Liquid Impingement Erosion: Modeling Droplet Impacts onto Elastic Solids

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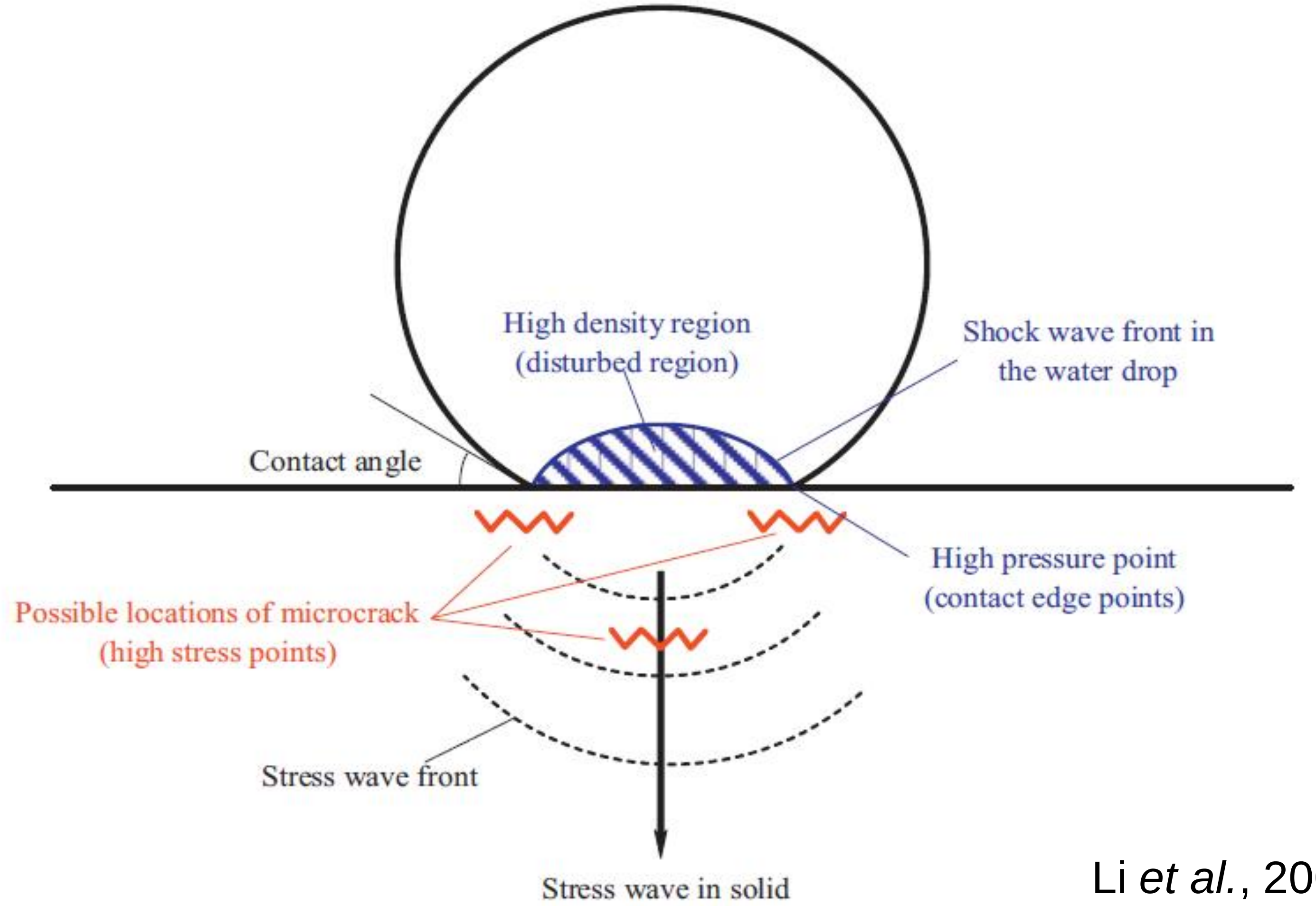
Contents

Fluid-Solid Interaction (FSI)

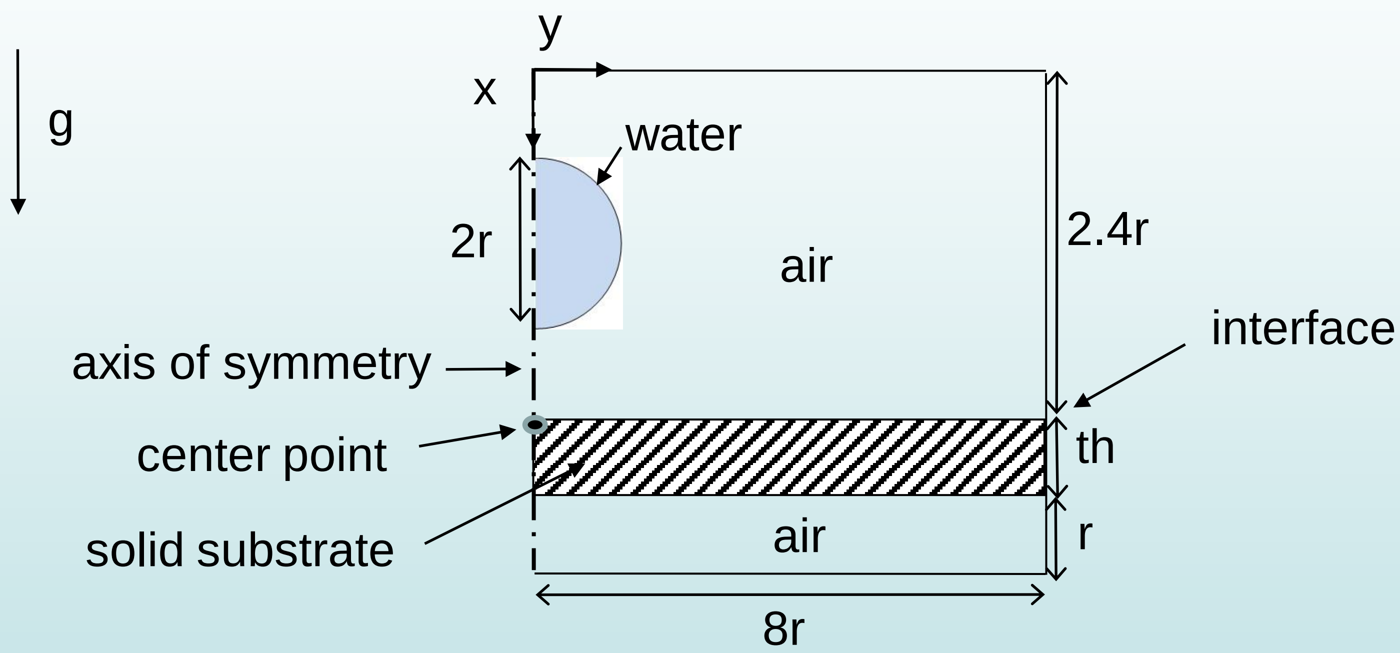


Li *et al.*, 2008

Objectives

- Modeling single droplet impact on an elastic solid
- Capturing droplet deformation upon impact
- Obtaining coupled liquid pressure and solid stress
- Finding maximum transient stress in the solid
- Studying the effect of impact velocity, substrate thickness, droplet diameter, solid material
- Comparing the results with previous works

Computational domain



Note: Not to scale

Governing equations

Fluid:

$$\nabla \cdot V_f = 0$$ (Continuity)

$$\rho_f \frac{\partial V_f}{\partial t} + \rho_f (\nabla V_f) V_f = \nabla \cdot \sigma_f + \rho_f g$$ (Momentum)

Solid:

$$\rho_s \frac{\partial V_s}{\partial t} + \rho_s (\nabla V_s) V_s = \nabla \cdot \sigma_s + \rho_s g$$ (Elastic deformation)

Coupling Eq'ns:

$$\sigma_s n = \sigma_f n$$ (Force balance)

$$V_s = V_f$$ (No-slip condition)

Governing equations cont'd

$$\sigma_f = -p_f I + \rho_f \nu_f \left(\nabla V_f + \nabla V_f^{\ T} \right)$$ (Fluid stress tensor)

$$\sigma_s = \frac{1}{J} F \left(\lambda_s \left(trS \right) I + 2\mu_s S \right) F^T$$ (Solid stress tensor)

$$F = I + \nabla U_s$$ (Deformation gradient tensor)

$$S = \frac{1}{2} \left(F^T F - I \right)$$ (St. Venant-Kirchhoff tensor)

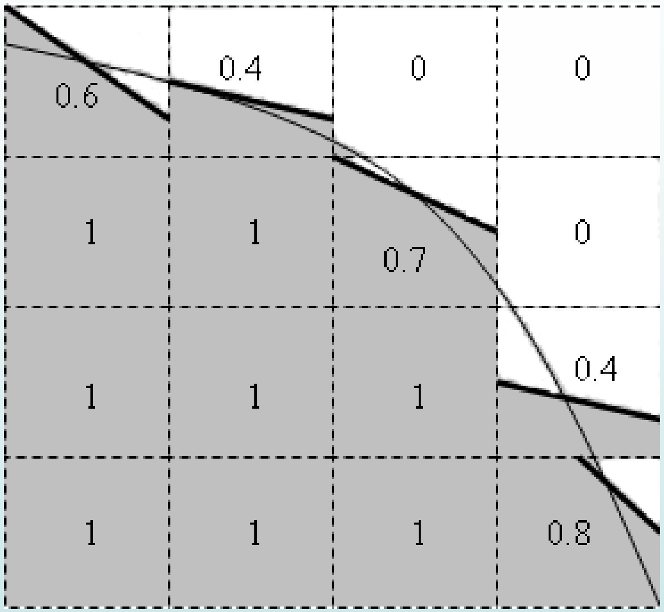
$$\lambda_s = \frac{\nu_s E}{(1 + \nu_s)(1 - 2\nu_s)}$$

$$\mu_s = \frac{E}{2(1 + \nu_s)}$$

(Lamé coefficients)

Volume of Fluid method

$$\begin{cases} \alpha_l = 0 & \textit{Gas phase} \\ 0 < \alpha_l < 1 & \textit{Interface} \\ \alpha_l = 1 & \textit{Liquid phase} \end{cases}$$



- Advection**:**

$$\frac{\partial \alpha_l}{\partial t} + \nabla.(V_f \alpha_l) = 0$$

- Interface Reconstruction**:**

Piecewise Linear Interface Calculation (PLIC) of Youngs, 1982.

Impact conditions

- Substrate materials: Martensitic stainless steel, Ti-6Al-4V
- Substrate thicknesses: 2.5, 5.0, 10.0 mm
- Drop diameters: 0.5, 1.0 mm
- Impact velocities: 10, 20, 40 m/s

Equivalent stress:

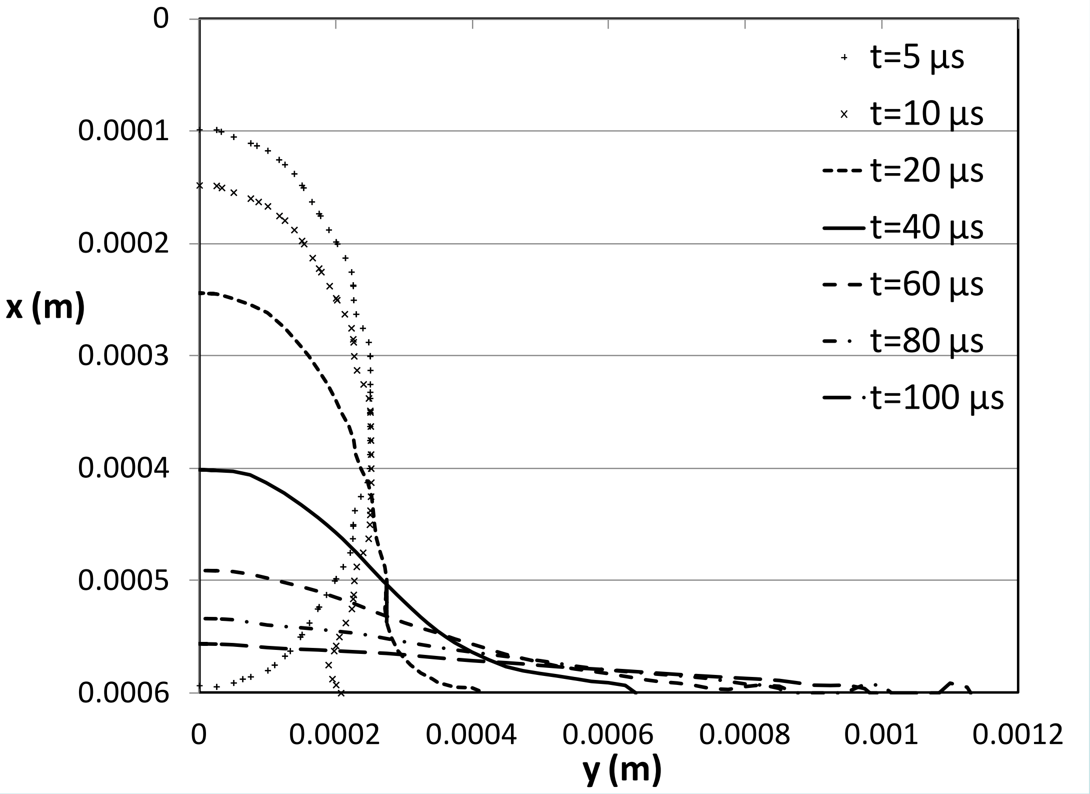
$$\sigma = \sqrt{\frac{1}{2}\left[(\sigma_{11}-\sigma_{22})^2+(\sigma_{11}-\sigma_{33})^2+(\sigma_{22}-\sigma_{33})^2+6(\sigma_{12}^2+\sigma_{23}^2+\sigma_{13}^2)\right]}$$

Material properties

Fluid properties	Air	Water
Density (kg/m^3)	1	1000
Kinematic viscosity (m^2/s)	1.48e-05	1e-06
Surface tension (N/m)	-	0.07

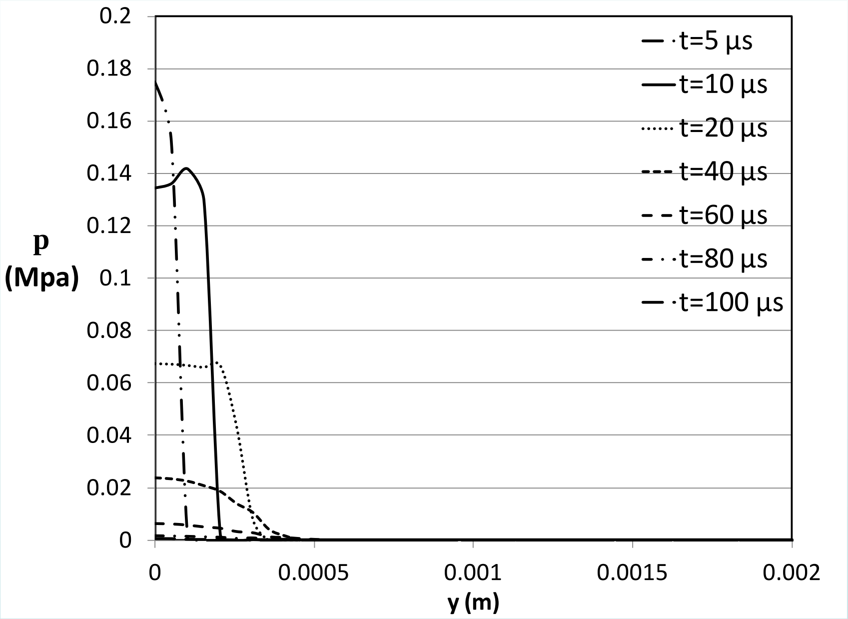
Solid properties	Stainless Steel	Ti-6Al-4V
Density (kg/m^3)	7850	4430
Poisson ratio	0.3	0.342
Young’s modulus (Gpa)	200	113

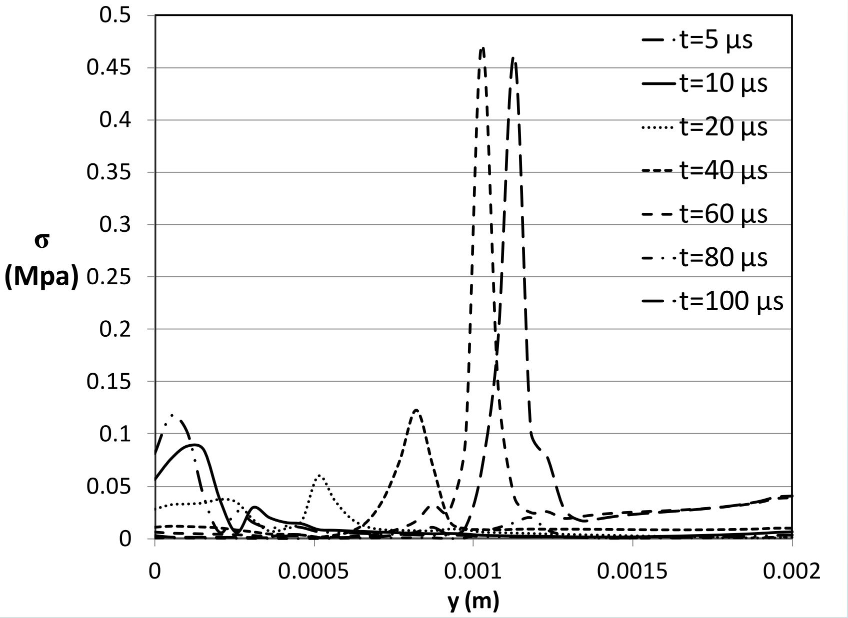
Droplet deformation



(SS, V=10m/s, D=0.5 mm, th=10 mm)

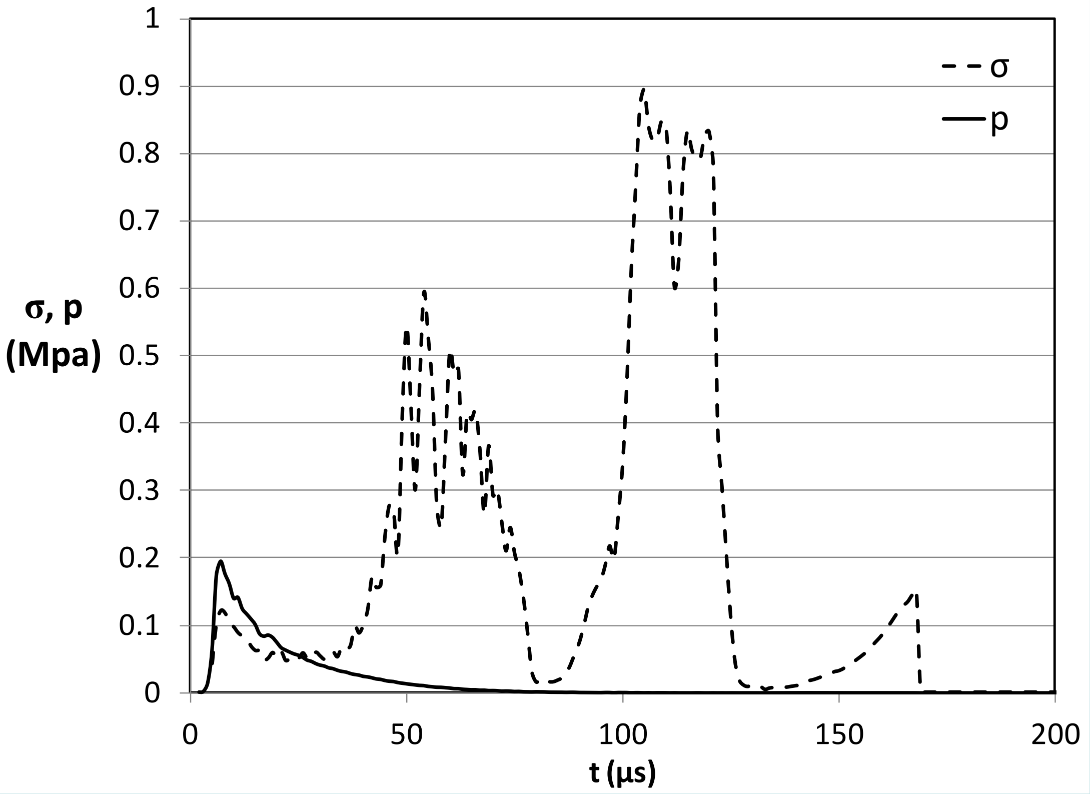
Pressure/stress along interface





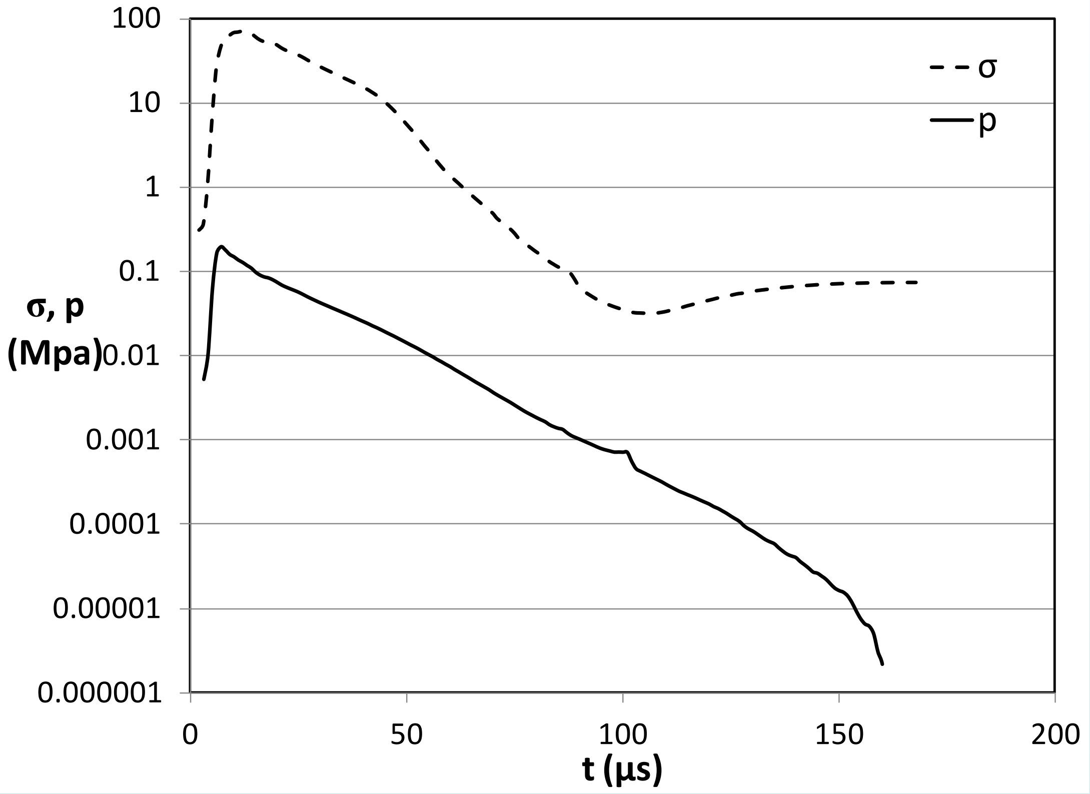
(SS, V=10m/s, D=0.5 mm, th=10 mm)

Peak stress/pressure, interface



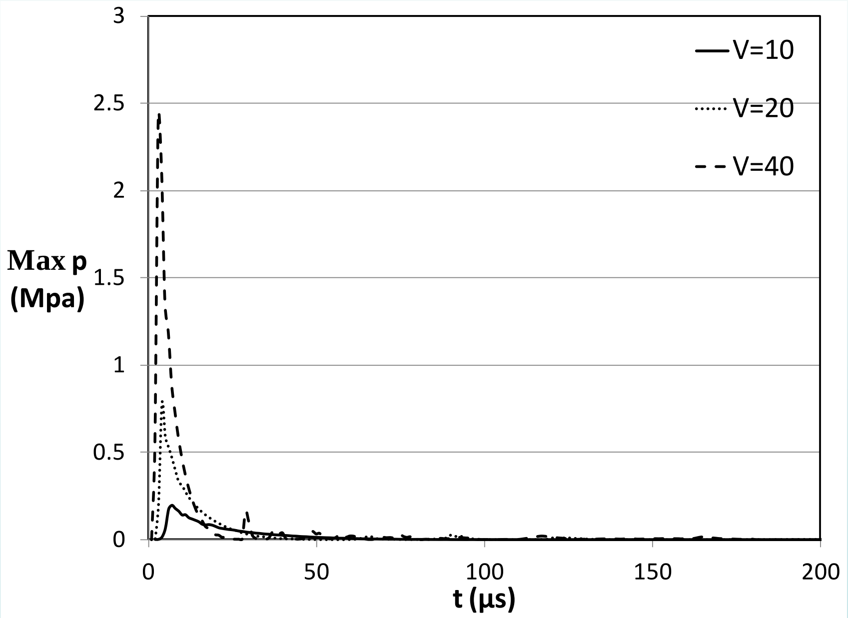
(SS, V=10m/s, D=0.5 mm, th=10 mm)

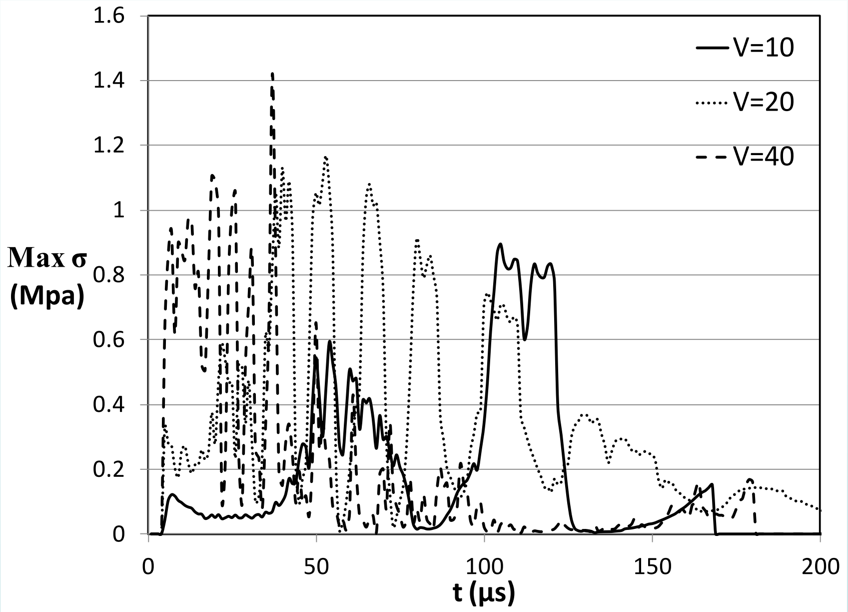
Peak stress/pressure, axis



(SS, V=10m/s, D=0.5 mm, th=10 mm)

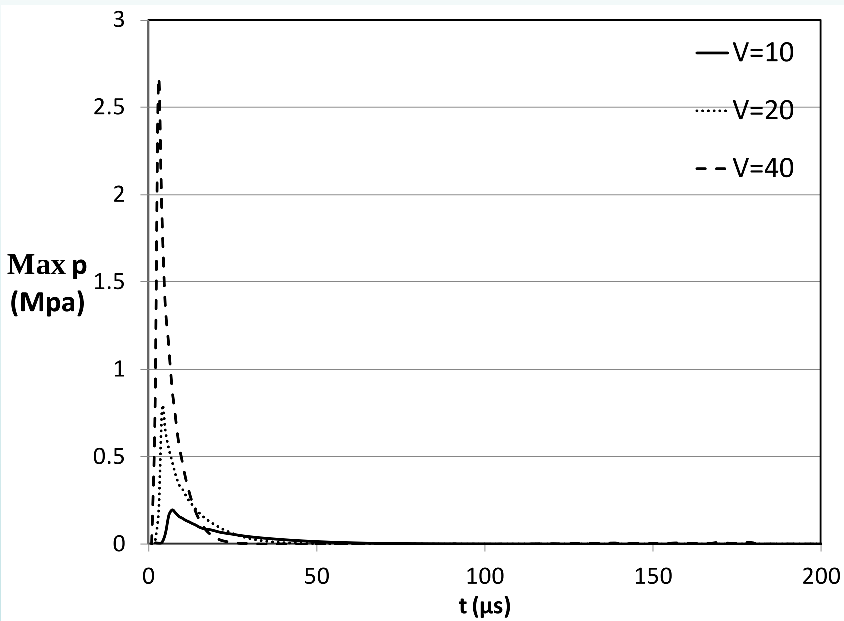
Impact velocity, interface

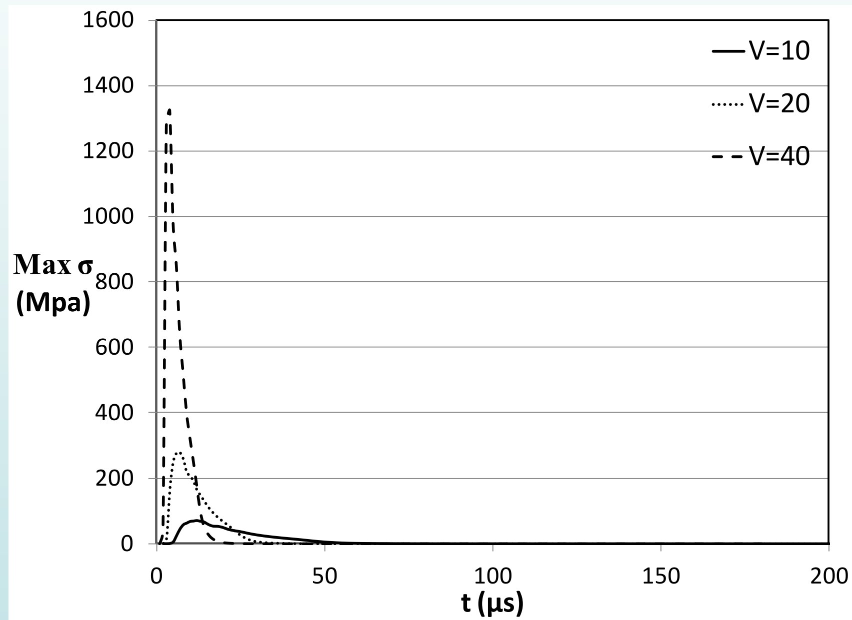




(SS, D=0.5 mm, th=10 mm)

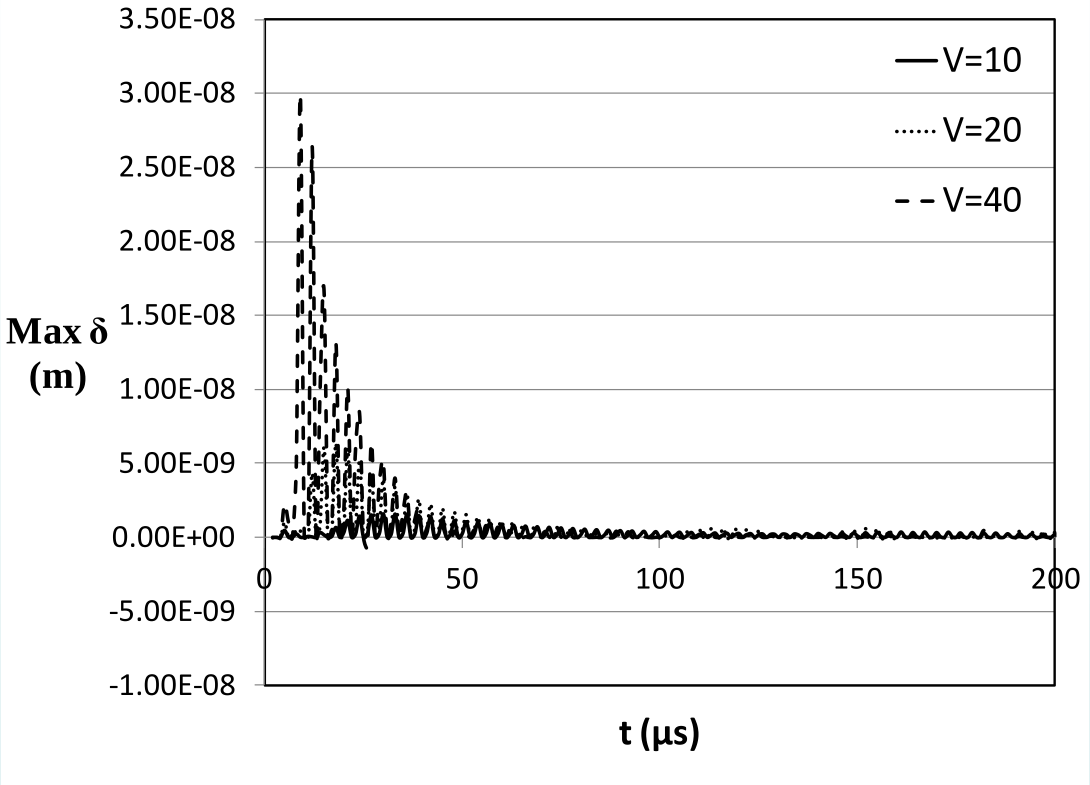
Impact velocity, axis





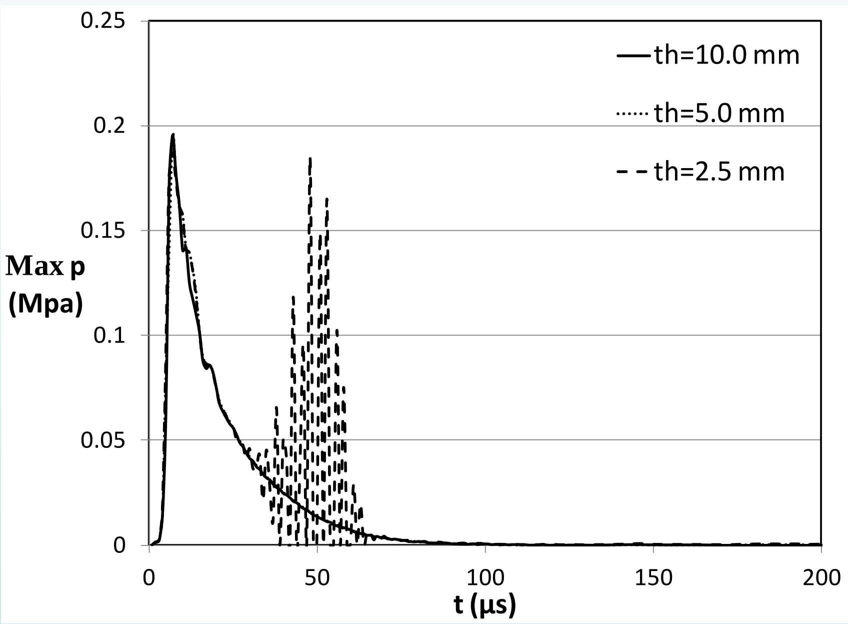
(SS, D=0.5 mm, th=10 mm)

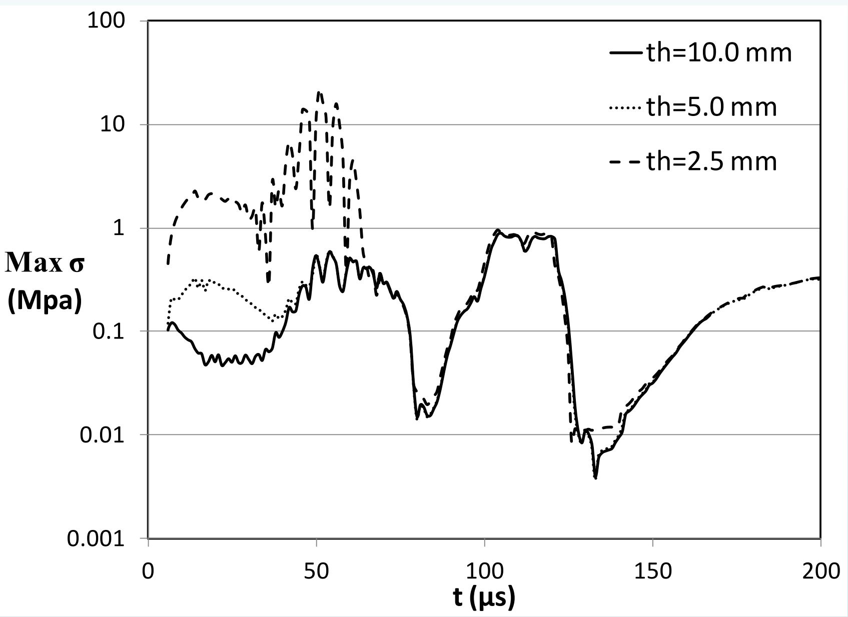
Impact velocity, deflection



(SS, D=0.5 mm, th=10 mm)

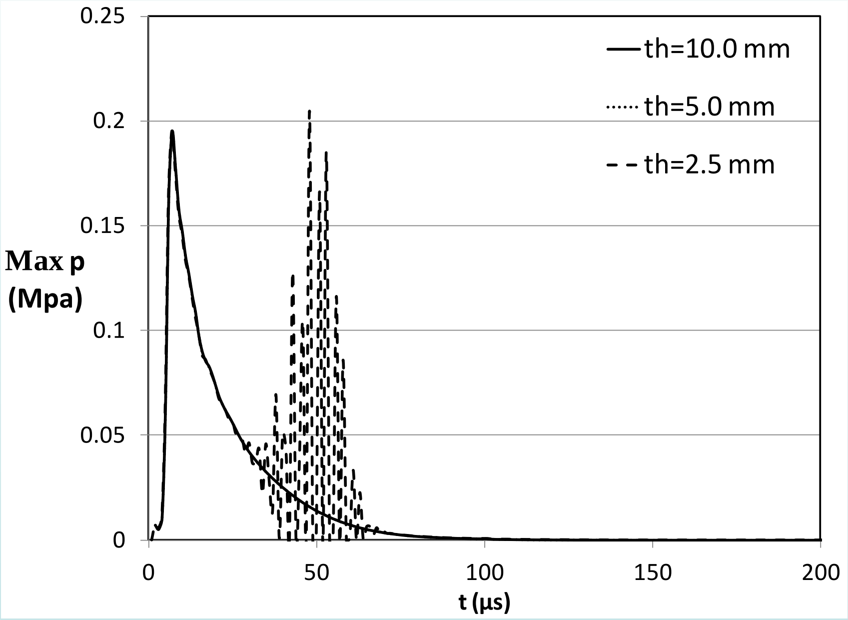
Substrate thickness, interface

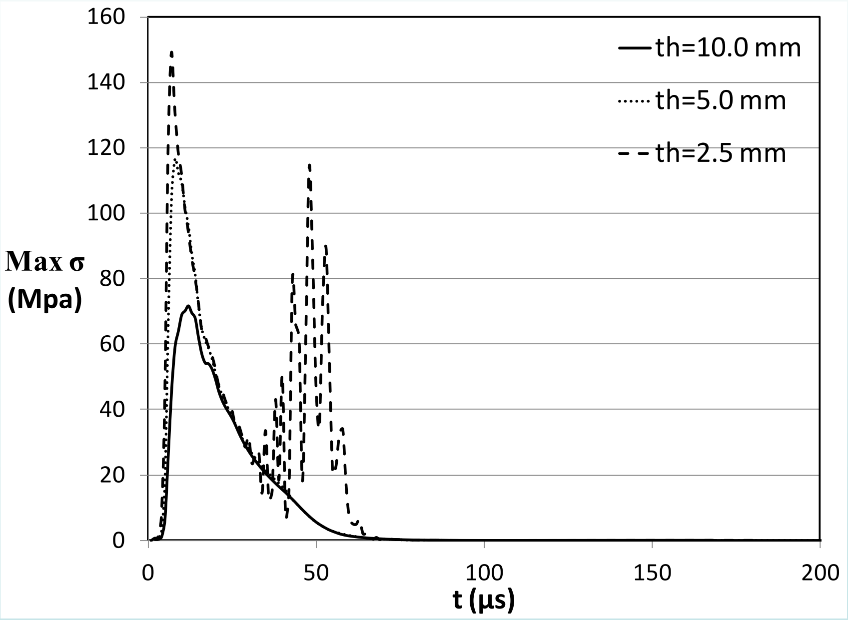




(SS, V=10m/s, D=0.5 mm)

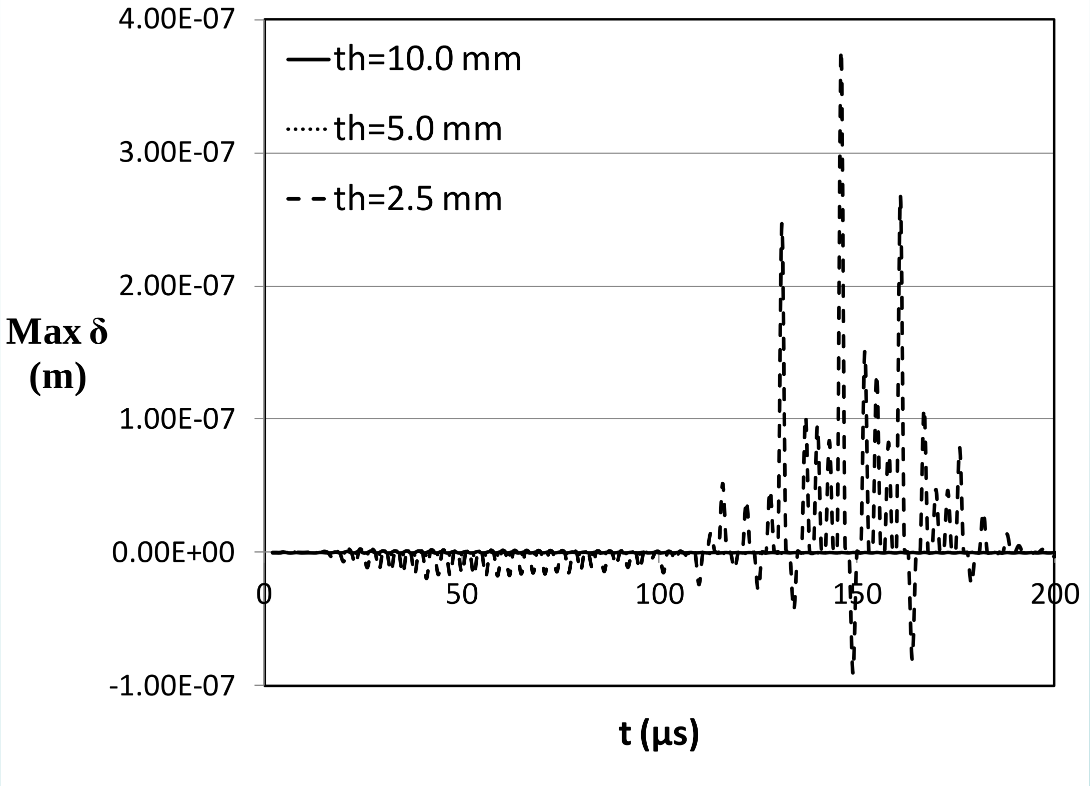
Substrate thickness, axis





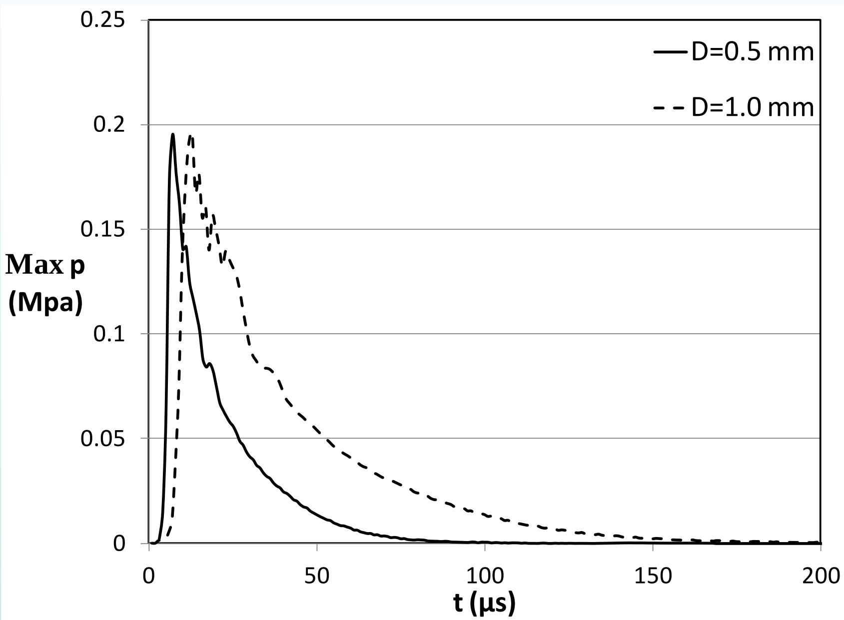
(SS, V=10m/s, D=0.5 mm)

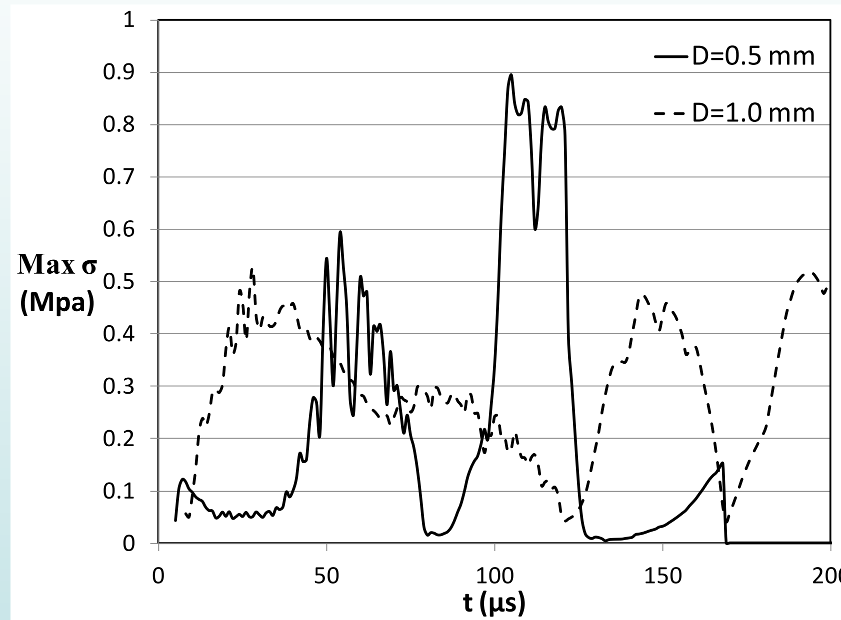
Substrate thickness, deflection



(SS, V=10m/s, D=0.5 mm)

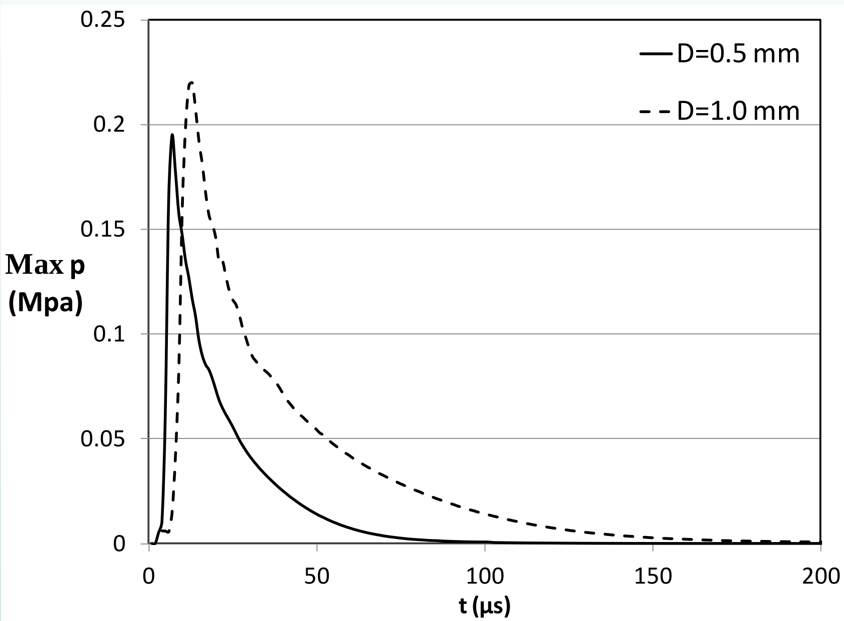
Droplet size, interface

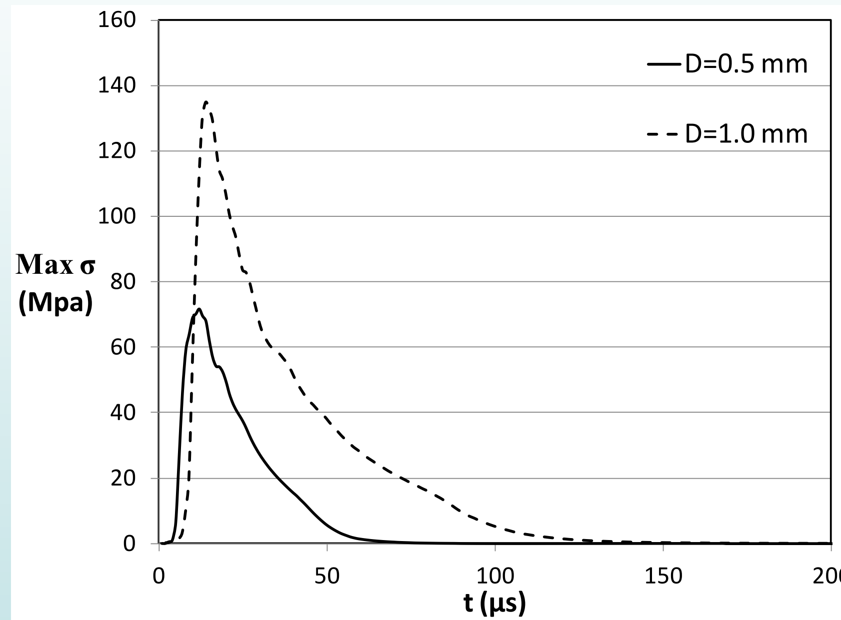




(SS, V=10m/s, th=10 mm)

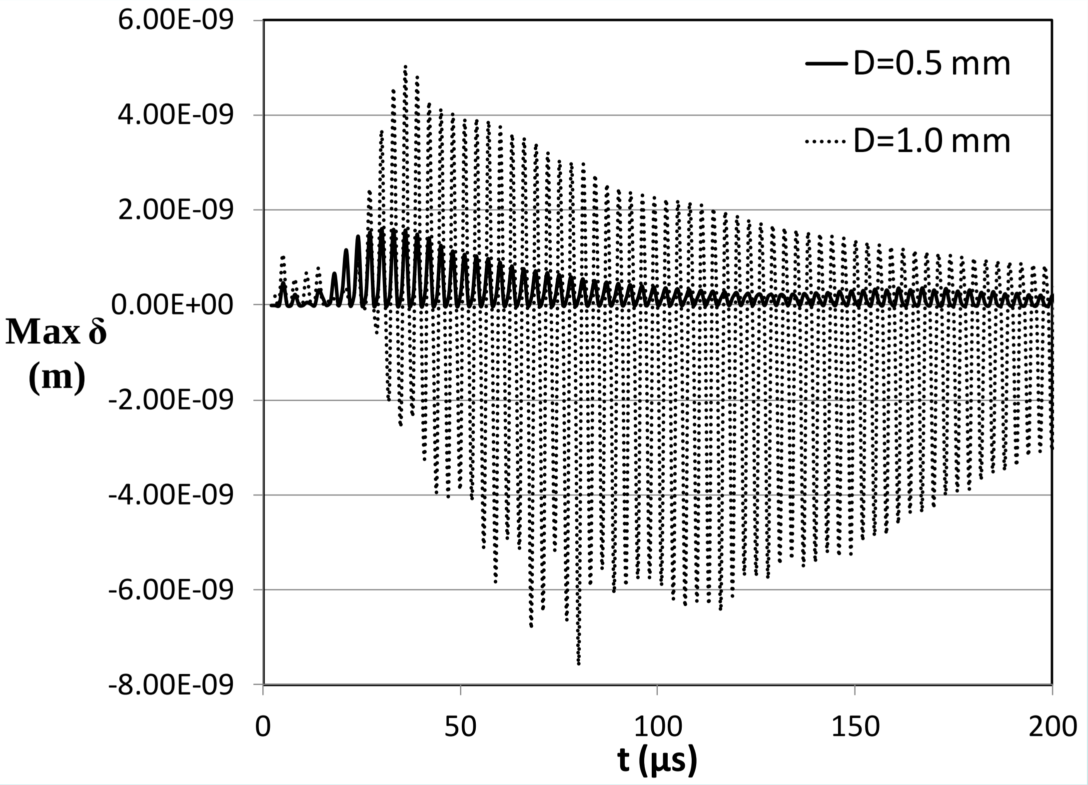
Droplet size, axis





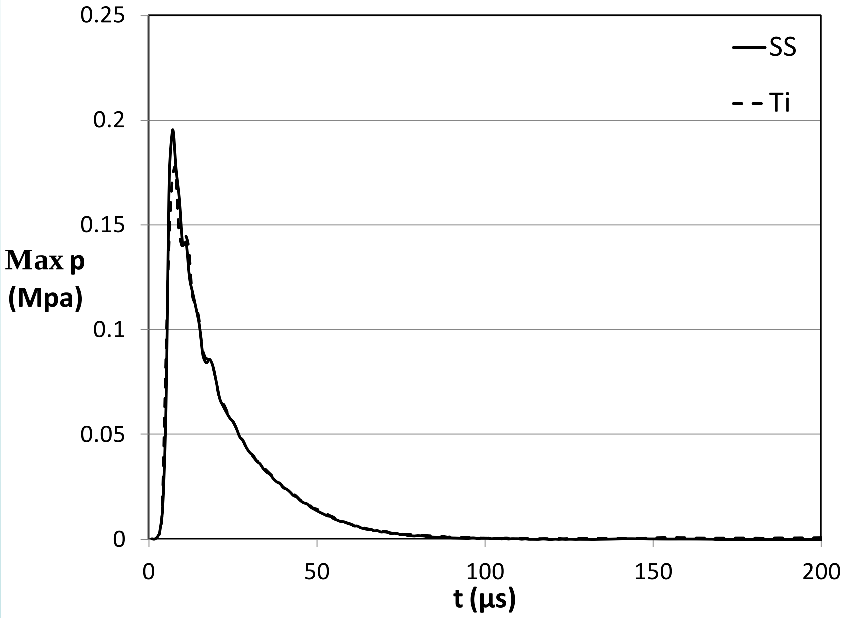
(SS, V=10m/s, th=10 mm)

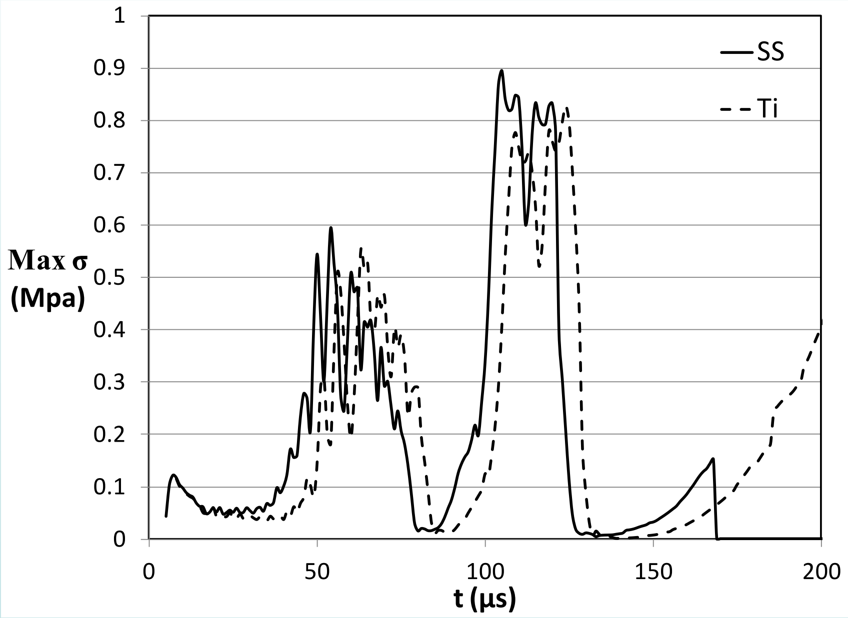
Droplet size, deflection



(SS, V=10m/s, th=10 mm)

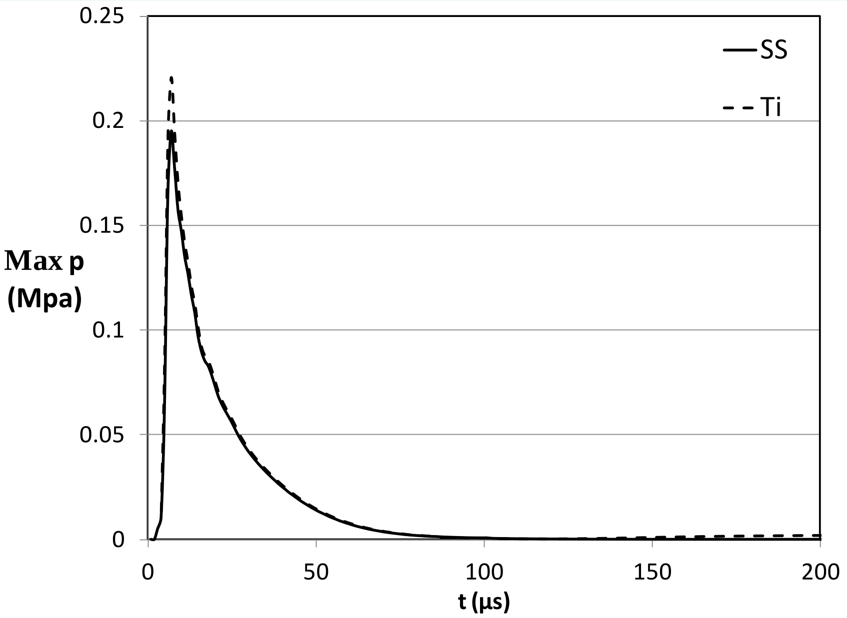
Solid material, interface

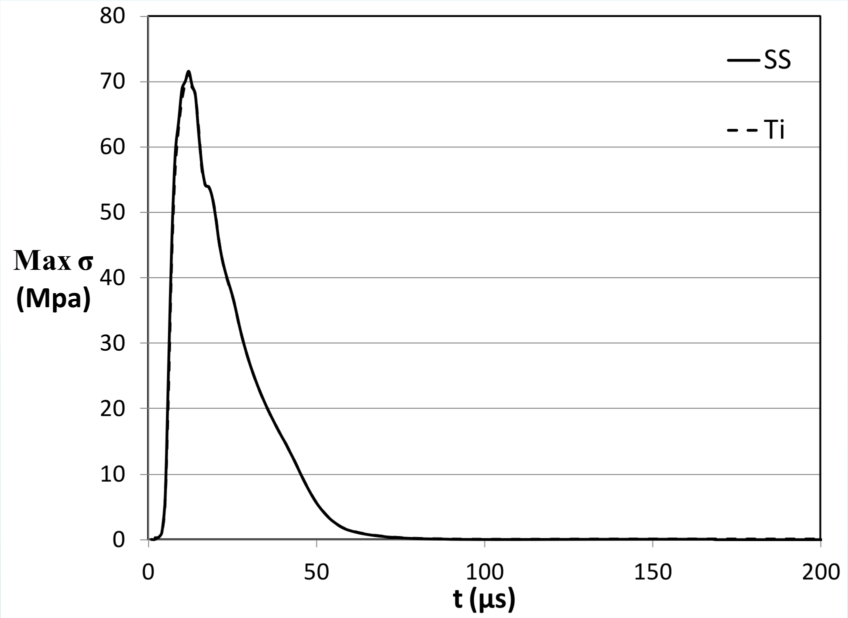




(V=10m/s, D=0.5 mm, th=10 mm)

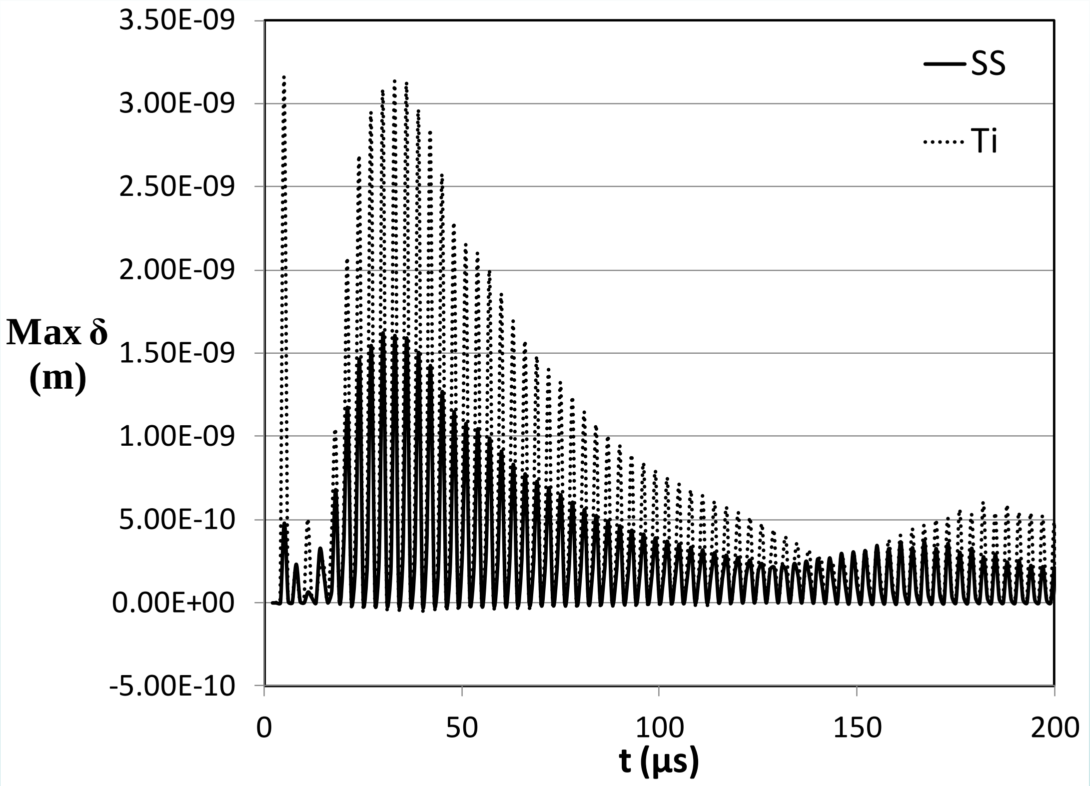
Solid material, axis





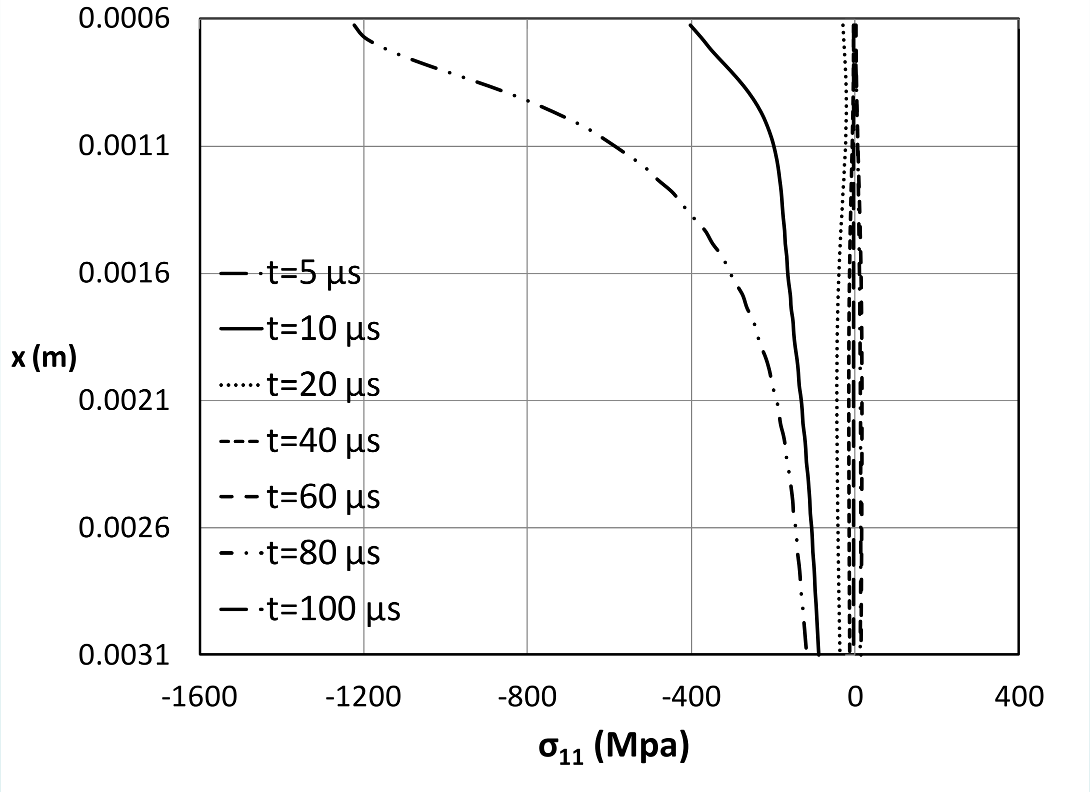
(V=10m/s, D=0.5 mm, th=10 mm)

Solid material, deflection



(V=10m/s, D=0.5 mm, th=10 mm)

Tensile Vs. Compressive stresses



(SS, V=40m/s, D=0.5 mm, th=2.5 mm)

Summary of numerical results

- Highest stress captured right below the interface
- Tensile stress appeared after loading stage in the solid
- Peak transient stress and maximum deflection were increased by increasing impact velocity and droplet size
- Peak transient stress and maximum deflection were decreased by increasing the substrate thickness
- Deflection was larger for Ti than SS although behavior was similar

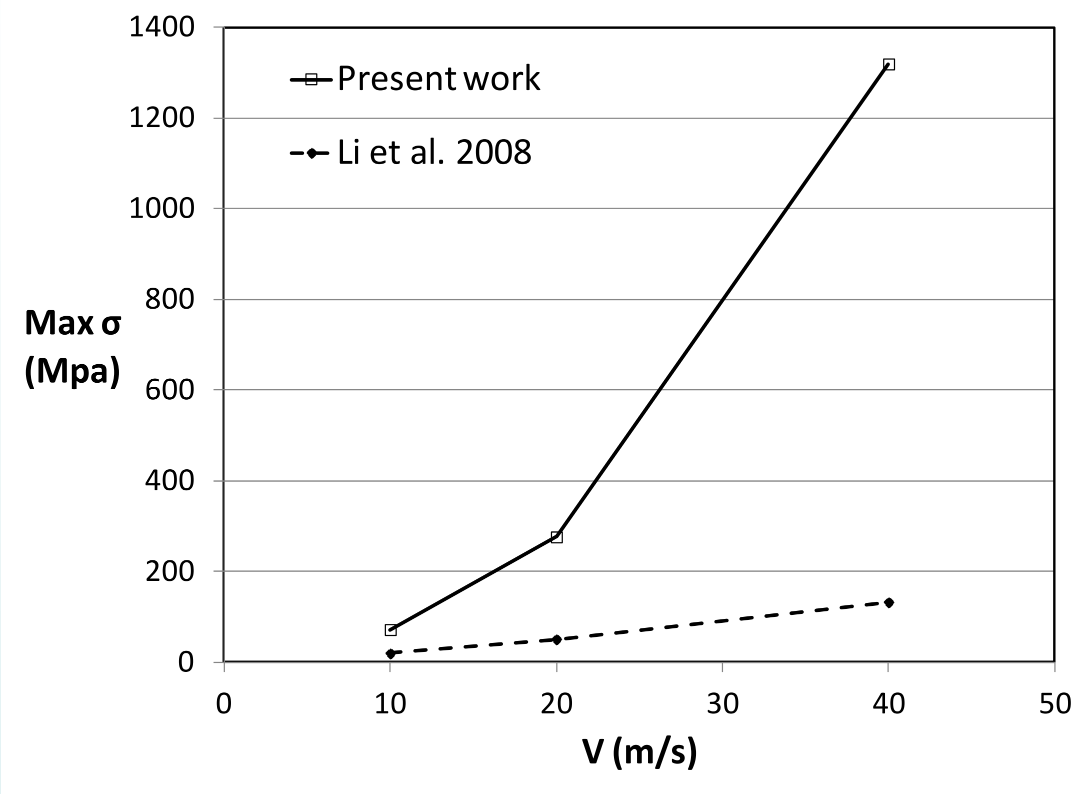
Comparison with literature

Similarities:

1. 2-D axisymmetric
2. SS substrate

Differences:

1. Fluid equation
2. Substrate thickness
3. Drop size



(SS, D=0.5 mm, th=10.0 mm)

Future work

- Validation of impact results for low/moderate velocities by experimental studies
- Modeling droplet impact at high velocities
- Using compressible equations to solve the fluid
- Implementing Dynamic Grid Adaption in the fluid solver
- 3-D modeling of the drop-solid interaction
- Modeling multiple impacts with on/off-axis orientation

Thank you!

Questions?