Abstract

Hot-dip galvanising is commonly used in industry to increase the corrosion resistance of cold-rolled steel products for commercial use such as roofing and walling of buildings. Traditionally, the zinc coated steel surface is characterised by a relatively smooth surface with large spangle relief which is detrimental to corrosion resistance. One of the techniques to modify the surface appearance consists of a water-mist spray solution which allows for the creation of a large number of nucleation sites giving rise to micro rather than macro spangles, thereby producing a much smoother surface. In addition, controlling the spray parameters allows the hot, zinc coated, steel surface to be `roughened' facilitating its bonding to concrete or for lamination. The proper control of water droplet impact parameters such as impact velocity, droplet diameter and crater size is essential for a successful implementation of this technique. Certain aspects of the second of these processes, the production of rough, non-skid galvanised steel sheet surfaces, has been addressed by this thesis.

Although an experimental investigation of the effect of such water droplet parameters on the formation of zinc surface characteristics such as crater diameter and depth would provide a great deal of valuable data it is fraught with difficulties. The presence of hot metal surfaces exceeding 450^{o}C and the boiling and evaporation of water droplets taking place at very small time scales (microseconds) all combine to make an experimental study difficult to implement not to say unsafe. On the other hand computer simulations with a properly constructed mathematical model are a valuable tool for the investigation of these parameters.

A comprehensive modelling of the process would include the process of heat transfer: such as conduction through a vapour layer, internal droplet and vapour convection, radiation from the hot surface, solidification of the zinc liquid layer; as well as the fluid dynamical aspects: such as surface tension at the droplet-air, droplet-zinc and zinc-air interfaces, the droplet impact phenomena such as spreading and splashing and the formation of impact craters and wave propagation in a thin viscous zinc layer. As a first stage in the modelling exercise this thesis will concentrate on an investigation of single water droplet impact on a thin liquid zinc layer with a steel substrate which provides a simplified and computationally tractable model of the spraying process.

The objectives of this thesis are twofold: firstly, the development and construction of an accurate, robust mathematical model and, secondly, the solution of the model for the impact of a single water droplet onto a thin liquid layer of zinc on a steel substrate. This model must be able to deal with rapidly deforming moving interfaces and maintain stability in the presence of very large density and viscosity ratios. This moving boundary problem requires the tracking of three fluid interfaces while also maintaining incompressibility. The Godunov-Marker-Particle Projection Scheme developed in this thesis is able to satisfy these requirements. Through a combination of approximate projection methods, Godunov convective differencing, Marker-Particle interface tracking and velocity filters the method is able to treat viscous, multi-fluid free surface flows. The modelling of free surface flows with more than two separate immiscible fluids, to the author's knowledge not yet published in the literature, is a secondary aim of the thesis.

A major part of the thesis deals with the thorough testing of each aspect of the combination of numerical methods used: firstly, the Poisson solver with discontinuous coefficients and homogeneous boundary conditions used in the approximate projection method, analytical solutions for the construction of an initial solenoidal velocity field, testing of the projection and velocity filters and kinematic tests of the Marker-Particle method for tracking of fluid interfaces; secondly, dynamical tests of the viscous incompressible Navier-Stokes equations for: an exact solution, the Lid-Driven Cavity and the Rayleigh-Taylor instability. The combined method is also successfully tested on the limited two-fluid droplet-solid and droplet-liquid impact problems before solving the thesis problem.

It is shown that, for the impact of a single water droplet onto a thin liquid zinc layer, impact crater growth, diameter and depth, are linearly dependent on impact velocity. For a given impact velocity, crater diameter is not effected by increasing zinc layer depth although crater depth is linearly dependent. The time at which the droplet commences penetration of the zinc layer is inversely dependent on impact velocity and the maximum crater diameter and depth are nonlinearly dependent on impact velocity. The model shows that, within the convective timescale, droplet impact on thin liquid zinc layers can be approximately described by droplet spreading on a solid zinc surface. The droplet is shown to spread preferentially to the zinc layer splashing after completion of spreading. This shows that adjustment of the droplet impact velocity or zinc layer depth can vary the surface roughness appropriately.

Useful References

1. The relevant papers of Bill Rider, especially regarding The Marker-Particle Method and Approximate Projection Methods.
2. The papers of Elbridge Gerry Puckett on Projection Methods.
3. In addition the papers of Michael Minion, Ann Almgren, Louis Howell, John Bell, Phillip Colella, David Brown, Philip Marcus and William Crutchfield are all important.

This is my PhD work which was supervised by Professor Songping Zhu of The School of Mathematics and Applied Statistics of the Faculty of Informatics at Wollongong University and Dr Cat Tu of BlueScope Steel Research Laboratories.