

Review of Optimizing powder coating parameters and comparing the effects of single and dual coats on mild steel

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Abstract—This study focusses on optimizing powder coating parameters and compares the effects of single and dual coatings on mild steel, emphasizing the significance of dry film thickness. Key parameters under consideration include curing temperature, application technique, dry film thickness (DFT) and Coating Process Parameters. By systematically varying these parameters, the aim is to identify optimal conditions that enhance adhesion, durability, and overall coating performance. Standardized testing methods are employed to evaluate both single and dual coating systems in terms of corrosion resistance, abrasion, and impact. In this study we are findings that dual coating performance over the single coating, to achieve greater dry film thickness (DFT) and improved long-term durability. Optimal conditions for dual coating are characterized by elevated curing temperatures and increased dry film thickness (DFT) result in enhanced adhesion and resistance to environmental degradation. In contrast, single coatings, while effective for less demanding applications, demonstrate limitations in protective capabilities over time. This study underscores the importance of optimizing powder coating processes to achieve desired dry film thickness, which is crucial for ensuring longevity and effectiveness. The insights gained will serve as a valuable resource for industries aiming to improve the performance of mild steel applications through advanced powder coating technologies.

Index Terms—Dry Film Thickness (DFT), Curing Temperature, Single Coat vs Dual Coat, Mild Steel Coating, Coating Process Parameters, Corrosion resistance, Impact.

I. INTRODUCTION

Coatings are frequently used to protect the surface of machine parts and to give them special functional properties. Copper and its alloys can be used as coating materials to increase the thermal and electrical

conductivity of products [1,2]. The origins of powder coating technology can be traced back to the late 1940s when thermoplastic powder was first used as a coating for metal and other surfaces through a process known as flame spraying. This involved feeding plastic powder into a flame spraying apparatus, where the particles would melt and be propelled onto the substrate by hot gases. The first pass transfer efficiency (FPTE) and film uniformity in a corona charging powder spray process were dependent on total air volume, powder output, powder properties and spray gun voltage [3-5]. The total air volume was used as a medium to transfer the powder from the fluidizing bed to the coating target surface. For a uniform mass flow of the powder, the powder must be well dispersed, thus providing a dilute phase flow [4,6]. Airflow and the aerodynamic force play a very important role in transporting particles from the spray gun to the region near the coated part [5]. A relatively high air volume and associated turbulence hinder the deposition of paint particles from reaching close to the target surface [7,8]. The total air volume affects not only the penetration of powders into the recessed area of the coated object, but also the transfer efficiency of the coating system [9]. The transporting air must be strong enough to guide the particles in the direction of the spray, but the particles will lose their momentum when approaching the target surface and this is where the electrostatic force should be dominant for higher deposition rates [10,11]. The gun-to-part distances also affected the powder FPTE and coating quality [12,13]. Distances of 3 to 12 inches provided the desired results, depending on the nozzle type, part configuration and number of guns used [14]. A significant development in powder coating came in the mid-1950s when Erwin Gemmer pioneered the

fluidized-bed coating process. This method involved dipping a heated object into a bed of powder that had been fluidized or turned into a fluid-like state by air or another gas. Gemmer, who had been involved in developing flame spraying processes and materials at Knapsack-Griesheim laboratories, sought a more efficient coating method than flame spraying. The first patent applications for this process were filed in Germany in May 1953, and the Polymer Corporation acquired the rights to the Knapsack-Griesheim patents. The Polymer Corporation then made a concerted effort to develop, license, and sell fluidized bed coating technology in North America. However, the adoption of this coating process was initially slow. By 1960, annual sales of coating materials had begun to increase, marking a turning point in the acceptance of powder coating technology. [15] In the United States, powder coating adoption initially lagged, with installations below 450 thousand due to a lack of expertise in the methodology. Additionally, the cost of available powder coating materials was high, efficient production techniques had not been developed, and production volumes were low. However, today, powder coating is widely embraced, with thousands of installations in OEM factories and custom coating jobs. It has become the preferred method for coating a variety of items, including lawn and garden equipment, metal furniture, electrical cabinets, lighting, shelving, store fixtures, and automotive components.

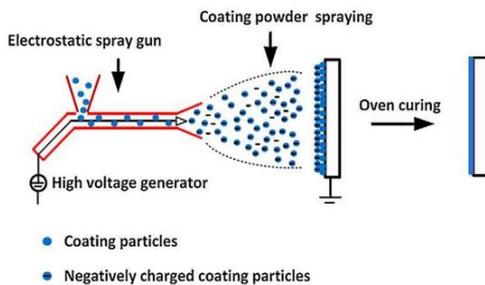


Figure-1 Electrostatic powder coating.

II. POWDER COATING PROCESS

The manufacturing of powder coatings was different from other kinds of coatings. Resin, pigment, filler, curing agent and other additives were mixed in certain proportion. Then the compositions was extruded, crushed and screened to gain powder of coating. The powder always was stored at room temperature. The

powder coatings often operated by two kinds that electrostatic spraying method applied for thermoset powder coatings and fluidized bed dipping method used for thermoplastic powder coatings. After that, the powder was heated to melt and cure. Finally, a smooth bright permanent film on articles was formed to achieve the purpose of decoration and corrosion. There are two methods for the production of powder coatings, such as dry process production and wet process production [17].

III. ELECTROSTATIC POWDER COATING TECHNIQUE

Powder coating involves applying a dry coating. Unlike traditional liquid coatings that are dissolved or suspended in a liquid medium such as solvent or water, powder coating is applied in a granular form. This material is finer than ground pepper but coarser than flour and is applied directly to the surface to be coated. The powder is created by blending various components such as binders, resins, pigments, fillers, and additives, and then processing them through an extruder into a continuous mass. This homogenous mass is cooled, broken into small chips, and ground into powder. Each powder particle contains all the necessary components to form the finished coating [16].



Figure-2 The concrete production diagram of melt mixing method [17].

IV. OBJECTIVE

- To get optimum dry film thickness
- To minimize the blister defect
- To minimize the color difference defect
- To minimize the pin hole defect

V. LITERATURE REVIEW

The application of powder coating technology has grown steadily by double digits globally over the last ten years [18]. There is a great need for research to provide more effective methods of applying powder coatings because of this rapid expansion. Powder coating is a dry finishing technique that coats items with fine pigment and resin particles. Compared to traditional liquid coating applications, this approach offers substantial economic and environmental benefits. Almost all volatile organic compounds are not needed when using powder coating, which has the potential to recycle all of the resources efficiently. Electrostatic spray coating is the most common process used for the application of powder coatings on metal finishing. The process consists of four main steps: (1) transport the coating powder from a fluidized bed feeder to the spray gun, (2) charge the particles within the gun, (3) deposit the powder on the grounded workpiece inside a booth, and (4) collect the overspray and recycle it to the feeder. Following coating, each workpiece is transported to the oven for the last stage of curing.

The process of electrostatic spraying is intricate and necessitates the adjustment of multiple process parameters to attain the intended outcome. However, research on electrostatic spraying process has been slow compared with the fast deployment of the process.

Regrettably, the intrinsic intricacy of the powder flow and electrostatic phenomena within the spray booth may have impeded study endeavors. Airflow, electricity, and gravity work together to control the path of charged particles as they go from the spray gun to the grounded target. Particles are carried to the part by the spray gun's air stream and are pushed in the direction of the grounded target by the electric force. The aerodynamic and gravitational forces acting on the particles must be countered by the electric force, which is the product of the particle charge and the field strength [18].

The particle is drawn to the grounded metal component by the charged particle once it approaches or reaches the target. A charged powder particle placed adjacent to a metal surface creates a mirror charge Q , or an equal-valued but oppositely polarized charge inside the metal. In addition to being attracted to one another and holding the powder particle to the metal surface, these two charges of equal value and opposing polarity also produce a second electric field. The

particles of succeeding layers of powder coating must generate mirror image charges over the first layer of powder coating that has been applied to a metal surface. This results in reduced adhesion.

At the same time, the electric field strength inside the coating layer grows and more charges build up on the powder layer. When the charged powder is constantly sprayed onto a grounded object, the air trapped between the powder particles is finally ionized by the field strength, which causes micro-sparks to form inside of it [18]. Both positive and negative ions are produced in large quantities during the coating layer's ionization process. Positive ions attempt to escape from the coating layer in the direction of the gun's negative electrode because opposing charges attract. The powder's trajectory is changed as the positive ions exit the coating layer and neutralize the charges of arriving particles. Back ionization Q , a common electrostatic phenomenon, dramatically reduces coating efficiency and finish quality.

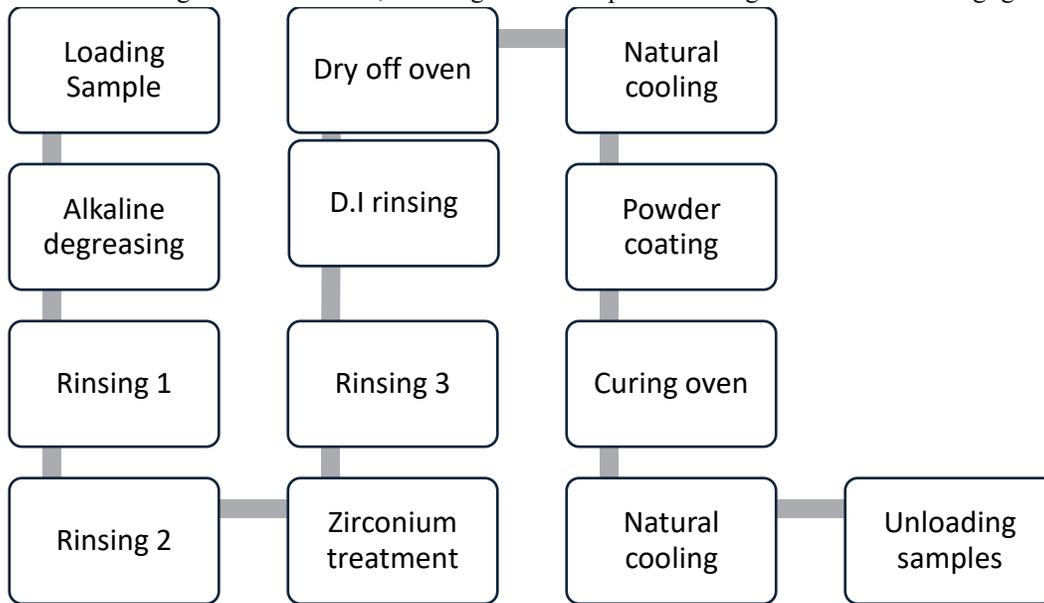
Electrostatic painting utilizes the power of attraction between opposite charges for a cleaner and more efficient painting experience [19]. Similar to how a statically charged balloon sticks to a wall, the object being painted (like a wrought iron fence) is grounded, giving it a negative charge. Meanwhile, the paint particles receive a positive charge through a special spray gun. This creates a strong magnetic pull, drawing the paint particles towards the object and ensuring an even coat that wraps around all surfaces, even intricate ones. Because the attraction is electrostatic, there's minimal overspray, minimizing mess and wasted paint

An iterative strategy was employed to systematically investigate the process parameters affecting powder coating application, aiming to identify conditions that yield uniform coatings.

The spray cloud's shape and the amount of ejected powder coating are controlled by two key parameters: conveying air pressure and dosing air pressure. Conveying air, set between 0.0 and 6.0 bar, plays a significant role in determining the conveyed powder coating quantity by transporting it from storage to the gun through the hose system. Higher conveying air pressure results in more powder coating ejection. Dosing air, adjustable between 0.0 and 6.0 bar, is added to the powder-air mixture to enhance kinetic propulsion, affecting the particle concentration. For lower powder output, a dosing air pressure of 0.6–1.6

bar is recommended, while larger powder mass flows benefit from a lower pressure of 0.2–0.6 bar [120]. Interestingly, a study documented in the context of conventional electrostatic powder coating processes noted a correlation between increasing conveying air velocities and enhanced coating efficiency, resulting in thicker powder coatings. This improvement was observed when employing a novel powder coating feed system designed to disperse agglomerated coarse powder particles into individual particles. Consequently, it can be inferred that the powder coating particles possess a higher charge density, preventing them from being dislodged from the substrate surface despite the heightened air flow velocity [21]. Optimizing powder coating thickness requires careful consideration of conveying and dosing air pressure. At low settings, powder particles lack sufficient acceleration to reach the grounded substrate, resulting

in inadequate film build-up. Increasing dosing air pressure can mitigate this by enhancing particle velocity and deposition efficiency. However, excessively high conveying air pressure can overwhelm the dosing effect, leading to a dispersed powder cloud with insufficient particle acceleration. Again, strategically increasing dosing air pressure proves beneficial. By diluting the overall particle concentration, it allows for more effective particle targeting and promotes a more uniform, thicker coating [22]. Within the range of conveying air pressures between these extremes, there is a harmonious balance between the total powder quantity and the kinetic energy of individual particles. As a result, most of the particles successfully reach the substrate surface and adhere efficiently, facilitated by the formation of liquid bridges and subsequent melting. In this scenario, the impact of dosing air is minimal or negligible



Block diagram for electrostatic powder coating process.

VI. GUN VELOCITY

Following that, an analysis was conducted on the impact of the powder coating gun's velocity in relation to the substrate (as depicted in Figure 2a). Five samples underwent coating using the specified pneumatic parameters. The axial velocity of the gun, referring to its speed along the substrate (as shown in Figure 2a), was adjusted between 20 and 100 mm/s. All other parameters remained consistent with the

previous experiments. The graphs in Figure 2 display the average axial powder coating thickness (represented by unfilled circles on the left axis) along with the corresponding axial standard deviation (depicted by error bars) and the relative axial standard deviation (represented by black squares on the right axis). As the axial velocity of the powder coating gun increased from 20 to 100 mm/s, the layer thickness decreased from 1262 to 323 μm. At the same time, the relative axial standard deviation increased from 3.34%

to 4.37% with the rising gun velocity. This decrease in applied powder mass with increasing gun velocity led to lower coating thickness, aligning with findings in existing literature [22-24].

For attaining a substantial powder coating thickness while minimizing the relative standard deviation, it is evident that lower axial velocities of the powder coating gun are preferable. Consequently, an axial powder gun velocity of 40 mm/s was chosen for subsequent experiments. This selection aligns with findings in literature regarding conventional electrostatic powder coating processes, despite variations in the powder adhesion mechanism that do not appear to impact the correlation between gun velocity and the resulting coating thickness [24].

VII. NOZZLE DISTANCE

To explore the impact of enhanced powder particle adhesion in the automated process described, variations were made in the nozzle distance, ranging from 10.0 to 20.0 cm. The coating thickness initially increases up to a nozzle distance of 12.5 cm, then decreases as the distance continues to increase. Within the distance range of 10.0 to 15.0 cm, the axial standard deviation remains relatively consistent, but it rises with greater nozzle distance. The interplay between axial layer thickness and axial standard

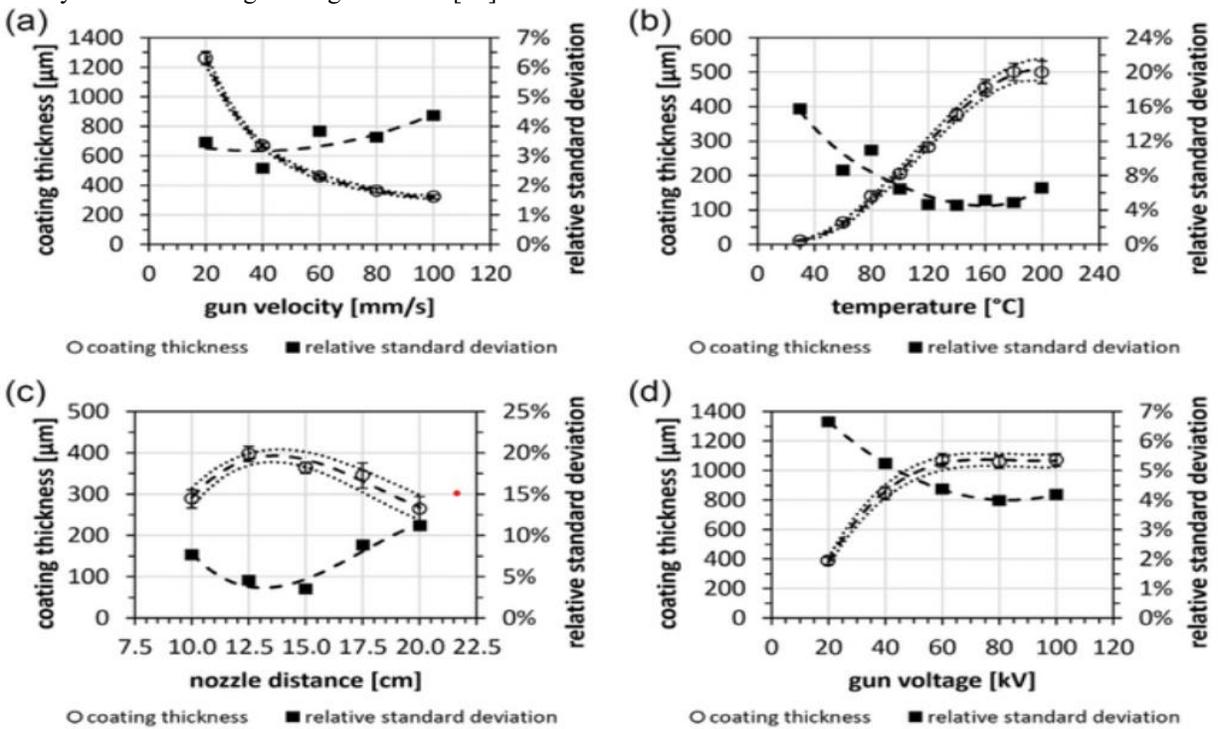


Figure - 3 Effect of parameter deviation generates a parabolic curve for the relative axial standard deviation.

The intricate relationship between the coating thickness profile and the nozzle distance can be explained as follows: the design of baffle plate nozzles results in fewer powder particles in the central region of the spray cloud compared to the peripheral areas, especially at shorter nozzle distances [25-26]. As the distance increases, the spray cloud becomes more uniform, leading to a higher concentration of particles in the central area of the spray cloud, affecting the substrate. Consequently, the thickness of the powder coating film applied to the substrate increases up to a

nozzle distance of 12.5 cm. However, as the distance between the powder coating nozzle and the substrate continues to increase, gravitational force becomes more dominant, resulting in fewer powder coating particles reaching the substrate [27].

Furthermore, particle velocity decreases with distance from the nozzle, indicating a stronger gravitational force [28]. Karidkar et al. using the Taguchi method, parameters were optimized for a powder spray process [29]. Increasing nozzle distance resulted in decreased film thickness [30]. The developed method aligns with

the literature on electrostatic powder deposition, indicating that nozzle distance remains a crucial factor for successful layer deposition, even with increased particle adhesion.

VIII. GUN VOLTAGE

Electrostatic forces significantly impact particle adhesion and film formation efficiency in traditional electrostatic powder coating processes. The gun voltage used to charge particles plays a crucial role in process control [30]. Capillary bridges mediate adhesion in this process, making particle charge less of an influence. To study the impact of particle charge, the gun voltage varied from 20 kV to 100 kV (Figure 3d). Surprisingly, the axial coating thickness gradually increases with high voltage up to 60 kV and then levels off. As the coating thickness increases, so does the axial standard deviation. However, increasing the powder coating gun voltage up to 60 kV reduces the relative axial standard deviation. After that, the relative axial standard deviation remains relatively stable, likely due to charge saturation.

Similar charge saturation effects have been reported in literature. Dastoori et al. found that layer thickness reached a maximum at 50 kV after analyzing the effect of gun voltage from 30 to 80kV. Increasing the voltage did not result in thicker layer [32]. Electrostatic charging, despite increased particle adhesion, has a significant impact on the deposition process by influencing particle transport to the grounded substrate.

In many applications, the corona gun and substrate move relative to each other. The powder flow and high voltage are activated when the substrate approaches the gun. Powders fluidized in a fluidized bed and transported by a powder pump through a hose become triboelectrically charged, typically with a positive polarity [32]. To obtain a negative charge distribution, the particles' initial positive triboelectric charge must be neutralized first. To achieve a uniform negative charge distribution and maintain the negative corona process, the gun voltage must be sufficiently high. When the gun voltage is reduced, some particles may not reach the desired charge level. To reduce the need for high voltage but low ion current, powder-coating equipment manufacturers use an ion robber electrode attached to the corona gun. This diverts some

of the ion current to the electrode, delaying the onset of back corona on the substrate.

IX. CONCLUSION

This review has explored the optimization of powder coating parameters and compared the effects of single and dual coats on mild steel. Key factors such as curing temperature, application techniques, powder composition, and film thickness were identified as critical to achieving high performance in terms of adhesion, durability, corrosion resistance, and aesthetics. The comparison of single and dual coatings shows that dual coats offer superior protection, particularly in harsh environments, by providing enhanced resistance to wear and corrosion. While dual coats increase thickness and cost, they offer a more robust protective layer. In contrast, single coats are more cost-effective and suitable for less demanding applications. Ultimately, the choice between single and dual coatings depends on the specific requirements of each application, balancing performance, cost, and environmental factors. Future research should focus on refining powder coating processes to further optimize material use, performance, and sustainability in industrial applications.

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