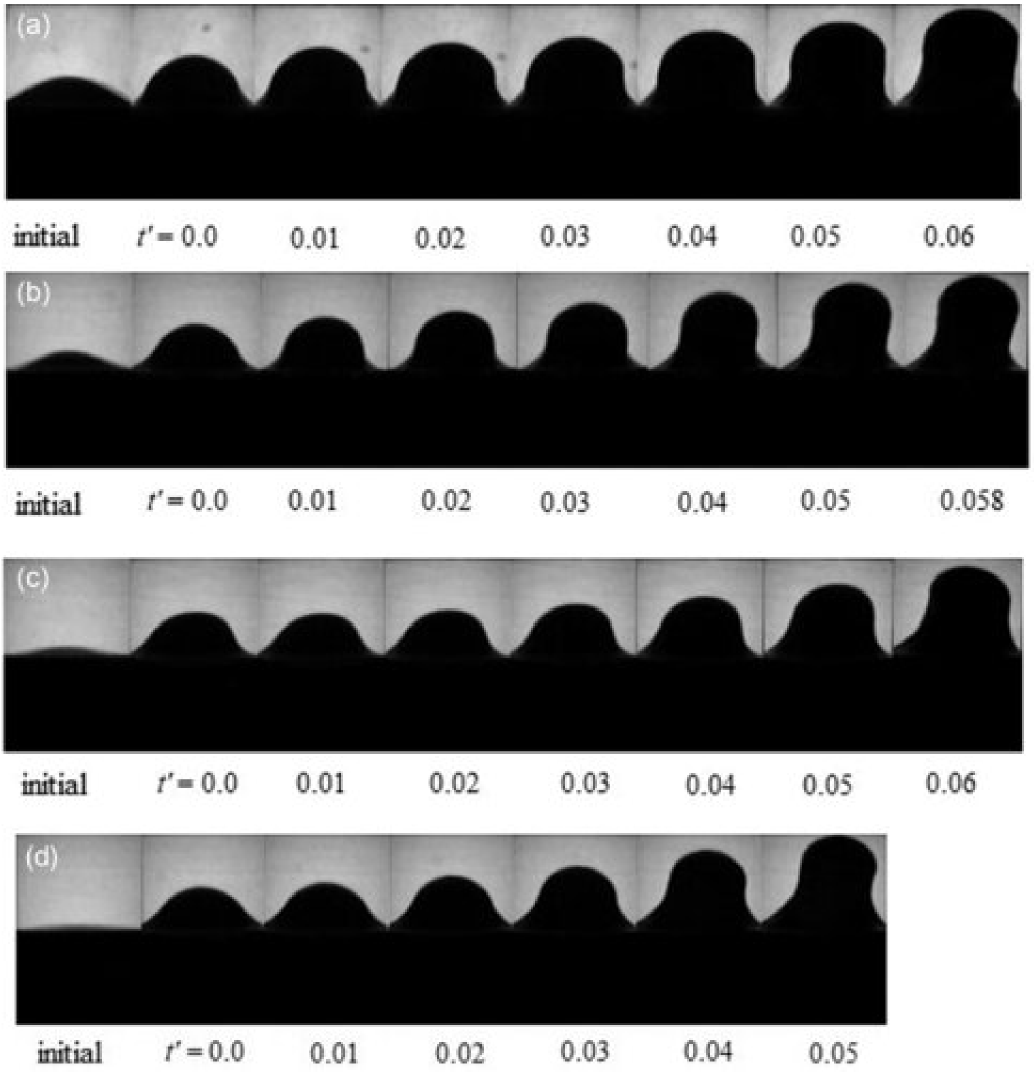
PHYS.ORG

Behold the mayo: Experiments reveal 'instability threshold' of elastic-plastic material

May 8 2019



Experimental images for 3D initial perturbation. Credit: Arindam Banerjee

Arindam Banerjee, an associate professor of mechanical engineering and mechanics at Lehigh University, studies the dynamics of materials in extreme environments. He and his team have built several devices to effectively investigate the dynamics of fluids and other materials under the influence of high acceleration and centrifugal force.

One area of interest is Rayleigh-Taylor instability, which occurs between materials of different densities when the density and pressure gradients are in opposite directions creating an unstable stratification.

"In the presence of gravity—or any accelerating field—the two materials penetrate one another like 'fingers,'" says Banerjee.

According to Banerjee, the understanding of the instability is mostly confined to fluids (liquids or gases). Not much is known about the evolution of the instability in accelerated solids. The short time scales and large measurement uncertainties of accelerated solids make investigating this kind of material very challenging.

Banerjee and his team have succeeded in characterizing the interface between an elastic-plastic material and a light material under acceleration. They discovered that the onset of the instability—or "instability threshold"—was related to the size of the amplitude (perturbation) and wavelength (distance between crests of a wave) applied. Their results showed that for both two dimensional and three dimensional perturbations (or motions) a decrease in initial amplitude and wavelength produced a more stable interface, thereby increasing the acceleration required for instability.

These results are described in a paper published today in *Physical Review E* called "Rayleigh-Taylor-instability experiments with elastic-plastic materials." In addition to Banerjee, co-authors include Rinosh Polavarapu (a current Ph.D. student) and Pamela Roach (a former M.S.

student) in Banerjee's group.

"There has been an ongoing debate in the scientific community about whether instability growth is a function of the initial conditions or a more local catastrophic process," says Banerjee. "Our experiments confirm the former conclusion: that interface growth is strongly dependent on the choice of initial conditions, such as amplitude and wavelength."

In the experiments. Hellman's Real Mayonnaise was poured into a Plexiglass container. Different wave-like perturbations were formed on the mayonnaise and the sample was then accelerated on a rotating wheel experiment. The growth of the material was tracked using a high-speed camera (500 fps). An image processing algorithm, written in Matlab, was then applied to compute various parameters associated with the instability. For the effect of amplitude, the initial conditions were ranged from w/60 to w/10 while the wavelength was varied from w/4 to w to study the effect of wavelength ("w" represents the size of the width of the container). Experimental growth rates for various wavelength and amplitude combinations were then compared to existing analytical models for such flows.

This work allows researchers to visualize both the elastic-plastic and instability evolution of the material while providing a useful database for development, validation, and verification of models of such flows, says Banerjee.

He adds that the new understanding of the "instability threshold" of elastic-plastic material under acceleration could be of value in helping to solve challenges in geophysics, astrophysics, industrial processes such as explosive welding, and high-energy density physics problems related to inertial confinement fusion.

Understanding the hydrodynamics of inertial confinement

Banerjee works on one of the most promising methods to achieve nuclear fusion called inertial confinement. In the U.S., the two major labs for this research are the National Ignition Facility at the Lawrence Livermore National Laboratory in Livermore, California—the largest operational inertial confinement fusion experiment in the U.S.—and the Los Alamos National Laboratory in New Mexico. Banerjee works with both. He and his team are trying to understand the fundamental hydrodynamics of the fusion reaction, as well as the physics.

In inertial confinement experiments, the gas (hydrogen isotopes, like in magnetic fusion) is frozen inside pea-sized metal pellets. The pellets are placed in a chamber and then hit with high-powered lasers that compress the gas and heat it up to a few million Kelvin—about 400 million degrees Fahrenheit—creating the conditions for fusion.

The massive transfer of heat, which happens in nanoseconds, melts the metal. Under massive compression, the gas inside wants to burst out, causing an unwelcome outcome: The capsule explodes before fusion can be reached. One way to understand this dynamic, explains Banerjee, is to imagine a balloon being squeezed.

"As the balloon compresses, the air inside pushes against the material confining it, trying to move out," says Banerjee. "At some point, the balloon will burst under pressure. The same thing happens in a fusion capsule. The mixing of the gas and molten metal causes an explosion."

To prevent the mixing, adds Banerjee, you have to understand how the molten metal and heated gas mix in the first place.

To do this, his group runs experiments that mimic the conditions of inertial confinement, isolating the physics by removing the temperature gradient and the nuclear reactions.

Banerjee and his team have spent more than four years building a device specifically for these experiments. Housed on the first floor of Lehigh's Packard Laboratory, the experiment is the only of its kind in the world, as it can study two-fluid mixing at conditions relevant to those in inertial confinement fusion. State-of-the-art equipment is also available for diagnosing the flow. The projects are funded by the Department of Energy, Los Alamos National Laboratory and the National Science Foundation.

One of the ways that researchers like Banerjee mimic the molten metal is by using mayonnaise. The material properties and dynamics of the metal at a high temperature are much like those of mayonnaise at low temperature, he says.

The team's device re-creates the incredible speed at which the gas and molten metal are mixing. They gather data from the experiments they run and then feed it into a model being developed at Los Alamos National Lab.

"They have taken a very complicated problem and isolated it into six or seven smaller problems," explains Banerjee. "There are materials scientists working on certain aspects of the problem; there are researchers like me who are focused on the fluid mechanics—all feeding into different models that will be combined in the future."

More information: Rinosh Polavarapu et al, Rayleigh-Taylor-instability experiments with elastic-plastic materials, *Physical Review E* (2019). DOI: 10.1103/PhysRevE.99.053104

Provided by Lehigh University

Citation: Behold the mayo: Experiments reveal 'instability threshold' of elastic-plastic material (2019, May 8) retrieved 24 April 2024 from https://phys.org/news/2019-05-mayo-reveal-instability-threshold-elastic-plastic.html