STUDIES OF EPOXY POWDER COATED GALVANIZED STEEL SUBSTRATE VIA ELECTROSTATIC POWDER COATING SYSTEM

MOHD RAZALI BIN AJER

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Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

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ABSTRACT

This research deals with epoxy powder coating on the electrolytic galvanized steel sheet via electrostatic powder coating system. Normally, the film thickness and powder coverage of the coated powder is not optimum. It leads to non- protection of the parts from rusty and corrosion besides having many defects such as orange peel, rough surface, poor adhesion and inconsistencies of colour tone. In order to produce good coating quality, the processing parameters must be optimized. In this research, there have three variable parameters need to investigate. The variable parameters are total air volume, powder output and spraying distances. These parameters were screening to determine the significant effects to the coating quality. The screening result shows the spraying distance does not have significant effects and it was discarded. The experiments were carrying out to determine the optimum combination of powder output and total air volume. It is purposely to produce sample with good coating quality besides improved the first pass transfer efficiency (FPTE). All samples were tested using same processes that are pre-treatment, dry-off, powder spraying and curing. The method used to investigate the coating characteristic are thickness measurement, Buchholz indentation test, cross cut test, colour visual checking, particle cross-linking struture and surface profile analysis. The instruments used to evaluate the samples are coating thickness gauge, Buchholz indentor, multi blade cutting tools, spectrophotometer, scanning electron microscope (SEM) and surface profiler. The experimental result shows the combination of 4.0 m^3/h of total air volume and 150 g/min of powder output produce good coated sample with optimum thickness and colour tone. It also has good particle crosslinking structure and surface profiler. The coating indentation resistant and adhesion for this sampe is able to protect the galvanized steel from corrosion and rusty.

ABSTRAK

Kajian ini membincangkan berkenaan dengan lapisan serbuk epoxy pada kepingan besi bergalvani menggunakan system lapisan serbuk elektrostatik. Kebiasaannya, ketebalan lapisan dan liputan lapisan serbuk adalah tidak optimum. Ia akan membawa kepada tiada perlindungan bahan daripada karat dan hakisan selain mempunyai banyak kecacatan seperti permukaan kasar seperti kulit oren, kurang kelekatan dan ketidakseragaman warna. Dalam usaha untuk menghasilkan kualiti lapisan yang baik, parameter proses mestilah dioptimumkan. Dalam kajian ini, terdapat tiga parameter pemboleh ubah yang perlu dikaji. Parameter tersebut ialah jumlah isipadu udara, pengeluaran serbuk dan jarak penyemburan. Parameter ini akan ditapis untuk menentukan kesan-kesan yang ketara pada kualiti lapisan. Keputusan tapisan mendapati jarak semburan tidak mempunyai kesan yang ketara dan ianya telah diabaikan. Eksperimen telah dijalankan untuk menetukan kombinasi yang optimum untuk pengeluaran serbuk dan jumlah isipadu udara. Ianya bertujuan untuk menghasilkan sampel yang mempunyai kualiti lapisan yang baik sekaligus memperbaiki kadar kecekapan penghantaran yang pertama. Kesemua sampel telah diuji menggunakan proses yang sama iaitu pra-rawatan, pengeringan, penyemburan serbuk dan pembakaran. Kaedah yang digunakan untuk mengkaji sifat-sifat lapisan ialah pengukuran ketebalan, ujian lekukan Buchholz, ujian keratan silang, pemeriksaan warna, analisis struktur zarah dan ciri-ciri permukaan. Peralatan yang digunakan untuk menilai sampel ialah tolok ketebalan lapisan, pelekuk Buchholz,alat pemotong pelbagai bilah, spectrophotometer, imbasan mikroskop elektron dan pembentuk permukaan. Hasil eksperimen menunjukkan kombinasi 4.0 m^3/h jumlah isipadu udara dan 150 g/min pengeluaran serbuk menghasilkan sample lapisan yang baik dengan ketebalan lapisan dan warna yang optimum. Ianya juga mempunyai struktur zarah-zarah dan profil permukaan yang baik. Rintangan lekukan dan kelekatan juga mampu untuk melindungi besi bergalvani daripada karat dan hakisan.

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1	Cutting edge
a	Width across all six cutting edges
l	Indentation length (mm)
h	Indentation depth (μm)
αB	Indentation resistant
OEMS	Original equipment manufacturers
EG	Electrolytic Galvanized
DSC	Differential Scanning Calorimetry
DMTA	Dynamic Mechanical Thermal Analysis
FPTE	First Pass Transfer Efficiency
ISO	International Organization for Standardization
OFAT	One factor at a time
CIE	Commission International d'Eclairage
SEM	Scanning electron microscope
SCI	Specular component included
SCE	Specular component excluded
BSE	Back-scattered electrons

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CHAPTER 1

INTRODUCTION

1.1. History of powder coating technology

The history of powder coating technology started around late 1940s when thermoplastic powder applied as coatings to metal and other substrates by flame spraying. In this process, a plastic powder fed through a flame spraying apparatus where the plastic particles melted and propelled by the hot gases to the substrate. A patent issued in Great Britain to Schori Metallising Process Ltd. in 1950 described a process for forming a coating in which thermoplastics powder applied to a heated substrate by dipping or rolling the heated parts in the plastic powder. This process is difficult to practice and never achieved commercial success.

A major breakthrough in powder coating occurred in the mid-1950s, when Erwin Gemmer conceived the fluidized-bed coating process, in which a heated object is dipped into a fluidized bed of powder. Gemmer involved in developing flame spraying processes and materials in the laboratories of Knapsack-Griesheim, a manufacturer of specialty gases and searching for a more efficient method than flame spraying for coating objects with powder. The first patent applications filed in Germany in May 1953. The basic patent issued and the Polymer Corporation acquired rights to the Knapsack Griesheim patents. The Polymer Corporation mounted an aggressive effort to develop, license and sell fluidized-bed coating technology in North America. However, acceptance of this coating process was rather slow. In 1960, the annual sales of coating powders in United States below 450 thousand because of a lack of expertise in the methodology. In addition, the available powder coating materials is expensive, efficient production techniques had not been worked out and volume of production is low.

Today, powder coating is widely accepted with thousands of installations in the factories of original equipment manufacturers (OEMS) and custom coating job. It is the preferred method for coating many familiar items such as lawn and garden equipment, metal furniture, electrical cabinets, lighting, shelving and store fixtures and automotive components.

1.2. Electrostatic powder coating technique

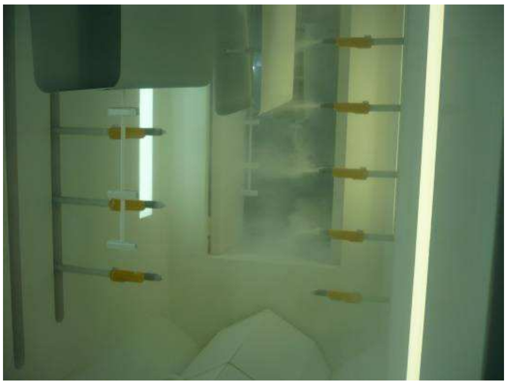
Electrostatic powder coating technique is one of the most environmentally friendly and economical technologies in surface treatment. Since early 60's, powder coating paints have been available on the market and the problem free production and processing made powder coating a well established and commonly recognized technique. Powder coating is a dry coating. Instead of being dissolved or suspended in a liquid medium such as solvent or water, powder is applied in a granular form. This material is finer than ground pepper but coarser than flour. It is applied directly to the surface to be coated. The powder created by blending the various components such as binders, resins, pigments, fillers and additives and then processing through an extruder into a continuous mass. This homogenous mass is cooled and broken into small chips which are then ground into the powder. Each powder particle contains within it the necessary components for reforming into the finished coating. After the powder applied to the part typically using an electrostatic spray process, the part passes through an oven and melting into a smooth film on the surface of the part. Figure 1.1 and 1.2 shows the electrostatic powder coating system used for this research.

Powder centre

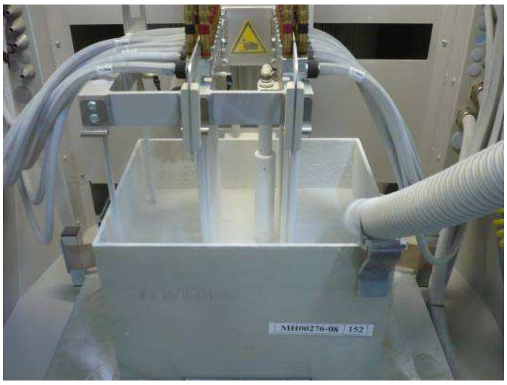
Display panel

Fresh powder system

Control panel



Spray booth



Fluidized bed

Figure 1.1: ITW Gema electrostatic powder coating

Degreasing and rinsing tank

Pre-treatment system

Dry off oven

Baking oven

H_2O Water treatment

Pre-treatment control panel

Figure 1.2: Combat pre-treatment, oven and conveyor system

Although powder coating is an economical technology in surface treatment, it needs further research to improve some critical issues in powder coating system. The main issue for powder coating is normally the film thickness after cured is not optimum. Insufficient of film thickness will cause the parts surface have poor powder coverage. It leads to non protection of the parts from rusty and corrosion. If the film thickness is very high, the coating layer is easy to peel off and having poor adhesion. This research was targeted to determine the optimum thickness of the coating film. The optimum thickness will have good surface protection to the corrosion and rusty. The coated films also have a good adhesion and indentation resistant. The methods used to evaluate the coating characteristic are thickness measurement, cross-cut test, Buchholz indentation test, particle structure analysis and surface profile. These methods will be explained in detail in chapter 3.

There are some parameters considered to get the optimum coating thickness. The parameters are powder output, total air volume and spraying distances. All of these parameters were affected to the powder mass flow rate. The powder mass flow rate is the mass of substance which passes through a given surface per unit time. The powder mass flow rate in electrostatic powder coating is depending on the powder output and total air volume. The amount of powder moving out from the nozzle must be supported by optimum total air volume to ensure the powder reach the parts. This research were carried out 15 experiments to investigate the significant effect of the processing parameters and 25 experiments to determine the optimum combination of powder output and total air volume.

The other challenge in powder coating is to get maximum first pass transfer efficiency during powder spraying. In powder coating, transfer efficiency is the ratio of the quantity of powder deposited on the part to the quantity of powder directed at the part. Transfer efficiency is given as a percentage, with 100% being most desirable. It is always desirable to improve first-pass transfer efficiency, maximize the efficiency of the initial coating application to minimize costs. Collection of any overspray which can be conditioned for reuse will affect the transfer efficiencies. Overall transfer efficiency will be higher if using the reclaim system. But, more cost benefits can be realized by achieving high first-pass transfer efficiency. The most efficient application occurs when

100% of the applied coating deposited uniformly on the part, leaving no excess coating for collection, disposal or reuse. Use of a reclaim system can push overall efficiency to 90% or greater. Maximizing first-pass transfer efficiency will reduce the amount of powder over sprayed and subsequently the amount of reclaim generated. High first pass transfer efficiency will generate smaller quantities of reclaim. The reclaim powder can be reuse. However, it can not be 100% reuse because the reclaim powder may have some dust or additives. It must be mixing with fresh powder. Based on the previous paper, the powder output and total air volume are strongly influences the first pass transfer efficiency of the powder to the parts. This research determined the optimum level of air to support the powder to the parts to get the maximum transfer efficiency. It shows clearly that increasing in transfer efficiency is one improvement that can lower costs, improve productivity and increase quality.

During powder spraying, there have three forces acting to ensure the powder reach the parts. The forces are aerodynamic, gravity and electric force. The aerodynamic force must be overcome the gravity force to ensure the powder can reach to the parts. Aerodynamic force is the resultant force exerted on a body by the air in which the body is immersed and is due to the relative motion between the body and the fluid. An aerodynamic force arises from the force due to the pressure on the surface of the body. The powder must be supporting by sufficient air volume to ensure the aerodynamic force overcome the gravity force during powder spraying. If the air volume is not optimum, the gravity force will overcome the aerodynamic force. It will cause the powder falling down before reach the parts as well as reducing the first pass transfer efficiency. This paper will carry out experimental investigation to determine the optimum combination of powder output and the total air volume to ensure the powder can reach the parts with the maximum transfer efficiency.

1.3. Advantages

Over the past decade, powder coating has been increasingly accepted as the preferred finishing process for the future. The advantages for electrostatic powder coating are shows in table 1.1 below.

Table 1.1: Advantages of the electrostatic powder coating system

Advantages	**Description**
Economy	I. Material utilization is much higher with powder, making material costs much lower. 92% to 98% of powder may be applied to the parts versus an average of 60% with an electrostatic liquid system and the other 40% is waste and must be disposed off. II. Since most of the material is used on the part, there is very little waste. III. The powder is not considered hazardous waste, so the cost of disposal is minimal compared to the high cost of toxic waste disposal. IV. Air loss from the curing oven is minimized as there is only a very small amount of volatile substance that must be exhausted. The cost of maintaining oven temperatures is therefore minimized. V. Powder is simpler to spray, so less skilled labour is needed, training is easily done and fewer errors are made in coating. VI. It saves scrap, labour and ultimately, operating costs.
Excellence	I. The cured powder finish is less susceptible to damage than a liquid finish. There is less need for repair work on the finished item and packaging is less elaborate, saving time and cost on rework and packaging. II. Epoxy, acrylic and hybrid powders provide excellent adhesion and hardness for improved resistance to chipping, abrasion, corrosion and chemicals and it is flexible enough to be formed without cracking. III. Polyester powders provide additional advantages in ultraviolet and weathering resistance.

Table 1.1: Advantages of the electrostatic powder coating system (cont)

Advantages	Description
Ecology	Powder is the overwhelming preference of the EPA, eliminating: I. Solvent fumes and VOCs from spray booth and oven exhausts that pollute the air. II. Potentially toxic sludge and water that can contaminate the earth and must be disposed of as hazardous waste.

The limitation is electrostatic powder coating not as easy to apply smooth thin films. As the film thickness is reduced, the film becomes more orange peeled in texture due to the particle size of the powder. For optimum material handling and ease of application, most powder coatings have a particle size in the range of 30 to 60 μm. For such powder coatings, film build-ups of greater than 60 μm required to obtain an acceptably smooth film. The acceptable surface texture depends on the end product.

1.4. Problem statement

“The significant effect of the processing parameters need to be determine because it will affect the coating quality”

“The combinations of the powder output and total air volume must be optimizing to have good coating characteristic”

“The thickness must be optimum to have good particle cross-linking structure and surface profile to protect the surface from any defects such as corrosion and rusty”

1.5. Objectives

The objectives for this research are listed below:

1. To investigate the significant effects of the powder output, total air volume and spraying distances to the coating characteristic
2. To determine the optimum combination of powder output and total air volume to have optimum thickness besides having maximum first pass transfer efficiency of the powder to the parts and good coating quality

1.6. Scopes

The scopes for this research are listed below:

1. The samples substrate used for this research is electrolytic galvanized (EG) sheet metal
2. The type of powder used for this research is thermosetting resin epoxy powder
3. All experiments used automated appliances for the electrostatic powder coating processes

1.7. Limitations

The limitations for this research are listed below:

1. The metallic colour can not be studying because it has special effects for the powder contact, charging characteristic and surface appearances
2. The other types of sheet metal exclude electrolytic galvanized (E.G) cannot be studying because it has different surface contact characteristic

CHAPTER 2

LITERATURE REVIEW

2.1 Coating powders

There have two types of powders that are commonly used for electrostatic powder coating. The powders are thermoplastic and thermosetting resin.

Richart (2000) conducted experiments to investigate melt viscosity of thermosetting and thermoplastic powder. Thermoplastic resins have a melt viscosity higher than thermosetting resins at normal baking temperatures. Therefore, difficult to thermoplastic resins sufficiently to obtain complete hiding in thin films. Thermoplastic resins are much more difficult to grind to a fine particle size than thermosetting resins. Grinding must be carried out under cryogenic conditions. In order to produce fine powders, a cryogenic system was established using liquid nitrogen where a jet-vortex mill used as a grinding mill.

Waelde (2005) investigated the particle size distribution and application for thermosetting and thermoplastic powder. Thermosetting powder was used for electrostatic spraying because the system was designed to have a maximum particle size of about 75 µm. The thermoplastic powders are predominant in the fluidized-bed coating process where heavier coatings applied and a larger particle size can be tolerated. Fluidized-bed powders typically contain only about 10 to15% of particles below 44 µm whereas the high end of the particle-size distribution ranges up to about 200 µm. It is not possible to develop thin coated film.

Rusk et al. (2000) investigated the melting flow characteristic of the thermosetting and thermoplastic powder that can affect to the coating appearances. Rusk et al. found thermosetting resins are more versatile than thermoplastic resins. The resin agent system possesses a low melt viscosity allowing application of smoother films. Necessary level of pigment and fillers required to achieve thin film can be incorporated without affecting flow, gloss and texture. Manufacturing costs are lower because compounding was carried out at lower temperatures. The resins are friable and can be ground to a fine powder without using cryogenic techniques. Thermoplastic resin have poor melt flow characteristic compared with thermosetting powder. The way to improve the melt flow characteristics of a polymer is by lowering the molecular weight and blending with a compatible resin of lower molecular weight. However, it can result in poor physical properties or a soft film in the applied coating. Attempts to improve the melt flow by increasing the application temperature are limited by the heat stability of the polymer. If the application temperature is too high, the coating shows a significant colour change or evidence of heat degradation.

Litchneker (1999) studied the chemical reaction and cross-linking of the thermoplastic and thermosetting resin. Thermoplastic coatings do not chemically react upon temperature increase but it flow and melt on the substrate. Thermosetting coatings also melt upon temperature increase, but under go a simultaneous chemical reaction and polymerize through cross-linking into resistant film. Once this chemical reaction has occurred the powder coating cannot melt again. It have better chemical and impact resistant after cured compared with thermoplastic coating

Pekarik (2009) investigated the physical properties of the thermosetting and thermoplastic powder. The physical properties of a thermoplastic powder depend upon the type of resin and initial molecular weight. Thermosetting resin systems are low-molecular-weight solids that go through a melt fusion and chemical reaction to form higher-molecular-weight polymers. Thermosets are characterized as heat cured and will not remelt when heat is applied. It have better surface appearances and adhesion to steel compared with thermoplastic resin. Thermoplastic powders had some limitations including high fusion temperatures, poor adhesion to metal and high applied cost.

Palmer (2008) presents on the thermoplastic and thermosetting powder delivers a colour textures and effect in powder coating. Thermosetting powder coatings were based on lower molecular weight solid resins and melt when exposed to heat. After it flow into a uniform thin layer, it chemically cross-link within themselves or with other reactive components to form a reaction product of much higher molecular weight. These newly formed materials are heat stable and will not soften back to the liquid phase when heated. Thermosetting powders are derived from three generic types of resins that are epoxy, polyester and acrylic. From these resin types, several coating systems are derived. Resins used in thermosetting powders can be ground into fine particles necessary for spray application and a thin film finish. A thermoplastic powder coating is one that melts and flows when heat is applied but continues to have the same chemical composition once it cools and solidifies. Thermoplastic powders exhibit excellent chemical resistance, toughness and flexibility. It is applied mainly by the fluidized bed application technique in which heated parts are dipped into a vat where the powder is fluidized by air. It is also used in many thick film applications.

Graves (2009) deals with chemical composition of thermoplastic and thermosetting powders. Thermoplastic powders melt and flow when heat is applied but it continue to have the same chemical composition once it cool and solidify. Thermosetting powder coatings also melt when exposed to heat, but it then chemically cross-link within themselves. Thus the cured coating has a different chemical structure than the basic resin.

Although thermosetting resin have better characteristic than thermoplastic, it also has many type of thermosetting powders that are epoxy, polyurethane, polyester, hybrid and acrylic. Horber (2003) was carried out experiments to investigate the impact, heat, chemical and corrosion resistant for different type of thermosetting powder. Epoxy resin powders have very good impact, heat and corrosion resistant. It also has excellent chemical resistance to solvents, acids and alkaline liquids compared with other type of thermosetting powder. A disadvantage of epoxy resin powders is it chalking and yellowing tendency when exposed to UV light. Chalking does mean loss in aesthetics but not in anti corrosive benefits. Hybrid powder has better resistance to yellowing and reduced chalking tendency compared to pure epoxies. But, it has poor resistance to solvents in comparison with epoxy resin powders. The acrylic powder coating has good weather resistant and also has high gloss level. However, it required special storage and incompatibility with other powder coatings.

Rouw (1998) investigated the adhesion to steel of epoxy powder. The method used to investigate is peel adhesion test. Result from this paper shows epoxy powder having good adhesion to steel. It also has excellent resistance against aggressive chemicals and corrosion. Although epoxies have shortcomings in the field of weatherability, it has excellent anticorrosion performance that make sure these resins still remain as an important building block of functional powder coatings.

Mafi et al. (2005) investigated the cure characterization of epoxy and polyester clear powder coatings using Differential Scanning Calorimetry (DSC) and Dynamic Mechanical Thermal Analysis (DMTA). The result shows the mechanical properties such as hardness, flexibility, the appearance of the film surface and the chemical resistance of the cured film affected by the degree of cross-linking during the curing process. For both type of thermosetting powder, it has good chemical resistant because once cured, it can not react with chemical. The degree of cross-linking for the epoxy and polyester clear powder coating cured in different curing temperatures are probably similar. Both type of powder having good coating characteristic due to the strong cross-linking between particles.

Merch (2000) deals with the coating characteristic of epoxy powder. Thermosetting coating powders based on epoxy resins have been used longer than any other resin system. This is because solid epoxy resins had the necessary combination of low molecular mass and melt viscosity. If the epoxy coatings are exposing to weather, it lose gloss. However, it can protect the substrate for many years.

2.2 Application method

For powder coating, there have three main types of application method that are fluidized bed coating, electrostatic fluidized bed coating and electrostatic spray coating.

Liberto (1997) investigated the variable parameters and function of the application method for powder coating. For fluidized bed coating, the main variables are the temperature of the part enters the fluidized bed, the mass of the part being coated, dip time, and post heat temperature. Other variables such as motion of the part in the bed, density and temperature of the powder in the bed also affect the quality of the coating. The process is useful in coating objects having a high surface to mass ratio such as fabricated wire goods and expanded metal. For electrostatic fluidized-bed coating, it is an ideal method for continuously coating webs, wires, fencing and other parts that are fabricated in continuous lengths and essentially two-dimensional. Electrostatic spray coating is the most widely utilized method for the application of powder coatings. In a typical high voltage system, powder is maintained in a fluidized-bed reservoir, injected into an air stream and carried to the gun where it is charged by passing through a corona discharge field. The charged powder is transported to the grounded part to be coated through a combination of electrostatic and aerodynamic forces. The powder is held by electrostatic forces to the surface of the substrate which is subsequently heated in an oven where the particles fuse and form a continuous film. This method is suitable to create a low film thickness besides having good coating appearances.

Landrock (1999) investigated the ability of the electrostatic powder spraying and fluidized bed process to coat the object. For electrostatic powder spraying, the thickness of the coating is between 30 to 75µm. The difficult shape of parts can be coated using this method. The colour can be changed relatively simply. For fluidized bed process, it is used to coat the parts that required very high thickness more than 250 µm. The parts to be coated must be simple shape. Colour change is a massive undertaking.

Mark (2000) studied the characteristic of electrostatic fluidized bed and electrostatic spraying process. The electrostatic fluidized bed s ideally suited to substrates that have relatively small vertical dimension. The electrostatic fluidized bed is able to coat some object such as flat sheets on one side only opposed to the conventional fluidized bed that required dipping of the entire parts. The electrostatic fluidized includes and integral control panel and utilized the same powder supply unit as the manual electrostatic spray system. For electrostatic spraying process, it can coat the parts that have complex shapes. It also can coat the part on one or both side.

Gujral (2009) had done a paper deals with the application method of powder coating. For the electrostatic spray coating, it can obtain the final solid, tough, abrasion resistant coating. The efficiency of the process can be increased to 95% material usage by collecting the powder. For the fluidized bed coating, the products that are preheated above the melt temperatures of the powder are dipped in the fluidized bed. The powder melts and fuses into a continuous coating. This coating method is used to apply heavy coats in one dip with 75 - 250 µm thickness. It is possible to build a film thickness of 2.5mm using higher preheats temperatures and multiple dips. For the electrostatic fluidized bed coating, product size is limited and inside corners have low film thickness owing to the well known Faraday cage effect.

2.3 Charging system

Electrostatic powder coating system has four common types of charging system that are electrostatic (corona), super corona, tribo and bell.

Horber (2007) investigated the effectiveness of the charging system used in powder coating. Electrostatic charging was used high voltage to generate powder with free electron. The powder will go trough to the gun tip to generate negative charged powders. Due to its charging principle with a constant supply of electrostatic charge, this type of gun can be used with all application scenarios and virtually all powder types. It is therefore also referred to as a general purpose gun. Super Corona is used in all coating scenarios requiring both thicker powder layers and a high coating quality with regard to the visual appearance. It required higher powder consumption compared with the electrostatic charging. Super corona is suitable for the complex shape to prevent back ionization. For the bell charging, the powder was charge via the charging edge of the rotating deflector disc. Bell charging was used to coat large flat surface of sheet metal. The powder consumption is very high compared with electrostatic and super corona. The other type of application method is tribo charging. The tribo method was charges the powder by friction. Tribo charging has poor flexibility and powder reclaim. Not every powder can be processed with a tribo charging gun. Fresh powder was charged the best whereas several times recycled powder cannot be reused.

Kreeger (1994) investigated the particle charging characteristic using different type of application method. For electrostatic charging, the strong electrostatic field results in effective charging and higher deposition. However, strong field lines lead to Faraday Effect whereas corner and crevices was not properly covered by powders. These effects can be eliminated respectively by voltage change or used of super corona rings. Electrostatic field lines support the powder particle to move towards the work pieces. Film thickness can be simply change by voltage variation. For tribo charging, performance is strongly influences by uncontrolled air streams. Charging of particles takes more time and efficiency reduces during long run. It also needs precise specification for the cleanliness and humidity of the compressed air

Graves (2009) investigated the charging characteristic of electrostatic and tribo charging. Electrostatic charging uses a negative polarity on the electrode as negative polarity produces more ions and less prone to arcing than positive polarity. In tribo charging, the powder particles was charged by causing them to rub at a high velocity on a surface and thereby, transferring the charge. Without an external power supply and a charging field in front of the gun, tribo charging virtually eliminates the problem of "faraday cage effect." The powder particles take on a positive charge inside the gun due to the loss of electrons. The particles are free to be directed to where they are needed. However, the powder flows into recessed area is difficult to reach by nozzle direction and air flow.

Takeuchi (2008) had done a paper to improve charging characteristic of coating powder in electrostatic powder coating system. The charging characteristics of coating powders were improved for both corona and tribo charging type spray guns. The blow-off measurements showed the charge-to-mass ratio of coating powders deposited on the substrate was larger than that of undeposited powders for both types of spray gun. The charge-to-mass ratio of the coating powders was increased by adding a pair of auxiliary electrode to the corona-charging spray gun. Free ions from the corona-charging spray gun were decreased by applying a magnetic field in the spraying space. The polymer tube of a tribo charging spray gun that contained a negative charge control agent was able to charge all the coating powders sufficiently positive.

Shirar (2006) investigated the coating thickness of corona and tibo gun. Corona guns are particularly good at applying thin films onto parts. However, as coating thickness increases, charge build up on a part from both charged powder and free ions. This charge can repel incoming powder particles and limit the coating thickness. Tribo guns producing few free ions can be an excellent choice for applying thick films. A film builds of several hundred microns on an unheated part in a single pass is possible with a tribo gun.

Dastoori et al. (2005) deals with measurement of the electrostatic powder coating properties for corona and triboelectric coating guns. Measurements have been made of the deposited powder layer for conventional electrostatic corona powder guns and triboelectric guns. By selectively removing the powder layer under computer control conditions, measurements of the powder thickness and the adhesive properties of the powder layer have been obtained for variation in the coating process and detailed comparisons have been obtained for both coating systems. There are many variables that can affect the powder coating thickness and adhesion. The measurement of the light transmitted through the powder layer is inversely proportional to the thickness. Comparative results show that the build up of the powder layers reaches the maximum in 6 to 8 s. However with the corona gun, the build up is much faster. The adhesion properties will have a direct relationship to the electrostatic charging characteristics and the attractive image force, which is holding the powder to the substrate. Initial results show that the light transmission and adhesion decrease monotonically with coating time. The self-limiting effects occur at the maximum coating thickness. Coating thickness is hyperbolically proportional to coating time. Adhesion tests show that the highest adhesive strength occurs before the self-limiting effect for a corona-charging system.

2.4 Processing parameters

For electrostatic powder coating system, there are many processing parameters can affect the coating quality as describe in previous paper.

Chen et al. (1995) studied the transfer efficiency models for electrostatic powder coating process. The first pass transfer efficiency (FPTE) and film uniformity in a corona charging powder spray process depend upon a number of parameters. The parameters are powder spraying air flow and booth air flow patterns, spray gun voltage and powder properties. Air was used as a medium to transport powder from the fluidizing bed to the target surface to be coated. For a uniform mass flow of the powder, the powder must be well dispersed providing a dilute phase flow. A relatively high spray air velocity containing coarser paint particles may provide a better Faraday cage penetration if the particle charge and electric field are well-controlled. However, a high air velocity and associated turbulence may hinder deposition of paint particles, particularly the fine fraction from reaching close to the target surface. Excessive air flow will decrease FPTE and wrap around painting properties of powder coating. The adverse effect will be very significant when powders containing relatively fine particles were used to achieve uniform film. The booth air flow pattern and the spray air velocity pattern must therefore be optimized.

Lam (1998) presents a numerical simulation of corona charging powder coating system. The variable parameters that can affect to the coating quality are powder material, flow rate, powder charging and the adhesion on to the workpieces. Powder flowability and fluidization is very important in powder coating process. In order to have uniform coating, the powder must flow through the gun and be well dispersed while maintaining a uniform mass transfer rate. Even minor changes in dispersion and flow characteristic alter the film properties.

Matsui et al. (2009) had make improvement of the powder coating by increasing the conveying air speed using atomized powder coating system. The coating thickness in the recessed area was clearly increased with increase of the volume of conveying air from 80 to 120 L/min has yielded a 13% in the average coating thickness. For most of the conventional powder coating systems, the conveying air of approximately 80 L/min has been recommended as the empirical standard to avoid decreasing the transfer efficiency and specifically prevent blowing off a part of the powders deposited on the object.

Takeuchi (2008) deals with the improvement of coating characteristic in powder coating. The issue that strongly affect the coating quality are particle size distribution (PSD) in the powder cloud sprayed from the gun, powder mass flow rate (PMF) delivered to the gun, the volume of the conveying air and the charge density of powder particles. The volume of the conveying air affects not only the penetration of powders into the recessed area of the object to be coated but also the transfer efficiency of the coating system. It has been believed that increasing the conveying air decreases the transfer efficiency. It is desirable that the powders are sprayed with a higher speed conveying air to improve the penetration, but too higher speed airflow blows off a part of powder particles from the surface of the powder layer deposited on the object.

Shah et al. (2006) presented on numerical investigation of coarse powder and air flow in an electrostatic powder coating process. The experiment was carried out to investigate 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 modelled as a three-dimensional turbulent continuous gas flow with solid particles as a discrete phase. The main variable parameters are powder charging, powder transport region in which the charged powder travels from the spray gun to the earthed work piece under the effect of aerodynamic, electrostatic and gravity forces and powder deposition to the work pieces. The important parameters that affect the powder travelling are air flow rate, powder spray rate and applied voltage

Yanagida et al. (1999) introduced a new powder flow control system for electrostatic powder coating. In electrostatic powder coating system, a high grade appearance is required and it is very important that the thickness is uniform. Combination of powder output and conveying air is very important aspect which can affect the coated quality. Yanagida et al. tried to improve performance of powder feed system in order to respond to an aforesaid severe quality demand. Concretely, the development was examined for the purpose of improvements upon the responsiveness of powder feed and total control of conveying air flow rate.

Wang et al. (2004) had done the experimental study of particle trajectory in electrostatics powder coating. The particles must be well dispersed in the air stream, providing a homogeneous powder cloud in front of the target. In reality, a completely uniform multiphase suspension is very hard to achieve due to the non-uniformity in particle size and shape inherent in the most coating powder. The powder flow is heavily influenced by the airflow within the booth. Inappropriate booth airflow can cause very fine and large particles to miss the target entirely decreasing the transfer efficiency. The trajectory of charged particles travelling from the spray gun to the grounded target was governed by the combination of aerodynamic, electric and gravitational forces. The air stream from the spray gun carries the particles to the part, while the electric force pushes the particles towards the grounded target. The electric force, which is equal to the product of the particle charge and the field strength, needs to be strong enough to overcome the aerodynamic and gravitational force exerted on the particles.

Shah et al. (2006) deals with comparison of electrostatic fine powder coating and coarse powder coating by numerical simulations. The air flow rate is one of the variable parameters that can affect on the First Pass Transfer Efficiency (FPTE). Airflow by means of the aerodynamic force plays a very important role in transporting particles from spray gun to the region near the coated part. Once the particles are in the region near the coated part, the electrostatic force will plays key role in depositing the particles onto the coating target surface. From the experiment, the FPTE initially increases and then decreases when the airflow rate increases. The airflow rate initially helps the particles to reach the coating part to increase the transfer efficiency. But further increase in the airflow rate eventually decreases the FPTE because the increased turbulence makes the particles more dispersed near the region of the coated part and missed the coating part. It leading to reduced FPTE for a definite coating part. The transporting air must be strong enough to direct the particles in the direction of the spray, but the particles will lose their momentum when reaching near the target surface where the electrostatic force should be dominant for higher deposition rate.

Power (2005) investigated the gun to parts distances that allows for optimum coverage and application efficiency. Typically, a distance of 8 to 12 inches can provide the desired results depending on nozzle type, part configuration and number of guns used. Adjust powder pump delivery rates and application pressures to provide needed delivery with minimal powder overspray. Control of spray gun pattern size is best accomplished by selecting the proper nozzle and varying the distance between the gun and the part. Some applicators try to coat too much surface area with one spray gun. There are practical limits on gun to part distance and powder delivery rate and velocity should not be increased to compensate for excess distance. Higher delivery rate and added velocity reduce dwell time in the electrostatic field. Increased gun-to-part distance dramatically reduces first-pass transfer efficiency. Consideration must be given to part configuration, powder composition, gun to part distance and powder delivery rate and pressure.

Stribling et al. (1998) investigated the processing parameters that can affect to the powder transfer efficiency. The parameters are gun to part distance, powder flow rate, booth canopy design, booth air flow and powder properties. The powder flow was regulated by controlling the air supplied to the pump. For the powder pump and fluidizing gun flow rate, the purpose of the pump is to supply powder to the gun at a uniform and consistent rate. The lowest flow rate possible is the ideal condition for first-pass transfer efficiency while still maintaining coverage through each gun. For the gun to part distance, the distance between the parts and the tip of the gun will affect transfer efficiency. There are many variables with gun placement that depend on line speed and part specification. Generally, it starts at 3 to12 inches away from the part.

Guskov (1996) investigated the effect of the gun to part distance to the powder transfer efficiency. The number of free ions flowing to the part for a gun-to-part distance of 3 inches will be significantly greater than the number of ions flowing to the part at a gun-to-part distance of 10 inches. The author also was investigated the relationship between the transfer efficiency of the powder coating process and gun current for fix powder flow rate and conveyor speed a gun to part distance of 3, 6 and 12 inches. It is clear that for gun to part distances of 6 to 12 inches, maximum transfer efficiency is achieved at some current level. At the 3 inch distances between the gun and part, the maximum transfer efficiency was reached at lower current setting.

2.5 Coating characteristic and testing method

For the electrostatic powder coating system, there have many coating characteristic need to be investigating to determine the optimum combination of variable parameters that gives the best surface quality of coated parts. The coating characteristics are such as thickness, colour tone, surface structure, adhesion and weather resistant as describe in previous paper. There have many type of testing method can be used to identifying the responses.

Graves (2009) deals with finishing solution beyond the surface. Powder coating can look like completely cure, yet still be unable to provide the complete physical properties. Use of quality control testing is a key part of the process. The main tests need to be carrying out to determine the coated quality are thickness measurement, colour checking, impact resistant, hardness and adhesion. Powder coating obtain it full physical and chemical properties when completely cured at the proper temperature for enough time. Use of these tests will ensure the parts confirmed the specification and having high quality.

Spindler (1994) investigated the coating characteristic for the electrostatic powder coating. The thickness needed was determined by the amount of protection needed, required appearance and cost. The value to be determined in comparing powder coatings is the thickness at which the powder coating hides the colour and texture of the underlying surface. The ability of a coating to hide can be determined by readings with a spectrophotometer, taken on special black and white panels over sprayed with the coating to be tested to determine the contrast ratio. The contrast ratio is a percentage value that was determined mathematically from a spectrophotometric measurement taken of a sample over black and then over white. The contrast ratio was expressed as a percentage, with the higher values indicating better hiding. A value of 100 pct represents complete hiding for the sample. Values over 98.2 pct are generally accepted as high enough for most applications. At this value, the observer would have difficulty seeing a visual contrast between the paint presented over black and white. Visual comparisons are also effective in assessing the actual minimum thickness required for hiding on a coated part. This value will vary from one powder to another and can be determined by taking thickness readings on parts.

Beamish (2009) investigated the coating thickness in electrostatic powder coating system. Coating thickness is an important variable that plays a role in product quality, process control, and cost control. The normal standard used in powder thickness measurement is the mil. There are other benefits to precisely measuring finish thickness whether to meet International Organization for Standardization (ISO), quality and customer requirements for process control. Applying excessive film thickness risks the possibility of incomplete cure and can drastically reduce overall efficiency. Too much powder coating may result in poor adhesion and tends to peel off chip from the substrate. Regular testing can reduce the number of internal reworks and customer returns due to finishing defects.

Lomax (2009) presents the test method to determine coating thickness, common application and innovations in coating thickness instrument. The eddy-current method of coating thickness measurement measures non-conductive coatings on non-ferrous conductive substrates, non-ferrous conductive coatings on non-conductive substrates and some non-ferrous metal coatings on non-ferrous metals. Common applications for eddy-current coating thickness measurement include liquid or powder coating over aluminium and non-magnetic stainless steel.

Barletta (2009) deals with use of sliding spherical contact geometry to characterize the scratch response of a clear polyester topcoat electrostatically sprayed onto metallic substrate and baked under different time-temperature programs in a convection oven. The thickness of the coated substrates was measured using a coating thickness gauge in accordance with ISO 2178 and ISO 2370. The coating thickness was evaluated by averaging five measurements equally spaced on the surface of the coated substrates. Lastly, samples with a coating thickness more than ±10% outside the prescribed range of 60 to 80 µm were discarded.

Darner (1999) presented the testing method to check the coated quality. The cured powder coating film can be checked for a wide range characteristic. Depending upon the specification, various tests need to be carried out on test panels. For most tests there exists a value with a negative and positive tolerance. Many of the performance criteria have internationally standardized procedures for the test method and can therefore be easily compared. Details of some of the most common test used across a range of industries were listed in **Appendix K** together with examples of relevant testing standard. It is important to note that for any particular powder coating application there may be a technical or quality standard to meet which refer to specific tests and testing equipment.

2.6 Summary

From previous paper, there are many processing parameter can affect the transfer efficiency and coating quality. The main parameters are particle size distribution, powder mass flow rate and charge density of powder particle. In order to optimize the powder mass flow rate, there have three parameters need to be analysis. The parameters are powder output, total air volume and spraying distances. Many authors investigated about the powder output, total air volume or spraying distances. However, there are no papers investigated about the combination of thereof. Although powder output is optimum, it must be supported with optimum total air volume to ensure the powder have maximum first pass transfer efficiency. Airflow by means of the aerodynamic force plays a very important role in transporting particles from spray gun to the region near the coated part. The gun to parts distances of 3 to 12 inches can provide the desired results depending on nozzle type, part configuration and number of guns used.

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