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How preparation of suspensions affects the electrophoretic deposition phenomenon

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ABSTRACT

Electrophoretic deposition (EPD) is a simple process using an easy-to-use apparatus; however, the development of this technique has faced many difficulties despite the long history of its use in many laboratories. Present study is an endeavor to highlight less mentioned parameters such as preparation techniques, aging, elution, and temperature, which make EPD an unrepeatable technology even in the laboratory scale. The experiments were carried out based on ceramic oxides including ZnO and SnO2 in organic liquids such as acetone, ethanol, and methanol to prepare the suspensions. DC electric fields were applied on metal electrodes. Our experiments have shown that less mentioned parameters such as preparation techniques, aging, elution, and temperature play an important role in EPD outcome as that of well-known factors such as deposition duration, concentration of the suspension and intensity of the applied electric field. Failure to adjust for these less mentioned parameters may be the reason for unsuccessful industrial applications of EPD.

1. Introduction

Electrophoretic deposition (EPD) is a low cost and facile method to form a layer of ceramic (mostly oxides of metals) particles on the surface of a metal and has been used since 1933 [1]. In this method, dispersed particles in an organic liquid are made to move toward a particular electrode in the presence of an electric field. A simple setup for this technique is shown in Fig. 1.

Electrophoretic deposition is used in ceramics processing, surface coating and formation of composite materials [2,3]. Electrophoretic deposition has a number of applications in electronic devices, electrophoretic painting and display technology [4]. Despite its low cost and easy to use setup, the industry is not sufficiently motivated to use it as a mass production coating technique.

Based on Hamaker's equation [5] the deposition weight during the EPD can be estimated by the Eq. (1):

$$\frac{dw}{dt} = f\mu EAc \tag{1}$$

where μ is the electrophoretic mobility, E is the electrical field, A is the surface area of the electrode, c is the particle's mass concentration in the suspension, and f is a coefficient taking into consideration that not all particles reaching the substrate electrode are incorporated into the deposit ($f \leq 1$). Any changes in the mobility of ceramic particles is directly attributed to the surface forces [6]. However, the preparation method and environmental parameters are not considered in Eq. (1) and the role of these two parameters on surface fces is unpredictable. Numerous articles have addressed the fundamental principles of EPD [7–11]. A few of them have studied the role of aging on EPD [12–16]. Mobility of particles in a suspension is indirectly proportional to temperature as given by Eqs. (2) and (3).

$$\mu = \frac{2}{3}\frac{\epsilon_0\epsilon_r\xi}{\eta}f(\kappa r) \tag{2}$$

where ϵ_0 is the permittivity of vacuum, ϵ_r is the relative permittivity of the solvent, $\xi$is the solvent viscosity, and $f(\kappa\ r)$ is the Henry coefficient, which depends on the relation between the thickness of the double layer $(1/\kappa)$ and the core radius (r) of the particle [17].

$$\frac{1}{k} = \left(\frac{\epsilon_0\epsilon_r KT}{e^2\Sigma i n_i z_i^2}\right)^{\frac{1}{2}} \tag{3}$$

where e is the electronic charge, n_i is the concentration of is with charge z_i, K is the Boltzmann constant and T is the absolute temperature.

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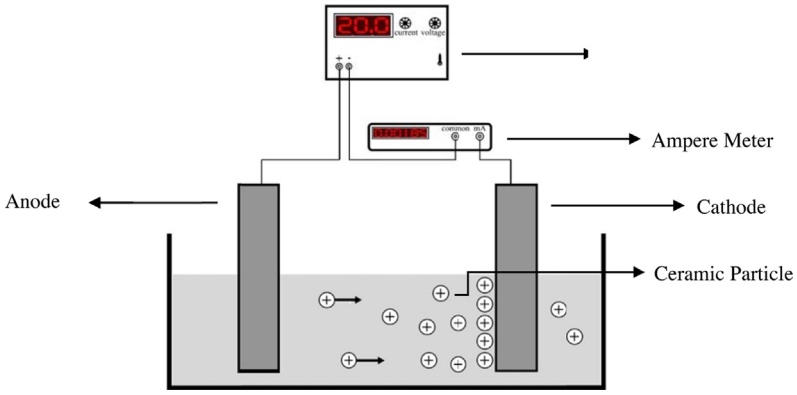

Fig. 1. Schematic view of simple electrophoretic deposition process.

The role of impurities in the EPD process have been less studied [8,18,19]. Although in all these reports, the role of impurities introduced into the suspension from various sources has been considered, there are no reports about the impurity coming from the elution process which includes small amounts of the washing agent or even water from incomplete washing process [20].

The details of suspension preparation process are not described in the literature, as it is usually considered as an insignificant factor. However, the role of side effects on the mobility of the particles has been mentioned in some reports [3,21]. The importance of the suspension or electrode preparation is also addressed [22,23]. These side effects may change the stability of the suspensions and the result of the EPD.

Our study addresses the importance of above mentioned factors through experiments, which can make some unexpected changes in the deposition yield.

2. Experimental

Materials used in our series of experiments were ZnO (8846), SnO_2 (7818), acetone (1.00013.2500), ethanol (1.00983.2500), and methanol (1.06012.2500). All produced by Merck Company. Stainless 304 steel electrodes ($2 \times 1\,cm^2$) have been used for the deposition process. Beakers (25 mL) were used as containers and dispersion was carried out in a SONOSWISS SW3H ultrasonic bath for 15 min. In addition, a DC electric field of 100 V was applied. These were the constant conditions for all the experiments and the test duration was five minutes. The temperature of the lab during summer and autumn was 25 °C.

To have a better sight by looking at the numbers and figures in the text, ten depositions with ZnO were carried out in acetone for which the average deposition weight was measured to be $0.0025\,gr\,cm^{-2}$ (ZA). In addition, five depositions were performed with ZnO in ethanol for which the average deposition weight was $0.0019\,g\,cm^{-2}$ (ZE). Finally, five depositions were carried out with ZnO in methanol for which the average deposition weight was $0.0016\,g\,cm^{-2}$ (ZM).

For SnO_2, ten depositions with the same conditions as ZnO were carried out in which the average deposition weight in acetone, ethanol, and methanol was 0.0017 (SA), 0.0019 (SE), and 0.0021 (SM), respectively.

3. Results and discussions

The results of EPD tests varied widely even at identical deposition conditions (voltage, time, and concentration). We selected two main categories and four subcategories to probe the importance of environmental parameters as illustrated in Fig. 2.

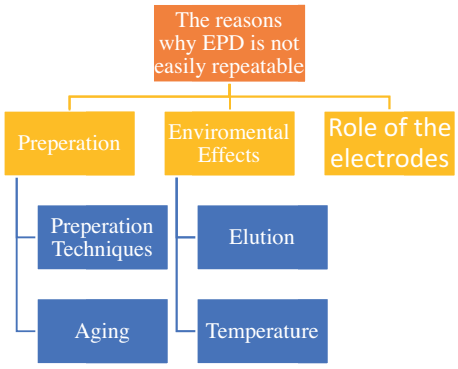

Fig. 2. A schematic view of the main and sub categories.

3.1. Preperation

3.1.1. A-1 preperation techniques

Colloidal particles of size 1 μm or less gets easily dispersed and are more stable in the suspension compared to bigger particles, which need continuous hydrodynamic agitation to stay dispersed in the suspension [1]. The reason being, gravitational force is not strong enough to influence small particles, but it can affect bigger particles or agglomerates. Brownian motion is for a single particle at very low concentration of the particle in a fluid. When it comes to higher concentrations, even nanometer sized particles may not remain stable and well-dispersed without any repulsive forces [24].

It is essential in the EPD process to make a stable suspension. Researchers use different ways including shaking and stirring for dispersing the particles (mostly nano-particles) in their medium. A simple and recently developed means for dispersing particles in a liquid medium is the ultrasonic bath [25]. This method has its own limitations, which affects the stability of the suspensions.

To study the role of ultra-sonic sound waves on the stability of the suspensions, we used an indigenously developed Turbidimeter for ZA and ZE suspensions. Blue LEDs are used light source and Cadminum sulfide (CdS) detectors are used as light detectors. They are placed correspondingly at three different heights in a test tube. As the stability of particles in the liquid decreases, the light received by the detectors will increase. The intensity of the light received by the detectors is measured in millivolts. A schematic view of the Turbidimeter is given in Fig. 3.

A simple ultra-sonic bath may send usual or degassing mode waves toward the sample. We checked the degassing mode and the usual one for ZA and the degassing mode for ZE. The data is shown in Fig. 4.

According to the data in Fig. 4, the mode of ultra-sound waves influences stability of particles. Initial stability of two suspensions