FLYER-PLATE IMPACT SIMULATIONS USING SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

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Summary An attempt to reproduce the free surface velocity data obtained from a flyer-plate impact experiment using computer simulations has been made. A hydrocode based on the meshless method Smoothed Particle Hydrodynamics (SPH) has been developed and validated with the flyer-plate experimental data produced by [1].

INTRODUCTION

A thorough understanding of the spallation and the fracture of solids in impact-like situations is necessary in the field of ballistics and high speed impact studies. The uniaxial state of strain created in flyer-plate impact experiments makes the analysis simple and provides a benchmark for SPH computations. In particular, free surface velocity (v_{fs}) profiles measured from VISAR (Velocity Interferometer System for Any Reflector) contain signatures of events like elastic-plastic transition, phase transformation, spallation and fracture. The objective of the ongoing work is to calibrate the deformation, spallation and thermal sensitivity of selected materials in a manner that predicts their VISAR response.

SMOOTHED PARTICLE HYDRODYNAMICS (SPH) AND CONSTITUTIVE RELATIONS

Application of SPH to solid dynamics simulations was first reported in [3]. In this method, the field variables and their spatial gradients on a particle are approximated by the weighted summation of the corresponding quantities on the neighbouring particles defined over a compact support domain. In this work, the SPH formulation given by [4] is followed. To compensate for the incomplete support domain suffered by a particle on the boundary, a method called normalization as described in the [4] is followed. The numerical problem of tensile instability ([2]) is overcome by following the dual particle method suggested by [5]. The domain is discretized into stress particles and velocity particles in which the former carry stresses, densities, internal energies and the internal variables, while the later carry velocities and accelerations. A quantity unknown on a particle is obtained by the Moving Least Squares (MLS) interpolation from the neighbouring particles on which it is known. Traction boundary conditions are applied as suggested in [5].
The pressure term of the Cauchy stress tensor, $-p$ is given by the Mie-Gruneisen equation of state (EOS), $p\left(\rho, e\right) = \left(1 - \frac{1}{2}\Gamma\chi\right) p_{\mathrm{H}}\left(\rho\right) + \Gamma\rho e$, where p_{H} is the Hugoniot curve and $\chi = \frac{\rho}{\rho_0} - 1$. The other details of the EOS can be found in [4]. The constitutive relation for deviatoric Kirchoff stress tensor $\boldsymbol{\tau}'$ is given in Jaumann rate form as,

$$\hat{\boldsymbol{\tau}'} = 2\mu \boldsymbol{D}' - \frac{3\mu}{\bar{\sigma}}\dot{\bar{\epsilon}}\boldsymbol{\tau}', \tag{1}$$

$\boldsymbol{D}'$ is the deviatoric strain rate tensor, $\boldsymbol{W}$ is the spin tensor, μ is the shear modulus, $\bar{\sigma}$ is the equivalent stress, $\bar{\epsilon}$ is the accumulated plastic strain, $\dot{\bar{\epsilon}}$ is the equivalent plastic strain rate given by

$$\dot{\bar{\epsilon}} = \dot{\epsilon_0}\left[\frac{\bar{\sigma}}{g\left(\bar{\epsilon}\right)}\right]^{1/m}, \text{ where } g\left(\bar{\epsilon}\right) = \sigma_0\left(1 - \alpha\left(T - T_0\right)\right)\left(1 + \frac{\bar{\epsilon}}{\epsilon_0}\right)^n \tag{2}$$

and $\dot{\epsilon_0}$, α, σ_0, ϵ_0, m, n are material constants and T_0 is the reference temperature.

RESULTS FROM FLYER-PLATE IMPACT SIMULATIONS

In order to assess the efficacy of the SPH code developed, the impact of a steel flyer with a target made of Tungsten-Sintered Alloy (WSA) (Fig. 2(a)) is simulated. The flyer is treated as elastic. For the WSA target the constitutive model described in the previous section is applied. The material constants for the plastic response of WSA have been determined by fitting the stress strain curves obtained by [1], while the elastic constants and the constants for the EOS for both WSA and Steel are taken as it is from [1].

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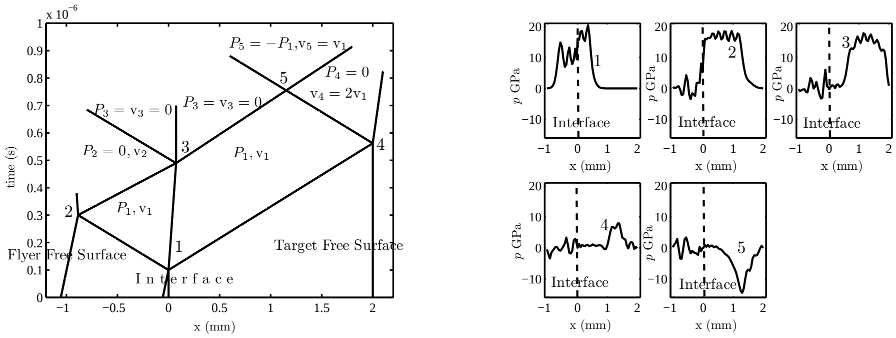
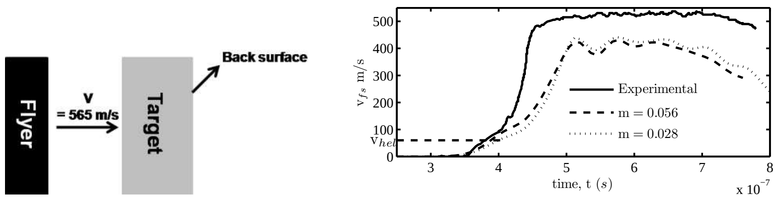
The $\mathrm{x}-t$ diagram (Fig. 1(a)) for the plate impact experiment described, systematically shows the occurence of different states of pressure and velocity after the impact, predicted from the $1-\mathrm{D}$ analysis. Fig. 1(b) shows the pressure distributions along the thickness of the flyer and target from the simulations at times indicated on the $\mathrm{x}-t$ diagram. The effect of the rate sensitivity exponent m in the power law hardening, eq. 2, on the v_{fs} profile has



(a) (b)

Figure 1: (a) $\mathrm{x}-t$ diagram showing the history of events after impact (b) Pressure distributions along the thickness of the flyer and target just after the states $(1-5)$ indicated in (a). Here, $P_1 = 14.56\mathrm{GPa}$, $\mathrm{v}_1 = 190.32\mathrm{m/s}$ and $\mathrm{v}_2 = -184.36\mathrm{m/s}$.



(a) (b)

Figure 2: (a) Schematic showing the flyer-target plate impact (b) Comparison of free surface velocity (v_{fs}) profiles from the simulations for different rate sensitivity exponents at an impact velocity $\mathrm{V} = 565\ \mathrm{m/s}$ with experimental data.

been studied (Fig. 2(b)). The HEL of WSA, σ_{hel}, has been calculated from the v_{fs} at the elastic plastic transition, $\mathrm{v}_{fs} = \mathrm{v}_{hel}$, as 3.01 GPa using $\sigma_{hel} = \frac{1}{2}\rho_0 C_L \mathrm{v}_{hel}$, where ρ_0 and C_L are the initial density and logitudinal wave velocity respectively.

CONCLUSIONS AND FUTURE WORK

Signatures of spallation are routinely pickep up by VISAR data. Description of fracture initiation and damage propagation are being embedded in the SPH routine to assess the performance of various materials.

References

[1] Rohr I., Nahme H., Thoma K., and Anderson C.E. (Jr.). Material characterisation and constitutive modelling of a tungsten-sintered alloy for a wide range of strain rates. *Int. J. Imp. Engrg.*, 35:811–819, 2008.
[2] Swegle J.W., Hicks, D.L., and Attaway S.W. Smoothed particle hydrodynamics stability analysis. *J. Comput. Phys.*, 52:374, 1995.
[3] Libersky L.D., Petschek A.G., Carney T.C., Hipp J.R., and Allahdadi F.A. High strain lagrangian hydrodynamics. *J. Comput. Phys.*, 109:67–75, 1993.
[4] Randles P.W. and Libersky L.D. Smoothed particle hydrodynamics: Some recent improvements and applications. *Comput. Methods Appl. Mech. Engrg.*, 139:375–408, 1996.
[5] Randles P.W. and Libersky L.D. Normalized sph with stress points. *Int. J. Numer. Meth. Engng*, 48:1445–1462, 2000.