ABSTRACT

Powders are critical to manufacturing and synthesis processes across the chemical, pharmaceutical, food, and consumer-products industries. Many powders feature cohesive properties, and when stored in hoppers and silos, they consolidate over time, progressively increasing bed strength and reducing flowability. The resulting flow obstructions: arching, ratholing, and incomplete discharge cause costly production downtime. Wall-parallel air injection devices are flow aids that deliver bursts of pressurized air along vessel walls to reinitiate flow. Despite widespread industrial use, the mechanism by which delivered pulses alter the strength state of a consolidated powder bed has not yet been characterized. In this work, a ball indentation hardness method was adapted to spatially map hardness across large-scale consolidated powder beds using low-cost instrumentation, and its repeatability was assessed. A prilled paraffin wax served as a surrogate for proprietary industrial powders and was consolidated under loads from 0 to 11.5 kPa for times from 0 to 24 hours. Calibration testing established a density-hardness relationship consistent with published compaction models, supporting the full-scale measurements. Tracer visualization of unconsolidated beds revealed a deformation front suggestive of classical shear-failure geometry, while hardness mapping of consolidated beds after being pulsed showed spatially nonuniform softening concentrated near the free surface, with the mean bed hardness reduced by roughly half after a pulse cycle. These observations motivate a proposed flow-initiation mechanism driven by stress-wave propagation through the interparticle contact network. A finite element framework using the Drucker-Prager Cap constitutive model was developed to support future simulation of air pulse boundary conditions. The characterization methods and proposed mechanisms presented in this work provide a foundation for future predictive modeling of air injection flow aids, though full computation validation remains as future work.