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High velocity impact modelling of ice into ice: application to outer Solar System landers and penetrators

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Abstract

We present a new, robust, material model (incorporated within ANSYS AUTODYN) for water ice which successfully models impacts at velocities up to 1 km s^{-1}. This work forms part of an ongoing programme aiming to provide a validated hydrocode model for ice which will give us the ability to predict the kinematics of a wide range of impact events in the solar system. The material model operates within thermodynamic and kinetic constraints, so that material damage for ice can be closely correlated, and validated, between simulated and experimental results. This is a core requirement for technology development programmes aimed at future space mission encounters with icy planetary surfaces, including robotic penetrators and landers. Such payloads include the recently proposed penetrator for the Jupiter-Ganymede Orbiter (JGO) and/or Jupiter-Europa Orbiter (JEO) onboard the Europa-Jupiter System Mission (EJSM). Here we present the results of modelling of high velocity impacts into ice using ANSYS AUTODYN (in 2D and 3D) using the SPH solver. These results agree with available data from impact cratering and collisional disruption experiments.

1. Introduction

In order to better understand impact cratering and fragmentation processes on icy bodies made by hypervelocity micrometeoroids, small or large scale impact cratering, or collisional disruption, it is important to understand the behaviour of water ice when exposed to high strain-rate impact damage. However, even pure water ice under terrestrial conditions is difficult to simulate (in impact models) and, to-date, there is no coherent, complete, or satisfactory material water ice model. It is difficult to create a general strength model for water ice, since its behaviour is governed by a large number of parameters and environmental conditions (i.e., it's purity, physical temperature, porosity etc.). The material model for water ice presented here has been derived from high strain rate data (similar to the strain rates experienced during high velocity impacts) for polycrystalline water ice at temperatures between -10^{o}C and -20^{o}C, and it complements recently published material models for high velocity impact modelling into icy surfaces [1], [2], [3].

2. Water ice material model

The material model for water ice is composed of a polynomial Mie-Gruneisen EoS and a constitutive model derived from available high strain-rate data. It also takes into account as many material properties as possible, such as grain size distribution and temperature. A full description of the derivation of the ice strength model is found in [4]. At high strain rates ice is brittle [5] and therefore we use a simplified Johnson-Cook strength model which is a function of the quasi-static yield strength (54 MPa [6], [7]) and normalized effective strain-rate [8] only. Tensile crack softening is modelled using a Rankine plasticity model for brittle materials [9], with a failure stress of 8 MPa [10] and a fracture energy of 15 J m^{-2} [11].

3. Modelling results

We model ice impact experiments (in 2D and 3D) for impact velocities up to ~1 km s^{-1} and the results (Figures 1 and 2) agree with the experimental results presented in [12], [13], [14] to within 10 %.

4. Application to the penetrators

A penetrator payload has been proposed for the forthcoming EJSM mission for JEO and/or JGO [15]. Modelling of a penetrator impact into an icy surface using the presented ice model provides valuable insight into the final penetrator depth as well as the cratering morphology and the degree of damage in the vicinity of the penetrator. This modelling supports a positive outcome for the survivability of both the penetrator and the communication system.

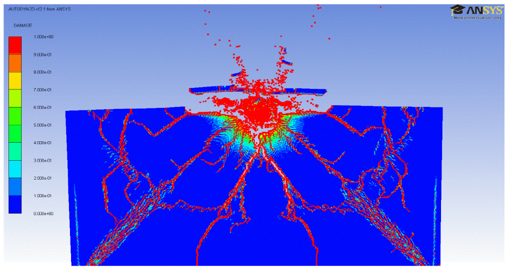

Figure 1. Cratering of a pollycrystalline icy projectile, Ø15 mm and 10 mm long into a large ice target at 388 m s^{-1}. Contours show magnitude of the damage. D_{crater}=86 mm, D_{spall}=162 mm, D_{pit}=31 mm, H_{pit}=31 mm, $H_{terrace}$=10 mm. (D=diameter, H=depth)

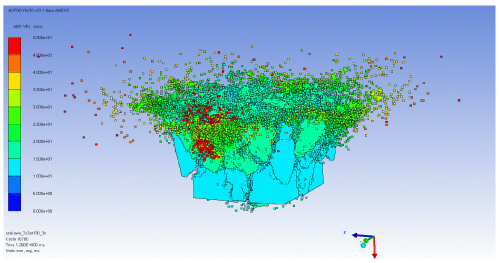

Figure 2. Collisional disruption of Ø15 mm and 15 mm long cylindrical ice projectile into a 30x30x30 mm ice block at 100 m s^{-1}. The colours represent absolute velocity of the material. $V_{antipodal}$=15 m s^{-1}.

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References

[1] Senft, L. E. and Stewart, S. T.: Modeling the morphological diversity of impact craters on icy satellites by, Icarus, 2009, in revision.

[2] Sherburn, J. A. and Horstemeyer, M. F.: Hydrodynamic modeling of impact craters in ice, IJIE, 37(1), 27-36, 2009.

[3] Wei, Z. Gang, W., Zhong-Cheng, M. and Chang, L.: Numerical simulation on the damage characteristics of ice targets by projectile hypervelocity impact, SCCM, 28 June – 3 July, 2009, Nashville, USA, 2009.

[4] Miljković, K., Jones, A., Price, M. C.: High velocity impact modelling into ice in AUTODYN: application to outer Solar System landers and penetrators, IJIE, 2010, submitted.

[5] Carney, K.S., Benson, D. J., DuBois, P. Lee, R.: A phenomenological high strain rate model with failure for ice, Int J Solids Struct, 43, 7820-7839, 2006.

[6] Rist, M. A. and Murrell, S. A. F.: Ice triaxial deformation and fracture, J. of Glaciology, 40, 135, 305 – 318, 1994.

[7] Shazly, M., Prakash, V., Lerch, B.A.: High strain-rate behavior of ice under uniaxial compression, Int. J. Solids Struct. 46, 1499–1515, 2009.

[8] Kim, H. and Keune, J. N.: Compressive strength of ice at impact strain rates, J Mater Sci, 42, 2802–2806, 2007.

[9] Clegg, R. A, Hayhurst, C. J., Robertson, I.: Development and application of a Rankine plasticity model for improved prediction of tensile cracking in ceramic and concrete materials under iompact, 14th DYMAT, November 14-15, 2002, Sevilla, Spain, 2002.

[10] Stewart, S. T. and Ahrens, T. J.: Correction to the dynamic tensile strength of ice and ice-silicate mixtures (Lange and Ahrens, 1983), LPSC XXX, 15-19 March, 1999, Houston, USA, 1999.

[11] Dempsey, J. P., Adamson, R. M., Mulmule, S. V.: Scale effects on the in-situ tensile strength and fracture of ice. Part II: First-year sea ice at Resolute, N.W.T., Int J. Fracture, 95, 347–366, 1999.

[12] Kato, M., Iijima, Y.-I., M. Arakawa, Y. Okimura, A. Fujimura, N. Maeno, H. Mizutani: Ice-on-Ice Impact Experiments, Icarus, 113, 2, 423-441, 1995.

[13] Shrine, N.R.G., Burchell, M.J. and Grey, I.D.S: Velocity Scaling of Impact Craters in Water Ice over the Range 1 to 7.3 km s−1, Icarus, 155, 2, 475 – 485, 2002.

[14] Arakawa, M. Maeno, N., Higa, M. Iijima, Y.-I., Kato, M.: Ejection Velocity of Ice Impact Fragments, Icarus, 118, 2, 341-354, 1995.

[15] Gowen, R. et al.: An update on penetrarors for Ganymede and Europa EJSM 3rd Workshop, ESTEC 18-20 January, 2010.