

ELECTROPHORETIC DEPOSITION AND CHARACTERISATION OF SODIUM ALGINATE COATINGS ON COMMERCIAL PURE TITANIUM

MACIEJ WARCABA^{1*}, TOMASZ MOSKALEWICZ¹, ZOYA HADZHIEVA², ALDO R. BOCCACCINI²

¹ FACULTY OF METALS ENGINEERING AND INDUSTRIAL COMPUTER SCIENCE, AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, CZARNOWIEJSKA 66, 30-054 KRAKÓW, POLAND

² INSTITUTE OF BIOMATERIALS, UNIVERSITY OF ERLANGEN-NUREMBERG, CAUERSTR. 6, 91058 ERLANGEN, GERMANY
*E-MAIL: MWARCABA@AGH.EDU.PL

[ENGINEERING OF BIOMATERIALS 158 (2020) 54]

Introduction

Titanium and titanium alloys are a very important group of metallic biomaterials. They have low density, relatively low elasticity modulus, good electrochemical corrosion resistance and good biocompatibility. These materials are generally used in orthopaedic surgery and dentistry. On the other hand, their application as bone implants is restricted by poor osseointegration [1]. To improve the direct bone-to-implant contact, bioactive and biodegradable coatings are often applied. In this work, sodium alginate coatings were fabricated on titanium substrates by electrophoretic deposition (EPD). EPD is a surface engineering method used for the deposition of polymeric, ceramic and composite coatings, especially for biomedical applications [2]. Sodium alginate is one of the most important biopolymers. Due to its biodegradability, biocompatibility and non-toxicity, it is widely used as a matrix of composite coatings [3]. The aim of the present work was to elaborate the conditions of EPD of pure sodium alginate (SA) coatings on commercially pure titanium and to characterise the coating microstructure, surface topography and selected properties.

Materials and Methods

A commercially pure titanium CP-Ti Grade 1 was used as a substrate material for coating deposition. Two different ways of substrate preparation were used before deposition, (i) in as-received condition and (ii) after chemical treatment by washing in acetone, soaking in a 0.06 M solution of Na₃PO₄·12H₂O at 80 °C, washing in hot water and soaking in a solution of 5 ml HF 40% + 35 ml HNO₃ 70% in 60 ml H₂O for 5 minutes. Synthetic SA powder was used as a coating component. The suspension used for EPD consisted of a different concentration of SA of 2 g/l, 4 g/l or 8 g/l in a different volume ratio of distilled water to EtOH of 20/80, 40/60 and 60/40. The counter electrode was made of austenitic stainless steel (AISI 316L). The EPD was performed at the constant voltage of 3, 5, 7, 10 and 12 V for the deposition time of 300 s. The zeta potential (ZP) was measured for the real suspensions in the pH range of 3-12. The microstructure of the coatings was investigated by light microscopy (LM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The surface topography of the coatings was analysed by optical profilometry and by atomic force microscopy (AFM). The contact angle and surface free energy (SFE) were investigated. The adhesion of the coatings to the titanium substrates was determined by a cross cut adhesion test in accordance with ASTM D3359-B.

Results and Discussion

The homogeneity of coatings obtained by EPD can be controlled by the chemical composition of the suspension and process parameters. It was found that, in the case of a dispersion phase consisting of the distilled water to EtOH volume ratio of 20/80 or 40/60, the precipitation of SA was observed for all the investigated concentrations of SA. The zeta potential of the suspensions consisting of distilled water and EtOH in the volume ratio of 60/40 containing a different concentration of SA equalled 2 g/l, 4 g/l and 8 g/l and was negative in all the investigated pH range of 3-12. Thus, the SA particles were negatively charged and moved towards the anode under the electric field. The highest values of ZP for different concentrations of SA (2, 4 and 8 g/l) were -56.1 mV (for pH=10), -66.0 mV (for pH=9) and -90.6 mV (for pH=7), respectively. Macroscopically homogeneous coatings were obtained from the suspension containing 4 g/l and the volume ratio of distilled water to EtOH of 60/40 at the voltage of 10 V during 300 s. The coatings deposited from the suspension containing 2 g/l of SA were thin and not uniform. The coatings deposited from the suspension containing 8 g/l contained numerous gas bubbles. After EPD at a voltage lower than 10 V, the coating was not continuous and only partially coated the substrate, but if the voltage was higher than 10 V the substrate oxidized. The thickness of the coatings deposited from the suspension containing 4 g/l of SA was in the range of 840–980 nm. Electron microscopy investigation revealed that the coatings were dense and homogeneous. It was found that they were characterized by average surface development. Selected surface topography parameters of the coatings, e.g. R_a (the average roughness), R_q (the root mean square roughness) or R_{max} (maximum vertical distance between the highest and lowest point) equalled 197.4 ± 60.1 nm, 254.0 ± 80.2 nm and 1651.6 ± 521.0 nm, respectively. Tape tests showed that the coatings revealed slightly better adhesion to the chemically treated titanium substrates than to the as-received ones. The coatings exhibited a hydrophilic character. The contact angle for distilled water and diiodomethane equalled 47.7 ± 5.8 and 46.5 ± 3.6, respectively, while SFE equalled 57.3 ± 5.6.

Conclusions

Sodium alginate coatings were successfully deposited on titanium substrates by EPD. Uniform coatings were obtained from the suspension containing 4 g/l of SA in a volume ratio of distilled water to EtOH of 60/40 at a potential difference of 10 V during 300 s. The obtained coatings were homogeneous and exhibited average surface development. The coatings exhibited slightly better adhesion to the chemically treated substrates in comparison to the as-received substrates. The coatings exhibited a hydrophilic character. Further optimisation of the substrate preparation and characterisation of the coatings are in progress.

Acknowledgments

This work was supported by the National Science Centre, Poland (decision no DEC-2018/31/G/ST5/00429). The authors also acknowledge support from the German Science Foundation (DFG) (project BO 1191/25-1).

References

- [1] L. Salou, A. Hoornaert, G. Louarn, P. Layrolle, *Acta Biomater.*, 11 (2015) 494 - 502
- [2] A. R. Boccaccini, S. Keim, R. Ma, Y. Li, I. Zhitomirsky, *J. R. Soc. Interface*, Suppl 5 (2010) 581 - 613
- [3] Q. Chen, L. Cordero - Arias, J. A. Roether, S. Cabanas - Polo, S. Virtanen, A. R. Boccaccini, *Surf. Coat. Technol.* 233 (2013) 49 - 56