Electroplating of Nickel on Various Metal Surfaces

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Abstract:- **The nickel plating process has been being used extensively for decorative, engineering, and electroforming purposes since many years ago. In a nickel plating, there are many controlled parameters for different purposes. The main objective of the paper is to study electro-plating of nickel for corrosion resistance depending on reaction time and various substrates. The electrolytic nickel plating was carried out by using nickel anode and the substrate metal cathodes (Iron, Brass, Zn-Fe alloy, Aluminium) in the presence of boric acid additive. The applied voltage 2-3V and applied current 200-300 mA must be applied from the transformer which gives a maximum constant 12 V D.C out-put. The electrolytic nickel plating occurs at the cathodes surface, therefore the potential of cathode substrate must be lower or nearly equal to the electrode potential of Ni. Brass (Cu-Zn) alloy cathode substrate is given the good results for the nickel plating among other cathodes of aluminium (Al), iron (Fe) and zinc-iron alloy (Zn-Fe). The thickness of nickel coated film in each substrate is in the order of Brass > Fe > Zn-Fe > Al. Finally, the thickness and physical appearance of Nickel coated film on different metal surfaces will be discussed depending on reaction time.**

Keywords:- *Nickel Plating, Electrolytic Cell, Reaction Time, Various Substrate, Corrosion Resistance.*

I. INTRODUCTION

Electroplating is widely used to coat a metal, with a thin layer of another metal. Nickel plating involves adding a thin layer of nickel onto a metal object for a variety of reasons. There are many electroplating such as gold plating, copper plating and etc., used for industrial, engineering and decorative. Among them, Nickel electroplating is becoming an increasingly versatile process used for surface finishing processes. It is because nickel is one of the most often employed to increase the corrosion resistance or electrical conductivity of the underlying substrate [1]. The most important property in engineering end uses is, generally corrosion and resistance but wear resistance, solder ability, and magnetic and other properties may be relevant in specific applications. In these engineering application area, Nickel plating is very useful and famous because of its smoothness, different brightness color and low cost. In this coating Nickel on metals, there are three most popular types, Bright nickel plating, Electroless nickel plating and Dull nickel plating.

Bright nickel plating adds bright nickel plating to an item, it must be submitted to an electric current. Bright nickel plating produces a bright mirror like finish due to its elevated sulphur content. This type of plating is especially adapted for bumpers, rims, exhaust pipes and trims for cars, motorcycles and bikes as well as lighting fixtures and plumbing. It is also ideal for restoring any machinery mechanisms that are worn. Unlike other forms of nickel plating, electroless nickel plating is applied using an autocatalytic reaction and does not involve an electric current. It is ideal for preventing corrosion and wear and for anything that requires an elevated hardness. Kitchen instruments, door knobs, bathroom taps, office equipment, drive shafts, rotors and oil field valves are Nickel coated by this technique. Dull Nickel plating is similar to bright nickel plating but produces a dull, matte finish. It is hard wearing, malleable and offers significant corrosion resistance. The plating technique is used as an undercoat for chromium, tin plating, silver plating and gold plating for machine parts, springs or things where movement is required [2]. As the different in Nickel plating techniques, the operating parameters are also different. In each of these Nickel plating types, the physical appearance and thickness of Nickel is usually changed depending on various operating parameters. The following are some previous researches which discussed how much influence the operating parameters on the process of Nickel plating.

In [2], A. Brenner and *et al* discussed about of Nickel plating on steel by chemical reduction. Their work was developed for the production of adherent nickel deposits of good quality on steel. The deposition of nickel was brought by chemical reduction of a nickel salt with hypophosphite in a hot ammonical solution. The reduction occur only at the surface of the immersed metal with the production of a coating of nickel of 96 to 97 percent purity.

Next publication was submitted by N. V. Mandich and *et al* [4]. The mechanisms of the work were detailed and starting with the role of inorganic builders, through surfactants and solvent actions. The fundamentals of formulating science and know-how are fashioned for different types of industrial formulations using a number of typical formulas as appropriate examples were discussed and they proved the important of the cleanliness of the surface for coating.

After that, J. Song and *et al* proposed the corrosion protection of conductive surfaces [5]. Their work investigated different ways to minimize the consumption of gold for electrical contacts and to improve the performance of gold plating. Other plating materials used for corrosion protection of electrically conductive surfaces are tin, nickel, silver and palladium. Finally, the work also compared properties and results of different plating materials used for corrosion protection of electrically conductive surfaces and

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the testing of corrosion resistance of electrically conductive surfaces.

Another Nickel plating was proposed in [6]. In this work, the nickel plated electrodes were prepared by electro-deposition technique on mild steel surface modified with in-situ deposition of nickel titanate. The extent of polarization of the nickel plating on mild steel with nickel titanate was lower than that of nickel plating on mild steel. Their results showed that the nickel plating on nickel titanate modified mild steel gave better adherence than the nickel plating on bare mild steel surfaces.

In [7], the properties and the effect of operating parameters on nickel plating was discussed as a review publication. It presented the appearance and other properties of the electrodeposited material, nickel deposition can be varied, over a wide range, by controlling the composition and the operating parameters of the plating solution. The properties of nickel and the different effects of the operating parameters on nickel plating, together with the simulation and design tools, are also reviewed.

In [8], corrosion of electroless deposited Nickel-Phosphorus was presented by A. Sosa Dominguez and *et al*. In this work, coatings for solar-to-thermal energy conversion had been deposited onto carbon steel substrates from a nickel sulphate electroless bath, as a source of nickel and sodium hypophosphite as a reducing agent. The results of their work showed a decrease of corrosion resistance but associated with the increase of four times the surface area of black coatings.

The proposed paper present the Nickel electroplating for corrosion resistance depending on reaction time and various substrates. The paper is composed of four sections. The section I is the introduction of Nickel plating and the previous work. In section II, materials and proposed method will be presented. The section III is the experimental results and discussions. Finally, conclusions of the paper will be presented in section IV.

II. MATERIALS AND METHOD

The main objective of the paper is to study electro-plating of nickel on various metal surfaces and examined on the corrosion resistance of electrolytic nickel coated film by using electrolytic nickel plating technique.

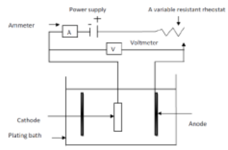
A. The Construction of Electrolytic Cell

The following electrolytic parts are required to construct the electrolytic cell: namely, electrical connection, electrodes and the electrolytic vessel. The nickel plate was used as anode. Iron, brass, zinc-iron alloy and Aluminium metals were used as the substrate for nickel plated surfaces. Metal plates were cut in suitable size of length 4.5cm in length and 3.5 cm in width, the distance between two electrodes was 0.5 cm apart. The surface was made smooth with sandpaper.

(a)

(b)

(c)



(d)

(e)

Fig.1:- Description of proposed Nickel plating process. (a) Nickel plates, (b) and (c) Iron Plates, (d) Schematic diagram of proposed process and (e) Actual image of proposed Nickel plating process.

The smooth surface was cleaned to remove any previous deposits by immersion in dilute nitric acid (1:1) rising with distilled water, then boiling with fresh nitric acid (1:1) for about one minute. It was placed on a watch glass and dried for 3 to 4 minutes in an electric oven. It was weighed and measured the thickness of nickel after cooling in air for 5 minutes. Beaker (150 cm3) was employed as electrolytic vessel in the present electrolysis process. The vessel contains nickel plate anode, iron plate cathode and nickel electrolyte solution. The vessel was dipped into the water bath to maintain the temperature. Electrolyte solution was added to the electrolytic vessel and electrical connection was set up. The assembled electrolytic unit is shown in Fig. 1.

The burbles of oxygen gas were evolved at the anode surface when the electricity was passed through the electrolytic cell. When the cell voltage was slowly increased by adjusting the rheostat, the current through the electrolytic cell was slowly increased. The cell voltage reached to (2V-3V), the evolution of oxygen gas was moderate rate and the nickel metals were coated on cathode. The current flow through the electrolytic cell was about 100-300mA.

The experimental conditions are,

Anode = Nickel
Cathode = Iron
$NiCL_2.6H_2O$ concentration = 0.15 g dm^{-3}

H_3BO_3 = 0.38 g dm^{-3}
Total volume = 100 cm^{-3}
$NiSO_4.6H_2O$ Concentration = 3.0 g dm^{-3}
Cell voltage = 2V
Current = 230 mA
pH = 3.5
Temperature = 30 Ċ

After 15 minutes electroplating the electrodes were raised and at the same time they were washed with a continuous stream of distilled water from a wash bottle up to the upper edge of the electrodes. The electrodes were removed from the solution and the circuit connection must not be cut during the process. When the electrodes were thoroughly washed, the connection of the circuit was cut out

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and the electrodes were dipped into a beaker of distilled water and then it was rinsed with analytical grade acetone. The electrodes were dipped into a beaker of distilled water and then it was rinsed with analytical grade acetone. The electrodes were dried at 100-110 °C for about 3 minutes in an electric oven. It was weighed after cooling in air about 5 minutes and the thickness of the casted film was measured by micrometer. Then the thickness of the coasted film was calculated by the following relation.

$$\text{Thickness (mm)} = \frac{mass\ gain}{nickel\ costed\ area \times density\ of\ nickel} \quad (1)$$

B. Determination of Effective Electroplating Reaction Time

The electrolytic plating process was run 5 minutes interval continuously. Then the physical appearance and thickness of coated nickel film were determined Section II-A. Similarly the electroplating process was carried out by the following schedule of the electroplating reaction time 5 minutes, 10 minutes, 15 minutes, 20 minutes, 25 minutes, 30 minutes, 1 hour, 2 hours and 3 hours and the physical appearance and thickness of nickel coated film were tabulated in Table II and Fig. 2.

C. Determination of Various Substrate for Nickel Plating Process

The required apparatus and chemicals were employed as described in Section II-A. The construction of electrolytic cells contain electrolyte solution and operational conditions were similarly carried out by the above procedure Section II-A. The nickel plating process was run one hour continuously interval but the cathodes which was coated substrate were varied as Iron (Fe) plate, Brass (Cu- Zn alloy) plate, Zinc-Iron alloy (Zn-Fe) plate and Aluminium plate. The physical appearance and thickness of nickel coated film were tabulated in Table II and Fig. 2.

D. Action of Acids, Bases and Organic Solvents on Nickel Coated Plate

The prepared electrolytic nickel coated plate was placed in a clean and dry watch glass and then 1 drop of 1M HCL was sported. It was kept for about 5 minutes. No chemical reaction was found to take place. Further addition of 1drop of 1M HCL to the above plate was performed. The reaction examination was recorded in Table III. Similarly the other reagents 3M HCL, 6M HCL, 12M HCL, 1M H2SO4, 3M H2SO4, 12M H2SO4, 18M H2SO4, 1M HNO3, 2M HNO3, 3M HNO3, 1M KOH ,2M KOH, 3M KOH, 1M HCOOH and 1M CH3COOH, 2M CH3COOH, 6M CH3COOH, 7M CH3COOH were tested by the above procedure and the results so obtained were shown in Table III.

E. Determination required amount of additive Boric Acid (H3BO3) in Electroplating Process

For this study, experiment runs were performed by varying the concentration of boric acid in an electrolyte solution, keeping time of electroplating at 1 hour, while similar operational conditions and electrochemical techniques were employed as described in section IIA. The concentrations of boric acid in electrolyte solution were 0.1 kg dm-3, 0.2 dm-3, 0.3 kg dm-3, 0.4 kg dm-3, were used for each experiment and the operational conditions were employed as shown in section II-A. The resulting physical appearance and the thickness of nickel coated film were recorded in Table II and Fig 2.

F. Determination of Suitable Additive in Electroplating Process

In the present research work, the construction of electrolytic cells and operational conditions were similarly carried out by the above procedure sections (A). The pH of the electrolyte solution was kept constant at 3.5 but the additive were varied as the following schedule of concentrated sulphuric acid (2.3 g/100 cm3), concentrated hydrochloric acid (5.2 g/100cm3) and boric acid (3.8g/ cm-3) for each experiment.

III. RESULTS AND DISCUSSIONS

The principal objective of this research work is to study the electrolytic nickel plating on other substrates (Brass, Zn-Fe alloy, Al) and examination of decorative properties of electrolytic nickel coated film. The following parameters on nickel electroplating will be discussed on details.

A. The Effective Electroplating Reaction Time

In this proposed work, 30 g per 100 cm3of nickel sulphate was used in electrolyte solution. The applied cell voltage 2 to 3 V and the current 200 to 300 mA were applied on the electroplating process. Then the experiment runs were performed to determine the thickness and physical appearance to the desired electroplating reaction time 5 minutes, 10 minutes, 15 minutes, 20 minutes, 25 minutes, 30 minutes, 1 hour, 2 hours and 3 hours and the physical appearance and thickness of nickel coated film were tabulated in Table I. The brightness of Nickel coated film is good result with increasing the electroplating reaction time. But the experiment is run constant prolong time, the current ampere of the electrolytic cell was rapidly increased. When the applied current ampere more than 300 mA, the evolution of oxygen gas is more favourable and nickel deposition is forbidden. If the electroplating reaction time is before 45 min, the applied current ampere may be constantly followed between 200 mA to 300 mA. After 45 min, the fluxtuation of the applied current may be occurred and it must be needed to control the current between 200 mA to 300 mA. The thickness of nickel coated film was recorded in Table I.

No.	Reaction Time / min	Thickness / mm	Physical Appearance
1	5	0.01	Bright
2	10	0.02	Bright
3	15	0.03	Bright
4	20	0.05	Bright
5	25	0.06	Bright
6	30	0.09	Smooth bright
7	60	0.18	Smooth bright
8	120	0.36	Smooth bright
9	180	0.54	Smooth bright

TABLE I:- Thickness of nickel coated film Obtained by Using Various Electroplating Reaction Time

B. The Effects of Electrolytic Nickel Plating on Various Substrates

Substrates which is coated surfaces were used Iron (Fe) plate, Brass (Cu- Zn alloy) plate, Zinc-Iron alloy (Zn-Fe) plate and Aluminium plate. They are used as cathode and it must be heeded to make smooth with sandpaper and cleaning.

No.	Substrate (cathode)	Initial thickness/ mm	Final thickness/ mm	Thickness of nickel coated film/mm	Physical appearance
1	Iron(Fe)	6.05	6.23	0.18	bright
2	Brass (Cu-Zn)	6.15	6.35	0.20	Smooth and bright
3	Zinc-iron alloy(Zn-Fe)	6.02	6.37	0.15	bright
4	Aluminium (Al)	6.22	6.20	-0.02 (dissolved)	-

TABLE III:- Thickness and Physical Appearance of Nickel Coated Film in Various Metal Surface

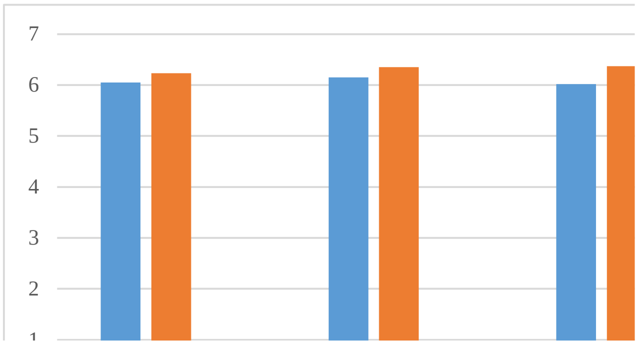

Fig .2:- The Thickness of Nickel Film Coated on Various Cathodes

The employed operational conditions and electrochemical technique have been mentioned in Section II-A and II-B. In the process, Brass (Cu-Zn) substrate more thickness nickel coated film 0.02 mm was obtained and Aluminium (Al) cannot be used as substrate for the nickel electroplating process. The results are summarized in Table II and Fig.2. It can be seen that Brass (Cu-Zn) substrate gives smooth, brightness and thickness nickel coated film. It is so because the brass cathode is made to lower the resistance and increase the conductivity of the solution. The thickness of nickel coated film in each substrate is in the order of Brass > Fe > Zn-Fe > Al as shown in Table II and Fig. 2.

C. Examination of Corrosion Resistance of Electrolytic Nickel Coated Film

The corrosion resistance of electrolytic nickel coated film was examined by treating with various concentration of acids, alkalis and some organic solvents. Operational conditions were similarly carried out by the above procedure sections II-D. The results so obtained were summarized in Table III. From this table, it was obvious that the electrolytic nickel coated film was resisted by corrosion. But it cannot be resisted to the dilute 3M HNO3.Therefore nickel plating provides resistance to corrosion for many commonly used articles, example, pins, paper clips, scissors, keys, fastener, etc., as well as for materials used in food processing, the paper and pulp industries and the chemical industries which often are characterized by severely corrosive environments.

No.	Chemical tests	Observation
1	Hydrochloric Acid(1M HCL, 3M HCL, 6M HCL, 12M HCL)	decorrosive
2	Sulphuric Acid(1M H_2 SO_4, 3M H_2 SO_4, 12M H_2 SO_4, 18M H_2 SO_4)	decorrosive
3	Nitric Acid(1M HNO_3, 2M HNO_3)	decorrosive
4	Nitric Acid(3M HNO_3)	corrosive
5	Sodium hydroxide(1M NaOH, 2M NaOH, 3M NaOH)	decorrosive
6	Potassium hydroxide(1M KOH ,2M KOH, 3M KOH)	decorrosive
7	Formic Acid(1M HCOOH)	decorrosive
8	Acetic Acid(1M CH_3COOH, 2M CH_3COOH, 6M CH_3COOH, 7M CH_3COOH)	decorrosive

TABLE IIIII.:- Corrosion Resistance of Electrolytic Nickel Coated Film

IV. CONCLUSIONS

As mentioned in the experimental section, the iron substrate was coated with nickel by using the electroplating process. The advantages and disadvantages of experiments were also scrutinized in the section of results and discussions. The electrolytic nickel plating was carried out by using nickel anode and the substrate metal (Fe) cathode in the presence of boric acid additive. The electrodes must be needed to clean by the suitable methods before set up the electrical connection. The applied voltage 2-3V and applied current 200-300 mA must be applied from the transformer which gives a maximum constant 12 V D.C out- put. The good results of electrolytic nickel plating was obtained in result tables. Electrolyte nickel plating occurs at the cathode surface, therefore, the electrode potential of cathode substrate must be lower or nearly equal to the electrode potential of nickel. Brass (Cu-Zn) alloy cathode substrate is given the good results for the nickel plating among other cathodes of aluminium (Al), iron (Fe) and zinc-iron alloy (Zn-Fe). The thickness of nickel coated film in each substrate are in the order of Brass > Fe > Zn-Fe > Al. Aluminium (Al) metal cannot be used for the electrolytic nickel plating process as cathode.

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