Numerical Simulation of Thermal Spray Coating Formation

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Abstract

A three-dimensional model of free-surface flows with heat transfer, including solidification, was used to model the build-up of a coating layer in a thermal spray process. The impact of several nickel particles on a stainless steel plate in different scenarios was considered. Particles diameter ranged from 40 to 80 μm and their impact velocity ranged from 40 to 80 m/s. Particles were initially super-heated; their temperature ranged from 1600 to 2000°C. Fast growth of solidification was found to be one cause of particle splashing in thermal spray coatings. Different splat morphologies obtained from the numerical model were comparable with those obtained from the experiments. Simulation of the sequential impact of two nickel particles showed side-flow jetting and particle splashing observed in experiments. The numerical model proved to be capable of simulating different impact scenarios that occur in a thermal spray; this was demonstrated by simulating nine consecutive particles during their impact on the substrate. Several characteristics of a coating layer build-up such as particle splashing and formation of small satellite droplets and rings around the splat could be seen in the numerical results. Particle splashing is one possible cause of porosity formation in thermal spray coatings.

Introduction

Physical properties of thermal spray coatings, e.g. porosity, are sensitive to a large number of process parameters (such as particle size distribution, velocity, temperature and degree of solidification; substrate material and temperature) which are optimized by trial and error [1]. Better control of the process requires a fundamental understanding of the fluid flow and heat transfer that occurs during the impact, spreading, and solidification of molten droplets.

Several numerical models of droplet impact on a surface including heat transfer have been developed. Most of these works focused on the normal impact of a single droplet on a surface, a scenario which is axisymmetric, or 2D [2-6]. Far less has been published on droplet impact which is not axisymmetric, and thus must be considered three-dimensionally. The 2D/axisymmetric models have some limitations: the impact has to be normal and 3D aspects of the flow, for example fingering, during the spreading cannot be modeled. In a thermal spray process, droplets may not impact in a direction normal to the substrate, several droplets may impact the substrate simultaneously, and droplets may impact on previously solidified splats. Modeling droplet impact and solidification in these situations requires a 3D model. Bussmann et al. [7] developed a 3D numerical model of free surface flows. They presented the results for two scenarios of 3D droplet impacts: the impact on an incline and the impact on a sharp edge. The model was validated by a comparison between the numerical results and experimental photographs. The impacts were considered to be isothermal; no energy equation was solved in the model.

The objectives of our study were: to extend the Bussmann et al. [7] 3D computational model to include heat transfer and solidification, and to use the model to study important characteristics of a coating layer build-up in conditions typical of a thermal spray process. We simulated nickel particles during their impact on a substrate and on previously solidified splats in different scenarios: normal impact of a single particle, sequential impact of two particles and multiple impact of nine consecutive particles. A wide range of particle size (40 to 80 μm) and temperature (1600 to 2000°C) and the impact velocity (40 to 80 m/s) was considered. The conditions used for the single and sequential impacts were those of the experiments performed by Pershin et al. [8].

Numerical method

Fluid Flow. Fluid flow in an impacting droplet was modeled using a finite difference solution of the Navier-Stokes equations in a 3D Cartesian coordinate system assuming laminar, incompressible flow. The flow Reynolds