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Stardust interstellar dust calibration: modelling impacts on Al-1100 foil at velocities up to 300 km s^{-1}.

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Abstract

We present our initial results from hydrocode modelling of impacts on Al-1100 foils, undertaken to aid the interstellar preliminary examination (ISPE) phase for the NASA *Stardust* mission interstellar dust collector tray [1]. We used *Ansys Autodyn* [2] to model impacts of a 1 µm diameter glass sphere into *Stardust* foil (100 µm thick Al-1100) at velocities up to 300 km s^{-1}. It is thought that impacts onto the interstellar dust collector foils may have been made by a combination of interstellar dust particles (ISP) [3], interplanetary dust particles (IDP) on comet- and asteroid-derived orbits, β micrometeoroids, nanometer dust in the solar wind [4] and secondary ejecta from the spacecraft [5]. The characteristic velocity of the potential impactors thus ranges from a few km s^{-1} (for secondary ejecta), perhaps ~ 20 to 70 km s^{-1} for ISP and IDP [6], up to hundreds of km s^{-1} for the nanoscale dust accelerated by the solar wind [4]. There are currently no extensive experimental calibrations for the higher velocity conditions, and the main focus of this work was therefore to use hydrocode models to investigate morphometry of craters, as a means to determine an approximate impactor speed.

1. Al-1100 strength model

A Cowper-Symonds [7] strength model and a Mie-Gruneisen equation-of-state (EoS) were used as material parameters for the Al-1100 target. This strength model enables the modelling of the effects of the very high strain rates (>>10^8 s^{-1}) present during the impact. A 2-D 300 (y) × 200 (x) cell half-space Lagrangian mesh was used to model the target. The mesh was graduated so as to give a high resolution (cell size = 0.05 × projectile radius) at the impact region. Shock transmission boundaries were placed on the edges of the target to emulate a semi-infinite target. To account for melting of the target material we used a modified version of the Cowper-Symonds equation which incorporates a thermal softening term, α:

$$Y = Y_o\left(1+\left(\frac{\dot{\varepsilon}}{D}\right)^{\frac{1}{q}}\right)\cdot\alpha \quad , \qquad (1)$$

where Y_o is the quasi-static yield strength (50 MPa), $\dot{\varepsilon}$ is the strain rate (s^{-1}), D and q are constants controlling the strain-rate dependence and have values of 3.4 x 10^4 s^{-1} and 1.0 respectively. α is the thermal softening term:

$$\alpha = \left(1-\left(\frac{T-T_a}{T_m-T_a}\right)\right)\ [\alpha = 0, \quad T > T_m], \qquad (2)$$

where T is the physical temperature (K) and T_a is the ambient temperature (K). T_m is the melting point (K) given by [8]:

$$T_m = T_{m0}\left(\frac{P}{6.049}+1\right)^{0.531}, \qquad (3)$$

where P is the pressure (GPa), T_{m0} is the melting point under STP (993 K), and T_m is the pressure dependent melting point. Note that α was constrained between 0 and 1, and the yield strength, Y, was capped to a maximum value of 5 GPa [9].

2. Results

Figure 1 shows crater formation from a 1 µm diameter sphere impacting the Al-1100 target at 6.1 km s^{-1}. The red region indicates molten aluminium which has a yield strength of zero. Note the ejection of target material out of the crater.

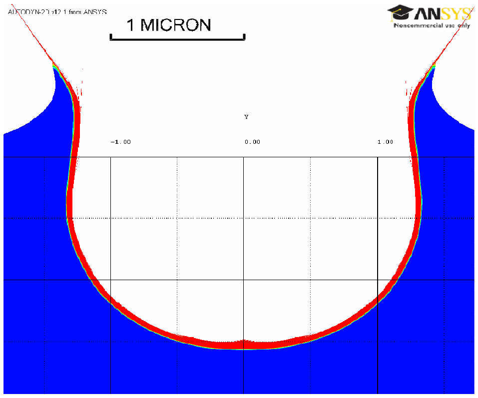

Fig 1: *Autodyn* simulation of a 1 µm diameter glass sphere impacting Al-1100 at 6.1 km s^{-1}, 10 ns after initial impact contact. The red region illustrates where the aluminium is in a molten state.

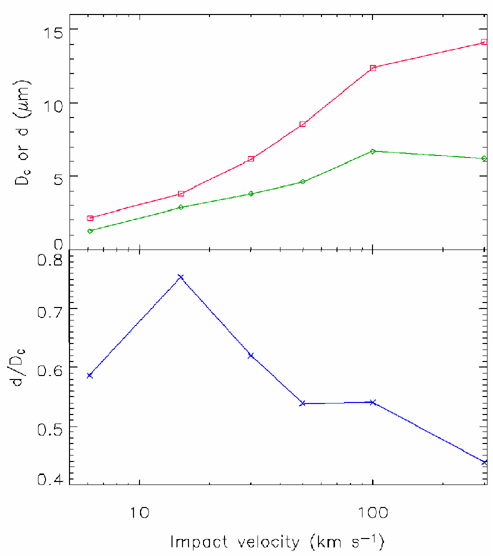

Fig 2: Upper plot: crater diameter D_c (red line, square symbols) and crater depth d (lower green line, diamond symbols) vs. impact velocity. Lower plot: d/D_c vs. impact velocity.

Figure 2 shows the modelled crater diameter, D_c and depth, d, as a function of impactor velocity (upper plot) and the depth-to-diameter ratio (lower plot). As the impact velocity increases the diameter/depth ratio changes with relatively shallower craters at higher velocities (due to the increased amount of target melt) with a predicted maximum at ~15 km s^{-1}.

4. Discussion

Using a new strength model for Al-1100 we have modelled the crater dimensions of a 1 µm glass sphere impacting at velocities between 6 – 300 km s^{-1}. The modelling indicates that the depth/crater diameter ratio may be a useful metric from which the impact velocity can be derived (assuming that the density of the impactor can be inferred from other analysis techniques). This inferred velocity can then be used to determine the origin of the impactor; a interstellar particle with an estimated velocity of 20-30 km s^{-1}; a β-micrometeoroid with a velocity of several 10s of km s^{-1}; or a ultra-high velocity nanoparticle with a velocity of ~300 km s^{-1}. At the very highest velocities modelled here, it is probable that the strength model and EoS are inaccurate and that molecular dynamic simulations of nano-scale projectiles are a more appropriate tool, although they are necessarily size-limited by computational demand. Additionally, the results presented are for a *solid* impactor and it is likely that real impacts are from both solid particles and porous aggregates. Further modelling is ongoing in order to determine the effect of impactor porosity on crater morphology.

References

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