Modeling Sequential Impact of Two Molten Droplets on a Solid Surface

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Introduction

Physical properties of thermal spray coatings, such as porosity, are sensitive to a large number of process parameters (e.g.: droplet 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.

In a previous study [2], we developed a 2D/axisymmetric model to simulate the impact of molten tin droplets on a steel plate; the predictions of the model were compared with photographs of impacting droplets. Modeling the impact of several droplets or the impact on a previously solidified splat, however, requires a 3D model.

The objectives of this study are: to develop a 3D numerical model of free-surface flows and heat transfer including phase change, and to demonstrate that the model can simulate a complex phenomenon of the impact of a droplet on a previously solidified splat.

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 coordinates assuming laminar, incompressible flow. The flow Reynolds number (assuming radial flow over a flat plate in the droplet after impact) was estimated to be at most 10^4, too small to induce turbulence. The surface profile of the deforming droplet was defined using the ''fractional volume of fluid'' scheme. Details of the fluid flow model are given by Bussmann et al. [3]. A constant contact angle of 90° was prescribed as a boundary condition. In an earlier study, we found that for typical plasma spray processes the capillary effects are negligible, suggesting that using a constant value of contact angle does not affect the results significantly [4].

Heat transfer. Heat transfer in the droplet was modeled by solving the energy equation, assuming densities of liquid and solid to be constant and equal to each other:

$$\frac{\partial h}{\partial t} + (\vec{V}\cdot\vec{\nabla})h = \frac{1}{\rho}\vec{\nabla}\cdot(k\vec{\nabla}T) \qquad (1)$$

where $\vec{V}$ represents the velocity vector, h the enthalpy, T the temperature, ρ the density and k the thermal conductivity. Since the energy equation has two dependent variables –temperature T and enthalpy h- we used the enthalpy transforming model [5] to convert the energy equation to one with only one dependent variable: the enthalpy. The final form is

$$\frac{\partial h}{\partial t} + (\vec{V}\cdot\vec{\nabla})h = \frac{1}{\rho}\vec{\nabla}\cdot(\beta\vec{\nabla}h) + \frac{1}{\rho}\nabla^2\phi \qquad (2)$$

where in the solid phase:

$$h \le 0; \quad \beta = \frac{k_s}{C_s},\ \phi = 0 \qquad (3a)$$

at the liquid-solid interface: