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Effect of Pretreatment Process on the Adhesion and Corrosion Resistance of Nickel-Boron Coatings Deposited on 8620H Alloy Steel

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In this work, Ni-B coatings were electrodeposited on the 8620H steel substrates, the substrates were carried out with different pretreatment including without pretreatment, after sandblasting by glass sand and after sandblasting by emery powders. The results of scratch test indicated that the best adhesion strength of Ni-B coatings occurred at the 8620H steel substrates carried out with sandblasting by emery powders, the Ni-B coatings still did not be damaged when the load increase to 50 N. The i_{corr} values of Ni-B coatings deposited on different pretreatment condition such as without pretreatment, after sandblasting by glass sand and after sandblasting by emery powders are approximately at 9.46×10^{-6}, 8.62×10^{-6} and 2.31×10^{-6} A/dm^2, respectively. All the samples carried out with a wear process at a load of 20 N, the i_{corr} values of Ni-B coatings deposited on different conditions 1.96×10^{-5}, 1.54×10^{-5} and 6.72×10^{-6} A/dm^2, respectively. The results show that the Ni-B coatings deposited on the 8620H steel substrates carried out with sandblasting by emery powders has the best adhesion strength and corrosion resistance due to the Ni-B coatings did not be damaged during wear process.

Keywords: Ni-B coatings, adhesion strength, sandblasting

1. INTRODUCTION

8620H alloy steel is a kind of Ni-Cr-Mo alloy steel, it has a high wear resistance due to via a surface carburizing hardening process. 8620H alloy steel has some excellent mechanical properties such as high tensile strength, high percent elongation (EL%) and high toughness [1-3]. Therefore, 8620H steel is suitable for manufacturing parts for engineering such as gears, bearings, power screws, automotive parts, etc. Although 8620H steel has excellent mechanical properties, it still has a poor performance on its corrosion resistance. Unavoidable, the surface treatment technology must to be applied on 8620H steel such as paint, electroplating and electro-less plating.

Recently, Ni-B coatings has been developed as a protection layer on metal substrates due to its good corrosion resistance, high hardness, and high wear resistance [4]. In general, there are two methods to prepare Ni-B coatings including electro-less plating and electroplating [5-8]. The boron source of Ni-B coatings carried out by electro-less plating or electroplating come from dimethylamine borane (DMAB) or trimethylamine borane (TMAB) in the plating solution [9-11]. The former is an autocatalytic redox process, the electrochemical reactions occur without the requirement of an external source of electric current [12], the latter is a typical coating method of metal or alloy thin films that has advantages including low cost, and easy to control deposited rate [13]. However, Ni-B coatings deposited through electro-less plating suffer a slow deposition rates (i.e. only can obtain an ultra-thin films), low bath life, difficult to control the composition of deposition. These shortcomings will limit the application of Ni-B coatings on the wear resistance and corrosion resistance. Conversely, electrodeposition process has some advantages includes; higher deposition rates, low cost, low porosity, high purity, ease of control of alloy composition. Therefore, electroplating process is more suitable for Ni-B coatings to apply in industry. Generally, the corrosion resistance of coatings depends on their physical properties such as the adhesion, hardness and roughness of the substrates. In the electro-less process, previous studies have indicated that it is necessary to use substrates having a high roughness to be able to prepare a coating with less porosity and better corrosion resistance [14-16], but their different roughness of substrates was only carried out with different grade numbers of sandpaper for grinding, and the relationship of adhesion and corrosion resistance between different roughness of substrates was not deeply studied.

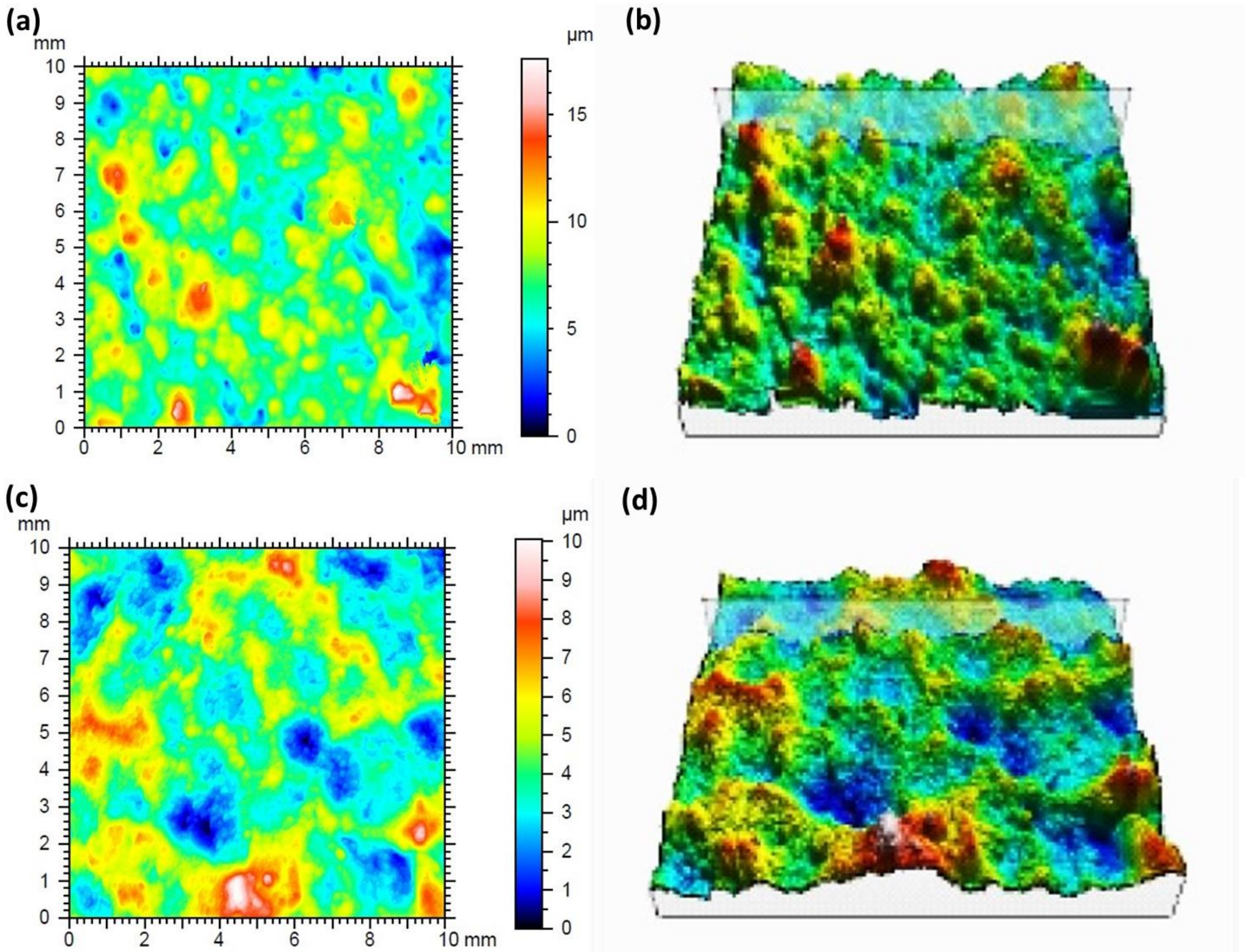
Therefore, in this study, the electroplating process were used to prepare Ni-B coatings that expected to obtain the thickness of Ni-B coatings greater than that of prepared using electro-less process. The effect of different pretreatment process of substrates on the adhesion and corrosion resistance of Ni-B coatings are studied.

2. EXPERIMENTAL

The Ni-B coatings were electrodeposited on 8620H alloy steel substrates with a dimension of 40 × 30 × 2 mm. The 8620H alloy steel substrates are put into ethanol carried out an ultrasonic cleaning process for 10 minutes and then cleaning by DI water, activated by 3 wt.% NaOH solution for 1 min and soaked into a 15 wt. % HCl solution for 30 seconds before electrodeposited process. All the Ni-B deposits were electroplated with a fixed current density at 3 A/dm^2 in an electrolyte containing 320 g/L $Ni(NH_2SO_3)_2$, 10 g/L $NiCl_2•6H_2O$, 40 g/L H_3BO_3, 3 g/L TMAB for 40 min. The above electroplating parameter is the optimal parameters that studied in our previous studies [17,18]. Before electroplating process, the 8620H alloy steel substrates were carried out different pretreatment process such as sandblasting by glass sand and emery powders, respectively. The roughness of substrates were measured using a 3D surface profilometer (Chroma 7503, Taiwan), each sample was measured three times.

The morphology of the Ni–B coatings were analyzed using scanning electron microscopy (JEOL JSM-IT100, Japan). The potentiodynamic polarization of Ni-B coatings were measured by a standard three-electrode cell system carried out with an Autolab-PGSTAT30 potentiostat/galvanostat controlled by a GPES (General Purpose Electrochemical system) software and stabilized at open circuit potential (OCP) before test. The potentiodynamic polarization experiments were conducted in 3.5% NaCl solution at room temperature. The potential was ramped from −0.4 V and 0.6 V with a scanning rate of 0.45 mV s^{-1}. Before the measurement, the samples were degreased and rinsed with DI water. The adhesion property of Ni-B coatings electroplated on 8620H alloy steel substrates were measured by a scratch tester (Micro Scratch Tester (MST^3), Aton Paar GmbH, Germany). The load was from 0 N to 50 N, and the load was gradually applied to the Ni-B coatings to measure the critical load that the Ni-B coating could withstand before it was peeled off from the substrate.

3. RESULTS AND DISCUSSION



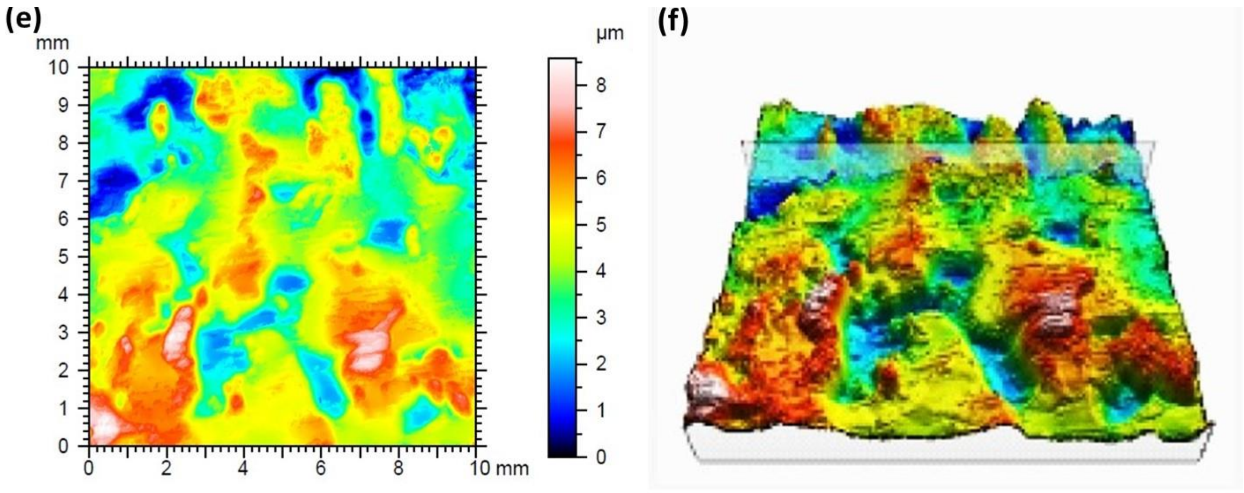


Figure 1. The surface profiles of the 2D top view and 3D profiles of 8620H alloy steel substrates with different pretreatment process: (a) without pretreatment, (b) after sandblasting by glass sand, (c) after sandblasting by emery powders.

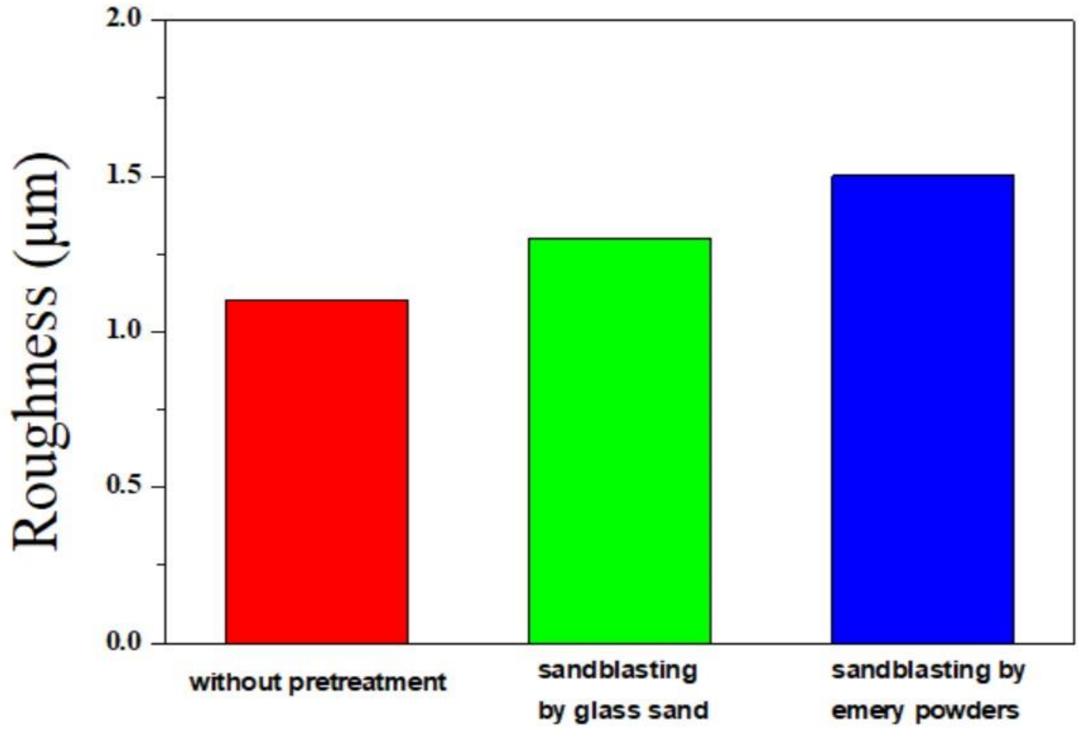


Figure 2. The surface roughness of 8620H steel substrates carried out with different pretreatment process: without pretreatment, after sandblasting by glass sand and after sandblasting by emery powders.

Fig. 1 shows the surface profiles of the 2D top view and 3D profiles of 8620H alloy steel substrates with different pretreatment process. The surface morphology of substrates without pretreatment has smaller surface undulation (Fig. 1(a)(b)), the substrates after sandblasting by emery powders has obviously valleys and peaks (Fig. 1(e)(f)), the ups and downs of surface of the substrates sandblasting by glass sand is between the samples without pretreatment and sandblasting by emery powders (Fig. 1(c)(d)). The average roughness of the substrates carried out different pretreatment process is shown in Fig. 2. The roughness of substrates without pretreatment is approximately at 1.1 µm, after sandblasting by glass sand is approximately at 1.3 µm, and after sandblasting by emery powders is approximately at 1.5 µm. The result presents that the 8620H alloy steel substrates has the greatest roughness after sandblasting by emery powders. The previous studies indicated that the adhesion of coatings would be improved in a high roughness condition [14-16], and we expect that the 8620H steel substrates carried out with a pretreatment process via sandblasting by emery will enhance the adhesion of Ni-B coatings.

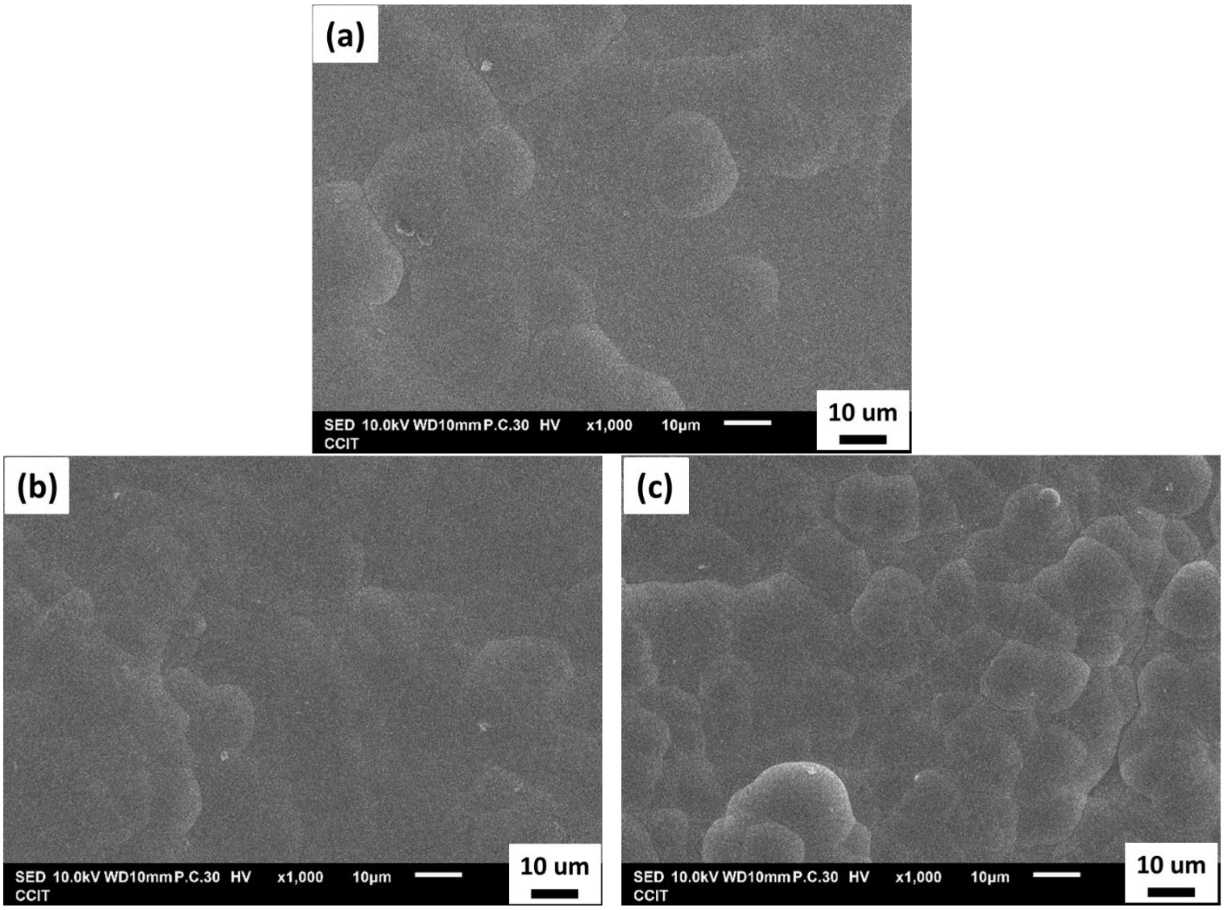


Figure 3. SEM morphologies of Ni-B coatings deposited on 8620H steel substrates carried out with different pretreatment process: (a) without pretreatment, (b) after sandblasting by glass sand, (c) after sandblasting by emery powders.

Fig. 3 presents the surface morphology of Ni-B coatings electrodeposited on the 8620H steel substrates carried out different pretreatment processes. A typical nodule structure presented on the surface of Ni-B coatings, the amount of nodule structure increase with the increase of roughness of 8620H steel substrates. The size of nodules present on the surface appears smaller when the roughness is higher, and this result is agree with the study of Vitry et al. [14]. It can also be attributed to the nucleation of the nickel nodules on the substrate is easier when the substrate is rougher. The higher density of nodules on the rougher substrate is also agree with the study of Liu and Gao [19]. Fig. 4 shows the cross-sectional images of Ni-B coatings electrodeposited on the 8620H steel substrates carried out different pretreatment processes. Fig. 4(a) presents the thickness of Ni-B thin films deposited on

8620H steel substrates without pretreatment process is approximately at 12.9 μm, the coatings is deposited on a smooth surface of substrates, the SEM image shows the Ni-B coatings seem to have a good adhesion with 8620H steel. The thickness of Ni-B thin films deposited on 8620H steel substrates after sandblasting by glass sand is approximately at 11.2 μm, the coatings is also deposited on a smooth surface of substrates and has good adhesion with 8620H steel (Fig. 4(b)). The above samples (substrates without pretreatment and carried out with sandblasting by glass sand) show a less obvious nodular structure on the surface morphology can be attributed to a lower surface roughness of 8620H steel substrates (see Fig. 3(a)(b)). Fig. 4(c) presents the cross-sectional image of Ni-B coatings deposited on 8620H steel substrates after sandblasting by emery powders, the thickness is approximately at 12-16 μm. Apparent valleys and peaks appear on the surface of the substrate and some residual emery particles embedded into 8620H steel, this condition may cause an obvious nodular structure on the surface morphology (Fig. 3(c)).

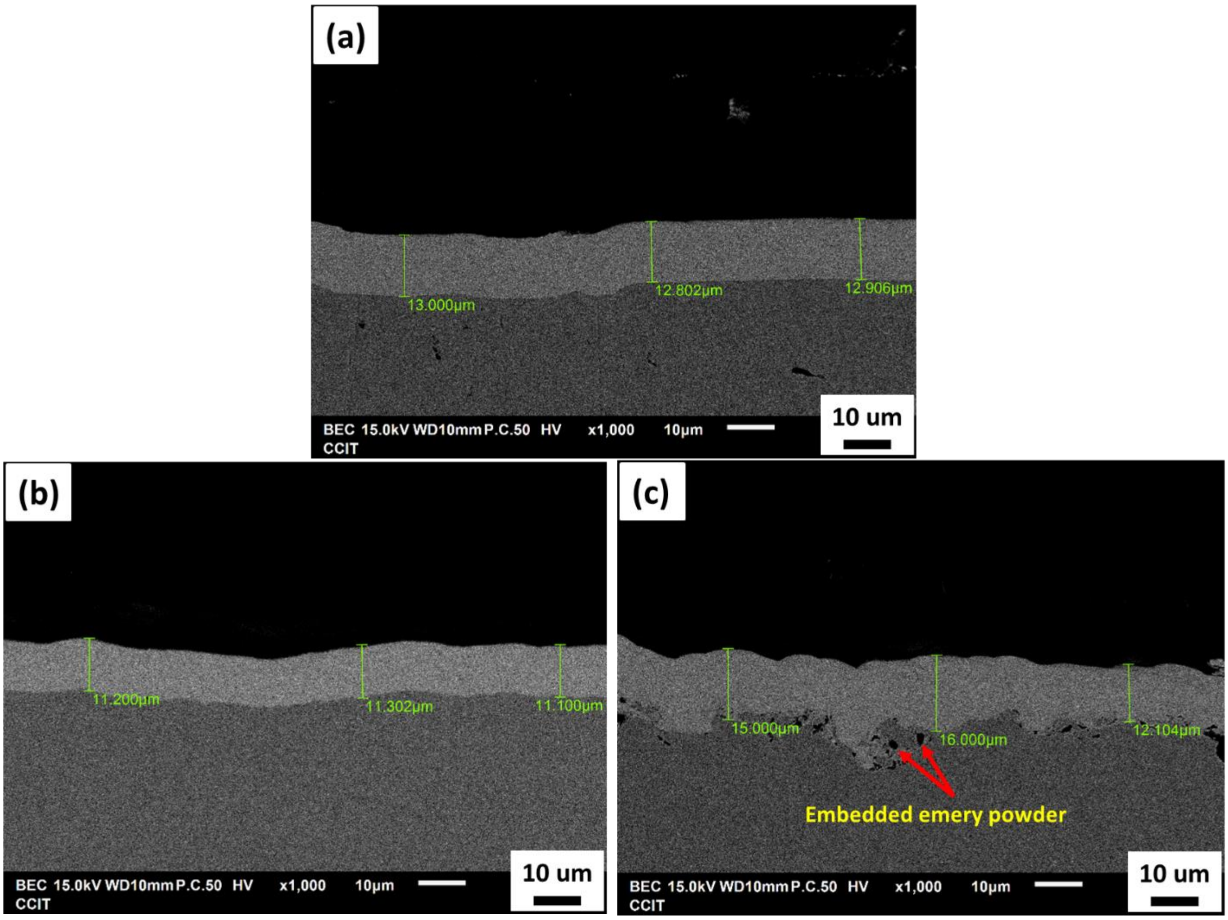


Figure 4. The SEM cross-sectional images of Ni-B coatings deposited on 8620H steel substrates carried out with different pretreatment process: (a) without pretreatment, (b) after sandblasting by glass sand, (c) after sandblasting by emery powders.

The adhesion of Ni-B coatings were estimated by scratch test. In the scratch test, the indenter is used to yield a scratch on the coatings surface, a continuously increasing load from 0 N to 50 N was applied on coatings in this study. The coatings will be damaged under a critical load, thus the adhesion of coatings can be analyzed [20]. Fig. 5 shows the scratched surface of Ni-B coatings electrodeposited on 8620H steel substrates carried out with different pretreatment process. The red arrow presented in Fig. 5(a) and Fig.5(b) shows the critical load before damage features of Ni-B coatings in the substrates without pretreatment and after sandblasting by glass sand. The Ni-B coatings deposited on the substrates after sandblasting by emery powders did not find damage features till the load increase to 50 N (see Fig. 5(c)). The calculated critical load of Ni-B coatings deposited on substrates carried out with different pretreatment process are shown in Fig. 6. The Ni-B coatings deposited on substrates without pretreatment was damaged at 26 N, the coatings deposited on substrates after sandblasting by glass sand was damaged at 22 N, the coatings deposited on substrates after sandblasting by emery powders was not damaged. The results of scratch test present that the Ni-B coatings deposited on the substrates after sandblasting by emery powders has the best adhesion. Lin et al. [21] study the effect of surface roughness of substrate on adhesion of Ti/TiN/Zr/ZrN multilayer coatings and indicated that when the thickness of thin films less than 2 μm, the critical load of multilayer increase with the decrease of surface roughness of steel substrates due to the thin films need a smooth surface of substrates. Conversely, in thick films, Hagen et al. [22] indicated that the adhesion strength of coatings increase with the surface roughness of substrates from 57 μm to 252 μm. Therefore, in this study, the thickness of Ni-B coatings are greater than 11 μm, the higher adhesion force of Ni-B coatings need be provided by high surface roughness of substrates and the result is agree with the study of Hagen et al. Gu et al. [15] also indicated that electro-less nickel coatings deposited on blasted substrate is thicker and more uniform than that on the polished one, it can be attributed to the electro-less nickel plating on a rougher substrate is more compact and defect-free. The same results also present in this study.

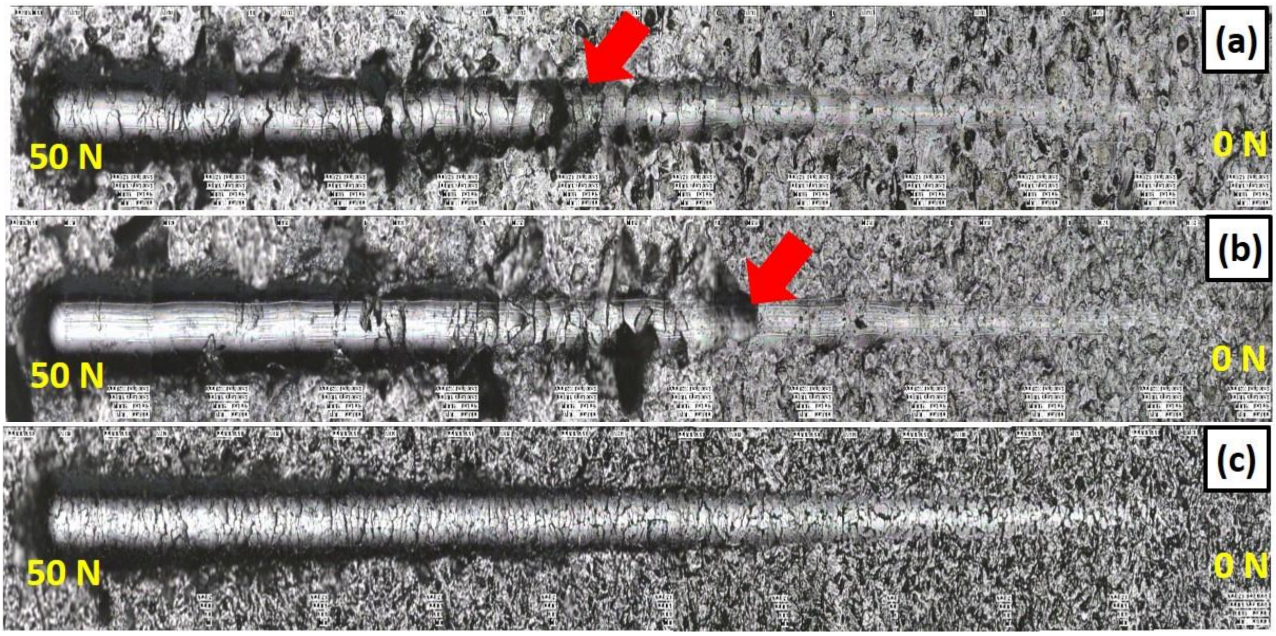


Figure 5. The scratch test images of Ni-B coatings deposited on 8620H steel substrates carried out with different pretreatment process: (a) without pretreatment, (b) after sandblasting by glass sand, (c) after sandblasting by emery powders.

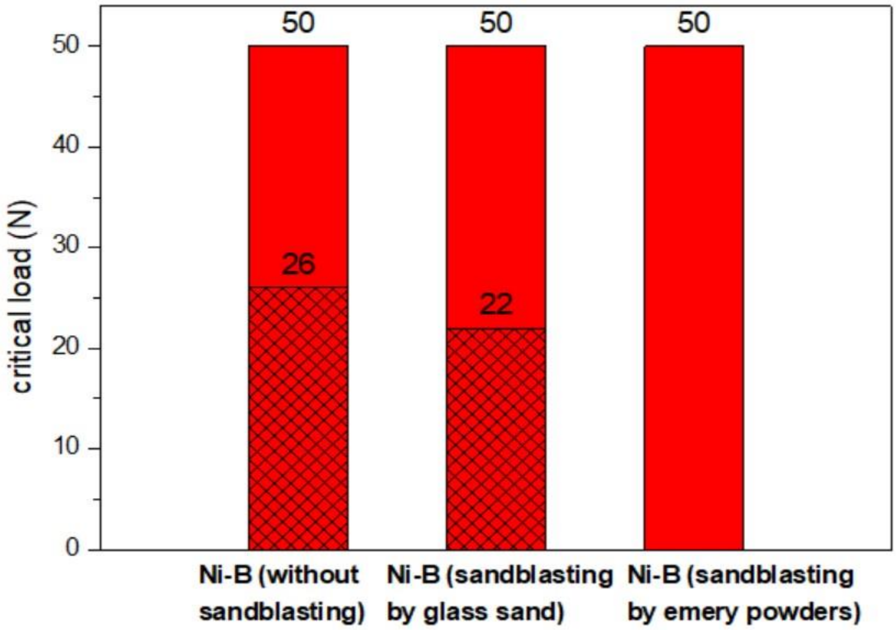


Figure 6. The analysis of critical load of Ni-B coatings deposited on 8620H steel substrates carried out with different pretreatment process: without pretreatment, after sandblasting by glass sand after sandblasting by emery powders.

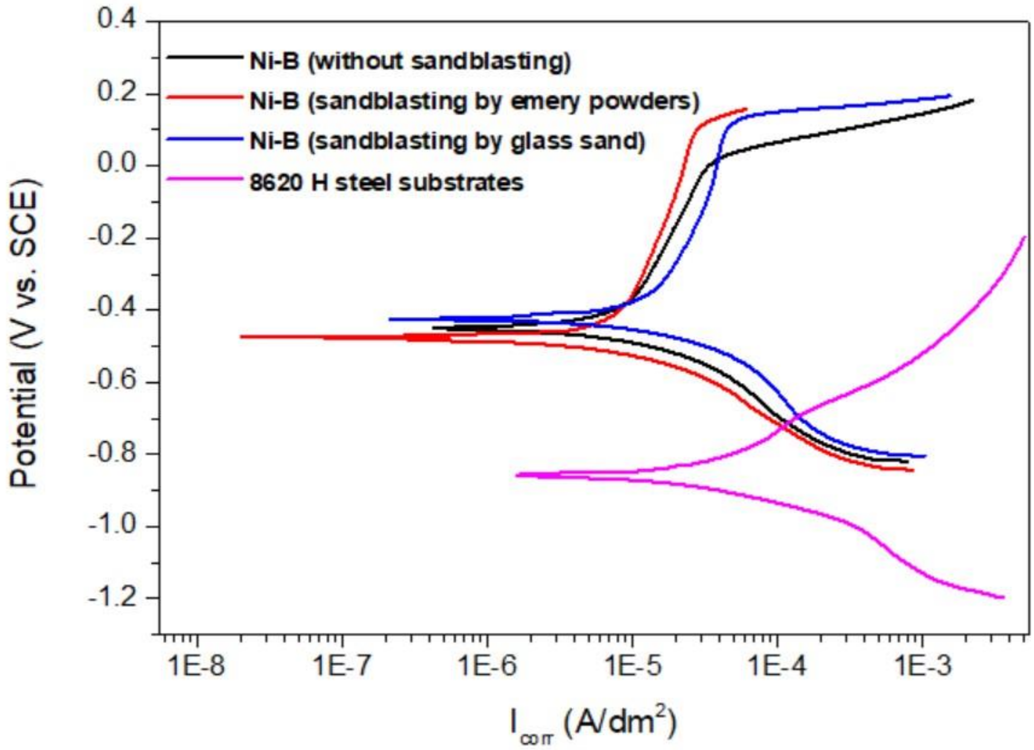


Figure 7. Polarization curves of Ni-B coatings deposited on 8620H steel substrates carried out with different pretreatment process including without sandblasting, sandblasting by emery powders and sandblasting by glass sand.

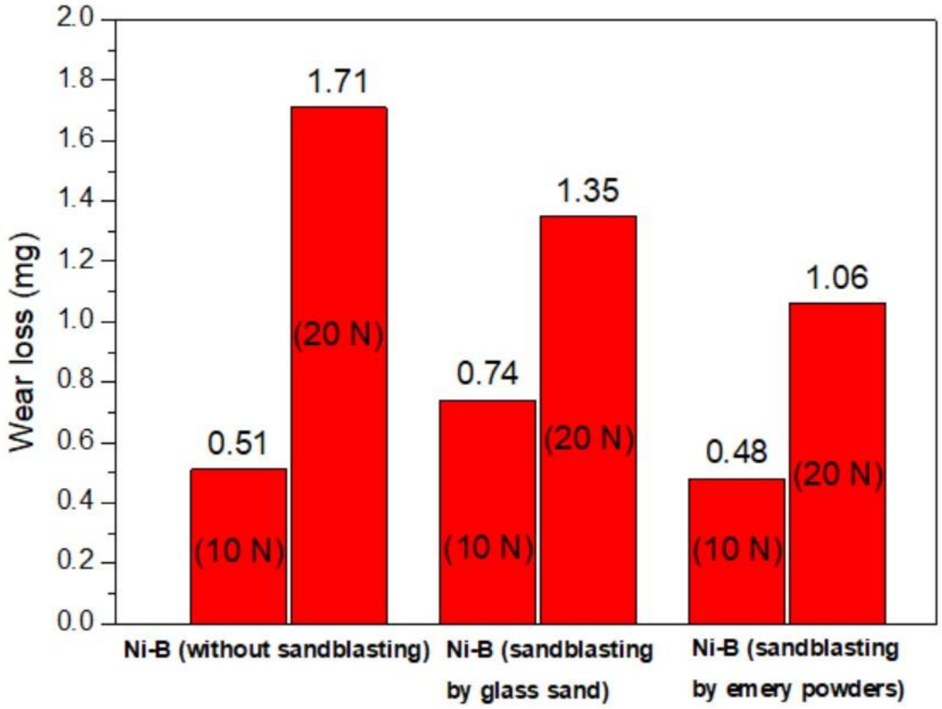
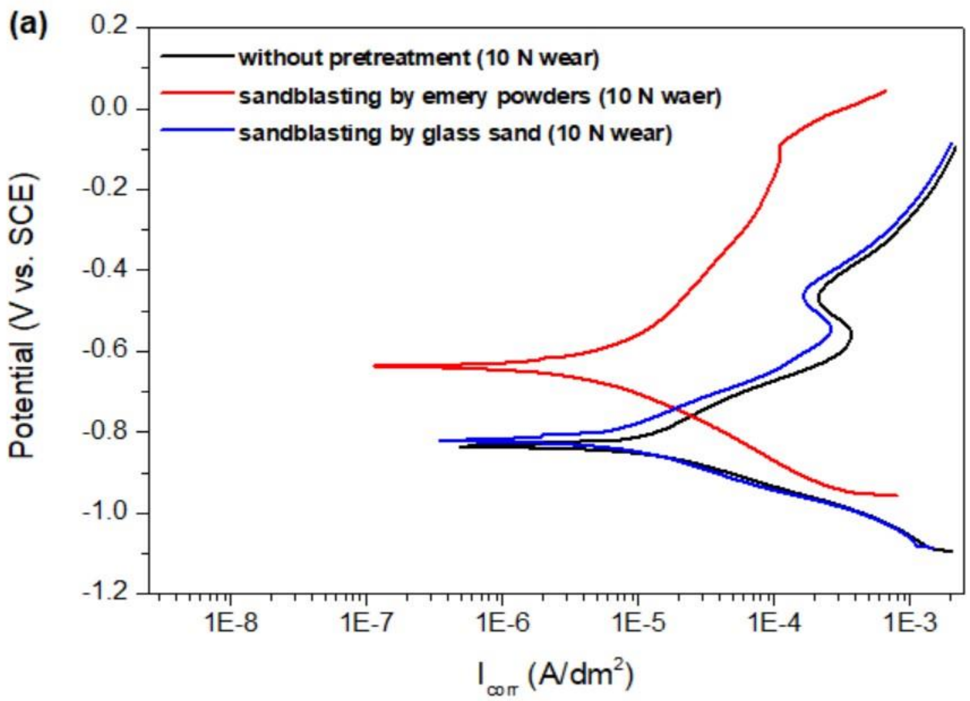


Figure 8. The wear loss of the Ni-B coatings deposited on 8620H steel substrates with different pretreatment process (without pretreatment, after sandblasting by glass sand, after sandblasting by emery powders) and carried out with a wear process under the load at 10 N and 20 N.

Fig. 7 presents potentiodynamic polarization curves of Ni-B coatings electrodeposited on the 8620H steel substrates carried out with different pretreatment such as without pretreatment, after sandblasting by glass sand and after sandblasting by emery powders.



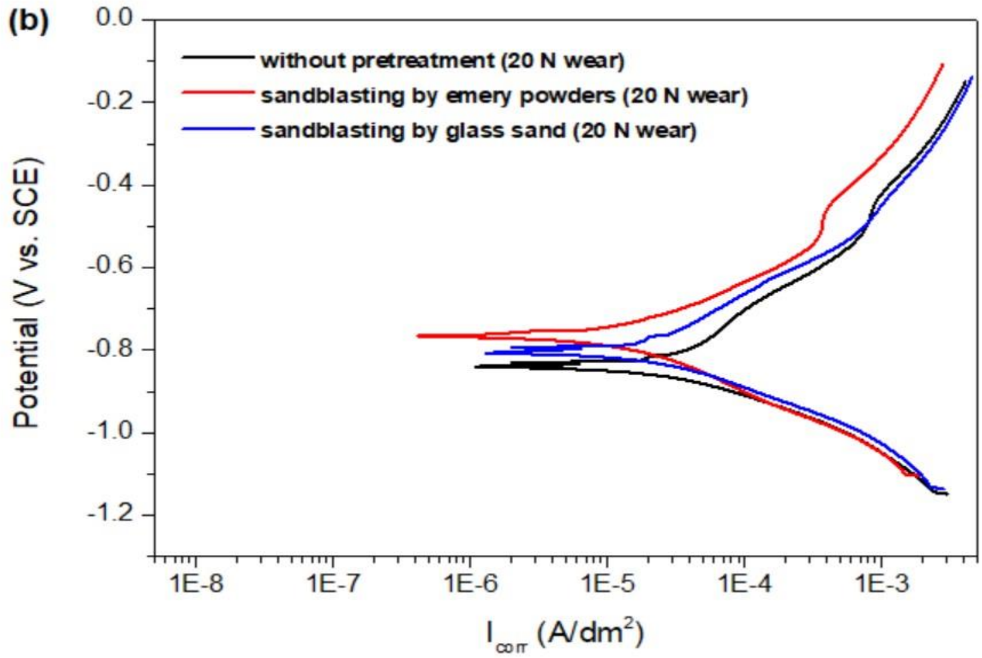


Figure 9. Polarization curves of the Ni-B coatings deposited on 8620H steel substrates with different pretreatment process (without pretreatment, after sandblasting by glass sand, after sandblasting by emery powders) and carried out a wear process with different load: (a) 10 N, (b) 20 N.

The i_{corr} value of 8620H steel is approximately at 2.86×10^{-5} A/dm^2. The i_{corr} values of Ni-B coatings deposited on 8620H steel substrates carried out with different pretreatment are approximately at 9.46×10^{-6}, 8.62×10^{-6} and 2.31×10^{-6} A/dm^2, respectively (shown in Table 1). The Ni-B coatings deposited on 8620H steel substrates has the best corrosion resistance. The above results indicated Ni-B coatings has a better corrosion resistance and can protect substrates from a corrosion environment.

If the workpieces are applied in a condition that is in a sliding and corrosive environment, the adhesion of the coating on the substrates become very important. The Ni-B deposited on substrates after sandblasting by emery powders has the best adhesion can be attributed to the rougher surface of substrates provides better adhesion of the coatings (see fig.4(c)). In order to study the corrosion resistance of Ni-B coatings after a wear process, the Ni-B coatings were worn using a wear tester. The load of wear tester were set up at 10 N and 20 N (near critical load of Ni-B coatings), respectively. The wear loss of Ni-B coatings with different treatment worn under a load at 10 N is 0.51, 0.74 and 0.48 mg, respectively (see Fig.8). The smallest wear loss (0.48 mg) occurred at the Ni-B coatings deposited on the 8620H steel substrates after sandblasting by emery powders. When the load of wear tester increases to 20 N, the wear loss of Ni-B coatings with different treatment is 1.71, 1.35 and 1.06 mg, respectively (see Fig.8). The smallest wear loss (1.06 mg) still occurred at the 8620H steel substrates after sandblasting by emery powders. The results also show that the Ni-B coatings deposited on 8620H steel substrates after sandblasting by emery powders has the best adhesion strength, and this agree with the results of scratch test.

Table 1. Corrosion resistance of Ni-B coatings analyzed from 3.5 wt.% NaCl solution: 8620H steel substrates, Ni-B coatings deposited on the substrates with various pretreatment process, Ni-B coatings deposited on the substrates with various pretreatment process and carried out with different load wear test.

Sample code	I_{corr} (A/dm^2)	E_{corr} (V vs. SEC)
8620H steel substrates	2.86×10^{-5}	-0.872
substrates without pretreatment	4.10×10^{-6}	-0.443
substrates after sandblasting by glass sand	5.42×10^{-6}	-0.425
substrates after sandblasting by emery powders	2.11×10^{-6}	-0.472
substrates without pretreatment (10 N wear)	8.61×10^{-6}	-0.832
substrates after sandblasting by glass sand (10 N wear)	5.42×10^{-6}	-0.814
substrates after sandblasting by emery powders (10 N wear)	2.19×10^{-6}	-0.635
substrates without pretreatment (20 N wear)	1.96×10^{-5}	-0.843
substrates after sandblasting by glass sand (20 N wear)	1.54×10^{-5}	-0.813
substrates after sandblasting by emery powders (20 N wear)	6.72×10^{-6}	-0.764

The corrosion resistance of Ni-B coatings carried out using wear tester are shown in Fig. 9. Fig. 9(a) presents the potentiodynamic polarization curves of Ni-B coatings deposited on various conditions and carried out with a wear process at 10 N, the i_{corr} is also shown in Table 1. The i_{corr} of Ni-B deposited on substrates without pretreatment is approximately at 8.61×10^{-6} A/dm^2, Ni-B deposited on substrates after sandblasting by glass sand is approximately at 5.42×10^{-6} A/dm^2, and Ni-B deposited on substrates after sandblasting by emery powders is approximately at 2.19×10^{-6} A/dm^2. All the i_{corr} values of various samples are quite close (the sample of sandblasting by emery powders still has the smallest i_{corr}), this indicated that all the Ni-B coatings are not yet damaged by wearing at 10 N. When the load of wear tester increase to 20 N, the i_{corr} values of various samples has a significantly change, the i_{corr} of the samples of without pretreatment and sandblasting by glass sand reduced to 1.96×10^{-5} and 1.54×10^{-5} A/dm^2, respectively (see Fig. 9(b) and Table 1). The decrease of i_{corr} indicated that the Ni-B coatings deposited on the substrates without pretreatment and sandblasting by glass sand were damaged by wearing at 20 N. The i_{corr} of the samples of sandblasting by emery powders still maintain at 6.72×10^{-6} A/dm^2, indicating the Ni-B coatings is not yet damaged by wearing at 20 N.

4. CONCLUSIONS

The effects of pretreatment process such as without pretreatment, after sandblasting by glass sand and after sandblasting by emery powders on the adhesion strength and corrosion resistance of Ni-B coatings deposited on 8620H steel substrates were investigated. The best adhesion strength of Ni-B coatings occurred at the 8620H steel substrates were carried out with sandblasting by emery powders, the Ni-B coatings did not be damaged in the applied load from 0 N to 50 N during scratch test. The i_{corr} values of Ni-B coatings deposited on different pretreatment condition such as without pretreatment, after sandblasting by glass sand and after sandblasting by emery powders are approximately at 9.46×10^{-6}, 8.62×10^{-6} and 2.31×10^{-6} A/dm^2, respectively. After a wear process (load equal to 20 N), the i_{corr} values of Ni-B coatings deposited on different pretreatment condition become 1.96×10^{-5}, 1.54×10^{-5} and 6.72×10^{-6} A/dm^2, respectively. Both of Ni-B coatings deposited on substrates carried out with without pretreatment and sandblasting by glass sand has a significantly decrease on their corrosion resistance. The i_{corr} value of Ni-B coatings deposited on substrates carried out with sandblasting by emery powders only has a slightly change due to the Ni-B coatings did not be damaged during wear process.

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