International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Performance Improvement of Powder Coating on Automobile Surfaces by Controlling and monitoring Parameter through Spray Gun: Review

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ABSTRACT

As environmental regulations become increasingly stringent and consumer awareness regarding environmental protection rises, there is an urgent need to minimize the use of volatile organic compounds (VOCs). Powder coating, which consists of solid powder without any solvent, has emerged as a viable solution. Its superior application performance and eco-friendliness have led to its widespread adoption in the automotive industry, particularly for coating metal surfaces of vehicles, including the body and wheels. In recent years, the utilization of powder coatings has expanded rapidly, with a growing emphasis on functional powder coatings. Based on the resin used for film formation, powder coatings can be categorized into two main types: thermosetting and thermoplastic powder coatings. Each type possesses distinct advantages and disadvantages, making them suitable for various applications. Numerous studies and reports have been conducted to enhance the properties of powder coatings. The components of these coatings are extruded, crushed, and screened to produce the final powder, which is typically stored at room temperature. Application methods for powder coatings include electrostatic spraying and fluidized bed dipping. Following application, the powder is heated to melt and cure, resulting in a smooth, durable film that serves both decorative and protective purposes against corrosion. The preparation process for powder coatings is generally divided into dry and wet production methods. A summary of the development of powder coatings, including advancements in resins, pigments, and fillers, is provided, along with an overview of future trends in this field.

Keywords: Powder Coatings, Classification, Process Flow of Preparation, Research Progress

I. INTRODUCTION

In the early days of the automotive industry, approximately a century ago, vehicles were coated with a varnish-like substance that was manually brushed onto their surfaces. This initial layer was then sanded and smoothed before additional varnish was reapplied to create multiple layers of coating. Once several layers were established, the vehicles underwent polishing to achieve a glossy finish. Some manufacturers, such as Ford with its Model T line, utilized a combination of brushing, dipping, and pouring techniques to ensure comprehensive coverage and protection of various car components. The entire coating process was conducted manually, often resulting in a timeline of up to 40 days from the start of application to the point when the coating was dry and the vehicle was ready for sale.

Between the 1920s and 1940s, the automotive industry began to adopt spray equipment and alkyd resin-based enamels, which significantly reduced both application and drying times to a week or less. The introduction of these spray coating technologies led to more uniform surface finishes, requiring less sanding.

Automotive coatings continue to advance in response to customer demands and environmental regulations, while also aiming to reduce manufacturing and ownership costs. A notable development in this field is the emergence of smart coatings, which have the potential to greatly enhance surface durability and introduce additional functionalities. These properties may include self-healing capabilities, super-hydrophobicity, self-stratification, self-sensing, soundproofing, and vibration damping. For instance, a smart coating could adapt to environmental changes to prolong its lifespan, and a self-healing coating could react to mechanical abrasions or corrosive incidents through activation by UV light, heat, or mechanical stimuli.

Self-healing can be accomplished through the use of shape memory polymers that respond to variations in temperature and humidity, or to ultraviolet radiation. Additionally, self-healing mechanisms can be facilitated by the expansion of specific clays, such as montmorillonite. Other advanced coatings feature internal sensing abilities that allow for either passive or active activation of fluorescent molecules or quantum dots. In the passive scenario, the sensing system communicates with an external detector to signal and initiate modifications or repairs to the coating. Conversely, in the active scenario, the sensing system independently generates the response signal.

2. Classifications of Powder Coatings

There are two primary systems of powder coatings based on the type of resin used: thermoplastic and thermosetting systems. Thermosetting powder coatings consist of thermosetting resin, a curing agent, pigments, fillers, and various additives. In contrast, thermoplastic powder coatings are composed of thermoplastic resin, pigments, fillers, plasticizers, and stabilizers.

Thermosetting coatings include epoxy resin, polyester resin, and acrylic resin, each combined with different hardeners. Epoxy resin powder coatings are known for their exceptional properties, including corrosion resistance, hardness, flexibility, and impact strength. Polyester resin, characterized by its polar groups, results in powder coatings that exhibit high gloss, excellent flow, and aesthetic appeal. Acrylic resin powder coatings are favored for their weather resistance, color retention, pollution resistance, strong adhesion to metals, and superior film appearance, making them suitable for decorative applications.

On the other hand, thermoplastic coatings typically include polyethylene, polyamide, polyvinyl chloride, and polyvinylidene fluoride. Polyethylene powder coatings are recognized for their outstanding corrosion resistance, excellent electrical insulation, and ability to withstand ultraviolet radiation. Polyamide powder coatings offer high mechanical strength, impact resistance, and hardness, along with low vacuum properties. Polyvinyl chloride powder coatings are notable for their excellent solvent resistance, good corrosion resistance, impact resistance, and ability to prevent food contamination, as well as their high electrostatic spraying insulation strength. Poly trifluorovinyl chloride is a cost-effective option that provides superior corrosion resistance compared to acid-resistant enamels, effectively resisting hydrochloric acid, dilute sulfuric acid, hydrogen chloride, and chlorine corrosion.

3. TRENDS IN AUTOMOTIVE COATING PROCESSES

Current trends in the automotive coating process are driven by the need to reduce manufacturing costs, enhance customer satisfaction through aesthetic appeal and corrosion resistance, and address environmental issues. Significant attention has been devoted to modern automotive coating systems, which exhibit a level of sophistication that meets the expectations of consumers globally. In comparison to three decades ago, the issue of corrosion has been largely mitigated, and the durability and appearance of topcoats are now deemed satisfactory for the lifespan of a vehicle. Notably, the global adoption of two-layer topcoats has ensured that the color, gloss, and chip resistance of automotive coatings remain in commendable condition during the initial 7-10 years of a vehicle's operation. Additionally, aesthetic considerations are increasingly aligned with automotive design trends. Therefore, an examination of the latest developments in automotive coatings will be discussed in the following sections.:

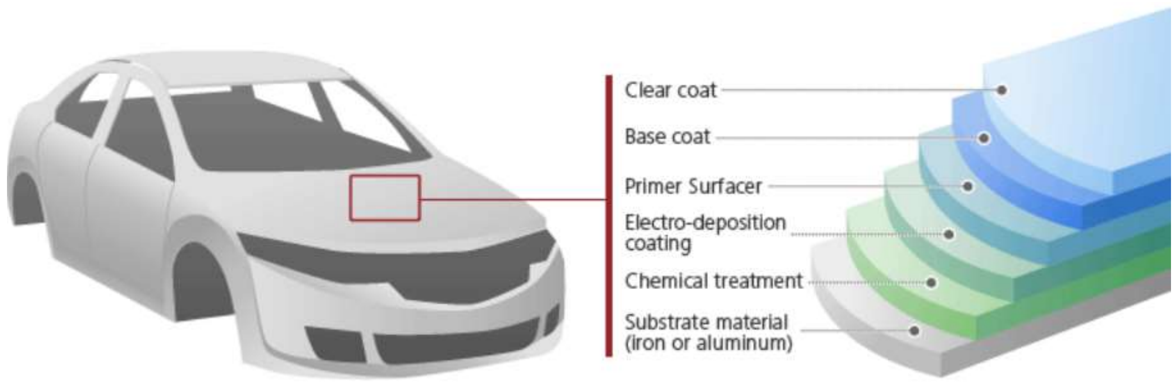
Fig.1. Powder Coating

One approach to mitigating the emission of volatile organic compounds (VOCs) has been the substitution of liquid coatings with dry, particulate solid coatings, commonly referred to as 'powder coatings.' These coatings are formulated with significantly low levels of volatile solvents, typically around 2%, which is considerably less than that found in traditional paint systems. Presently, the automotive sector employs powder coating for various components, including wheels, bumpers, hubcaps, door handles, decorative trim and accent parts, truck beds, radiators, and numerous engine components. Additionally, a transparent powder topcoat has been developed, which is currently being utilized by BMW and Volvo in their latest vehicle models. Furthermore, General Motors, Ford, and Chrysler have established a consortium to evaluate this topcoat within their production processes.

4. MODERN AUTOMOTIVE COATING PROCESSES

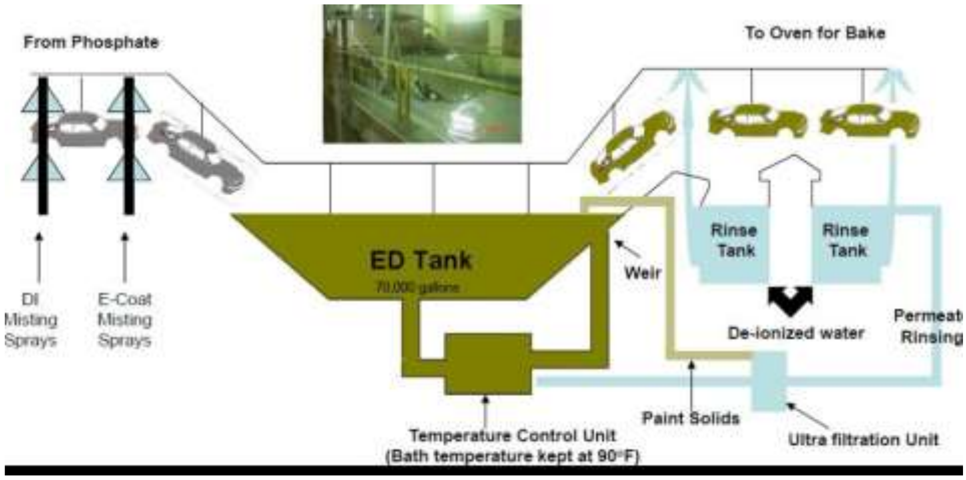
A modern automotive coating method consists of five main steps. They include the following

1) **PRIMER**



One method to reduce the emission of volatile organic compounds (VOCs) involves replacing liquid coatings with dry, particulate solid coatings, commonly known as 'powder coatings.' These coatings are designed with significantly lower levels of volatile solvents, typically around 2%, which is much less than what is found in conventional paint systems. Currently, the automotive industry utilizes powder coating for a variety of components, such as wheels, bumpers, hubcaps, door handles, decorative trim and accent parts, truck beds, radiators, and many engine components. Moreover, a transparent powder topcoat has been developed and is now being used by BMW and Volvo in their latest vehicle models. Additionally, General Motors, Ford, and Chrysler have formed a consortium to assess the integration of this topcoat into their manufacturing processes.

2) ELETRODEPOSITION



E-coating is a process that entails immersing automobile bodies in a coating solution while simultaneously applying an electric current to both the body and the liquid electrodeposition (ED) paint solution. This charged method allows the ED paint to reach areas that traditional spray techniques may miss. During the process, a combination of resin, binder, and a pigment-containing paste is introduced into the ED tank. The automobile body is submerged in this tank, where an electric current is applied; the solution typically comprises 80-90% deionized water and 10-20% paint solids. The resin serves as the foundation of the final paint film, offering corrosion resistance, durability, and strength, while pigments contribute to the color and gloss of the finish. Following the E-coating, the automobile body is placed in a bake oven, where it is heated to 160°C for 10 minutes to cure the film and optimize its performance characteristics. The temperature and duration of heating primarily improve chip resistance and the adhesion of the film to the body, with less impact on corrosion protection. To enhance the smoothness and luster of the topcoat, some sanding is typically conducted to rectify any surface imperfections before proceeding to the next application phase. A prevalent issue in the E-coating process is the formation of water spots that can mar the coated surfaces. If such spots are detected, they must be addressed through sanding. Therefore, it is crucial to utilize well-deionized water and to regularly check its conductivity. Additionally, operators may incorporate surfactants or ultrafiltrates into the water rinse area to mitigate or eliminate the occurrence of water spots.

5. AUTOMOTIVE COATING PERFORMANCE

The evaluation of automotive coatings can be approached from various perspectives, such as the longevity of both exterior and interior paint finishes, as well as their aesthetic qualities. Nonetheless, there are constraints regarding the properties of the paint, the capabilities of the application processes, and, most critically, the budget allocated for enhancing the finish. As a result, each automotive manufacturer establishes its own standards for color and appearance, aiming to meet or surpass the benchmarks set by competitors and the expectations of consumers. In assessing coating performance, we consider several key features:

a) Coating Quality: This can be evaluated based on three primary criteria: resistance to harsh environmental conditions, durability, and visual appeal.

b) Color: Achieving a uniform and consistent color is vital for conveying a high-quality finish and minimizing customer dissatisfaction. This aspect is significant not only at the point of sale but also throughout the vehicle's lifespan. Factors affecting color tone include the orientation and concentration of pigments.

c) Corrosion Protection: Automotive coatings encounter a variety of environments and conditions throughout their service life. The degradation of the coating is influenced by three main factors: the formulation of the coating, the intensity of the environmental conditions, and the duration of exposure. Prolonged exposure to ultraviolet light from the sun, heat, and humidity can have detrimental long-term effects, varying in severity based on climatic and weather conditions.

6. LITERATURE SURVEY

Filler materials serve not only to enhance the thickness of powder coating films but also to improve their durability, hardness, and various other properties. It is important to note that different fillers possess distinct characteristics.

Grigoriev A. Y. et al. [1] demonstrated that the hardness of the friction surface in composites is influenced by the strain hardening susceptibility of the filler metals, which accounts for the variations in wear resistance. Their research focused on the tribological properties of PA-6 and PA-6 composites with gradient-filled surface layers incorporating tin, lead, and bismuth nano-films at concentrations of up to 1.2 wt%.

Vähä-Nissi M. [2] examined the porosity and average pore size of powders with a similar polymer to $CaCO_3$ ratio in conventional paper coatings. This study assessed the viability of utilizing highly filled powders comprising 100 parts by weight of calcium carbonate and 10 parts by weight of polymer, which serves as a binder, to reduce energy consumption during the curing process while enhancing adhesion and hardness properties. Kalaee M. et al. [3] investigated the catalytic influence of $nCaCO_3$ on the curing reaction of polyester/epoxy powder coatings. Their findings highlighted the effects of static acid-coated $CaCO_3$ nanoparticles on the morphology, curing behavior, adhesion, and hardness of the polyester/epoxy blend powder coatings. Additionally, a study [18] evaluated the scratch and wear performance of two thermosetting powder coatings with varying weight fractions of filler. The filler, $bMoS_2$ solid lubricant, exhibited superior scratch resistance in epoxy composite coatings compared to polyester composites. Piazza D. et al. [4] conducted an investigation into the characteristics of powder coatings utilizing epoxy/MMT particle nanocomposites with intercalated structures, in comparison to epoxy/barium sulfate micro-composites. The findings indicated that epoxy/MMT particles exhibited superior anticorrosion and physical properties relative to the epoxy/barium sulfate micro-composites. Additionally, the incorporation of MMT into the epoxy matrix resulted in organic coatings with enhanced thermal stability, excellent adhesion, and improved barrier and thermal properties. These advantageous performances are attributed to the effective dispersion and interaction of MMT with the epoxy matrix. Furthermore, the type and volume fraction of filler particles significantly influence the various properties of the coatings.

Mirabedini S. M. et al. [5] explored the application of a novel filler, HDK fumed silica nanoparticles, in powder coatings. The introduction of HDK fumed silica nanoparticles led to improvements in tensile strength, elastic modulus, hardness, energy to break, and adhesion strength of the coating, which can be ascribed to the enhanced dispersion and chemical interactions between the nanoparticles and the polymeric matrix. Currently, the development of fillers with multifunctional capabilities is essential to fulfill the demands for high-quality coatings.

Puig M. et al. [6] investigated the use of organo-modified silica particles with silages (OSP) as an adhesion promoter in polyester powder coatings. The results demonstrated that organo-modified silica particles not only enhanced the adhesion properties but also provided improved corrosion protection for the coatings.

7. CONCLUSION

Automotive coatings are subjected to an extensive range of environments and environmental challenges. The focus on customer expectations, along with the drive to enhance efficiencies and comply with environmental regulations through innovative processes, has advanced automotive coatings to a level previously unimagined a century ago. The visual quality of a surface plays a crucial role in shaping a customer's perception of product quality. Furthermore, as manufacturers strive to deliver surfaces with superior characteristics, customer expectations regarding the attributes associated with coatings continue to rise. This paper provides a thorough and current overview of these innovative processes and coating technologies, aimed at benefiting industrial practitioners and researchers alike. It chronicles and discusses recent advancements in automotive coatings, linking them to enhancements in production technologies and paint formulations. Additionally, modern automotive coating techniques are examined in detail, and the discussion extends to recent trends in automotive coating processes and potential future advancements.

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