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Deformation and Solidification of Molten Particles on a Substrate in Thermal Plasma Spraying

M. Pasandideh-Fard, J. Mostaghimi
University of Toronto
Toronto, Canada

Abstract

In the present study, the flattening and simultaneous solidification of a liquid droplet upon its impingement onto a solid surface has been numerically simulated and an extensive set of results has been generated to represent this complex deformation process. The numerical solution for the complete Navier-Stokes equations is based on the modified SOLA-VOF method using rectangular mesh in axisymmetric geometry. For the solidification part of the deformation process, based on a one dimensional *Stefan* problem in heat conduction, a numerical procedure has been developed. The results for the complete deformation process and the effect of some important input data including impact velocity, droplet diameter, viscosity, surface tension and contact angle have been discussed. Comparing our predictions with some available data reveals a good agreement, therefore, the model may be considered to be well suited for investigating the droplet deformation.

THERMAL PLASMA SPRAYING has been receiving increasing attention in last three decades. The industrial significance of this process lies in the possibility of the deposition of melted and accelerated micron sized particles upon a substrate, in order to produce a strong mechanical and anticorrosive coating on preshaped parts. Flattening and solidification of these particles impinging onto the substrate surface are two major associated problems. These two phenomena involve very rapid changes in the dynamic and thermal state of the molten particles that depend on many factors, some of them being unknown or not well known. The principle difficulty of the problem arises from the fact that both phenomena occur simultaneously in an extremely short time. Characterizing the deformation behaviour of the droplets during impingement, including flattening and simultaneous solidification, requires solution of the motion and energy equations to determine the exact behaviour and interaction of the droplets at any time.

The first numerical work in this field was done by Harlow and Shannon [1], who investigated the behaviour of the deformation of a single droplet upon its impingement onto a flat plate and into a pool of the same liquid. They used the "Marker and Cell" method to solve the full Navier-Stokes equations in cylindrical coordinates. However, in their calculations, the effects of the surface tensions and viscosity have been completely neglected. Moreover, their efforts are only concerned about the flow dynamics of the problem regardless of heat transfer. Very recently a numerical effort, which is based on a commercial code called FLOW-3D, has been performed by Trapaga and Szekely [2] to investigate the spreading process of droplets upon impact onto a surface. The equations of fluid flow including continuity equation, classical Navier-Stokes equations and the equation of fluid fraction are solved using the "Marker and Cell" method and the implicit-continuous 3-dimensional extension of the SOLA-VOF code. However, only the fluid flow aspects of the problem is considered and the solidification part of the deformation process has not been tackled. Liu et al. [3] have also investigated this problem. In their approach, modelling the deformation and interaction of tungsten droplets with different impact velocities, different viscosity and surface tension was accomplished on the basis of the solution of the full Navier-Stokes equations and the Volume of Fluid(VOF) function by using the RIPPLE code. Nevertheless, their study is only concerned on the flattening process of a droplet impingement onto a surface. A numerical investigation for the deformation and solidification of a droplet on a cold substrate has been performed by Watanabe et al. [4]. They used the SMAC(Simplified Marker and Cell) algorithm which was developed by Amsden and Harlow[5] to solve the Navier-