Researchers find universal law for material evolution

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It's a problem that materials scientists have considered for years: how does a material composed of more than one phase evolve when heated to a temperature that will allow atoms to move? In many cases, a rod-like phase embedded in another will break up into smaller domains very much like the droplets at the end of a stream of water, resulting in dramatic changes in the properties of the material.

Now, researchers at the McCormick School of Engineering and Applied Science at Northwestern University, together with collaborators from the Riso National Laboratory for Sustainable Energy in Denmark and the Swiss Light Source at the Paul Scherrer Institut in Switzerland have answered an important question about this break-up process: How does it happen, and how long does it take?

Researchers found the answer is universal among materials — a rare case in the materials world — and their results are published online August 1 in the journal *Nature Physics*.

Peter Voorhees, Frank C. Engelhart Professor of Materials Science and Engineering at Northwestern, Erik Lauridsen from Risø, and two graduate students spent five, 24-hour days at the Swiss Light Source (SLS) at the Paul Scherrer Institut, using 4-D synchrotron-based X-ray tomographic microscopy (a relatively new approach that allows for very fast measurements of a material in three-dimensions and in time) to observe the evolution of the rod-shaped phases (a phase is a region of a material that has a unique composition or atomic structure) during the

break-up process. They measured the details of what happened — the shape of the interfaces of the rods as they broke up — and five days later, they over two terabytes of information to analyze. (In between shifts at the SLS, the team had to make trips to the local electronics store to buy more storage space for their data.)

They found that the shape of the interfaces during break-up becomes universal, no matter what material is used. This sort of universality allows them to predict the dynamics of the break-up process in a vast array of materials, like steel and even noncrystalline materials like polymers.

Voorhees then brought the experimental data to Michael Miksis, professor of engineering sciences and applied mathematics, and the two of them and a graduate student described the process theoretically. They developed equations to calculate the time required for the pinching process to happen, and they found that the kinetics of the process is fixed early on and is the same, no matter the material.

"If it's a rod that's pinching off by diffusion in the material this is it," Voorhees said.

The process has an impact on a wide range of materials, including steel and polymers. For example, many metal parts are made by casting, when a liquid metal is poured into a mold and solidifies into the shape of the part. As the liquid solidifies it forms tree-like structures called dendrites, and if one of the arms of the dendrites break off, it can lead to a change in the properties of the solidified material. The airplane industry, for instance, spent a long time developing solidification methods to avoid this problem when casting jet turbine blades. Another example is polymer solar cells, which use a complicated mixture of two types of polymers. When heated up, the mixture evolves by a process that involves pinching, which ultimately alters the properties of the mixture

and the efficiency of the solar cell.

The experiments took place two and a half years ago, and Voorhees and his colleagues are still analyzing the results.

"I think it was really exciting to have a broad range of expertise on this project," he said. "There's no doubt we couldn't have accomplished what we did without an interdisciplinary group like this. It is incredibly exciting that the results are so broad-reaching and applicable to many materials."

The title of the paper is, "Universality and self-similarity in pinch-off of rods by bulk diffusion."

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