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Electrostatic Charges of Abrasive Powders: The Role of Particle Size and Humidity

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Abstract: Electrostatically coated abrasives have drawn vast attention in many industrial applications. Therefore, influence of humidity on the electrical properties of α -SiC and α -Al₂O₃ abrasive powders with three μ m-range particle sizes are here investigated using electrostatic charge and DC resistivity analysis. From the three particle size ranges used, 15–16 μ m, 60–63 μ m and 153–156 μ m, the intermediate one (60–63 μ m) is found to be associated with the highest charge values, measured using a double Faraday cup method, as well as the highest resistivity for both materials. However, comparing SiC and Al₂O₃ powders, the latter ones present about twice larger charges in dry and normal humidity states accompanied by several orders of magnitude larger resistivity. Under humid conditions all the powders reveal diminishing charge and resistivity values.

Keywords: grinding coatings; SiC; Al₂O₃; electrostatic charge; double Faraday cups; zeta potential

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1. Introduction

Grinding coatings or coated abrasives are widely used in our life from household needs to construction, decoration, furniture and automotive industry. In its turn the fabrication of coatings uses electrostatic method [1], i.e., abrasive powders are attached to a flexible base filled with glue under an electric field. Therefore, knowing the surface electrostatic charges can lead to a better understanding of the particles' interaction with the electric field and surfaces. The measurement and quantification of the surface electrostatic charges of the powder particles is then quite relevant to optimize the fabrication conditions.

There are several possible methods to measure the surface charges, including Kelvin probe microscopy (KPM) and zeta potential (ZP) measurements, but they all have limitations. KPM is one of the most advantageous methods, but it can be applied only to the materials with nm-scale roughness [2]. The granulometry of abrasive powders, following the FEPA (Federation of European Producers of Abrasives) standard, ranges for coated abrasives between P12 and P5000 [3]. The indicated number means the quantity of the abrasive grains per square centimetre of support. The higher number corresponds to the finer sandpaper grains and vice versa. Therefore, KPM is inapplicable for the abrasive powder characterisation with separated particles of micron size range. ZP measurement or zetametry can help to estimate the surface charge and it is a widely used method, but it can only be performed in liquid media and on relatively small particles [4,5]. Finally, the electrostatic charge at the particle surface can be measured using Faraday cup method [6]. A double Faraday cup consists of two stainless steel cylindrical cages, of different sizes, concentrically set and isolated to each other by a Teflon plate. The device is connected to an electrometer with input impedance high enough to measure the charge as small as pC. When the outside cage is grounded to screen out external signals and the powder is dropped in the inner cage, an equal charge is induced on the cage metallic wall, resulting in a potential V_c drawn from the capacitor, C_f , in the feedback loop of the electrometer. The magnitude of the output voltage recorded by the electrometer directly yields the magnitude of the charge, $Q = V_c \times C_f$, as long as C_f is a known parameter of the electrometer [6].

The double Faraday cup electrostatic charge measurements of >99.5% pure Al_2O_3 powders with regular hexagonal particle shape have been reported by Lorite et al. [6] as a function of the particle size, being however concentrated on the particle size below 90 μm . The charge was found to switch from few nC/g negative values to much lower positive values at the particle size of about 1 μm [6]. No electrostatic charge characterisation at atmospheric conditions has been reported so far for SiC powders to the best of our knowledge. Therefore, in this work SiC and Al_2O_3 abrasive powders with over 10 μm in average large particles are systematically characterized and compared to establish the relation between the particle size, humidity, resistivity and electrostatic charges.

2. Materials and Methods

Commercially available P120, P320 and P1200 black silicon carbide SiC (purity > 99%) and semi-friable fused aluminium oxide Al_2O_3 (purity > 97%) abrasive powders from Imerys (Paris, France) were studied in this work. The powder crystal phase was analysed with an X-ray diffractometer PANalytical X'Pert-Pro (Malvern, UK), using Cu K α radiation. The θ –2 θ scan technique was adopted to collect the X-ray diffraction (XRD) intensity data from 20° to 80° with a 0.026° step. The morphology of the powders was observed by scanning electron microscopy (SEM, Hitachi, S-4100, Tokyo, Japan) under the accelerating potential of 25 kV. Compositional analysis of the films was carried out by built-in energy dispersive spectroscopy (EDS) system (QUANTAX 400, Bruker, Billerica, MA, USA). The particle size distributions together with the average particle size were determined by particle size analyser (Coulter LS 230, Indianapolis, IN, USA), using the laser scattering technique in aqueous medium. When possible, the surface charge of the powder particles in the aqueous media was estimated by Zeta-potential measurements carried out in pH range from 2 to 12 using a Malvern Zeta sizer (Nano ZS, Malvern, Worcestershire, UK).

The surface resistivity of the powder particles as a function of the particle size was evaluated from two probe I–V characterisation using a source meter (Keithley 2410, Cleveland, OH, USA), providing 10 V potential. The powders with weight of 0.6 g were located in a cylindrical mould made of Teflon and pressed to ~100 MPa with two stainless steel press punches, with diameter of 1 cm, which also served as electrodes. In addition to powders in an untreated state, powders dried at 120 °C for 24 h and identically dried powders further exposed to a humid environment for another 24 h were studied. The environment with relative humidity (RH) of about 91% was reached using a glove box, where boiling water was placed. The powder surface charge as a function of humidity was measured using the double Faraday cup connected to an electrometer (Keithley 6514, Cleveland, OH, USA) with input impedance of $10^{14} \Omega$, high enough to measure down to pC charges (see Appendix A, Figure A1). The outside cage of the Faraday cup was grounded to define a reference point, as well as steel scoop used to put 2 g of the powders into the inner cage without tribo-charge. Before the measurements the powders were dried at 120 °C for 24 h. The humidity variation was carried out using silica gel and boiling water in a glow-box, where the powders stayed for at least 10 min before the measurement. All the electrical measurements were repeated at least 3 times for each powder to define the measurement uncertainty.

3. Results and Discussion

XRD patterns of SiC and Al_2O_3 powders are shown in Figure 1. While Al_2O_3 powders reveal mainly α -phase (corundum) [7] with structure shown in inset of Figure 1b, SiC present 4H- and 6H-modifications of α -phase [8,9], with the phase ratio of about 1:2 and structures indicated in inset of Figure 1a. The phase ratio was determined by HighScore Plus software, associated with the XRD equipment, using the reference intensity ratio method.

Figure 1. XRD patterns of P1200 (top), P320 (middle) and P120 (bottom) SiC (a) and Al_2O_3 (b) powders. Insets illustrate the crystal structure of SiC (4H and 6H polymorphs) and Al_2O_3 (corundum). Peaks marked by numbers 4 and 6 indicate XRD lines corresponding to 4H and 6H phases of SiC, respectively.

SEM micrographs presented in Figure 2 evidence the sharp angle morphology of the powder particles independently on the powder material and particle size, as should be expected for abrasive powders rather different from alumina powders with smooth hexagonal particle shape reported by Lorite et al. [6]. Figure 3 provides the particle size distribution and average size values for SiC and Al_2O_3 P120, P320 and P1200 powders. There are evident main peaks and average particle values of 15–16 μm for P1200, 60–63 μm for P320 and 153–156 μm for P120 powders.

Figure 2. Cont.

Figure 2. SEM micrographs of P1200 (a,b), P320 (c,d) and P120 (e,f) SiC (a,c,e) and Al_2O_3 (b,d,f) powders.

As mentioned in the introduction, zeta potential measurements can be used for estimation of the particle surface charges, but with limitations. As a result, we could also perform these measurements but only for P320 and P1200 SiC and Al_2O_3 powders, whereas average particle size of P120 powders appeared to be too large for reliable ZP determination. In general, ZP values were found to be negative for both P320 and P1200 SiC and Al_2O_3 particles, as seen in Figure 4. The absolute value increases with increasing pH value, particularly in the low-pH acidic range. A tendency towards a magnification of the negative zeta potentials with increasing pH is observed due to deprotonation of the surface hydroxyls [5]. In the high-pH basic range, ZP absolute values are slightly higher for Al_2O_3 comparing with SiC particles, independently on the particle size. That points to the higher surface charge for Al_2O_3 particles in regard to SiC ones, at least in the basic liquid media.

Figure 3. Particle size distribution of P1200 (dash line), P320 (solid line) and P120 (dash-dot line) SiC (top) and Al₂O₃ (bottom) powders of together with their mean size values.

Figure 4. Zeta potential ZP of SiC P1200 (open triangles), SiC P320 (solid triangles), Al₂O₃ P1200 (open circles) and Al₂O₃ P320 (solid squares) powders as a function of pH. Lines are guides to the eye. P120 could not be reliably measured because of too large average particle size. The continuously negative ZP values observed in these powders is related to silica contribution.

According to the literature, however, ZP of both SiC and particularly Al_2O_3 is known to switch from positive to negative when pH increases with isoelectric point above 8 for Al_2O_3 and below 5.5 for SiC [4,10]. On the other hand, composites of Al_2O_3 with SiO_2 were reported to have no isoelectric point, revealing negative ZP for pH values from 2 to 11 [5,11]. Therefore, we have performed EDS analysis of the commercial powders under study and found out peaks corresponding to Si in spectra of semi-friable fused aluminium oxide and peaks of O in spectra of black silicon carbide, both indicating the formation of silicon oxide (see Appendix A, Figure A2). Thus, continuously negative ZP values observed in this work should be related to silica contribution.

The powder resistivity of SiC and Al_2O_3 as a function of average particle size is presented in Figure 5 at different humidity conditions. Untreated powders have rather different electrical resistivity of about $10^6 \Omega \text{ cm}$ for SiC and 10^8 – $10^{10} \Omega \text{ cm}$ for Al_2O_3 . For both SiC and Al_2O_3 powders the resistivity is larger for P320 powders with intermediate average particle size of 60–63 μm . However, rather similar values in order of $10^6 \Omega \text{ cm}$ are recorded for SiC and Al_2O_3 powders when they are measured after wetting in atmosphere of 91% RH. On the other hand, the resistivities measured for the powders dried in atmosphere of 17% RH behave very differently for SiC and Al_2O_3 . For SiC, no significant variation is observed, implying that surface modification effect is masked by intrinsically somewhat low resistivity of $\text{M}\Omega \text{ cm}$ order. Similar order of resistivity was reported for SiC powder with average particle size of 54 μm [12]. For Al_2O_3 , however, there is up to 5 orders of magnitude variation between the resistivities of humid and dry powders, while untreated powder reveals intermediate values. Similar variation of the powder resistivity with humidity has been reported for Al_2O_3 powders with 320- μm mean diameter [13]. Such high variation indicates that the resistivity of intrinsically insulator Al_2O_3 can be strongly suppressed by the humidity effect on enhanced surface area, characteristic for powders.

Figure 5. Resistivity of SiC (a), Al_2O_3 (b) and both SiC (open symbols) and Al_2O_3 (solid symbols) powders (c) as a function of average particle size at 17% RH (circles), 52% RH (squares) and 91% RH (diamonds). Lines are guides to the eye.

The electrostatic charge values are shown in Figure 6 as a function of humidity for SiC and Al₂O₃ P120, P320 and P1200 powders. Identically to the resistivity, the highest charge with negative sign (the same as the sign of ZP) is measured for Al₂O₃ P320 powders, reaching up to 1.6 nC/g in absolute value. The charge is about twice higher than that for SiC P320 powders and much higher than that of sub-nC/g range for all other powders at humidity values below 50%. However, when humidity increases toward 91% RH the electrostatic charge diminishes for all the powders in correlation with the surface resistivity decrease observed in Figure 5b.

Figure 6. Electrostatic charge of P1200 (solid triangles), P320 (open circles) and P120 (open squares) SiC (top) and Al₂O₃ (bottom) powders. Lines are guides to the eye.

Here we advocate that the non-monotonous behaviour between the smallest particles of both powders and the ones of the biggest particle size might be related with some interplay between the raw material and silica additive properties from one side and the surface area variation from another side. Lower surface areas associated with the largest particle size will decrease the reactivity of these powders and, hence, the reactivity towards humidity, surface charges and resistivity. Regarding the considerable charge values observed on nominally semiconducting SiC powders, revealing up to 5 orders of magnitude lower resistivity than that of Al₂O₃, it can be attributed as well to the formation of silicon oxide surface layer [14].

4. Conclusions

In this work a comparative study of α -SiC and α -Al₂O₃ abrasive powders was performed and the relation between the particle size, humidity, resistivity and electrostatic charge was established. In terms of particle size, 15–16 μ m, 60–63 μ m and 153–156 μ m, the intermediate one is found to be associated with the highest charge values as well as the highest resistivity for both materials. However, comparing SiC and Al₂O₃ powders, the latter ones present about twice larger charges measured using a double Faraday cup method

in dry and normal humidity atmosphere conditions accompanied by several orders of magnitude larger resistivity. At humid conditions all the powders reveal diminishing charge and resistivity values. Significant charge values observed on nominally semiconducting SiC powders are attributed to the formation of silica surface layer.

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Appendix A

Figure A1. Scheme of double Faraday cup method for powder surface charge measurement, including presentation of the cups and their components.

Figure A2. Energy dispersive spectra of commercial black silicon carbide SiC (solid line) and semi-friable fused aluminium oxide Al_2O_3 (dash line), indicating presence of silicon oxide in both powders.

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