Effect of thermal evaporation deposited silver nanoparticles on the antibacterial behavior of plasma electrolytic oxidation coated AZ31B magnesium alloy

1st Ming-Hsuan Chang[a,#] , 2rd Chuan-Ming Tseng [a,*],
[a] Department of Materials Engineering, Ming Chi University of Technology, New Taipei City, Taiwan.
Corresponding author. Email: cmtseng@mail.mcut.edu.tw
#Presenting Author and * Corresponding Author

Morphology Analysis (SEM)

The average size of AgNPs is directly proportional to the deposition time, increasing as the time extends. According to SEM analysis, the HVE-PEO (5 min) specimen, with the shortest deposition time, exhibited the smallest AgNPs, averaging approximately 56.6 nm on flat surfaces and 63.6 nm within the pores. At a deposition time of 10 minutes, the silver particle size on the coating surface significantly increased to 132.9 nm, with pore particles reaching 132.7 nm. For the HVE-PEO (15 min) specimen, the particle size further increased to 223.5 nm on the surface and 225.36 nm in the pores. This phenomenon is attributed to the nucleation and growth processes inherent in the HVE mechanism. As evaporation time increases, in addition to the formation of new nuclei, the aggregation of existing particles and the development of island structures are intensified, resulting in the continuous growth of particle size over time.

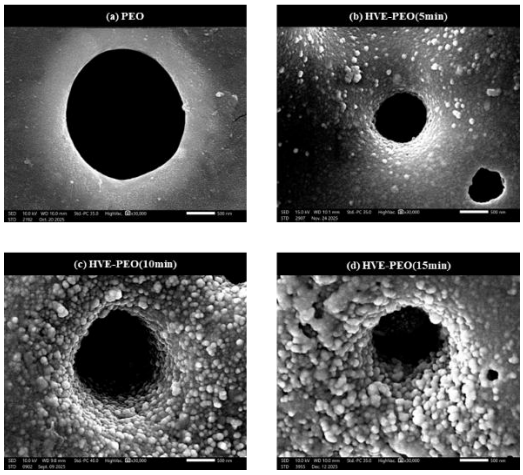


Fig. 1 SEM-SEI images of pores on Ag-deposited PEO coatings prepared with different HVE deposition times: (a) PEO; (b) HVE-PEO (5 min); (c) HVE-PEO (10 min); (d) HVE-PEO (15 min).

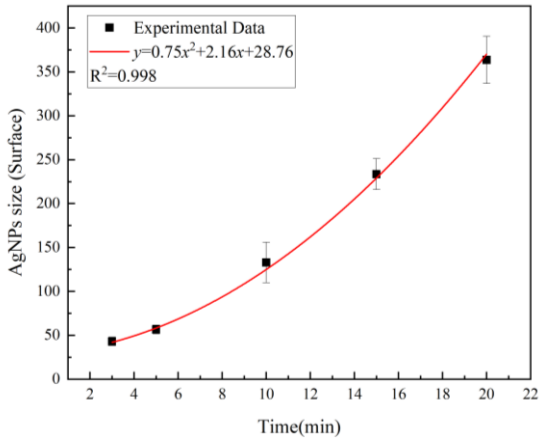


Fig. 2 Fitting curve of AgNP size as a function of HVE deposition time

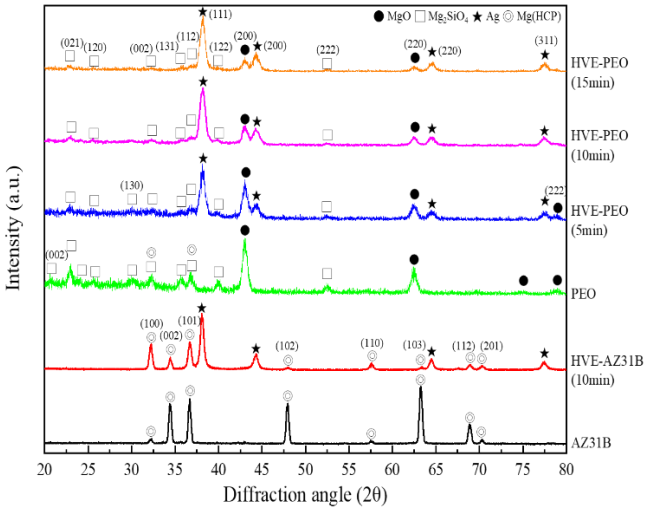
Table1. Surface AgNP Size Statistics of HVE-PEO Coatings

Sample	Surface	Pores
HVE-PEO (3min)	42.96 ± 4.77	30.44 ± 3.95
HVE-PEO (5min)	56.61 ± 4.93	63.63 ± 9.80
HVE-PEO (10min)	132.9 ± 22.94	132.75 ± 15.67
HVE-PEO (15min)	223.53 ± 17.57	225.36 ± 21.48
HVE-PEO (20min)	363.59± 26.84	379.45 ± 43.62

Phase Composition (XRD)

XRD patterns of the HVE-deposited Ag layers on AZ31B PEO coatings. The PEO coating is primarily composed of MgO and Mg_2SiO_4 (forsterite) phases. The presence of Mg_2SiO_4 confirms that silicate ions from the electrolyte participated in the plasma discharge reaction and were incorporated into the ceramic layer. Regarding the Ag-deposited samples, characteristic diffraction peaks corresponding to the face-centered cubic (FCC) Ag structure (JCPDS No. 04-0783) were identified at the (111), (200), (220), and (311) planes. This confirms the

successful deposition of crystalline Ag nanoparticles on the porous PEO surface. As the HVE deposition time increased from 5 to 15 min, the intensity of the Ag diffraction peaks notably increased. Meanwhile, the characteristic peaks of the underlying PEO layer (MgO and Mg_2SiO_4) remained visible, indicating that the Ag adhered to the surface as nanoparticles or a thin film without altering the phase composition of the PEO substrate.



Antibacterial Performance

The antibacterial tests against E. coli revealed a distinct size-dependent efficacy for Ag-decorated PEO coatings. While the porous structure of pure PEO coatings favored bacterial adhesion, the introduction of AgNPs significantly inhibited growth. The HVE-PEO (5 min) sample, with the smallest particle size (~56 nm), exhibited the highest activity, achieving a 96.82% antibacterial rate after just 30 minutes of contact and 100% after 90 minutes. In comparison, the HVE-PEO (15 min) sample showed a lower rate of 87.66% at 30 minutes due to the reduced specific surface area of larger particles. The mechanism suggests that smaller AgNPs serve as potent localized ion sources on the bacterial cell wall, facilitating rapid ion release and membrane penetration.

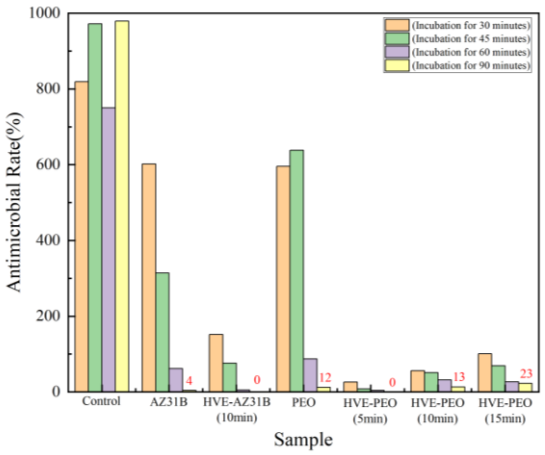


Fig. 3 Colony-forming unit (CFU) counts of E. coli on HVE-Ag/PEO coatings prepared with different deposition times after contact durations of 30, 45, 60, and 90 min.

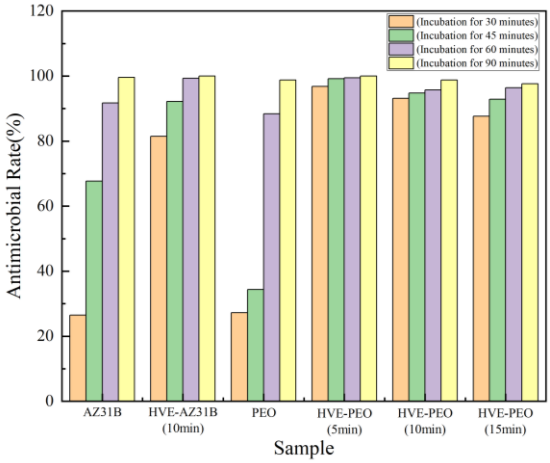


Fig. 4 Antibacterial efficiency of HVE-Ag/PEO coatings prepared with different deposition times against E. coli after contact durations of 30, 45, 60, and 90 min.

Conclusion

1. The bioceramic coating consists mainly of MgO and Mg_2SiO_4 phases. SEM imaging confirmed the presence of silver as nanoparticles (AgNPs) on the PEO surface, verifying the successful fabrication of AgNPs on the AZ31B magnesium alloy using the HVE technique.

2. HVE-PEO (5 min) demonstrated superior antibacterial activity, achieving a 100% reduction rate within 90 minutes. This efficacy is attributed to the high specific surface area of smaller AgNPs (~56 nm), which facilitates rapid silver ion release.