Simulation of Hail Impact Using the Smoothed Particle Hydrodynamic Method in Abaqus/Explicit

Abaqus Technology Brief

Summary

Numerically simulating high speed ice or hail impact is challenging because of the extreme deformation, fragmentation, contact, and material model complexity. In this Technology Brief we demonstrate how the Smoothed Particle Hydrodynamics functionality in Abaqus/Explicit can be used to analyze ice impact. Favorable comparison with experimental data will be shown.

Background

Ice or hail impact is an important design consideration in the aviation, energy, and astronautics industries. Physical testing of impact scenarios can be expensive and impractical. Numerical simulations provide a cost effective and convenient tool for including hail impact scenarios in the design process.

Typically a high speed event, hail impact can occur with velocities over 30 m/s and strain rates above 10 s^{-1} [1], accompanied by extreme deformation and fragmentation of the material (Figure 1). Naturally occurring ice is a complex polycrystalline structure with spatially varying mechanical properties that depend on temperature and grain size. The compressive strength of ice, which plays a dominant role in impact situations, is characterized by the loading rate and velocity [2].

Regular Lagrangian finite element methods may have difficulties in handling the extreme deformation scenarios of ice impact. Such a simulation would normally involve very fine meshes, long run times, and possible loss of accuracy by prematurely deleting elements to resolve distortion issues. Hence, a mesh-free method would be an attractive alternative.

Key Abaqus/Explicit Features and Benefits

- Smoothed Particle Hydrodynamics method to efficiently model large deformation with fragmentation
- Robust general contact to automatically handle interaction between particles and regular finite elements
- Advanced material models
- Convenient meshing with a method to convert regular finite elements to particles

Smoothed Particle Hydrodynamics

Smoothed Particle Hydrodynamics (SPH) is a particle method derived in the context of interpolation theory, where properties at a particle (point) are smoothed over a finite region. The SPH method has advantages over traditional Lagrangian or Eulerian methods in its ability to naturally track free surface boundaries, capture extreme deformation with fragmentation, and efficiently handle a small material to void ratio. Since there is no physical mesh associated with the method, the issues arising from element distortions are automatically eliminated.

The SPH implementation in Abaqus/Explicit employs an efficient linear No Binary Search (NBS) algorithm to identify neighbor particles within local support [3]; provides options to use a mean flow correction configuration update (XSPH) [4] or the corrected kernel of Randles and Libersky (NSPH) [5]; handles interaction between SPH particles and other Lagrangian bodies through the Abaqus/Explicit general contact capability; allows for

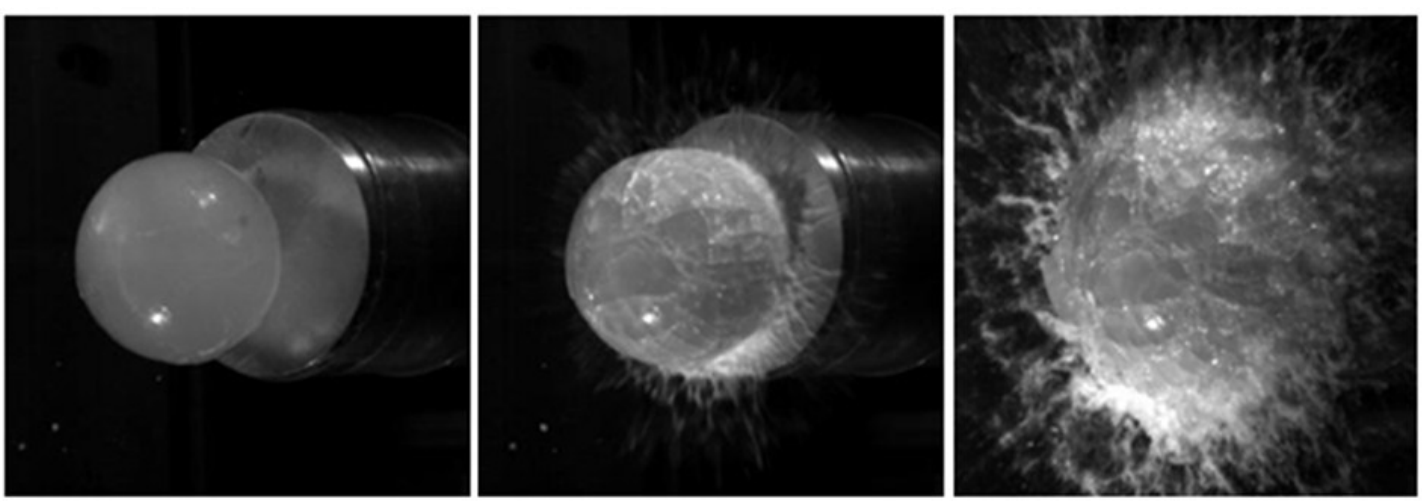

Figure 1: Ice deformation and breakage pattern [2]

"gluing" to other finite element meshes; provides the functionality to convert finite element meshes to particles based on various criteria, including stress/strain state, time and user defined criterion; and supports an extensive library of solid and fluid material models.

Analysis Approach

In this Technology Brief, a controlled ice impact experimental test [2] is reproduced numerically. The test configuration is shown in Figure 2.

Spherically shaped ice particles are fired from a gas gun against a measuring plate which records the time history of the forces generated by the impact. The ice particle is 50.8 mm in diameter with an initial velocity of 60 m/s.

The ice particle is modeled as a 3D sphere (Figure 3). A rate dependent plasticity model is used for the ice constitutive behavior, and a tensile failure criteria is included to allow for fragmentation. The ice material properties are defined with the parameters specified in [2]. The target is modeled as a rigid body constrained in all 6 degrees of freedom, and the reaction forces are measured at the reference node.

A very convenient Abaqus/CAE feature to convert regular finite element meshes to particles has been leveraged for this study. In general, the finite element to particle conversion can be based on a number of criteria, including time, stress, strain, and user defined. This capability speeds the model building process by converting a part initially defined with a finite element mesh to particles at time t = 0. This feature can also be used to convert regular finite elements to particles when they are no longer capable of carrying load without excessive distortion.

Results and Conclusion

The reaction force time history from the simulation compares well with experimental data, as shown in Figures 4 and 5. Figure 6 compares the predicted and recorded deformation states at different time frames and shows that the simulation is able to predict the longitudinal crack patterns consistent with experimental observations.

These results demonstrate that the SPH functionality in Abaqus/Explicit can be leveraged in numerical simulations of ice impact with no inherent restrictions due to mesh distortions and extreme deformations.

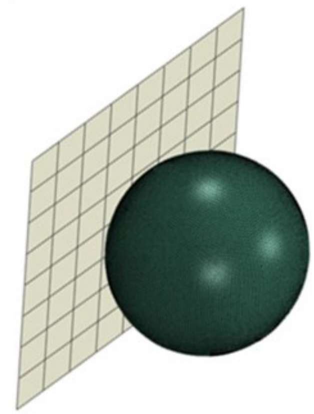

Figure 3: Abaqus/CAE geometry

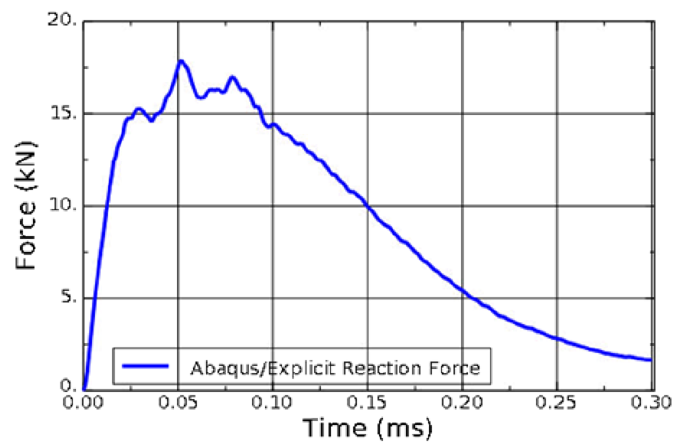

Figure 4: Abaqus/Explicit prediction of ice impact force

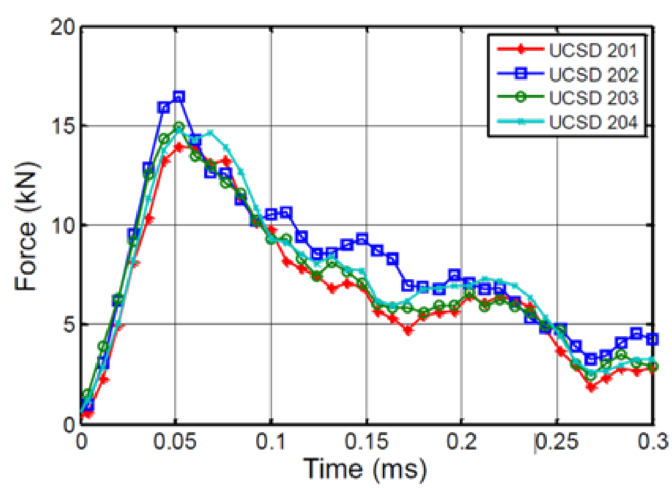

Figure 5: Experimentally measured ice impact force, velocities ranging from 59.3 to 62.6 m/s [2]

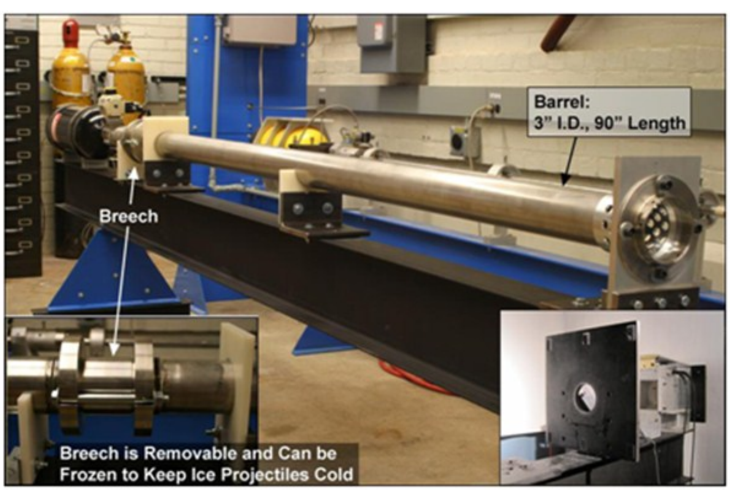

Figure 2: Experimental setup [2]

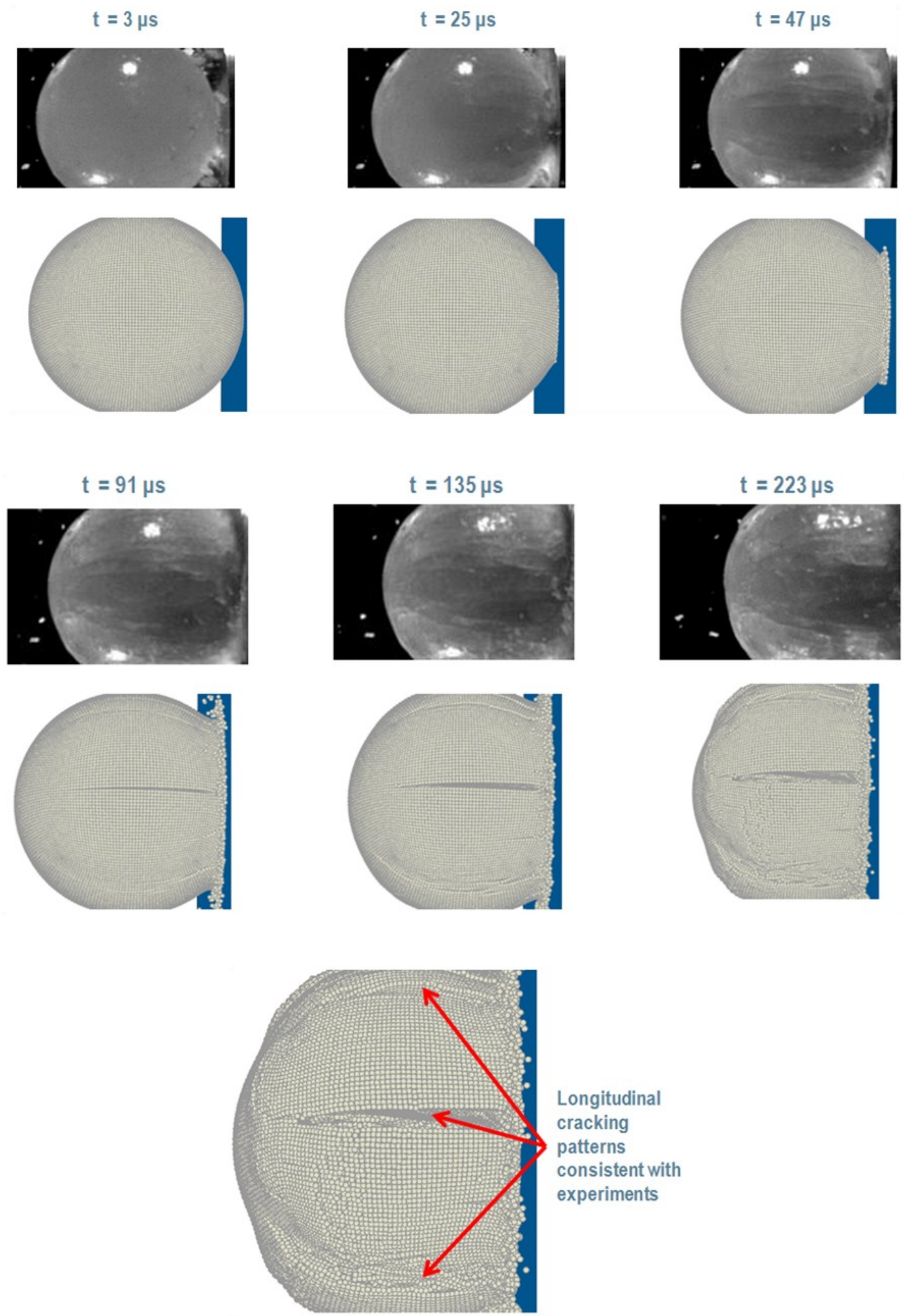

Figure 6: Comparison of ice particle deformation. Experimental photos courtesy [2]

Acknowledgement

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References

1. Kim, H., and J. N. Kuene, "Compressive Strength of Ice at Impact Strain Rates," Journal of Material Science, Vol. 42, pp. 2802-2806, 2007.
2. Jeffery Dwayne Tippmann, 'Development of a Strain Rate Sensitive Ice Material Model for Hail Ice Impact Simulation, MSc Thesis, University of California, San Diego, 2011.
3. Munjiza, A., and K. R. F. Andrews, "NBS Contact Detection Algorithm for Bodies of Similar Size," International Journal for Numerical Methods in Engineering, Vol. 43, pp. 131-149,1998.
4. Monaghan, J., "Smoothed Particle Hydrodynamics," Annual Review of Astronomy and Astrophysics, Vol. 30, pp. 543-574,1992.
5. Libersky, L.D., P. W. Randles, T.C. Carney, and D.L. Dickinson, 'Recent Improvements in SPH Modeling of Hypervelocity Impact,' International Journal of Impact Engineering, Vol. 20, pp. 525-532, 1997.

SIMULIA References

For additional information on the Abaqus capabilities referred to in this document please see the following Abaqus 6.13 documentation references:

- Analysis User's Guide
  - 'Smoothed Particle Hydrodynamic Analysis,' Section 15.2.1
  - 'Finite Element Conversion to SPH Particles,' Section 15.2.2
  - 'Particle Elements,' Section 33
  - 'Defining General Contact Interactions,' Section 36.5.1

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