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Impact-activated solidification of dense suspensions

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Shear-thickening, non-Newtonian fluids have typically been investigated under steady-state conditions. This approach has produced two pictures for suspension response to imposed forcing. In the weak shear-thickening picture, the response is typically attributed to the hydrodynamic interactions giving rise to hydroclusters, small groups of particles interacting through lubrication forces. At the other end of the spectrum, in the discontinuous shear-thickening regime, the response can be seen as a system-wide jamming that is ultimately limited in strength by the system boundaries. While these steady-state pictures have proven extremely useful, some of the most interesting phenomena associated with dense suspensions is transient and local in character. A prototypical example is the extraordinarily large impact resistance of dense suspensions such as cornstarch and water. When poked lightly these materials respond like a fluid, but when punched or kicked they seem to temporarily "solidify" and provide enormous resistance to the motion of the impacting object. Using an array of experimental techniques, including high-speed video, embedded force and acceleration sensing, and x-ray imaging, we are able to investigate the dynamic details this process as it unfolds. We find that an impacting object drives the rapid growth of a jammed, solid-like region directly below the impact site. Being coupled to the surrounding fluid by grain-mediated lubrication forces, this creates substantial peripheral flow and ultimately leads to the sudden extraction of the impactor's momentum. With a simple jamming picture to describe the solidification and an added mass model to explain the force on the rod, we are able to predict the forces on the impactor quantitatively. These findings highlight the importance of the non-equilibrium character of dense suspensions near jamming and might serve as a bridge between the weak and discontinuous shear-thickening pictures.