INTRODUCTION

Currently, 7.55 billion people live on Earth. This figure will rise to 9.7 billion by 2050 and 11.2 billion by 2100, says the UN forecast. In particular, the group of people aged over 60 will grow considerably. This has a strong impact on the medical sector due to the increasing number of aging patients. For example, the number of implants required is increasing every year.

Metallic implants play an important role in the field of biomaterials, given their excellent mechanical properties. Due to their high mechanical stability and fracture toughness, they are superior to ceramics and polymers as materials for orthopedic implants. However, their application is limited due to the uncontrolled release of toxic metal ions. For example, due to corrosion of stainless steel implants, Ni and Cr ions release into the body in an uncontrolled manner which may cause inflammation, affect the biocompatibility of implant, and prove fatal for adjacent body organs.

To overcome the shortcomings of conventional metallic biomplants, a new class of degradable Mg implants is studied nowadays. Mg is a light metal, and in addition to a high strength-to-weight ratio, it shows good thermal and electrical properties as well as excellent vibration damping. Since magnesium is essential for human metabolism and occurs naturally in body, it can be easily excreted through urine. No toxic dose is known, which makes this metal safe to be used...
as an implant. The degradation products can be either excreted or integrated into the natural metabolic process. Only the burst release of these products can pose a problem. In static implant conditions, high purity Mg material degrades quickly at the start and stabilizes at a rate of 0.25 mm/year. This rate is very slow, and coating the implant with biocompatible material further slows it down. It is also observed that, in static conditions, the corrosion products accumulate on the surface of the materials and serve as a protective layer resulting in a lower rate of degradation than in dynamic conditions. Due to its degradation property, it can be used as a temporary implant that does not need to be removed by a second surgery. Additionally, medical costs can be reduced and the risks of further surgical intervention can be avoided.

The high degradation rate of Mg implant can cause premature mechanical failure of implants before the tissues completely heal and gain their mechanical strength. To slow down this degradation so that it matches the healing rate of tissues, the magnesium substrates can be coated with various biocompatible materials and their combinations, for example, chitosan, zein, gelatin, hydroxyapatite (HA), and bioactive glasses. Much work has been done on the composite coatings, and their application can significantly promote bone growth, protect against corrosion, and increase the functionality and durability of the implants.

Protein-based biodegradable polymers have widely been used for biomedical applications, as many of them show excellent biocompatibility. One of the materials which are suitable for such a coating is the natural protein called zein. Zein is a long-chain protein from the group of prolamins, which is present in the form of the yellowish powder obtained from the endosperm of maize. It is thermally stable up to 280°C and represents the main storage protein of maize, which comprises about 80% of all proteins in maize. Due to its excellent biocompatibility and biodegradability, cell attachment, and proliferation properties, it is considered as a protective film for temporary degradable implants. Owing to its molecular weight, degree of polymerization, and chemical structure, zein has good film-forming properties. Zein exhibits particularly good properties (low water vapor permeability and high resistance to microbial attack) when it is present as a tough, shiny, grease-proof, and hydrophobic coating. Furthermore, zein is amphiphilic, which means that it has both hydrophilic and hydrophobic properties. This nature allows zein to be combined with both types of polymers to produce compatible materials that have better properties than their components. BG is a popular bioceramic that exhibits excellent biocompatibility and can bind strongly to hard and soft tissues. This binding occurs as a result of a rapid sequence of chemical reactions on the surface of the implant when it is introduced into living tissue. The reason for the strong bond is the formation of a HA layer on the BG surface, which is chemically and structurally comparable to the mineral phase of natural bone.

degradation products of BG, such as soluble silicon dioxide or calcium ions, can also promote the production of growth factors and cell reproduction and activate the gene expression of osteoblasts. As a result, BG can stimulate natural bone growth, in addition to that wound healing of soft tissue is significantly improved. Thus, fabricating the composite coatings based on the combination of 45S5 bioactive glass and zein can, thus, promote the osteointegration of Mg-based implants.

Electrophoretic deposition (EPD) is a simple cost-effective technique, capable of producing highly uniform films at room temperature. The first step in the EPD process is the preparation of the stable suspension of the particles which are intended to be deposited. After the preparation of a stable suspension, an electric field is applied due to which the charged particles or molecules migrate toward an oppositely charged electrode and deposit thereby coagulation. In addition to the above advantages, EPD allows coating 3D shape objects.

In this work, pretreated magnesium is coated with zein/BG by EPD. SEM images confirmed that a uniform layer of zein/BG composite was obtained. FTIR spectroscopic analysis confirmed the presence of zein and BG in the composite coatings obtained via EPD. Furthermore, zein/BG coatings showed appropriate wettability for the initial protein attachment. The zein/BG coatings obtained via EPD on the Mg substrate will be further studied for the in vitro bioactivity by immersion in simulated body fluid. Moreover, the effect of the coatings on the corrosion and degradation behavior will also be investigated. To the best of the authors’ knowledge, this is the first study showing the successful EPD of zein/BG on Mg substrates for potential orthopedic applications.

2 MATERIALS AND METHODS

2.1 Materials

Zein powder (CAS number 9010-66-6) and 45S5 Bioactive glass were obtained from Sigma-Aldrich. A magnesium rod with a purity of 99.98% and a diameter of 10 mm was purchased from chemPUR (CAS number 7439-95-4) and was used as the substrate.

2.2 Electrophoretic deposition (EPD) of zein and zein/BG

2.2.1 Zein/BG suspension

First, the zein solution was prepared by magnetic stirring of 6 wt.% zein, 20 wt.% distilled water, and 74 wt.% ethanol on a hot plate with gentle heating. An amount of 10 mL of acetic acid was used for 100 mL of zein solution to adjust the pH of ~3. To ensure homogeneity and bring
the solution to room temperature, the solution was again magnetically stirred for 30 minutes at ambient temperature. Subsequently, 5 g/L of 45S5 BG was added and the suspension was placed in an ultrasonication bath for 90 minutes. The optimum concentration of zein and BG concentration and suspension pH = 3 was chosen on the basis of previous studies, which has shown appropriate results for orthopedic applications.

2.2.2 Sample preparation

Magnesium samples were cut into 10 mm diameter disks of 2-3 mm thickness. The edges were smoothed with 600-800 grit size SiC abrasive papers, and a flat side of the samples was ground with 800 grit size abrasive paper. A grinding solution of ethanol and glycerol (3:1) was repeatedly applied to the sandpaper to prevent overheating. The following step involved polishing each sample three times for 2 min with cotton cloths using three different diamond suspensions with a particle size of 6, 3, and 1 μm. The lubricant used was a mixture based on ethanol and neutral soap. In the end, the samples were placed in an ultrasonic bath for 5 min in ethanol to remove the polishing residue. Later samples were rinsed with fresh ethanol and dried under hot air.

Chemical treatment

The chemical treatment was performed according to Zhao et al with slight modifications. First, a solution of 200 mL of ultrapure distilled water and two drops of phosphoric acid (H₃PO₄) with a mass fraction of ≤85 wt.% Carl Roth® (CAS number 7664-38-2) was prepared by magnetic mixing (pH ≈ 2.5). Subsequently, the solution is heated to 40°C with constant magnetic stirring, and samples were placed in this suspension for 30 minutes and later dried under cold air. Next, a solution of 200 mL of ultrapure distilled water and 1.32 g of di-ammonium hydrogen phosphate (DAHP) ((NH₄)₂HPO₄) from Merck® (CAS number 7783-28-0) was prepared (0.05 mol/L DAHP). With constant magnetic stirring, the suspension is heated to 80°C and samples were immersed for 60 minutes. In the end, the samples were washed with ethanol for 3 minutes to remove residual waste and dried under hot air.

2.2.3 EPD parameters

The optimal parameters were first tested on stainless steel samples. Table 1 shows the different parameters, in which the electrophoretic deposition of zein on stainless steel was investigated. Two samples were made for each parameter to verify the results. The procedure for selecting the parameters was based on the method of trial and error.

| pH  | Time [min] | Voltage [V] |
|-----|------------|-------------|
| 5   | 2          | 5           |
| 5   | 2          | 10          |
| 5   | 2          | 15          |
| 5   | 3          | 20          |
| 5   | 3          | 5           |
| 5   | 3          | 10          |
| 5   | 3          | 15          |
| 5   | 3          | 20          |
| 5   | 3          | 5           |
| 5   | 4          | 5           |
| 5   | 4          | 10          |
| 5   | 4          | 15          |
| 5   | 4          | 20          |
| 5   | 5          | 5           |
| 5   | 4          | 10          |
| 5   | 5          | 15          |
| 5   | 5          | 20          |
| 5   | 7          | 5           |
| 5   | 7          | 10          |
| 5   | 7          | 15          |
| 5   | 7          | 20          |
| 5   | 9          | 5           |
| 5   | 9          | 10          |
| 5   | 9          | 15          |
| 5   | 9          | 20          |
| 4   | 5          | 5           |
| 4   | 4          | 10          |
| 4   | 7          | 5           |
| 4   | 7          | 10          |
| 4   | 9          | 5           |
| 4   | 9          | 10          |
| 3   | 5          | 5           |
| 3   | 5          | 10          |
| 3   | 7          | 5           |
| 3   | 7          | 10          |
| 3   | 9          | 5           |
| 3   | 9          | 10          |

During the experiments, the current density was recorded every 15 seconds. After the time had elapsed, the electrodes were changed, and the suspension was stirred magnetically (RT 10 Power Magnetic Stirrer). The coated substrates were stored horizontally and dried at room temperature overnight.

The parameters utilized for optimizing zein/BG coatings on the Mg substrate are summarized in Table 2. Two
to five samples were produced with the same parameters. It is important to mention that the design of the experiment was developed after the literature survey, which indicated the range of pH, deposition time, and applied voltage that can be applied for depositing zein/BG on 316L SS and Mg substrates.

After optimizing the coatings on stainless steel, the EPD on magnesium was done. Here, a stainless steel substrate was used as the anode and magnesium (substrate) as the cathode. The lower half of the steel electrode and the magnesium sample were placed exactly opposite and parallel to each other. It is important to mention that after five or six deposits, the suspension was changed.

### 2.3 Characterization of coatings

In order to investigate the morphological enhancement after the pretreatment of magnesium, the samples were examined before and after with a light microscope of the type Eclipse LV150N from Nikon®. The data were also evaluated by Nikon® with the software NIS Elements.

Scanning electron microscope (SEM) of model AURIGA 4750 from Carl Zeiss AG® was used to study the surface morphology of the coatings. The samples were fixed to the holders with silver paste (ACHESON 1415 from Plano®) and sputtered with gold by Q150R Rotary-Pumped Sputter Coater from Quorum Technologies® to prevent the effect of charging.

Furthermore, the composition was investigated by Fourier-transform infrared spectroscopy (FTIR). Nicolet 6700 device from Thermo Scientific® in the transmittance mode at the wavelength range of 400-4000 cm⁻¹. The examinations were carried out under a resolution of 4 cm⁻¹ and 40 spectral scans. After that, the spectrum was smoothed, but at most with a factor of 15.

The contact angle measuring device DSA 30 from the company Krüss® was used, which wets the sample with a drop of water (volume of droplet = 5 µL) and uses the integrated camera to determine the contact angle between the drop and the surface. At an angle below 90°, the wetted surface is hydrophilic, while at an angle above 90° it is hydrophobic.³⁸,³⁹

### 3 RESULTS AND DISCUSSION

#### 3.1 Microstructural examination of Mg after pretreatment

In Figure 1 (A), pure magnesium can be seen under the light microscope. The morphology is typical of the ground surface with small grooves. (B) shows the result of pretreatment on magnesium with phosphoric acid (H₃PO₄) and di-ammonium hydrogen phosphate (DAHP). After pretreatment, the surface of the substrate is completely coated with small crystals. This is consistent with the research by Zhao et al.³⁷ who also describes a dense film formation of flower-like clusters after 60 minutes. Although there are some cavities between the clusters, still there is the effective protection of the substrate.³⁷

#### 3.2 Suspension stability

Experimentally, the stability of a suspension is analyzed by measuring the Zeta potential. Besra and Liu⁴⁰ describe that this depends on intermolecular interactions and the pH value. Ma et al.⁴¹ describe that suspensions with a zeta potential of ±30 mV show sufficient physical stability. The

| pH | BG Concentration [g/L] | Time [min] | Voltage [V] |
|----|------------------------|------------|-------------|
| 3  | 1                      | 5          | 5           |
| 3  | 1                      | 5          | 10          |
| 3  | 1                      | 7          | 5           |
| 3  | 1                      | 7          | 10          |
| 3  | 1                      | 9          | 5           |
| 3  | 1                      | 9          | 10          |
| 3  | 3                      | 5          | 12          |
| 3  | 5                      | 5          | 12          |

**TABLE 2** Suspension-related and EPD parameters used for depositing zein/BG on Mg substrate

**FIGURE 1** Optical microscope images: (A) Pure magnesium; (B) Pretreated magnesium, the pretreatment was done with the phosphoric acid (H₃PO₄), and di-ammonium hydrogen phosphate (DAHP)
zein/BG suspension with zeta potential of +30 ± 5 mV was made at pH = 3. The suspension showed no signs of sedimentation during the whole process of electrophoretic deposition. This suggested that the suspension had sufficient stability.

Although some stability is necessary during the process of electrophoretic deposition of charged particles or molecules, too high values of the zeta potential and thus stability can reduce the electrophoretic mobility of the particles, as the electric field may not be able to overcome the electrostatic inter-particular repulsion forces. For this reason, there may be a reduced separation rate.40

Zein shows a positive zeta potential in acidic environments (pH ≈ 3). According to Kaya and Boccaccini,13 the zein molecules in the suspension have a positive charge and therefore migrate toward the cathode. Hum et al42 describe that the BG particles encapsulate the positively charged zein molecules; however, due to their hydrophilia they are not embedded in the hydrophobic zein matrix. Figure 2 shows the mechanism of electrophoretic deposition of the zein /45S5 Bioglass Suspension. The positive charge of the zein molecules determines the location of the deposition. In this case, it is the cathode. The surrounding bioglass particles have a negative charge, but this is eliminated by the presence of ethanol and zein in solution.21

3.3 | EPD of Zein and Zein/BG coatings

Since magnesium is a very expensive material, the EPD parameters were first optimized on 316L SS. Table 1 lists the parameters used to perform EPD of zein on 316L SS Substrate. The experiments elucidated that the lower values of applied voltage (5 or 10 V) yield better results than higher voltages (15 or 20 V). On the basis of visual inspection and SEM images (not listed here), the best parameters were selected for the deposition of zein on 316L SS substrate, as shown in Table 3.

These values are partly consistent with the literature. Kaya and Boccaccini13 have also detected a voltage of 10 V as optimal for the coating of zein on stainless steel, but they used a deposition time of 10 minutes. In this work, however, the shorter duration was chosen, because the coatings were homogeneous due to lower bubble formation.

The next step was to add BG at the concentrations of 1, 3, and 5 separately in the prepared zein suspension and then kept in an ultrasonic bath for 90 minutes. This ensured a uniform dispersion of the BG particles in a zein suspension. The parameters used for electrophoretic deposition are listed in Table 2. Since the pH value of three yielded the best results for the zein coatings. Therefore, pH was kept constant at the value of ~3, but deposition time and applied voltage were varied to achieve uniform zein/BG coatings. From the preliminary visual inspection and SEM images, it was concluded that the applied voltage of 12 V, BG concentration of 5 g/L, and a deposition time of 5 minutes yielded the best results. The relative increase in the applied voltage (for zein/BG) compared to that of the zein was due to the more electric field is required to move the BG particles to the corresponding electrode.

In addition, the current density [A/cm²] was measured and recorded every 15 seconds during the EPD experiments conducted at the optimum values. The plot of current density vs deposition time for a pH of 3, an applied voltage of 12 V, deposition period of 5 minutes, and BG concentration of 5 g/L of BG are shown in Figure 3.

It can be seen that the current density is hardly exposed to fluctuations. In addition, the values of all experiments are very close together. After determining the optimum EPD parameters for depositing zein/BG on 316L SS substrate, the
same value of current density was achieved (by varying the applied voltage) for depositing zein/BG on Mg substrate. To obtain the same value of the current density as in the preliminary tests, the applied voltage applied was modified to 14.5 V.

Figure 4 shows that the current density is almost constant during the EPD experiment conducted for depositing zein/BG coatings on the Mg substrate. However, the values of current densities for the individual samples are a bit further apart compared to the separation on 316 L SS. This can be attributed to the pretreatment of magnesium samples, where it was difficult to create the same conditions for the test execution due to the lack of equipment. Therefore, the result of individual samples may differ slightly.

**TABLE 3** Optimized EPD parameters for depositing zein on 316L SS

| Parameter | Unit | Value |
|-----------|------|-------|
| pH        | —    | 3     |
| Voltage   | [V]  | 10    |
| Time      | [s]  | 5     |

**FIGURE 3** A plot of current density vs deposition time during electrophoretic deposition on 316L SS at pH 3, 12 V, 5 min, and 5 g/L BG

**FIGURE 4** A plot of current density vs deposition time during electrophoretic deposition on Magnesium (pH 3, 14.5 V, 5 min, 5 g/L BG)
3.4 | Morphology of Zein coatings

Figure 5 shows the zein coatings deposited on 316L SS via EPD (pH = 3, deposition voltage = 10 V, and deposition time = 5 minutes). The characteristic structure of zein can be seen as a homogeneous, porous film on the surface of the substrate. This statement is supported by the investigations of Naseri et al. The resulting pores hardly differ in size. On the left, the coating covers the entire substrate surface and shows no signs of damage. Based on these observations, a successful coating of zein on 316L SS was obtained.

The zein/BG coatings deposited on 316L SS via EPD (at pH = 3, deposition voltage = 12 V, deposition time = 5 minutes, and concentration of BG = 5 g/L) are shown in Figure 6. The figure shows that the characteristic cluster-like structure of zein spreads over the surface of the substrate. Moreover, the presence of BG was visible as the well-distributed particles which have integrated into the layer of zein. In addition to the grid-like structure, some pores could also be seen in the zein film, which according to Naseri et al. can be partially blocked with agglomerated BG particles, due to this reason the porosity and pore size is lower than that of the pure zein coating. Similar integrated morphology is achieved in zein/HA coatings done on stainless steel. However, only a small
leveling in the distribution of BG particles on the substrate surface could be seen here.

Figure 7 shows the coating of magnesium with zein/BG. In addition to the already described typical structure of zein and the visible pores, BG particles can again be detected, which are distributed unevenly over the surface. Compared to pure zein coating, this film (zein/BG) is more homogeneous. The addition of BG causes the coating to become more uniform and to have significantly fewer deep spaces.

3.5 | FTIR analysis

Figure 8 shows the FTIR spectrum of the zein/BG coatings obtained via EPD on Mg substrates. FTIR spectrum of zein/BG from 1650 to 1500 cm$^{-1}$ showed a similar trend as that of the pure zein. In the region of 1650 to 1500 cm$^{-1}$ Amide I and Amide II, peaks are observed which are characteristic peaks confirming the presence of zein. Pishbin 44 describes that the intensity of the C=O oscillation at 1650 cm$^{-1}$ (Amide I) decreases significantly compared to the N–H vibration at 1540 cm$^{-1}$ (Amide II) after the addition by BG, which is the sign of hydrogen bonds between the zein and the BG. In addition, this bond could cause the stabilization of the glass particles in the suspension and lead to a co-deposition of glass and polymer. The effect of adding BG is visible in the range of 1500–600 cm$^{-1}$ by overlapping peaks. Thus, peaks due to the presence of BG are visible at 1430 cm$^{-1}$ ($\text{CO}_3^{2-}$), 1000 cm$^{-1}$ ($\text{PO}_4^{3-}$), and 800 cm$^{-1}$ (Si–O–Si).

3.6 | Wettability

The biocompatibility of the implant is often judged by wettability, surface roughness, and surface chemistry. The optimum combination of these properties determines the suitability of the implanted device. The wettability of the coating surface has a great influence on the initial accumulation of proteins, which later determines the adhesion behavior of cells. Therefore, coatings must be produced that promote the binding of proteins to the foreign material. Figure 9 shows the measured value of contact angles for pure magnesium and its coating with zein and zein/BG. All the measured values of contact angles are below 90° and thus in the hydrophilic range which means good wettability. The contact angle of pure magnesium is about 40°, and this value is at the lower bound of the preferred range. The zein coating on Mg increased the contact angle compared to that of the pure magnesium. Here, the value is 70 ± 2°, which is in accordance with the results of Muthuselvi and Dhathathreyan. Zein/BG obtained via EPD on Mg substrates showed a contact angle of ~60°, which is very close to the ideal value of 35–80° according to Lee et al. BG has surface-bound silanols (Si–OH), which give the coated substrate a hydrophilic character and thus reduce the contact angle. The coating with zein and BG thus causes the contact angle to shift further in the vicinity of the ideal value, and thus, an improved protein and cell adhesion are possible. This coating, therefore, has potential for application in orthopedic implants. To show the statistical difference between values of three systems, one-way analysis of variance (ANOVA) was conducted ($P \leq .05$).

4 | CONCLUSIONS

The zein/BG composite coatings were fabricated on pretreated pure magnesium substrate using the electrophoretic deposition having the potential to improve the corrosion behavior of Mg. Optimal parameters were concluded from a series of experiments based on trial and error, first done on stainless steel. A voltage of 12 V, a BG concentration of 5 g/L, a pH of 3, a deposition time of 5 minutes, and an inter-electrode distance of 10 mm were selected as the ”best” parameters. SEM images showed the uniform deposition of zein/BG coatings on Mg substrates. Moreover, BG particles were uniformly dispersed in the zein matrix. FTIR analysis confirmed the presence of zein and BG in the composite coatings. Wettability studies confirmed that the contact angle values are appropriate for the initial protein attachment. Future studies will investigate the corrosion of the zein/BG coated substrate. Moreover, the effect of BG in the coatings will also be investigated by immersing the coatings in SBF to track the possibility of achieving close interaction between the implant and bone.

ORCID
Muhammad Atiq Ur Rehman https://orcid.org/0000-0001-5201-973X
REFERENCES

1. Medical implants market analysis from 2019 to 2023 – global size, growth, share, trends, statistics, key players and regional forecast to 20232019. [cited 2020 May 5]. https://www.medgadget.com/2019/07/medical-implants-market-analysis-from-2019-to-2023-global-size-growth-share-trends-statistics-key-players-and-regional-forecast-to-2023.html#

2. Pishbin F, Simchi A, Ryan M, Boccaccini A. A study of the electrophoretic deposition of Bioglass® suspensions using the Taguchi experimental design approach. J Eur Ceram Soc. 2010;30(14):2963–70.

3. Seitz JM, Eifler R, Bach FW, Maier H. Magnesium degradation products: effects on tissue and human metabolism. J Biomed Mater Res Part A. 2014;102(10):3744–53.

4. Wang H, Shi Z. In vitro biodegradation behavior of magnesium and magnesium alloy. J Biomed Mater Res Part B. 2011;98(2):203–9.

5. Heise S, Virtanen S, Boccaccini AR. Tackling Mg alloy corrosion by natural polymer coatings—A review. J Biomed Mater Res Part A. 2016;104(10):2628–41.

6. Poinern GEJ, Brundavanam S, Fawcett D. Biomedical magnesium alloys: a review of material properties, surface modifications and potential as a biodegradable orthopaedic implant. Am J Biomed Eng. 2012;2(6):218–40.

7. Boccaccini AR, Dickerson JH. Electrophoretic deposition: fundamentals and applications. J Phys Chem B. 2013;117:1501.

8. Ahmed Y, Yasir M, Ur Rehman MA. Fabrication and characterization of chitosan/bioactive glass composite coatings on Mg alloy substrates. Electrochim Acta. 2017;232:456–64.

9. Neelameggham S, Reddy GVR, Elachi SK, Krishna PR. Magnesium and its alloys as orthopedic biomaterials: a review. Biomaterials. 2006;27(9):1728–34.

10. Zhang L-N, Hou Z-T, Ye X, Xu Z-B, Bai X-L, Shang P. The effect of selected alloying element additions on properties of Mg-based alloy as bioimplants: a literature review. Front Mater Sci. 2013;7(3):227–36.

11. Hornberger H, Virtanen S, Boccaccini AR. Biomedical coatings on magnesium alloys – a review. Acta Biomater. 2012;8(7):2442–55.

12. Seitz JM, Eifler R, Bach FW, Maier H. Magnesium degradation products: effects on tissue and human metabolism. J Biomed Mater Res Part A. 2014;102(10):3744–53.

13. Heise S, Virtanen S, Boccaccini AR. Tackling Mg alloy corrosion by natural polymer coatings—A review. J Biomed Mater Res Part A. 2016;104(10):2628–41.

14. Poinern GEJ, Brundavanam S, Fawcett D. Biomedical magnesium alloys: a review of material properties, surface modifications and potential as a biodegradable orthopaedic implant. Am J Biomed Eng. 2012;2(6):218–40.

15. Demir M, Ramos-Rivera L, Silva R, Nazhat SN, Boccaccini AR. Zn-based composites in biomedical applications. J Biomed Mater Res Part A. 2017;105(6):1656–65.

16. Ahmed Y, Yasir M, Ur Rehman MA. Fabrication and characterization of zein/hydroxyapatite composite coatings for biomedical applications. Surf Coat Technol. 2020;304:151716.

17. Boccaccini AR, Dickerson JH. Electrophoretic deposition: fundamentals and applications. J Phys Chem B. 2013;117:1501.

18. Corni I, Ryan MP, Boccaccini AR. Electrophoretic deposition: from traditional ceramics to nanotechnology. J Eur Ceram Soc. 2008;28(7):1353–67.

19. Zhao H, Cai S, Ding Z, Zhang M, Li Y, Xu G. A simple method for the preparation of magnesium phosphate conversion coatings on a metallic substrate. Surf Coat Technol. 2018;342:1–6.
AZ31 magnesium alloy with improved corrosion resistance. RSC Adv. 2015;5(31):24586–90.

38. Muthuselvi L, Dhathathreyan A. Contact angle hysteresis of liquid drops as means to measure adhesive energy of zein on solid substrates. Pramana. 2006;66(3):563–74.

39. Ahmed Y, Rehman MAU. Improvement in the surface properties of stainless steel via zein/hydroxyapatite composite coatings for biomedical applications. Surf Interfaces. 2020;100589. https://doi.org/10.1016/j.surfin.2020.100589

40. Besra L, Liu M. A review on fundamentals and applications of electrophoretic deposition (EPD). Prog Mater Sci. 2007;52(1):1–61.

41. Ma K, Huang D, Cai J, Cai X, Gong L, Huang P, et al. Surface functionalization with strontium-containing nanocomposite coatings via EPD. Colloids Surf B. 2016;146:97–106.

42. Hum J, Naseri S, Boccaccini AR. Bioactive glass combined with natural derived proteins as composite materials for the application in bone tissue engineering. Biomed Glas. 2018;4(1):72–81.

43. Naseri S, Hum J, Lepry WC, Miri AK, Nazhat SN, Boccaccini AR. Fabrication and characterization of zein–bioactive glass scaffolds. Bioinspired, Biomimetic Nanobiomater. 2015;4(1):73–8.

44. Pishbin F. Development and Characterisation of Bioactive Coatings Based on Biopolymer and Bioactive Glass Obtained by Electrochemical Means. Imperial College London, 2013.

45. Lee JH, Khang G, Lee JW, Lee HB. Interaction of different types of cells on polymer surfaces with wettability gradient. J Colloid Interface Sci. 1998;205(2):323–30.

46. Wang Y, Wang W, Zhong L, Wang J, Jiang Q, Guo X. Superhydrophobic surface on pure magnesium substrate by wet chemical method. Appl Surf Sci. 2010;256(12):3837–40.

How to cite this article: Ahmed Y, Nawaz A, Singh Virk R, Wadood A, Rehman MAU. Fabrication and characterization of zein/bioactive glass deposited on pre-treated magnesium via electrophoretic deposition. Int J Ceramic Eng Sci. 2020;2:254–263. https://doi.org/10.1002/ces2.10066