The secret of nanoparticle packing in cement

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Cement production is responsible for 5% of carbon dioxide emissions. If we are to invent a "green" cement, we need to understand in more detail the legendary qualities of traditional Portland cement. A research group partly financed by the Swiss National Science Foundation (SNSF) is tackling this task.

Discovering the perfect composition of Portland cement, the most common type of cement, was the result of years of experience as well as repeated trials and errors. Emanuela Del Gado, SNSF professor at the Institute for Building Materials of the ETH Zurich, explains that its success is the result of two key factors: its legendary hardness and the availability of its constituent elements.

5% of carbon dioxide emissions

The flipside of the coin: its production requires burning calcium carbonate. This process is responsible for approximately 5% of all carbon dioxide emissions or the equivalent of the entire 2007 emissions of India. But a more sustainable recipe for cement has to meet high standards both in terms of material hardness and accessibility to raw materials.

Because of the massive ecological impact of cement production, various research groups worldwide are trying to understand why the mixture of this powder and water sets to such hardness.

Different densities at the nano level

Researchers of the Massachussetts Institute of Technology (MIT) have concentrated on studying the behaviour of concrete at the nano level. In their experiments, they used an instrument capable of applying mechanical stress at the sub-micro level. As a result, they were able to show that densities vary strongly from one measuring point to the other at this scale. But they were not able to explain why.

This is where physicist Emanuela Del Gado enters the scene. She takes a special interest in amorphous materials whose constituents combine in a disorderly manner. Her studies of such materials focus on the nano level. "It is at this level and not at the atomic level that certain material properties are revealed. This also applies to hydrated calcium silicate, a major component of cement which plays an important role in the setting process," she explains.

Packing particles of different sizes

The researchers first developed a packing model of hydrated calcium silicate nanoparticles. They then devised a method for observing their precipitation based on numerical simulations. This approach has proven successful (*). "We were able to show that the different densities on the nano scale can be explained by the packing of nanoparticles of varying sizes. At this crucial level, the result is greater material hardness than if the particles were of the same size and it corresponds to the established knowledge that, at macroscopic level, aggregates of different sizes form a harder concrete."

Until today, all attempts to reduce or partially replace burnt calcium carbonate in the production of cement have resulted in less material hardness. By gaining a better understanding of the mechanisms at the nano level, it is possible to identify physical and chemical parameters and to improve the carbon footprint of concrete without reducing its hardness.

More information: E. Masoero, E. Del Gado, R. J.-M. Pellenq, F.-J. Ulm, and S. Yip (2012). Nanostructure and Nanomechanics of Cement: Polydisperse Colloidal Packing. *Physical Review Letters*. DOI: 10.1103/PhysRevLett.109.155503

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