CHAPTER 1

Introduction

1.1 Background

Impingement of a metal droplet on a substrate is an integral part of several engineering applications like thermal spray coating and spray forming. During thermal spray coating, the impingement of metal droplet on the substrate results in substrate coating. The quality of coating is a direct result of the impingement process in which splats are formed. Spray forming is a process of metal droplet deposition that produces near-net shaped preforms directly from molten metals and alloys. In these processes, in a single operation, a liquid metal stream is atomized into fine droplets, which impact on a substrate to form a bulk deposit.

Rapid solidification of the droplets upon impingement enhances the mechanical properties of spray-formed products without requiring extensive secondary processing. Since their microstructures exhibit amorphous phase, refined grains, reduced phase segregation, and increased solubility of alloying elements, the bulk deposits exhibit excellent mechanical properties. The performances of these processes are strongly related to the impingement of individual droplets on the substrate. Therefore, considerable research studies have been carried out to characterize individual droplet impact, usually driven by an interest in a particular process. These studies include extensive modeling of droplet deposition, some of which are supported by experimental studies. Most of these modeling activities have focused on the impingement of a droplet on to a surface to predict quantities such as the extent of maximum spread and the final equilibrium diameter, the rate of heat transfer to the substrate, and the solidification rate.

1.2 Current Problems

Due to interaction of several complex phenomena, comprehensive modeling of the droplet deposition is a challenging task. The flow of liquid droplet upon impingement is itself a complex phenomenon. Heat transfer and solidification occurring concurrently with the flow adds further to the complexity. Further the heat transfer in the liquid metal droplet is dependent on the less understood flow of heat through liquid-substrate air gap. While studying the reported research activities on modeling of liquid metal droplet impingement upon a substrate, it was found that none of the models took into account all the important phenomena associated with the droplets, viz., fluid flow, convective and conductive heat transfer, surface tension, solidification and resistance to heat flow through the air gap. Finally the validation of the mathematical model has been a challenge due to the small size of droplet and the short time period of the impingement process. Thus the present study aims at the development of a comprehensive mathematical model of impingement of liquid metal droplet upon a substrate and experimental validation of the same using Jackson – Hunt theory.

1.3 Key Idea

In the present work comprehensive 2-D (axi-symmetric) modeling of deposition of a spherical liquid metal droplet on a substrate has been attempted on FLUENT 6.3.16 platform. The comprehensive model is based upon volume of fluid method and incorporates the fluid flow, effect of surface tension on the fluid flow, heat transfer in the droplet, surrounding air and the substrate, resistance to the heat flow due to the air gap, natural convection, solidification and variation of the physical properties with temperature.. The resistance to heat transfer due to air gap was estimated using inverse modeling approach.

Further the validation of the droplet impingement model was done using Jackson – Hunt theory. According to Jackson – Hunt theory inter-lamellar spacing in a solidified eutectic alloy is related to the velocity of the solidification front. Since very few studies have been carried out on sequential deposition, the comprehensive mathematical modeling of sequential impingement of Al-33wt%Cu double droplets on 304 stainless steel substrate was also attempted on FLUENT 6.3.16 platform and the model was validated using Jackson – Hunt theory.

Thus the objectives of the present study include the following:

i) Development of a comprehensive model, which incorporates the complex interactions of all the important phenomena, of impingement of Al-33wt%Cu on 304 stainless steel substrate on FLUENT 6.3.16 platform. .

ii) Validation of the model using Jackson – Hunt theory.

iii) Simulation of sequential impingement of double Al-33wt%Cu droplets on a 304 stainless steel substrate.

This chapter (Chapter 1) provides a brief introduction of the present work along with its primary objectives and a brief look at the gaps in the modeling of impingement of liquid metal droplet on a substrate. Chapter 2 presents a literature review on the subject matter of droplet impingement on a substrate. Formulation of mathematical model of impingement of Al-33Cu droplet on a substrate and that of solidification of Al-33Cu in different molds, along with the governing equations, assumptions, discretization schemes and solution methods are presented in Chapter 3. Chapter 4 describes different experimental procedures involved in the present study. Chapter 5 describes the (a) result of the inverse modeling for determination of the thermal resistance of air gap between Al-33Cu and 304 stainless steel, (b) result of modeling of impingement of single droplet on a substrate along with the experimental validation of the same using Jackson-Hunt theory, and (c) result of the modeling of sequential impingement of two droplets. Further, in this chapter, results obtained have been discussed in the light of the state-of-arts knowledge in this field. Chapter 6 presents the conclusions of this study and future scopes.