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Cold Sintering of Functional Materials

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The Cold Sintering Process (CSP) is a chemo-mechanical powder consolidation technique that enables the densification of ceramic powders into robust monoliths at ultra-low temperatures, typically below 300°C. It utilizes uniaxial force, and a transient fluid to facilitate such densification. CSP overcomes the limitations of conventional ceramic processing, which requires temperatures above 1000°C, enabling the creation of unique ceramic-polymer, ceramic-2D, ceramic-metal, and other nanocomposites with novel functionalities. CSP holds significant promise for energy reduction and decarbonization within the ceramics industry due to its lower processing temperatures. CSP has been utilized to engineer high functionality piezoelectric, dielectric, semiconductor, superconductor, thermoelectric, electrolyte, and electroactive materials.

Densification by CSP is enabled when the ceramics matrix is mixed with a compatible transient fluid which permits dissolution. When uniaxial force is applied, differences in pressure between highly stressed grain contacts and less stress pores create a chemical potential gradient, from differences in solubility within these regions to promote mass transport from grain contacts to porous regions. Thus, CSP details a 3-step densification process, involving 1. Dissolution of material at highly stressed grains, 2. Transport to less stressed pores, and 3. Reprecipitation in porous regions. This densification process is understood as a geological creep process observed within Earth's upper crust, pressure solution creep. However, in-situ dilatometry studies under isothermal and non-isothermal densification of various ceramic and composite systems have identified pressure exponentials, sintering exponentials, and activation energies, which suggest that not only is densification driven by a pressure solution creep mechanism, but there are additionally other secondary creep processes.

Herein we present the progress our group has made in understanding the fundamental creep processes driving densification, and the various ceramic and nanocomposite systems we have engineered, with the objective of accelerating the implementation of CSP into industry.

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