Powder Technology 190 (2009) 230–235

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Characterisation of electrostatic properties of powder coatings in relation with their industrial application

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ARTICLE INFO

Available online 2 May 2008

Keywords:
Electrostatics
Tribo-charging
Powder coatings
Fluidisation
Pneumatic conveying

ABSTRACT

The aim of this work was to develop an experimental set-up allowing the measurement of tribo-charging during handling and transport of powders. The experimental set-up included a fluidisation unit, a transport pipe and two "Faraday cups" allowing continuous monitoring of particles charge. Several batches of industrial powder coatings were tested. The investigated parameters were the length and the fouling of the conveying pipe. The experimental device and procedure permitted to classify conveniently the tested powders according to their ability to be charged. More specially, a net difference between electrostatic properties of two powder primers, which behave very differently in the industrial application unit, was pointed out. Furthermore, it was established that tribo-charging is essentially governed by the nature of the flow conditioner added to powder coatings. The results showed that the net amount of acquired tribo-charge increases with the length of the conveying pipe. However the polarity of charges could change with the pipe fouling.

1. Introduction

Powder handling operations lead most often to electrostatic charging of products due to collisions with surfaces of a different material type (particle/particle or particle/wall contacts). Although electrostatic phenomena play an important and ever emerging role in many industrial applications (e.g. powder coating, xerography, and pharmaceutical processing) they are regarded by many as a trouble and a hazard source. In fact, numerous processes such as pneumatic conveying, sieving, fluidisation and mixing, result on tribo-charging of powders. The electrostatic charges acquired by particles can thus affect the behaviour of handled products and their quality. Typical examples are poor flowability, pipe fouling and electrostatic discharge that can ignite flammable dust clouds or organic vapours. Factors affecting charging properties include particle size and shape, nature and work function of the contacting surface and the particulate material, area and frequency of contacts [2], surface purity, and atmospheric conditions [1–5]. However, electrostatics and the associated charge generation mechanisms in such systems are multifaceted and not fully understood [3]. In order to better understand and control the electrostatic consequences, it is important to develop laboratory-scale equipments allowing the properly measurement of tribo-electric charging of powders.

2. Electrostatic applications in car painting field

Among all manufacturing processes for automotive production, the painting operation 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 large advantages over conventional paints from ecological and economical points of view [6].

PSA Peugeot-Citroën is the first car manufacturer to use multi-colour powder primers and extend henceforth the use of this technology for new plants. In the electrostatic powder coating process (Fig. 1), the powder paint is fluidised and transported through a pipe to a special charging corona bell. In the corona bell, the powder is electrostatically charged and sprayed toward the 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 over sprayed powder during the electrostatic application process can be reused [7].

The industrial application of this technology shows that electrostatic properties of powders play an important role on the efficiency of the application [8]. In fact, the tribo-electric charge acquired by the powder particles during the storage up to the spraying step can largely affect the amount of the deposited layer and the deposition efficiency.

The aim of this work was to develop a test allowing characterization and classification of powder coatings according to their ability to

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0032-5910/$ – see front matter
doi:10.1016/j.powtec.2008.04.072

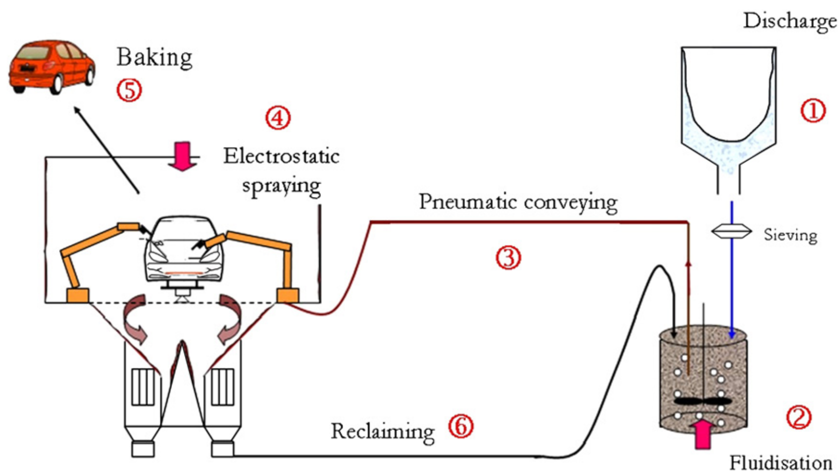

Fig. 1. Schematic diagram of industrial application process.

acquire tribo-electric charges during the fluidisation and pneumatic conveying steps of the application process.

3. Experimental

3.1. Materials

Two powder primers were used as the basis of this work. The powders were supplied by two different manufacturers. The principal physical and electrical properties of powders are summarized in Table 1. The mean particle size of both products measured by laser diffraction analysis (Malvern, mastersizer) was about 25 µm and their true density was 1350 kg m^{-3} (Micromeritics, Accupyc 1330). According to these properties the powders belong to the cohesive group-C powders of the Geldart classification. Both products were polyester/epoxy thermosetting hybrid resins but contained different types of flow conditioners. The powder designated $A_{0.2\%Si}$ contained 0.2% of fumed silica and the primer $B_{0.2\%Al}$ the same amount of another flow conditioner (fumed alumina). Note that flow conditioners (also called Glidants) are nano-sized powdery additives used to improve the flowability of powders by coating the particles and decreasing interparticle forces [2,9,10]. The use of flow conditioners in powder paints used in automotive industry is almost unavoidable because of small and narrow size distribution of particles that make them very cohesive. These particle size characteristics are necessary for the high-grade appearance requested in car manufacturing.

Despite the similar physical properties and chemical nature, the application of the two powders $A_{0.2\%Si}$ and $B_{0.2\%Al}$ revealed that they behave differently in the industrial unit. In particular, the film thickness and the deposition efficiency (i.e. mass ratio of deposited and sprayed powder) were higher for the primer $A_{0.2\%Si}$.

In addition, the determination of electrical resistivity (Chilworth cell) and permittivity (LCR meter, Agilent, Model 4263b) revealed no significant difference between the two powders (Table 1). Consequently, these intrinsic electrical properties cannot be responsible for the two products behave differently. A systematic work was hence necessary to elucidate the effect of the coating agent and the tribo-charging acquired prior to corona spraying on the process efficiency. A parametric experimentation was carried out using two series of five batches (Table 2). Each series included one of the basic primers (Glidant-free A or B) as well as four batches containing different amounts of fumed silica or fumed alumina (0.1 and 0.2% w/w).

Table 1
Principal properties of industrial powder primers used in this study

Powder coatings	Flow conditioner	Particle mean size (µm)	True density (kg m^{-3})	Resistivity (Ω m)	Permittivity (−)
Primer $A_{0.2\%Si}$	Fumed silica (0.2% w/w)	25±1	1350	$2.0\ 10^{14} \pm 0.5\ 10^{14}$	4.5
Primer $B_{0.2\%Al}$	Fumed alumina (0.2% w/w)	25±1	1350	$2.2\ 10^{14} \pm 0.2\ 10^{14}$	4.5

3.2. Tribo-charging measurement set-up

To measure the tribo-charging properties of powders an instrumented set-up was developed (Fig. 2). The experimental device reproduces different steps of the industrial unit before corona spraying. It includes the fluidisation step followed by the pneumatic transport of powder through a pipe of known length made from polyurethane (0.01 m ID). The pipe was exactly the same as that used in the industrial unit. A venturi pump, fed by two air inlets, allows feeding of the powder. The first inlet (j) controls the suction air to remove particles from the bed and the second inlet (k) is used to dilute and obtain the desired powder concentration. Doing so, it is possible to vary separately the powder mass flow and the air velocity through the pipe. Note that the powder mass flow rate was maintained at 0.0033 kg s^{-1}.

During each experiment, the charge corresponding to fluidisation and pneumatic transport as well as the mass of the remaining powder in the fluidised bed were monitored.

3.2.1. Tribo-charging assessment during pneumatic conveying

As schematised in Fig. 2, at the end of the conveying pipe, the total charge of particles is measured by a home-made terminal Faraday cup. The powder is collected by a fabric filter placed in the inner cylinder of the Faraday cup (Fig. 3). A perforated plate placed at the back of the inner cylinder allows the air to escape. It is established that the filter does not disturb the measurement whether the filter is insulator or conductive [11,12]. An outer grounded cylinder is used for protecting the inner cylinder from atmospheric noise. Note that this device measures the total charge acquired during all steps including the fluidisation, the suction and the transport. In order to measure the net amount of charge gained during pneumatic conveying two experiments must be carried out at the same conditions. In the first run,

Table 2
Laboratory-made powders containing different amounts of flow conditioners

Flow conditioner	−	Fumed silica		Fumed alumina	
Flow conditioner content	0%	0.1%	0.2%	0.1%	0.2%
Primer base	A	$A_{0.1\%Si}$	$A_{0.2\%Si}$	$A_{0.1\%Al}$	$A_{0.2\%Al}$
	B	$B_{0.1\%Si}$	$B_{0.2\%Si}$	$B_{0.1\%Al}$	$B_{0.2\%Al}$

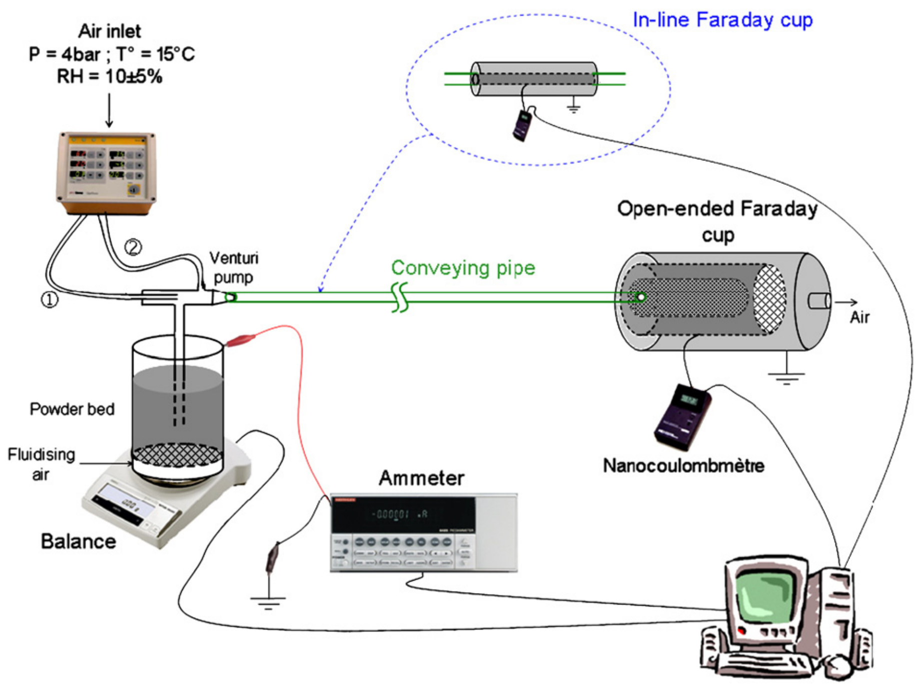

Fig. 2. Schematic diagram of experimental set-up.

conducted without any conveying pipe, the powder is directly collected at the outlet of the venturi pump. This measurement gives the initial charge of particles at the entrance of the conveying pipe. Then a second run is conducted with the pipe. The difference between the charges measured by these two runs corresponds to the net charge of particles acquired during the conveying transport.

3.2.2. Fluidisation tribo-charge

As shown in Fig. 4, a picoammeter (Keithley 6485) is connected between the metallic fluidisation column and the earth to measure the charge acquired by the powder during the fluidisation step. It is however important to note that this charge can only be measured if some part of the powder is removed from the bed. Indeed, when the fluidisation 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 an amount of 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. When the powder flow stops, the charge equilibrium is established and the current drops off to zero. The ratio of fluidisation charge, Q_{fluid}, to powder mass flow, m, is deduced by integrating the current, I, as a function of time:

$$\frac{Q_{fluid}}{m} = \frac{1}{m}\int_0^t I \cdot \mathrm{d}t$$

3.2.3. Tribo-charging due to wall/particle contacts

Besides the fluidisation charge and the total charge due to the transport, an additional Faraday cup was used to measure electrostatic charge of particles generated during their transit inside a short metallic pipe (Fig. 5). This open Faraday cup is situated at the entrance of the conveying pipe (11 mm, stainless steel) and connected to a nanocoulombmeters (Monroe model 284-3). A grounded outer pipe forms an electrical shield and avoids external surrounding charges to affect the measurement. The device permits to measure the tribo-

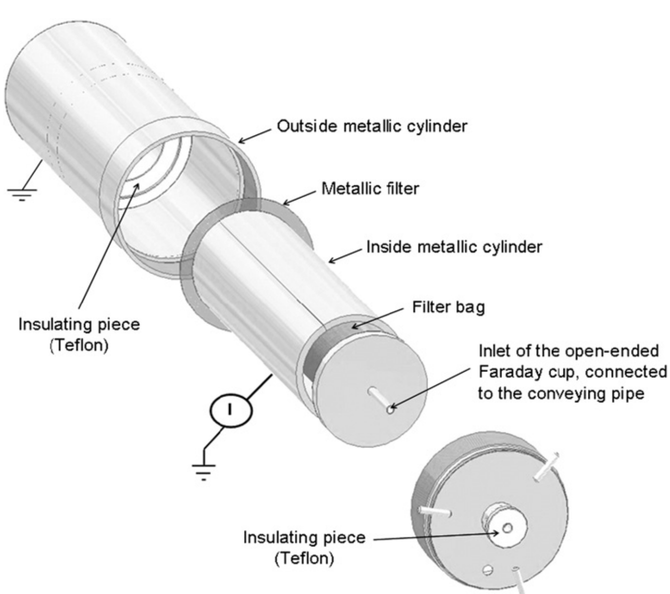

Fig. 3. Terminal Faraday cup.

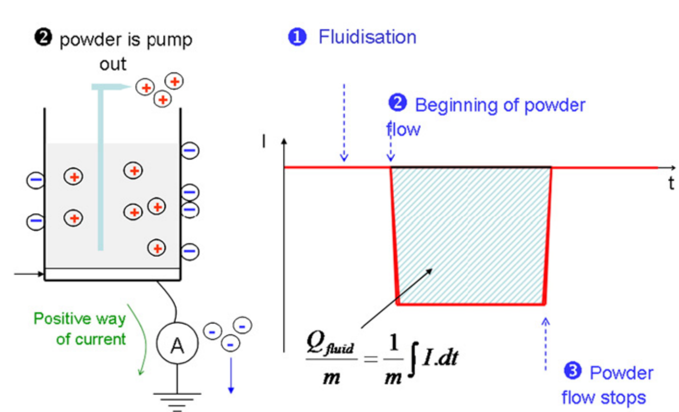

Fig. 4. Fluidisation charge measurement.

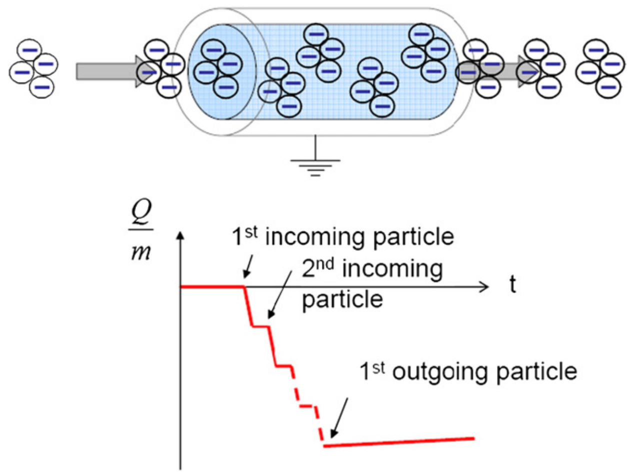

Fig. 5. Powder charge measurement inside a metallic pipe.

charge caused by particle/wall contacts. Then, it is possible to arrange different tested powders into so-called tribo-electric series so that each material is charged positively when it is rubbed against the previous.

As the powder flows through the metallic pipe, there is charge generation due to both particle–particle and particle–wall contacts (Fig. 5). However, taking into account that the particles residence time inside the pipe is short (the length of the stainless steel pipe is 0.1 cm and the powder velocity is about 25 m s^{-1}) and because the particles motion is mono directional, tribo-charging is basically governed by particle–wall contacts and the measured charge is the charge exchange with the metallic pipe. Since the outgoing particles have a different net charge than the incoming particles, when the flow is established the specific charge (Q/m) increases or decreases depending on whether the powder gives or receives electrons.

4. Results and discussion

4.1. Fluidisation

The fluidisation charge was only measured for the two industrial primers, $A_{0.2\%Si}$ and $B_{0.2\%Al}$. Fig. 6 shows that the acquired charge during the fluidisation step did not vary with the pipe length (i.e. the overall pressure drop generated by pneumatic transport). Nevertheless, a net difference is observed between the two powders. The powder $B_{0.2\%Al}$ exchange more charge (−4 nC/g) than the powder $B_{0.2\%Al}$ (−0.2 nC/g). However, as we will see later, the fluidisation exchange is negligible compared to the tribo-charge exchanged during the pneumatic conveying.

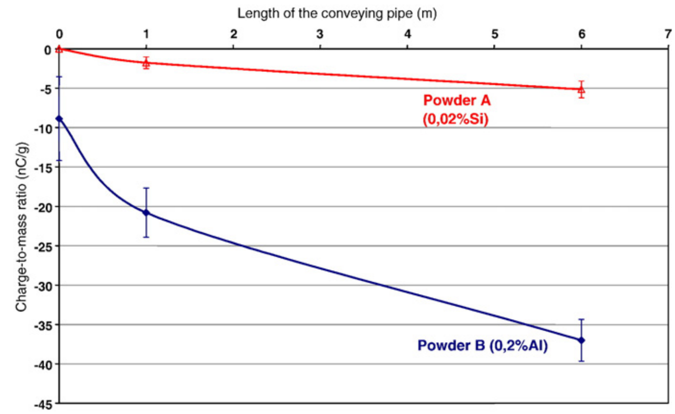

Fig. 7. Influence of the length of the conveying pipe.

4.2. Pneumatic conveying charge

The total charge acquired by the two industrial powders, $A_{0.2\%Si}$ and $B_{0.2\%Al}$, was measured at different lengths of the conveying pipe using the terminal Faraday cup. The results are given in Fig. 7. Each trial was made with a new pipe to keep a similar wall roughness. As illustrated in Fig. 7, the tribo-charge of the powder primers increases with the tube length. In fact, the longer the pipe is, the higher are the number of contacts and the resulting charge.

Furthermore, during the transport step it was observed that some powder stuck to the wall of the conveying pipe. To estimate the evolution of the tribo-charge as a function of the pipe fouling some trials were made with a 6 m length polyurethane pipe. For each trial, the tested powder was collected and reused several times (up to 53 consecutive cycles). As illustrated in Fig. 8, the charge decreases with the fouling of the conveying pipe and tends to stabilize [13]. In addition, it can be noticed that the fouling of the pipe has more influence on the powder $B_{0.2\%Al}$ than the powder $A_{0.2\%Si}$. The fact that the polarity of the tribo-charge acquired by the primer B changed can be explained by the change of the nature of contacts. Indeed, for the first trials, the contacts leading to tribo-charging are particle–wall interactions whereas after a number of trials, the contacts occur between the flowing particles and the particles that stick to the pipe. It can be concluded from these results that the powder B has a higher tendency to clog up the pipe walls.

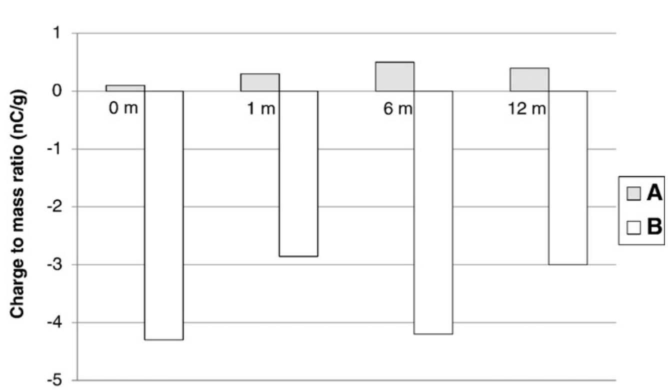

Fig. 6. Fluidisation charge of the two industrial batches.

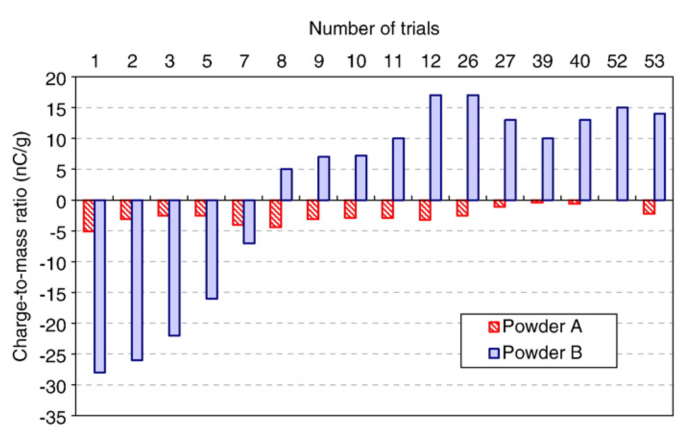

Fig. 8. Influence of the fouling of the pipe on the net charge during the conveying.

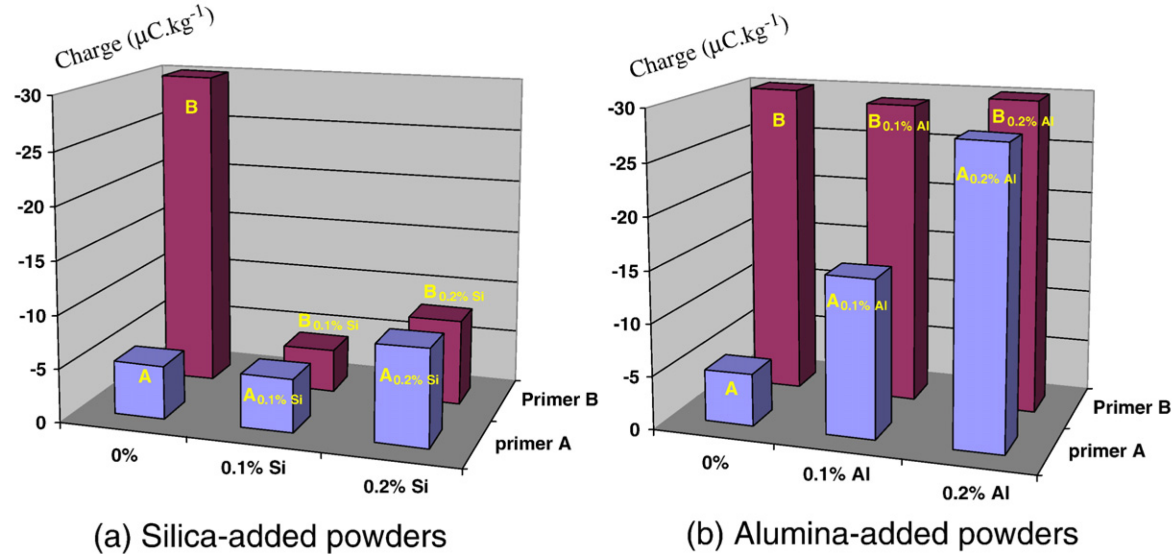

Fig. 9. Net conveying charge measured for laboratory-made powders containing different amounts of flow conditioner (see Table 2).

In addition, it can be expected that the flow conditioner has an important role in the ability of powders to be charged. In order to point out this effect, further trials were carried out with several laboratory-made powders containing different amounts of flow conditioner (Table 2).

As we can see in Fig. 9-a, in the absence of flow conditioner, the primer B exchange more charge than the primer A. This more important charge measured for powder B is in agreement with observations made during the application of this powder in the industrial unit. However, the use of silica as flow conditioner leads to a slight increase of tribo-charging for the primer A but reduces markedly the charge of the primer B. An interesting observation is that both primers behave similarly when they are coated with similar amounts of fumed silica.

On the contrary, Fig. 9-b shows that the fumed Alumina has no effect on the net charge-to-mass ratio of the primer B whereas the tribo-charging of the primer A increases with increasing the amount of this additive. However, similarly to fumed silica, it can be noted that as the amount of fumed Alumina increases the tribo-charging of the two primers becomes increasingly similar.

Although these results appear rather paradoxical, they can be explained by two main hypotheses:

- Tribo-charging is mainly governed by the state of particles surface rather than the chemical nature of major compound. For coated particles, this suggestion assumes that the tribo-charging is controlled by the nature of the coating agent (flow conditioner) provided that particles are completely covered by the additive. This can explain why the tribo-charging of glidant-added primers A and B is similar when they are coated with an equal amount of the same flow conditioner.
- The powder coatings used in this study could be classified according to their work function as summarized in Table 3. In this table, each material is charged negatively when it is rubbed against a material which is situated at a higher level (i.e. a material which has a lower work function).

Table 3
Tribo-electric classification of basic materials used in this study

Work function	Low	Conveying pipe (Polyurethane)
	↓	Primer A
		Fumed Si
	High	Primer B and Al

Making these hypotheses, it becomes possible to describe the trends observed in Fig. 9. As the Polyurethane pipe has the lowest work function, all powders charge negatively in contact with the pipe. The fumed silica has a work function higher than primer A and lower than the primer B. Its use leads then to an increase in tribo-charging of the primer A whereas the tribo-charging of the primer B diminishes. In addition, as the fumed Alumina has a close work function to that of the primer B it does not affect the tribo-charging of the primer B. On the contrary, the addition of fumed alumina increases the tribo-charging of the primer A which has a higher work function than Alumina.

Note that this classification is also consistent with the results obtained by the in-line open Faraday cup detailed above (Section 3.2.3). In fact, the tribo-charge measured due to particle/wall contacts inside the in-line metallic pipe showed that the primer B acquired much more charges than the primer A.

5. Conclusions

In this work an appropriate device allowing the measurement of tribo-charging during the handling of automotive powder coatings were developed. The tribo-electric 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. It was shown that the experimental device is able to distinguish industrial powder primers in relation with their ability to acquire tribo-charges. The results corroborate well with the behaviour of powders in the industrial process.

Furthermore, it was established that the formulation of the powder and the nature of the fluidity agent have a considerable influence on the charging process of powder primers. In this study, the powder containing Alumina as flow conditioner acquires more charge than the powder containing silica.

Acknowledgements

The authors are very grateful toward Professor Tatsushi Matsuyama of the Faculty of Engineering, Soka University of Tokyo, Japan, for his invaluable help and relevant advices.

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