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Strong Form Meshless Solution Procedure for Thermo-Mechanical Modelling of Steel Production Processes

Gašper Vuga[1], Boštjan Mavrič[1], Tadej Dobravec[1], Umut Hanoglu[1], Izaz Ali[1], Božidar Šarler[1,*]

[1]Laboratory for Fluid Dynamics and Thermodynamics, Faculty of Mechanical Engineering, University of Ljubljana, Aškerčeva 6, 1000 Ljubljana, Slovenija
e-mail*: bozidar.sarler@fs.uni-lj.si

ABSTRACT

The Radial Basis Function - Finite Differences (RBF-FD) method presents a novel, strong-form meshless approach for solving partial differential equations. The method generalises the classical finite difference (FD) framework, enabling arbitrary domains to be discretised using homogeneously arranged computational nodes. While the RBF-FD method performs well for problems with smooth solution fields, it may become unstable in cases involving sharp interfaces that arise from geometry or material data. Such challenges commonly appear in elastoplasticity, where stress fields exhibit discontinuous differentiability across the elastic–plastic transition. To address this issue, we propose a hybrid RBF-FD formulation that combines RBF-FD with the classical FD method. The local interpolation problems utilise augmented polyharmonic splines together with second-order finite differences. For Neumann-type boundary-condition stabilisation, we introduce a novel stabilisation technique. The developed discretisation approach is further extended to a one-way coupled thermo-mechanical model in which temperature governs the mechanical response. The solution procedure is implemented under a 2.5D (generalised plane strain) assumption and verified on various elastic, thermo-elasto-plastic and visco-plastic benchmark problems. In addition to previously developed strong-form meshless simulation systems for reheating furnaces and hot rolling, the proposed approach is further extended to modelling the high-temperature continuous casting of square billets. A 2.5D travelling slice (TS) is considered, which moves along the casting direction and enables the inclusion of the straightening process. The cooling of the TS, together with the inner ferrostatic pressure, governs the thermo-elasto-visco-plastic mechanical response, allowing for the prediction of critical regions prone to hot tearing. The developed 2.5D model is subsequently applied to the cooling of long steel bars on a cooling bed. The model considers a set of bars positioned on the cooling bed that interact through thermal radiation and computes the resulting thermo-mechanical response, including induced residual stresses and bar bending. The results demonstrate that the proposed numerical approach can be successfully applied to complex industrial steel production processes.