Towards a PFEM-based unified thermo-fluid-solid simulation tool for phase change problems

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The present work focuses on the solution of coupled thermo-fluid-solid problems with phase change. We present our first step towards simulating Laser Melt Bonding (a.k.a. Selective Laser Melting) at the mesoscale, where the melting and re-solidification take place and residual stresses are created. The approach uses the particle finite element method (PFEM) (S.R. Idelsohn, E. Oñate, F. Del Pin, "The particle finite element method: a powerful tool to solve incompressible flows with free-surfaces and breaking waves", Int. J. Numer. Meth. Engng, 61(7), 964–989. 2004), which combines the flexibility of particle methods and the robustness of the Finite Element Method.

Certain industrial phase change problems, such as additive manufacturing and welding, melt the material using a concentrated heat source (e.g. laser or electron beam). Moving it across the material results in the molten and solidified regions of the material being unknown a priori and evolving continuously. This makes traditional Fluid-Structure Interaction (FSI) approaches difficult to use. This is further aggravated by the strong interaction between the melt pool and the solid, as is the case in the mentioned applications. As a result, most approaches in the literature ignore either the solid mechanics or the fluid dynamics at the mesoscale.

We therefore propose a 2D phase change simulation tool based on the PFEM. Generally, the PFEM can simulate fluid flows and large deformations in solids. Our in-house 2D PFEM fluid solver (M.L. Cerquaglia, D. Thomas, R. Boman, V.E. Terrapon, J.-P. Ponthot, "A fully partitioned Lagrangian framework for FSI problems characterized by free surfaces, large solid deformations and displacements, and strong added-mass effects", in Comput. Methods Appl. Mech. Engrg. 348 409-442, 2019) is extended to incorporate phase change capabilities and a linear elastic solid. Both phases can then co-exist in one computational domain and change state as a function of temperature. Using this approach we model the phase change around a heat source in a unified way. A tight coupling is ensured and an external coupling of a fluid and solid solver is avoided.