Numerical modelling of high shear melt conditioning (HSMC)

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High-shear melt conditioning (HSMC) results in grain size reduction without the addition of grain refiners. In high shear processing, a rotor-stator mechanism (the high shear device) is immersed into the bulk liquid.

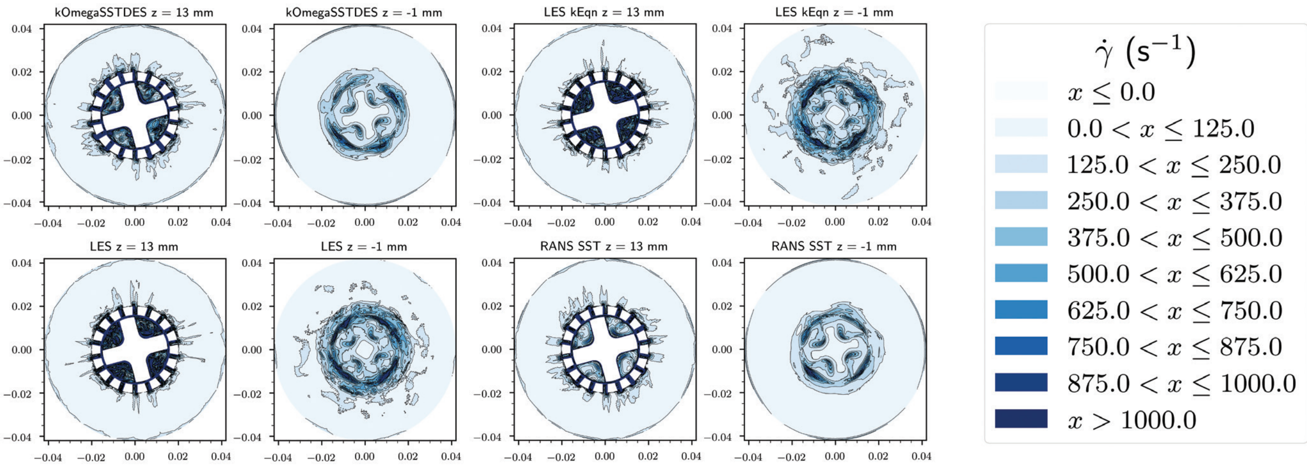

FIGURE 1. Strain rate field in an 80 mm Ø mould with rotor at 1000 RPM. Z planes are along the axis of the rotor.

High shear melt conditioning (HSMC) results in grain size reduction without the addition of grain refiners. In high shear processing, a rotor stator mechanism (the high shear device) is immersed into the liquid bulk. The rotor rotates at high speed inside a cylindrical stator surrounded by a series of small holes. The high shear rate is due to the high speed of the rotor tip and the small gap between the rotor blades and the stator. The resulting break up and dispersion of oxide inclusions can lead to a uniform structure, hence better material properties.

The flow pattern inside the melt bulk is crucial to the mixing and deagglomeration process and affects the efficiency of the mixer. The mixing zone, also known as a pseudo-cavern for shear-thinning liquids, is of paramount interest. However, the flow around the mixer is complex, thus making optimisation of the process challenging. While the literature has different recent examples of numerical studies of rotor stators, all of them to date treat turbulence using the Reynolds-Averages Navier-Stokes (RANS) approach. RANS can predict flow features around the mixer; however, they severely under-predict the global turbulent energy dissipation rate ε. The flow pattern around mixers is rich in non-uniform and inherently transient structures, thereby necessitating the use of better turbulence models.

In this work, a turbulence model is used to predict flow in a rotor-stator device, shearing A6060 melt at 1000 RPM, in an 80 mm Ø mould. The average torque around the rotor is around 0.08 Nm, corresponding to an average power of 35 W and power number of 2.0. The flow equations, solved using the interDyMFoam solver of OpenFOAM, are closed by using two Large Eddy Simulation (LES) models: the Smagorinsky [1] and Yoshizawa [2] subgrid scale models, a Detached Eddy Simulation (DES) model (k-ω SST) [3] and the RANS k-ω SST model [3].

Both LES models yield similar predictions, with similar order of magnitudes for strain rate and similar complex flow structures below the mixer. Large strain rate values are confined to the mixer volume, implying deagglomeration can occur only within the mixer volume. Turbulent mixing is prominent throughout the bulk region within the height of the stator rows. In this region, any inclusions are expected to be evenly distributed. Through the stator holes, the jet is always generated at the leading edges and recirculations at the trailing edge, regardless of the rotor position, with the largest flow rates occurring at the top rows.

However, the RANS and DES models both underestimate the strain rate both inside and under the mixer. This discrepancy will lead to inaccurate evaluation of deagglomeration rates when coupling flow to a deagglomeration model, should these turbulence closures be used. Moreover, the LES model evaluations were tractable on the BCAST high-performance computing facility, yielding results for the 80 mm Ø mould within two weeks. This paves the way for optimisation studies of the flow pattern and deagglomeration rate around the rotor-stator mixer.

HSMC will be focussed on in the future and studied numerically using an LES model and an uncertainty quantification framework to determine the optimum rotation speed and mixer geometry, to maximise the pseudo-cavern around the mixer and the strain rate within the mixer region.

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