Public Abstract

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Title:Recent Efforts on Model-Based Simulation of Engineering Problems " Multiphysics and Multiphase Interactions

Simulation-Based Engineering Science (SBES) is playing a more important role in gaining new knowledge and providing guidance for engineering activities, in particular, in the fields in which time scale and/or spatial scale make physical experiments dramatically expensive or even impossible. The success of SBES heavily relies on the development of algorithms that provide the bridge between the models describing physical and engineered systems and the computational devices that generate the digital representations of simulations. My efforts on the development of algorithms that simulate multiphysics and multiphase flow are presented in this dissertation.

The first part of the dissertation describes the algorithms for the multiphysical model that simulates the laser drilling process. During laser drilling, heat conduction, melt flow, and vaporization occur in a very short time period. Vaporization also produces the recoil pressure that drives melt flow and complicates the heat transfer and material removal rate. To get a more realistic picture of the melt flow, a series of differential equations were developed that govern the process from pre-heating to melting and evaporation. In particular, the Navier-Stokes equation governing the melt flow is solved with the use of the boundary layer theory and integral methods. Heat conduction in a solid is investigated by using classic solutions with the corrections that reflect the change in boundary condition from constant heat flux to Stefan condition. The dependence of saturation temperature on the vapor pressure is taken into account by using the Clausius-Clapeyron equation. Both constantly rising radial velocity profiles and rising-fall velocity profiles are considered. In spite of the assumed varying velocity profiles, the new model predicts that the drilling hole profiles are very close to each other in a specific super alloy for given laser beam intensity and pulse duration. The numerical results show that the effect of melt flow on material removal can be ignored in some cases. The solutions derived can be applied to new cases to determine the role of melt flow and vaporization on laser drilling profile evolution and to study the solid material removal efficiency.

The second part of this dissertation describes a new method that simulates the interaction between fluid and solid elements. The discrete element method (DEM) has been used to deal with the interactions between solid elements of various shapes and sizes, while the material point method (MPM) has been developed to handle the multi-phase (solid-liquid-gas) interactions involving failure evolution. A combined MPM-DEM procedure is proposed to take advantage of both methods so that the interaction between solid elements and fluid particles in a container could be better simulated. In the proposed procedure, large solid elements are discretized by the DEM, while the fluid motion is computed using the MPM. The contact forces between solid elements and rigid walls are calculated using the DEM. The interaction between solid elements and fluid particles are calculated via an interfacial scheme within the MPM framework. The proposed procedure is illustrated by representative examples. The convergence of numerical solutions and the factors affecting the simulation fidelity is also discussed. This study provides an alternative approach for simulation of granular flow that involves solid-fluid interactions.