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Design and Application of Process for Energy-saving and Environmentally Friendly Automotive Painting

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Abstract: The automotive industry has been developing for nearly a century, and the automotive manufacturing process has been gradually improved. In the process of automobile manufacturing, coating production is an indispensable part, but also the most energy-consuming production link. With the decreasing of ore energy, as well as the increasingly stringent requirements for environmental protection in various regions, the high energy consumption, non-environmental protection, low efficiency and other problems that exist in the current automotive body coating process are exposed more obviously, and a new coating process is needed to upgrade the original process. This paper reduces the emission of industrial waste water and waste gas by adopting new materials such as film pretreatment, "wet-on-wet" coating adhesive and high-solids coating, and at the same time optimises the coating on-line method, medium-free coating process and spraying method to improve the production efficiency and reduce the production cost. Through the use of new materials and new processes, a set of new automotive coating processes with low energy consumption and high efficiency has been designed and applied in automotive enterprises.

Keywords: Automobile, Painting, Wet-on-Wet Process, Film Pretreatment, High Solid Coating

1. Introduction

The development of the domestic automobile manufacturing industry has a history of several decades, and the painting process of automobiles has also been gradually upgraded and optimised with the development of the automobile manufacturing industry. In the process of automobile manufacturing, the painting production line is the most energy-consuming production link, so the use of energy-saving painting process promotes the realisation of clean painting production, but also reduces the production cost of automobiles [1]. Automotive painting is a typical representative of modern industrial painting, which belongs to the advanced protective and decorative painting, about 95% of the internal and external surface area of the car to rely on painting to protect and decorate, painting has become one of the four major processes of automobile factories [2]. In the increasingly fierce market competition, to continuously improve its production efficiency, reduce production costs, and effectively control product quality in the production process is a serious problem facing the development of the automotive industry [3]. At present, most of the process of automobile body for the coating of phosphating pretreatment supporting electrophoresis, solvent-based medium coating and top coat. The process has been applied to the automotive body painting industry for many years, but there are shortcomings such as high energy consumption, high cost of waste water and waste residue treatment, and unfriendly materials to the environment. By utilising green manufacturing production for automotive painting, automotive companies can reduce VOC, CO_2 and wastewater emissions, and reduce the consumption of paints and solvents. It can save energy and resources, improve product efficiency and create a good working environment [4]. In order to solve the problems in the traditional automotive body coating process, this paper improves the original coating process and materials, reduces the coating energy consumption, makes the chemicals more friendly to the environment, improves the production efficiency and reduces the production cost.

2. Material Selection

2.1. Pre-treatment Material

At present, the domestic automobile industry generally adopts the pretreatment method of phosphating, and many years of practice has proved that the pretreatment method of phosphating can meet the production demand and improve the corrosion resistance of electrophoretic coating film, but the large number of uses of phosphating method also exposes a lot of drawbacks [5]. The new process uses a thin-film pre-treatment process instead of the traditional phosphating process. Compared with phosphating, film pre-treatment has the advantages of low temperature, less slagging, no phosphorus and harmful heavy metals, and a variety of plates can be processed in a common line, which plays a great role in the reduction of the production cost of electrophoretic coating and phosphorus-containing waste residue and wastewater treatment cost [6]. The absence of phosphorus in the film pre-treatment process significantly reduces the cost of wastewater treatment and solid waste disposal. At the same time, the film pre-treatment process is used at room temperature, and energy consumption for coating pre-treatment is reduced as a result. The modification of the coating pretreatment process eliminates the need for a surface conditioning process and cancels the use of surface conditioners.

Table 1. *Comparison Of The Economics Of The Ambient Film Pre-treatment Process With The Original Process.*

Items	Original Process	Ambient Film Process
Pre-degreasing temperature	40-50°C	ambient temperature
Degreasing temperature	40-50°C	ambient temperature
Surface condition	Need	No need.
Phosphating (film) temperature	38-42°C	ambient temperature
Solid waste	0.8-1.2 g/m2	0.06-0.1 g/m^2
Phosphorous wastewater	30-60 kg/unit	none

As can be seen from Table 1, the new process in the coating pretreatment material consumption does not increase under the premise of the coating pretreatment energy consumption, sewage treatment costs and solid waste disposal costs have been significantly reduced, while the film pre-treatment for the use of low-temperature, but also extends the service life of the equipment, reducing the coating pre-treatment equipment maintenance costs.

2.2. Electrophoretic Coating

Electrophoretic coating as the most important automotive corrosion prevention key process, in the electrophoresis process, due to the complex structure of the car body, the car body cavity part of the region electric field strength is relatively weak, it is difficult to achieve the process requirements of the electrophoresis film thickness requirements, and thus to improve the electrophoresis film thickness of the inner cavity of the car body has always been a major automotive companies focus on the key points [7]. Figure 1 is a photograph of the appearance of a typical commercial vehicle. Film pre-treatment due to thin film layer, low coating resistance, the inner cavity on the film is difficult, need to choose a higher swimming penetration of electrophoretic coating and its matching. Its main performance indexes are as follows: solids 16% ~ 20%, pigment base ratio 18% ~ 24%, pH 5.5 ~ 6.2, conductivity 800-2200 μs/cm, bath temperature 27 ~ 33 °C. High Transparency Electrophoresis Coatings are designed to improve the conductivity of the electrophoresis bath and the electrical resistance of the electrophoresis wet film by adjusting the resin and curing agent system to achieve the improvement of the swimming penetration. After the increase of the swimming penetration, the thickness of the paint film on the outer surface is reduced while the thickness of the paint film in the inner cavity is increased, resulting in a reduction of the total consumption of electrophoretic coatings on a single vehicle compared to the conventional electrophoretic coatings.

Figure 1. *Commercial Vehicle Body Construction.*

2.3. Weld Sealant

Weld Sealant is a high solid, white viscous substance made of PVC resin, plasticiser, filler, thixotropic agent, stabiliser, etc. The solids are generally greater than 90%. The solid content is generally more than 90%. Weld sealant is usually constructed in the four doors and two covers of the body at the folded edges, the roof of the body, weld seams, etc., mainly to play the role of sealing, waterproofing, etc. [8]. Selection of welding seam adhesive materials suitable for "wet-to-wet" process, that is, no pre-drying type sealant, after the application of adhesive and topcoat with the drying, the cancellation of the sealant drying process, not only saves the investment in the adhesive drying room and the corresponding footprint, but also saves the energy consumption of baking, reducing the adhesive VOC (Volatile Organic Compounds) emissions, and to achieve the purpose of energy saving and emission reduction of coating.

2.4. Topcoat

The so-called environmentally friendly coatings are coatings that do not cause harm to the ecological environment and do not have a negative impact on human health, which is also known as "green coatings", so environmentally friendly coatings must be VOC-free and heavy metal salt-free coatings, the latter of which mainly refers to biologically hazardous lead, chromium, mercury, cadmium and other heavy metal salts. Environmentally friendly coatings are mainly high solid coatings (HSC), waterborne coatings (WC), powder coatings (PC) and ultraviolet electron beam (UV/EB) cured coatings [9]. High-solid coatings are selected to replace the original traditional solvent-based coatings, thus realising VOC control from the source and reducing VOC emissions caused by coating manufacturing, transportation, storage and application; at the same time, due to the improvement of the solid fraction of the original paints, the amount of coatings used in a single vehicle is reduced, thus lowering the cost of coating. As the solid fraction in the high-solid paint is increased from 50% to 60%, the paint consumption can be reduced by 7.9 tons per year according to the calculation of an annual production capacity of 20,000 units, while VOC emissions are reduced by 15.6 tons.

3. Process Design

3.1. Sled-in Process

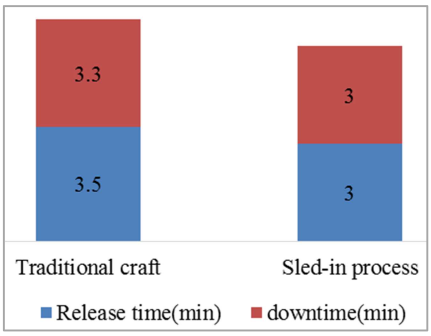

Figure 2. *Comparison Between Traditional Conveying Mode And Belt Skidding Mode.*

Paint skids are used throughout the entire paint line to link bodywork and equipment; in the paint shop process, paint skids generally need to be designed to fit the chassis structure of different vehicle models in order to achieve the effect of skid sharing: the design of the skid is critical to production [10]. The pre-treatment and electrophoresis section selects the skid-entry method to replace the original body and skid separation method, which realises the automation of pre-treatment and electrophoresis up and down lines, reduces the operating time of the personnel on and off the line, and improves the pre-treatment and electrophoresis production capacity.

As can be seen in Figure 2, the total length of the upper and lower lines is reduced by 0.8 min after the transformation with a skid in the tank, and the production beat of the electrophoresis section of the single-vehicle pre-painting treatment is shortened to 3 min, and the production capacity is increased from 18 units/hour to 20 units/hour.

3.2. Co-baking Process with Adhesive and Topcoat

The "wet-on-wet" process refers to the construction of the glue coating without drying oven drying directly for the construction of the middle coating, and then with the middle coating paint together into the middle coating drying oven for heating and gelatinisation molding. This process saves the investment and floor space of the gluing and drying equipment, and also saves the energy consumption of sealant drying [11]. The original process is to apply adhesive baking and curing and then topcoat spraying and baking, due to the need for two baking, thus consuming a large amount of energy, increasing the production cost. Improve the formula of glue material for painting, enhance the compatibility of glue and top coat, and improve the original process to bake the glue and top coat at one time, which reduces the energy consumption and shortens the production cycle and saves the production cost. The "wet-on-wet" baking process not only reduces the natural gas consumption by 115 m^3 per hour compared to the original process, but also shortens the gluing process by 30 min due to the reduction of baking.

3.3. No-Medium-Coating Process

Relative to the traditional coating process, no medium coating process, in the pre-treatment, electrophoresis process remains unchanged under the conditions of the reduction of the medium coating spraying room, levelling room, drying room, storage area, sanding room body, reducing the investment in equipment and energy consumption, reducing the process of using the area and the cost of production and operation, the overall area of the workshop will be reduced by 1/3 [12]. At the same time, the no-medium-coating process can reduce the amount of paint used, reduce the emission of VOC and other harmful substances, and at the same time shorten the coating time of a single vehicle to improve production efficiency. The no-medium-coating process saves the consumption of medium-coating materials by 1.5 kg/unit, and eliminates the natural gas consumption required for medium-coating and baking by 115 m^3/unit, which significantly reduces the cost of topcoat production.

3.4. Topcoat Is Applied by Robotic Painting Process

Automotive topcoat is the outermost coating of the vehicle, which is the primary carrier of the decorative appearance of the vehicle. The appearance, freshness, gloss and colour of the topcoat directly determine people's intuitive evaluation of the quality of the vehicle, and even affect the competitiveness of the vehicle in the market [13]. The modern automatic electrostatic spraying line adopts an intelligent automatic electrostatic spraying robot (Robot), achieving unmanned spraying. The automatic electrostatic spraying robot is not only suitable for the spraying of traditional organic solvent based coatings (intermediate coatings, topcoats, and topcoats), but also for the spraying of conductive water-based coatings after improvement. The degree of automation is very high, not only able to identify vehicle models and automatically change colors, but also able to automatically adjust the paint supply air volume according to the set process requirements, the speed and stroke (speed, trajectory) of the atomizing rotary cup, automatic cleaning, etc. [14]. Artificial spraying gun speed, gun distance, the amount of paint out of the spray gun is not easy to control, by the physical strength of the sprayer, personal emotions of the impact is relatively large, easy to produce uneven film thickness, hanging, orange peel and other film defects. It affects the passing rate of one time off the line, increases the workload of repair and delivery, and is easy to form the bottleneck of capacity enhancement. Robot spraying can overcome the fluctuating factors of manual spraying, equipment control parameters are stable, to ensure the consistency of the film quality, significantly improve the paint rate, a pass rate is also high, reduce the waste of paint and VOC emissions, to reduce the operating environment on the human body, low labour intensity, to ensure that there has been a higher production efficiency, reduce production costs.

As can be seen from Table 2, although the robot spraying one-time equipment investment is high, but the use of robots can significantly reduce labour costs and topcoat material consumption. After calculation, it is expected that the robot spraying 120,000 units about 3 years after the equipment investment can be recovered, the later can reflect the value of the new process.

Table 2. *Economic Comparison Between Robot Spraying And Manual Spraying.*

Item	manual spraying of paint	Robotic painting	Post-retrofit cost (based on an annual production capacity of 40,000 units)
Number of persons	6	4 persons, including 1 point filler, 2 equipment operators, 1 robotics engineer	Reduced of $160,000 per year
Initial Investment	0	Increase of $13 million	Increase of $13 million
Topcoat cost	$216 per unit	$107 per unit	Reduction of $4.36 million per year

3.5. Comparison of the New and Original Processes

Historically, automotive body painting application and management have been subject to the attention of the world's major automotive manufacturing enterprises, the use of new automotive body painting, greatly simplified the automotive production plant's painting process, to improve the painting of a qualified rate, and greatly reduce production costs [15]. The new process was compared with the original process in terms of process time and natural gas consumption and the results are shown in Table 3.

Table 3. *Comparison Between New Process And Original Process.*

Process	Process time (min)		Consumption of natural gas (m^3/h)	
	Original process	New process	Original process	New process
Hang up	3.5	3	0	0
Pre-treatment + Electrophoresis	51	51	30	0
Hang down	3.3	3	0	0
Electrophoretic baking	30	30	200	200
Glue	9	9	0	0
Glue Baking	30	0	115	0
Medium Coat Spraying	6	0	0	0
Medium Coat Baking	30	0	115	0
Topcoat spraying	12	12	0	0
Topcoat baking	30	30	200	200
Total	204.8	138	660	400

After the new process was used, the total painting time for a single vehicle was reduced by 66.8min, and the natural gas consumption was reduced by 260m3 per hour. At the same time, the application of high transmittance electrophoresis paint and topcoat robot spraying makes the material consumption of electrophoresis and topcoat also reduced significantly. The new process not only improves production efficiency and reduces material consumption, but also has outstanding performance in environmental protection and consumption reduction. The appearance of the car body after the implementation of the new process is shown in Figure 3.

Figure 3. *New Process Topcoat Appearance.*

4. Quality Test

4.1. Electrophoretic Performance

Electrophoretic paint film defects, as a common coating film drawback, seriously affect the underlying corrosion resistance and aesthetic appearance of the workpiece [16]. In order to test the quality reliability of the new process, the quality of the electrophoretic coating of the new process was tested, and the results are shown in Table 4.

The advantage of the new process is to ensure that the inner cavity electrophoresis paint film thickness, so that the outer surface film thickness of at least 3 μm, reducing the material cost, and can ensure that the salt spray resistance to meet the production requirements.

Table 4. *Performance Comparison After Electrophoresis Before and After Process Improvement.*

Item	Assortment		Test method
	Original process	New process	
Electrophoretic film thickness	18-25μm	16-21μm	GB/T 1764-79(89)
Adhesion	grade 0	grade 0	GB/T 9286-1998
Impact resistance (1 kg, 50 cm)	No cracks, wrinkles, flaking, etc. on both sides	No cracks, wrinkles, flaking, etc. on both sides	GB/T1732-1993
Salt spray test (1000h)	Unilateral spreading of corrosion<2mm	Unilateral spreading of corrosion<2mm	ASTM-B117

4.2. Properties of Composite Coating

In the process of painting automobiles, once improperly handled will have a serious impact on the quality of automobile painting [17], the performance of the composite coating is a key indicator for evaluating the quality of body coating, and the performance of the composite coating was tested after the implementation of the new process. As can be seen from Table 5, the new process not only has no reduction in the performance of composite coatings compared with the original process, but also realises the treatment of VOC from the source due to the application of high solid coatings, which reduces the VOC emissions from manufacturing, transportation, storage and other aspects, and is more friendly to the environment.

Table 5. *Performance Test Of Finish Paint.*

Test items	Original process	New process	Test method
Topcoat film thickness	35μm	35μm	Thickness Gauge
Gloss (60°)	≥95	≥95	GB/T 9754-2007
Freshness of enantiomorphism (DOI)	Light paint≥80 Dark paint≥85	Light paint≥80 Dark paint≥85	BYK Cellulite Meter
Adhesion	Level 0-1	Level 0-1	GB/T 9286-1998
Flexibility	≤1 mm	≤1 mm	GB/T 1731-1993
Impact resistance	≥30 cm	≥30 cm	GB/T 1732-1993
Pencil hardness	≥H	≥H	GB/T 6739-2006
VOC emission	>60mg/m^3	<60mg/m^3	GB/T 16297-1996

5. Conclusion

The new process uses new materials to design a new energy-saving and environmentally friendly painting process with quality up to standard. The new process enhances the production beat and reduces the energy consumption of a single vehicle, as well as reduces the consumption of materials, which effectively reduces the production cost of a single vehicle. While saving energy, the new process reduces environmentally unfriendly liquid and gas emissions. This process is suitable for the production of automobile bodies and is particularly suitable for the production of automobile with low production volumes.

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