

## **565f Multiscale Modeling for Quality-Constrained Thin-Film Development in Automotive Coating Material Applications**

*Jia Li and Yinlun Huang*

System modeling could be a challenging work, if product modeling and process modeling are simultaneously required. This is especially true if the system under study demonstrate various chemical and physical phenomena at different scales of length and time. Under such circumstances, multiscale modeling is always necessary to characterize the system behavior at different scales. Such modeling should help understand system behavior more comprehensively, and thus provide more convincing solutions for system performance improvement through multiscale integration.

In this work, a multiscale modeling method is proposed to model the dynamic phenomena demonstrated in paint spray of an automotive coating material application process. A multiscale model is developed utilizing transport equations, discrete phase change equations, as well as CFD implementation. At the process level, a macroscopic model is developed to characterize the operational behavior of a multi-zone spray booth. In detail, the model is developed to reveal turbulent airflow patterns and operational environmental conditions, as well as paint particle moving trajectory in operation. A solution approach takes into account the initial paint particle conditions from spray nozzles, process settings (airflow, booth temperature, humidity, etc.), and process/product geometries. Model-based simulation provides paint particle distribution on the target product surface, which is the key information to a microscopic model that describes paint thin film formation on vehicle panels.

The microscopic paint-thin-film-formation model is developed using a rule-based Monte Carlo (MC) simulation method. By this method, the stochastic particle behavior in deposition and wet paint layer formation within the microscopic scale are revealed. The factors considered include: (i) paint particle size distribution, (ii) particle velocity distribution, (iii) hitting position, and (iv) initial substrate surface (e.g., the thickness distribution of previous paint layer and its stiffness). As paint particles land on the substrate surface, a leveling model is activated to compute surface formation according to surface tension gradient and the paint gravity.

The microscopic film formation model is related to the product quality in term of film thickness and topology, while the macroscopic model presents processing concerns such as energy consumption due to airflow. This multiscale model establishes the connections between the product quality at the microscopic level and the energy issue at the macroscopic level. Various model-based process design strategies are derived for energy reduction with quality assurance. An industrial vehicle paint spray process is studied in detail to show the effectiveness of the multiscale modeling approach.