technische universität dortmund

Faculty of Mechanical Engineering

IUL Institute of Forming Technology and Lightweight Components

Impact-activated fluid-solid tool: towards more flexible high speed forming

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Outline

- Motivation and concept
- Experimental feasibility investigation
- Analytical modeling aspects
- Conclusion

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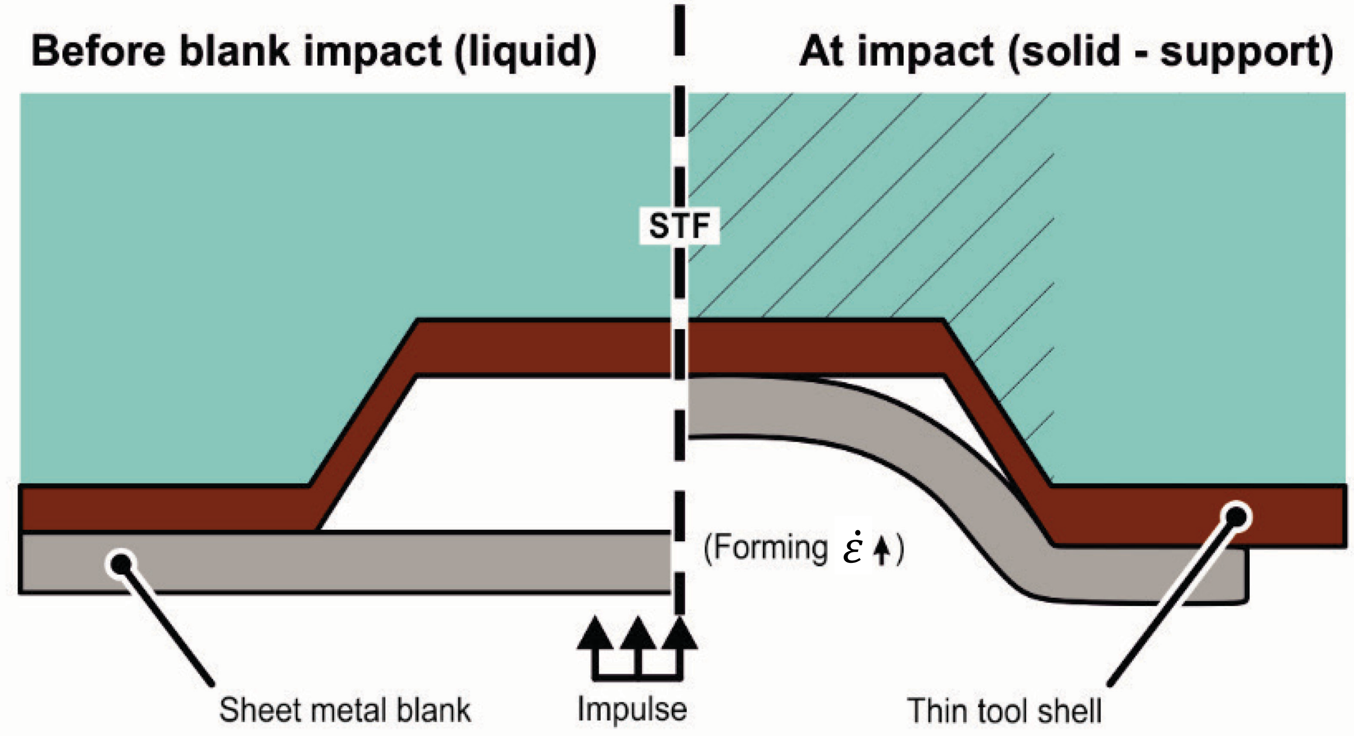
Need for more flexible (impulse) forming

Conventional: massive, geometry-bound tools, high lead time and costs, unsuited for individual batches

High speed forming can already remove heavy machinery and punch, but what about the die?

Idea*:

- Cheap thin shell governs part geometry (e.g. 3D-printed plastic)
- Mechanical support by reusable, refillable liquid acting as a solid upon impact
- Such substances are Shear Thickening Fluids (STF, colloidal dispersions)
- STF used in body armor, protective sport goods, extravehicular suits, …

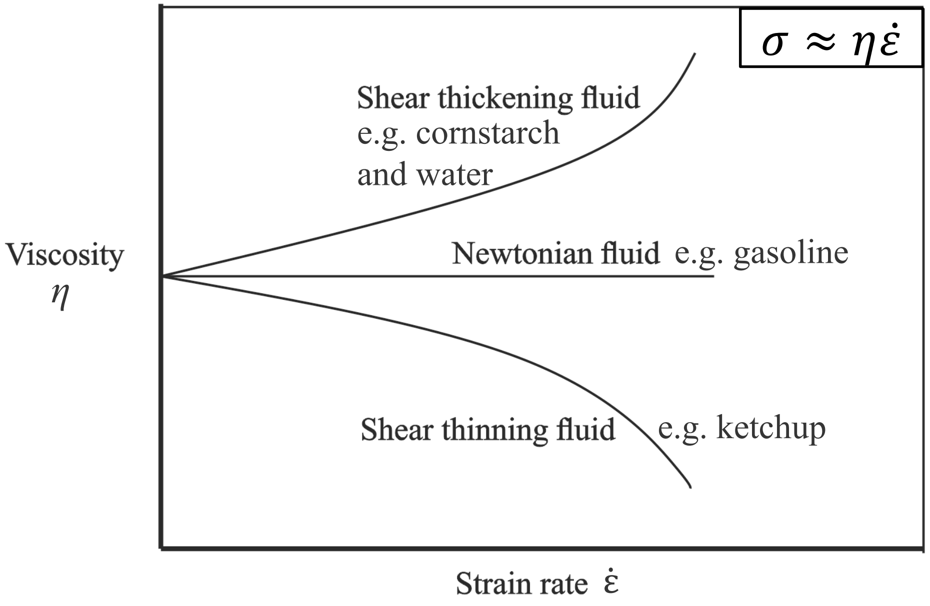


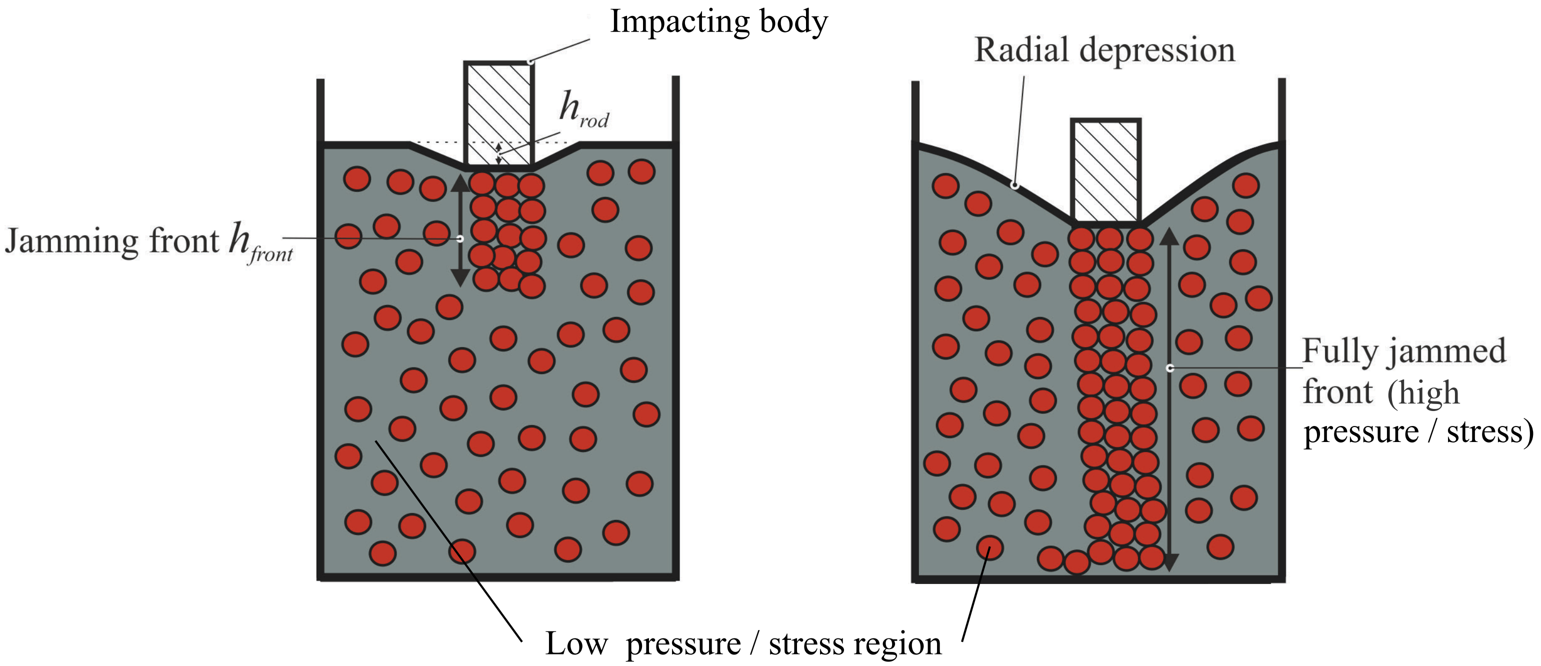
* Filed for patent by Hahn et al. (2020), DE 10 2020 006 753.0

STF mechanism

Jamming front theory* (others exist):

Locally condensed particles rapidly form 'jamming front' in surrounding liquid yielding a 'solid column' h

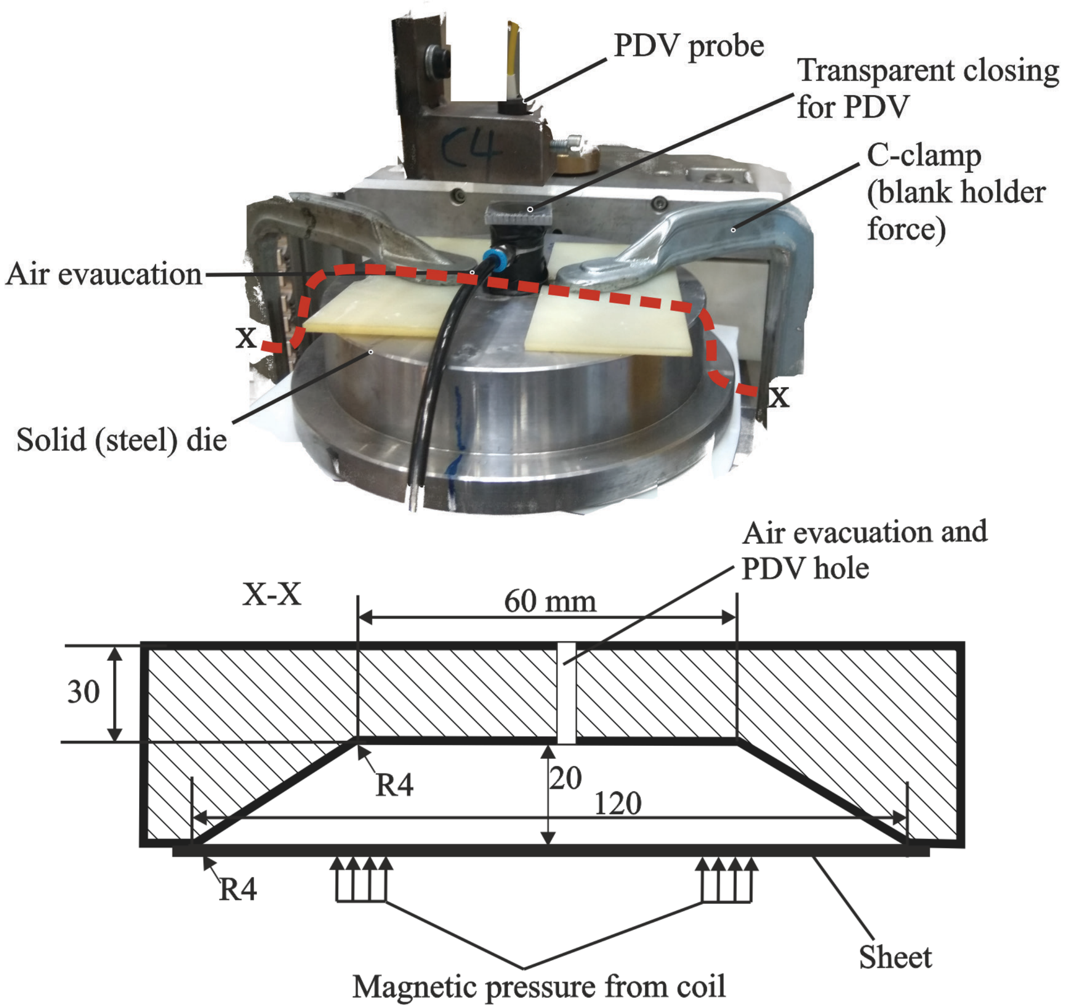


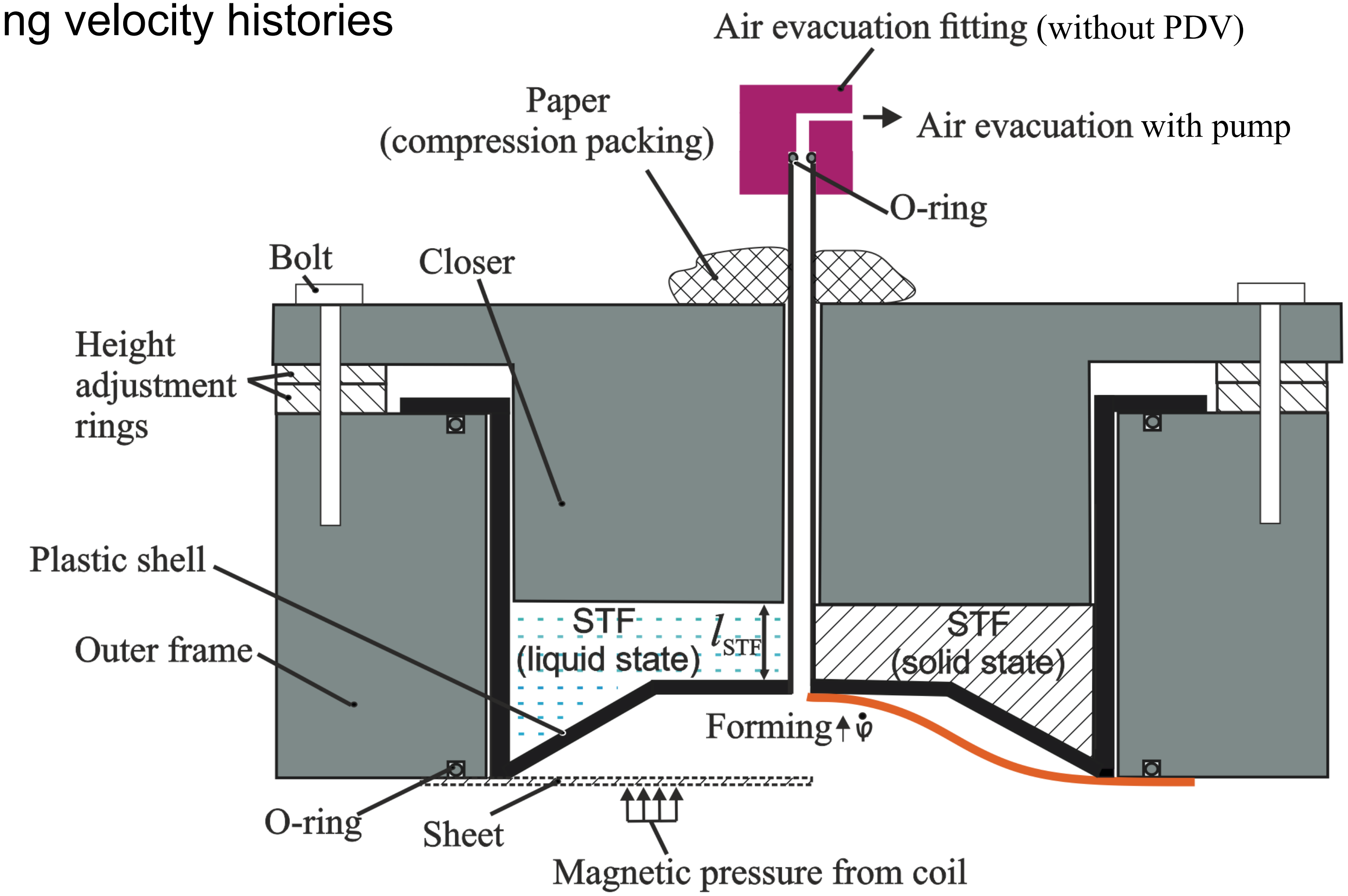


* Waitukaitis and Jaeger (2012)

Experimental setup

- Electromagnetic forming of 1 mm thick circular aluminum sheet (Al 99.5)
- Flat cone comparison: normal **solid steel** (left) vs. **STF die** (right)
- Photon Doppler Velocimetry (PDV) for determining velocity histories





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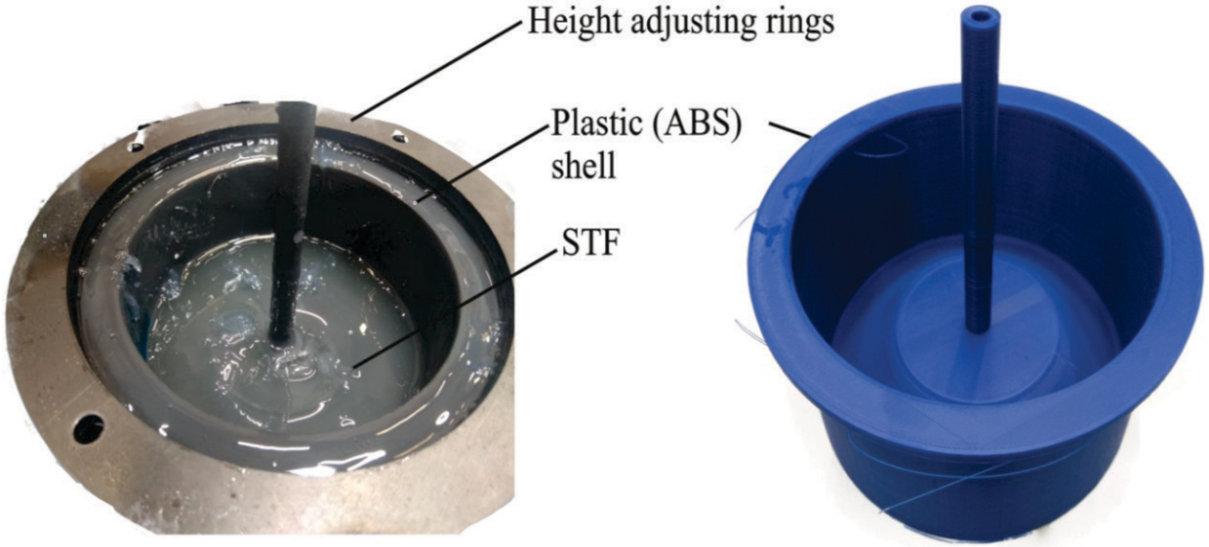
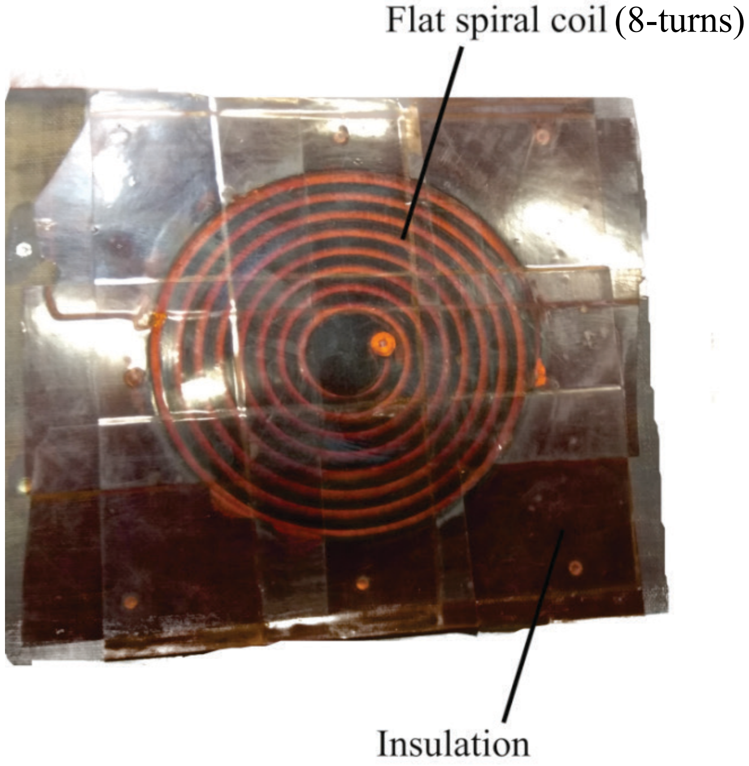
Experimental prerequisites

- Plastic shell: 5 mm wall thickness, 3D-printed on Ultimaker (ABS - Acrylonitrile Butadiene Styrene)
- 70wt% nano silica particles in glycol (STF Technologies LLC)
- Capacitor bank: Poynting SMU 612 FS (40-80 µF, max. 9 kJ)





No STF-backup: ABS shell directly fractures

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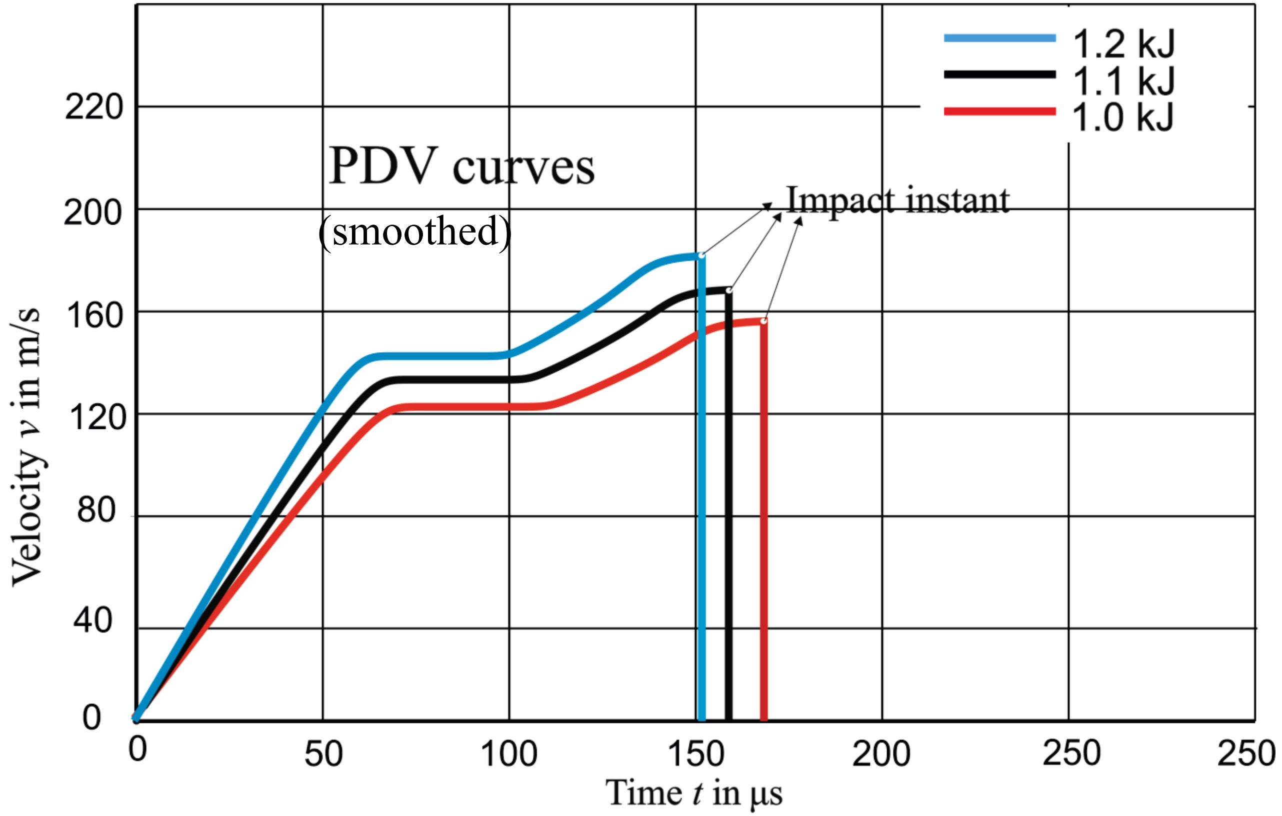
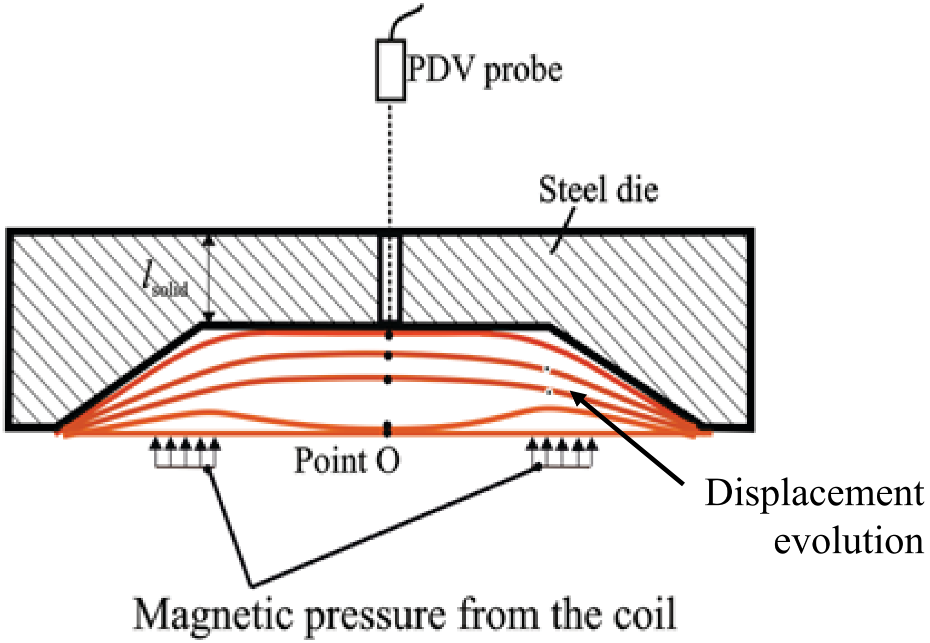
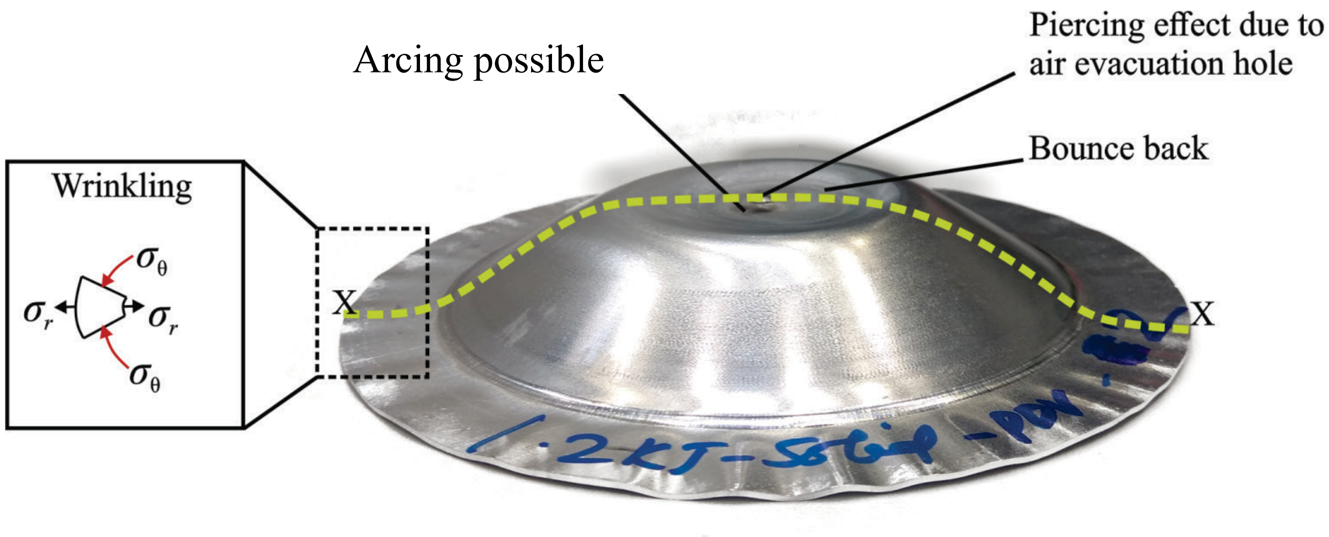
Experimental results – impact conditions

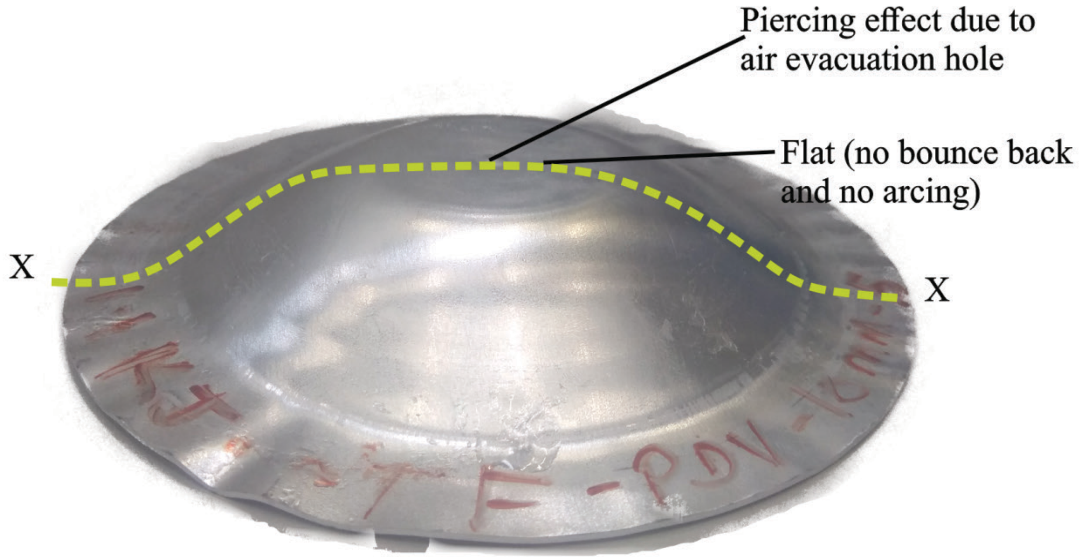
- Reproducible impact velocities (point O displacement = steel die cavity height)
- Charging energy < 1 kJ: no impact (insufficient die filling)
- Same energies (impact velocities) for STF die
- GOM ATOS for measuring part geometries





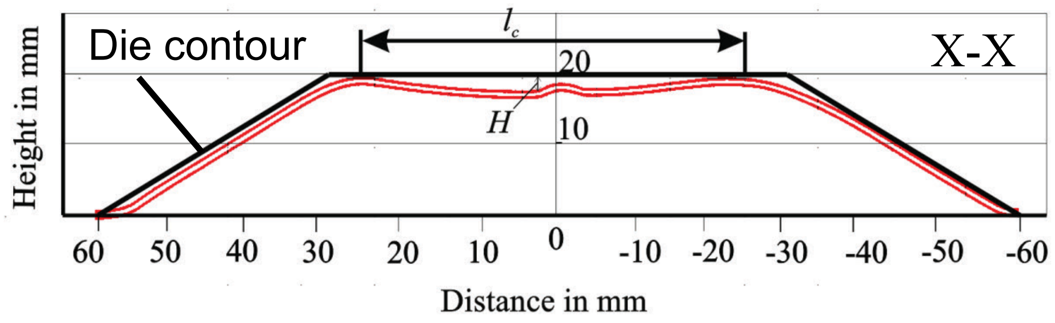
Experimental results – exemplary parts

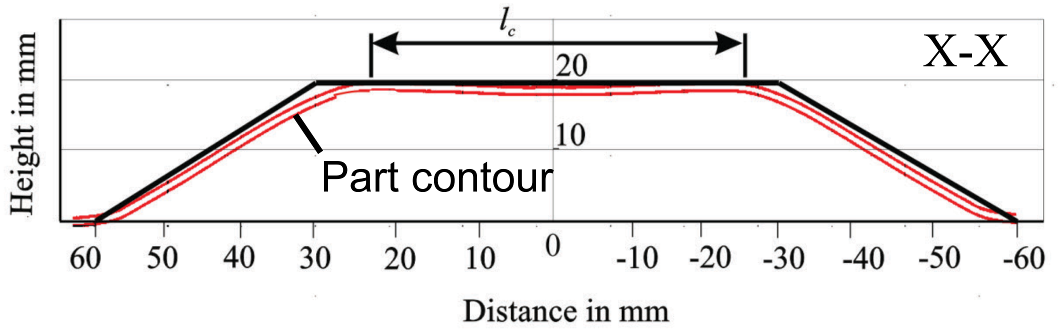




Steel die, 1.2 kJ (impact velocity 182 m/s)

STF die, 1.2 kJ (impact velocity 182 m/s)





- No STF-tool fracture (up to 5 repetitions per energy level conducted)
- STF increases geometric accuracy (reduced / eliminated bounce back *H*)

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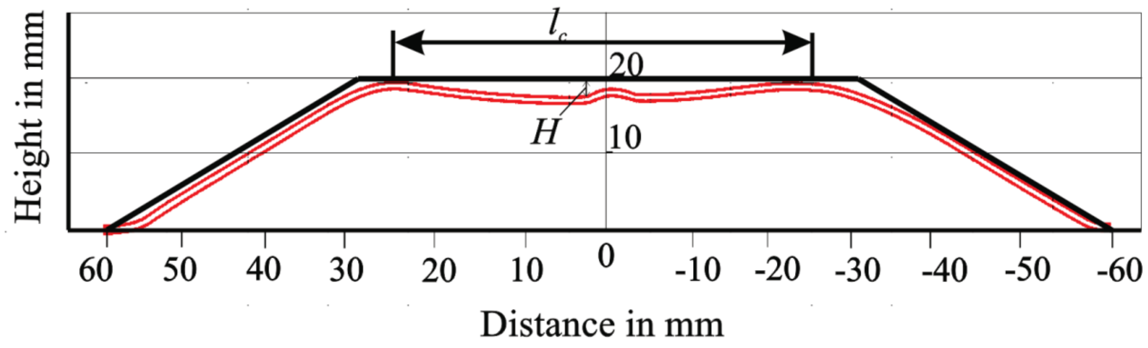
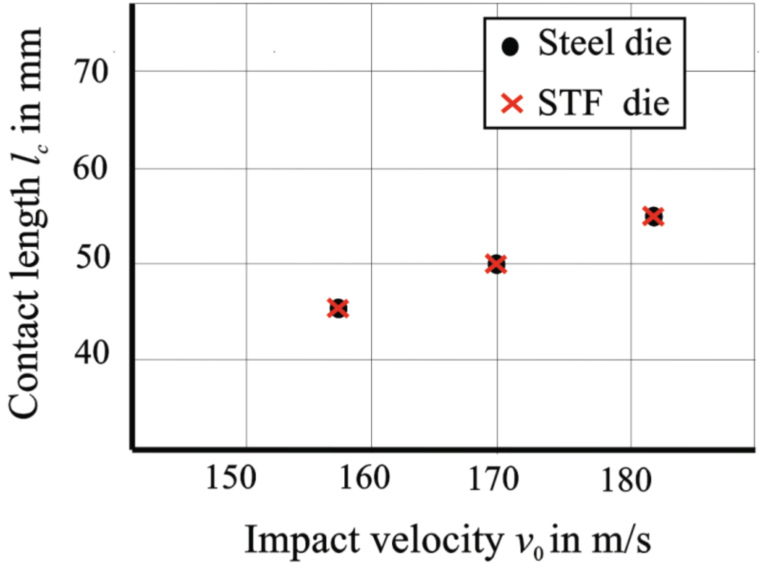
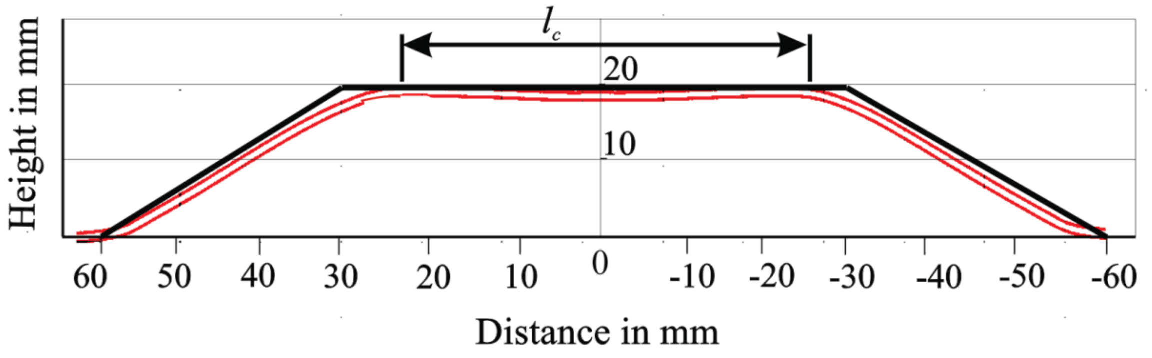
Experimental results – comparative overview

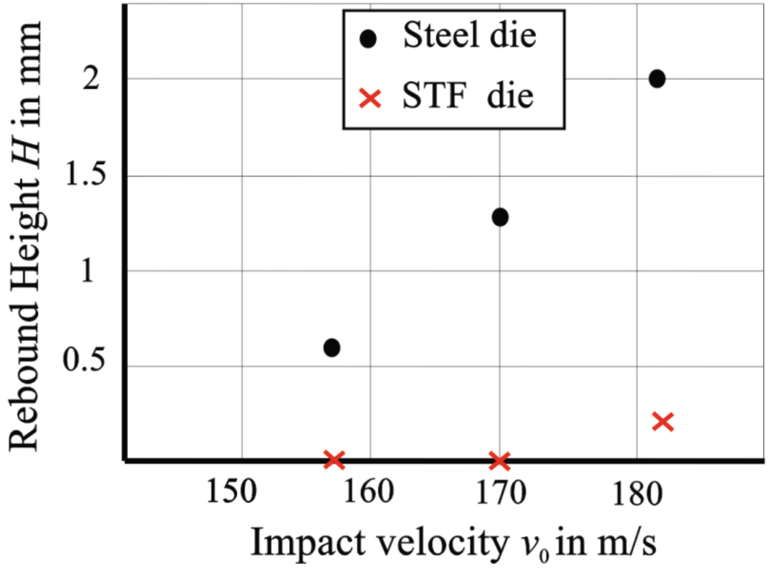
Contact length l_c – independent of die concept





Rebound height H – dependent on die concept





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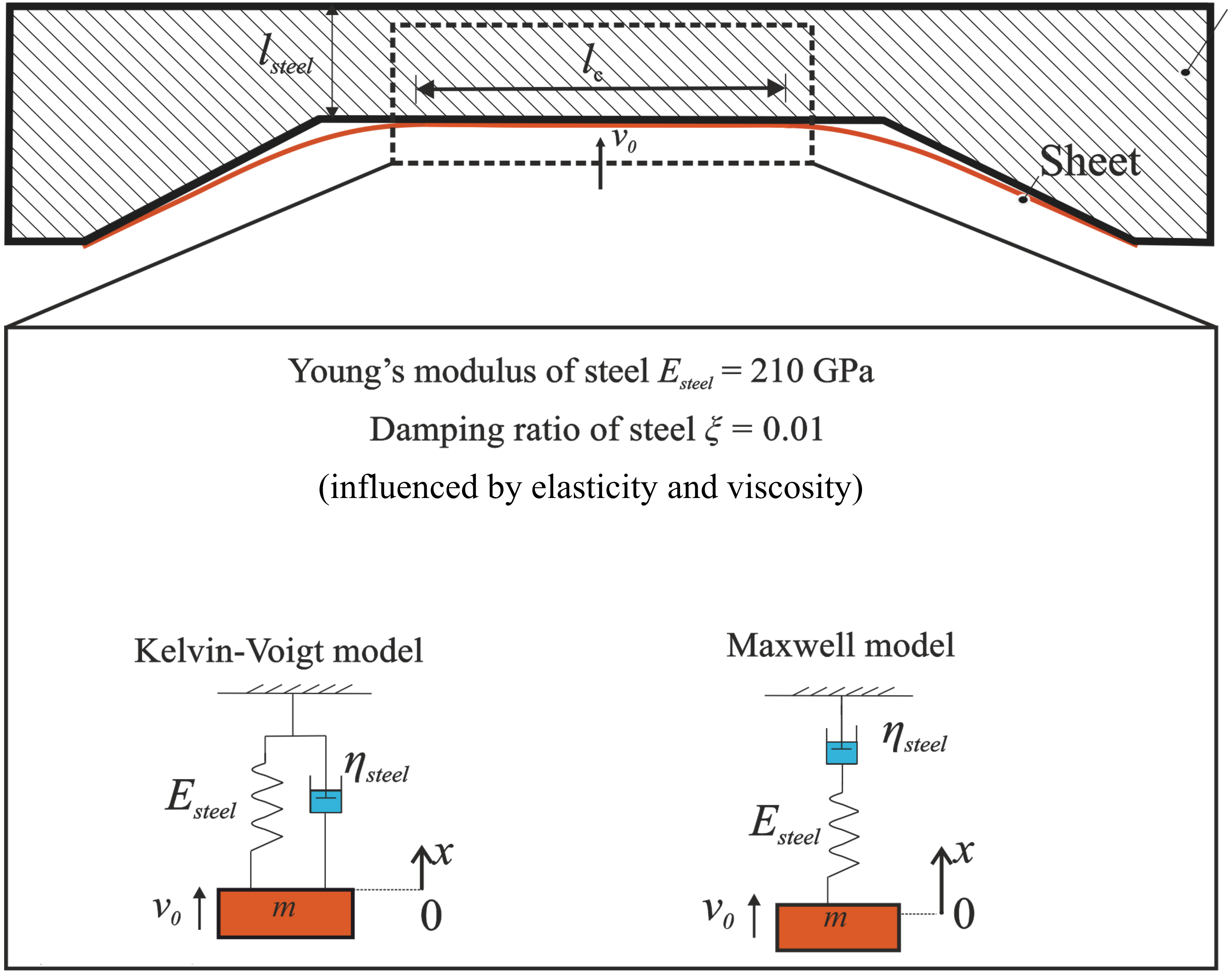
Analytical modeling (bounce back substitute model)



Sheet-die impact assumptions:

- Rigid sheet
- Friction neglected
- Known: dimensions, initial conditions, sheet mass fraction, tool stiffness
- Known or sought: damping

⇒ **Governing ODE solvable**

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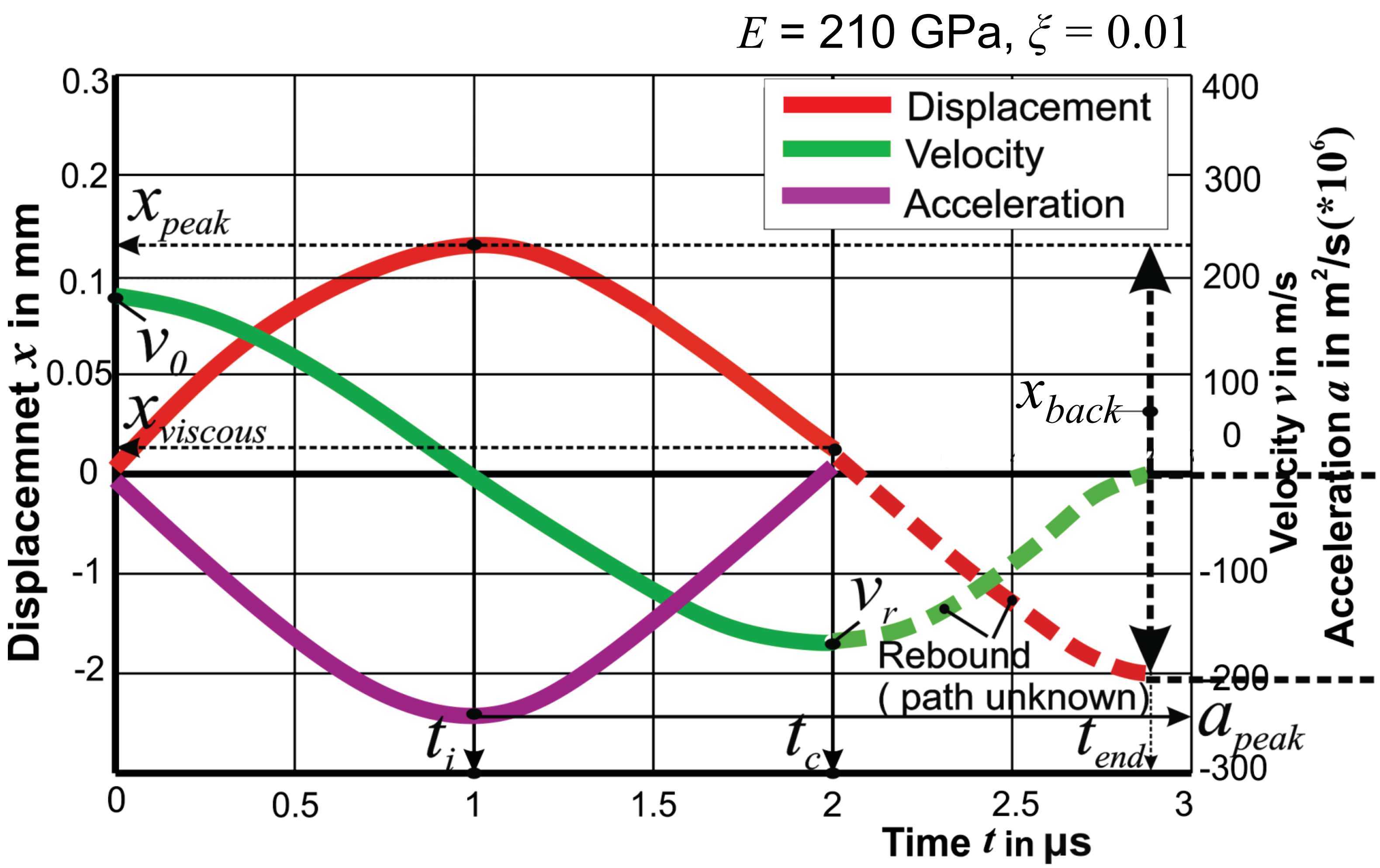
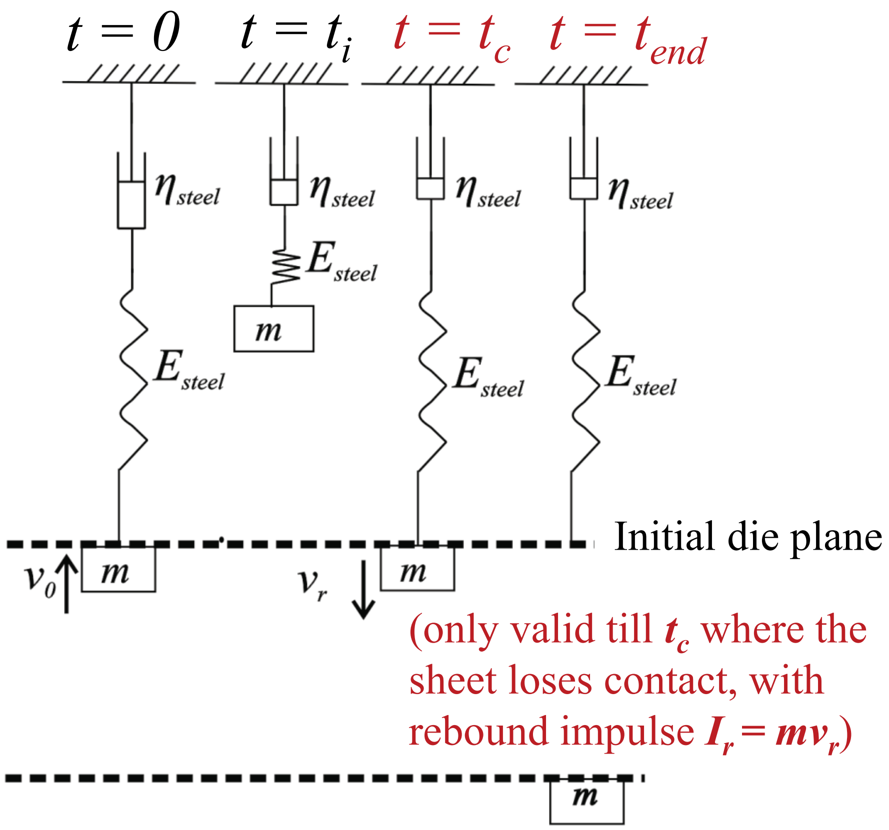
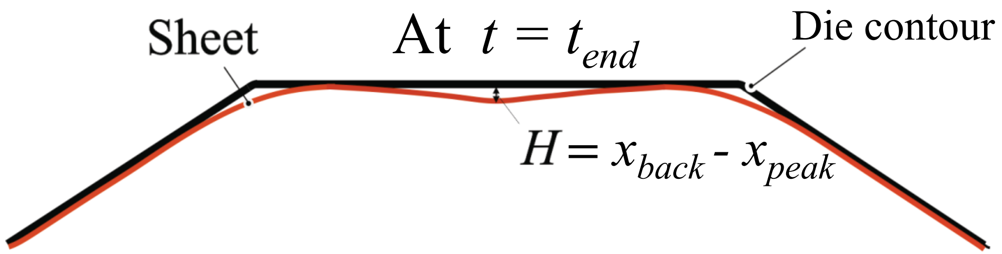
Solution characteristics (steel die)



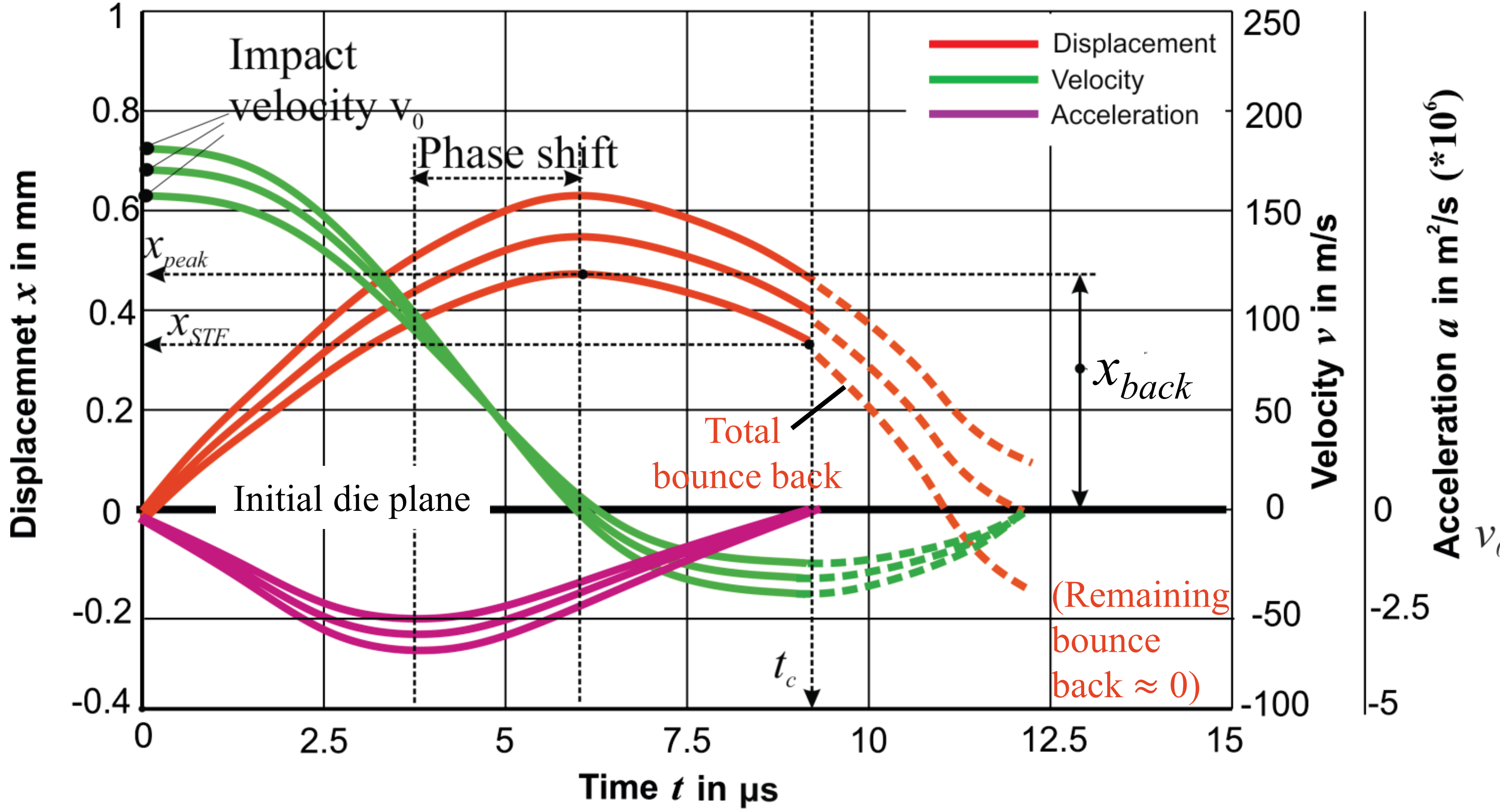


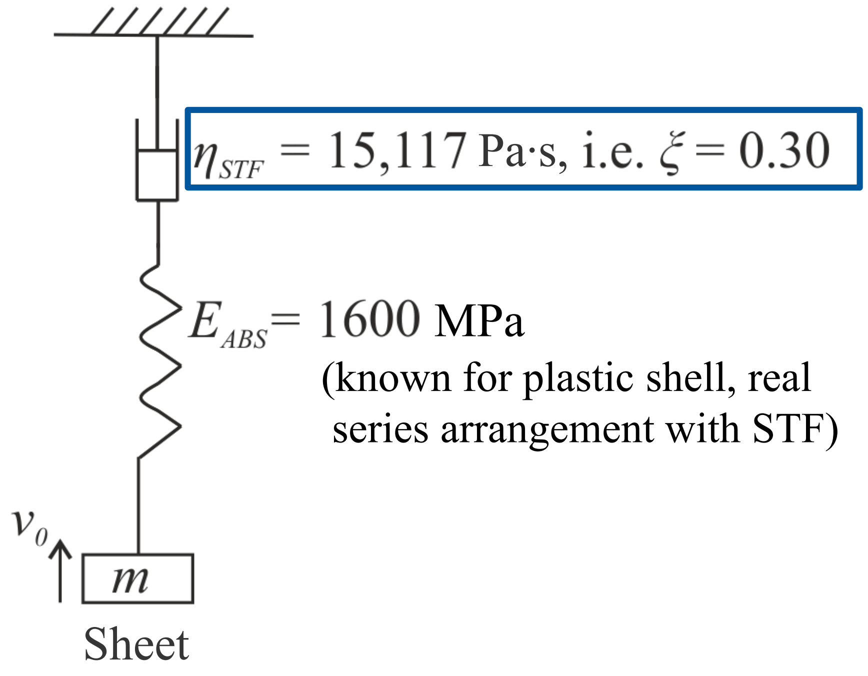


- Displacement and acceleration in-phase (mainly elastic response)
- Rebound from t_c on: $H^{Al} \cong 1.687 I_r$ (also derivable by: kinetic ≡ elastic sheet energy)

Solution characteristics (STF die)

Damping ratio ξ (resp. η_{STF}) unknown a priori ⇒ Minimize error between model and experiment over velocities v_0





- Phase shift observed (viscoelastic response)
- 'Const.-η model' predicts with average error of 14%
- Ca. 86% of initial impact energy absorbed by STF
- $x_{peak}^{STF} \approx 4x_{peak}^{Steel}$

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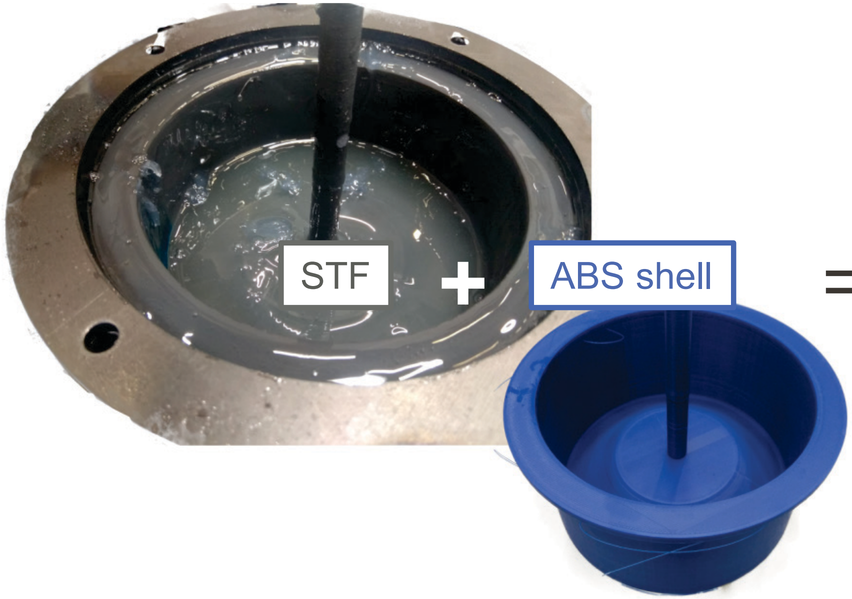
Conclusion

- General feasibility of flexible STF-tool concept shown for electromagnetic forming
- Reduced / eliminated undesired bounce or spring-back compared to massive steel die
- Reason: viscoelastic damping $\xi_{STF} = 0.3 \approx 30\xi_{Steel}$ ($\xi > 1 \Leftrightarrow$ 'negative bounce back' / penetration)
- Simplified analytical modeling suitable for a first tool / process design
- Future work: validation for other impulse processes / velocities, materials, part geometries



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Impulse-formed part (better accuracy)

Thank you for your attention

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