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A DISCONTINUOUS GALERKIN METHOD FOR MULTIPHYSICS WELDING SIMULATIONS

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Accurately simulating heat and fluid flow in laser and electron beam welding processes is an arduous task because of the complexity of the physical phenomenon at play. For instance, melt pool flows often develop steep gradients because of rapid transitioning from solid to liquid state and pronounced velocity variation across boundary layers. These difficulties are further compounded by natural and thermocapillary (liquid-tension induced, Marangoni effect) convection, free-surface deformation and tight coupling between the temperature and velocity fields. Because of these inherent specificities, attaining grid converged solutions is notoriously difficult and may necessitate excessively fine meshes when using standard discretization schemes [1].

Seeking enhanced resolution, we detail the development of a welding simulation model based on a high-order discontinuous Galerkin (DG) finite-element method [2, 3]. DG is a highly accurate and geometrically flexible discretization technique whose favorable numerical properties have been proven advantageous for simulating complex fluid phenomena. In this work, the DG approach is extended to the simulation of manufacturing processes involving metal fusion, such as welding. It is expected that the high-order solution representation will allow for a much more reliable capture of the very non-linear phenomena characteristic of these processes. Accessorily, the (absence of) continuity of the solution allows for a direct visual check of grid convergence.

Our numerical model implements a classical enthalpy-porosity constitutive law accounting for hydrodynamic and thermal effects occuring during the phase transition from solid to liquid metal [4]. Specifically, we consider the incompressible Navier-Stokes and energy equations augmented with phase-transformation thermodynamical effects, porosity-based mushy-zone modeling, Marangoni free-surface stresses and buoyancy-induced natural convection terms. The resulting constitutive equations are discretized with an interior-penalty formulation, and solved implicitly using a Newton-Krylov scheme. Two stabilization approaches for incompressible flows, namely the non-conforming pressure discretization [5] and an artificial compressibility local preconditioner [6], are compared.

This contribution concerns in particular implementation issues, as well as applicability and advantages of the DG framework to this type of simulation. The cost and accuracy benefits of high-order accurate finite-element formulations will be quantified through mesh and polynomial interpolation order refinement studies. Next to benchmark test cases, proof-of-concept simulations of fusion welding and additive manufacturing processes will be shown.

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