The mysteries of sand

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Playing with sand is normally a pastime for children on the beach. But physicists who have the same curiosity as children from all over the world and who rack their brains to unveil its mysteries, can also have fun with a handful of sand – and discover interesting phenomena. An example is the recently published work of a Brazilian researcher, carried out in a partnership with two Germans. The trio identified behavior in grains of sand that had as yet not been described and is only observed when the grains are shaken horizontally: the expansion and repeated collapse of the group of grains.

Sand, like other granular materials, exercises an almost hypnotic power over people. Formed by grains in a solid state, these materials sometimes behave as a solid and sometimes as a liquid – without the grains undergoing any change in their physical state. It is difficult not to be intrigued when you fill your hand with sand and watch it run through your fingers like water or see it behave like a solid material when you walk on it. "Explaining this behavior has been a problem for 200 years," says Jason Gallas, a physicist from the Federal University of Rio Grande do Sul and from the Federal University of Paraiba, who took part in the study. "Michael Faraday, better known for his work on electro-magnetism, also did experiments with granular materials." In his tests the English physician asked himself: how to characterize when granular materials behave like solids and when they act like fluids, flowing in an hourglass, for example?

Gallas and his colleagues, Thorsten Pöschel and Dirk Rosenkranz, from the Friedrich-Alexander University in Erlangen, Germany, were not working specifically on the problem that tormented Faraday. However, they discovered something that in the future may generate applications for the engineering of sophisticated materials. In a fairly simple experiment they placed granular material (quartz grains of aluminum oxide and ferrous oxide) on an acrylic tray that was shaken at different frequencies and widths under computer control. And then they watched what happened.

Shaken horizontally at 22 to 29 times a second, the grains moved, sank down close to the edges of the container and emerged in the central region. As the grains moved, the whole mass expanded slowly and occupied a greater volume in the central area of the tray and then collapsed abruptly and returned to their original volume.

What was difficult was interpreting what had happened. As the flow of grains is constant, the volume should also be, since the amount of sand that sank at the edges is the same that came to the surface in the central area.

Almost a vacuum

The first explanation that comes to mind is that as the grains move air accumulates below them and causes the expansion. But the researchers confirmed that this is not necessarily so. They repeated the experiments in a low pressure environment (almost a vacuum) and the result was the same. "If the air contributes anything to the effect it's very small," says Gallas.

The group has an hypothesis for explaining what happens, linked to a phenomenon called Reynolds dilation. Described by Osborne Reynolds in 1885, it helps explain the tendency of granular materials to expand in volume as a consequence of the rearrangement of the grains. "Roughly speaking we can think in terms of old stone bridges over rivers," is the example Gallas gives.

Just as these constructions had pillars linked by stone arches as their bases, it is imagined that the movement of the grains manages a three-dimensional restructuring of the material, which creates something similar to the arches and opens voids between the particles. However, with the accumulation of more and more grains the structure collapses and becomes compact.

A way of testing the hypothesis would be to conduct computer simulations showing in silico the effects observed. But, although Thorsten and Gallas are specialists in simulations there is no prospect of carrying them out immediately. Despite being a simple experiment, to carry out virtual simulations in three dimensions would be too complicated because it involves a large number of particles.

"This article is one of the highlights of our recent research," comments Pöschel, who heads up a group of granular material studies in Germany. In fact, it took more than 15 years from the first observation of the effect to publication. One of the reasons is that the researcher from Pöschel's group who started the experiment arranged another job and left the team. "We only returned to it now," says Gallas, who spent nine months in Erlangen working on the problem.

Gallas emphasizes that the interest of the group is basic science: helping to understand the complex phenomena of granular materials. But he points out that the research may generate applications in the future. Materials engineering would benefit a lot, especially in areas like the manufacture of ultra-hard ceramics, which involves compacting and processing grains. Understanding how the grains of the raw material behave may help compact the material to improve the quality of the product.

The same goes for the CD and DVD industry. The discs are made from granular plastic material. However, the manufacturing process is imperfect. "Typically there may be losses of up to 30% in the industrial manufacturing process of these objects. That's a lot," says Gallas, emphasizing that the way to improve these numbers is to understand the subtleties of the phenomena involved.

He and his colleagues are enthusiastic about the new effect, which is very pronounced in the movement of the grains, but even so still unknown. But they recognize that they are far from understanding it fully; not to mention other phenomena that may be discovered, as new studies are undertaken. "This is just the beginning," says the Brazilian.

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