Tribocharging behaviour of automotive powder coatings

Aline THOMAS¹², Khashayar SALEH¹, Pierre GUIGNON¹, Claire CZECHOWSKI²

¹ Chemical Engineering Department, CNRS-UMR 6067, Compiègne University of Technology, BP 20529, 60205 Compiègne Cedex
² Department of Materials and Painting Processes, PSA Peugeot Citroen, Velizy Technical Center, CC.09, 78943 Vélizy Villacoublay Cedex

khashayar.saleh@utc.fr

Abstract. The aim of this work was to build a device allowing the measurement of tribocharging during the fluidization and pneumatic transport of automotive powder coatings. The experimental setup included a fluidization unit, a transport pipe and two “Faraday cups” allowing continuous monitoring of particle charge. Two batches of industrial automotive powder primers, as well as several other types of powders were tested: alumina, silica... The experimental variables were the length of the conveying pipe and the air flow rate. The results showed that the net amount of acquired tribocharge increases with the length of conveying pipe. The experimental device and procedure allowed to well classify tested powders according to their rate of tribocharging and their maximum charge. More specially, this study pointed out a net difference between electrostatic properties of two powder primers, which behave very differently in the industrial application unit.

1. Introduction

Although electrostatic phenomena are regarded by many as a nuisance and hazard, they play an important and ever emerging role in many industrial applications, including, xerography, pharmaceutical processing and powder coating, [1].

The use of powder paints in automotive industry is one of emerging applications of the electrostatic phenomena [2]. Indeed, among all manufacturing processes for automotive production, the painting operation using liquid-based paints contributes most to direct environmental emissions. As a consequence of recent restrictions in European legislation concerning the volatile organic compounds (VOC) emissions, the trend in almost every finisher industrial field is to replace the conventional solvent-borne paints by new low-emission paint systems, including powder coating systems. Powder paints are very finely divided solvent-free polymer coatings, which present important advantages over conventional paints from ecological and economical points of view [3][4].

In the electrostatic powder coating process (Fig.1), the powder paint is fluidized and transported through a feed pipe to a special charging corona bell. In the corona bell, the powder is electrostatically charged and sprayed toward a grounded workpiece. The adhered powder is then heated, melts and cross-links to form a uniform layer over the workpiece. In addition, unlike the liquid paint systems in which non deposited paint is a lost, the oversprayed powder during the electrostatic application process can be reused [5].
The industrial application of this technology shows that electrostatic properties of powders play an important role on the efficiency of the application. In particular, the tribocharging of particles from the storage stage up to the bell can largely affect the amount of the deposited layer. Consequently, the main objective of this work was to develop an appropriate test to characterize and classify the tribocharging of powder primers during different steps of the process.

Triboelectrification describes the process of charge generated during powder handling, accounting for the sliding and frictional forces that are involved [6]. In fact, during the particle conveying process, solid particles always have a tendency to acquire electrostatic charges due to collisions with surfaces of a different material type. Electrostatics and the associated charge generation mechanisms in such system are complex and not fully understood [7].

Factors influencing charging properties include particle size and shape, nature and work function of the contacting surface and the particulate material, area and frequency of contact [8],[9], surface purity, and atmospheric conditions [10]. Consequences of charge generation upon particle dynamics and powder behavior are often unpredictable [1].

The results of this study showed that the net amount of acquired tribocharge increases with the length of conveying pipe. The experimental device and procedure allowed to well classify tested powders according to their rate of tribocharging and their maximum charge. More specially, this study pointed out a net difference between electrostatic properties of two powder primers, which behave very differently in the production unit.

2. Experimental

2.1. Materials
Originally, two powder primers (A and B) coming from two different suppliers were chosen for this study. The formulation of these products was different but can not be communicated except the nature of the flow conditioners that they contain. Note that, flow conditioners are nanosized powdery additives used to improve the flowability of powders by coating the particles and decreasing the Van der Waals forces. The flow conditioner was fumed silica for primer (A) and fumed alumina for primer (B). Their mean particle size is close to 25µm and the true density 1310 kg/m³. In addition, the tribocharging behavior of silica and alumina powders alone was evaluated.

2.2. Methods
The experimental setup is shown in Fig. 2. It includes the fluidisation step followed by pneumatic transport of powder through a pipe of known length made from polyurethane. The fluidisation is
carried out inside a metallic column. Its role is to help the venturi pump to suck out the powder and to push it through the conveying pipe. The venturi pump is supplied with two air inlets: the first inlet (\(\varphi\)) controls the air suction to suck out the powder and the other one (\(\varphi\)) is used to dilute the powder mass flow rate, which was maintained at 200g/min during this study. A continuous Faraday cup (\(\varphi\)), situated at the entrance of the conveying pipe permits to measure the acquired charge of particles during their transit in the internal pipe (11 mm, stainless steel). At the end of the conveying pipe, the powder is collected in a fabric filter placed in the inner cylinder of a second Faraday cup (\(\varphi\); external cylinder diameter = 200mm; length = 800mm) which is provided with holes allowing air to escape. Note that the filter does not disturb the measurement because it is unimportant whether the filter is insulating or conducting [11].

The fluidization charge is measured by a picoammeter Keithley 6485 connected to the fluidization column. The charge exchange by the powder during the contact with the metallic pipe in the small “Faraday cup” and the total charge acquired during the process in the open-ended Faraday cup are measured with nanocoulombmeters (Monroe model 284-3) [12]. During each experiment, the charge corresponding to Faraday cups as well as the current intensity from fluidisation unit and the mass difference of powder (balance Mettler Toledo PB8001L) in the fluidized bed are monitored.

2.2.1. Fluidization charge
It is important to note that the charge acquired by the powder during the fluidization step can only be measured if the powder is removed from the fluidization column. In fact, as shown in Fig.3, a picoammeter is connected between the hopper and the earth. When fluidization begins, some charges are exchanged between the powder and the walls of the hopper but the total charge is conserved, so no current is measured. If a part of the powder is removed from the bed, the charge conservation is upset and a current flow occurs to compensate the quantity of charge leaving the system. As the powder flow stops, the charge equilibrium is established and the current is equal to zero. The charge-to-mass ratio is deduced by integrating the current, \(I\), as a function of the time, \(t\):

\[
\frac{Q_{\text{fluid}}}{m} = \frac{1}{m} \int_0^t I dt
\]

2.2.2. Conveying charge
The charge exchanged with the conveying pipe is measured by a nanocoulombmeter directly connected to the inside stainless steel pipe. The outer pipe is grounded and forms an electrical screen
which prevents stray external charges from affecting the measurement. This measurement will give additional information on the tribocharging behaviour of the powder primers.

As illustrated in Fig.4, the powder flow generates charge accumulation in the metallic pipe due to the contact of particles and pipe walls. The longer the pipe is, the higher the number of contacts is and so the higher the charge will be. As the outgoing particles have a different charge than the incoming particles, when the flow is established the specific charge \( \frac{Q}{m} \) increases or decreases depending on whether the powder gives or receives electrons.

As the length of the stainless steel pipe is 10cm and the powder velocity is around 25m/s, the particles residence time inside the pipe is low. So, the measured charge is the charge exchange with the metallic pipe.

2.2.3. Total charge
The open-ended Faraday cage was used to statically measure the total electrical charge acquired by powders during all the steps of the process, that is to say: fluidization, sucking-up and transport in the insulating pipe [13].
3. Results and discussion

3.1.1. Fluidization charge

| Length of the conveying pipe (m) | Charge-to-mass ratio (nC/g) | 0 | 1 | 6 |
|---------------------------------|-----------------------------|---|---|---|
| Powder A                        | 0                           | 0 | 0 | 0 |
| Powder B                        | -4                          | -3 | -4 |

Table 1 Fluidization charge results

As shown in Tab.1, the charge-to-mass ratio acquired by each powder during the fluidization step is not very high. However, it is possible to discriminate the behavior of the two powders because the powder B exchange a slightly more charge than the powder A.

3.1.2. Conveying charge

| Charge-to-mass ratio (nC/g) | Powder A (0,20% Si) | Silica powder | Powder B (0,20% Al) | Alumina powder |
|-----------------------------|---------------------|---------------|---------------------|----------------|

Tab.2: Conveying charge results

As illustrated in Tab.2, during the flow through the stainless steel pipe, each studied powder behaves differently. In fact, we can see that powder primer A and Silica powder charge negatively, contrary to powder primer B and alumina powder which charge positively. As a reminder, the flow conditioner agent is fumed silica for powder A and alumina for powder B. Moreover, to perform its role, the fluidity agent should coat the surface of the particle to move them apart. So to conclude, the nature of the fluidity agent controls the charging process of the powder and may be an explanation for these different behaviors.

3.1.3. Influence of tube length

To study the influence of the tube length, we measure the total charge of the powder in the open-ended Faraday cup. The results are shown in Fig.5. The trials for different lengths of insulating tube show that the tribocharge of the powder primers seems to increase linearly with the tube length. It should be noticed that as the powder massflow rate is kept at 200g/min, the velocity of the air does not change too much between the different lengths of the pipe. Preliminary experiments with longer conveying pipes have shown that the charge-to-mass ratio reach a steady state with a 10 meter long pipe.

Moreover, it can be observed that the total charge acquired by the powder during its transit is more important for the powder containing alumina (powder B) than for the powder composed of silica (powder A) as fluidity agent.

This more important charge measured with powder B, can be linked to industrial observations made during the application of this powder in the production unit.
4. Conclusion

The triboelectric device developed in this work allows the measurement of the charge acquired in different steps of the process: in the fluidization hopper, during the conveying through a metallic pipe and also the charge acquired during the transport through an insulating pipe.

This study shows that this set-up allows to differentiate the triboelectric behavior of two powder primers used in the production unit and that behave completely differently. Indeed, it was displayed that the nature of the fluidity agent has an inconsiderable influence on the charging process of the powder.

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