Chaos in a melting pot

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Abstract

We often think of yielding of a soft solid as a problem depending on a single control parameter: the externally applied forcing (the stress). This is somewhat a simplification of what we can find in the natural world. For a broad class of materials called phase change materials the solid-fluid transition is actually controlled by two parameters: the stress and the temperature. A simple example is the wax of burning candle that solidifies while flowing down along it. In such a case, we are dealing with two coupled transport phenomena: of momentum (flow) and of heat. To gain insights into this coupling, we consider very basic rheological tests performed with a paraffin wax in conditions of controlled rate of shear and temperature. For a fixed shear rate, when the temperature is decreased integral measurements of the apparent viscosity reveal four distinct flow regimes. At high temperatures the entire material is in a fluid state and its viscosity follows the classical Arrhenius law. A slight decrease of the temperature below this range leads to the well known "shear induced crystallization" phenomenon manifested through a monotonic increase of the apparent viscosity with time.

A further decrease of the temperature leads to two "uncharted" flow regimes. First, a periodic behavior of the apparent viscosity is observed. If the temperature is decreased even further, a fully chaotic temporal evolution of the apparent viscosity is observed.

Direct visualization of the sample via polarized light rheomicroscopy reveals in this case a coexistence between solid and fluid material elements as well as a competition between flow induced crystallization and break up of the solid units by shear. Based on the rheological tests combined with the in-situ visualization we build a complete phase diagram of the flow states.

We conjecture that this novel chaotic flow regime may be explained in terms of a viscosity contrast initially triggered by the flow induced crystallization which finally paves the route to chaos in a melting pot. Before closing, we present 2D numerical simulations which fully support this phenomenological explanation.

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