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Solidification of Alloys under the Influence of External Fields

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Extended Abstract

To meet the future challenges of lightweighting and pollution reduction, especially relevant in transportation, it is necessary to improve the castability of light alloys, enhance grain and eutectic refinement in monolithic alloys, and to develop new high-strength composites using nano-reinforcers. To this respect, this lecture reviews the application of external physical fields electromagnetic and ultrasonic, used to significantly influence the microstructures and properties of solidifying light alloys, such as aluminium and magnesium. The emphasis of the lecture will be on the modelling side, with experiments used in parallel to validate simulations.

Electromagnetic AC/DC fields have been used traditionally to melt, stir and contain metals in liquid form, being especially useful in treating reactive or high temperature melts as in cold crucibles for Ti or Zr. Alternatively, electromagnetic levitation is used extensively to obtain thermophysical properties of metals in microgravity as in the ISS Tempus experiment, with DC fields used to suppress unwanted convection in terrestrial experiments. One aspect of EM interaction that has been less extensively studied, concerns the coupling of an imposed magnetic field with the thermoelectric currents naturally appearing at the solidifying front, leading to induced flow. I will demonstrate how this interaction (the field of Thermoelectric-Hydrodynamics (TEMHD)) can govern microstructure evolution and if used judiciously correct known casting defects.

Coming to the field of ultrasonics, pressure fluctuations in a liquid, can lead to the emergence of dissolved gas in the form of bubbles that can then float to the surface in a process known as degassing. Degassing is useful in reducing porosity in castings, for example by eliminating hydrogen from aluminium melts. Increasing the intensity of pressure fluctuations beyond a threshold causes bubbles to implode violently, resulting in singular conditions that favour nucleation and grain refinement, or alternatively leading to the breakup and dispersion of particle clusters added as reinforcers in composites. The traditional UST process involves an immersed sonotrode probe, vibrating at around 20 kHz. This can be applied directly in a crucible, or even in continuous DC casting through the launder. An alternative technique explored by my team, involves the use of EM induction providing a contactless way of vibrating the melt and so avoiding contact contamination. This allows treatment of high temperature or reactive melts. The latter process combines electromagnetics with acoustics, a truly multi-physics simulation challenge. It is shown that effective inertial cavitation (violent bubble collapse) requires careful tuning of the supply source frequency, to reach acoustic resonance. The additional benefit is that large volumes of metal can then be treated this way, without resort to complex multi-sonotrode arrangements.

I will explore these external field interactions with solidifying metal melts with a series of examples covering EM field melting and casting, microstructure control using TE forcing (the TEMHD effect), ultrasonic treatment and cavitation using traditional immersed probes in crucibles and DC casting launder and finally contactless US treatment using EM induction.