

# **Electroless Nickel Plating For Fabrication of Perforated Plate Heat Exchangers**

Sunil Kumar S. <sup>1</sup>, Nandi T. K. <sup>2</sup>

Assistant Professor, Dept. of Mechanical Engineering, College of Engineering Trivandrum, Trivandrum, Kerala, India<sup>1</sup>

Assistant Professor, Cryogenic Engineering Centre, IIT Kharagpur, Kharagpur, West Bengal, India<sup>2</sup>

**ABSTRACT:** Perforated plate heat exchangers (PPHEs) are made of alternately arranged high conducting perforated plates (e.g. Copper) and low thermal conductivity insulating spacers (e.g. Stainless Steel). This type of heat exchangers are being widely used in cryogenic refrigeration and liquefaction systems. Considering applications in wide temperature variations, high pressure and long service life, diffusion bonding is the most suitable method of fabrication of PPHEs. In general, nickel interlayer between copper and Stainless Steel aids in good diffusion between copper and Stainless steel. In this paper we present steps by step procedure for doing electroless nickel plating on copper plates before diffusion bonding. Several sample studies (both SEM and joint strength) on diffusion bonding between Cu and SS plates under varying nickel interlayer thickness and other bonding conditions like temperature and duration of bonding were conducted. Nickel interlayer is applied through electroless nickel coating on copper surface. Coating thickness is measured by an eddy current probe indigenously developed in the laboratory. It is hoped that the result of this work would provide necessary guidelines to the fabricators while making diffusion bonded PPHEs.

**KEYWORDS:** Electrolessnickel plating, Perforated plate heat exchangers, diffusion bonding, nickel interlayer.

## **I. INTRODUCTION**

Perforated plate heat exchangers (PPHEs) (Fig.1) are made of a stack of alternate layers of high thermal conductivity perforated plates and low thermal conductivity insulating spacers [1]. The plates receive heat from the hot fluid by convection and transfer the same by lateral conduction and by convection to the cold fluid. Spacers minimize the heat loss due to axial conduction and reduce the effect of flow mal-distribution by continuous reheadering between the plates. PPHEs are used in many applications such as cryogenic refrigeration, power engineering, chemical industries etc.

Copper is usually used as the material for the plates [2]. Using copper as the material for the plates, the preferred material for the insulating spacers is stainless steel. Zablotskaya et al [3] pioneered the making of Cu-SS PPHE by diffusion bonding. Controlling parameters for obtaining good diffusion bonding between Cu and SS are pressure, temperature during bonding and duration of bonding. Several researchers [4-5] have mentioned that using 15 to 20  $\mu\text{m}$  thick nickel interlayer may improve the diffusion bonding quality and bond strength. Good solubility of oxygen in nickel will prevent the formation of copper oxides that may restrict the inter diffusion of elements. Also nickel forms continuous solid solution with iron and copper and thus has better metallurgical compatibility. However, no systematic study on the effect of nickel interlayer thickness is reported. Yilmaz et al. [6] reported that diffusion bonding of Cu and SS at low pressure and high temperature might cause concentration of micro-voids on grain boundaries. These voids may lead to micro-cracks, a phenomenon popularly known as Kirkendall effect. Therefore, some more confirmatory studies are essential for arriving at optimum nickel coating thickness and other bonding conditions. Nickel coating over copper substrate is applied by electroless nickel plating technique.

In this paper we present steps by step procedure for electroless nickel plating done on sample copper plates before diffusion bonding. The paper presents some sample studies on diffusion bonding between Cu and SS discs demonstrating the effects of nickel coating thickness on the bond quality and joint strength at different diffusion bonding temperature and duration of bonding.

The procedure of applying nickel coating has been used successfully later for fabricating Perforated Plate Heat Exchangers (PPHEs) which were further tested for their leak tightness and were discussed in paper elsewhere [7]. It is expected that this paper will provide the necessary guidelines to the fabricators for applying uniform nickel coating while making their PPHEs by diffusion bonding

**II. STUDIES ON ELECTROLESS NICKEL PLATING**

Electrolessnickel plating is a very hard, highly corrosion and wear resistant deposit of Phosphorous-Nickel metal alloy. It has excellent adhesion to the copper plate and does not flake off. No electric current is required for deposition. Advantages of electroless nickel plating include uniform coating thickness on all surfaces of part, better surface finish,

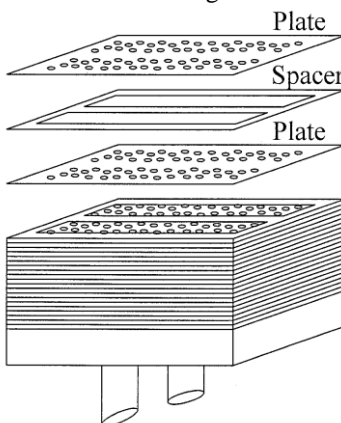


Fig. 1: Construction of a perforated plate heat exchanger

micron levels of tolerance etc. It can be applied to almost any substrate including cast iron, steels, stainless steels, copper, aluminum, nickel, brass, bronze, titanium. Table 1 describes the properties of nickel plating solution used.

Table 1. Properties of nickel plating solution used

Material	Melting point	Hardness	Wear resistance	Corrosion resistance	Ductility	Tensile strength
Alloy of Phosphorous-Nickel	880°C	45-50 Rockwell C	after heat treatment compares with hard-chrome	Resistance to many organic and inorganic environments.	high	around 100,000 psi

**III. DIFFUSION BONDING**

Diffusion bonding has been studied on several diffusion bonded Cu and SS samples. Samples have been prepared using tough pitch (electrode grade) or OFHC grade copper and stainless steel (304 L) materials. Two types of samples are prepared; i) for studying the bond quality at the inter-metallic interface through a scanning electron microscope (SEM) and ii) for measuring the mechanical strength of the joints by using a universal testing machine (UTM). Surface roughness of the samples is maintained at less than 0.5µ. Materials selected for the study and their compositions are given in Table 2. Samples for SEM study are made by using copper and SS disks each having 30mm in diameter and 5mm in thickness. For mechanical strength measurements, samples are made as per the ASTM standards. Diffusion bonding has been done by using a 5 tonne vacuum hot press unit applying 10 MPa pressure on the samples. The details about the heating cycle are described in author’s thesis. Fig. 2 illustrates the schematic of electroless nickel plating procedure.

Table 2. Composition of the materials used for diffusion bonding study

Materials	Composition (%)
SS-AISI 304 L	C-0.05, Cr-18.58, Ni-8.02, Mn-1.55, Si-0.53, Cu-0.21, Co-0.71, P-0.11, Fe-balance
Tough pitch Cu-97.3% pure	Si-0.25, S-0.06, Ti-0.02, Fe-0.77, Co-0.45, Sn-1.16, O <sub>2</sub> -0.04, Cu-balance
OFHC Cu-99.95% pure	Si-0.02, Mn- 0.02, O <sub>2</sub> -0.001, Cu-balance

#### IV. STEPS IN ELECTROLESS NICKEL PLATING

##### 1. Cleaning

The given copper plate of roughly 30 mm diameter is polished using emery paper with different grit sizes 400, 600, 900 and 2000 to a high degree of surface roughness followed by wiping with a clean cloth. Then it is cleaned by soap solution and measured the surface roughness value using a profilometer with Ra as 0.02micron.

Plate is then put into the cleaner tank. The cleaner tank consists of a heater dipped in Elnico CREC powder solution which has been prepared already. Copper plate is connected to the anode of DC power supply and cathode of which is connected with SS plate. The solution is heated by a heater and its temperature is controlled by varying current using a dimmerstat. This removes the surface particles and oil from the copper plate. This process is followed by ultrasonic cleaning with acetone. Ultrasonic cleaning follows pickling process. Pickling is done to remove inorganic surface films and expose the metal to the plating bath.

##### 2. Etching

Then the plate goes to etchant solution which consists of 50% H<sub>2</sub>SO<sub>4</sub>, 20% HNO<sub>3</sub> and 30% DM water. Etching follows tap water rinsing followed by the plate brightened in bright dip tank by dipping the plate in 5% H<sub>2</sub>SO<sub>4</sub> solution. Then the plate goes to tap water rinsing followed by hot water rinsing maintained at a temperature around 60°C with a heater. This then follows DM water rinsing.

##### 3. Plating

The copper plate and ms panel together in contact is put in to the plating bath. This is done because plating gets started very soon in ms panel and then it starts in copper plate. Once the plating is initiated the plate may be separated from the ms panel and then independently dipped in the bath. Four samples have been made ready with electrolessnickel coating with different plating times like 3min, 5min, 25min and 45 min to study the different characteristics of diffusion bonding.

##### 4. Treatment after plating

The plating is followed by hot water rinsing and 5% ammonia water rinse and after that the plate is rinsed in hot water and DM water and then it is dried. The prepared samples are kept in glass bottles with acetone for diffusion bonding studies later.

Table 3 gives the details about making the plating bath. Elnico 820 and Elnico 820N are chemicals for medium phosphorous electroless nickel plating. Table 4 gives the constraints to be maintained for the bath while plating.

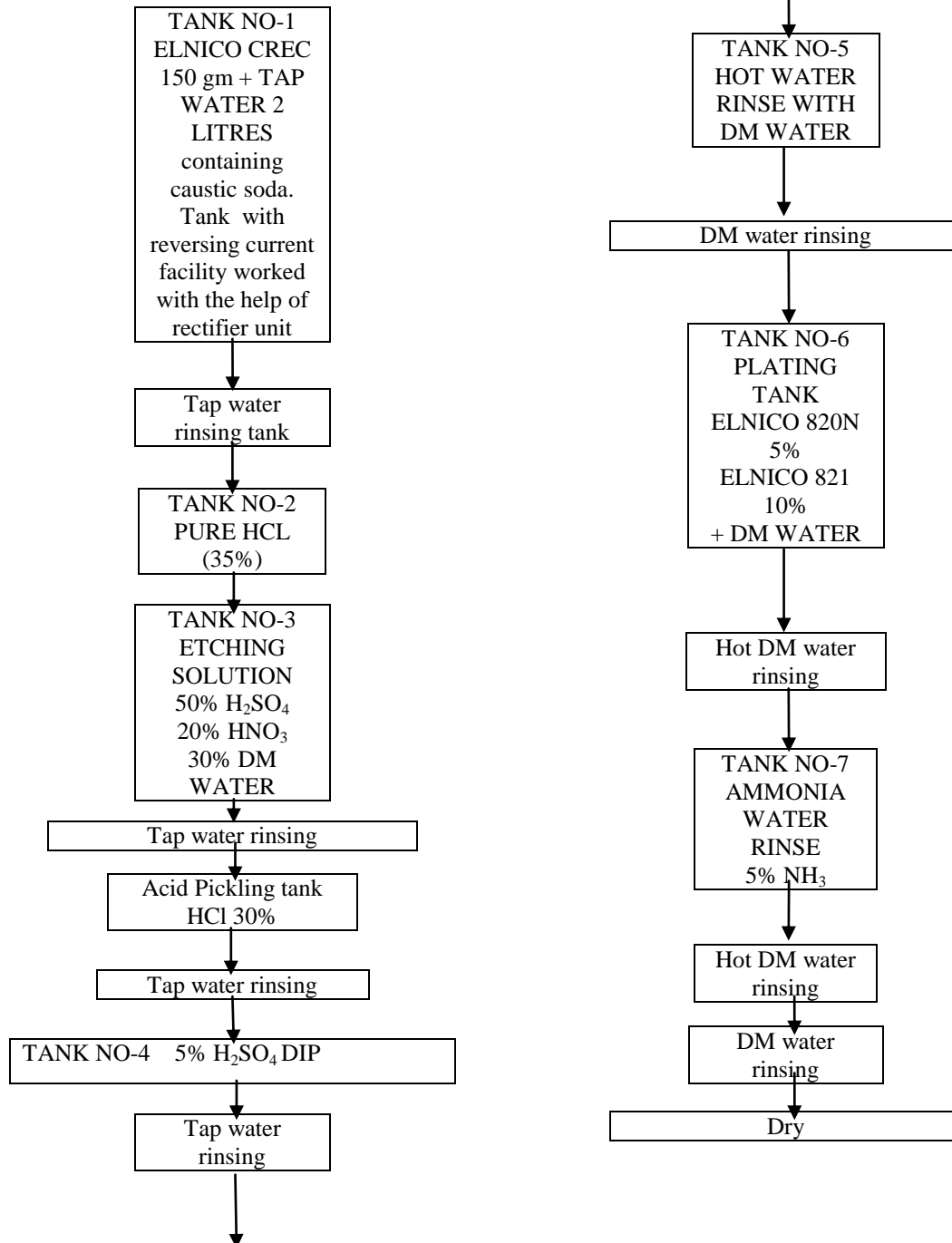


Fig. 2: Steps in Electroless nickel plating

Table 3. Details of making bath for Electroless nickel plating

Plating bath	By Vol	1litre
DM water	85%	850ml
Elnico 820	10%	100ml
Elnico 820N	5%	50ml

Table 4. Constraints to be maintained for the bath

PH	4.5-4.8	Agitation	Mechanical or Air
Temp	88°C	Filtering	Wattman Filter
Plating rate	10 micron/hr	Heater	4 kW
Loading	15 inch <sup>2</sup> /lit	Tank	316 SS, polypropylene tanks polyethylene, plastic tank liners

### V. INTERFACE STUDY

Samples fabricated by diffusion bonding are cut by a wire cut electro discharge machine. The cutting surfaces are polished and cleaned as recommended for obtaining good SEM photographs. The SEM photographs of the interfaces are shown in Fig.3 and Fig.4. Sample without nickel interlayer (Fig. 3) shows poor diffusion at the interface. Good diffusion bonding, however, can be observed in Fig. 4. The elemental distribution in a Cu-SS joint is obtained through an electron probe micro-analyzer (EPMA) [8]. The concentration profiles indicated interdiffusion of elements to a depth of 20-25 micron in either side of the interface. The details are given in the author's thesis [8].

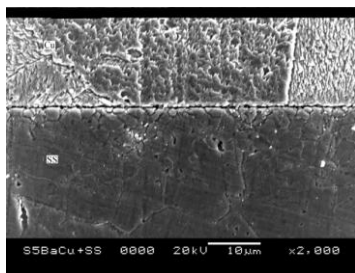


Fig. 3: Cu-SS interface without nickel interlayer

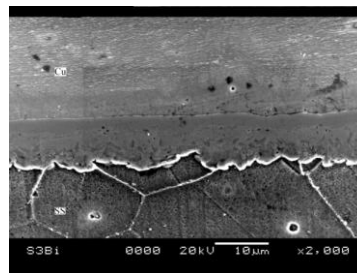


Fig. 4: Cu-SS interface with 25-30 micron nickel interlayer

### VI. BOND STRENGTH

Separate samples have been prepared for finding out joint strength as per ASTM standards. Several tests have been conducted for finding mechanical strength in a diffusion bonded Cu-SS joint. Further details of testing are available in the author's thesis [8]. Details of these samples, operating conditions during bonding and their joint strengths are given in Table 5.

Table 5. Studies of mechanical strength of Cu-SS304L diffusion bonded joints

Grade of Copper	Nickel interlayer thickness ( $\mu$ )	Bonding temp. ( $^{\circ}$ C)	Holding time (under press. and temp.) Min	Ultimate tensile strength (MPa)	Nature of bond
Tough pitch	10-15	850	60	Failed during machining	Poor bonding
-do-	15-20	825	30	56	-do-
OFHC	nil	825	30	Failed during machining	-do-
-do-	10-15	825	30	74	-do-
-do-	20-25	850	30	126	Good bonding
-do-	25-30	850	60	190	Very good bonding

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**VII. CONCLUSION**

Electroless nickel plating facility has been successfully installed in the laboratory. Experimental investigation on interface and joint strength of samples proves that electroless nickel plating aids diffusion process between Copper and Stainless steel. It is seen that joint strength increases with increased nickel coating thickness. However, no significant improvement in joint strength was observed for joints with more than 30 micron nickel interlayer. Hence it is concluded that optimum interlayer thickness of nickel should be between 25 and 30 micron.

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