
Center for Transportation Infrastructure and Safety

# Modeling of Laser Cladding with Application to Fuel Cell Manufacturing

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16. Abstract

This project is aimed at graduate research training of students interested in pursuing careers in transportation areas. Each year, financial support was provided to recruit eight new graduate students interested in pursuing a doctoral degree in a transportation area. These students could pursue doctoral studies in any department at Missouri S&T. In departments where a master's degree is the highest degree awarded, students pursuing a master's degree with a thesis option will be considered. Areas stated in the goals, interests and objectives of the State Departments of Transportation and Missouri Department of Transportation in particular were considered for support in this project.

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## Modeling of Laser Cladding with Application to Fuel Cell Manufacturing

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### 1 Introduction

Polymer electrolyte membrane (PEM) fuel cells have many advantages such as compactness, lightweight, high power density, low temperature operation and near zero emissions. Although many research organizations have intensified their efforts towards commercialization of fuel cells, several technical problems are yet to be overcome. One of the important issues is the availability of low cost bipolar plates. Thus far carbon-based bipolar plates have been the main focus of the development activities. These materials will fulfill all requirements in the near future. Nevertheless, further cost reduction and an increase of power density is beneficial for fuel cell technology [1]. Bipolar plates based on coated metals offer a high potential to reduce costs and enhance power density. Aluminum, stainless steel, titanium, and nickel are considered possible alternative materials for the bipolar plate in PEM fuel cells. These metals need to be coated properly because bipolar plates are exposed to an operating environment with a pH of 2–3 at high temperatures. Borup and Vanderborgh [2] suggest that coatings for bipolar plates should be conductive and adhere to the base material properly to protect the substrate from the operating environment. Laser cladding is considered an alternative coating process for solid or modular metallic bipolar plates. In laser cladding, the coating material is metallurgically bonded with the substrate, which is very important for the functioning of bipolar plates. The advantages of laser cladding include chemical cleanliness, localized heating, low dilution of the cladding material by the substrate and rapid cooling rates. To understand the relationships between the fuel cell component performance and manufacturing process parameters and variability, a numerical model has been developed to simulate the physical phenomena associated with laser cladding of bipolar plates. This report summarizes the numerical model developed.

### 2 Numerical modeling

Figure 1 shows a schematic diagram of the calculation domain, including the substrate, melt pool, remelted zone, deposited layer and part of the gas region. In this study the continuum model by Bennon and Incropera [3, 4] is adopted to derive the governing equations for melting and solidification with mushy zone. For the system of interest, the conservation equations are summarized as follows:

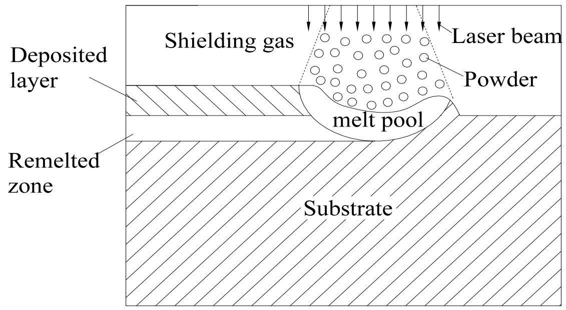



Figure 1: Schematic of the calculation domain

Continuity

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{V}) = 0 \tag{1}$$

Momentum

$$\frac{\partial}{\partial t}(\rho \vec{V}) + \nabla \cdot (\rho \vec{V}\vec{V}) = \nabla \cdot (\mu_l \frac{\rho}{\rho_l} \nabla \vec{V}) - \nabla p - \frac{\rho}{\rho_l}(\vec{V} - \vec{V}_s) + \rho \vec{g} + S_1 \tag{2}$$

Energy

$$\frac{\partial (\rho h)}{\partial t} + \nabla \cdot (\rho \vec{V} h) = \nabla \cdot (k \nabla T) - \nabla \cdot (\rho (h_l - h)(\vec{V} - \vec{V}_s)) + S_2 \tag{3}$$

In eqns. (1)-(3), the continuum density, specific heat, thermal conductivity, vector velocity and enthalpy are defined as follows:

$$\rho = g_s \rho_s + g_l \rho_l \quad c = f_s c_s + f_l c_l \quad k = g_s k_s + g_l k_l$$

$$\vec{V} = f_s \vec{V}_s + f_l \vec{V}_l \qquad h = f_s h_s + f_l h_l \tag{4}$$

The liquid fraction temperature relationship is given by:

$$g_l = \begin{cases} 0 & \text{if } T < T_s \\ \dfrac{T - T_s}{T_l - T_s} & \text{if } T_s \le T \le T_l \\ 1 & \text{if } T > T_l \end{cases} \tag{5}$$

The other volume and mass fractions are obtained by:

$$f_l = \frac{g_l \rho_l}{\rho} \quad f_s = \frac{g_s \rho_s}{\rho} \quad g_s + g_l = 1 \quad f_s = 1 - f_l \tag{6}$$

The phase enthalpy for the solid and the liquid can be expressed as:

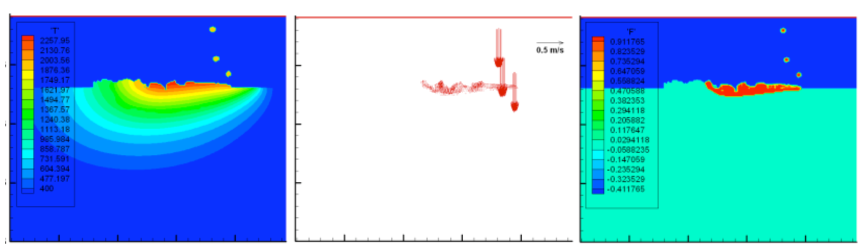
$$h_s = \int_0^T c_s(T)dT \qquad h_l = \int_0^{T_s} c_s(T)dT + \int_{T_s}^{T} c_l(T)dT + L_m \tag{7}$$

where $L_m$ is the latent heat of melting.

The melt pool configuration is defined in terms of a volume of fluid function, F(x,y,t), which satisfies the conservation equation:

$$\frac{\partial F}{\partial t} + (V \cdot \nabla)F = 0 \tag{8}$$

The governing equations and all related supplemental equations and boundary conditions are solved through an iterative scheme, which is based on the SOLA-VOF algorithm by Nichols et al. [5]. The parameters for simulations are chosen based on the capability of our experimental facilities. Fig. 2 shows the simulated temperature, velocity and VOF function fields. The simulation results under different process parameters have been verified with experiments.



(a) Temperature (b) Velocity (c) Volume of fluid

Figure 2: Simulation results at t = 130 ms (laser power: 910W, travel speed: 20ipm, powder mass flow rate: 4.68g/min)

## 3 Conclusions

A comprehensive numerical model has been developed for laser cladding of coated metallic bipolar plates in PEM fuel cells. The model considers heat transfer, melt pool fluid dynamics, powder particle dynamics, etc. It can be used to predict thermal history of the process, coating dimensions and melt pool dimensions.


## Acknowledgements

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