SOFT MATTER

Brittle for breakfast

Crushing a brittle porous medium such as a box of cereal causes the grains to break up and rearrange themselves. A lattice spring model based on simple physical assumptions gives rise to behaviours that are complex enough to reproduce diverse compaction patterns.

Nicolas Vandewalle

Cereal is a breakfast staple, but it also harbours some interesting physics. Inside the box, ingredient number one is air: cereal granulates form packings containing voids of various sizes. Compressing the box can make for a denser packing, but the flakes simply break when pressed together, rather than rearranging to fill the voids. Writing in *Nature Physics*, François Guillard and colleagues[1] have rationalized the spectacular compaction behaviours of this class of soft material — providing a complete picture of the dynamics of heterogeneous structures appearing in puffed-rice packs (pictured).

Cereal flakes are a good example of a brittle porous medium: a system containing particles that tend to break under compression instead of rearranging. Cohesive powder agglomerates, snow and foams all fall into the same class. Understanding the physics behind their random packing equilibrium has a long history[2], dating back to the seminal works of John Bernal[3]. For rigid objects, compaction experiments have provided evidence for hidden heterogeneous structures in random packings: force chains that can span anywhere from a few grains to the entire pile. These chains are at the origin of the jamming of granular flows through a bottleneck[4], and they explain why removing some carefully chosen grains can leave the stability of a granular heap unaffected. We know now that heterogeneity is the rule for granular materials.

Much less, however, is known about brittle grains. But it seems that the same rule applies: dynamical heterogeneities are indeed observed when the system is crushed. Compaction bands have been observed, in which the material experiences high volumetric strain rates accommodated by severe grain breakage and pore collapse[1]. These bands reveal the complex nature of these soft materials. More importantly, this behaviour may have major consequences in industries that manipulate products such as flakes, powders and grains. For example, compaction band structures should be avoided as much as possible in pharmaceutical powder systems requiring a homogeneous composition.

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Guillard *et al.*[1] provided experimental evidence confirming earlier reports of propagating compaction bands in puffed rice[5]. They showed that, when brittle soft matter is pressed, three different compaction patterns can be obtained depending on the experimental conditions. Erratic compaction bands were found when the system was crushed slowly, suggesting that the heterogeneities appeared and disappeared randomly in the system. For intermediate crushing speeds, oscillatory propagating compaction bands were found. These bands seemed to propagate from the bottom to the top of the container, in response to pressure applied by a piston moving downwards from the top. For higher speeds, densification was almost homogeneous. All three dynamical compaction behaviours have also been found in other systems[5] belonging to this class of soft material. For example, oscillatory patterns have been discovered in powder flows[6] and in snow[7].

The authors proposed a lattice of springs to describe a brittle porous medium[1]. In their toy model, each spring was able to break several times at specific thresholds, mimicking the multiple breaking events of the porous medium during loading — and giving rise to propagating bands. Although it was based on simple physical assumptions, the numerical model successfully reproduced all compaction patterns. This is a remarkable achievement that could serve as a basis for more elaborate models dedicated to applications and other materials. Other conditions should be investigated, such as flows through a bottleneck close to jamming — a situation often encountered in powder systems.

From their numerical simulation results and experimental evidence, Guillard *et al.*[1] were able to map all compaction behaviours in a single phase diagram using only two dimensionless numbers. The phase variables were the ratios of elastic and breakage characteristic times, and dissipation and breakage times. Elastic and dissipation characteristic times were already relevant for describing classical granular materials. By introducing short breakage times, the authors succeeded in reproducing compaction bands and the formation of various dynamical patterns. Rationalizing the wide variety of compaction patterns in a single diagram represents real progress towards a better understanding of crunchy matter.

There is little doubt that these ideas will inspire new research into brittle soft matter. We are yet to understand flow regimes, packing structures and segregation patterns in these systems. And this future exploration will perhaps change the way we think about the crispy flakes featured on our breakfast table. ❐

Nicolas Vandewalle is in the Department of Physics, University of Liege, 4000 Liege, Belgium.
e-mail: nvandewalle@ulg.ac.be

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