Original Article

A novel Ni-B/YSZ nanocomposite coating prepared by a simple one-step electrodeposition at different duty cycles

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A R T I C L E    I N F O

Article history:
Received 29 August 2019
Accepted 27 November 2019
Available online 11 December 2019

Keywords:
Nanocomposite coating
Ni-B/YSZ
One-step electrodeposition
Corrosion resistance
Yttria-stabilized zirconia

A B S T R A C T

A novel Ni-B nanocomposite coating reinforced by yttria-stabilized zirconia (YSZ) nanoparticles were fabricated by a simple one-step electrodeposition process. The influences of pulse duty cycle on the structure, surface, and properties of the Ni-B/YSZ nanocomposite coating were examined. All coatings exhibit compact, crack-free and nodular-like structures. The Ni-B/YSZ coatings present nanocrystalline structure with 10 nm in size. The preferred orientation was the Ni (111) texture. The topography and roughness were evaluated by AFM. It indicated that duty cycle influences the particle content, nodule size, roughness, micro-hardness and corrosion behaviors. The roughness (S\textsubscript{a}) are 31–51 nm, depending on the duty cycles. The high duty cycle (90%) could enlarge the nodule size. The doped YSZ nanoparticles and the low duty cycle could enhance the hardness, corrosion and wear resistance. A maximum hardness of 823.5 HV was obtained at the duty cycle of 30%. The duty cycle of 30% is the optimal value for the best corrosion and wear resistance, hardness, and desirable electrochemical stability of the nanocomposite coating.

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1. Introduction

Ni-B matrix has many merits in terms of hardness, wear, and corrosion resistance [1,2]. It was widely applied as a hard or functional matrix in petrochemical, automotive, electronics, aerospace and nuclear industries [3,4]. However, with the development of extreme environmental applications, more demanding requirements are imposing a need to further improve its corrosion and wear resistance as well as its service life. Therefore, many methods have been tried, including optimization of the fabrication process, alloying with other elements, or incorporating a second reinforcement phase into the Ni-B coating [5].

The addition of ceramic particles into the Ni-B alloy was developed to further enhance its hardness and corrosion resistance. Literature has reported on Ni-B nanocomposite coating reinforced by AlN [6], Al\textsubscript{2}O\textsubscript{3} [7], SiC [8], TiO\textsubscript{2} [9] and diamond [10] particles. Waware et al. [11] developed Ni-B-Ti\textsubscript{2}O\textsubscript{3} composite coatings by electrodeposition and illustrated the improvement in hardness, elastic modulus, and corrosion resistance after the incorporation of Ti\textsubscript{2}O\textsubscript{3} into Ni-B matrix. Ünal and Karahan [12] incorporated hBN particles in Ni-B matrix and found a decrease in corrosion rate of the produced composites. Tao et al. [13] reported that the addition of Sc could increase the hardness of Ni-B-Sc up to 1484 HV. Shakoor et al. [7] fabricated Ni-B-Al\textsubscript{2}O\textsubscript{3} composite coatings through
electrodeposition and proved that the presence of Al₂O₃ in Ni-B led to higher mechanical and corrosion-resistant properties. Pancrecious et al. [14] reported that the ceria doped Ni-B alloy exhibited low corrosion current density and high wear resistance. However, compared to the other Ni-based matrix such as Ni-Co and Ni-W, the open literature on Ni-B coatings strengthened by nanoparticles were still scarce.

Yttria stabilized zirconia (YSZ) has many merits, such as the excellent thermal stability, high fracture toughness, and high hardness, which make it applicable in composite coatings [15,16], sensors, catalysts, electrodes, buffer layers and thermal insulators. YSZ is a very promising ceramic reinforcement for composite coating [17]. Although there are many reports on nano YSZ, few researches have been done on the preparation of Ni-B/YSZ composite coating. Its corrosion and wear behaviors have not been investigated yet [18].

In pulse current (PC) electrodeposition, the duty cycle is a critical parameter that influences the structure and properties of the electrodeposits. Sen et al. [19] investigated the effect of duty cycle on the properties of Ni-CeO₂ coating and reported that CeO₂ content, crystallite size, and hardness were affected by the duty cycles. Yang and Cheng [20] fabricated Ni-Co-SiC composite coating and found that the micro-hardness and corrosion resistance were enhanced at a low duty cycle. The low duty cycle benefits the fine-grained morphology and the high SiC content. Kammerdhag et al. [21] prepared Zn-Ni-Al₂O₃ composite and revealed that the duty cycle of 33% led to a finer and smoother surface morphology, enhanced strength, higher corrosion resistance compared to that at higher duty cycles or through DC mode.

However, few works have investigated Ni-B/YSZ nanocomposite coating prepared at different duty cycles. Hence, the present work aims to fabricate Ni-B/YSZ nanocomposite coatings by one-step pulse electrodeposition to improve its protective performance, especially the microhardness, corrosion and wear resistance. Considering that the duty cycle has significant effects on the electrodeposits, the effect of duty cycle on the morphology, structure, corrosion and wear resistance of the Ni-B/YSZ nanocomposite coatings were investigated for the first time.

### 2. Experimental procedures

#### 2.1. Electrodeposition

YSZ nanoparticle doped Ni-B matrix nanocomposite coatings have been prepared by one-step pulse electrodeposition process. Table 1 provides the electrolyte composition and

<table>
<thead>
<tr>
<th>Electrolyte composition (gL⁻¹)</th>
<th>Electrodeposition conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>NiSO₄ 6H₂O</td>
<td>pH</td>
</tr>
<tr>
<td>NiCl₂ 6H₂O</td>
<td>Temperature</td>
</tr>
<tr>
<td>H₂BO₃</td>
<td>Deposition time</td>
</tr>
<tr>
<td>Trimethylamine Borane (TMAB)</td>
<td>Average current density (iₚ)</td>
</tr>
<tr>
<td>Yttria-stabilized zirconia (YSZ)</td>
<td>Duty cycle (t)</td>
</tr>
<tr>
<td>Saccharine</td>
<td>Frequency (f)</td>
</tr>
<tr>
<td>Sodium dodecyl sulfate (SDS)</td>
<td>Stirring rate</td>
</tr>
</tbody>
</table>

#### Fig. 1 – Schematic diagram of the experimental device.

operating parameters. YSZ nanoparticles were commercially product with dimension less than 50 nm supplied by Shanghai Chawei Nanotechnology Co. Ltd., China. The experimental device was established as shown in Fig. 1, which was composed of a nickel plate as anode and a copper sheet as cathode with a distance of about 3.0 cm between them. Before electrodeposition, all the substrates were polished with alumina polishing paste (0.1 μm), ultrasonically treated in acetone, soaked in a deoiling solution containing surfactant (pH 9-11) and rinsed by purified water in sequence. Immediately before electrodeposition, the pretreated samples were soaked in a dilute hydrochloric acid solution for less than 1 min. After electrodeposition, the products were thoroughly treated (rinsing by water, ultrasonic cleaning) to remove the adsorbed YSZ from the surface.

Before the experiment, the electrolyte should be pretreated, including adjusting the pH to 4.0 ± 0.1, ultrasonically treated for 10–20 min and magnetic stirring at 400 ± 50 rpm for 0.5–1 h. During the electrodeposition process, magnetic stirring was run simultaneously to prevent the aggregation of nanoparticles. The applied pulse current mode and the relationship between these parameters were presented in Fig. 2. The r, f, iₚ, iₐ, T₀m, Tₐ Off represent the pulse duty cycle, frequency, peak current density, average current density, current on time (s), and current off time (s), respectively. The effects of the duty cycles of 30, 50, 70, and 80% on the structure and properties of the nanocomposite coating were examined.

#### 2.2. Characterization

Surface morphology was analyzed by Hitachi S4800 SEM, and the composition was determined by affiliated Oxford EDS.
Atomic force microscope (AFM, NT-MDT Prima) was utilized to analyze the topography and roughness of the coating. The phase composition and the average crystallite size of the nanocomposite coating were determined using D8 advance-Bruker XRD with Cu Kα radiation (λ = 0.15418 nm) in 2θ 20–90° at 5°/min. The average crystallite size was obtained according to Scherrer Eq. (1).

\[
D = \frac{k\lambda}{\beta \cos \theta}
\]  

(1)

Where D represents the average crystalline size, k represents the constant coefficient (0.94), λ represents the X-ray wavelength (0.15418 nm), β represents the FWHM of the peak at θ in radian. Vickers hardness was measured by HV-1000A hardness tester under the applied load and time 100 gf and 15 s. Wear test was measured using a UMT-3 friction and wear tester at frequency 5 Hz and amplitude 5 mm under 10 N for dry-sliding. Counterparts were SiC balls with a diameter of 3 mm. The whole sliding distance was 50 m. A surface profiler (Alpha-Step IQ) was used to measure the wear track profile. Corrosion behaviors were measured by EIS on a CHI 660E potentiostat. The as-deposited sample with 1 cm² surface area was the working electrode. SCE and platinum sheet were the reference and auxiliary electrodes, respectively. EIS was measured in a three-electrode cell from Ecorr under 10 mV disturbance amplitude in the frequency of 10⁵–10⁻² Hz. Each sample coating has been immersed in 3.5 wt.% NaCl solution for 1, 48, and 168 h and was measured separately.

### 3. Results and discussion

#### 3.1. YSZ nanoparticles characterization

The YSZ nanopowder has been examined by TEM and XRD methods. Fig. 3(a) displays that the shape of YSZ nanoparticles is close to spherical-like with dimensions of 15–40 nm. The size obtained by TEM observation is within the range provided by the supplier (<50 nm). Beltowska-Lehman et al. [22] reported that particle shape largely affected the content and uniform distribution of nanoparticles in the metal matrix. The spherical-like particles led to a better incorporation into a metal matrix compared to irregular ones [23]. Agglomerations of particles were also noticed for high surface energy of the nanomaterial. How to better disperse nanoparticles and prevent their agglomeration is still a crucial task and needs to be investigated further. Fig. 3(b) illustrated that the YSZ nanopowder is composed of tetragonal and monoclinic phase. The tetrahedral zirconia was the main component. It illustrated that the primary diffraction peak of ZrO₂ was the (020) plane, which is located at 30.1°.
3.2. Cross-sectional observation

Fig. 4 presents the cross-section of the Ni-B/YSZ nanocomposite coating. It can be seen that the coating thickness is about 5–10 µm, which varied with the electrodeposition parameters. The bulk of the composite coating is uniform and compact. Defects such as crack, gap, delaminating have not been observed. The interface bonding between the coating and substrate is good. Fig. 4(b) shows the enlarged view of the local region marked with a yellow rectangle in Fig. 4(a). It illustrated that the nanoparticles in size about 20–40 nm had been uniformly embedded in the Ni-B metallic matrix. Fig. 4(c) shows the EDS element line scan of the cross-section of the coating sample, which demonstrated the interface between the coating and substrate. No defects were observed between the particles and matrix.

3.3. Surface morphology and chemical composition

Fig. 5 displays the morphology of the Ni-B/YSZ nanocomposite coatings obtained with different duty cycles. All coatings are compact, smooth, crack-free, and present nodular or cauliflower-like morphology. It was noticed that the surface of the Ni-B/YSZ nanocomposite coating contains smooth and agglomerated areas, corresponding to the Ni-B matrix and the YSZ agglomeration, respectively [13]. As the duty cycle increases, the dimension of the microscopic nodular or “cauliflower” grains decreases. At low duty cycle (30%), the cauliflower-like protrusion is not very much accentuated comparing to the main Ni-B matrix. The nodule size is larger at 30% compared to that of the other duty cycles. Rahman et al. [24] reported that in this case the transverse growth is superior to vertical growth, which is ascribed to the segregation of metalloid B at grain (colony) boundary. At high duty cycle (90%), more protruding nodules emerged on the surface of the coating due to that the vertical growth is more preferred compared to lateral growth, leading to a rougher surface. The boundary of the crystalline grains is distinct at a relatively low duty cycle. Waware et al. [6] reported that nodular size is dependent on the segregation of metalloid (such as B, S, P) in Ni. Wasekar et al. [25] revealed that more metalloid (B, etc.) in Ni coating could produce more metalloid segregates at the grain boundary, leading to the smaller Ni grains and the larger nodules. Fig. 5 indicated that the clusters of YSZ aggregations (white dots) exist in the Ni-B/YSZ nanocomposites for the high surface energy of the nanopowder. The surface roughness is determined by both the nodular-like structure and the incorporated particles/agglomerates [26]. In pulse current mode, the low duty cycle offers more zero current time to allow the YSZ to arrive the cathode and replenish their consumption during the co-deposition process. So, more particles were co-deposited. Besides, YSZ offers more nucleation sites for crystal growth, which result in grain refinement. It was also found that some YSZ particle clusters (white aggregations) were dispersed on the deposited composites.

EDS spectra (Fig. 6) indicates that the coating comprises 81.98–83.18 wt.% Ni, 10.77–11.50 wt.% Zr, 2.39–2.74 wt.% Y and some B, C and O elements. It certified that YSZ were co-deposited in the metallic matrix. B is a light element and its content is low. The results measured by the EDS method may be inaccurate and are not suitable for the calculation of its wt%. The B content is low, and it was not detected by EDS. The amount of Zr embedded in the composites first slightly decreases and then increases when duty cycle increases. The amount of YSZ nanoparticles, in the range of 17.8–19.1 wt.%, was calculated based on Zr, Y content measured by the EDS and the stoichiometry of ZrO2 and Y2O3 compounds. It indicated that the duty cycle affects the structure and composition of the nanocomposites, for instance the YSZ content.

![Fig. 4 – (a) Cross-sectional images of the nanocomposites; (b) local enlarged details and (c) EDS element line scan.](image-url)
3.4. **Phase composition and crystallite size**

Fig. 7 depicts the XRD spectra of the Ni-B/YSZ nanocomposite coatings prepared at different duty cycles. The peak attributed to B was not found, indicating the formation of a single solid solution of B in Ni lattice. The small peak at 30.1° is attributed to the YSZ nanoparticles. Pancrecious et al. [14] found that the particles (CeO₂) were not observed in the XRD patterns owing to their low concentration. Tao et al. [13] reported that the Ni-B coating was usually supersaturated solid solution of B (1.4 Å) in Ni (1.62 Å) lattice. The presence of B could restrain the growth of Ni crystals, so the grains of Ni were largely refined. Waware et al. [6] reported that the addition of AlN, Ti₂O₃ [11] particles into Ni-B coatings causes a noticeable change in structural and mechanical properties, which exhibits a crystalline structure. The crystalline nature of the Ni-B nanocomposite is related to the lower B content compared to the binary Ni-B. The Cu peaks were also detected due to the thin thickness of the coatings. When duty cycle increases, the crystallite size of the Ni-B/YSZ nanocomposites based on Ni (111) plane was almost unchanged. The calculated crystallite size is about 10 nm. Lee et al. [1] and Matsui et al. [27] reported that nanocrystalline structure has advantages in ductility, hardness and wear resistance.

It was noticed that the (200) peak is very small and the (220) peak disappeared. The Ni (111) plane was the primary texture. The relative texture coefficient (RTC) of the Ni (111) texture is close to 100%, suggesting the preferred ori-
entation. It illustrated that the phase composition and the preferred orientation are independent of the duty cycles. This nanocomposite coating exhibits a nanocrystalline structure. Pavlatou et al. [28] proposed the reason that the addition of nanoparticles inhibits the growth of the already formed grain, which could provide more nucleation sites and immobilization the grain boundary. Then, they promote the formation of nanocrystal structure.

3.5. AFM topography and roughness

Surface topography of the Ni-B/YSZ coatings fabricated at \( r = 30\% \) and 90\% were investigated by AFM with an analysis area of 10 \( \times \) 10 \( \mu \text{m} \). Fig. 8 shows that the coating fabricated at \( r = 30\% \) has a compact surface with granular structure. Meanwhile, some hill-like protrusions are dispersed on the surface of nanocomposites. The average roughness \( (S_a) \) are 38.75 and 50.34 nm and the root mean square roughness \( (S_q) \) are 60.94 and 76.59 nm, corresponding to sample of Fig. 8(a and b), respectively. At the low duty cycle (30\%), it is evident that the nodule size is small. The diameter of the dispersed hill-like protrusions is less than 1 \( \mu \text{m} \), and its height is about 800 nm. When duty cycle is 90\%, large nodules emerged containing the distributed fine grains (Fig. 9). When \( r = 90\% \), the \( S_a \) are 47.72 and 31.45 nm and the \( S_q \) are 66.30 and 48.32 nm, corresponding to the samples of Fig. 9(a and b), respectively. Comparing with Fig. 8, the coating fabricated at higher duty cycle (90\%) exhibited larger nodule structure (3 \( \mu \text{m} \)), which was composed of smaller grains. The boundary of the crystallite grain can clearly be distinguished in Fig. 9. Although the diameter of
the nodular structure increased (from less than 1–3 μm), the height of the nodule was not increased, which was about 500 nm. AFM analysis suggested that a relatively smaller duty cycle benefits smooth and fine-grained structure. The high duty cycle is helpful to the growth of the nodule to a larger one.

3.6. Microhardness and wear resistance

Fig. 10 presented the hardness of the as-plated Ni-B/YSZ coatings fabricated at different duty cycles. It was noticed that the hardness varied with the duty cycles. The maximum hardness was achieved at \( r = 30\% \). The hardness first decreased and then increased and finally slightly decreased with the duty cycle increasing from 30\% to 90\%. The lowest hardness was 486 HV at 50\%, and the maximum hardness was 823.5 HV at 30\%. The random incorporation of B in Ni enhanced the hardness [14]. The factors affecting the hardness include the following aspects: the embedded YSZ content in the nanocomposite coating, the change of the crystallite structure such as the formation of nanocrystalline structure, coating composition, and the element distribution. In general, the low duty cycle and the high peak current density led to high hardness of the nanocomposites.

Fig. 10 – Hardness of Ni-B/YSZ nanocomposite coatings with duty cycles.

Fig. 11 presents the wear track profiles of the Ni-B/YSZ nanocomposite coatings prepared at different duty cycles under dry-sliding conditions (10 N, 5 Hz, 50 m). The wear track profiles are an intuitive way to compare the wear rates of these different samples. The deeper depth and the larger area of the wear track profiles indicate the more wear volume loss and the
higher wear rates. It shows that the depth and the area of the wear track profiles for the sample prepared at the duty cycle of 30% were the smallest, indicating the least volume loss in the wear tests. Under dry-sliding condition, the sample prepared at 30% has the best wear resistance. However, many factors could affect the wear resistance, such as the structure, the phase composition, the nanoparticles, the roughness and the grain size. Therefore, many influencing factors and the mechanism about the wear behavior of the nanocomposites have not been fully clarified yet, and further research is still needed in the future works.

3.7. Corrosion resistance

Electrochemical behaviors of the Ni-B/YSZ coatings fabricated at different duty cycles were studied by electrochemical impedance spectra (EIS) methods after they have been immersed in 3.5 wt.% NaCl solution for 1, 48 and 168 h, respectively. Fig. 12(a and b) shows the Nyquist curves of the Ni-B/YSZ nanocomposite coatings, which were immersed for 1 h. At this stage (1 h), all impedance curves present a depressed semicircle in various sizes, which are similar to the literature [29–31]. It shows that when the duty cycle increases from 30 to 90%, the radius of the impedance arc first increases and then decreases with the maximum value at 50%, revealing the best corrosion resistance at 50% in the first hour of immersion in 3.5 wt.% NaCl solution [32]. Fig. 13 shows the equivalent electrical circuits (EEC) models for fitting the Nyquist plots. In the EEC models, the $R_s$, $C_{PE}$, $R_{ct}$, $C_{PE,dl}$, $R_f$, $C_{PE}$ represent the solution resistance, coating resistance, coating capacitance, charge transfer resistance, double layer capacitance, resistance and capacitance of the produced surface film, respectively. The corrosion parameters with the duty cycles and the immersion time were provided in Table 2. In the first hour, the Nyquist plot could be fitted by the EEC model (a) (Fig. 13a). As can be seen in Table 2, with the increase of the duty cycle, the $R_{ct}$ increases from 132.91 kΩ·cm² at 30%–193.16 kΩ·cm² at 50%, and then decreased to 82.79 and 96.68 kΩ·cm², corresponding to 70 and 90%, respectively.

When the immersion time reaches 48 h, the EIS plot of 30% (Fig. 12c, d) exhibited the highest corrosion resistance with a maximum $R_{ct}$ value of 202.73 kΩ·cm². In this stage, the EEC model (a) (Fig. 13a) was still well fitted the Nyquist plots. As can be seen in Table 2, the $R_{ct}$ was 202.73, 95.40, 129.40 and 124.37 kΩ·cm², corresponding to the coating obtained at 30, 50, 70 and 90%, respectively. It indicated that the corrosion resistance of the coating prepared at the duty cycle of 50% decreased largely compared to the others. At this stage, the coating of 30% has the highest corrosion resistance.

Fig. 14 shows the Nyquist and Bode diagrams with the immersion time for Ni-B/YSZ nanocomposite coatings, which were obtained at $r = 30$ and 50%. In the first stage (1 h), the bode plot presents a broaden peak, suggesting a corrosion mechanism with a one-time constant EEC model (a) (Fig. 13a). In the second stage (2 days), the Bode plots still displayed a one-time constant EEC model corresponding to the Fig.13a. In the third
stage (7 days), the Bode plots present a three-time constant EEC model corresponding to Fig. 13c. The fitted parameters to EIS after immersion for 7 days illustrated that the $R_p$ for the sample of 30% increased from 139.91–202.73 kΩ·cm$^2$, then decreased to 44.08 kΩ·cm$^2$, corresponding to 1 h, 2 and 7 days, respectively. The $R_p$ value for the coating prepared at 90% increased from 96.68–124.37 kΩ·cm$^2$, and then decreased to 43.56 kΩ·cm$^2$, corresponding to 1 h, 2 and 7 days, respectively. It indicated that the coating prepared at the duty cycle of 30% has the highest protection capability against corrosion compared to that of 90%.

### Table 2 – Corrosion parameters for Ni-B/YSZ coatings with duty cycle and immersed time.

<table>
<thead>
<tr>
<th>Time</th>
<th>Coatings</th>
<th>$R_s$ (Ω·cm$^2$)</th>
<th>$R_i$(kΩ·cm$^2$)</th>
<th>$CPE_0$(μF·cm$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 hour</td>
<td>30%</td>
<td>5.69</td>
<td>132.91</td>
<td>19.27</td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>6.39</td>
<td>193.16</td>
<td>14.63</td>
</tr>
<tr>
<td></td>
<td>70%</td>
<td>4.24</td>
<td>82.79</td>
<td>25.22</td>
</tr>
<tr>
<td></td>
<td>90%</td>
<td>7.45</td>
<td>96.68</td>
<td>21.01</td>
</tr>
<tr>
<td>2 days</td>
<td>30%</td>
<td>5.99</td>
<td>202.73</td>
<td>31.75</td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>5.50</td>
<td>95.40</td>
<td>18.52</td>
</tr>
<tr>
<td></td>
<td>70%</td>
<td>5.97</td>
<td>129.40</td>
<td>32.35</td>
</tr>
<tr>
<td></td>
<td>90%</td>
<td>2.27</td>
<td>124.37</td>
<td>19.49</td>
</tr>
</tbody>
</table>

Fig. 12 – Nyquist and Bode diagrams of Ni-B/YSZ coatings after immersed for (a, b) 1 h and (c, d) 2 days.

Fig. 13 – Equivalent electrical circuits (EEC) models (a)-(c).

4. Conclusions

Ni-B nanocomposite coatings reinforced by yttria-stabilized zirconia (YSZ) nanoparticles were synthesized by one-step pulse electrodeposition process at different duty cycles. The influences of the duty cycles on the structure, hardness, corrosion and wear properties of the coatings were investigated. The nanocomposite coatings are compact, uniform, and exhibit nodular or cauliflower-like morphologies, which were decorated with YSZ aggregations. The surface contains smooth area of Ni-B matrix, nodular grains and agglomerated area of particles. Ni-B/YSZ nanocomposite exhibits a crystalline structure with the only preferred orientation of the Ni (111) texture. The presence of YSZ particles in the Ni-B matrix facilitates the increase in hardness, corrosion and wear resistance, as well as the grain refinement. The coating exhibits a nanocrystalline structure with 10 nm in crystallite size. The duty cycle affects the structure (morphology, roughness, nodule size, crystallite size), the composition (YSZ particles content) and the properties (hardness, corrosion and wear resistance) of the Ni-B/YSZ nanocomposite coating. The
The roughness of the coating is in range of 31–51 nm ($S_a$), which is dependent on the different duty cycles. The low duty cycle benefits the improvement in hardness of the composite coating. The high duty cycle (90%) could enlarge the nodule size compared to that of the low duty cycle (30%). A maximum hardness of 823.5 HV was obtained at the duty cycle of 30%. Electrochemical and wear tests illustrated that 30% was the suitable duty cycle for the optimal corrosion and wear properties, hardness and service life of the Ni-B/YSZ nanocomposite coating. The enhanced mechanical, anti-wear and anti-corrosion properties by the inclusion of YSZ nanoparticles in the Ni-B matrix would extend its service life in an aggressive environment such as seawater media.

Conflicts of interests

I would like to declare on behalf of my co-authors that no conflict of interest exists in the submission of this manuscript. There have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (51679076), the Fundamental Research Funds for the Central Universities (2019B15914).

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