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EFFECT OF ELECTROLESS Ni-Co-P AND Co-P COATINGS ON CAVITATION EROSION RESISTANCE

S. A. Karrab
Faculty of Engineering Misurata University- Libya
E-mail :sgarrab2005@yahoo.co.uk

Mohammed S. Aboraia
Mining and Metallurgical Engineering Department, Assiut University, Assiut71516, Egypt
E-mail: maboraia@hotmail.com

M. A. Doheim
Mining and Metallurgical Engineering Department, Assiut University, Assiut71516, Egypt
E-mail: mohdoheim@yahoo.com

S.M. Ahmed
Mechanical Engineering Department, Majmaah University, Saudi Arabia
E-mail: shemy2007@yahoo.com

Abstract

In the present work, electroless Ni-Co-P and Co-P coatings were produced on AISI 1045 steel with and without post-heat treatment. The properties of electroless coatings were characterized using an optical microscope, and microhardness tester. The cavitation erosion resistance of coatings was evaluated using a vibratory cavitation test. The test was carried out both in tap water and 3 wt.% NaCl solution, respectively.

The electroless deposition characterized with low thickness films and it was higher for Ni-Co-P than for Co-P. The morphology of Ni–P and Co-P deposits were also dissimilar. Maximum hardness of heat treated samples was found to depend on the solution composition and occurs at temperature 400°C. The highest erosion resistance was observed in coatings after heat treatment at temperature of 650 °C, when measured in both tap water and 3 wt. % NaCl solution. However, the Co-P coatings specimens could not resist cavitation erosion in 3 wt.% NaCl solution. The results showed also that the cavitation erosion resistance is independent on surface hardness.

Keywords: Electroless Ni-Co-P and Co-P coatings; Heat treatment; cavitation erosion

1. Introduction

With the increase in the speed of hydraulic machines, cavitation erosion has become a serious threat to the components of those machines, which leads to loss of performance and reliability for those machines. The problem becomes more ferocity and may even lead to premature failure of those machines if they were operating in a hostile electrolyte. In such cases, hydraulic machinery faces the combined effect of corrosion and cavitation erosion. Therefore, the designers are trying to reduce and eliminate these grave effects by increasing the resistance of wet surfaces for those machines. The electroless deposition technique is a low-cost and low temperature method suitable for producing a protective coating with good wear or corrosion properties of normal engineering materials such as carbon steels.

Among the various types of electrolessly deposited metals, electroless nickel has gained immense popularity due to its ability to provide a hard, wear-resistant and corrosion-resistant surface [1-7]. Subsequent heat treatment is an important factor that the wear resistance of the coatings can be improved considerably, which can be attributed to eliminate any hydrogen embrittlement and precipitate hard inter-metallic Ni_3P compound [7, 8-10]. From previous studies by the authors [7], it was found that the maximum hardness of heat treated samples was found to depend on the solution composition and occurs at temperature 300 °C or 400°C. The highest cavitation erosion resistance of the coatings was observed for the heat treated deposits at a temperature of 650 °C.

Electroless cobalt is less common than nickel, in spite of the similarity in the physical-chemical properties. The practical applications of the cobalt coatings utilize mainly their magnetic properties [11,12]. Due to the contamination of the environment with Cr (IV) salts during the last years, intensive investigations are carried out to replace the solid chromium coatings by nickel- or cobalt-based nanometer thickness composite coatings, deposited electroless or electrochemically [13,14].

In the present study Co-P and Ni-Co-P deposits were produced by using hypophosphite based baths. The effect of heat treatment on the hardness and the cavitation erosion resistance of the deposits has been investigated.

2. Experimental procedures

2.1. Coating deposition

In this investigation, AISI 1045 carbon steel cylindrical bar of 16 mm in diameter was used as substrate. The steel composition (wt.%) was as follows[15]: C% 0.42-0.48, Si% 0.15- 0.35, Mn% 0.3-0.9, P% 0.03 max, S% 0.035 max, and Fe. The samples were cut as flat-surfaced discs of 14mm in diameter and 10mm height. The samples were polished with SiC emery papers (from grades #80 to #1000). The preparing treatment of the substrates and plating procedures were as follows:

1- Rinsing by immersion in distilled water (DW) at room temperature (RT) for 3 min.
2- Ultrasonically degreased in acetone for 5 minutes
3- Rinsing by immersion in DW at RT for 3 min
4- Alkaline cleaning in 40 % NaOH for 30 Sec.
5- Rinsing by immersion in DW at RT for 3 min.
6- Acid pickling in 10% HCL (MW= 36-46) for 60 Sec.
7- Rinsing by immersion in DW at RT for 3 min.
8- By using inert metallic wire the samples were hanged in the plating solutions when its temperature reaches 70 °C. Solution stirring is carried out by a magnetic stirrer with 110 RPM. After plating completed (after 60min) the samples are immediately washed thoroughly with distilled water.

The binary Co-P alloys and ternary Ni–Co–P alloys were electrolessly deposited by using a sulfate bath. The detail of chemical composition of the electroless plating baths of coatings and their operating conditions for binary and ternary deposited alloys are given in Tables 1and 2, respectively.

Table 1. Electroless Cobalt Phosphorus plating

Chemical Name	Formula	Function	Amount
Nickel chloride	NiC12- 6H2O	Nickel source	10 g/L
Cobalt Chloride	CoCl	Cobalt source	30 g/L
Sodium hypophosphite	NaH2PO2	Reducing Agent	20 g/L
Ammonium chloride	NH4C1	Adjusting pH	50 g/L
Sodium citrate	Na3C6H5O7 - 2H2O	Complexing agent	85
Temp	80-90 Deg C		
PH	9		

Table 2. Electroless Nickel-Cobalt-Phosphorus plating

Chemical Name	Formula	Function	Amount
Cobalt chloride	CoC12- 6H2O	Cobalt source	30 g/L
Sodium hypophosphite	NaH2PO2	Reducing agent	20 g/L
Ammonium chloride	NH4C1	Adjusting pH	50 g/L
Sodium citrate	Na3C6H5O7 - 2H2O	Complexing agent	80
Temp	80-90 Deg C		
PH	8-9		

Coated samples were thermally treated in a tube furnace under nitrogen atmosphere. The coatings were isothermally heat treated at different temperatures of 300, 400, 650 °C for 1 h, then the samples were allowed to cool down in the furnace.

The surface morphologies and elemental compositions of the coatings were characterized by optical microscope and X-ray energy dispersive spectrometer. The hardness of coatings and substrate was measured using an (Adolph I, Buehler, Inc) Vickers diamond indenter at a load of 100 g for a loading time of 20 s. The average of five repeated measurements is reported.

2.2 cavitation erosion test

The cavitation erosion tests were carried out using vibratory with the stationary specimen as shown in Fig. 1. The horn-tip induced cavitation vibrates at 19.5 ± 0.5 kHz and amplitude of 50 µm. The specimen was placed co-axially with the horn-tip and was held stationary at the distance L from the horn tip as shown in Fig.1. The separation distance L between the stationary specimen and the horn tip was initially adjusted using a dial gage and maintained at a value of 0.8 mm, in the present study, to obtain significant value of erosion rate [16].

The cavitation tests were performed in tap water and 3% NaCl solution. The specimen and the end of the stepped horn were immersed in 1200 ml open beaker having 700 ml of test liquid. Since the test liquid temperature markedly affects the degree of erosion [17, 18] the test liquid temperature in the beaker was kept constant at 27 ± 1 °C by circulating cooling water around the beaker as shown in Fig.1. Prior thermocouple measurement tests showed that the temperature of the liquid film on the specimen surface rose rapidly regardless of the constant temperature in the beaker. It was found for 10 min. (Maximum interval test time), that the film temperature did not exceed the controlled temperature of the beaker by more than 2°C.

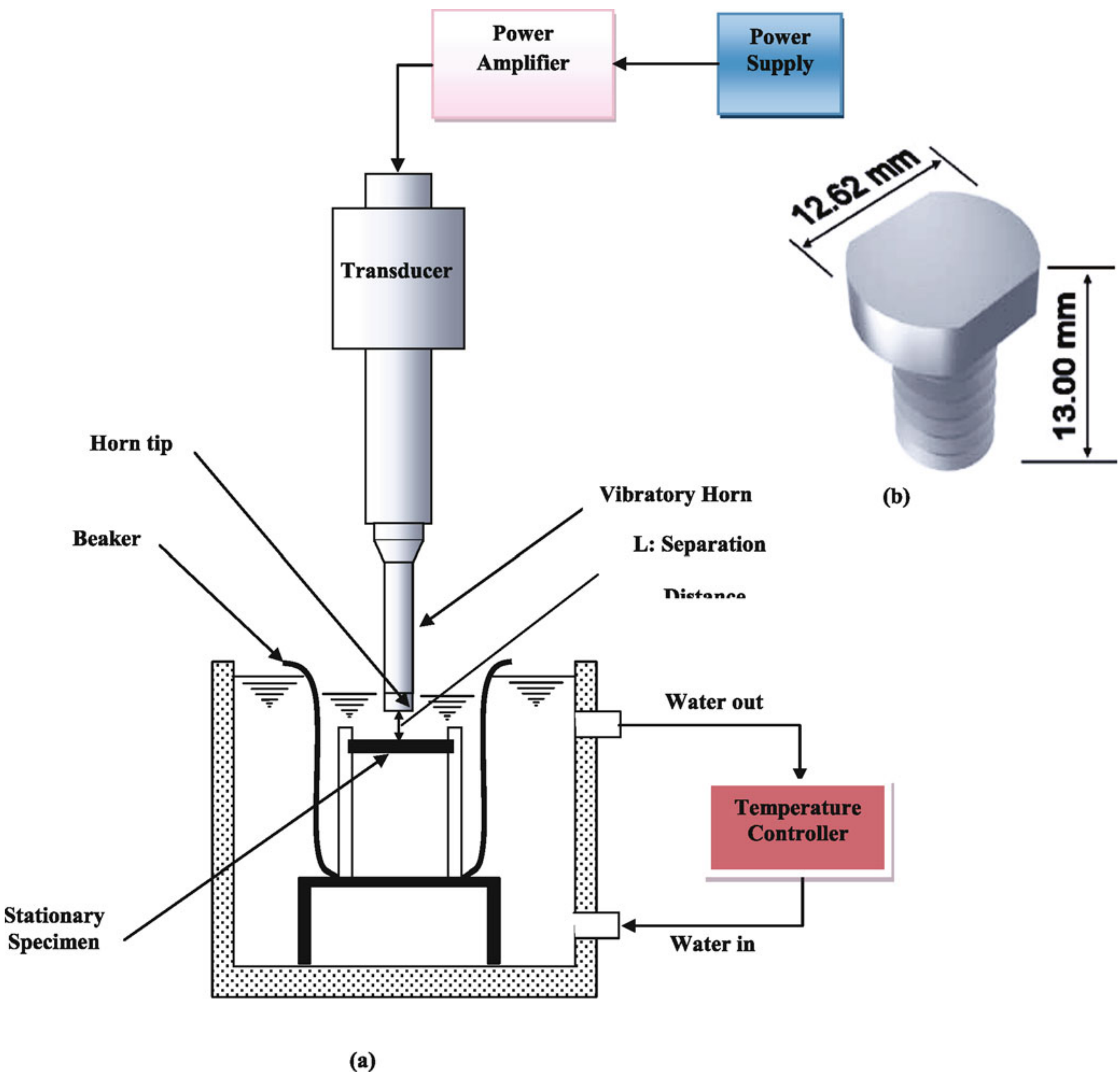

Fig. 1 (a) Schematic view of test apparatus, (b) Horn's disc

3. Results and discussion

3.1 Characterization of coatings

Fig. 2 shows the optical images of the surface morphologies of the Ni–Co–P and Co–P deposits obtained in the most stable alkaline baths. It was observed that Ni–Co–P deposits forming dense and regular nodular structure, while the Co–P deposits characterized with more even, but specifically (“needle-like”) structured and somewhat porous surface (pitting).

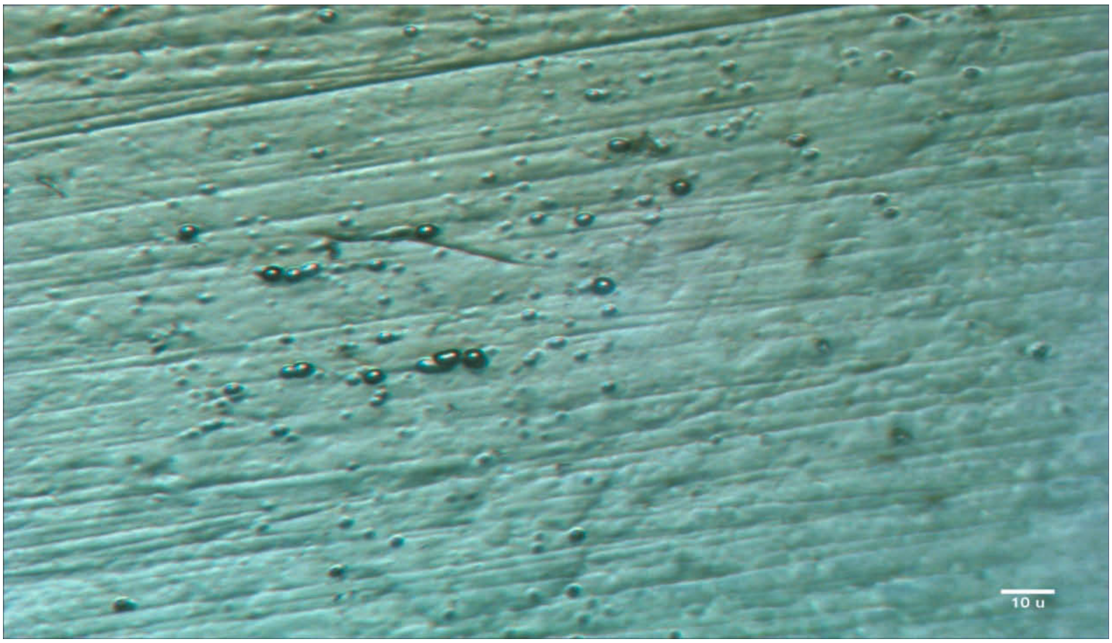

Fig. 2-a. Surface morphology of Co-Ni-P deposit on substrate without heat treatment

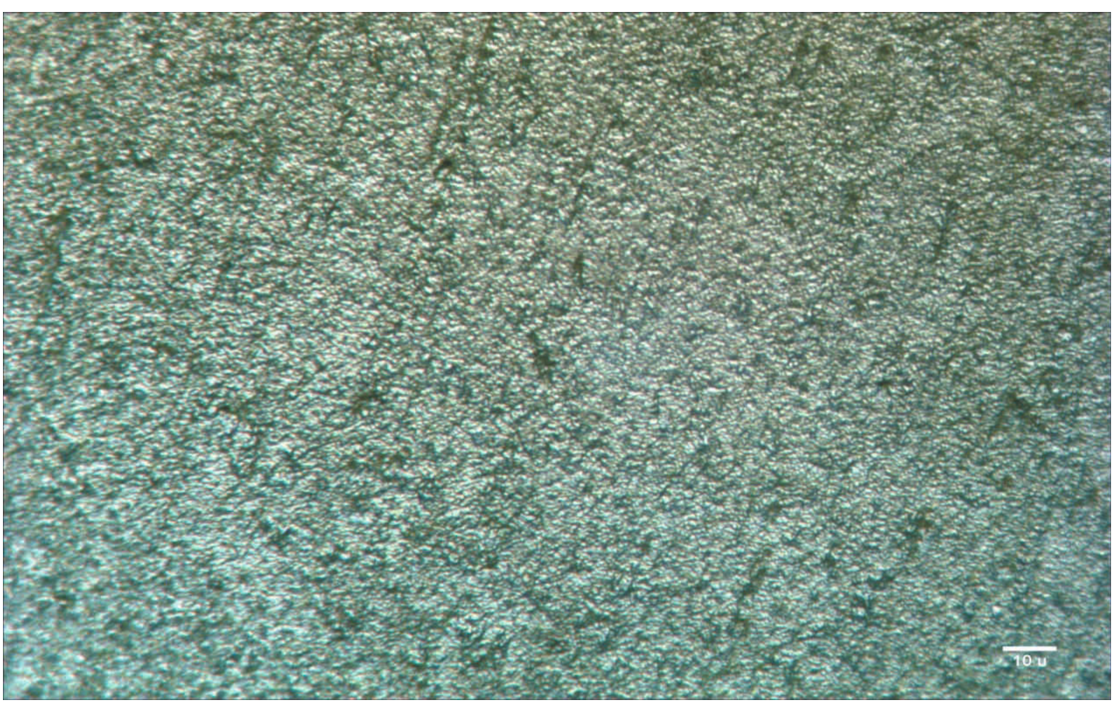

Fig. 2-b. Surface morphology of Co-P deposit on substrate without heat treatment

The deposit thickness of Ni–Co–P and Co–P deposits was determined from optical micrographs of the metallographic cross-sections for the electroless coating at 1h and heat treatment at 400 °C as shown in the Figure 3. The thickness was about 1 and 8 µm for Co–P and Ni–Co–P deposits, respectively. The results indicate that the electroless cobalt deposit thickness is smaller than that for nickel deposits [7]. Matsubara et al.[19] and Kim et al. [20]. Alberts et al.[21] discussed a decrease in deposition rate with the increase in cobalt content in the electroless plating bath. They suggested that Co forms a stable oxide with the dissolved oxygen that reduces effective Co ion concentration in the solution. They also reported that the electroless deposition of Co is diffusion controlled. Probably these two factors reduced the deposition rate of Ni-Co-P.

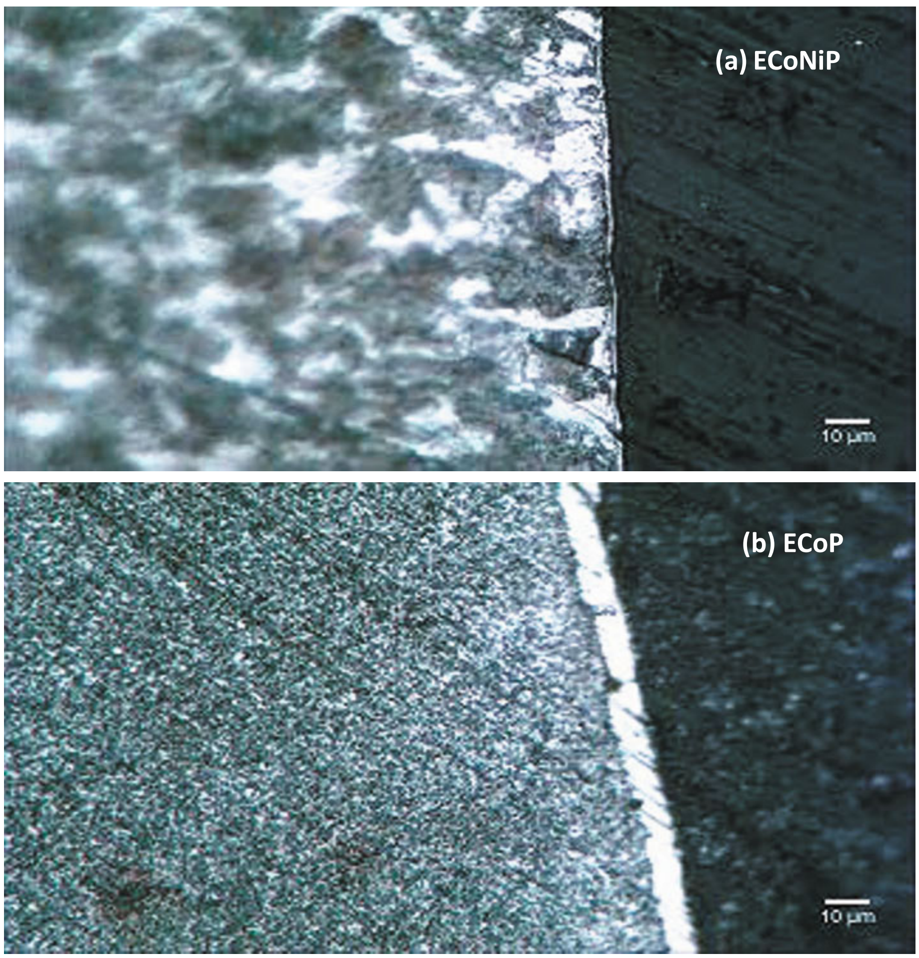

Fig. 3. Cross-sectional micrograph of Co-P and Co-Ni-P deposits

The post heat treatment of coating affects its properties significantly. Mechanical properties of electroless coatings such as hardness and wear resistance are enhanced by heat treatment at different temperatures. Figure 4 shows the results obtained from the microhardness measurements performed on the samples under investigation. As generally observed, due to the thermally induced microstructural changes as reported in literature, heat treatment had a pronounced influence on the hardness value compared with the value corresponding to the as-deposited state. However, this influence differs with the solution and temperature. Results show that the maximum hardness is at 400 °C. As the temperature increases over 400 °C, the hardness drops dramatically. Many researchers reported similar results [e.g.22,23] for Ni deposit. The hardness increase is attributed to the crystallization of nickel and to the precipitation of fine particles of Ni_3P phase. Use of higher heat treatment temperatures and longer times lead to the progressive hardness decrease, which can be attributed to the nickel grain growth and to the phosphides coarsening [24]

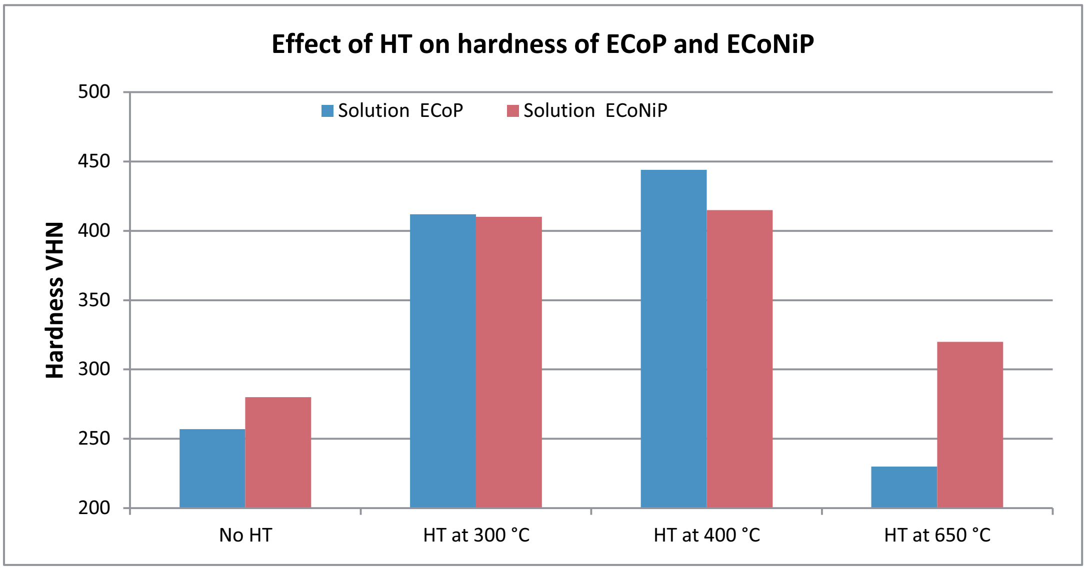

Fig.4. Effects of heat treatment on hardness of Co-Ni-P and Co-P deposits

<u>3.2; Cavitation erosion resistance of deposits</u>

The wear resistance of Co-Ni-P and Co-P deposits and the effect of heat treatment temperature was determined by measuring the cumulative weight loss in tap water and 3% NaCl water. The effectiveness of the coating in combating wear was identified by comparing the coating's resistance to those of the substrate. The cumulative weight loss of deposits and substrate in tap water and 3% NaCl water is shown in Fig. 5 and 6, respectively. Results show that the heat treatment of the coatings with a clear impact on cavitation erosion. In general, the heat treatment of Co-Ni-P and Co-P deposits at a temperature of 650 ° C gives the best erosion resistance for both tap water and 3 wt.% NaCl solution. Except that Co-P coating removed totally after short time (less than 20 minutes) for the test in salt water. This is due to the synergistic effect cavitation erosion and corrosion. These results are consistent with the results of Pearlstein and Weightman [25]. They reported that electroless cobalt deposits tarnish readily when exposed to saline conditions to form a most unpleasant-appearing mottled brown condition.

One of the unique characteristics of electroless deposition after a post-heat treatment is the superior wear resistance of the coatings [24]. The enhancement in the wear resistance is attributed to the achievement maximum hardness after post-heat treatment of coatings. Generally optimal heat treatment regime is 400 °C for 1 hour as it results in maximal hardness of electroless nickel coatings. It is also reported [2] that annealing at temperatures other than 400 °C adversely affects the wear performance of electroless nickel coatings. This may be attributed to the formation of inter-metallic phases that reduces the coating adherence to the substrate. The results, in this work, show that the maximum hardness is obtained 400 °C for Ni-Co-P and Co-P coatings. However, the best erosion resistance enhancement was obtained from post heat treated deposits at a temperature of 650 °C. This is in agreement with that reported in the literature [26] that there is no correlation between cavitation erosion resistance and material property or combined of properties.

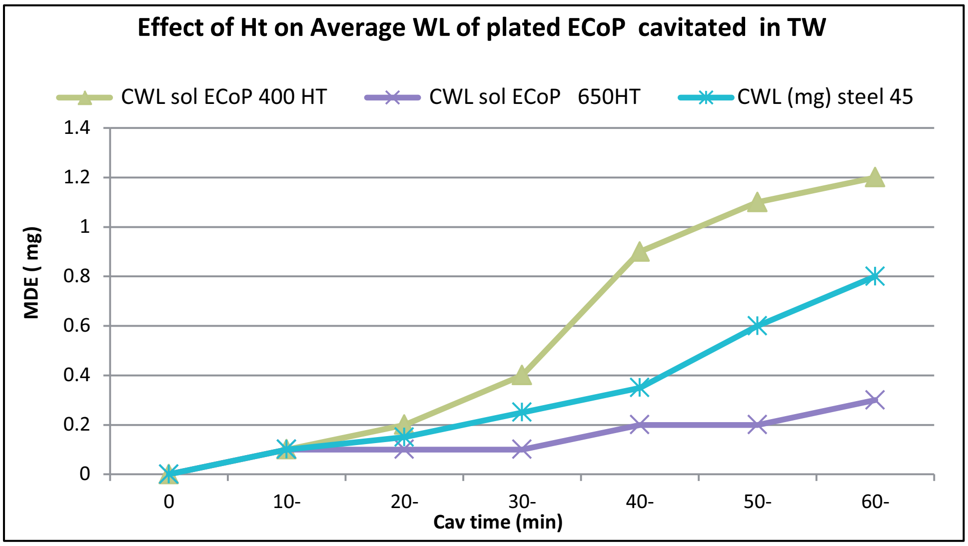

Fig. 5-a. Effect of Heat Treatment on cumulative weight loss in tap water of electroless Co-P plated on steel 45 substrate

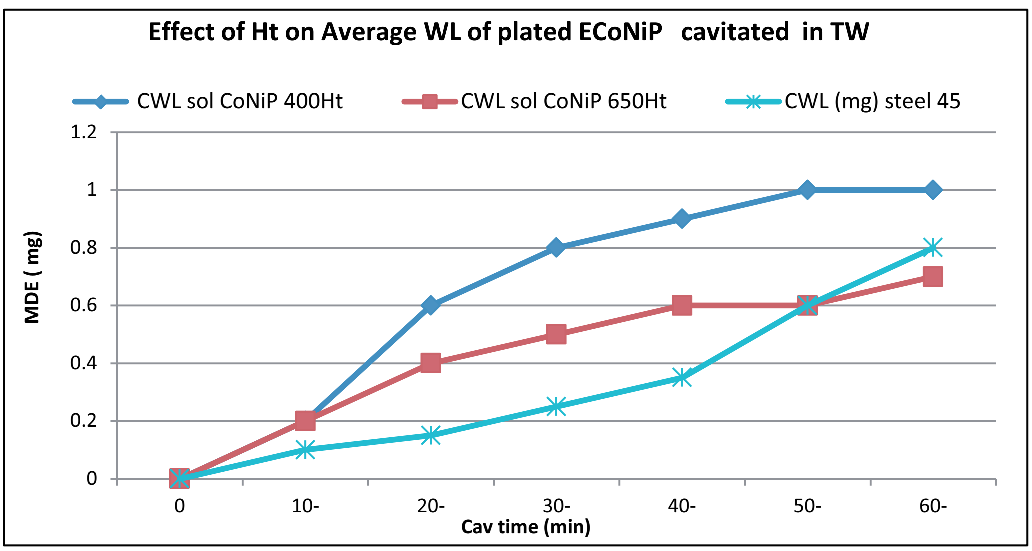

Fig. 5-b. Effect of heat treatment on cumulative weight loss in tap water of electroless Ni- Co-P plated on steel 45 substrate

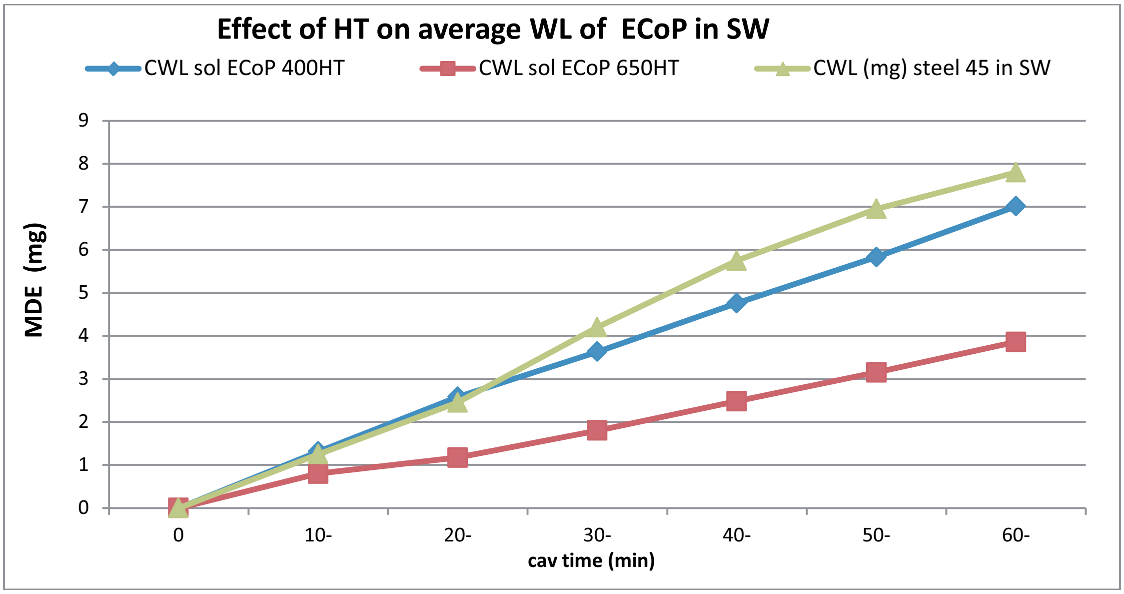

Fig. 6-a. Effect of Heat Treatment on cumulative weight loss in 3 wt.% NaCl solution of electroless Co-P plated on steel substrate

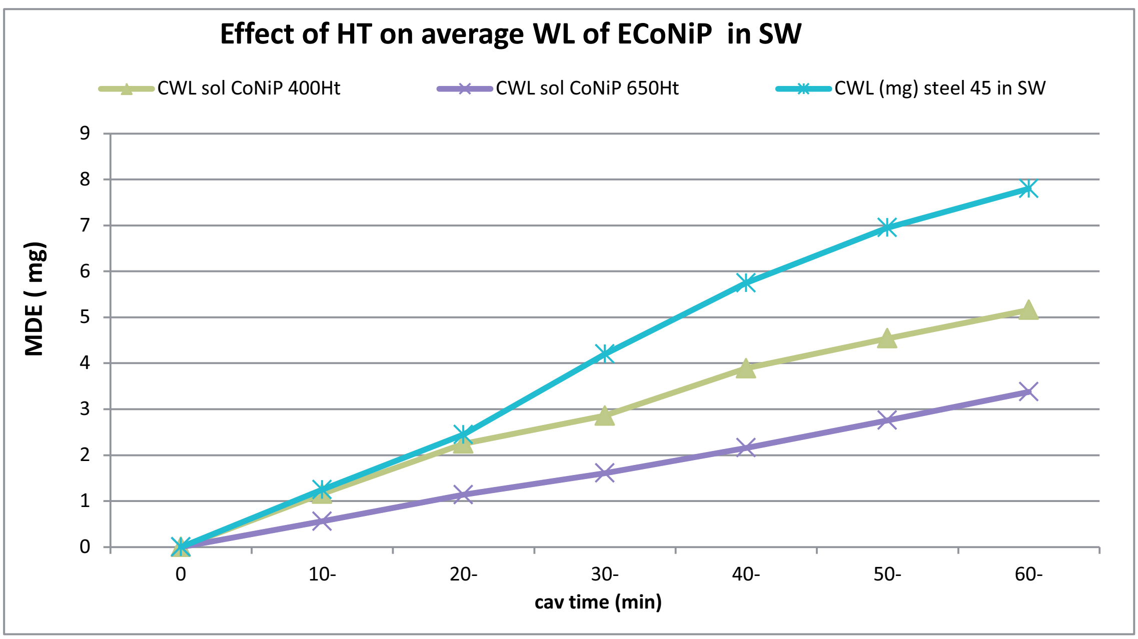

Fig. 6-b Effect of Heat Treatment on cumulative weight loss in 3 wt.% NaCl solution of electroless Ni-Co-P plated on steel 45 substrate

4. Conclusions

The cavitation erosion, microhardness, morphology and thickness of electroless Ni-Co-P and Co-P deposited on AISI 1045 carbon steel at alkaline baths for 1 h are investigated. The conclusions may be summarized as follows;

1. The cavitation erosion resistance depends on coating type, and deposit heat treatment temperature.

2. The erosion resistance does not depend on hardness, which has maximum value after heat treatment at temperature of 400 °C The erosion resistance is the best at heat treatment temperature of 650 °C at which the hardness is the least.

3. It is found that the electroless deposition of Ni-Co-P and Co-P are different in film thickness and in morphology.

4. Co-P coatings are not resistant to cavitation erosion in 3 wt.% NaCl solution

5. References

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