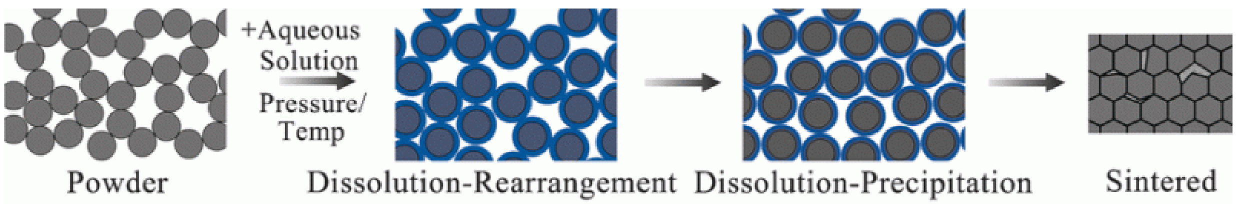
Cold sintering of ceramics instead of high-temperature firing

August 16 2016



Credit: Wiley

Both hobbyists' pottery and engineered high-performance ceramics are only useable after they are fired for hours at high temperatures, usually above 1000 °C. The sintering process that takes place causes the individual particles to "bake" together, making the material more compact and giving it the required properties, like mechanical strength.

In the journal *Angewandte Chemie*, American researchers have now demonstrated that sintering can also take place at significantly lower temperatures. This cold sintering process is based on the addition of small amounts of water to aid the key transport processes that densify the material.

"Since the stone age, ceramics have been fabricated by sintering at high temperatures," reports Clive A. Randall from Pennsylvania State University (USA). "This includes the Venus of Doli Vestonice, one of the oldest ceramic objects." The traditional firing process may now become unnecessary for many ceramic materials, because a broad spectrum of inorganic materials and composites can also be sintered between room temperature and 200 °C.

In conventional high-temperature sintering processes, individual ceramic powder particles densify into a hard, dense object. The driving force for this process is the reduction of the high surface free energy of the powder by material diffusion—a process that only occurs at high temperatures. "In contrast, cold sintering relies on interfacial solution effects in water for the densification of the material; a process that occurs at low temperatures and over much shorter time frames, minutes instead of hours, when pressure is applied," says Randall.

Small amounts of interfacial water serve as a transient liquid phase. The details vary for different systems, but for a number of ceramic materials the first step is dissolution of the sharp edges of the boundary surfaces between the particles, reducing the surface free energy of the powder. Then, under appropriate pressure and temperature combinations, the dissolved material diffuses through the liquid and preferentially precipitates away from the contact areas between the particles. This process closes the pores and makes the material more compact.

Says Randall: "Cold sintering functions for a broad palette of inorganic compounds, including metal oxides, carbonates, halides, phosphates, and multimaterial systems (composites). The properties of the cold sintered samples were equivalent to those sintered by conventional methods." The Penn State scientists examined the process in detail using sodium chloride, alkali molybdates, and vanadium oxide amongst other materials.

"Composites of ceramics with metals, polymers or other ceramics are in high demand, but because of their different thermal stabilities, shrinkage and possible chemical incompatibilities, systems made from different materials are not so easy to sinter at high temperatures," says Randall. "These problems are minimized in cold sintering and most importantly, this process opens exciting sustainable and low cost manufacturing possibilities for ceramics and their composites." Composites made by the cold sintering of ceramics with metals, polymers, or other ceramics should make it possible to develop new properties and materials systems for next-generation technologies.

More information: Jing Guo et al. Cold Sintering: A Paradigm Shift for Processing and Integration of Ceramics, *Angewandte Chemie International Edition* (2016). DOI: 10.1002/anie.201605443

Provided by Wiley