Ultimate strength of a colloidal packing saturated with a solvent

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The consolidation of colloidal particles in drying colloidal dispersions is influenced by various factors such as particle size and shape, and inter-particle potential. The capillary pressure induced by the menisci, formed between the top layer of particles in the packed bed, compresses the bed of particles while the constraints imposed by the boundaries result in tensile stresses in the packing. Presence of flaws or defects in the bed determines its ultimate strength under such circumstances. In this study, we determine the asymptotic stress distribution around a flaw in a two dimensional colloidal packing saturated with liquid and compare the results with those obtained from the full numerical solution of the problem. Using the Griffiths criterion for equilibrium cracks, we relate the critical capillary pressure at equilibrium to the crack size and the mechanical properties of the packed bed. The analysis also gives the maximum allowable flaw size for obtaining a crack free packing.

Experiments performed to test the above predictions show that the stress required to fracture a cylindrical colloidal packing saturated with solvent under axial tension varies inversely with the three-half powers of the diameter. The predicted critical stress required to initiate cracks from flaws shows the same scaling with flaw size. Close inspection of the failed sections of the packing revealed flaws entrapped during the drying process. The maximum capillary pressure sets the critical flaw size below which the crack will not nucleate, thereby giving the ultimate strength of the colloidal packing. The experiments show that if the flaw size can be restricted below the critical value, large colloidal packings free of cracks can be synthesized.

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