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Short communication

Investigation of granular impact using positron emission particle tracking

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ABSTRACT

We present results from an experimental study of granular impact using a combination of high-speed video and positron emission particle tracking (PEPT). The PEPT technique exploits the annihilation of photons from positron decay to determine the position of tracer particles either inside a small granular bed or attached to the object which impacts the bed. We use dense spheres as impactors and the granular beds are comprised of glass beads which are fluidised to achieve a range of different initial packing states. For the first time, we have simultaneously investigated both the trajectory of the sphere, the motion of particles in a 3-D granular bed and particles which jump into the resultant jet, which arises from the collapse of the cavity formed by the impacting sphere.

1. Introduction

Granular impact is a fundamentally important topic in many applications, especially crater formations, which are ubiquitous on the surface of planets. Such craters, formed in hypervelocity impacts can be scaled in a similar fashion to those seen in laboratory experiments, whereby the crater diameter scales with the impact energy to the power $\frac{1}{4}$, i.e., $D_{crater} \sim E^{1/4}$ [1].

Laboratory experiments invariably involve the impact of dense projectiles onto loosely packed, dry granular beds. In such circumstances, the initial stages of impact can exhibit fluid-like behaviour, in the form of an ejecta sheet [4,5], sinking into the loose bed [3,7] and eventually a jet, shown in Fig. 1, resulting from the hydrostatic collapse of the cavity behind the projectile [6,9,11].

The above-surface events are readily observed, whilst the subsurface motion of the projectile within the bed and the motion of the bed itself are more difficult features to capture. This has previously only been achieved for the projectile using a tether [3,13,14] or with the use of X-ray tomography [9,10]. In the latter, X-ray imaging allowed the determination of changes in local packing fractions. In this communication, we report the use of positron emission particle tracking (PEPT) in granular impact to simultaneously track the motion of the projectile within a granular bed and the motion of individual particles in the bed.

2. Experimental methods

The PEPT technique exploits the decay of a radioisotope, which is incorporated into a tracer particle. During the decay, a positron is emitted and annihilates with an electron thus releasing back-to-back gamma-rays. The gamma rays are detected using positron cameras and thus the location of the tracer particle can be triangulated to within approximately 2 mm at an acquisition rate of over 10 kHz (see [2,8]). The PEPT technique has been documented in many prior studies, including applications to granular flows (e.g., [12]). In our experiment, the tracer particles used were aluminium oxide particles with diameters approximately 100 μm, chosen to match the size of the glass beads used in the granular bed (75–125 μm). The beads were poured into a cylindrical container 7 cm in diameter, whilst the projectile, a steel sphere was 2 cm in diameter. Due to the geometrical constraints of the setup ($D_{cyl}/D_0 = 3.5$), there will be wall effects. However, as in previous work [4,5], this effect is constant throughout the experiments so that we can neglect this aspect in our analysis. Three reproducible packing fractions, $\phi \approx 0.55$, 0.60 and 0.62 were achieved in this study by first fluidising the entire bed, then reducing the inlet air flow to the desired level. The sphere was released using an electromagnet positioned directly above the centre of the granular bed. A tracer particle was attached to the top of the sphere using adhesive tape, whilst multiple tracers were also placed in the bed. As such, the initial location of the tracer particles in the bed was random. A typical impact event is shown in Fig. 1, taken from a high-speed video sequence. Both the ejecta and jet, which arise from the collapse of the cavity, are seen. The jet, in particular, is a feature we focus on herein.

3. Results

Fig. 2(a) plots sphere trajectories within the granular bed (outlined in blue) for three different packing fractions. The sphere was tracked from approximately 100 mm above the surface of the bed until it came to rest. The bottom of the line plots indicates where the sphere

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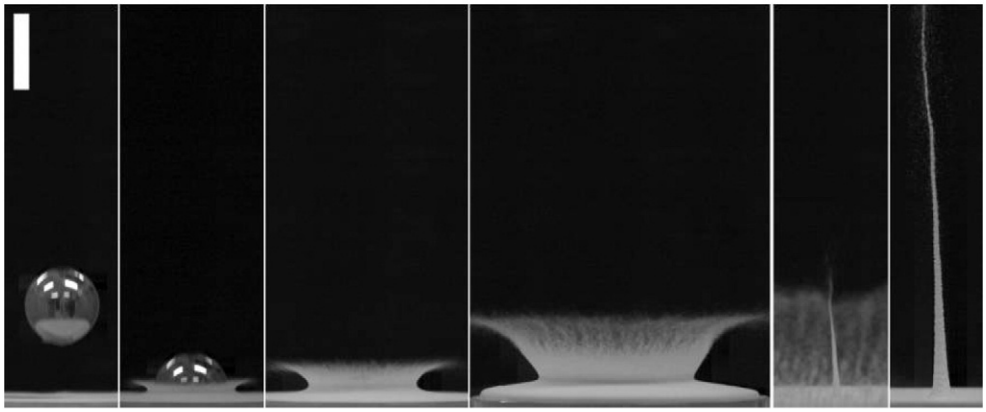

Fig. 1. Image sequence from a high-speed video clip of a 20 mm steel sphere impacting onto a bed of glass beads. The times from impact are $t = -10$, 5, 10, 30, 100 and 180 ms. The scale bar is 2 cm.

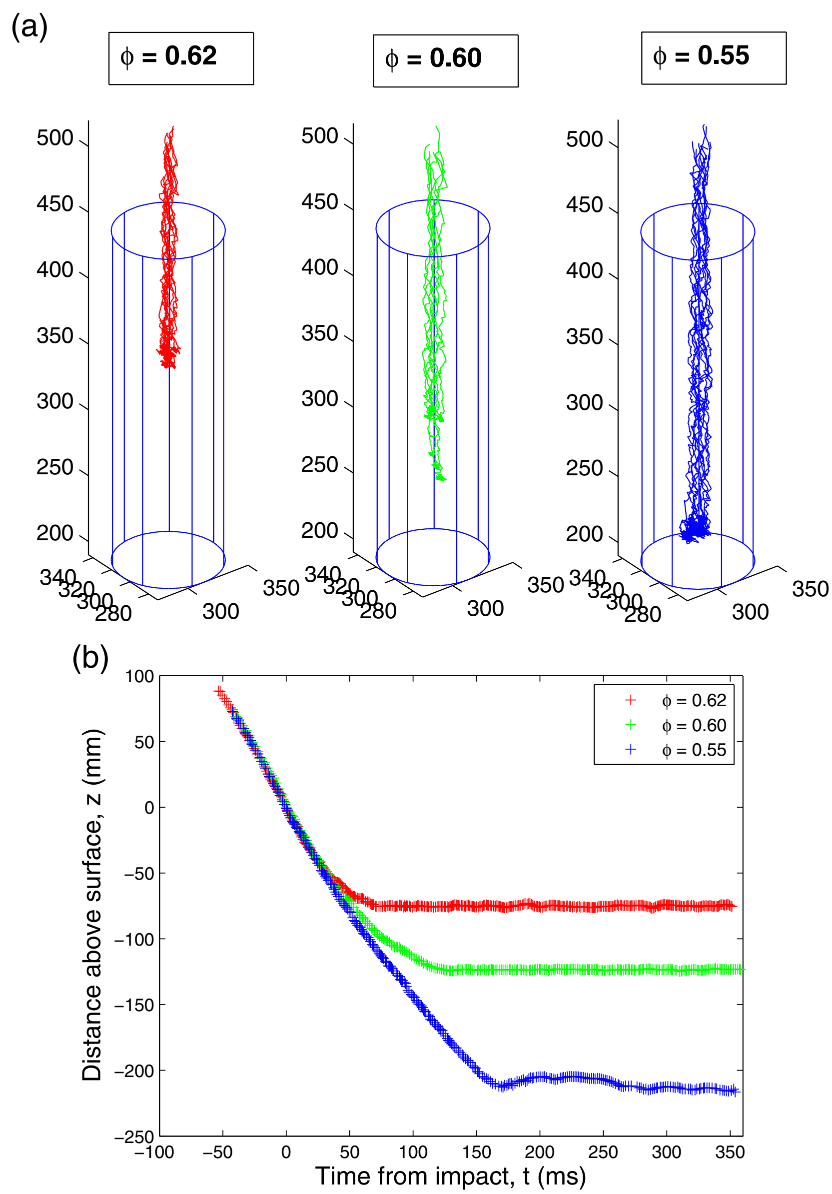

Fig. 2. (a) Ball trajectories determined by PEPT with the tracer particle attached to top of sphere. The three plots correspond to the three different initial bed conditions. The blue lines depict the edge of the cylinder filled with the granular media. (b) Depth of sphere centre vs. time curves for individual realisations from each of the three initial bed conditions. The blue data points, for the lowest packing fraction, show that the ball hits the bottom of the cylinder and exhibits a small bounce. In all cases $V_0 = 1.81$ m/s, $D_0 = 20$ mm, $Fr = 34$.