THERMO-ELECTRIC MAGNETIC EFFECT DURING SOLIDIFICATION: IN SITU OBSERVATION AND THEORETICAL INTERPRETATION

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Abstract: In the case of application of permanent magnetic field on liquid metals, some recent results revealed a dual effect on the liquid metal flow. Firstly, the magnetic field has a selective damping action on the flow at the scale of the crucible, due to the breaking part of the Lorentz forces. Secondly, the interaction of thermo-electro-electric currents near the solid-liquid interface (planar or dendritic front) with the applied magnetic field leads to the generation of electromagnetic forces (Thermo-Electric Magnetic effect), which act both on the liquid and on the solid at the scale of the meso-microstructures. We have investigated the TEM effect both theoretically, numerically and experimentally. The TEM forces may generate significant liquid motions, both in the bulk as well as in the mushy zone. This has been clearly shown by some theoretical investigations and numerical modeling using COMSOL software. It is also shown that TEM forces exist in the solid phase. We have been able also to calculate analytically the TEM forces acting on solid particles, e.g., sphere, cylinders. More complex shapes were dealt with numerical modeling. We have performed experimental investigation of the influence of a permanent magnetic field applied during the columnar and equiaxed solidification of Al-4wt%Cu. In situ visualization was carried out by means of synchrotron X-ray radiography. The TE forces when they are not curl-free, generate fluid flows both in the liquid bulk and in the mushy region. The latter effect was confirmed by the in situ experiments. Significant segregations and channeling effects were observed in the mushy zone. The experimental results also show that the TEM forces on the solid may lead to dendrite fragmentation as well as grain motions. It is shown that the TEM forces are responsible for a motion of dendritic/equiaxed particles, perpendicular to the direction of gravity. A heuristic analysis allowed us to estimate the fluid velocities and the velocities of the solid particles. A good agreement was found with the experimental data. Similar observations were also made during equiaxed growth in a temperature gradient. The in situ observation of the grain trajectories for various values of the temperature gradient demonstrated that gravity and TEM forces were the driving forces which controlled the grain motion (see figure below).

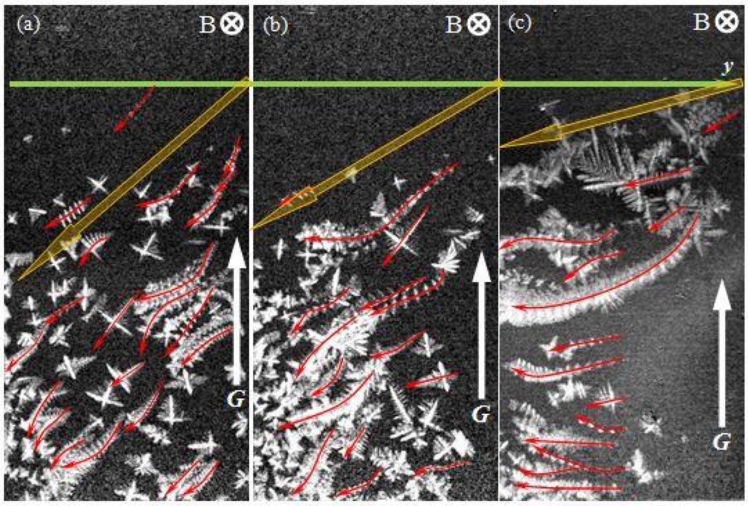

Figure: Successive - time overlaying images of equiaxed grain movements showing their deflections with different magnitude thermal gradients. (a) G = 500 K/m; (b) G = 1000K/m; (c) G = 2000K/m. (B = - 0.08 T; cooling rates are 2 K/min).