Numerical modelling of the melt conditioned direct chill (MC-DC) casting process

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Direct-chill (DC) casting is a semi-continuous casting method that produces wrought aluminium and magnesium alloys.

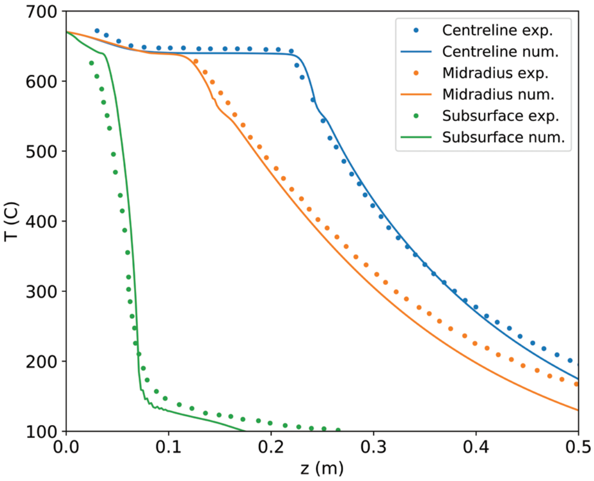

FIGURE 1. Validation of the DC casting model using temperature measurements from Vreeman et al. *Journal of Heat Transfer*, 124 (2002), 947.

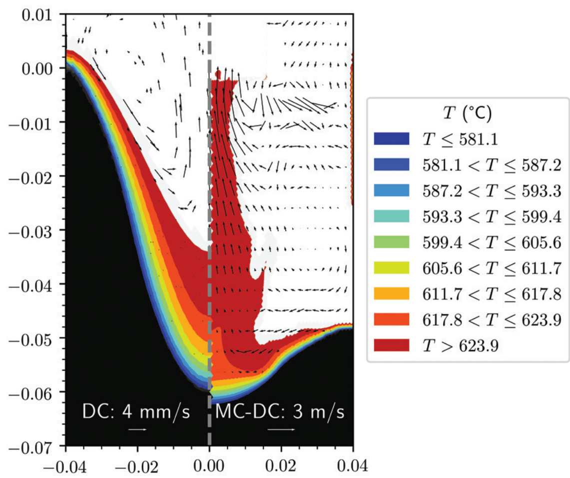

FIGURE 2. Comparison of the sump profile between (left) conventional DC casting and (right) MC-DC. Velocity arrows are of different scales for DC and MC-DC.

A fine and uniform microstructure is desirable for DC cast billets: beneficial effects include enhanced thermo-physical properties and improved extrudability, machinability, and surface finish for downstream processing. Treatment of the melt with high-shear melt conditioning (HSMC) results in grain size reduction without the addition of grain refiners. Numerical modelling can be used to understand this effect, and can be used to optimise the melt conditioned direct chill (MC-DC) casting process for key parameters, such as geometry of the mixer, operating temperature and the speed of rotor. Modelling is also a suitable alternative to costly experiments, which may be neither feasible nor practical in high temperature, opaque and highly reactive melts.

A single-region formulation that is derived from conservation of mass, momentum, energy, and species is used to represent this problem. The formulation is implemented in the open-source library OpenFOAM, by adapting the buoyantPimpleFoam solver to DC casting process, and validated against temperature measurements in a binary Al-Cu alloy cast (Figure 1). Rotation is implemented using the sliding mesh method. While flow in conventional DC casting is laminar, the flow around the mixer is highly turbulent. Reynolds-Averaged Navier-Stokes (RANS) equations can predict the turbulent flow features around the mixer; however, they severely under-predict the global turbulent energy dissipation rate. HSMC simulations therefore necessitate better turbulence models. In this work, the continuum equations are closed by using a Large Eddy Simulation (LES) model, with the Yoshizawa subgrid scale model. This model is applied to the casting of AZ31 in an 80 mm Ø mould, sheared at 4000 RPM using a 42 mm Ø mixer (Figure 2).

While the distribution of shear rate and mass flow rate is highly non-uniform in the sump, the temperature gradient in the presence of high shear is higher across the mushy zone and the sump is shallower than in conventional DC casting. The large flow rate below the mixer draws melt at the liquidus temperature through large recirculations near the mould wall. The shell at the mould near the graphite-hot top interface re-melts, leading to the reduced sump depth. The slurry is sucked towards the mixer, where it is re-melted during the transit. The net effect of these recirculations is a smaller slurry zone and consequently a larger temperature gradient across the sump. The increased heat extraction and the corresponding larger temperature gradient lead to an effectively larger cooling rate, i.e. a smaller local solidification time within the mushy zone for the same casting speed. This can in turn lead to a finer, more uniform grain structure in the resulting billet.

This model is now ready for performing design of experiments to optimise the operating conditions and geometry of the mixer against the desired sump profile. These parametric studies will be run on the BCAST high-performance computing facility using the uncertainty quantification framework Dakota. The model will be further extended to study macrosegregation, by considering the effect of grain motion using a mean-field approach.

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