Development of multilayer Ni-Co alloy coatings by pulsedsonoelectrodeposition for better corrosion protection

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Abstract : Ni-Co alloy coatings have been developed in multilayers on copper by periodically pulsating the ultrasound effect, parallel to the process of electrodeposition. Laminar coatings having alternative layers alloys of different composition have been developed by turning the sonicator probe(kept at at 1.2 Wcm^{-2}) ON(t_{ON}) and OFF(t_{OFF})periodically, keeping the current density (c. d.)constant at 4.0 Adm^{-2}. Multilayer Ni-Co alloy coatings have been developed by periodic modulation of the ultrasound effect (at optimal c.d. = 4.0 Adm^{-2}). The deposition conditions, in terms of pulsing period and number of layers have been optimized for the highest performance of coatings against corrosion. The corrosion behaviors of both monolayer and multilayer Ni-Co alloy coatings (deposited for 600 s) have been evaluated by electrochemical methods. Corrosion data revealed that multilayer Ni-Co alloy coatings having 150 layers, represented as (Ni-Co) $_{2/2/150}$ exhibit almost 10 times better corrosion resistance compared to its monolayer counterpart (deposited with no ultrasound pulsing effect). Improved corrosion resistance of multilayer sonoelectrodeposited Ni-Co alloy coatings have been discussed in the light of changed surface morphology, phase structure, composition of alternate layers, and number of layers formed, supported by Scanning electronmicroscopy (SEM), Energy dispersive spectroscopy (EDS) and X-Ray diffraction (XRD) study.

Keywords: Corrosion behavior, Multilayer Ni-Co alloy,Sonoelectrodeposition.

I. INTRODUCTION

A new division of materials having alternate layers of alloys/metal with different composition/ microstructure is called as composition modulated multilayer alloys (CMMA) [1].This class of materials have been extensively used for coating application due to their better corrosion and wear resistance properties [2].These properties can be improved by tuning the current density (c.d.), composition, number of individual layers and so on. There are two methods to produce CMMA coatings. The first method called, dual bath technique in which deposition is carried out by using two separate plating baths on a substrate in an alternate manner. But in another method, called Single bath technique, deposition is done directly from a single bath having mixture of ions by changing the c.d. alternatively [1]. Both techniques have their own advantages and disadvantages. Since chances of contamination of the deposit in SBT is less compared to in DBT, the former is preferred. This change in properties of coatings of metals/alloys can be brought about by bringing modulation in the mass transfer process at cathode film. This can be accomplished by changing c.d., temperature,magnetic field intensity and ultrasonic field[3],[4].There are several reports pertaining to the production of multilayer alloy coatings by pulsing the c.d. alternatively, with varying degree of layering. The coating configurations have been optimized by pulsing the c.d. in different patterns (square, triangular and trapezoidal) for their better corrosion performance [5]-[7]. The electrodeposition of Ni and Ni-Co alloys,Ni-Co and its composites based monolayer and multilayer for better corrosion protection have also been reported [8]-[10]. In continuation of multilayer Ni-Co alloy coatings, the present work aims at the development of multilayer Ni-Co alloy coating, using the ultrasound effect as means to modulate the mass transfer process at cathode, parallel to the process of electrodeposition.

Ultrasound is a kind of mechanical energy. When Ultrasound is transmitted through a liquid medium in the form of waves, it induces vibrational motion of the molecules which alternately compress and stretch the molecular structure of the medium. Therefore, the distances between the molecules vary as the molecules oscillate about their mean position. If the intensity of ultrasound in a liquid is increased, a point is reached at which the intramolecular forces are not able to hold the molecular structure intact [11]. Consequently, it breaks down; and cavitation bubbles are created.In transient cavitation, the bubbles grow over one (sometimes two or three) acoustic cycle to double their initial size and finally collapse violently. Thus created motion in the ions due to cavitation force the ions towards cathode surface.During transient cavitation collapse of the bubbles will takes place near the electrode surface. So liquid jet penetrates into the bubble in a perpendicular direction to the cathode surface leading to the fast movement of ions towardsthe cathode.As a result there exists a decreased diffusion layer thickness with increased mass transport reaction rates. This very

process of acoustic effect, due to ultrasound waves can be used to modulate the mass transport process at cathode film. It can be used to modulate the composition of the deposit (alloy) on cathode. Thus periodic modulation in the ultrasound waves (in terms of power density) allows the growth of coatings with periodic modulation in composition. In other words, layered coatings having alternatively different compositions can be developed in multilayers by pulsing the ultrasound wave periodically, alongside the process of electrodeposition. In the present study, multilayer Ni-Co alloy coatings have been tried to develop by modulation of ultrasound effect by keeping the power density (p.d.) constant, by turning the sonicator probe ON and OFF periodically. The first half of the paper explains the optimization of deposition condition for the development of sonoeletrodeposited monolayer Ni-Co coating, and the second half details the optimization of deposition condition for ultrasound assisted multilayer Ni-Co alloy coatings.

II. EXPERIMENTAL

The composition of optimized Ni-Co bath, used throughout in the present study is given in Table 1.The deposition conditions, like composition and operating variables (c.d., pH and temperature) were arrived by the standard Hull cell method. The mixture containing, cobalt sulphate ($CoSO_4.7H_2O$), nickel sulphate ($NiSO_4.6H_2O$) as salts, ascorbic acid as antioxidant, glycerol as additive were prepared in distilled water. All reagents used were of LR grade (Merck, Mumbai, India). The pH of the bath was adjusted to 3.5 by proper addition of either NH_4OH or HCl, depending on the requirement (Micro pH Meter, Systronics -362).

Table 1 - Bath composition and operating parameters used for electrodeposition of Ni-Co alloy coatings

Bath composition	Amount, g/L	Operating parameters
Cobalt sulfate	14	p^H : 3.5
Nickel sulphate	131	Temperature : 303K
Sulphanilic acid	0.75	Anode : Nickel
Ascorbic acid	2.5	C.d. range: 1.0 A dm^{-2}- 7.0 A dm^{-2}
Boric acid	30	
Glycerol	15 m/L	

All depositions were carried out at room temperature, under condition of constant agitation on polished thin copper plate (7.5 cm ×3.0 cm) in a rectangular PVC cell. The substrate was polished metallurgically to get the mirror finish, degreased with trichloroethylene, and then pickled in 1:1 HNO_3. The deposition was carried out on known surface area (3 cm ×3cm), leaving the other region covered by cellophane tape. Pure nickel plate was used as anode for electrodeposition, with same exposed surface area as that of cathode(substrate). The cathode and anode were placed parallel and 5cm apart during deposition. All coatings were cleaned using distilled water, followed by air drying. Electrodeposition of Ni-Co alloy has been carried out under the influence of induced ultrasound effect and deposition conditions were optimized, for coatings of maximum protection from corrosion . The sonoelectrodeposition was carried out at constant c.d. using DC power analyzer (Agilent Technologies, N6705A, USA), at different p.d.s using an ultrasound generator (SONIC Vibra-cell^{TM} VC 750, 20 kHz, maximum power 750 W, with sonicator probe(electrode) of 13 mm tip diameter). All depositions were carried out for a constant time (10 min), for comparison purpose. Sonoelectrodeposition was accomplished with the combined effect of two driving forces: one is c.d.,expressed in A dm^{-2}, and the other one is p.d., expressed in W cm^{-2}.Here, c.d. acts as the driving force for reduction of metal ions, and p.d. for modulation of mass transfer at EDL.

The multilayer Ni-Co alloy coatings have been developed by turning the ultrasound generator ON and OFF periodically during deposition. The composition of alloy layers have been changed alternately by turning the ultrasonic probe ON and OFF periodically. The coating configuration of sonoelectrodeposited monolayer Ni-Co and its multilayer coatings were represented by $(Ni\text{-}Co)_{4.0/X}$[X =power density (0.6, 0.9, 1.2 W cm^{-2})] and $(Ni\text{-}Co)_{p/q/r}$where p and q indicates ON and OFF time of sonication in seconds, and r represents number of layer formed for total time of deposition (600 secs).

2.1 Electrochemical characterization

The Ni-Co monolayer and multilayer coatings obtained were subjected to corrosion study by conventional three electrode assembly system, using potentiostat/galvanostat(Gill AC, ACM instruments, with version-5 software). Saturated calomel electrode (SCE) has been used as the reference electrode and platinum electrode as the counter electrode. The corrosion tests were carried out, taking 1 cm^2 exposed surface area of the coatings in 5% HCl at 298K.Potentiodynamic polarization study was carried out in a potential ramp of ±250 mV around equilibrium potential, at a scan rate of 1 mV s^{-1}.Electrochemical impedance spectroscopy (EIS) study was made using 10 mV perturbing AC voltage, and corresponding Nyquist plots were analyzed.The corrosion rates(CR's) were expressed in mm $year^{-1}$, determined by the Tafel extrapolation method [12].

2.2 Characterization

All sonoelectrodeposited Ni-Co alloy coatings were further analyzed for the composition, phase structure and surface morphology.The surface morphology of coatings were analyzed using Scanning electron microscope(SEM, Zeiss Ultra 55 Germany) and formation of layered coatings was confirmed by (SEM, Model JSM-6380 LA from JEOL, Japan).The composition and phase structure of coatings were

analyzed using Energy dispersive X-ray spectroscopy(Oxford EDS, X-act) and X-ray diffraction study (Rigaku- miniFlex 600, using Cu K_α) respectively.

III. RESULTS AND DISCUSSION

3.1 Sonoelectrodeposition of Ni-Co coatings

Hull cell method was used to set the optimal electrolytic conditions for the deposition of bright,uniform and corrosion resistant Ni-Co alloy coatings over wide range of c.d., using procedure described elsewhere [13].The experimental results revealed that under optimal conditions of c.d. =4.0 A dm^{-2}, the bath produced good coating showing the least CR(22.4×10^{-2} mm $year^{-1}$) i.e. without the effect of ultrasonication. Keeping this c.d. as optimum, the corrosion protection efficacy of both monolayer and multilayer Ni-Co alloy coatings were tried to be increased by taking the benefit of ultrasound effect by inducing continuously and periodically. Accordingly, first Ni-Co alloy coatings were deposited under different conditions of p.d.(at 0.6,0.9 and 1.2 Wcm^{-2}), and their corrosion performance was evaluated, and corresponding corrosion data are reported in Table 2.

Table 2- Corrosion data of sonoelectrodeposited Ni-Co alloy coatings at different p.d.'s at constant c.d. of 4.0 A dm^{-2}

Coating configuration	p.d. (W cm^{-2})	Wt. % Ni in the deposit	Wt. % Co in the deposit	$-E_{corr}$ (mV vs SCE)	i_{corr} (µA cm^{-2})	$CR\times10^{-2}$ (mm $year^{-1}$)
$(Ni\text{-}Co)_{4.0}$	-	78.18	21.82	229.7	20.8	22.4
$(Ni\text{-}Co)_{4.0/0.6}$	0.6	68.67	31.33	215.4	9.3	10.4
$(Ni\text{-}Co)_{4.0/0.9}$	0.9	62.17	37.83	241.2	8.3	9.0
$(Ni\text{-}Co)_{4.0/1.2}$	1.2	56.48	43.52	247.1	7.4	7.9

From the CR data, We observed that sonoelectrodeposited Ni-Co alloy coatings are more corrosion resistant compared to its conventional alloy coating (developed without the use of ultrasonic effect, where p.d. =0 W cm^{-2}). It may be observed that at p.d. = 1.2 Wcm^{-2}, Ni-Co alloy exhibits the least CR (7.9×10^{-2} mm $year^{-1}$).The wt. % Co in the deposit was also found to be increased drastically as may be seen from the data in Table 2. This drastic increase in the wt.% of Co is attributed to an increase of limiting c.d. (i_L) of Co caused by thinning of the electrical double layer (EDL) due to ultrasonic effect [14], as variation in the thickness of EDL depends on both geometry and p.d. of ultrasonicator probe. Hence, it may be concluded that ultrasound effect has decreased the CR of Ni-Co alloy coatings by increasing its Co content by increasing its i_L. The thickness of EDL decreases with increase in power densities attributed to increase in limiting current density of cobalt ions and EDL thickness formed at the electrode-electrolyte interface is given by a relation[15].The microstructure of Ni-Co alloy coatings, deposited at different p.d.s are shown in the Fig.1, in comparison with that of conventional Ni-Co alloy (deposited at 0 W cm^{-2}).It may be noted thaton increasing the p. d. from 0 W cm^{-2} to 1.2 W cm^{-2}, the Co content of the alloy increased from about 21.8wt.% to 43.5wt.%, due to action of the increase of Co or decrease of Ni content may be reasoned by the fact that nickel ion being smaller in size compared to cobalt ions, kinetic movement of Ni ions towards the cathode leads to creation of bubbles, during ultrasonic streaming[16]. Hence, a large difference in the surface morphology of sonoelectrodepoisted Ni-Co alloy coatings with p. d. is due to an increase of Co content of the alloy affected by ultrasonic steaming. cavitation and ultrasonic microsteaming, caused by ultrasonic vibration [16].

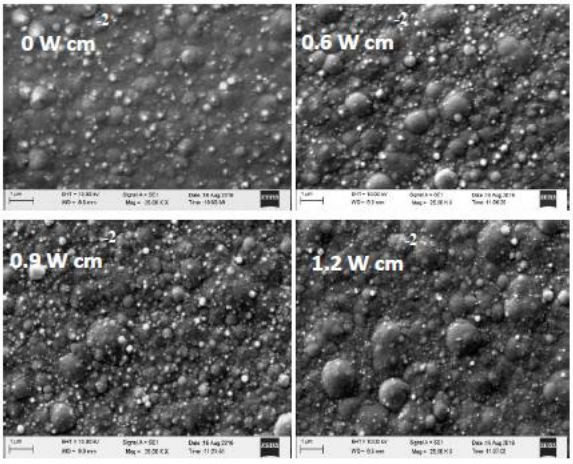

Fig.1:SEM image of Ni-Co alloy coatings deposited at different p.d.at constant c.d. = 4.0 Adm^{-2} using same bath

3.3 XRD Study

XRD patterns of sonoelectrodeposited Ni-Co alloy coatings obtained at different p.d.s(0 W cm^{-2} to 1.2 W cm^{-2}) are shown in the Fig.2.It may be noted that the orientations of all phases are same in all coatings developed in both presence and absence of ultrasonic field effect. However, the intensity of reflection corresponding to (220) phase of fcc Ni structure (JCPDS 01-087-0712) decreased drastically with increase of p. d. as shown Fig.2. The intensity of a distinct peak of conventional Ni-Co alloy, observed at $76.3^0$for (220) plane decreased with increase of p. d. The Ni-Co alloy coatings exhibiting peritectic phase structure of (112) and (311) reflections are corresponding to the combination of both fcc and hcp structures. The wt. % Co in the deposit was found to be increased (or wt. % Ni

decreased), when the ultrasound field is applied, which is evidenced by (002)(JCPDS 15-0806).The (200) plane at 51.5^0 corresponds to Co structure(JCPDS15-0806).One more distinct peak at 73.9^0 corresponds to $CoNiO_2$ structure evidenced by (311)(JCPDS10-0188). Hence, from XRD study it may be inferred that p. d. has vital role on the composition, and hence the phase structure of Ni-Co alloy coatings.

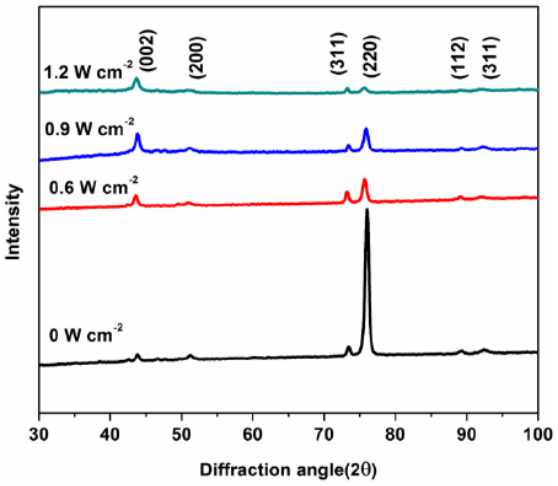

Fig.2: XRD peaks showing the crystallographic orientation of Ni-Co alloy coatings deposited at different p.d.at constant c.d. of 4.0 A dm^{-2}.

Thus, it may be concluded that the surface morphology, phase structure and composition of Ni-Co alloy coatings have changed significantly due to the effect of ultrasonication during deposition. The corrosion data reported in Table 2, demonstrated that Ni-Co alloy at 1.2 Wcm^{-2} showed the least corrosion rate. Hence, it has been selected as the optimal p. d. for development of multilayer coating, by changing the t_{ON} and t_{OFF} for different time intervals, keeping other parameters, like c.d. = 4.0 A dm^{-2} and pH = 3.5 constant.

3.4 Development of multilayer Ni-Co alloy coating

Multilayer Ni-Co alloy coatings have been developed using the same bath, by pulsing the ultrasound waves to go ON and OFF periodically (keeping constant p.d. of 1.2 Wcm^{-2}), parallel to the process of electrodeposition.In the present study, multilayers have been developed with different degree of layering, i.e. with 10, 30, 75, 100, 150 and 300 layers by pulsing the ultrasound probe to go ON and OFF at 30,10,4,3,2,1 (seconds) intervals. It may be noted from the compositional analysis carried out earlier, the Co content in alternate layers of alloy coating is 21.8 wt. % (p. d. = 0 Wcm^{-2}) and 43.5 wt. % (p. d. 1.2 Wcm^{-2}).

3.5 Potentiodynamic polarization study

The corrosion behavior of multilayer Ni-Co alloy coatings having different number of layers were evaluated by potentiodynamic polarization method and electrochemical impedance methods. The corrosion rates (CR's), determined by Tafel's method are reported in Table 3, and corresponding plot are shown in Fig. 3.

Table 3- Corrosion data of multilayer Ni-Co alloy coatings developed by pulsing ultrasound wave ON and OFF at different time intervals, keeping c.d. = 4.0 A dm^{-2}

Coating configuration	T_{ON} and T_{OFF} time		Number of layers formed	$-E_{corr}$ (mV vs SCE)	i_{corr} (µA cm^{-2})	CR×10^{-2} (mm Y^{-1})
	t_{ON}	tOFF				
$(Ni\text{-}Co)_{30/30/10}$	30	30	10	301	5.6	6.0
$(Ni\text{-}Co)_{10/10/30}$	10	10	30	326	4.1	4.5
$(Ni\text{-}Co)_{4/4/75}$	4	4	75	257	3.9	4.2
$(Ni\text{-}Co)_{3/3/100}$	3	3	100	254	2.3	2.5
$(Ni\text{-}Co)_{2/2/150}$	2	2	150	276	1.4	1.5
$(Ni\text{-}Co)_{1/1/300}$	1	1	300	270	1.6	1.8
$(Ni\text{-}Co)_{4.0/1.2\ Wcm\text{-}2}$	-	-	monolayer	247	7.4	7.9
$(Ni\text{-}Co)_{4.0\ Adm\text{-}2}$	-	-	monolayer	229	20.8	22.4

From corrosion data reported in Table 3,it may be noted that CR's of multilayer coatings decreases with increase in number layers up to 150 layers, and then start increasing at 300 layers. This increased of CR at 300 layers may be attributed to interlayer diffusion, due to very short ON time (1 sec) of sonication. Increase of CR at highest degree of layering may be explained as follows: During electroplating, there exists a continuous diffusion of metal ions towards the cathode due to both applied c.d. and p. d. But due to periodic pulsing of ultrasound waves, the mass transport process towards cathode has also been pulsated. Accordingly, due to very shortpulsing period, no change in mass transport process has been affected due to sonication. i.e.no much change in the composition of individual layers has taken place. In other words, there is no sufficient time for metal ions to relax against diffusion process due to applied ultrasound waves and to deposit with changed composition.Hence, at higher degree of layering CMMA Ni-Co coating tends to behave as its monolayer coating.

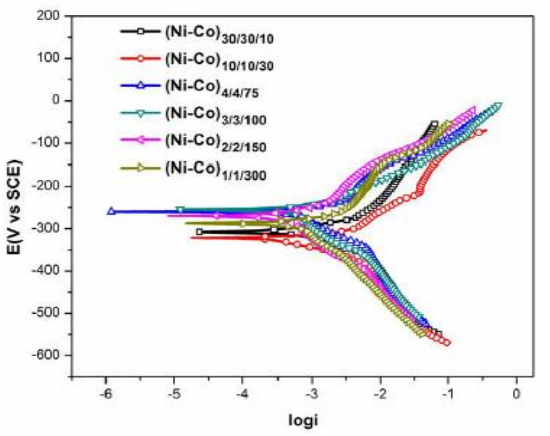

Fig.3:Potentiodynamic polarization behavior of sonoelectrodeposited multilayer Ni-Co alloy coatings having different number of layers deposited from same bath

3.6 Electrochemical impedance spectroscopy

EIS is a non-destructive method for studying the interfacial interaction of test material very accurately. Generally electrochemical reactions involve transfer of electron at the electrode surface, and this method gives information, like Ohmic conduction, charge transfer, interfacial charging, mass transfer at the electrode-electrolyte interface [18].Their representation are popularly called as Nyquist diagrams. Accordingly, the impedance response of multilayer Ni-Co alloy coatings having different number of layers are shown in Fig. 4.The impedance responses showed incomplete depressed semicircle in the studied frequency range, in addition to an increase of axial radius of the semicircle with increase in number of layers. Nature of Nyquist plots clearly indicate that the polarization resistance(R_p) of the coatings has increased progressively with increase in number of layers. The impedance response of $(Ni-Co)_{2/2/150}$ alloy coatings is characterized by the highest $R_p$value as shown in Fig. 4. This suggests that this particular coating is the most corrosion resistant compared to other coatings including its conventional monolayer and sonoelectrodeposited alloy coatings, as shown by the data in Table 3.

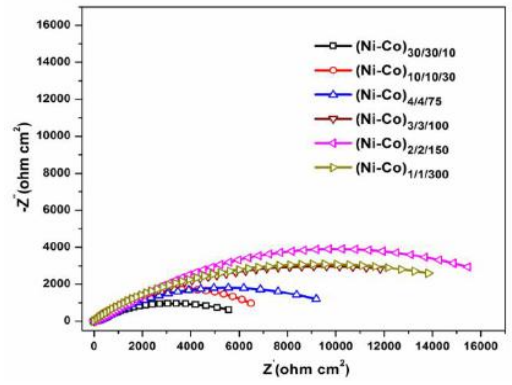

Fig. 4: EIS response of sonoelectrodeposited multilayer Ni-Co alloy coatings having different number of layers deposited from same bath

3.7 Comparison of monolayer and Multilayer coatings

A comparative account of corrosion rates Ni-Co alloy coatings deposited under different conditions, namely sonoelectrodeposited multilayer alloy coatings, sonoelectrodeposited monolayer and conventional monolayer alloy coatings (Table 3) reveals that multilayer alloy coatings are more corrosion resistant than sonoelectrodeposited monolayer and conventional monolayer counterparts.It may be noted from data in Table 3 that sonoelectrodeposited multilayer Ni-Co alloy coating having 150 layers, deposited with 2 sec ON time and 2 sec OFF time , represented as $(Ni-Co)_{2/2/150}$ is the most corrosion resistant (with least CR). Hence it has been considered as the optimal configuration of the coating for highest corrosion resistance, deposited from the bath. A comparison of corrosion behaviors of sonoelectrodeposited multilayer, sonoelectrodeposited monolayer and conventional monolayer Ni-Co alloy coatings under optimal conditions (abbreviated as $(Ni-Co)_{2/2/150,}$ $(Ni-Co)_{4.0/1.2\ Wcm-2}$ and $(Ni-Co)_{4.0\ Adm^{-2}}$, respectively) are shown in Fig. 5.

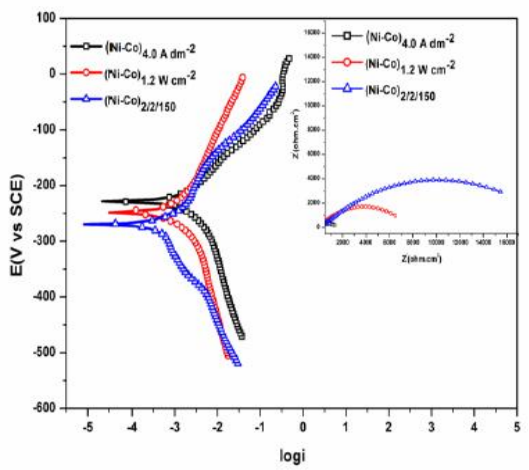

Fig. 5:Comparison of Tafels plots and Nyquist responses (shown in the inset) of Ni-Co alloy coatings developed under different conditions, namely $(Ni-Co)_{4.0\ Adm^{-2}}$, $(Ni-Co)_{4.0/1.2\ Wcm-2}$$(Ni-Co)_{2/2/150}$from the same bath at constant c.d. of 4.0 Adm^{-2}

It may be seen from nature of Tafel's plots and Nyquist response (shown in the inset of Fig. 5, that sonoelectrodeposited multilayer Ni-Co alloy coatings represented as $(Ni-Co)_{2/2/150}$,is the most corrosion resistant, compared to other coatings deposited from the same bath. Thus from the corrosion data it is clear that CMMA $(Ni-Co)_{2/2/150}$ coating (CR =1.5 $\times 10^{-2}$ mm Y^{-1}) is about 8 times more corrosion resistant than sonoelectrodeposited $(Ni-Co)_{4.0/1.2}$ coating(CR= 7.9$\times$ 10^{-2} mmY^{-1}), and 11 times more corrosion resistant than its conventional monolayer counterparts (22.4×10^{-2} mm Y^{-1}) without ultrasound effect, developed from the same bath for same duration of time.

3.8 SEM study for layered coating

Formation of coatings in multilayers, having alternate layers of alloys with two different composition was confirmed by acid test as explained below.A drop of 2N HCl has been treated on to the surface of electrodeposited copper, having $(Ni–Co)_{30/30/10}$ coating configuration. It is allowed to stay for about 60 sec for the deposit (layers) to dissolve partially. It is later washed in distilled water,and then dried. Inspection of the treated surface under SEM confirmed the formation of Ni-Co alloy coatings in layered manner due to effect of sonication. The surface morphology of the multilayer Ni-Co alloy coating before and after acid test is shown in Fig. 6a and 6b, respectively. The vortexes seen in Fig. 6b confirmed the dissolution of coatings in layered manner, indicating its formation also in layered fashion. Further, it may be noted that only alternate layers of alloys have dissolved more preferentially than the other. i.e. layer of one composition (having 78.2 wt.% Ni deposited at p.d. = 0 W cm^{-2}) dissolved less preferentially compared to the adjacent layer (having 56.5 wt.% Ni deposited at p.d. = 1.2 Wcm^{-2}).

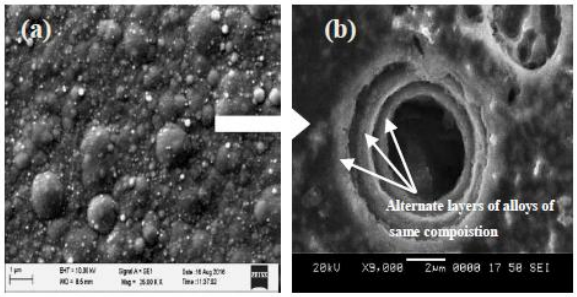

Fig. 6:SEM micrograph of the top surface of $(Ni–Co)_{30/30/10}$coating: a) before acid test and b) after acid test displaying the formation of alternate layers of alloys of differnet composition.

Thus, inspection of microscopic appearance of the surface of multilayer coating after corrosion test clearly demonstrated that multilayer Ni-Co alloy coatings were formed in layered fashion during deposition; which is responsible for increased corrosion protection of the CMMA Ni-Co alloy coatings, compared to its monolayer counterparts.The increased corrosion protection of multilayer Ni-Co alloy coatings, in relation to its monolayer alloy coating is attributed to increased number of interfaces (due to formation of layers of alloys having different composition). These interfaces make the corrosive agent to spread laterally through interfaces. However, in the case of monolayer alloy coating, corrosive agent diffuses directly towards substrate, and responsible for increased corrosion [19].

IV. CONCLUSIONS

In an effort to improve the corrosion resistance behaviour of Ni-Co alloy coating from a new sulphate bath using the benefit of ultrasonication, parallel to the process of deposition, following conclusions are drawn:

1. The corrosion rates of Ni-Co alloy coatings can be decreased drastically by inducing the ultrasound effect parallel to the process of electrodeposition.

2. Drastic improvement in corrosion resistance of sonoelectrodeposited Ni-Co alloy coating is attributed to an increase of Co content of alloy, due to an increase of its limiting c.d. (i_L).

3. The factors such as surface morphology, composition and phase structures, responsible for better corrosion resistance of the coatings were found to be mainly controlled by the power density (p. d.) used for deposition, supported by SEM, EDX and XRD study, respectively.

4. Corrosion rates of multilayer Ni-Co alloy coatings decreased with number of layers only upto 150 layers, and then increased due to interlayer diffusion.

5. Improved corrosion resistance of multilayer Ni-Co alloy coating is due to formation of alternative layers of alloys having two differnet composition (21.8 and 43.52 wt% of Co), formed due to periodic ON and OFF of sonication, parallel to the process of deposition.

6. Corrosion data showed that under optimal condition, CMMA $(Ni-Co)_{2/2/150}$ is about 8 times more corrosion resistant than sonoelectrodeposited $(Ni-Co)_{4.0/1.2\ Wcm^{-2}}$ coating and about 11 times more corrosion resistant than its conventional monolayer counterpart$(Ni-Co)_{4.0\ Acm^{-2}}$, deposited from the same bath for same depositon time.

7. The increased corrosion protection of multilayer Ni-Co alloy coatings, in relation to its monolayer alloy coatings is attributed to increased number of interfaces formed (due to layers of different composition) due to periodic pulsing of sound waves during depositon.

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