DOE/NV/25946--2079

AN APPROACH FOR MEASURING AND MODELING OF PLASTIC DEFORMATION OF METALLIC PLATES DURING HIGH VELOCITY IMPACT

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NAFEMS Americas Conference 2014, Colorado Springs, CO, USA May 28-30, 2014

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This work was done by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy and supported by the Site-Directed Research and Development Program.

Outline

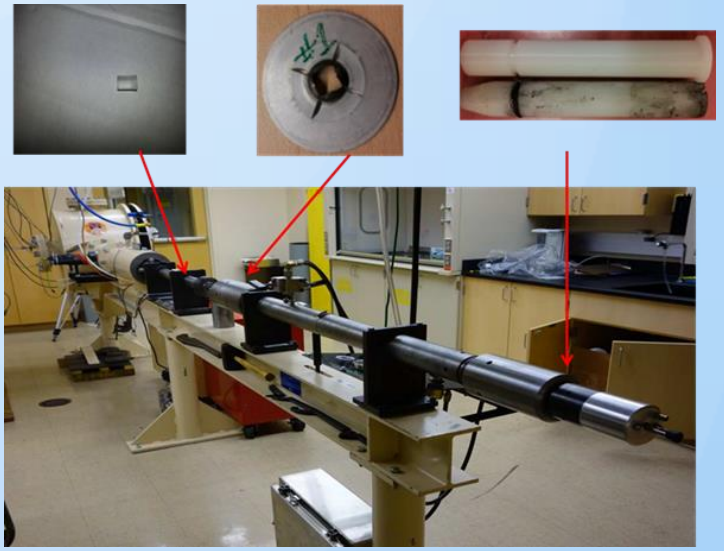
- Objective
- Experimental
- Computational Simulation
- Results and Discussion
- Simulation Comparison
- Conclusion
- Future Work

Objective

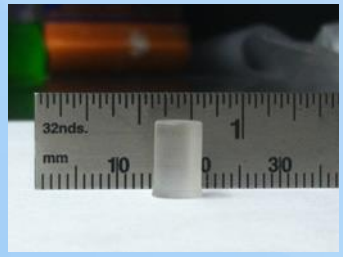
- During high velocity impact experiments, projectile impact creates extreme pressure waves that results in a significant localized deformation within a short period of time.
- Experiments under these conditions require sophisticated data acquisition technique to better understand the materials deformation mechanisms.
- Since these experiments are expensive, it is also beneficial to develop accurate computational models that can predict this kind of deformation in high velocity impact events.

Experiment: UNLV Two-Stage Light Gas Gun

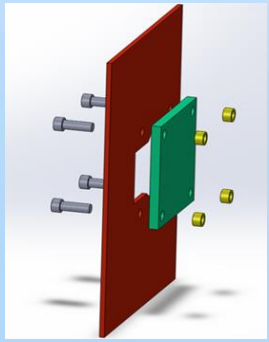
- A two-stage light gas gun is used to launch a cylindrical projectile into a target plate at a velocity range of 4.5-6 km/s.
- The gun uses either Hydrogen or Helium
  - Projectile: Lexan (5.6 mm diameter)
  - Target: A36 steel plate (152.4 × 152.4 × 12.7 mm)
- The target is bolted on a mounting plate during the experiment.
- Laser intervalometer system is used to measure projectile velocity.



UNLV Two-stage Light Gas Gun



Lexan Projectile



Target Mounting Plate

Target Chamber Assembly

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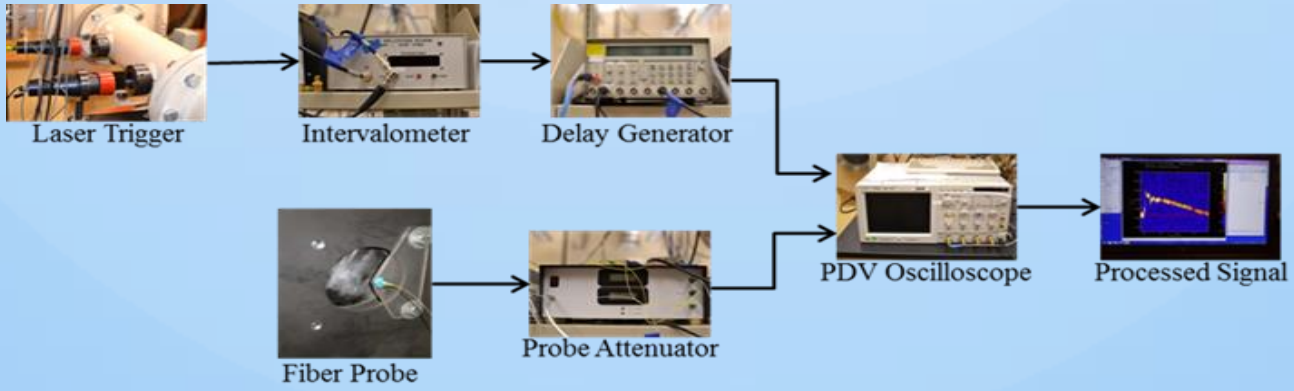
Experiment: Measurements

- Single channel Photonic Doppler Velocimetry (PDV) system is used to measure velocity from the back surface of the target plate.
- PDV is an interferometric technique which measures velocity using Doppler shift of reflected light from moving surface.

Laser unit assembly



Flowchart of a single probe PDV system

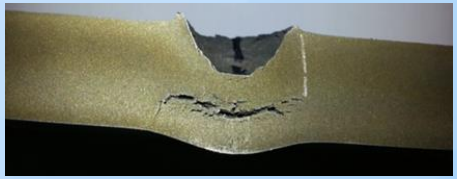
Experimental Results

- A small crater with a bulge on the back side of the target plate is created as a result of impact.
- **Spall failure**
  - Spalling happens close to the rear side of the target.
  - Shock wave reaches a free boundary surface and the surface is subjected to tensile force.
  - The material fails when the tensile pressure is above the material strength.
- **Physical measurements** of crater and bulge are taken typically after every experiment.

Front Side

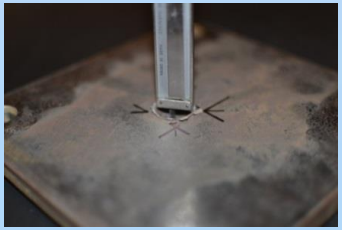
Back Side

Typical target plate after experiment



Spalling of target plate (sectioned)

Impact crater diameter measurement



Depth of penetration measurement

Bulge measurement

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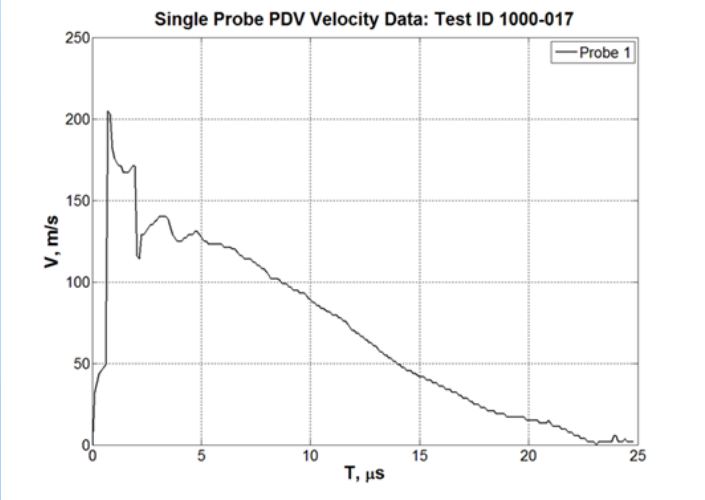
Results and Discussion

Test ID	PDV system details	Impact Velocity, km/s	Target after impact		
			Crater Diameter, mm	Penetration, mm	Bulge, mm
1000-016	single probe	5.338	17.01	6.32	2.32
1000-017		5.063	16.86	6.89	2.36

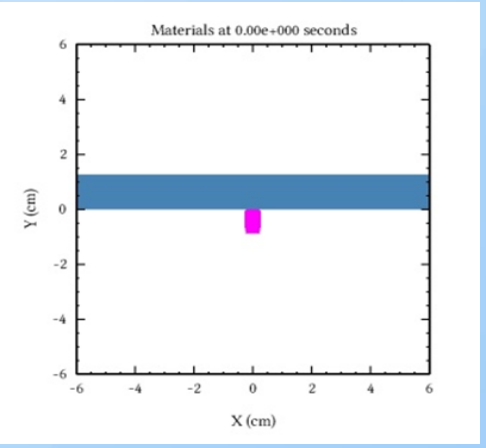
- Damage trends seem reasonable: Higher impact velocity results in larger crater and bulge. (Although some minor discrepancies in damage dimensions still exist!)
- All the values listed above are an average of typical physical measurements of crater.



Computational Simulation

- Two finite element methods are used to simulate the impact phenomena computationally:
  - Lagrangian based Smooth Particle Hydrodynamics (SPH) in LS-DYNA
  - Eulerian baed Hydrocode in CTH
- 2D axi-symmetric models are developed.
- Both models have no boundary conditions.

LS-DYNA SPH Model



CTH Model

Computational Simulation: Material Model

- Both LS-DYNA and CTH models use Johnson-Cook material model for both Lexan projectiles and A36 steel target plates.
- Parameters of Johnson-Cook material model are taken from the available literatures.

Material	A, MPa	B, MPa	C	M	N	T_{melt}, °K
Lexan (Littlewood)	75.8	68.9	0	1.85	1.004	533
A36 Steel (Seidt)	286.1	500.1	0.022	0.917	0.2282	1811

Littlewood, D.J., 2010. Simulation of dynamic fracture using peridynamics, finite element modeling, and contact: *ASME 2010 International Mechanical Engineering Congress & Exposition. Vancouver, British Columbia, Canada, November 12-18, 2010. ASME.*

Seidt, J.D. et al., 2007. High strain rate, high temperature constitutive and failure models for EOD impact scenarios: *Proceedings of the 2007 SEM Annual Conference and Exposition on Experimental and Applied Mechanics, Springfield, MA, June, 2007. Society for Experimental Mechanics, Inc., p. 15.*

Computational Simulation: Equation of State

- Both LS-DYNA and CTH models use Grüneisen equation of state (EOS) for both Lexan projectiles and A36 steel target plates.
- EOS parameters are also taken from the available literatures.

Material	ρ, kg/m^3	C_0 , m/s	S_1	ϒ
Lexan (Steinberg)	1190	1933	1.42	0.61
A36 Steel (Seidt)	7890	4569	1.49	2.17

Steinberg, D.J., 1996. Equation of State and Strength Properties of Selected Materials, Lawrence Livermore National Laboratories, Livermore, California.

Seidt, J.D. et al., 2007. High strain rate, high temperature constitutive and failure models for EOD impact scenarios: *Proceedings of the 2007 SEM Annual Conference and Exposition on Experimental and Applied Mechanics, Springfield, MA, June, 2007. Society for Experimental Mechanics, Inc., p. 15.*

Computational Simulation: Spall Parameter

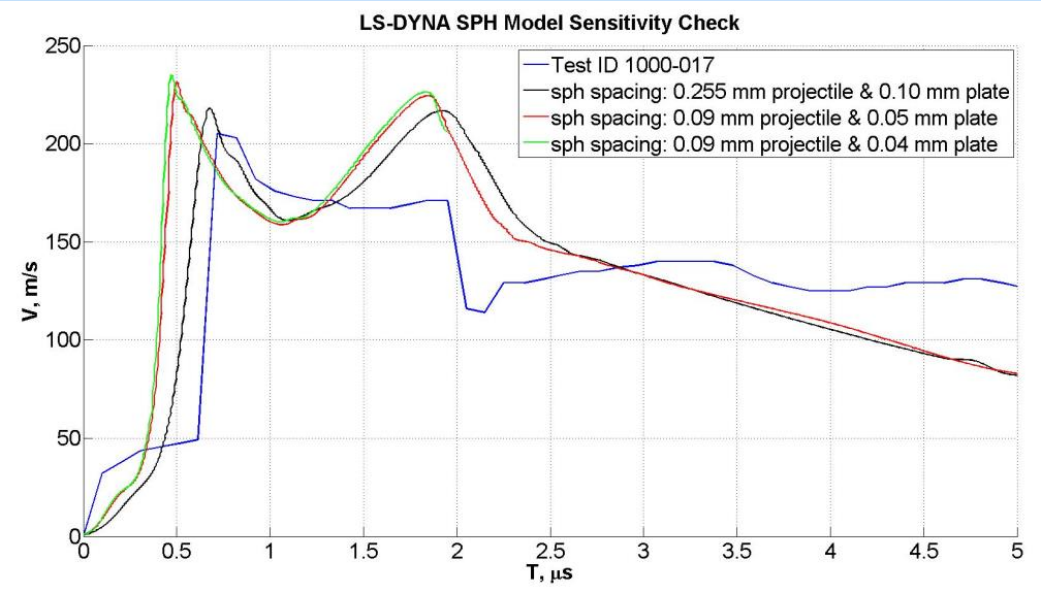
- In both LS-DYNA and CTH, spall failure is invoked when the tensile stress exceeds a certain pressure cut-off (i.e. P_{min}) value.
- In LS-DYNA , P_{min} value is defined in *MAT_JOHNSON_COOK card.

Lexan: P_{min} = - 160 MPa

A36 steel: P_{min} = - 700 MPa

Simulation Comparison: Model Sensitivity Check

- Mesh sensitivity of both models are studied.
- For LS-DYNA SPH model, 0.05 mm spacing between SPH particles gives the best result.
- For CTH hydrocode, a zone size of 0.03 mm x 0.03 mm is chosen after mesh sensitivity study.



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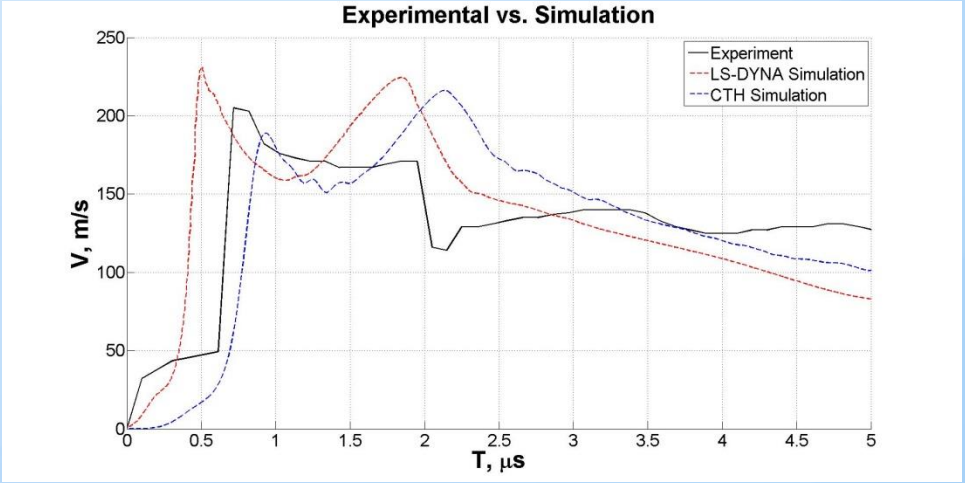
Simulation Comparison: Crater & Velocity

- Both LS-DYNA and CTH simulations have been able to capture the deformation progression due to impact.
- Free surface velocity profiles are also in reasonable agreement.
- Further refinement of the models are still in progress.

Typical LS-DYNA simulation

Typical CTH simulation



	Impact Velocity, m/s	Crater Dia, mm	Penetration, mm	Bulge, mm
Experiment	5063	16.86	5.76	2.36
LS-DYNA		15.90	5.04	2.17
CTH		15.70	5.73	1.90
Experiment	5338	17.01	6.32	2.32
LS-DYNA		17.10	5.87	2.14
CTH		15.70	5.73	2.02

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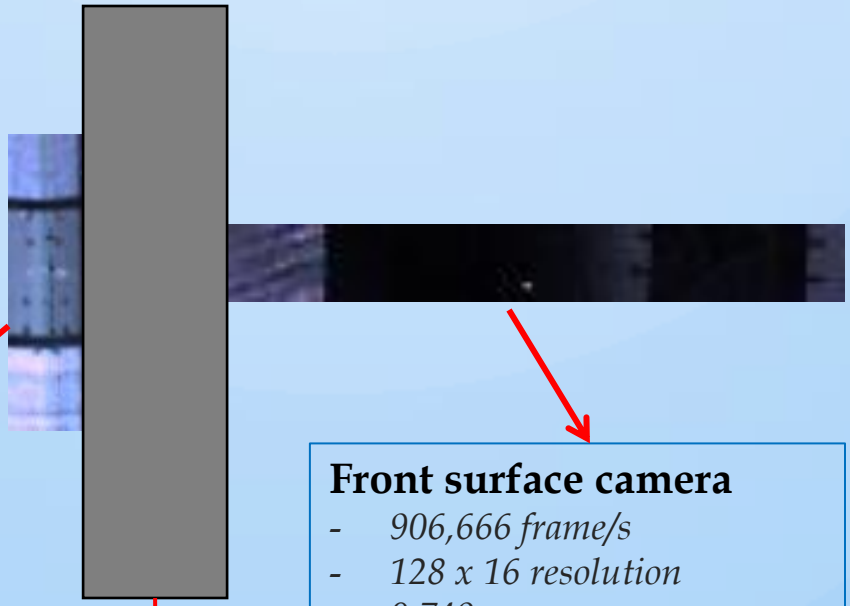
Recent Developments

- Free surface velocity measurement by multiplexed PDV (MPDV) in impact experiments.
- High speed camera to capture Video data and correlate to PDV/MPDV data.
- Investigation of phase transition in A36 steel by Electron Back Scattered Microscopy (EBSD).



Back surface camera
- *680,000 frame/s*
- *32 x 128 resolution*
- *1.09 μs exposure*

Front surface camera
- *906,666 frame/s*
- *128 x 16 resolution*
- *0.749 μs exposure*

Target

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Conclusion

- A series of two-stage light gas gun experiments have been performed to study the plastic deformation of steel plates during high velocity impact.
- Free surface velocity from back of the plate was measured using PDV system during these experiments.
- Simulation models developed in LS-DYNA SPH solver and CTH hydrocode reasonably simulate the experiments.
- The results of this study may be used to conduct a parametric study of the material models and the equation of the state to determine their sensitivities in accurately predicting the behavior of metallic materials during dynamic penetration events.

Thank You!