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Applied Research Laboratory
The Pennsylvania State University

Finite Element Analysis of Cold Spray Particle Impact

Cold Spray Action Team Meeting 6/22-6/23

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Outline

- Effect of Quasi-steady state yield strength ("A" parameter) on the Cold Spray Model – Johnson-Cook model
  - Effect of A on a single particle size
  - Particle size impact using experimental data
- Particle Size Comparison
  - 20 micron
  - 200 micron
- Material Comparison
  - Al6061 on Al6061
  - Copper on Al6061
- Effect of Particle Encapsulation on Deformation
  - Thick encapsulant coating
  - Experimental Validation with thin encapsulant

Material Properties (converted for Abaqus millimeter base unit usage)

Material	Density (tonnes/mm^3)	Young's Modulus (MPa)	Poisson's Ratio
Al6061	2.7×10^{-9}	68900	0.3
Copper	8.9×10^{-9}	115000	0.31
Nickel	8.88×10^{-9}	207000	0.31

Johnson-Cook Properties			
Material	Al6061	Copper	Nickel
A	200 MPa baseline, varied	90	163
B	203.4 MPa	292	648
C	0.011	0.025	0.006
n	0.35	0.31	0.33
m	1.34	1.09	1.44
Tm	925.37 K	1356 K	1726 K

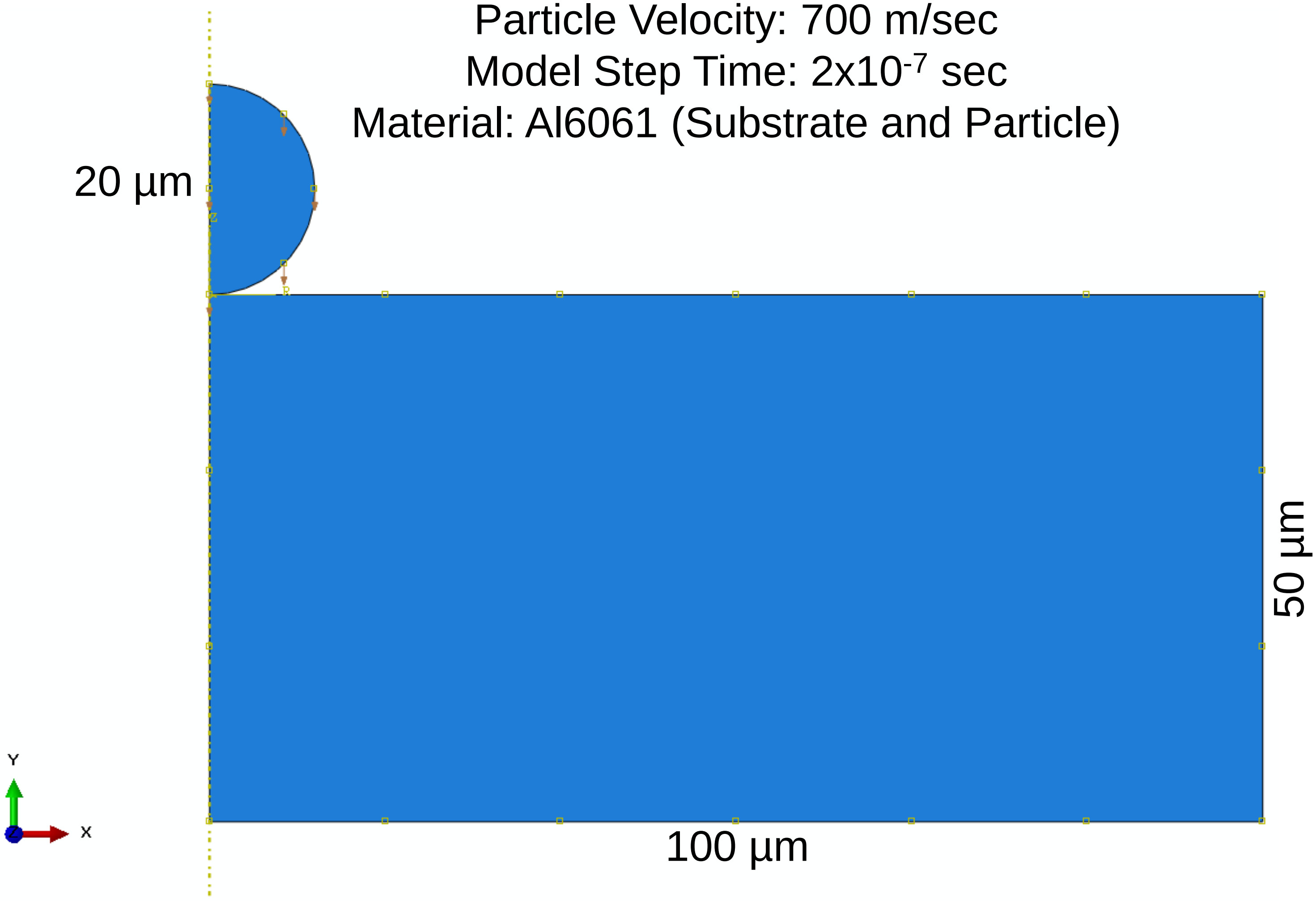
Tables of Consistent Units

Property or Load	Unit System as classified by the ANSYS command **/UNITS**				
	SI	CGS	MPA	BFT	BIN
Mass	[kg]	[g]	[tonne]	[slug]	$\frac{[lbf][sec]^2}{[in]}$
Length	[m]	[cm]	[mm]	[ft]	[in]
Time	[s]	[s]	[s]	[sec]	[sec]
Temperature	[K]	[K]	[K]	[°R]	[°R]
Velocity	$\frac{[m]}{[s]}$	$\frac{[cm]}{[s]}$	$\frac{[mm]}{[s]}$	$\frac{[ft]}{[sec]}$	$\frac{[in]}{[sec]}$
Acceleration	$\frac{[m]}{[s]^2}$	$\frac{[cm]}{[s]^2}$	$\frac{[mm]}{[s]^2}$	$\frac{[ft]}{[sec]^2}$	$\frac{[in]}{[sec]^2}$
Force	[N]	[dyn]	[N]	[lbf]	[lbf]
Moment	[N][m]	[dyn][cm]	[N][mm]	[ft][lbf]	[in][lbf]
Pressure	[Pa]	[Ba]	[MPa]	$\frac{[lbf]}{[ft]^2}$	[psi]
Density	$\frac{[kg]}{[m]^3}$	$\frac{[g]}{[cm]^3}$	$\frac{[tonne]}{[mm]^3}$	$\frac{[slug]}{[ft]^3}$	$\frac{[lbf][sec]^2 / [in]}{[in]^3}$

1 [cP] = 0.001 [Pa][s]
1 [lbf] = 32.2 [ft] / [sec]^2 * 1 [lbm] = 386.4 [in] / [sec]^2 * 1 [lbm]
1 [BTU] = 777.65 [ft][lbf] = 9331.8 [in][lbf]

Axisymmetric Model Setup
"A" Parameter

Particle Velocity: 700 m/sec
Model Step Time: 2x10^{-7} sec
Material: Al6061 (Substrate and Particle)

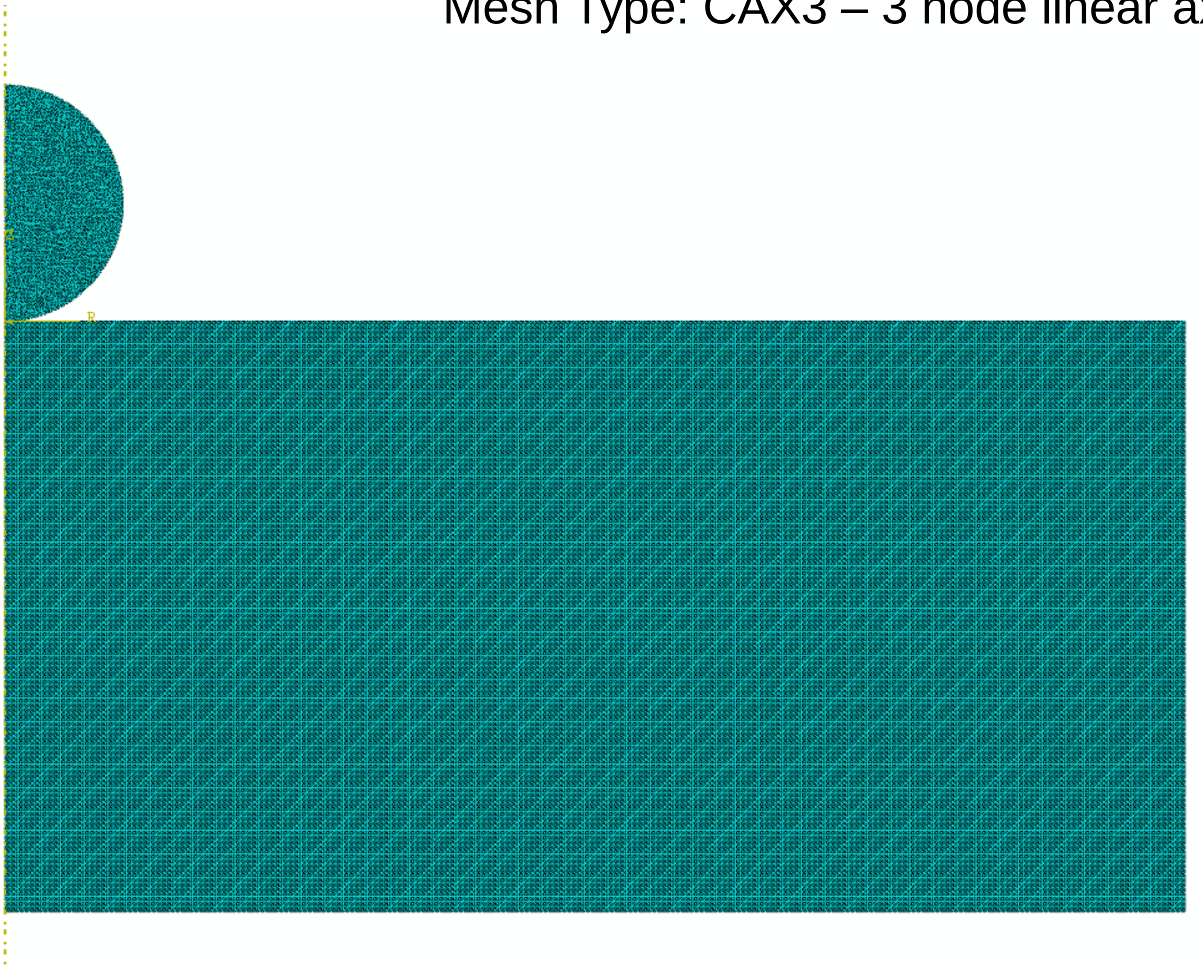


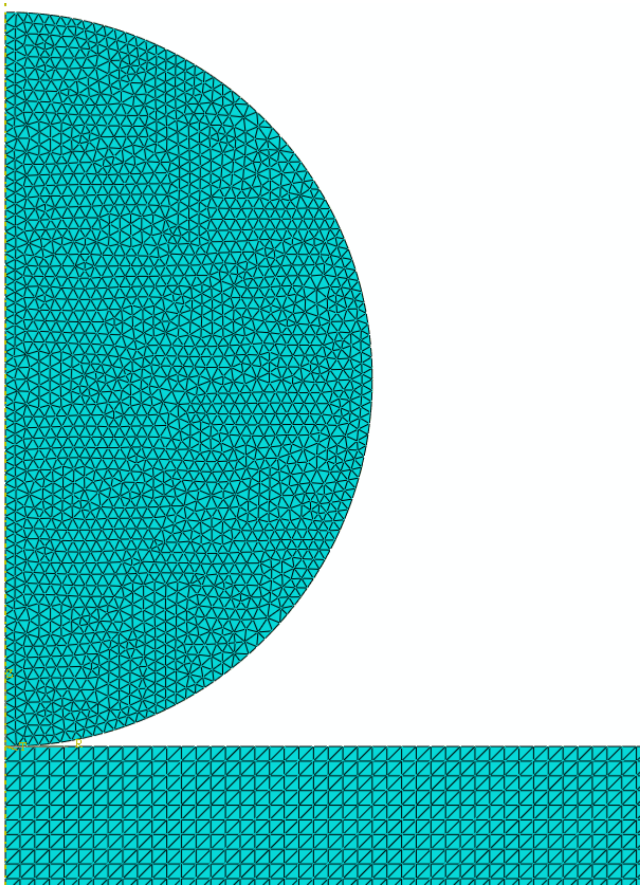
Mesh Setup “A” Parameter

Particle Element Amount: 9,861

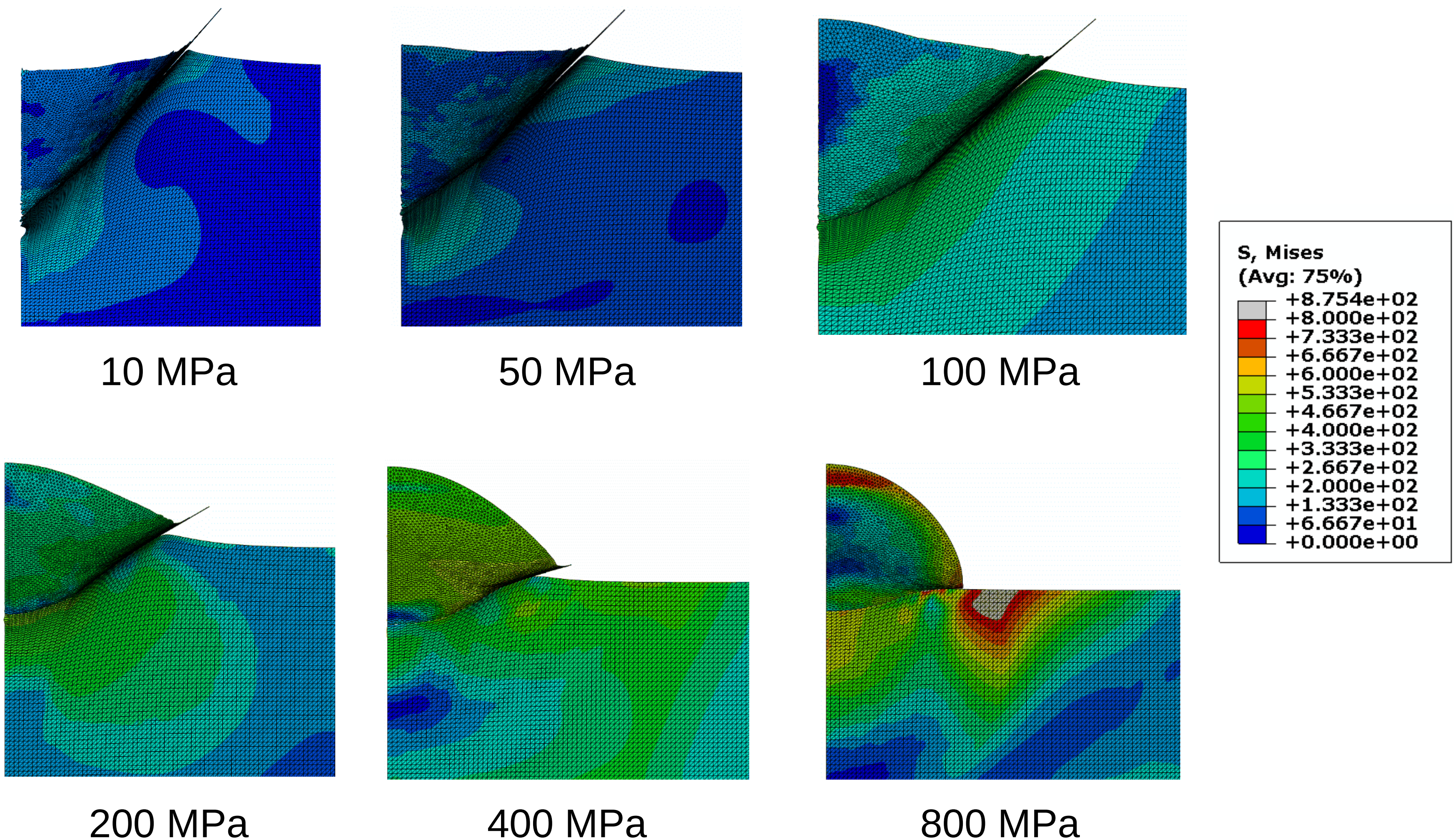
Substrate Element Amount: 62,500

Mesh Type: CAX3 – 3 node linear axisymmetric triangle





Effect of “A” parameter on deformation – von Mises Stress



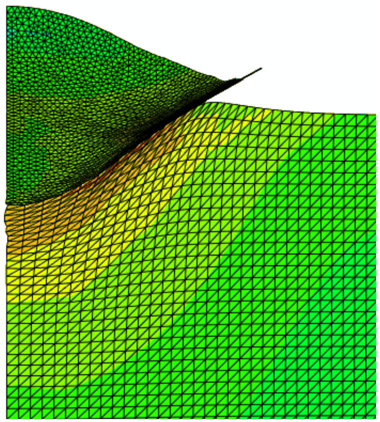
Effect of "A" parameter on model results
WPI Experimental Data

Model Setup:

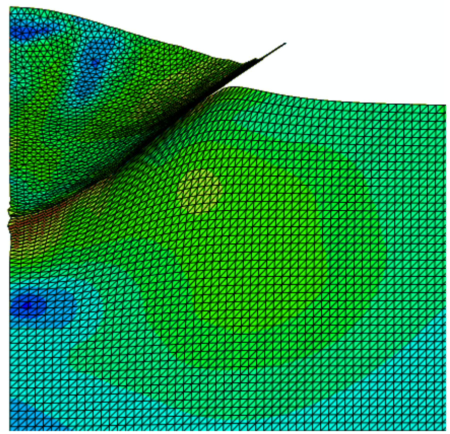
- Axisymmetric Construction
- Particle Diameter: 10-55 microns
- Particle: 6,000-10,000 CAX3 Linear Triangle Elements
- Substrate: ~60,000 CAX3 Linear Triangle Elements
- Particle Impact Velocity: 800 m/sec
- Particle Temperature: 500 K
- Substrate Temperature: 300 K

- Johnson-Cook "A" parameter varied using data supplied by WPI

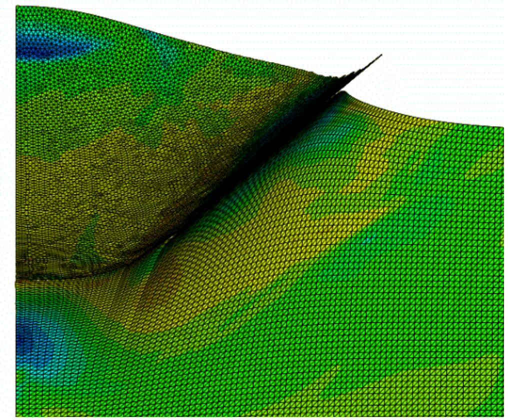
Effect of “A” parameter on model results – von Mises Stress
WPI Experimental Data



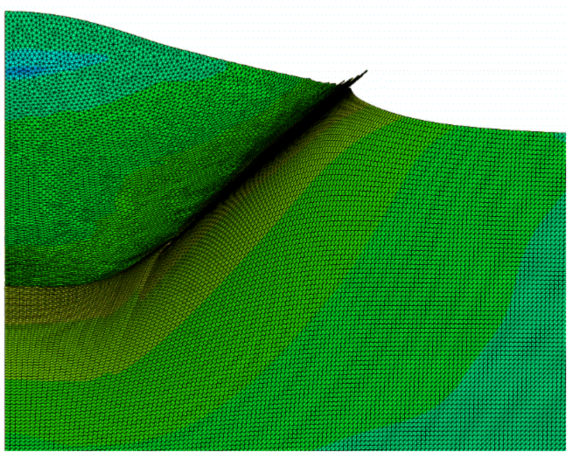
10 µm particle



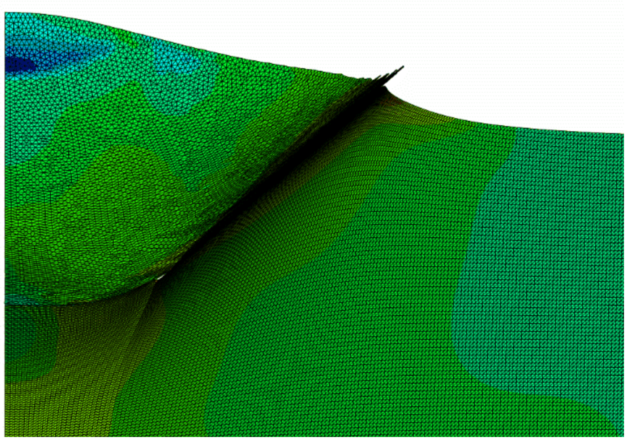
20 µm particle



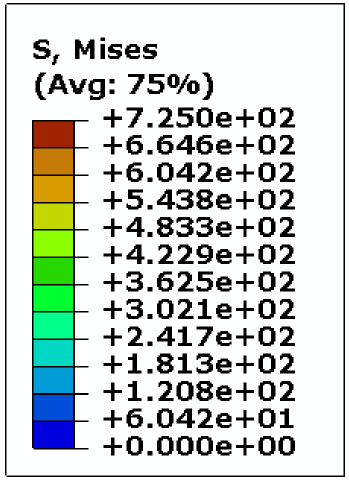
30 µm particle



40 µm particle



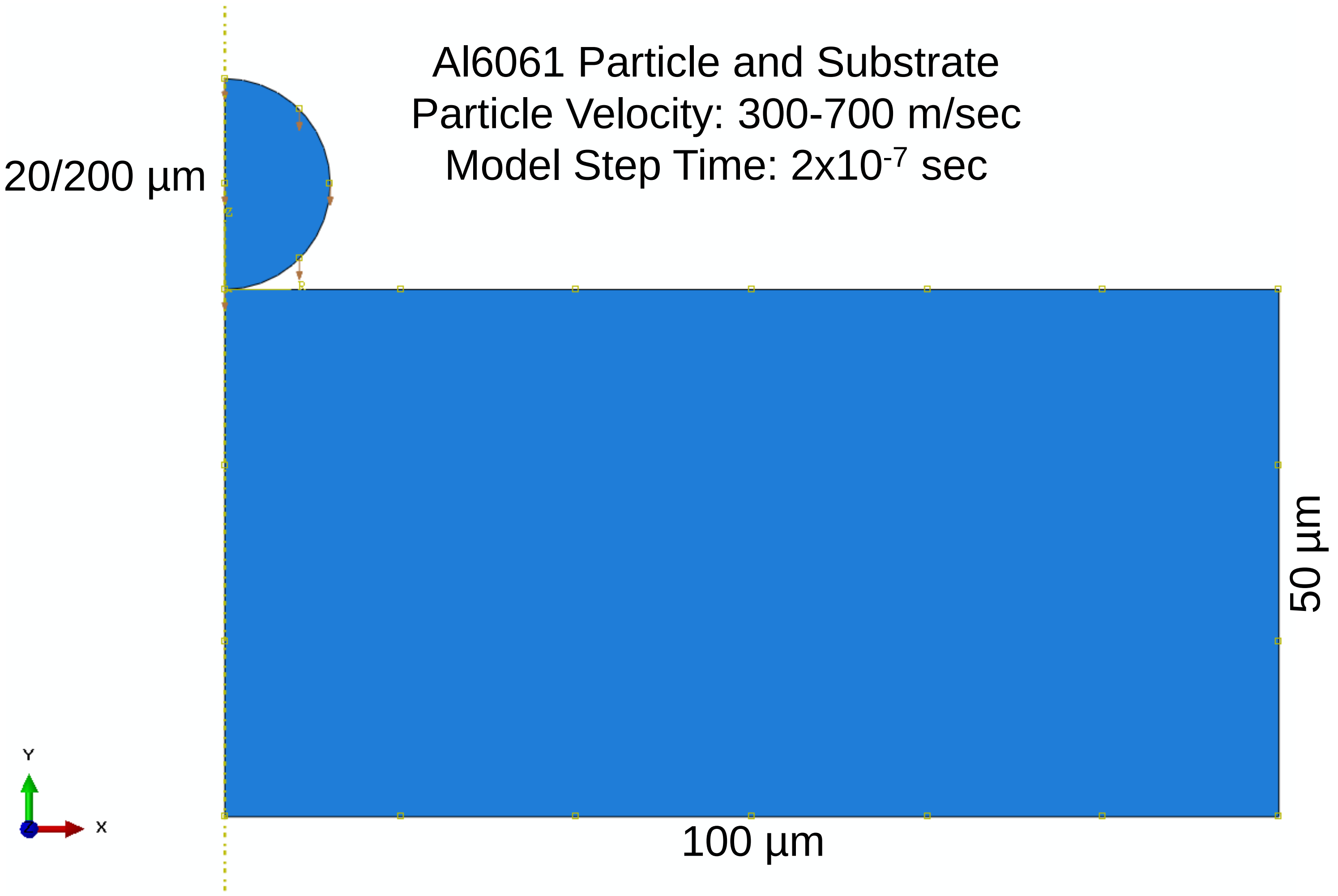
50 µm particle



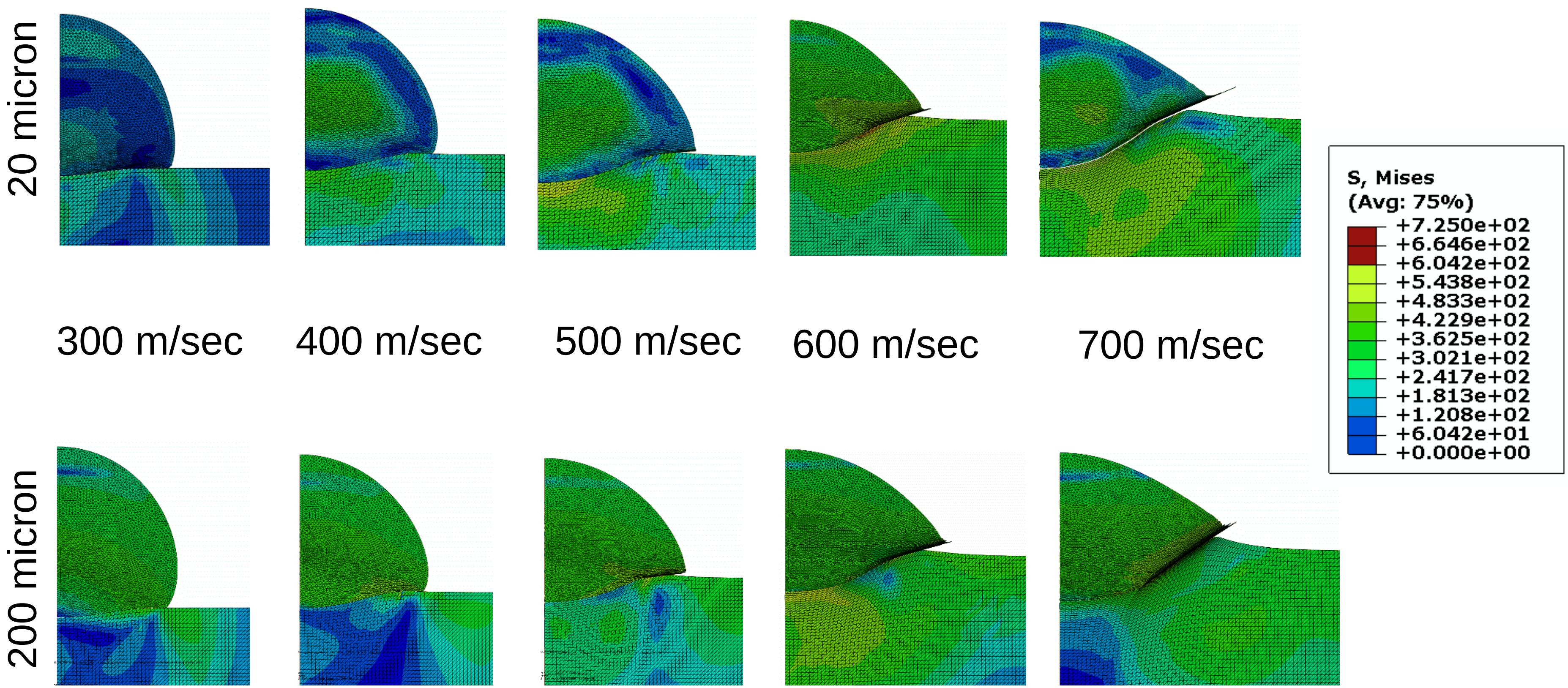
Particle Size Comparison

Axisymmetric Model Setup

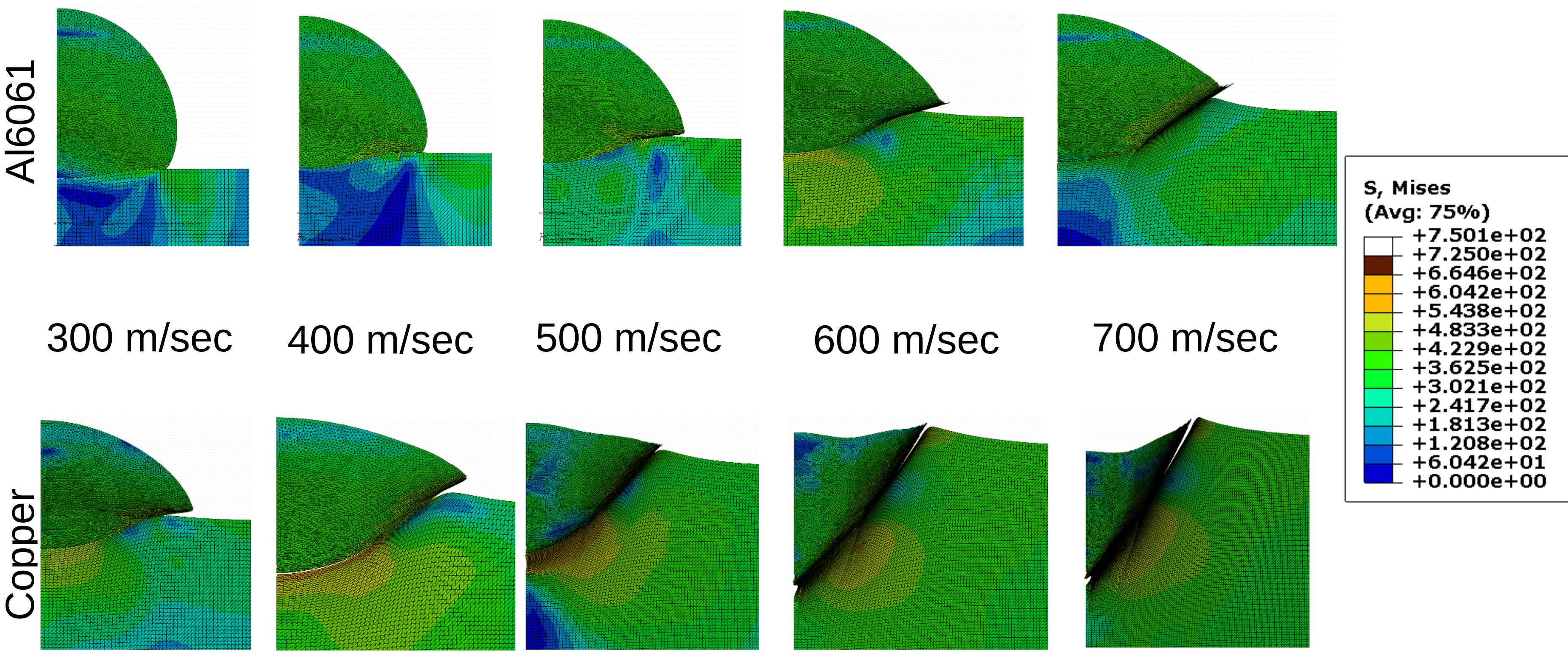
Al6061 Particle and Substrate
Particle Velocity: 300-700 m/sec
Model Step Time: $2x10^{-7}$ sec



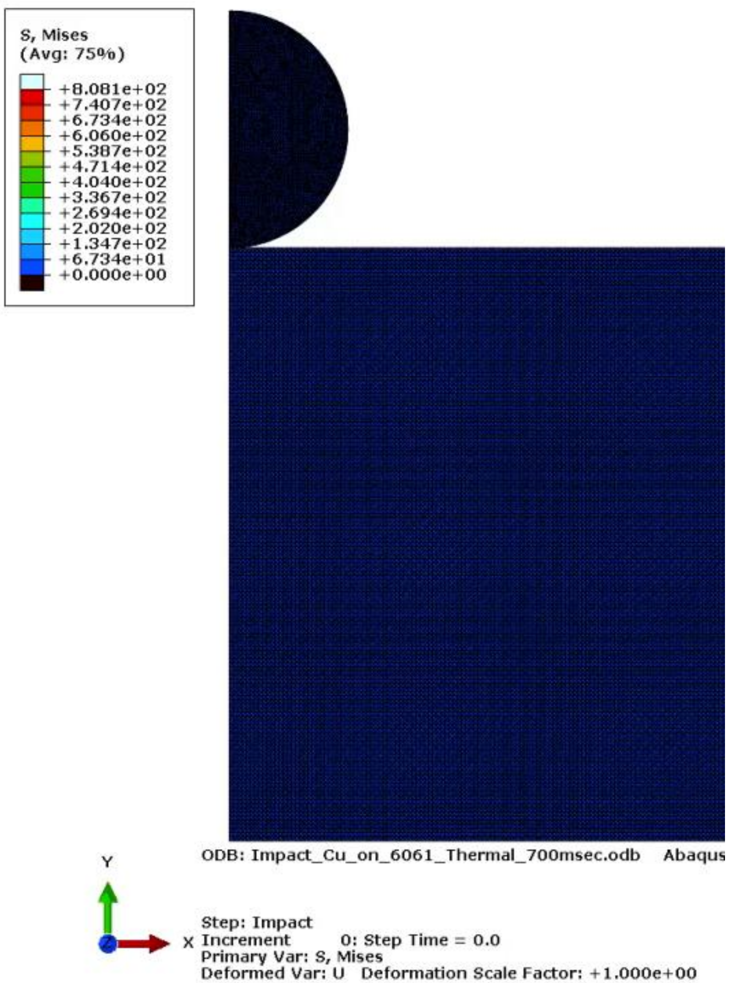
Particle Size Comparison Al6061 on Al6061 at 500K
von Mises Stress

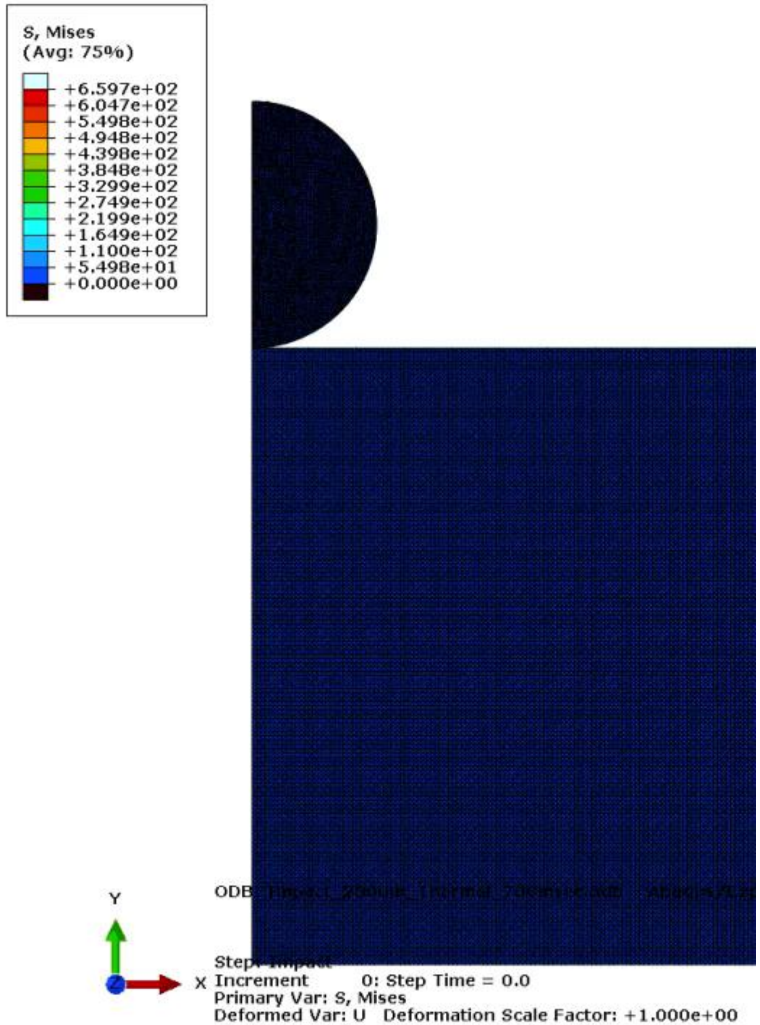


Al6061 vs. Copper Particle Stress Comparison 200 micron particles



Al6061 vs. Copper Particle Comparison

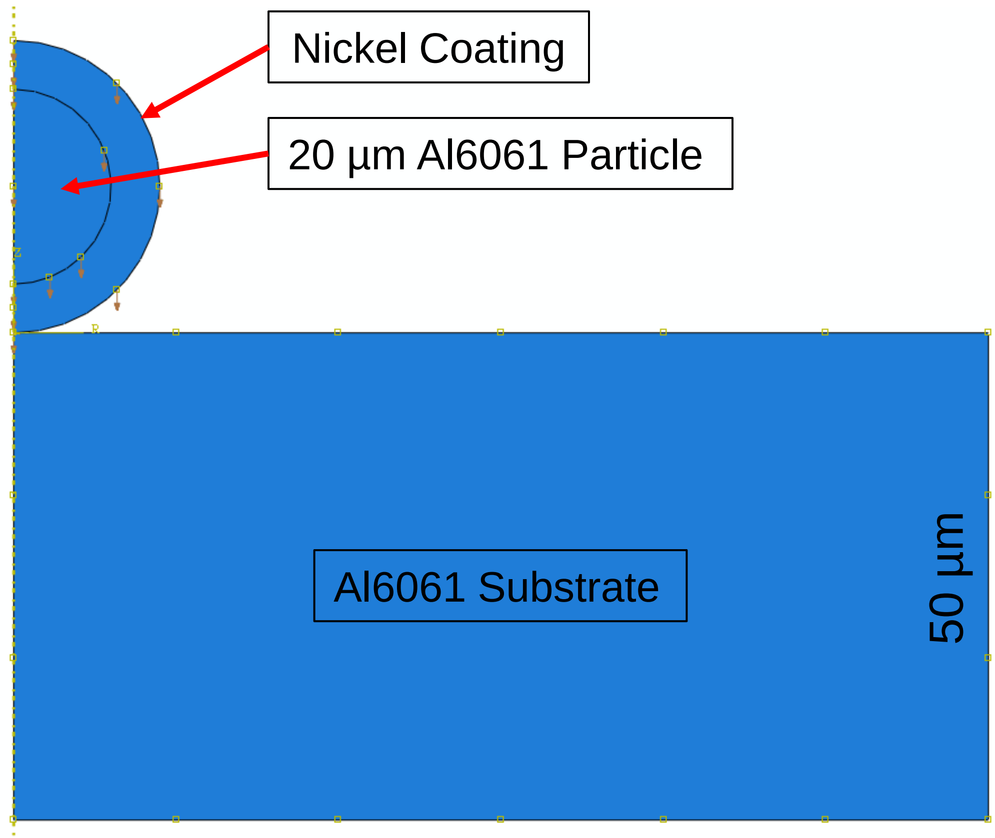


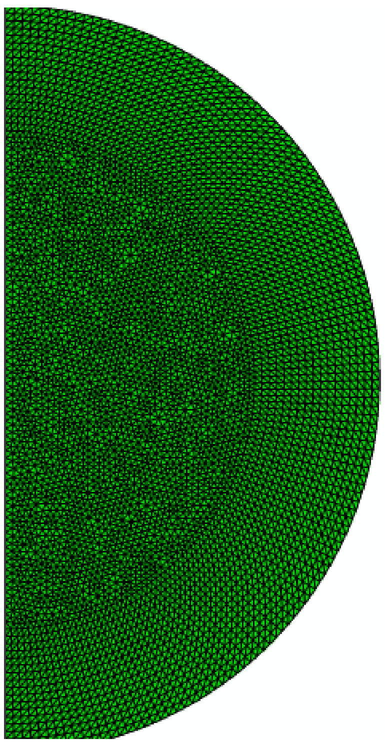


Effect of Encapsulation on Deformation

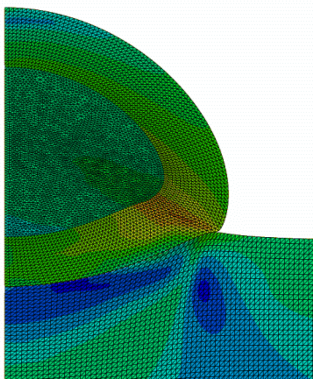
Model Setup:

- 20 µm Al6061 particle encapsulated with a 10 µm thick layer of nickel
- Particle velocity varied from 300-700 m/sec

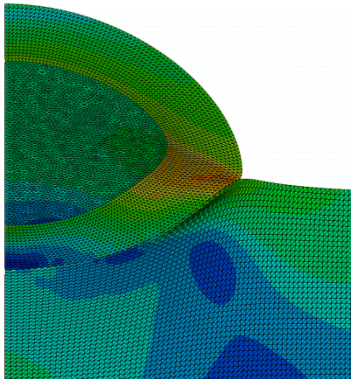




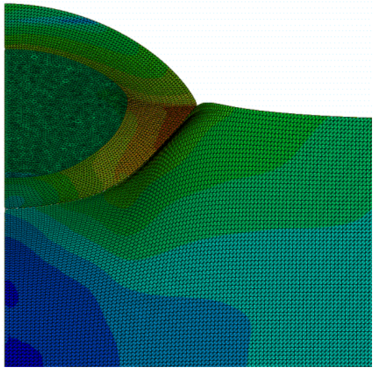
Effect of Encapsulation on Deformation
von Mises Stress



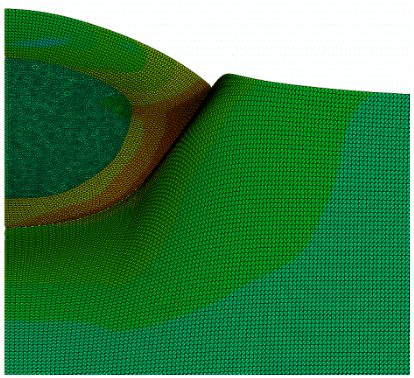
300 m/sec



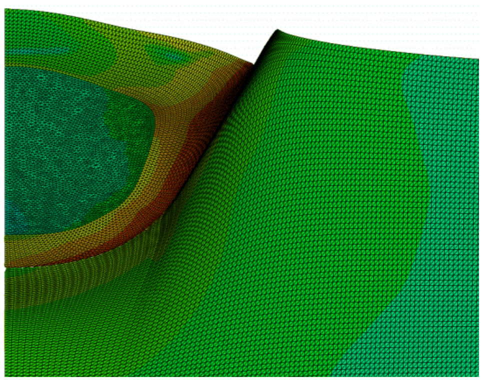
400 m/sec



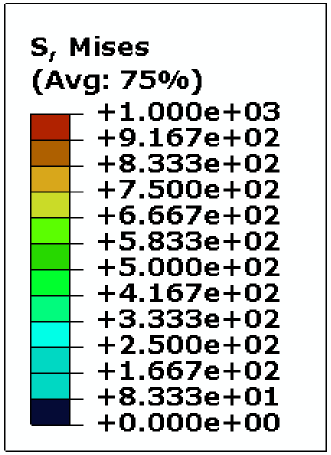
500 m/sec



600 m/sec



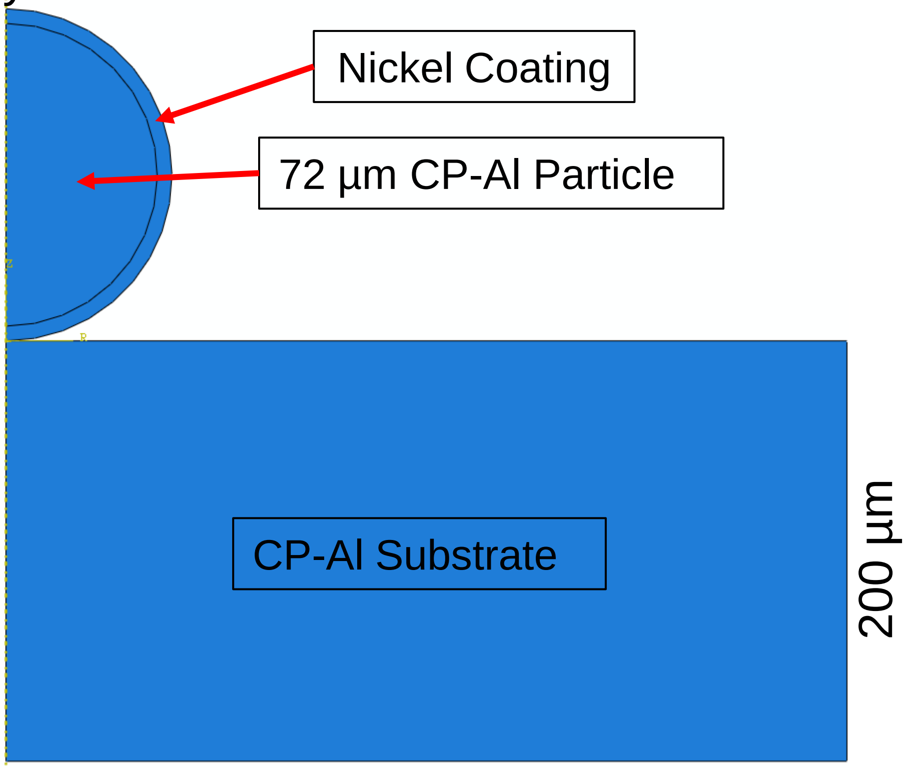
700 m/sec



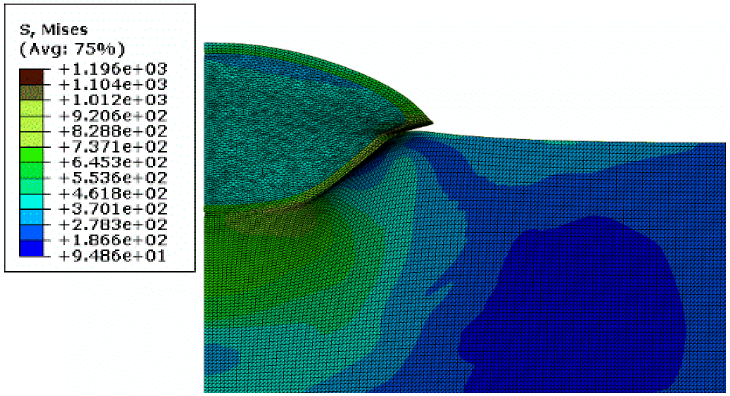
Effect of Encapsulation on Deformation
Experimental Comparison

Model Setup:

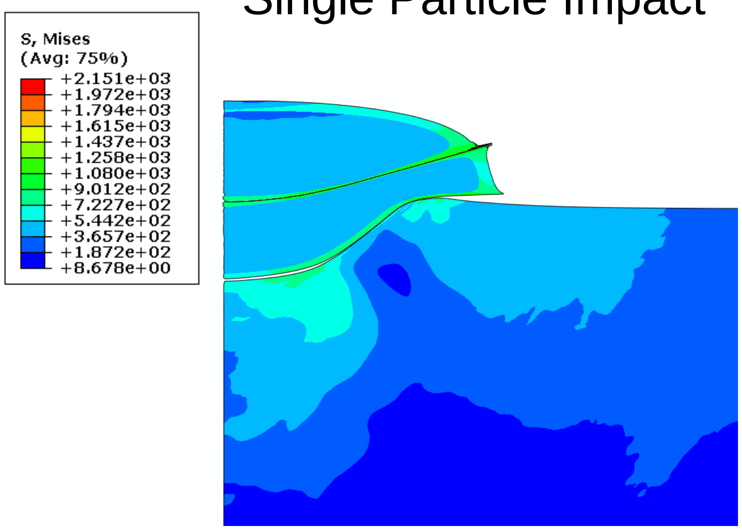
- 72 µm commercial purity aluminum particle encapsulated with a 7 µm thick layer of nickel
- Particle velocity: 800 m/sec



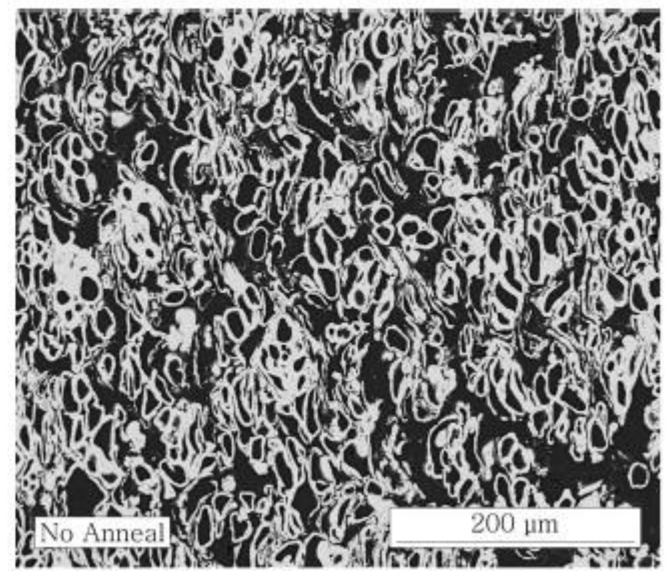
Effect of Encapsulation on Deformation
Experimental Comparison



Single Particle Impact



Multi-Particle Impact



Cold Sprayed Nickel
Encapsulated Aluminum

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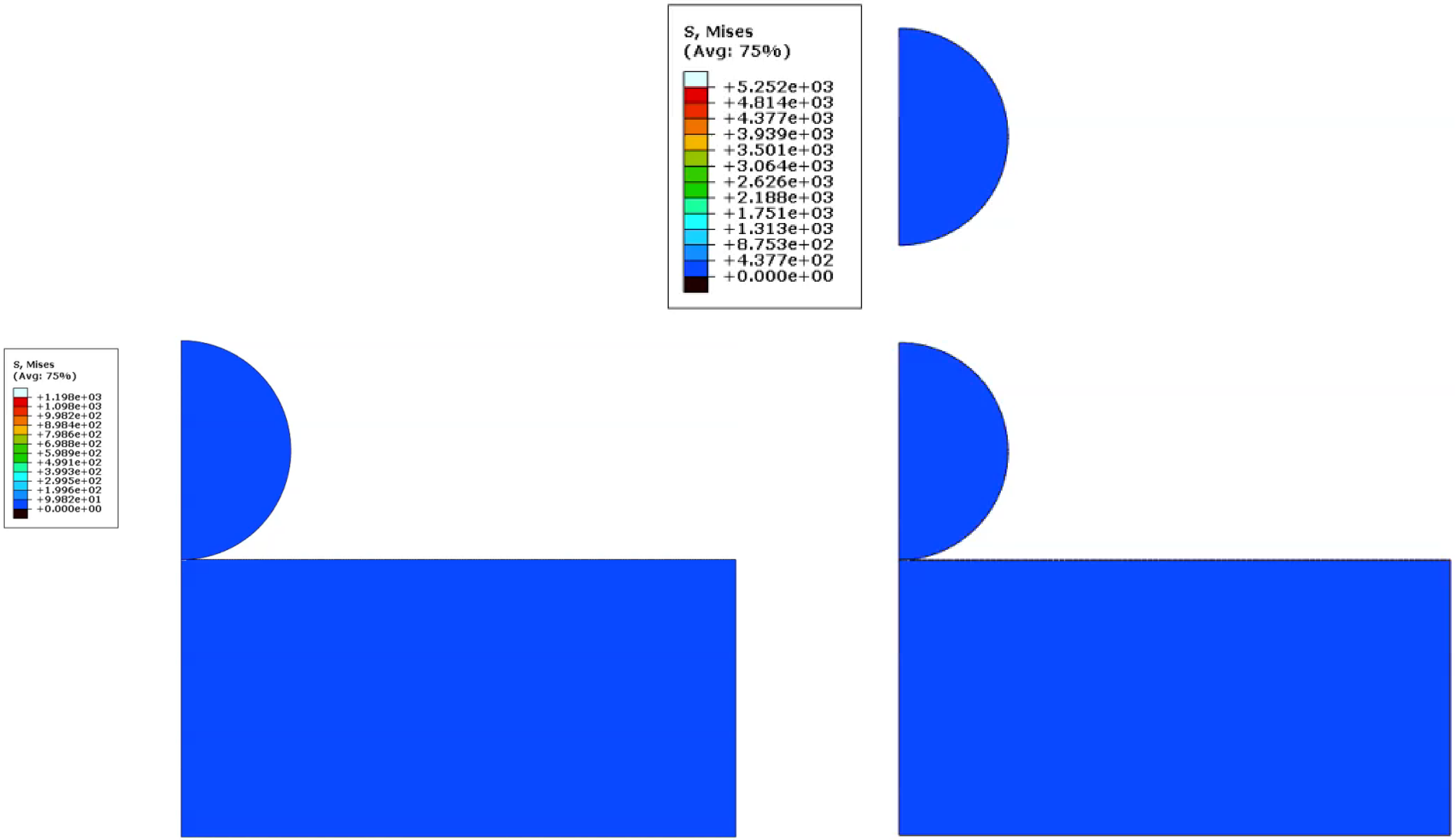
Effect of Encapsulation on Deformation
Experimental Comparison



Summary

- Axisymmetric Model
  - Comparable with other research
- Investigated "A" parameter in the Johnson-Cook model
- Varied the particle impact velocity
- Analyzed the effect of particle size on impact
- Four material systems were analyzed
  - Al6061 on Al6061
  - Copper on Al6061
  - Al6061 Encapsulated with Nickel on Al6061
  - CP-Al Encapsulated with Nickel on CP-Al

Next Steps/Future Work

- Confirm model with experimental data
- Move from axisymmetric modeling to 3D modeling
- Implement new material models using subroutines
  - Zerilli-Armstrong
  - Preston-Tonks-Wallace
- Compare new models with LS-DYNA
- Include adiabatic heating effects and thermal expansion
- Develop a strain energy bonding parameter for particle adhesion