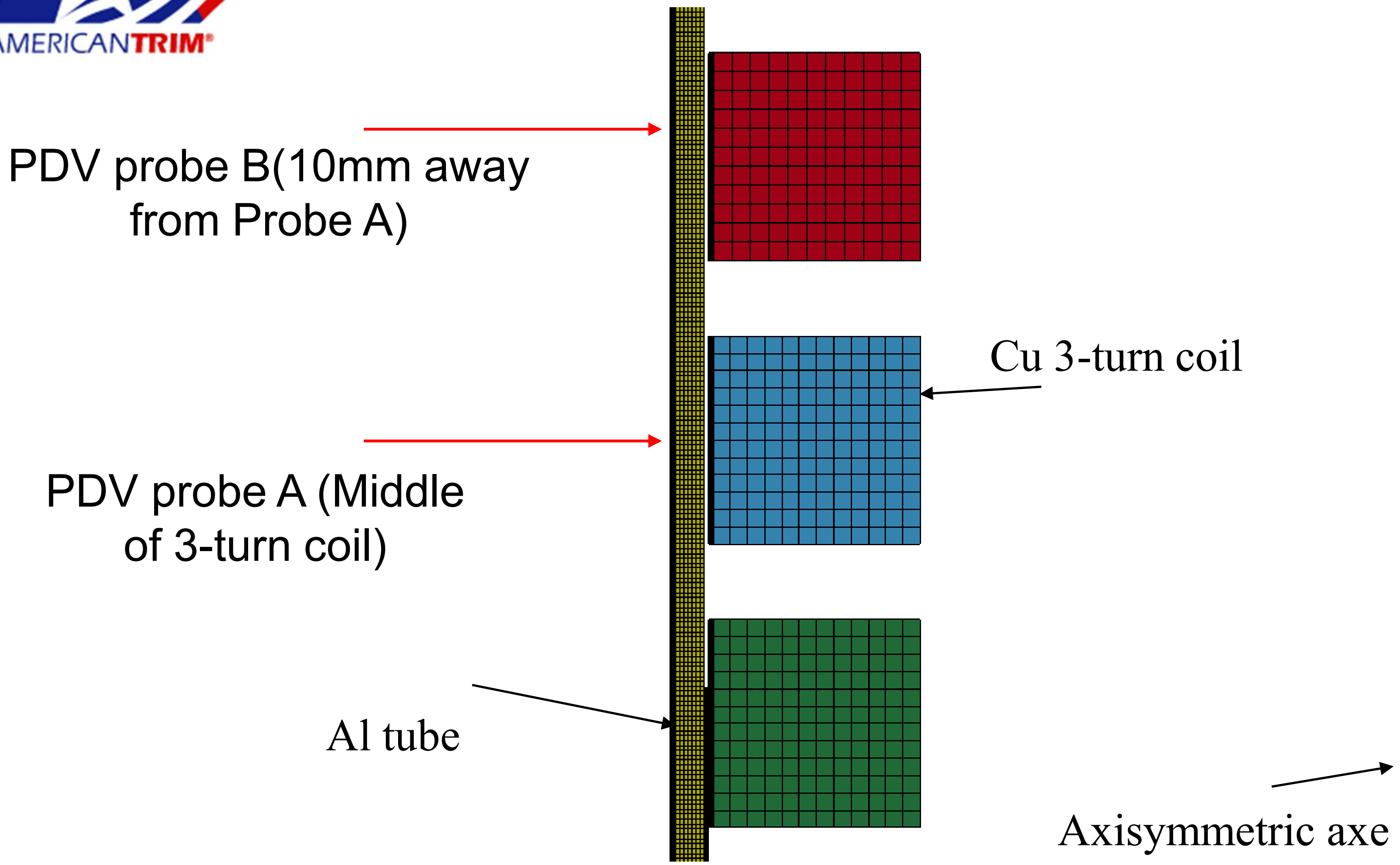
2D Axisymmetric Modeling

At the beginning of simulation

At the end of simulation



2D Axisymmetric Modeling (Closer look)



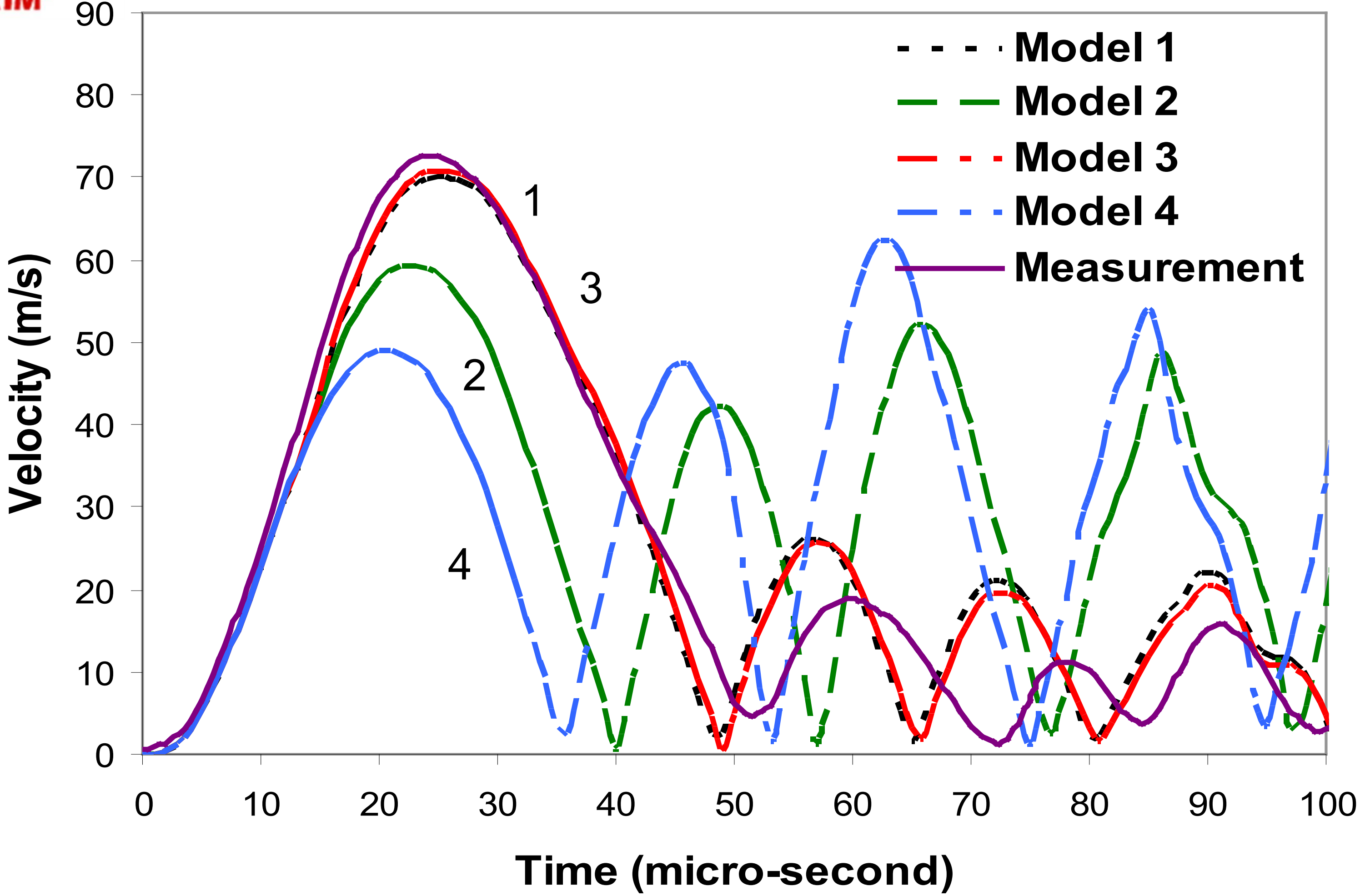
Johnson-Cook Strength Model

Johnson-Cook strength model was selected, because of high strain rate in electromagnetic forming.

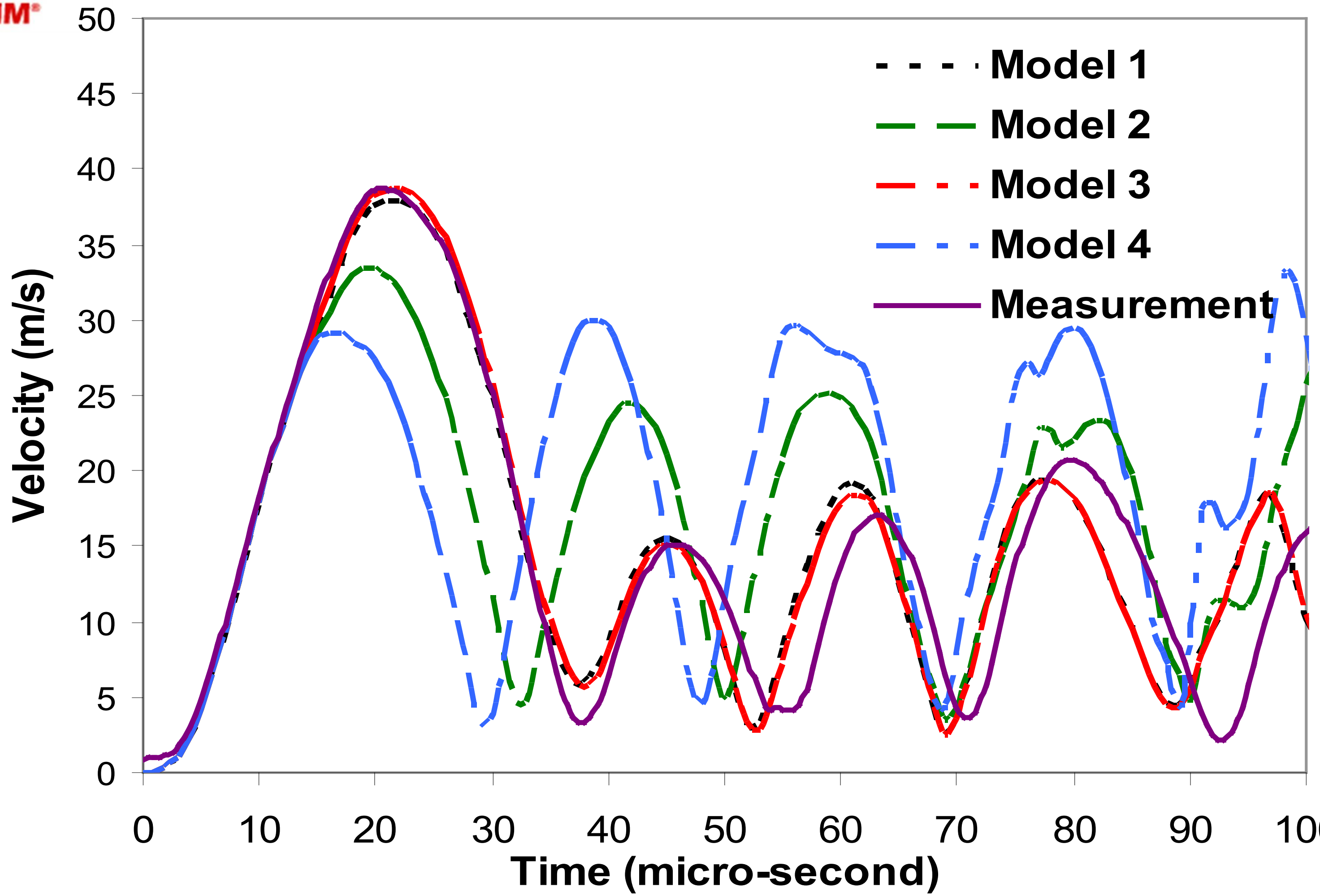
$$\sigma = (A + B\varepsilon^n)(1 + C\ln\dot{\varepsilon})(1 - T^{*m})$$

Model for Al 6061-T6	A (MPa)	B (MPa)	C	n	m	T_m (K)
Model 1 [1]	324	114	0.002	0.42	1.34	925
Model 2 [2]	275	500	0.02	0.3	1.0	925
Model 3 [3]	293	121.3	0.002	0.23	1.34	925
Model 4 [4]	289.6	203.4	0.011	0.35	1.34	925

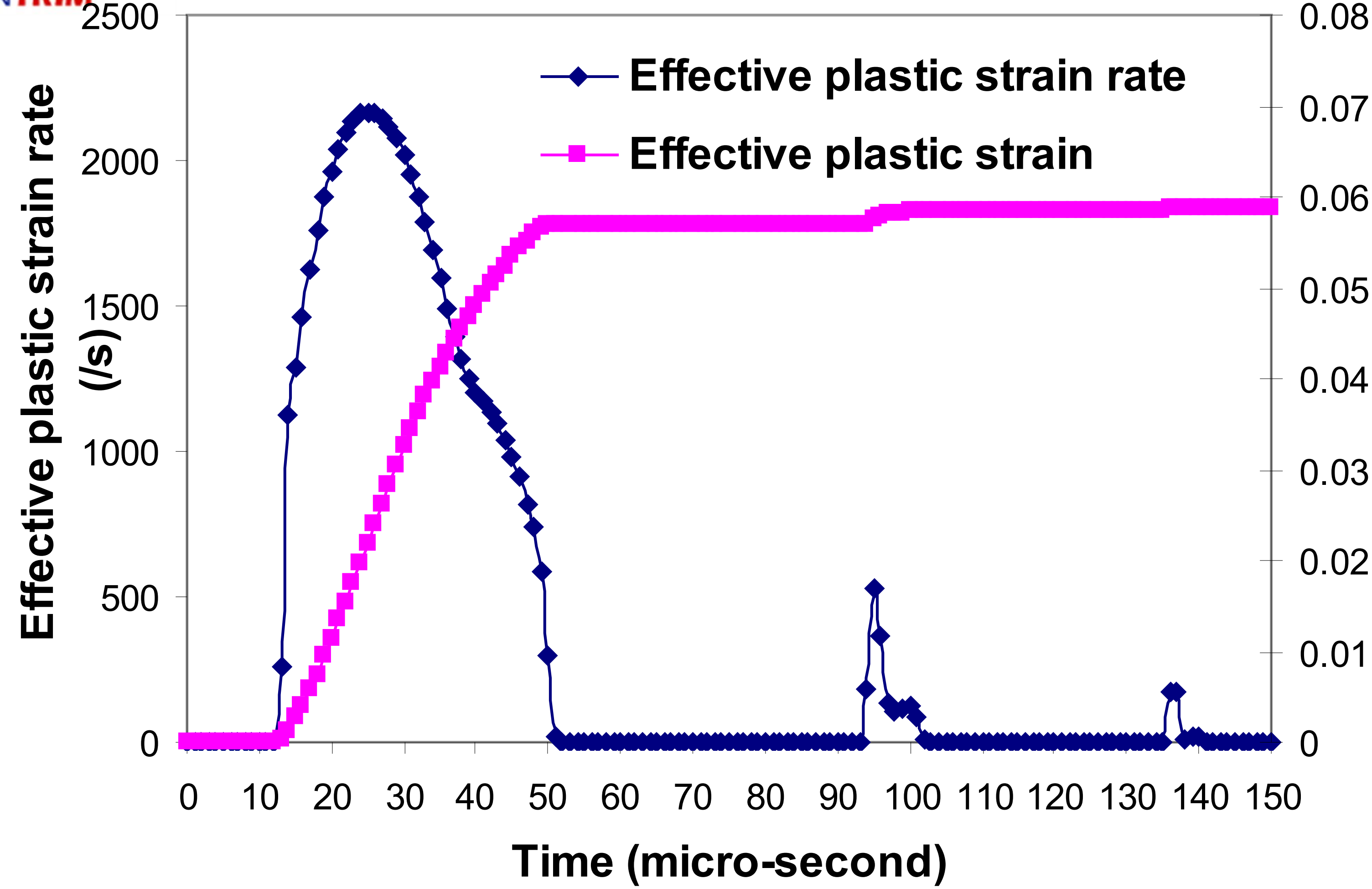
Comparison--- Velocity A (0.8 kJ)



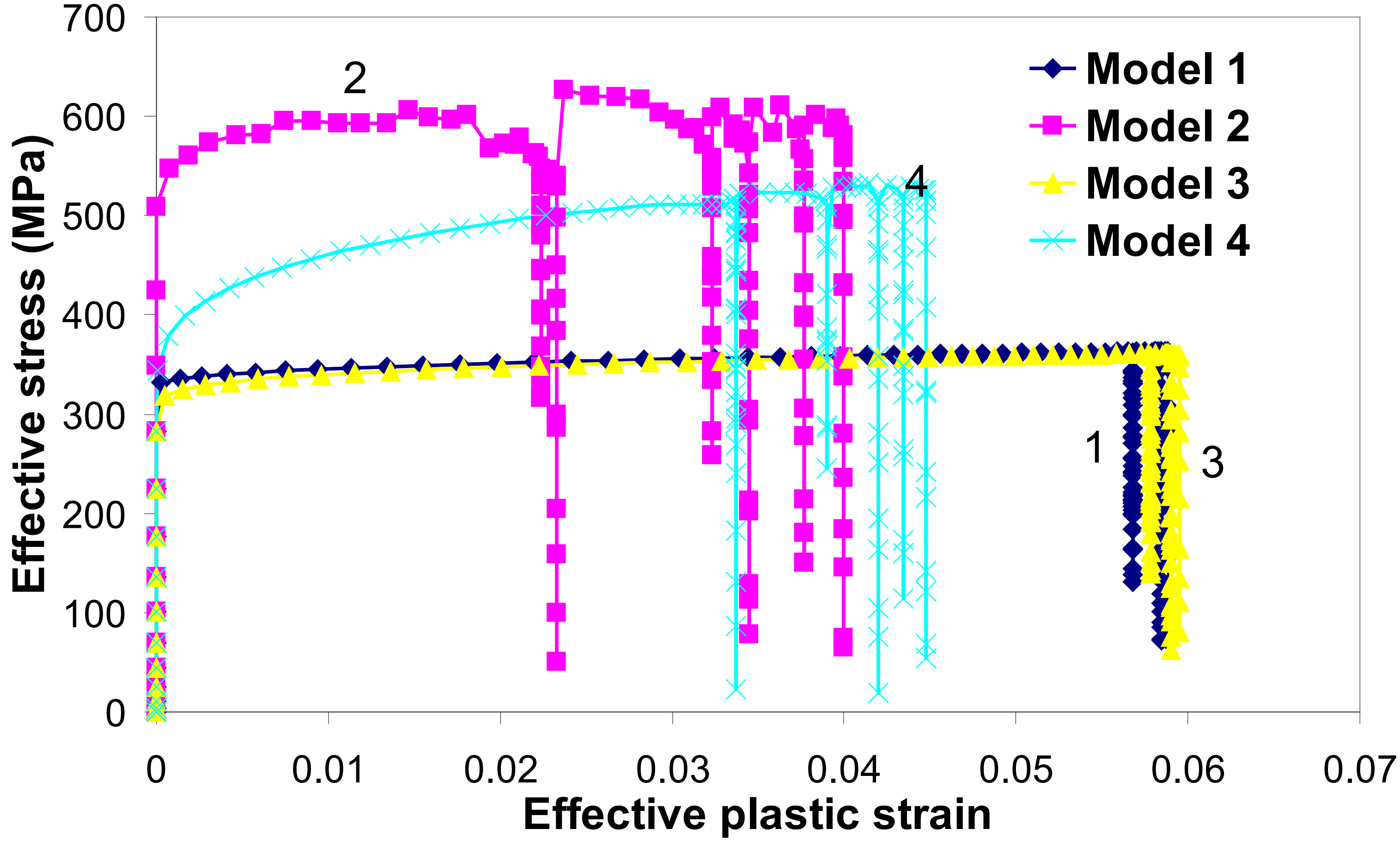
Comparison --- Velocity B (0.8 kJ)



Strain and Strain Rate for Position A (0.8 kJ)



Stress-strain Plots for Position A (0.8 kJ)



Parameters for J-C model

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

Model for Al 6061-T6	A (MPa)	B (MPa)	C	n	m	T_m (K)
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(1) Strain rate sensitivity C should be small for Al 6061-T6;

(2) Strain hardening has smaller effect than strain rate hardening in this case;

Summary

1) PDV was applied for the velocity measurement and Ls-dyna electromagnetism module was applied for the simulation of the Al 6061-T6 tube EM expansion;

2) Comparison between the numerical and experimental results showed the good agreement;

3) Four different parameter sets for Johnson-Cook strength model were used in the numerical simulation. The results showed that the value of the strain rate sensitivity for Al 6061-T6 should be small;

4) Strain rate hardening has larger effect in EM expansion;

Acknowledgement

The authors would like to thank Professor Glenn Daehn and Mr. Geoffrey Taber of the Ohio State University for the experiment and the velocity measurement using PDV, and Pierre L'eplattenier of Livermore Software Technology Corporation for LS-DYNA software support.

References of J-C strength model parameters:

(1) Corbett, B.: Numerical simulations of target hole diameters for hypervelocity impacts into elevated and room temperature bumpers. International Journal of Impact Engineering 33 (2006), p. 431-440.

(2) Elsen, A.; Ludwig, M.; Schaefer, R.; Groche, P.: Fundamentals of EMPT-Welding. Proceedings of 4th International Conference on High Speed Forming, Columbus, OH, 2010, p.117-126.

(3) Rule, W.: A numerical scheme for extracting strength model coefficients from Taylor test data. International Journal of Impact Engineering 19 (1997), p.797-810.

(4) Fish, J.: Al 6061-T6 - elastomer impact simulations. Technical report, 2005.

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Questions?