Rheology, Amorphous materials

Universality in the physics of jamming

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Abstract

We performed computer simulations to compress and shear glassy states of hard-spheres, which is the simplest glass. As the result we succeeded to generate a large number of jammed states with various densities and degree of anisotropy (Fig 1). We found the diverse jammed states are all marginally stable in the mechanical sense and exhibit universal criticalities. For instance, the number of surrounding particles at a distance r from a given particle shows a universal behavior independent of the jamming density ϕ j. From the left panel, we find that the average contact number is 6 meaning that the jammed states are just marginally stable. From the right panel we find the number of particles almost in contact obeys a power law with a universal exponent meaning that the system is in a critical state. The results of this work will promote basic understanding of the physics of glasses, which is far less well understood compared with that of crystals.

Background & Results

Historically it has been discussed for a long time how one can pack spheres most densely in a box. In 17 century J. Keppler predicted that the close packing or densest packing in 3 dimensions is the face-centered cubic (FCC) lattice. Only 400 years later this conjecture was proved to be true by Thomas Hale in 1998. The volume fraction of the close packing is 0.74048... Quite a different packing, called random close packing, was studied by J. Bernard and J. Mason experimentally in 1960 who found spheres randomly packed typically have volume fraction around 0.64. Later it was discovered that jammed states created by random packing can have various volume fractions depending for instance on the ways to prepare the initial configurations before compression. Jamming is an important phenomenon that controls the mechanical properties of various soft matters used in our daily like mayonnaise, toothpastes, e.t.c.

We found various jammed configurations can be generated not only by compression but also by putting shear on the container performing extensive numerical simulations of hard-sphere glasses by supercomputers. Shear-jamming has been known for the case of spheres with frictions but we showed the friction is not necessary. Moreover, we found the jammed states created by various different combinations of compression and shear all exhibit universal features as shown in Fig. 2: the average contact number is 6 (left), physical quantities exhibit universal critical phenomena (right). These features are very different from those of close packing: the contact number is 12, the configuration is unique and mechanically very stable.

Significance of the research and Future perspective

Our achievement will promote progress on the physics of glasses which is far less well understood compared with that of crystals.

Our result will be useful to control soft-matters commonly found in our daily life and industrial products.

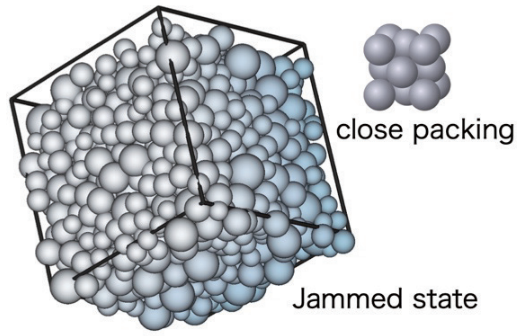

Fig. 1 Hard-sphere glass at a high density close to jamming density

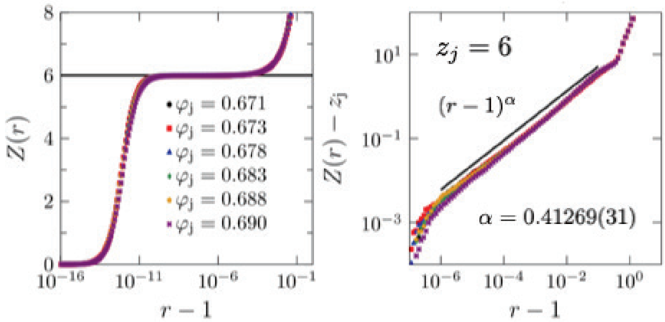

Fig. 2 Average number of particles at distance r from a particle

Patent
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