Phase Field Model for Dendritic Growth with Heterogeneities

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In the solidification of a metal the interface advances anisotropically. This process occurs when a fluid is subcooled below its solidification point, where the nucleated crystal grows without a preferred direction, forming microstructured patterns. This type of phenomenon is called dendritic growth. In order to model the system two functions are defined, the phase field $\psi(r, t)$ and the temperature field $T(r, t)$. The function $\psi(r, t)$ is an order parameter, where $\psi = 0$ and $\psi = 1$ represent the liquid and solid phases, respectively, and $0 < \psi < 1$ means the solid-liquid interface, that defines the solid-liquid interface. The time evolution of the phase field, $\psi$, is evaluated by the Ginsburg-Landau equation. This is the so called phase field model that is based on the variational principle and energy dissipation. The time evolution of $\psi$, determines the location where the solid-liquid interface has its minimum of energy.

We introduce heterogeneities in the system resembling fluid flow in porous media. Such heterogeneities appear as defects during the solidification process and affect the mechanical properties of the final material. These defects in the metal may appear as microporosities due bubbles imprisoned in the metal. In order to mimic these heterogeneities in the dendritic solidification we use the so-called freezing operator $\tilde{F}$ that takes value 1 with a probability $p$. The dendritic solidification shows a perimeter that grows quadratic with time. When some sites are not allowed to solidify according with some probability $p$ the solidification undergoes a transition from anisotropic to isotropic as $p$ grows. More precisely, that transition happens when $p \approx 0.004$. The quadratic function that governs the perimeter growth is $f(t) = a_0 + a_1 t + a_2 t^2$, and the parameter $a_2$ that defines the quadratic behavior of the growth is given by the power law $a_2 \propto p^\alpha$. The system shows two well defined exponentes that classifies the growth of the solid, where for $p \geq 0.04$ the exponent $\alpha = 1.464$ and $\alpha = 0.077$ for $p < 0.04$. 