EFFECTS OF NANO-HYDROXYAPATITE AND CARBON NANOTUBES HYBRID RATIO ON Ni-Co BIOLOGICAL COATING'S MECHANICAL PROPERTIES AND BIOCOMPATIBILITY

Xia Zhou[a)], Guohui Qu & Shangyu Song
Department of Engineering Mechanics, Dalian University of Technology, Dalian 116024, China

Summary Ni-Co alloy bio-composite coatings reinforced with nano-hydroxyapatite (nano-HA) and carbon nanotubes (CNTs) with different hybrid ratios were prepared on AZ91D magnesium alloy surface by the brush plating method to improve its biomechanics performance. The surface morphologies, tensile and nanoindentation properties of the coatings under different hybrid ratios were studied by experiments and simulation. The nanocomposite coatings show good mechanical properties and biocompatibility.

INTRODUCTION

Magnesium and its alloys in the field of biomaterials have increased considerably for the development of biodegradable bone implants because of their good biocompatibility and biodegradability [1]. Unfortunately, magnesium is highly susceptible to corrosion in physiological conditions, which results in the loss of mechanical integrity. So it is necessary to improve the corrosion resistance of Mg-based materials by surface modification. Composite electrodeposition is a process to combine nano-particles or fibers into metal matrix by electrodeposition. The resultant nanocomposite coatings usually have various novel properties. Nanocrystal Ni-Co alloy is a popular choice as the metal matrix for biocomposite coatings, while nanosized hydroxyapatites (HA) and carbon nanotubes (CNTs) are ideal reinforcements for the composites because of their excellent biocompatibility [2]. However, few have been reported on the simultaneous incorporation of HA nano-particulates and CNTs in electrodeposited Ni-Co alloy coating.
In this paper, the effects of nano-HA and CNTs hybrid ratio on mechanical properties of Ni-Co Alloy biological coatings by electrical brush-plating were studied.

EXPERIMENTAL CHARACTERIZATION AND SIMULATION

The Ni-Co/nano-HA+CNTs composite coating was deposited at room temperature using electrical brush-plating. The microstructure and surface morphology of the coatings were analyzed by scanning electron microscopy (SEM, JSM-5310) in conjunction with energy dispersive X-ray spectroscopy (EDS) and transmission electron microscopy (Tecnai G220 S-Twin, TEM). The stress-strain curves were obtained with an INSTRON 3345 testing machine at a constant strain rate of 1.67×10^{-3} s^{-1}. Mini dumb-bell-shaped tensile specimens with dimensions of 8 mm × 2 mm × 1 mm were cut from the double-sided brush plating sheets of the AZ91D magnesium alloy. Coatings with a thickness of 5 μm were deposited on the both surfaces of the magnesium alloy plates. The nanoindentation test was conducted with a standard Berkovich indenter using a Nanoindenter XP. The hardness and elastic modulus of the coatings were derived from the loading – unloading curves using the Oliver – Pharr method [3]. Besides, effects of nano-HA and CNTs hybrid ratio on tensile properties of the coatings were simulated based on the practical microstructure.

RESULTS AND DISCUSSION

Surface morphology and bioactivity of the composite coating

Fig.1(a) and (b) shows the SEM morphologies of Ni-Co alloy and Ni-Co/nano-HA+CNTs nanocomposite coatings. Fig.1(c) shows the TEM microstructure image of the nanocomposite coating. Contrary to the Ni-Co alloy coating (see Fig.1(a)), the Ni-Co/nano-HA+CNTs nanocomposite coatings are characterized by particulate-like structure and have more compact and fine granular morphologies (see Fig.1(b) and (c)), which indicates that the co-deposited HA nano-particulates and CNTs are uniformly distributed in the Ni-Co matrix of the composite coating.

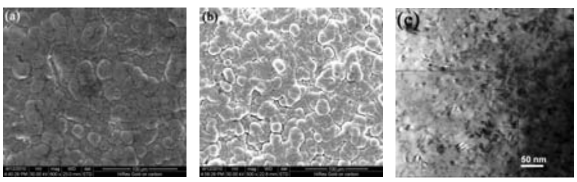

Fig.1 SEM micrographs of (a) Ni-Co coating, (b) Ni-Co/HA+CNTs composite coating, and TEM micrograph of (c) Ni-Co/HA+CNTs composite coating.

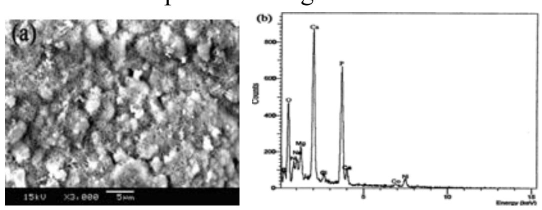

Fig.2 Ni-Co/HA+CNTs coating after being immersed in SBF for 20 days: (a) surface morphology, (b) EDS analysis.

a) Corresponding author. Email: zhouxia@dlut.edu.cn.

Effects of nano-HA and CNTs hybrid ratio on the mechanical properties of the coatings

Fig.3 shows the tensile stress-strain curves of double-sided brush plating tensile specimens. It was seen that for fixed adding amount of hybrid reinforcement, the yield and tensile strength of the composite coating increased with increasing hybrid ratio of nano-HA and CNTs. But when the hybrid ratio continued to increase to 30.38, the tensile properties of the coating-substrate system decreased due to the deterioration of coating adhesion. The microstructure-based tensile crack propagation simulation results also improved the effect trend of hybrid ratio on the stress-strain response (see Fig. 4(a) and (b)).

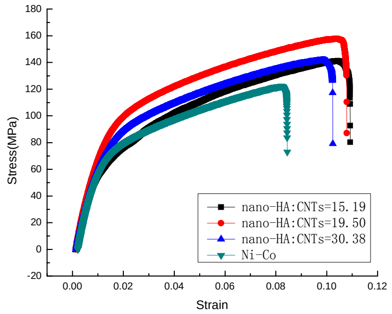

Fig.3 The stress-strain curves for the coatings

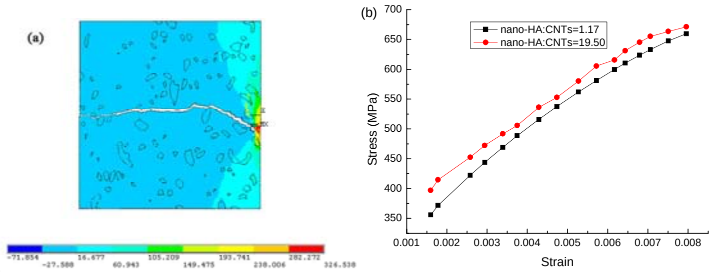

Fig.4 The microstructure-based (see Fig.1(c)) (a) crack propagation simulation and effect of hybrid ratio on (b) stress-strain response.

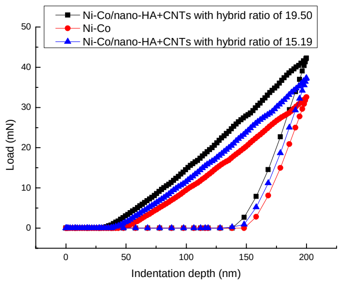

Fig.5 Load- indentation depth curves for the coating

Table 1 Hardness and elastic modulus of the coatings

	Ni-Co	Ni-Co/HA+CNTs with hybrid ratio of 15.19	Ni-Co/HA+CNTs with hybrid ratio of 19.50
Hardness(GPa)	8.15	9.63	11.12
Elastic modulus (GPa)	145.57	155.50	165.43

Fig.5 shows the representative load-indentation depth curves for the Ni-Co and Ni-Co/nano-HA+CNTs composite coatings with different hybrid ratios for nano-HA and CNTs. All indentations were made to a depth of 0.2 μm. With increasing hybrid ratio of nano-HA and CNTs smaller indentation depths were observed at the same load. This implies that the hardness and elastic modulus of the coatings were improved as the hybrid ratio of nano-HA and CNTs increased. The average hardness and elastic modulus of the coatings are presented in Table 1. The hardness and elastic modulus of the coatings increased with increasing hybrid ratio of nano-HA and CNTs. When the hybrid ratio of nano-HA and CNTs was increased to 19.50, the hardness and elastic modulus of the coatings were improved by 36% and 14%, respectively, compared with those of the pure Ni-Co alloy coating. The presence of well-dispersed nano-HA and CNTs with high stiffness and strength matching in the Ni-Co matrix is presumed to strengthen the Ni-Co coating considerably. The composite coating with the hybrid ratio of 19.50 for nano-HA and CNTs showed a hardness of 11.12 GPa and elastic modulus of 165.43 GPa, which were higher than those of the Ni-Co coating.

CONCLUSIONS

HA nanoparticulates and CNTs reinforced Ni-Co alloy composite coatings were successfully deposited on the surface of Magnesium alloy substrates using electrical brush-plating. The small addition of HA nanoparticulates and CNTs to the Ni-Co matrix could remarkably improve both the mechanical and biological properties of the Ni-Co coating. The electrical brush-plating method is shown to be very effective in producing dense and highly adhesive Ni-Co/nano-HA+CNTs composite coatings. Therefore, such these composite coatings are expected to be promising for high load-bearing orthopedic implants of bone tissue engineering.

References

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