Electrophoretic deposition of alumina and nickel oxide particles

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ABSTRACT

Electrophoretic deposition (EPD) of alumina and nickel oxide particles on nickel substrate has been investigated. Pure ethanol and a mixture of ethanol and water were used as solvents. The stability of Al₂O₃ and NiO suspension in two solvents was studied and compared in terms of zeta potential, electrophoretic mobility and conductivity. The influence of different solvents and deposition parameters such as suspension conductivity, applied voltage and time of deposition on the weight gain and the morphology of deposits were also evaluated. The results demonstrated that mixture of ethanol and water as a solvent appears to be advantageous over pure ethanol for EPD of Al₂O₃ and NiO from standpoint of a good stability of suspension, a higher electrophoretic mobility and also due to the uniform deposits in terms of microstructures and thicknesses. Studies the relationship between the increase in applied voltage during EPD and the decrease in conductivity, have shown that the increase in voltage was completely caused by the decrease in conductivity of suspension.

Keywords: Electrophoretic deposition; ethanol, solvents; conductivity; Al₂O₃; NiO

1. INTRODUCTION

Electrophoretic deposition (EPD) was first observed by a Russian scientist Reuss in his experiment with electric field to induce motion of clay particles suspended in water [1]. But the first practical use of this method was patented in the USA in 1933 with the deposition of thoria particles on a platinum cathode for electron tube [2]. EPD has received increasing attention because of its important advantages such as low equipment cost and starting material, possibility to realize unique microstructures and nanostructures as well as novel and complex materials combinations using complex substrates. Many different materials have been deposited by EPD, like ceramic materials [3, 4], functionally graded materials [5, 6], polymers [7] and combinations of different materials [8, 9] for important applications such as optics, thin films, fuel cells, high performance ceramic and composite coatings, biomaterials and electrochemical capacitors.

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Electrophoretic deposition is a process in which colloidal particles dispersed in a liquid medium migrate toward the electrode with the opposite charge under the influence of an electric field (electrophoresis) and are deposited on the substrates. The EPD of ceramics was first studied by Hamaker [10] in 1940, who proposed the first model of EPD kinetics (Eq.1.1) in order to predict the yield of deposition. It relates the deposited mass \( m \) (g) with suspension properties, such as concentration \( C \) (g m\(^{-3}\)) and electrophoretic mobility \( \mu_e \) (m\(^2\) s\(^{-1}\) V\(^{-1}\)), with the physical and electrical conditions imposed on the system, as the electric field \( E \) (V m\(^{-1}\)), deposition area \( S \) (m\(^2\)), and time \( t \) (s).

\[
\frac{m}{s} = C \cdot \mu_e \cdot E \cdot t \tag{1.1}
\]

Where m/s (g/m\(^2\)) is the weight gain of deposition.

\( E \) (Eq.1.2) can also be calculated from the relationship between the electric field \( E \), the current \( I \) (A) flowing through the cell, the suspension conductivity \( \sigma \) (S m\(^{-1}\)) and the electrode area \( S \).

\[
E = \frac{I}{\sigma S} \tag{1.2}
\]

The electrophoretic mobility of the particles is proportional to the zeta potential \( \zeta \) (mV) and to some solvent properties (dielectric constant \( \varepsilon \) and viscosity \( \eta \)) as determined by Eq.1.3 [11].

\[
\mu_e = \frac{\zeta \cdot \varepsilon}{\varepsilon \cdot \eta} \tag{1.3}
\]

Considering Eq.1.1, 1.2 and 1.3,

\[
\frac{m}{s} = \frac{C \cdot I \cdot \varepsilon \cdot \zeta}{1.5 \cdot \varepsilon \cdot \eta} = R \tag{1.4}
\]

\( R \) is the rate of deposition (g/s). For a single-component suspension, \( R \) is a constant and depends on the current density and suspension properties such as conductivity, zeta potential, dielectric constant, viscosity and solid content (initial concentration of the suspension). But, when two powders are mixed, many of the constants in Eq.1.4 change with respect to the component ratio. The choice of solvent is very important because the solvent is as a vehicle that carries particles in suspension and suspension properties are key parameters of the EPD process. The quality of the green forms prepared using the EPD method depend strongly on the stability of the suspension used. The suspension must be stable so that the particles have to remain dispersed throughout the solvent so they can move towards the electrode independently.

In EPD, organic solvents and/or water are used. Water is used as solvent for EPD mainly because of higher-temperature control during the process or a faster kinetics (because of a high dielectric constant), cost benefits [12, 13], and is beneficial in preparing stable suspensions of oxide powders. However, the electrolysis of water that accompanies EPD interferes with the quality of the deposits at high applied voltage [14, 15]. Even at low voltages, electrolysis of water occurs, and gas evolution at the electrodes is inevitable at
field strengths high enough to give reasonably good deposits. The electrochemical reaction in the electrodes when current is passed through affects the efficiency of the process and the uniformity of the deposits.

Therefore, organic solvents are more used in general due to the fact that organic solvents eliminate the electrode reactions and gas evolution commonly encountered due to electrolysis of water on application of electric field [1, 16]. However, pure organic solvents have needed high applied voltages. More, in pure organic solvents, the electric charge on the particles is very low which decreases the particle mobility by decreasing the zeta potential and by increasing the suspension viscosity so that a stable suspension cannot be achieved, hence the oxide powders cannot be readily deposited [17]. In an effort to overcome this disadvantage, we have estimated that a mixture of organic solvent and water such as a mixture ethanol and water as solvent could be an effective slurry for Al₂O₃ and NiO or their combinations to obtain uniform, dense and crack-free deposits. Ethanol and water are completely miscible. They may therefore to mix in all proportions, which is not the case in many other solvents.

Several authors have conducted electrophoretic deposition in a variety of different organic solvents. For example, Anné et al. [18] evaluated ethanol solvent and mixture of methylethylketone and butyl amine on the basis of electrophoretic yield rate and the electric field as a function of deposition time during EPD of Al₂O₃. They revealed that suspension composition determines whether a potential drop is generated at the deposition electrode or not and an electrical resistive layer was formed in ethanol solvent with certain additives.

Wang et al. [17] evaluated several organic solvents such as ethanol, acetylacetone, mixture ethanol-acetylacetone and ethanol-water during EPD of YSZ/Al₂O₃ composite. They related that mixture of ethanol and water was not as colloidally stable as for that of mixture ethanol-acetylacetone solvent, with serious sedimentation occurring after standing for a prolonged period. They also showed that pure ethanol or pure acetone solvent was not colloidally stable, and the green form was difficult to deposit from these suspensions.

Novak and Konig [19] compared electrophoretic deposition of alumina powder in ethanolic and in aqueous suspensions, and related that water suspensions appear to be advantageous over ethanol, from standpoint of higher achievable green and sintered densities of the deposits and higher deposition rates.

Mao-Sung Wu et al. [20] deposited NiO by EPD from isopropyl alcohol suspension containing iodine and water additives and revealed the well-dispersed suspension due to iodine and water additives. Lebrette et al. [21] evaluated water and mixed water-ethanol rich in water during EPD of TiO₂ and have shown that addition of ethanol makes it possible to keep a suitable stability of the suspension without influence the surface charge. As shown by examples above, Al₂O₃ and/or NiO based coatings have been intensively studied due to their potential applications in solar absorbers [22], thin film, oxide fuel cell electrode [23, 24], and electrochemical capacitors [20].

In the present work, we study and compare electrophoretic deposition of Al₂O₃ and NiO in pure ethanol and in mixture of 80 vol. % of ethanol and 20 vol. % of water. 20 vol. % of water was considered reasonable to prevent electrochemical reactions at electrodes that could influence the quality of deposits. In addition Wang et al deposited composites from mixture of ethanol and water with a ratio of 1:1 by volume as solvent and have reported that the suspension was colloidal less stable, with serious sedimentation occurring after standing for a prolonged period and the green form was not densely packed. The influence of
different solvents and deposition parameters on the weight gain and the morphology of deposits are investigated.

2. EXPERIMENTAL DETAILS

2.1. Materials

2.1.1. Dispersed phase

The dispersed phase is commercial high purity α-alumina powder (Baikowski international corp, BRA15, USA) with average particle size of 0.6 µm (D50), a specific surface area (BET) of 15 m²/g, and Nickel (II) oxide nanopowder (Sigma-Aldrich, USA) with particle size < 50nm (TEM). The details of physical and chemical properties of these powders are summarized in Table1 and Table2, respectively.

Table1. Properties of alumina powder (BRA, baikowski)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder color</td>
<td>white</td>
</tr>
<tr>
<td>Crystal Structure (alpha)</td>
<td>100 %</td>
</tr>
<tr>
<td>Ultimate Particle Size / TEM (nm)</td>
<td>150.00</td>
</tr>
<tr>
<td>Agglomerate Size d20 (µm)</td>
<td>0.30</td>
</tr>
<tr>
<td>Particle size (d50) (µm)</td>
<td>0.60</td>
</tr>
<tr>
<td>Sedigraph d90(µm)</td>
<td>2.60</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>3.98</td>
</tr>
<tr>
<td>Bulk density (g/cm³)</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Table2. Properties of Nickel (II) oxide nanopowder (Sigma-Aldrich, USA)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder color</td>
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</tr>
<tr>
<td>Purity</td>
<td>99.8 %</td>
</tr>
<tr>
<td>Particle size/ TEM(nm)</td>
<td>&lt; 50</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>6.67</td>
</tr>
<tr>
<td>Bulk density (g/cm³)</td>
<td>0.51</td>
</tr>
</tbody>
</table>

2.1.2. Solvents

Two solvents were used. Pure ethanol (Aldrich, U.S.A.) and mixture of 80 vol. % of ethanol and 20 vol. % of deionized water. Table 3 reports the physicochemical properties of solvents used. The calculations of the dielectric constant of the mixture were based on the following Eq.2.1 [25].

\[ \varepsilon_{\text{mixture}} = \%\text{ethanol} \times \varepsilon_{\text{ethanol}} + \%\text{water} \times \varepsilon_{\text{water}} \]  

Where \( \varepsilon \) is the dielectric constant.
Table 3: Physicochemical properties of solvents used

<table>
<thead>
<tr>
<th>Solvent Composition (vol)</th>
<th>( \rho ), relative density at 20(^{\circ})C (kgL(^{-1}))</th>
<th>( \eta/\eta_0 ) (at 20(^{\circ})C), relative viscosity to water</th>
<th>Dielectric constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% ethanol</td>
<td>0.7893</td>
<td>1.2010</td>
<td>24.3000</td>
</tr>
<tr>
<td>80% ethanol+20%water</td>
<td>0.8436</td>
<td>1.8770</td>
<td>35.4200</td>
</tr>
<tr>
<td>100% water</td>
<td>0.9982</td>
<td>1.0000</td>
<td>79.9000</td>
</tr>
</tbody>
</table>

2.1.3. Suspensions preparation

Suspensions of \( \text{Al}_2\text{O}_3 \) and NiO were prepared separately from pure ethanol and mixture ethanol and water (80/20 in volume) in a glass container. Hydrochloric acid adjusted the pH on acid side and sodium hydroxide on the basic side. Acetic acid was added to the suspension to stabilize the particles. Suspensions were first magnetically stirred for 15 min and then subsequently ultrasonicated in an ultrasonic bath for 24 h to ensure a good dispersion of particles. Electrophoretic mobility and the zeta potential (ZP) were measured via a Zeta Plus zeta-potential analyzer; the operational pH of the suspensions was measured by means of a pH meter (WTW, 315i) at room temperature (25.0 \(^{\circ}\)C ± 0.5). The properties of the suspensions which were used for the EPD experiments are listed in Table 4.

Table 4: Properties of the suspensions used for electrophoretic deposition (pH=3)

<table>
<thead>
<tr>
<th>Suspensions</th>
<th>Additives</th>
<th>( \zeta ) (mV)</th>
<th>( \mu_e ) ( (10^{-8} \text{m}^2/\text{V.s}) )</th>
<th>Conductivity (( \mu \text{S/cm} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% ethanol + ( \text{Al}_2\text{O}_3 )</td>
<td>Acetic acid</td>
<td>60.01</td>
<td>1.05</td>
<td>105</td>
</tr>
<tr>
<td>100% ethanol + NiO</td>
<td>Acetic acid</td>
<td>45.24</td>
<td>0.84</td>
<td>120</td>
</tr>
<tr>
<td>Ethanol-water +( \text{Al}_2\text{O}_3 )</td>
<td>Acetic acid</td>
<td>85.02</td>
<td>1.60</td>
<td>130</td>
</tr>
<tr>
<td>Ethanol-water + NiO</td>
<td>Acetic acid</td>
<td>70.13</td>
<td>1.36</td>
<td>140</td>
</tr>
</tbody>
</table>

2.1.4. Substrates

For the electrophoretic deposition technique, substrates must be necessary electrical conductor. A foil metallic nickel (Ni) was used as deposition substrate. The same substrate with the same dimension was used as the counter electrode. They were first ground with a coarse SiC paper and fine SiC paper to remove any dirt and grease particles followed by washing with acetone and finally with ethanol. The electrolytic cell was a glass beaker containing the counter electrode and the working electrode. The effective surface area of cathode and anode was 4 cm\(^2\) each and the distance between working and counter electrode was kept constant at 1 cm during the deposition.

2.2. Characterization of the deposition

During all depositions, constant voltage was applied across the electrodes yielding a variable current of 10–400 mA. VRW™ electrophoresis power supply was used and the cell current has been automatically recorded each minute during electrophoretic deposition. The
The conductivity of the suspension was measured using an YSI conductometer model. The schematic diagram of the cell used for the deposition is presented in Fig. 1. The substrates were dried after deposition, and the deposition yields were determined by weighing the dried deposits. The deposits were sintered at 1250 °C for 2 h and the microstructure of the sintered parts was observed by Scanning Electron Microscopy (SEM).

![Fig.1: Experimental Setup of EPD](image)

3. RESULTS AND DISCUSSION

3.1 The effect of solvents on suspensions conductivity, the zeta-potential and the electrophoretic mobility

Fig.2 shown the comparative results obtained with pure ethanol and mixture ethanol-water during electrophoretic deposition. As shown in Fig.2a (change of zeta-potential as function of pH), at lower pH alumina and nickel oxide particles were positively charged in all solvent and the surface charge changed from positive to negative as the pH increased. These results identify the isoelectric point (IEP) for alumina and nickel oxide particles in all solvents at approximately pH 6.5. All suspensions are most stable at pH between 2 to 5. From Fig.2a and b, it can be seen that values of ZP and electrophoretic mobility are much higher in acidic and alkaline regions in ethanol-water compared to pure ethanol solvent. These results suggest that water addition has increased values of zeta potential and electrophoretic mobility, probably due to the increase of dielectric constant in ethanol-water solvent provided by water. The electrostatic stabilization of alumina and nickel oxide particles by ionization is much more effective in ethanol-water solvent, due to the higher dielectric constant of water added. The activation energy for the ethanol oxidation has been reduced. However the IEP is the same in all suspension. This suggests that integration of water molecules into the ethanol network moves the slipping plane to the surface, increasing the repulsive potential between particles that leads to more suspension stabilization without altering the primitive structure of ethanol.

According to Fig.2c (change of suspensions conductivity with pH) the conductivity change with pH in the same directions, and increase sharply with excess acid or base. This shows that addition of water does not influence the particles surface. It is evident that suspension
conductivity is higher with ethanol-water suspension than with pure ethanol at the same deposition condition. From Fig.2, nickel oxide has mobility, ZP and conductivity values close to those of alumina.

![Fig. 2: Zeta-potential (a), electrophoretic mobility (b) and suspension conductivity (c) for Al$_2$O$_3$ and NiO in pure ethanol (1) and mixture ethanol-water (2) versus pH.]

3.2 The effect of solvents and the deposition parameters on the weight gain and the microstructure of deposits.

Suspensions of Al$_2$O$_3$ and NiO particles were prepared at concentration of 1/100ml with ethanol and ethanol-water under similar conditions to evaluate the influence of different solvents and deposition parameters such as electrical conductivity, applied voltage and time of deposition on the weight gain and the uniformity of deposits.

In Fig.3, the weight gain and electrical conductivity for Al$_2$O$_3$ and NiO deposited at 100 V as a function of deposition time are shown. The weight gain is low at lower deposition time and high at higher deposition time in all solvents. This increase of Al$_2$O$_3$ and NiO deposits weight gain with increasing deposition time was linear (linear correlation coefficients $R^2 \geq 0.99$) and in accordance with Eq.1.1.

Highest weight gain was obtained in ethanol-water suspension with all particles under the same conditions of deposition (Fig.3.b). Eq.1.1 suggests that the deposition weight gain
(mg/cm²) of the charged particles under EPD depends on many parameters. However, since the factors $E$, $\zeta$, and $\eta$ in this equation are constants, for a given solvent and particles, the weight gain in EPD can be readily controlled by $I$, $\sigma$, $t$ and $C$. In addition, the weight gain was linearly increasing with increasing deposition time, but at long deposition times, the adhesion of deposits to the substrate was deteriorated. This was more significant in ethanol-water solvent at very long deposition times of 40 min, which the deposits tend to fall off the substrate. However, at short deposition times, the weight gain of deposits was also low especially in the case in pure ethanol solvent.

It is apparent also from Fig.3 that suspensions conductivity of Al₂O₃ and NiO decreases linearly (linear correlation coefficients $R^2 \geq 0.95$) with deposition time in all solvent, probably due to a decrease or an increase of current or voltage, or by the loss of charge carriers from the suspension.

Anné et al. [18] reported also a linear decrease of conductivity versus time during Al₂O₃ EPD from ethanol suspension caused by a significant potential drop. But Dusoulier and al. [13] reported an increase of conductivity during YBa₂Cu₃O₇ EPD.

To determine the effect of applied voltage on the deposits weight gain and the morphology of deposits during EPD, several deposition experiments of 15 min were carried with different values of the applied voltage. The weight gain was observed as a function of the applied voltages in Fig.4 accordance at Eq.1.1. In ethanol-water suspension, the weight gain of Al₂O₃ and NiO deposits increases linearly with the applied voltage. However in pure ethanol suspension, the weight gain of Al₂O₃ and NiO deposits increases linearly with the applied voltage less than 150 V, but for applied voltage greater than 150 V, the weight gain of Al₂O₃ deposits is reduced significantly while the NiO deposits are unaffected. This may be due to the fact that the pure ethanol suspension was not well stabilized, the coarse Al₂O₃ particles (submicrometric) have not been well dispersed due to the lower number of protons generated in the bath. An increase in applied voltage leads to the deposition of the coarse Al₂O₃ particles. Since the thickness of the coating is proportional to the weight of the deposit, the plots of thickness of the coating versus applied voltage followed the same trend as that of the plots of weight versus applied voltage.
Fig. 3: Weight gain and conductivity for $\text{Al}_2\text{O}_3$ and NiO in pure ethanol (a) and mixture ethanol-water (b) at 100 V as a function of deposition time.

Fig. 4: Weight gain for $\text{Al}_2\text{O}_3$ and NiO in pure ethanol (1) and mixture ethanol-water (2) as a function of applied voltage (range 25 - 200 V). Time of deposition 15 min.
Fig. 5: SEM micrographs for $\text{Al}_2\text{O}_3$ deposits prepared at 100 V and 175 V for deposition time 15 min.
Fig. 6: SEM micrographs for NiO deposits prepared at 100 V and 175 V for deposition time 15 min.

The morphologies of Al₂O₃ and NiO films deposited from pure ethanol and mixture ethanol-water on Ni substrate at 100 V and 175 V are shown in Fig. 5 and 6 respectively.

With ethanol-water suspension, the thicknesses of Al₂O₃ and NiO deposits were increased with increases in applied voltages and the microstructures were relatively dense and uniform with a lower porosity. No bubbles caused by water electrolysis are found.

With pure ethanol suspension, the thicknesses of Al₂O₃ and NiO deposits were increased with increases in applied voltage less than 150 V (Fig. 4). However, for applied voltages greater than 150 V, the thicknesses and microstructures of Al₂O₃ deposits were significantly deteriorated while the NiO deposits were unaffected. It can be observed in Fig. 5b that the films deposited at high applied voltage (175 V) were cracked and very inhomogeneous due to probably the particle size of alumina (Submicron).

One possible explanation is that in pure ethanol solvent, the Al₂O₃ particles (due probably to their coarse size submicrometric) not being well dispersed caused by the lower number of protons generated in the bath. An increase in applied voltage leads to the deposition of the coarse Al₂O₃ particles which resulting in rough and inhomogeneity deposits.

Such high inhomogeneity, cracking and porosity limits the weight gain, hence thicknesses of deposits. It is also interesting to note that the grain size of Al₂O₃ films (submicron) in pure ethanol was noticeably larger compared to in ethanol-water (Fig. 5a compared to c).
The current and applied voltages versus EPD time for Al₂O₃ and NiO prepared from pure ethanol and mixture ethanol-water with concentration of 1 g/100ml are shown in Fig.7.

It is apparent from Fig.7a that the current increases rapidly during the first minute of deposition and remain practically constant for longer deposition times in all solvents. Fig.7b and c and Fig.8a and b (values of E- calculated according to Eq.1.2 as function of time for different solvents) show that the increase in voltages or the electric field with deposition time during EPD was very slightly in all solvents and all particles. This means that the electrical resistive at the electrodes was very low so that the increase in voltages might be due to a decrease in conductivity of suspensions. Currents values are higher in ethanol-water compared to pure ethanol suspensions for all particles due probably to its higher conductivities.

![Fig.7: Current (a) and applied voltage (b and c) for Al₂O₃ and NiO in pure ethanol (1) and mixture ethanol-water (2) as function of deposition time.](image-url)
An attempt was made to find a correlation between the deposition rate and the decrease in electrical conductivity. Several experiments from depositions were carried out under the same conditions for Al₂O₃ and NiO from the mixture ethanol-water. Experiments from deposition were carried out successively with the same slurry. The deposition time for each experiment was 2 min and between two experiments, the slurries were stirred for 3 min and conductivity was measured. The counter-electrode was also cleaned to avoid contamination of particles or charges. Fig. 9 shows the deposition rate and the conductivity for Al₂O₃ and NiO as a function of the number of deposition carried out. From Fig. 9, it is noticed that after 3 to 4 experiments, the deposition rates were significantly decreases. Meanwhile, the conductivities of slurries decrease. After 5 experiments, the conductivities of slurries (μS/cm) decreases from 2.5 to 1.3 for NiO and 1.75 to 0.75 for Al₂O₃. Simultaneously, the deposition rates (mg/min) decreases from 28 to 9 for NiO and 21 to 6 for Al₂O₃. The deposition rate and the electrical conductivity of slurry have practically the same linear correlation coefficients (R² > 0.99). Consequently, one can be considered that there is a relationship between the decrease in conductivity and the decrease in charges carriers from the suspension. From Fig. 10, which shows the conductivity plotted against the deposition rate during EPD, one can see clear the relationship between the conductivity and the deposition rate. This indicates clearly that, the decrease in conductivity is completely caused by the decrease in charges carriers from the suspension. Therefore, the increase in applied voltages as function of time during EPD was completely caused by the decrease in electrical conductivity and not by the creation of an electrical resistive layer at the electrodes.
4. CONCLUSION

In this work we studied and compared electrophoretic deposition of Al2O3 and NiO particles in pure ethanol and in mixture of ethanol and water. Acetic acid was used as dispersant to stabilize suspensions. The stability of all suspensions was studied and compared in terms of zeta potential, electrophoretic mobility and conductivity. The influence of different solvents and the suspension parameters such as electrical conductivity, applied voltage and time of deposition on the weight gain and the morphology of deposits were also evaluated. The results demonstrated that suspensions prepared by mixture of ethanol and water had good stability and higher values of electrophoretic mobility and weight gain. In this solvent, the microstructures of Al2O3 and NiO deposits were crack-free, relatively dense and uniform. No bubbles caused by water electrolysis are found. With pure ethanol suspension, the thicknesses and microstructures of Al2O3 deposits were significantly deteriorated by varying applied voltages (greater than 150 V), while the NiO
deposits were unaffected. This could be due to the coarse size of alumina particle which, have not been well dispersed in pure ethanol solvent caused by the lower number of protons generated in the bath. However, further study is needed to understand the relationship between the particle size, the applied voltage and morphology of the sintered coatings. Future work will be focused towards studying the correlation between the above factors. Studies the relationship between the increase in applied voltage with time during EPD and the decrease in electrical conductivity have shown that the increase in voltage was completely caused by the decrease in electrical conductivity of suspension and not by the creation of an electrical resistive layer at the electrodes. Additionally, there is a clear relationship between the decrease in electrical conductivity and the deposition rate. In all solvents, Al2O3 has electrophoretic mobility, ZP and conductivity values close to those of NiO.

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REFERENCES


