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Numerical investigation of coarse powder and air flow in an electrostatic powder coating process

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Abstract

The work presented here reports on the numerical simulation of an electrostatic powder coating process that uses a commercial computational fluid dynamic code, FLUENT v6.1. The purpose of this study was to understand the gas and particle flow fields inside a coating booth under given operating conditions and the effect of particle sizes on its trajectories and the final coating quality. The air and powder particle flows in a coating booth were modeled as a three-dimensional turbulent continuous gas flow with solid particles as a discrete phase. The continuous gas flow was calculated by solving Navier–Stokes equations including the standard $k-\varepsilon$ turbulence model with non-equilibrium wall function and the discrete phase was modeled based on the Langrangian approach. Since the solid phase volumetric fraction was less than 0.1%, the effect of particle–particle interaction on particle trajectories was not taken into account. In addition to drag force and gravity, the electrostatic force including the effect of space charge due to the free ions was considered in the equation of motion and implemented using user defined scalars and functions. The governing equations were solved using the second order upwind scheme. Information was provided on the particle trajectories with respect to the particle diameters that could be used to develop suitable operating conditions for the use of fine powders in a powder coating process.

Keywords: Powder coating; Numerical simulation; Electrostatics; Powder; CFD

1. Introduction

The concept of powder coating originated in the USA in the 1950s [1]. Significant growth has been achieved in the last two decades with its introduction into new markets, where liquid painting is traditionally used such as automotive clear top coatings, can and coil coatings, as well as coatings for industrial wood, plastics and paper. Electrostatic powder spray coating begins with a fluidization process where powder is mixed with compressed air that enables it to be pumped from a container and supplied to the powder spray guns. Powder flow is regulated by controlling air supplied to the pump. The powder supplied to the spray gun is charged using either a corona or tribocharging spray gun. Charged powder moves to the grounded workpiece where air supplied to the spray guns and the airflow in the coating booth helps to coat it. When the powder particles come close to the coating part, the electrostatic attraction between the charged powder particles and the grounded coating part makes powder adhere to the coating part.

The powder coating process is considered more economical and more ecological compared to wet painting due to the avoidance of the solvent and the nearly complete recycling of over-sprayed powder. With these benefits, it has attracted much interest in its further development. The uppermost goal for powder coating technology is to provide coatings that are at least equal in performance to liquid coatings without sacrificing ease of application and environmental advantages. There are several specific areas where powder coating technology advances are seen to be evolving: improving weatherability (exterior durability), thinner films, greater appearance offerings, and improved performance [2].

There are three main areas of interest in the powder coating process. One is the powder charging, the second is the powder

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transport region in which the charged powder travels from the spray gun to the earthed workpiece under the effect of aerodynamic, electrostatic and gravity forces, and the third is powder deposition/adhesion to the workpiece due to electrostatic attraction force. There are several important parameters. These include: (1) air flow rate; (2) powder spray rate; (3) applied voltage; (4) coating part shape, size and its position relative to the spray gun tip; (5) booth and gun design; (6) humidity; and (7) powder properties such as particle size distribution, chemical composition, tribo and corona charging characteristics, electrical restistivity, hygroscopicity, fluidity and shape distribution that play a significant role in the performance of a powder coating process. Optimization of all these parameters can lead to improved coating efficiency and coating quality.

Mazumder et al. [3] studied physical properties of the powder such as: (1) particle size distribution, (2) fluidity as a function of particle size and agitation of the fluidized bed, and (3) bulk charge-to-mass ratio and charge distribution. Their study showed that the mean particle size and the particle size distribution played an important role in coating quality. For uniform coating, powder flowability is of paramount importance and powder should be able to flow smoothly and be well dispersed through the spray gun while maintaining a constant mass flow rate. Barmuta and Cywinski [4] showed similar observations and stated that coating efficiency depended on the size fraction of the particles. It was also very important to observe the coating quality and to maintain the proper ratio of recycled powder to fresh powder in order to ensure constant coating quality. Sims et al. [5] tried to optimize the powder coating process so that a thin film could be employed with minimal surface defects. They determined the optimum high voltage or the electrostatic field at which the corona guns need to be operated to obtain a high First Pass Transfer Efficiency (FPTE) and a low free ion current. The FPTE was defined here as the ratio of the mass deposited on a coating part per unit time to the total mass sprayed through the spray gun. Clearly, the particle size, particle size distribution and flowability of the powder are very important parameters that affect the coating efficiency and quality. The particle trajectories inside a coating booth depend on the powder parameters and other operating conditions such as the airflow rate and applied electrostatic voltage at the spray gun electrode. Therefore, it is very important to study the particle trajectories for a given powder under certain operating conditions to understand its flow behavior.

Besides performing experiments, the validated numerical methods can also be used to simulate the coating process in order to provide significant insight into the process and to predict the effect of different operating parameters such as the airflow rate, powder spray rate, applied corona voltage, particle size etc. on the coating efficiency and quality. Ali et al. [6] developed a mathematical model for the electrostatic field of the corona powder coating system to simulate a single particle trajectory for a given charge to mass ratio, particle diameter and initial position. Adamiak [7] presented a numerical algorithm that combined the finite element method for electrostatic field analysis and the numerical integration of the equation for the particle trajectories to simulate the electrostatic field distribution and particle trajectories in a tribo-charge powder coating system. Several other researchers [8–10] also studied the powder coating process, but they focused more on understanding the effect of the electrostatic field. In 2001, Bottner and Sommerfeld [11] attempted to simulate the three-dimensional turbulent coating spray flow under the effect of an electrostatic field using the in-house code FASTEST which was based on a non-orthogonal, block-structured finite volume approach. The space charge effect was ignored when calculating the electrostatic field. They carried out the numerical simulations for two types of powder spray guns and two types of coating parts and suggested that numerical methods could be used to support and optimize the design of powder coating booths.

Ye et al. [12] used the commercial computational fluid dynamics (CFD) code, FLUENT, to simulate the three-dimensional electrostatic powder coating process using a corona spray gun. The simulations were carried out while considering the influence of airflow field, electrostatic field and the turbulent dispersion on the particle trajectories. The effect of the space charge due to the charged particles on the electrostatic field was accounted while the effect of the particle–particle interaction on the particle trajectories and two-way coupling between the discrete and continuous phase was ignored. Ye and Domnick [13] expanded above model using FLUENT v6.0 to include the effect of the space charge due to the free ions present in the corona discharge process. They found that the effect of the space charge was significant and it tended to increase the strength of the electrostatic field in the region between the two electrodes, especially near the grounded coating part.

The validated numerical model [14] has been used in this paper to study the complete electrostatic powder coating process using coarse 'regular' powder with a sauter mean diameter of 39 μm. The purpose of the study was to understand the air/particle flow field inside the coating booth under certain operating conditions and to have a greater insight into how powder particles with different sizes travel inside the transport region and their effect on the coating quality. The overall objective of the project was to develop a process whereby fine powder with a mean size of 15 μm can be used to achieve better coating quality.

2. Coating booth and powder spray gun set-up

The powder coating system used in this work consists of a coating booth and a powder spray gun. The coating booth is shown in Fig. 1 and has dimensions of 0.81 m (L) × 1.01 m (D) × 0.87 m (H). There is one suction hole 2.9 cm in diameter located on the top wall of the booth at the centre along the z-axis 10 cm from the back wall. The suction pressure should be sufficient to keep all the powder particles inside the coating booth and still have a minimum effect on the flow field between the spray gun and the coating part.

A Nordson corona-charging gun [15] is used in this study. As shown in Fig. 2, the spray gun consists of four parts, the pattern