ELECTROCHEMICAL BEHAVIOR OF NANOSTRUCTURED BIOGLASS®/ALGINATE COMPOSITE COATING ON MAGNESIUM ALLOY BY ELECTROPHORETIC DEPOSITION FOR ORTHOPEDIC APPLICATION

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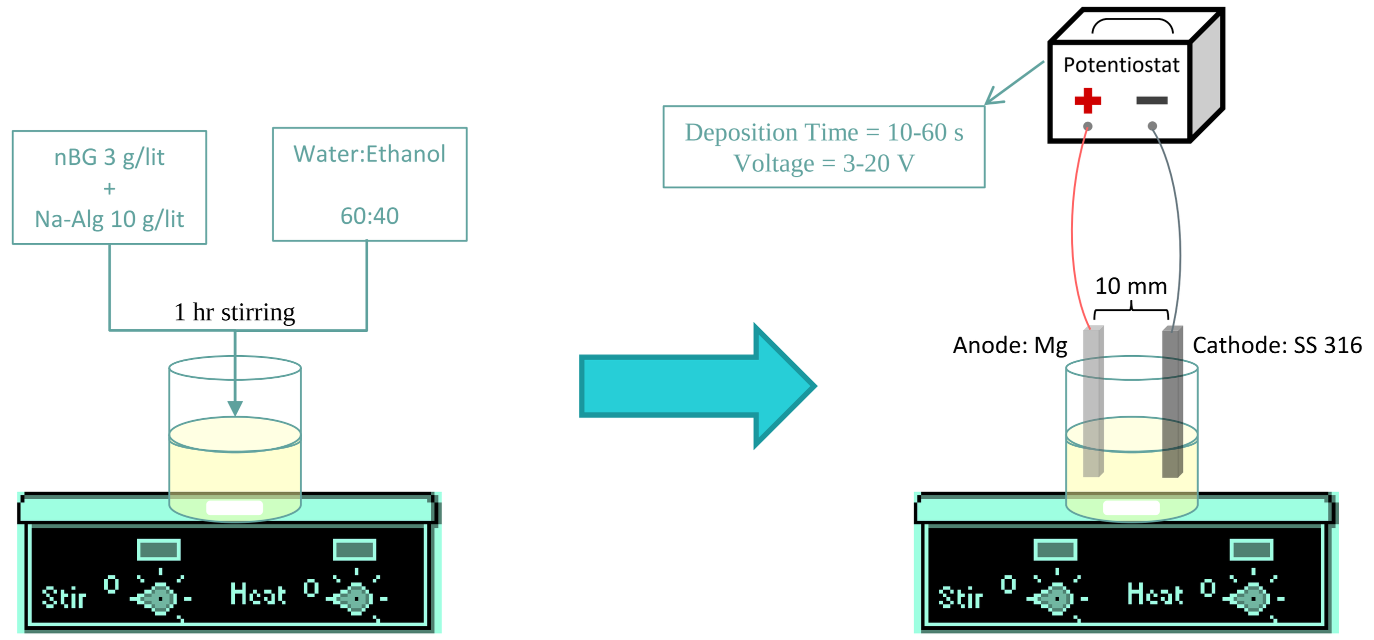
ABSTRACT

The present work aimed to develop the anodic electrophoretic deposition (EPD) of sodium alginate/nano-Bioglass® (Na-Alg/nBG) bioactive nanocomposite coatings on Mg-Zn-Ca alloy without any previous surface pre-treatment (other than polishing). In comparison with other alloys, such as stainless steel or titanium, the density and elastic modulus of magnesium are similar to those of natural bone, and corrosion products of Mg-Zn-Ca alloy are not harmful to the patient body. Alginate is an anionic natural polysaccharide which, due to its low toxicity and biocompatibility, has been studied for different biomedical applications. Through the presence of Bioglass® particles in the coatings, mechanical properties are advanced by increasing adhesion to the substrate and also increases the formation of hydroxyapatite after immersion in simulated body fluid (SBF). A stable water/ethanol EPD suspension was used to produce composite nBG/Alg coating for potential biomedical applications. nBG contents (3 g/L) were studied for a constant concentration of sodium alginate (10 g/L); DC voltage and deposition times varied between 3-20 V and 10-60 seconds, respectively. It has been revealed how electrophoretic deposition (EPD) occurs on the magnesium alloy surface. The coatings composition was analyzed by X-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR) and the surface of the coatings was studied with field emission scanning electron microscopy (FESEM). For investigating corrosion protection of bioactive coatings, polarization and electrochemical impedance spectroscopy (EIS) tests were used; samples were immersed in simulated body fluid (SBF) at 37°C and results were compared with the bare uncoated Mg-Zn-Ca alloy. The present work confirmed that electrophoretic deposition is a practical method for the co-deposition of Bioglass® nanoparticles and Na-Alg that can be used to produce a wide range of magnesium alloy coatings with tailored microstructures and surfaces with biomedical applications.

OBJECTIVES

- Formulation of a stable suspension of Bioglass® nanoparticles and alginate in water and ethanol with optimal weight ratio
- Application of nanocomposite coatings by anodic electrophoretic deposition on ZX504 alloy
- Effects of time and applied voltage on the coating process
- Investigation of corrosion properties in simulated body conditions

MATERIALS & METHODS



RESULTS

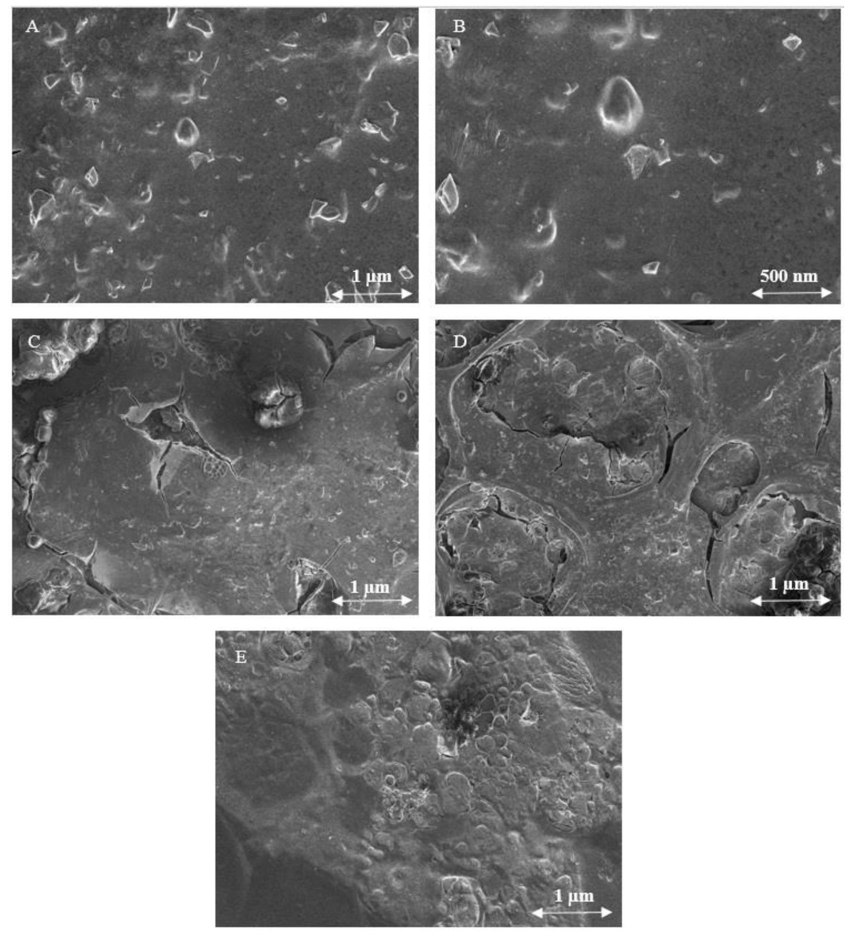


Figure 1: FESEM images of nBG/Alg coatings on ZX504 Mg alloys at different EPD parameters; double-layer coating at different magnification 15 V-15 s (A and B), single-layer coating 15 V-15 s (C), 30 V-15 s (D) and 5 V - 15 s (E).

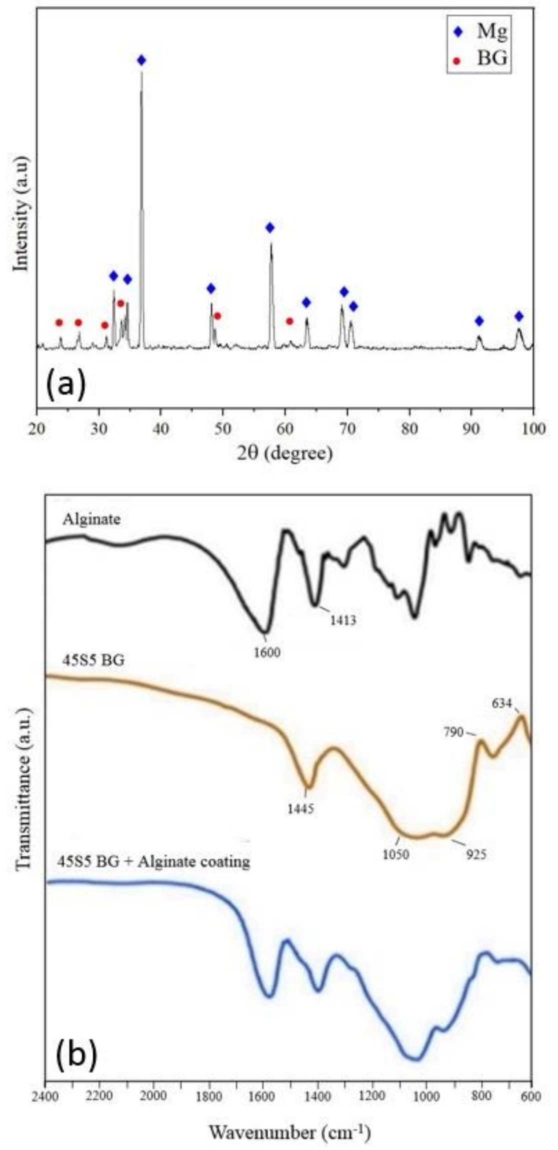


Figure 2: (a) XRD pattern of the nBG/Alg, and (b) FITR spectra of alginate powder, 45S5 bioactive glass and nBG/Alg coating.

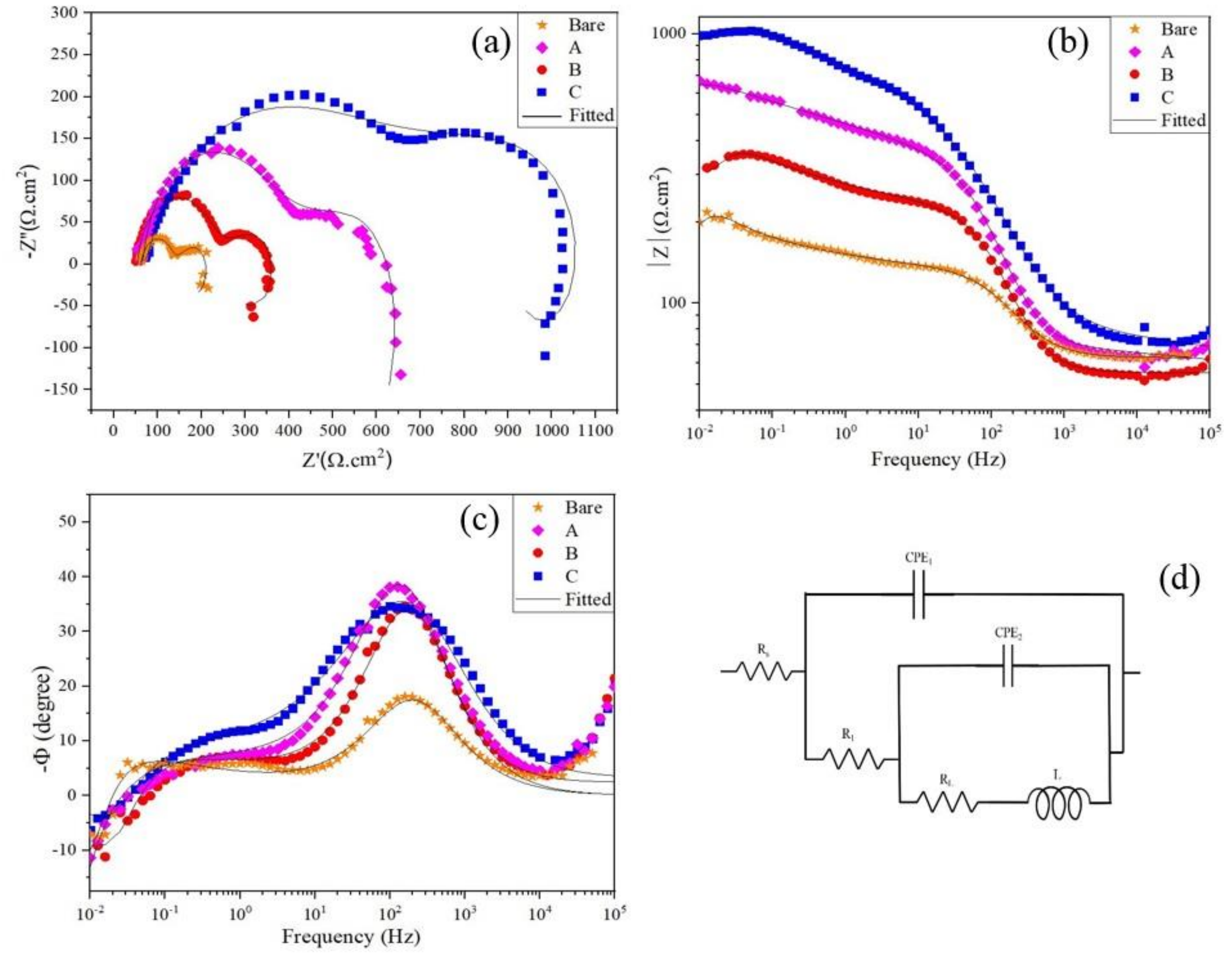


Figure 3: (a) Nyquist, (b) Bode-phase and (c) Bode-|Z| graphs showing coatings and non-coatings measured at 37°C in simulated body fluid, as well as the equivalent circuits derived from the fitting of the impedance measurements of (d) ZX504 and Alg-nBG coated substrate. Single-layer coating 15 V-15 s (A), single-layer 5 V-15 s (B), double layer 15 V-15 s (C).

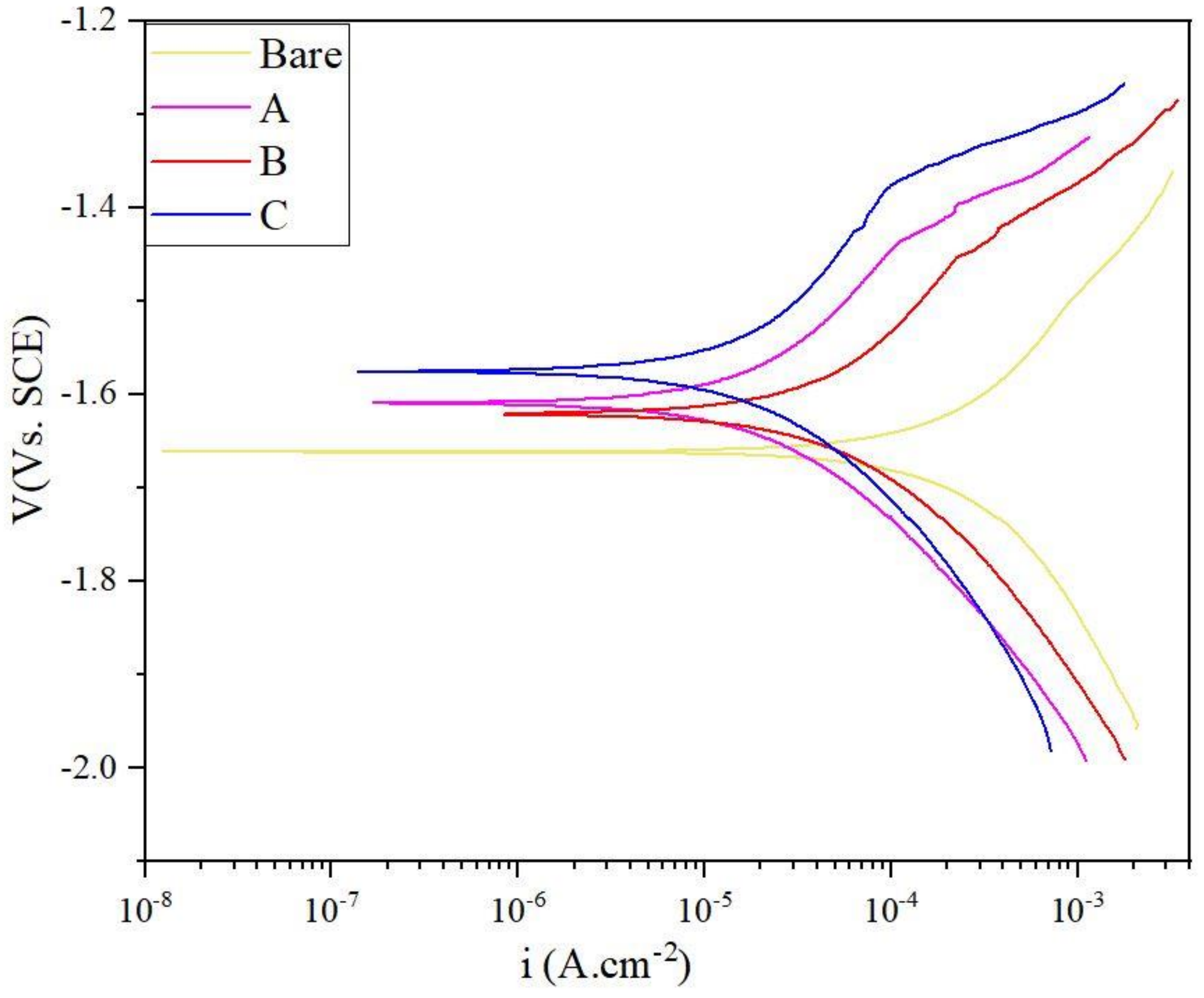


Figure 4: Potentiodynamic plots for ZX504 Mg alloy and single-layer coating 15 V-15 s (A), single-layer 5 V-15 s (B), double layer 15 V-15 s (C) surfaces with coating in simulated body fluid at 37°C.

Fig. 1 shows FESEM images of the magnesium alloy with composite coating (Alg + nBG) samples at different magnifications. The best quality composite coatings in terms of homogeneity and crack-free coating were obtained at double-layer coating at 15 V and 15 s.

As shown in **Fig 2a.** XRD analysis showed that the coating contained BG. Also **Fig 2b.** displays the FTIR spectrum of bioactive glass powders, alginate powder, and alginate-45S5 nanocomposite coatings. It appears that both alginate and bioactive glass components are present in the spectra of composite coatings, confirming good integration of the glass particles in the polymeric matrix.

For coated and uncoated specimens, Nyquist plots and Bode plots on the experimental medium (SBF at 37 °C) with corresponding open-circuit potentials (OCP) can be seen in **Fig. 3**. To obtain more information about what happens at interfaces, EIS data from coated and uncoated specimens were extracted using equivalent circuits (Fig. 3d). The results of the Nyquist plots (Fig. 3a) follow the results of the FESEM results in Fig. 1 which predicts a higher corrosion resistance with double-layer coatings due to fewer cracks and porosities.

Fig. 4 presents potentiodynamic polarization measurements using Alg-nBG coatings and uncoated ZX504 Mg alloy in SBF at 37 °C. After polarization tests, it was determined that among the coated specimens, 15 V-15 s (C) double-layer coating significantly enhanced the corrosion protection of the bare ZX504 alloy. According to the EIS measurements and FESEM observations, these results are accurate.

CONCLUSION

The purpose of this paper, the feasibility study is presented for the corrosion protection of a Mg-Zn-Ca alloy through the application of alginate-45S5 bioactive glass nanocomposite through anodic EPD. For the purpose of avoiding bubble formation and ensuring high colloidal suspension stability during EPD, ethanol/water ratio of 40:60 (vol%) was used to be the optimal solvent ratio and the suspension composition included 10 g/L alginate and 3 g/L 45S5 nano bioactive glass. Voltages 3 to 20 V for the nBG/alginate and deposition time of 10 to 60 s were determined and it was found that 15 V and 15 s were the optimal EPD parameters. The FESEM observation showed that high voltage (>15 V) and deposition time (>20 s) can cause the electrolysis of water, this causes bubbles to form on the electrodes as a result of gas generation. On the other hand, a low potential (<10 V) and deposition time (<10 s) produces very thin, inhomogeneous coatings that do not adhere to the substrate. The presence of nBG in the coatings was proved with XRD investigating and also FTIR analysis of the anodic EPD coatings revealed they contained alginate and nBG. In terms of corrosion behavior in SBF, the difference between the coatings and bare metal in the polarization curves and the EIS observations indicates the double-layer coating displayed greater corrosion resistance against bare metal and single-layer coating. Therefore, biocompatible alginate-bioactive glass nanocomposite coated ZX504 Mg alloy by anodic EPD can be considered as a good candidate for magnesium bioimplant from the corrosion resistance point of view.

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