

Relationship between electrostatic powder coating thickness measurements at different points on uneven surfaces

Relación entre medidas de espesor de recubrimiento electrostático en polvo en diferentes puntos sobre superficies irregulares

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Abstract

Measure relation of electrostatic powder coating thickness at different points on irregular surfaces. In this work, we found the relation between the thickness measures at different areas of a irregular surface, by the electrostatic powder coating on pieces with five different geometries and varyin slightly parameters like potential and application distance. At the products where the electrostatic powder coating are used, the thickness measure is an importante quality characteristic, however on the irregular surfaces is so noticeable when the thickness measure is not uniform on the entire piece. But when it is known that the thickness ratio varies from one area to another of the same piece, it is easier to establish a methodology that allows the process to have a measure of uniform thickness.

Electrostatic Powder Coating, Thickness, Finite Element

Resumen

Relación entre medidas de espesor de recubrimiento electrostático en polvo en diferentes puntos sobre superficies irregulares. En este trabajo se encuentra la relación entre las medidas de espesor de diferentes áreas de una superficie irregular, mediante la aplicación de recubrimiento electrostático en piezas con cinco geometrías diferentes y modificando levemente parámetros como potencial y distancia de aplicación. En los productos donde se utiliza el recubrimiento electrostático el espesor es una característica de calidad importante, sin embargo en las superficies irregulares es mas notorio cuando la medida de espesor no es uniforme en toda la pieza. Sin embargo cuando se conoce en que proporción varía el espesor entre un área y otra de la misma pieza, es mas fácil establecer una metodología en el proceso que permita tener una medida de espesor uniforme.

Recubrimiento electrostático en polvo, Espesor, Elemento finito

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Introduction

The application of electrostatic powder coating has been used since the 70's last century, and since its inception it was detected that it is complex to obtain a uniform thickness measurement in the coating layer, and when the substrate has a geometry irregular, that is, it was subjected to plastic deformation before the coating process, then it becomes more complex, since the deep regions in an irregular geometry cause the effect called the Faraday cage (EJF), which does not allow the dust particles reach the depths of the geometry.

In an electrostatic system for the application of electrostatic powder coating (for the case of this study it is paint), the electric field lines are directed from the electrode in the gun towards the substrate or surface to be covered, when the surface it is irregular so the electric field lines cancel out when reaching the deep regions so they do not penetrate to the bottom. The dust particles follow the electric field lines and since they do not penetrate to the deep regions then the dust does not reach either, causing smaller paint thickness measurements in those regions.

The effect of the Faraday cage in the electrostatic painting process has been known since this type of process arose; Efforts to solve it focus on controlling some individual or group parameters such as current intensity (Guskov, 1996), the amount of charge with respect to the mass of the dust cloud Q / m (Biris, 2011), the size of the particle (Rupp, 2012), etc.

Some equipment for the application of electrostatic powder paint, such as the WAGNER, have integrated programs with combinations of parameters appropriate to the type of surface to be covered; These surfaces are classified as flat surfaces, large surfaces and irregular surfaces, however the problem is not solved in a definitive way, and it is complicated because the EJF is inherent to electric fields on irregular surfaces, which means that it is not possible to eliminate it. completely, so research is focused on mitigating it in some way. Since the uniformity of the thickness measurement over the entire surface is an important characteristic to evaluate the quality of the product, it is considered advisable to carry out a study in which it is identified how the thickness measurement varies throughout the surface, and is related to the electric field intensity.

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With this objective, an experiment was designed with five types of surface which were covered by the electrostatic powder coating process to later measure the thickness at eight different points of each type of surface and thus determine the spatial variation in the measurement of thickness of each surface.

The structure of this document contemplates first the description of the electrostatic system, then a brief explanation of the finite element method, the materials, equipment and experimentation are specified, the results obtained and the general conclusions.

Electrostatic system

The set of equipment and materials that is needed to apply electrostatic coating either in powder or liquid is called electrostatic system, this study focuses on powder painting as electrostatic coating and in this section it is explained how is the paint application process and how to simulate electrostatic fields using the finite element method.

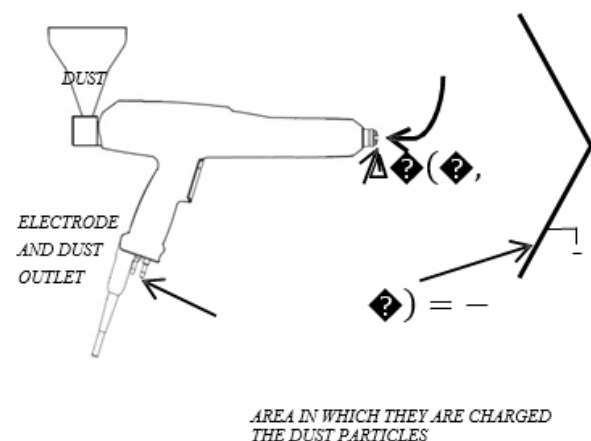


Figure 1 Electrostatic gun and substrate (drawing obtained from supplier's manual)

Equipment for electrostatic process

An electrostatic system for the coating process (Figure 1), includes an electrostatic gun with an electrode connected to a high voltage generator and a substrate connected to ground.

The gun is connected to a compressor, the air from the compressor drives the dust particles around the electrode, where the discharge corona is formed, and the particles are negatively charged and with the force of the electric field are directed towards the substrate.

$$\mathbf{E} = -\nabla u(\mathbf{x}, y) \quad (1)$$

The relationship between the electric field and charge density ρ is given by:

$$\varepsilon \nabla \cdot \mathbf{E} = \rho \quad (2)$$

Where ε is the permittivity of the material, substituting equation (1) in equation (2); the result is the Poisson equation of potential:

$$\Delta u(x, y) = -\frac{\rho}{\varepsilon} \quad (3)$$

The Poisson equation (3) describes how the potential and electric field lines are distributed. To solve this equation in an electrostatic system it is feasible to use the finite element method.

The finite element method in electrostatics

The finite element method has different ways of solving partial differential equations, one of the most used is the variational method. This method uses a functional, which is an expression of the potential energy in the domain. Through the minimization of the energy in each element, the electric field lines are obtained in the entire region. The equation to be solved for the electric field is the Poisson equation. Limit constraints are Dirichlet and / or Neumann conditions. The functional of the equation is:

$$I = \int_A \left\{ \frac{1}{2} \varepsilon_0 \left(\frac{\partial \Phi}{\partial x} \right)^2 + \frac{1}{2} \varepsilon_0 \left(\frac{\partial \Phi}{\partial y} \right)^2 \right\} dA - \oint \Phi \frac{\partial \Phi}{\partial n} dR \quad (4)$$

When the download is generated in the gun, an electric field is formed between the gun and the substrate. The electric field intensity is known by the potential gradient, which is represented as $u(x, y)$:

Where A corresponds to the region of integration, Φ is the potential and I is the functional. The first part of the functional represents the energy of the electric field.

By means of discretization, each element is defined according to a function, the number of its nodes and the potential, which is defined by the potential at the nodes.

$$\Phi = |N|(\Phi)^e = (N_i, N_j, N_k) \begin{bmatrix} \Phi_i \\ \Phi_j \\ \Phi_k \end{bmatrix} \quad (5)$$

Where $|N|$ is the matrix of functions of form. To find the minimum energy potential, the functional must be partially derived with respect to each node. Therefore:

$$\frac{\partial I^e}{\partial \Phi^e} = |K|^e \{\Phi\}^e \quad (6)$$

The matrix of each element is assembled into a global matrix and boundary conditions are applied.

$$|K|\{U\} = \{P\} \quad (7)$$

K represents the stiffness matrix; U is the vector of unknown potentials and P is the solution vector.

Methods

The experimentation was conducted in two ways, the first to calculate the electric field by the finite element method and the second to measure the thickness of the cured paint on the treated surface.

Design of experiments

An experiment was designed with 5 different geometries, three with angles of 60 °, 90 ° and 120 ° and two with a box shape with 1", depth and the width of the deep region in the first 1" and in the second of 2" (Figure 2), the material is low carbon steel, the paint used was Krhal, the variables to be measured are paint thickness in mils and electric field intensity in V / m.

Two different types of parameter combinations were used, each combination will be called treatment from here from now on, the first type of treatment is oriented towards measuring the thickness of paint and is numbered from one to eight (Table 1), the second type of treatment is for the calculation of the electric field intensity, said calculation was made the finite element method and the treatments are identified with the letters A, B, C and D (Table 2).

A 200 ° C convection oven was used to cure the paint for 10 minutes and a Positector 6000 thickness gauge was used.

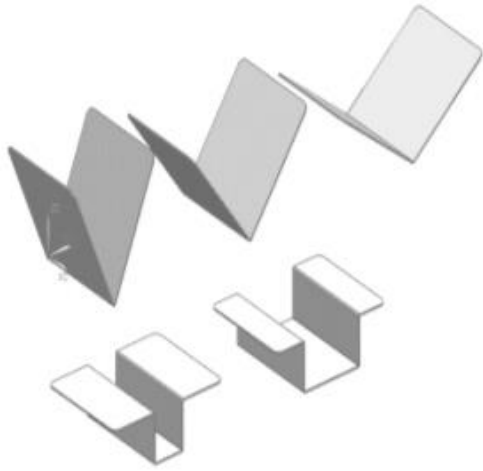


Figure 2 Five different geometries

Treatments for thickness			
Treatment	Voltage (kV)	Distance (cm)	% dust
1	70	15	50
2	70	15	60
3	60	15	50
4	60	15	60
5	70	20	50
6	70	20	60
7	60	20	50
8	60	20	60

Table 1 Parameters for measuring coating thickness

Electric Field Intensity		
Tratamiento	Voltage (kV)	Distance (cm)
A	70	15
B	60	15
C	70	20
D	60	20

Table 2 Parameters for calculating electric field

Electric field strength calculated with the finite element method

To calculate the electric field intensity, COMSOL® was used, a three-dimensional domain was established, forming a block in the shape of a rectangle, the small faces of the rectangle are found in the upper and lower part of the block, in the center of the upper face a point is located that represents the electrode, and the lower face takes the shape of the geometry to be analyzed (Figure 3); the boundary conditions were Dirichlet for the electrode with $u = V$ and for the grounded substrate with $u = 0$, the rest of the boundaries are Neumann with

$$\frac{\partial u(x, y, z)}{\partial x} = \frac{\partial u(x, y, z)}{\partial y} = \frac{\partial u(x, y, z)}{\partial z} = 0.$$

The calculation was made in eight different points of each piece (Figure 4), the same ones where the measurements of the thickness of the paint were made.

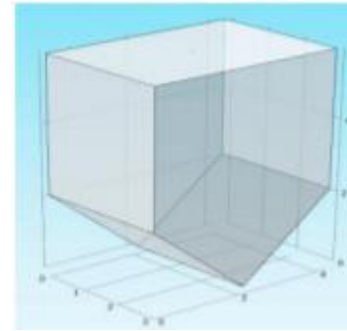


Figure 3 Domain

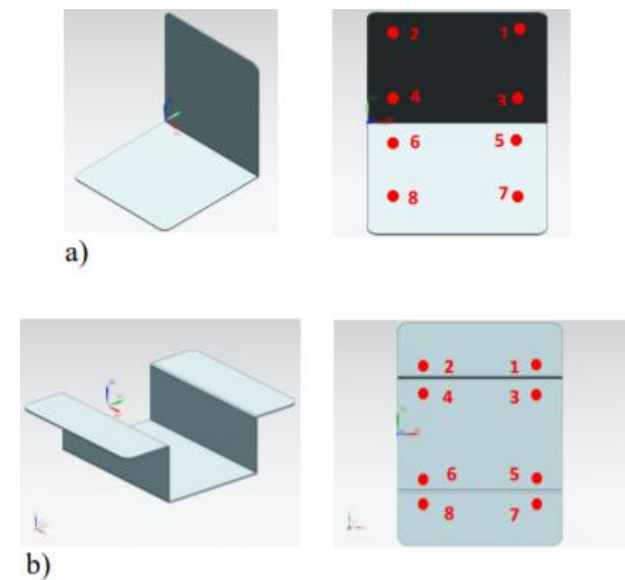


Figure 4 a) Points where thickness was measured in geometries with a center bend, b) Points where thickness was measured in geometries with deep regions

Results

The electric field intensity values were obtained at each point indicated, in the same way the thickness was measured at the same points and when graphing the results, similar patterns of variation were found between the electric field intensity graphs and those of the thickness, the Table 3 shows graphs of two of the geometries.

When the parameters that affect the thickness measurement are analyzed, the electric field intensity is not considered, however when reviewing the behavior of the thickness measurement in the eight measurement points and it was related to the measurement of the intensity and Electric field at the same points is observed as having similar variation patterns and when calculating the correlation between both parameters, it was found that the smallest correlation value is 67% and the largest is 99%, in addition the 50th percentile is 89% , which indicates that the smallest correlation values are more dispersed than the highest values. With the information obtained, it can be seen that the electric field intensity is a parameter that deserves to be more important if you want to control the uniformity of the thickness on an irregular surface.

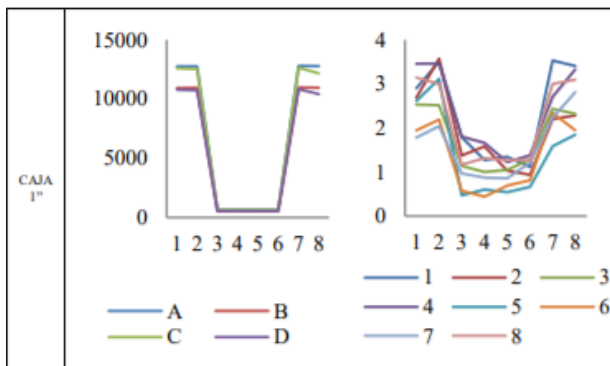


Table 3 Graph of electric field intensity and thickness of two different geometries

When it was observed that the behavior of the variation of the electric field intensity resembles the behavior of the variation of the thickness, the relationship between both parameters was measured by means of a correlation coefficient and it was found that the smallest correlation value is 67 % (table 4) which indicates that the thickness measurement is explained through the behavior of the electric field intensity at each measurement point.

Geom	A-1	A-2	B-3	B-4	C-5	C-6	D-7	D-8
60°	0.9659	0.9510	0.9415	0.8031	0.7659	0.7266	0.9591	0.9052
90°	0.8689	0.7107	0.8801	0.8865	0.7759	0.7650	0.7948	0.7250
120°	0.7217	0.8823	0.7177	0.7389	0.7010	0.6906	0.6720	0.7868
1"	0.9606	0.8622	0.9896	0.9011	0.8959	0.9809	0.8996	0.9973
2"	0.9747	0.9636	0.9741	0.8982	0.9852	0.9874	0.9779	0.9474

Table 4 Treatment correlation

Discussion

The thickness measurements on an irregular surface have important differences when comparing the thicknesses of the deep regions with the thicknesses of the upper regions, this is due to the effect of the Faraday cage.

References

Casaux, J., (2007), Critical thickness of electrostatic powder coatings from inside, *Journal of electrostatic*, 2007; 65: 764 – 774.

Chen, Y., Liang, X., Bai, & J., Xu, B., (2010), Finite element modeling of coating formation and transient heat transfer in the electric arc spray process, *International Journal of heat and mass transfer*, 2012; 13, 2012 – 2021.

Guskov, S., (1996), Electrostatic phenomena in powder coating, *Powder coating '96*, Nordson Corporation, Indianapolis Indiana.

Hayt, W.H. Jr. & Buck, J.A., (2006), *Teoría electromagnética*, México, Mc Graw Hill Interamericana Editores S.A. de C.V., 7ª ed.

Humphires, S. Jr., (2010), Finite element methods for electromagnetics, electronic edition of “Field solution on computers”, Ed. CRC Press a division of Taylor and Francis.

Hyuncheol, O., Kyoungtae, K., & Sangsoo, K., (2008), Characterization of deposition patterns produced by twin – nozzle electrospray, *Journal of aerosol science*, 2008; 39: 801 – 813.

Inculet, I.I., & Adamiak, K., (1993), Charge limits in corona charging of distorted liquid droplets, *IEEE Transactions on industry applications*, 1993; 29: 1058 – 1061.

Jalaal, M., Soleimani, S., Domairry, G., Ghasemi, E., Bararnia, H., Mohammadi, F. & Barari, A., (2011), Numerical simulation of electric field in complex geometries for different electrode arrangements using meshless local MQ-DQ method, *Journal of Electrostatic*, 2011; 69: 168 – 175.

Kreeger, K., (1994), Application variables for powder coating systems, Nordson Corporation.

Lackowski, M., Krupa, A. & Jaworek, A., (2010), Corona discharge ion sources for fine particle charging, *The European Physical Journal D*, 2010; 377 – 382.

Le Moyne, L., (2010), Trends in atomization theory, *International journal of spray and combustion dynamics*, 2010; 1: 49 – 84.

Matsusaka, S. & Masuda, H., (2002), Theoretical analysis of electrostatic forces between coated particles, *Advanced powder technology*, 2002; 13: 2: 157 – 166.

Nordson Corporation, (2004), *Corona charging and electrostatics for pipe coating*.

Plonus, M.A., (1994), *Electromagnetismo aplicado*, Barcelona, Editorial Reverté S.A.

Sarrate, J. & Clarisó, R., (2001), El método de los elementos finitos en problemas electromagnéticos: planteamiento y aplicaciones, *Revista internacional de métodos numéricos para cálculo y diseño en ingeniería*, 2001; 17: 1: 219 – 248.

Wu, Y., Castle, P. & Inculet, I.I., (2005), Induction charging of granular materials in an electric field, *IEEE Transactions on Industry Applications*, 2005; 41:1350 – 1357.

Ye, Q., Steigleder, T., Scheibe, A. & Domnick, J., (2002), Numerical simulation of the electrostatic powder coating process with a corona spray gun, *Journal of electrostatic*, 2002; 54: 189 – 205.