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Laser-induced heating of dynamic particulate depositions in additive manufacturing

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Many applications in additive manufacturing involve the dynamic deposition of powders and the in-flight heating of such material by a laser. In order to characterize such systems, the Discrete Element Method is employed. Specifically, the paper develops a modular discrete-element type multiphysics method for the simulation of the particle dynamics, interaction with a laser and detailed thermal behavior, which provides researchers with a framework to construct computational tools for this growing industry. In order to achieve this, from a simulation standpoint, the overall particle-mixture system is constructed by coupling submodels for each primary physical process together. An iterative staggering scheme is developed whereby, within every time step, each individual particle is solved, "freezing" the state of the remaining multiparticle system. The state of the particle is then updated and the algorithm moves to the next particle in the system and the process is repeated. The overall process sweeps through the entire system repeatedly until convergence in an appropriate norm. As the system evolves, an error estimate dictates the time-step size that is needed to induce convergence to below an appropriate error level. Essentially, this is an implicit time-stepping scheme, which is combined with an (internal) iterative staggering process. In order to control rates of convergence within a time-step, the algorithm adjusts the time-step size. If the iterative process does not converge within a desired number of iterations, below an error tolerance, the time-step is reduced. The degree of time-step reduction is determined by utilizing an estimate of the spectral radius of the coupled system. Since the construction of model and solution process is modular, one can easily replace physical submodels with other choices, making it easy to numerically experiment with a variety of models. Qualitative and quantitative analyses are provided, as well as three-dimensional numerical examples.

Keywords: particles, dynamic deposition, laser, heating

1. Introduction

A large variety of emerging advanced fabrication methods involve Additive Manufacturing (AM) processes, which are generally characterized as depositing materials onto substrates and bonding them together to create structures, as opposed to classical "subtractive" processes which remove material. The approach was pioneered in 1984 by Hull [36] and was a 2.9 billion dollar industry in 2015, with applications ranging from motor vehicles, consumer products, medical devices, military hardware