Some considerations on grazing particle beam impacts on uncoated and coated targets

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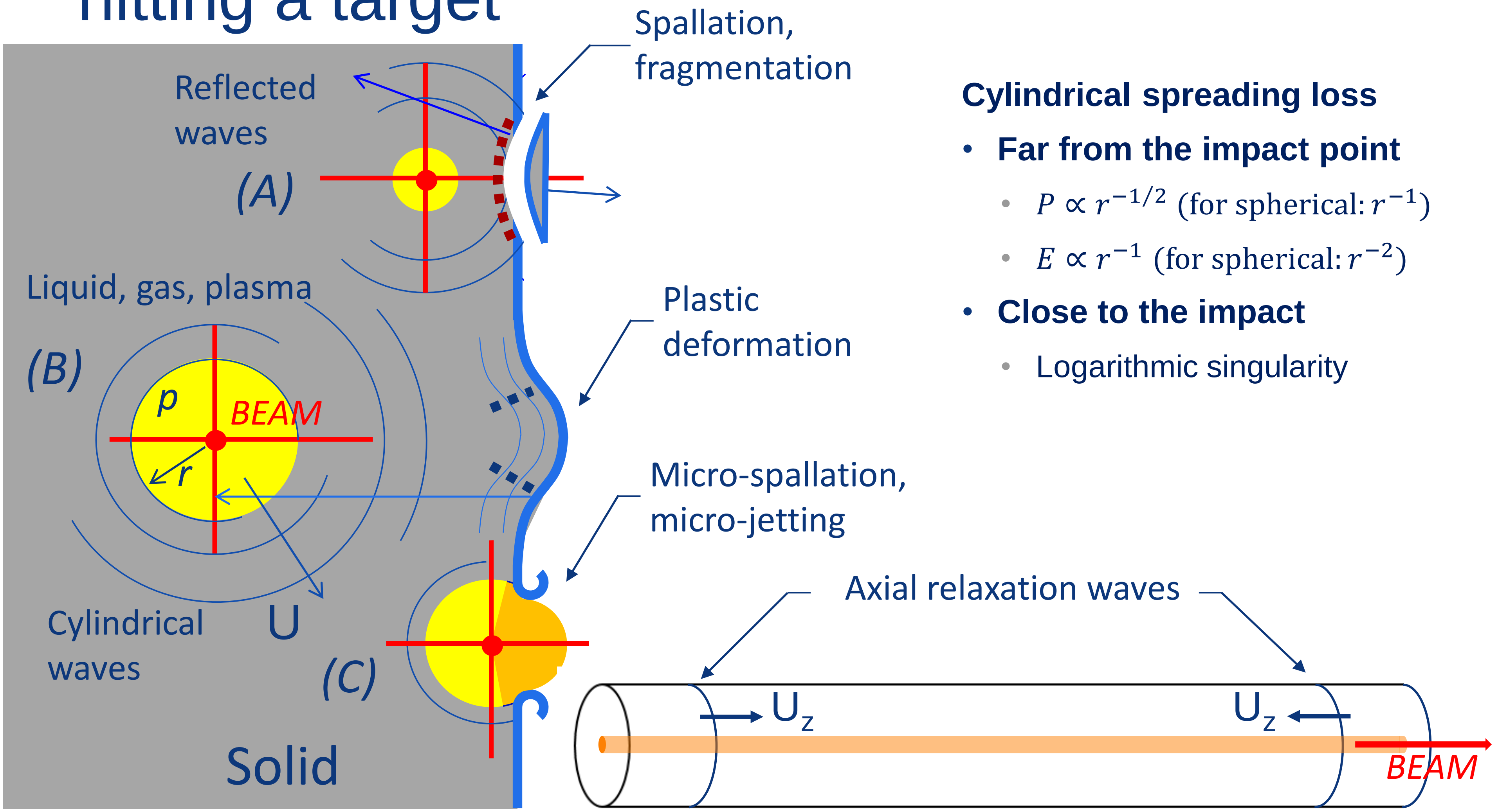
Phenomena induced by a particle beam hitting a target



Cylindrical spreading loss

- **Far from the impact point**
  - $P \propto r^{-1/2}$ (for spherical: r^{-1})
  - $E \propto r^{-1}$ (for spherical: r^{-2})
- **Close to the impact**
  - Logarithmic singularity

Failure of coated/uncoated free surfaces

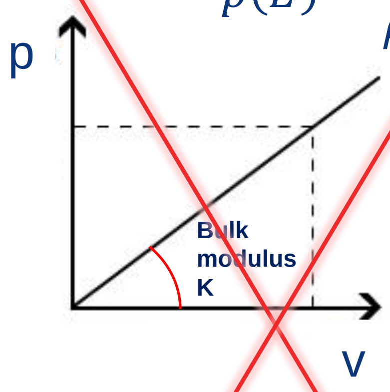
- Dynamic failure of a free surface: associated with **spallation and micro-spallation** phenomena (both related to cavitation)
- **Spallation** takes place when the amplitude of a **tensile wave** surpasses the spall strength of the material, in a **solid state**
- When a tensile wave propagates into a **molten (or gas)** material, the spall strength is null and a spray of microscopic droplets is ejected around. This phenomenon is called **micro-spallation**
- An intermediate scenario consists in the melting of an inner material volume, with the surroundings still solid. If the solid walls spall, there is an ejection of both molten material and solid fragments. This is typically called **micro-jetting**

Simulation tools

ANSYS

Linear Equation of State

$$p(E) = \frac{\alpha K}{\rho_0 c_v} E$$



Strain-rate-independent Yield

$$\sigma = f(\varepsilon, T)$$

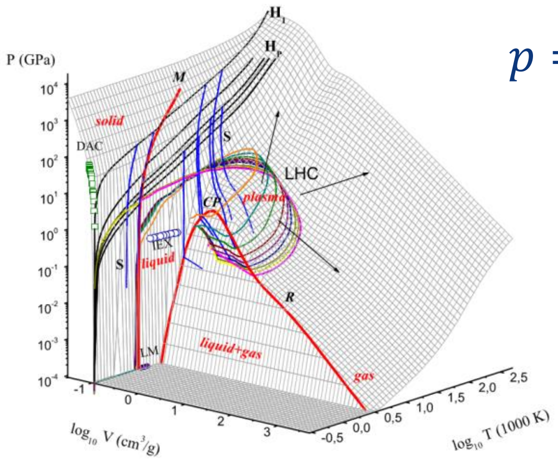
- ✓ Hollomon
- ✓ Ludwik
- ✓ Multilinear
- ✓ …

Static Failure Strength

$$\sigma < \sigma_{ult}$$

Autodyn and LS-Dyna

Polynomial and tabular Equations of State



$$p = f(\rho, E, T)$$

- ✓ Phase changes
- ✓ State transitions
- ✓ Coexistence regions
- ✓ Liquid, gas, plasma

Multi-parameter Yield Models

$$\sigma = f(\varepsilon, \dot{\varepsilon}, T)$$

- ✓ Johnson-Cook
- ✓ Steinberg-Guinan
- ✓ Johnson-Holmquist
- ✓ ....

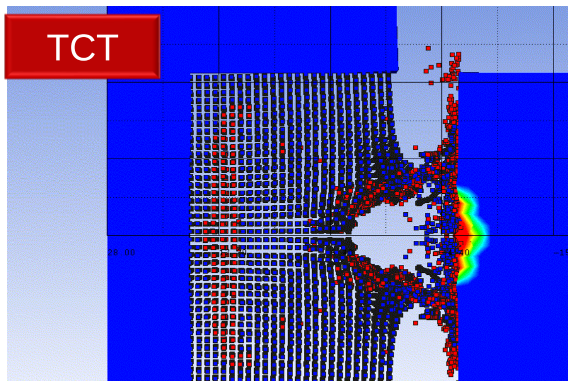
Dynamic Failure Models

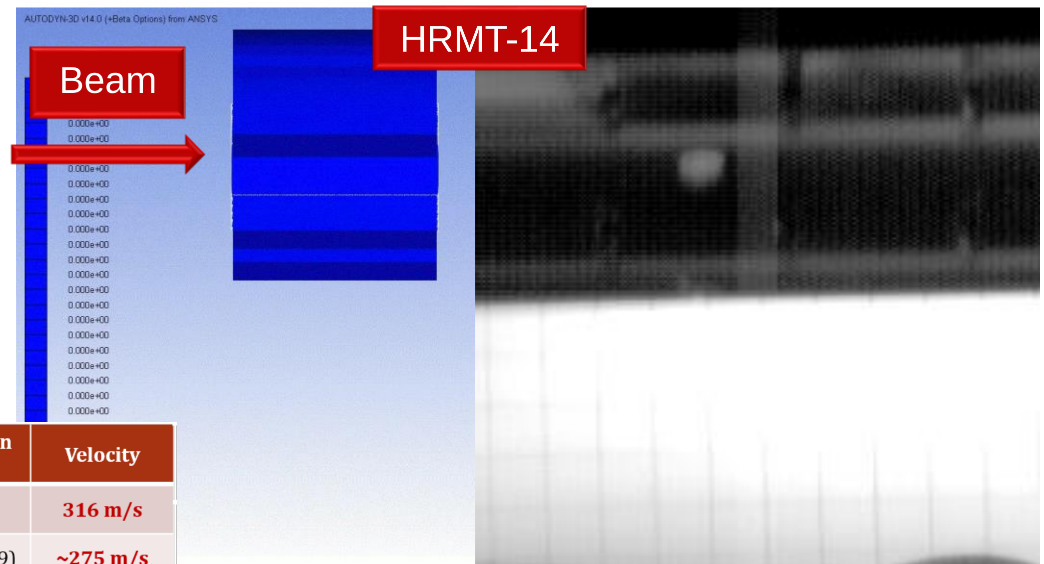
Damage $D = f(\varepsilon, \dot{\varepsilon}, T, \bar{\sigma} \dots) < 1$

Spallation $p < p_s(\varepsilon, \dot{\varepsilon}, T, D, c_0, K_c, Y)$

Simulation of spallation/micro-spallation of uncoated surfaces

- **Both Autodyn and LS-Dyna can simulate spallation**. From my experience, Autodyn is the most suitable: it has **SESAME tabular EOS** (LS-Dyna must use polynomials) and the **SPH method** to simulate fragmentation, not available in LS-Dyna. Adopted successfully for HRMT-14 (micro-jetting benchmarked with a high-speed camera)





Case	Bunches	p/bunch	Total Intensity	Beam Sigma	Specimen Slot	Velocity
Simulation	60	1.5e11	9.0e12 p	2.5 mm	9	**316 m/s**
Experiment	72	1.26e11	9.0e12 p	1.9 mm	8 (partly 9)	**~275 m/s**

- With LS-Dyna, a suitable method is **lagrangian with erosion** (available also in Autodyn, but it can simulate only the scratch/groove provoked by the impact, not the fragment size, velocity and divergence).

Simulation: coated surfaces

- From the theoretical point of view, **no difference from a coated and an uncoated surface**. Also, the same method (SPH) can be adopted. However, few practical diffic

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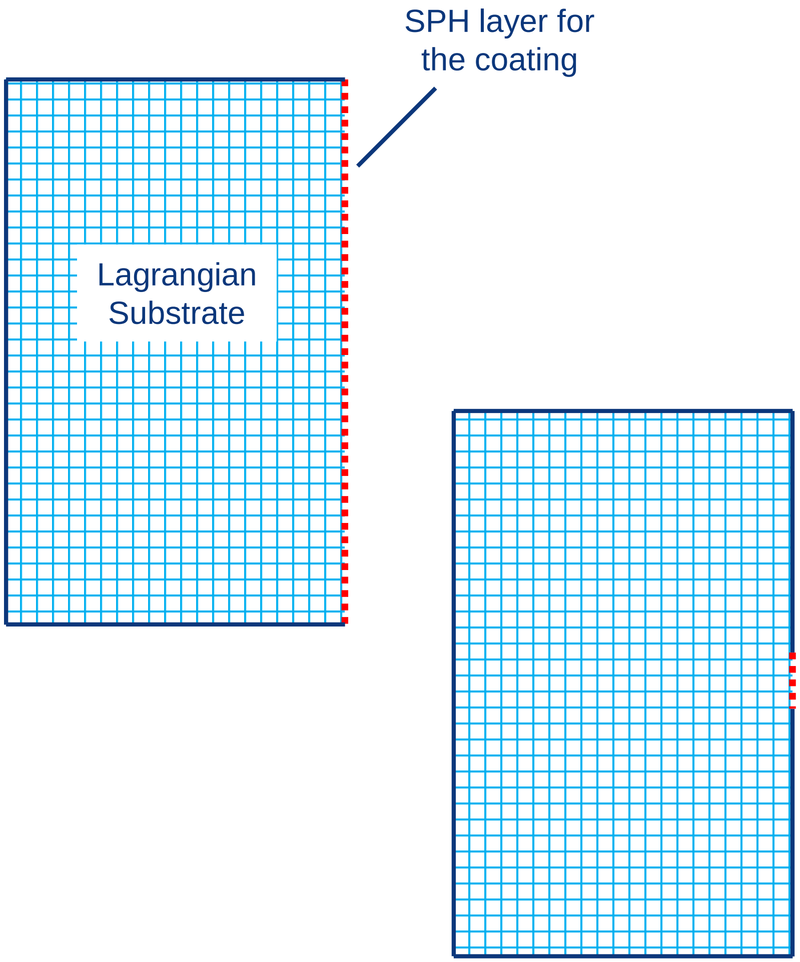
> If we melt the coating (**micro-spallation**), what is most important is the EOS.
>
> If we do not melt, but we detach (**spallation**), what is most important is the failure model.

- As a first trial, I would personally:
  1. Assume for the coating material one of the models available in literature for the bulk. EOS is probably very close to the bulk, strength model is likely not much relevant, what is important and can be parametrized starting from an initial assumption from literature is the **failure model**
  2. The interface can be assumed as perfect. The failure of the interface can be integrated in the coating failure model (e.g. Grady spall)
  3. See next slide

Simulation of coated surface: FE methods

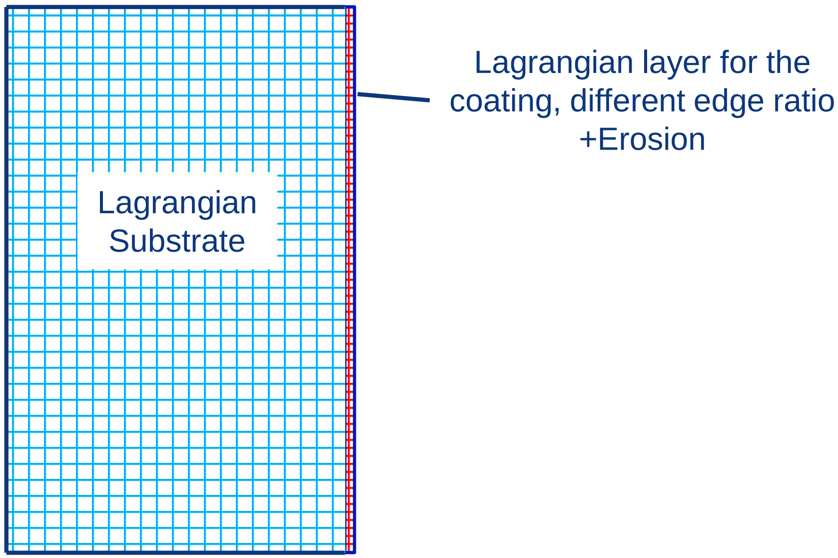
A. **Autodyn**: Lagrangian (substrate) +SPH (coating). Suitable when only the coating is expected to be ejected.

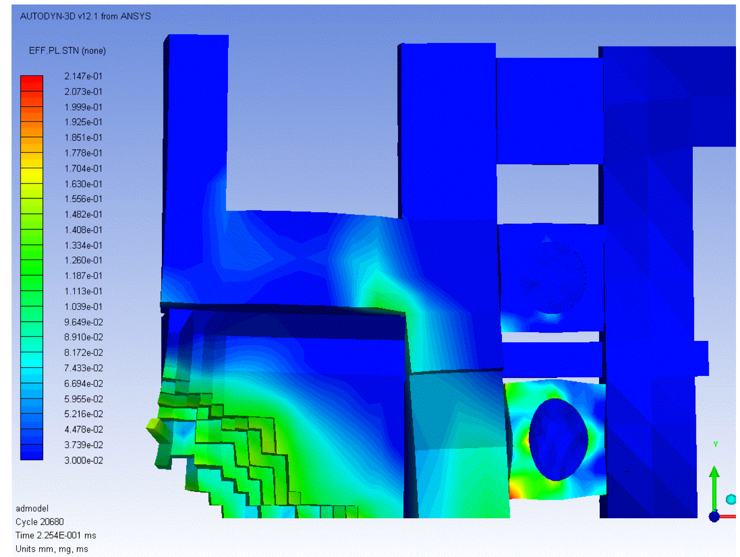


- Problem: with one layer of 2 micron x 45 mm x 1 m → **11 billions of SPH elements!**
- Also, time stepping **limited by the smallest element size**
- Possible solution: SPH only around the impact point and the most loaded Z section. With a SPH mesh of 2 micron x 5 mm x 100 mm -> **125 million elements**
- Or better: 2D simulation of the most impacted section (plane strain), it will tell us the maximum height of the groove → **2500 elements!**
- One can even think to simulate in 2D 4-5 sections to determine the groove length!

Simulation of coated surface: FE methods

B. Autodyn/LS-Dyna: Lagrangian (substrate) +Lagrangian (coating) with **erosion**.





- Erosion simulates the material ablation, allowing to reconstruct the groove produced after the impact. However: no info on the fragment size, velocity, etc.
- Advantage: lagrangian elements of the coating are not limit to a cubic shape (one could have e.g. elements 0.002 x 0.2 x 10 mm → 22500 els.)
- Problem: bad shape factor (high ratio L/t) strongly influences results, high energy error; also, still limited in terms of time step by the coating thickness
- Again, I would advise starting with a 2D simulation

Thanks for your attention