Corrosion Characterization in Nickel Plated 110 ksi Low Alloy Steel and Incoloy 925: An Experimental Case Study

Kiran Thomas¹, S. Vincent¹, Dipika Barbadikar², Shresh Kumar¹, Rebin Anwar¹, Nevil Fernandes¹

¹Department of Mechanical Engineering, BITS Pilani Dubai Campus, Dubai, UAE, 345055.
²Department of Mechanical Engineering, Manipal University Dubai Campus, Dubai, UAE, 345055.

Abstract. Incoloy 925 is an age hardenable Nickel-Iron-Chromium alloy with the addition of Molybdenum, Copper, Titanium and Aluminium used in many applications in oil and gas industry. Nickel alloys are preferred mostly in corrosive environments where there is high concentration of H₂S, CO₂, chlorides and free Sulphur as sufficient nickel content provides protection against chloride-ion stress-corrosion cracking. But unfortunately, Nickel alloys are very expensive. Plating an alloy steel part with nickel would cost much lesser than a part made of nickel alloy for large quantities. A brief study will be carried out to compare the performance of nickel plated alloy steel with that of an Incoloy 925 part by conducting corrosion tests. Tests will be carried out using different coating thicknesses of Nickel on low alloy steel in 0.1 M NaCl solution and results will be verified. From the test results we can confirm that Nickel plated low alloy steel is found to exhibit fairly good corrosion in comparison with Incoloy 925 and thus can be an excellent candidate to replace Incoloy materials.

1. Introduction

Incoloy 925 is used in high strength piping systems and petroleum industry generally. It is a high performance alloy having high creep and oxidation resistance. The resistance to sulphide stress cracking and stress corrosion cracking in sour crude oil and natural gas makes it preferable for manufacturing downhole and surface gas well components including tubular products, valves, hangers, landing nipples, tool joints and packers. They are used in environments where there is high temperature, mechanical stress and surface stability is required. It is a precipitation –hardenable-nickel-iron-chromium alloy. It can be age hardened by adding Aluminium and Titanium. Copper and Molybdenum are added to increase its resistance to corrosive media. Its chemical composition underlines that Nickel is the major constituent in Incoloy 925 with 44 %. The disadvantage of Incoloy 925 is the high cost involved in its procurement.

Nickel is considered useful for plating metal as it provides superior ductility, corrosion resistance, and hardness. Coating low alloy steel with Nickel will provide excellent corrosion characteristics and by varying the coating thickness we can use it as a substitute for Incoloy 925. It is extremely important to evaluate chemical stability of materials under potential environments and therefore study of corrosion characteristics is important. Corrosion characteristics of Incoloy 800 in Sodium Chloride and Sodium sulphate aqueous solutions at 80°C have been reported [1] before and the resistance to pitting resistance have been well examined. The experiments conducted in solutions with different
concentrations of Cl⁻ and SO₄²⁻ showed that the concentration range had no substantial effects on the anodic behaviour of the alloy. After polarization no localized corrosion was found in the samples [1]. Results obtained by exposing C-ring specimens of Incoloy 925 to a solution containing hydrogen sulphide, sodium chloride and acetic acid proved that the alloy resisted sulphide stress cracking. Test results of corrosion tests on Incoloy 925 on free sulphur environments show a very low corrosion rate of 0.028-0.030 mm/annum. Electrochemical polarization study has been carried out to study the corrosion behaviour of nickel coating and the polarization curves have revealed that the current density used during pulse electro-deposition plays a vital role in characteristics of Nickel coating. Thus the aim of the present work is to study the corrosion behaviour of nickel plated low alloy steel and Incoloy 925 in a saline medium by varying the thickness of nickel coating and understanding how coating thickness affects the corrosion rate.

2. Experimental details

The procedure for electroless nickel plating is as follows. The alloy was first degreased and cleaned. The activation of surfaces to be plated shall be performed after cleaning to ensure that the surfaces are ready for plating. The activation step removes films and oxide layers that may interfere with the plating process. Activation techniques are somewhat material dependent and include alkaline, acid and/or current reversals with electrocleaners.

The nickel plating process for plating thickness of 0.0005", 0.001" and 0.002" shall be in accordance with ASTM B733 with a phosphorus content in the 9% - 12% range [2-3]. The plating shall be qualified to a Class 2 heat treatment in accordance with ASTM B733. The plater shall have a plating procedure that defines bath operating conditions, bath monitoring frequency and tests, bath composition and bath replenishments. A bake or heat treat cycle is required of the plated product to (1) remove hydrogen from susceptible (to hydrogen embrittlement) substrates and (2) harden the nickel phosphorus plating to about 65 HRC. The heat treat process shall be to ASTM B733 Class 2. This requires a 500°F - 750°F (260°C - 400°C) heat treat cycle for typically 2 to 4 hours.

The corrosion behavior of nickel plated 110 ksi low alloy steel samples having different plating thickness (0.0005", 0.001" and 0.002") and Incoloy 925 (composition given in Table 1) was evaluated using Versastat 3 potentiostat. Test was carried out at room temperature in a three electrode cell having Ag-AgCl reference electrode and platinum gauge counter electrode. Prior to electrochemical measurements the specimen was washed in distilled water. For testing in neutral medium the electrolyte used was aqueous solution of 0.1M NaCl solution. The experiments were conducted at a scan rate of 0.0167 mV/s. Nickel plated low alloy steel samples having thicknesses of 0.0005 “, 0.001” and 0.002” were exposed to an area of 0.44 cm², 0.85 cm² and 0.63 cm² respectively. For Incoloy 925 the exposed area was 2.465 cm². The working electrode was allowed to obtain a stable open circuit potential (OCP) in the test solution. All samples achieved OCP in 30 minutes.

| Element | Cr | C | Mo | Ti | Co | Mn | Ni | Fe |
|---------|----|---|----|----|----|----|----|----|
| Wt. %   | 20.8 | 0.013 | 3.1 | 2.16 | 0.13 | 0.6 | 43.95 | 26.8 |
| Element | B | N | Al | Cu | P | S | Si | Ta |
| Wt. %   | 0.0038 | 0.004 | 0.2 | 1.7 | 0.01 | 0.001 | 0.2 | 0.01 |

Table 1: Chemical Composition of Incoloy 925
3. Results and Discussion

The potentiodynamic polarization measurements were performed on Incoloy 925 and 110 ksi Low Alloy Steel evaluate its corrosion behavior. Polarization results indicate that the corrosion process in the present system is under anodic control as reflected by the Tafel slopes. Corrosion current density ($i_{corr}$) and corrosion potential ($E_{corr}$) values were determined by applying Tafel extrapolation of polarization curves.

**Fig 1:** The polarization curves for nickel plated low alloy steel (0.0005” thick)

**Fig 2:** The polarization curves for nickel plated low alloy steel (0.001” thick)
Fig 3: The polarization curves for nickel plated low alloy steel (0.002” thick)

Fig 4: The polarization curves for Incoloy 925

Table 2: $i_{corr}$ and $E_{corr}$ for samples in NaCl solution

| Sl No | Sample                                      | $E_{corr}$ (mv) | $i_{corr}$ ($\mu$A/cm$^2$) | Corrosion rate (mm/year) |
|-------|---------------------------------------------|-----------------|-----------------------------|--------------------------|
| 1     | Nickel plated low alloy steel (0.0005")    | -454.74         | 196.88                      | 2.4168                   |
| 2     | Nickel plated low alloy steel (0.001")     | -415.8          | 88.4                        | 1.0853                   |
| 3     | Nickel plated low alloy steel (0.002")     | -395.54         | 20.58                       | 0.252                    |
| 4     | Incoloy 925                                 | -85.568         | 993.47                      | 0.0014                   |
Fig. 1 shows polarization curves for nickel plated 110 ksi Low Alloy Steel in 0.1M NaCl solution. The current density shows significant resistance after the E$_{corr}$ is reached indicating sign of passivity in the sample. The values of $i_{corr}$ and $E_{corr}$ for samples in NaCl solution are shown in Table 2. Though the nickel plated low alloy steel with plating thickness of 0.0005” shows resistance to material degradation once $E_{corr}$ is reached, overall corrosion rate of this alloy in NaCl solution is high.

Similarly corrosion behaviour of nickel plated low alloy steel with plating thickness of 0.001”, 0.002” and Incoloy 925 is shown in Fig. 2, 3 and 4 respectively. The corrosion current density is not increasing once the $E_{corr}$ is reached, showing significant resistance of samples to material degradation. Further the $i_{corr}$ and $E_{corr}$ values for these samples are reported in Table 2.

![Polarization Curves](image)

**Fig 5:** The polarization curves for all samples in 0.1 M NaCl solution

In order to compare the corrosion behaviour of nickel plated with varying thickness with Incoloy, a polarization curves were plotted together in Fig. 5. From Fig. 5, it can be clearly seen that Incoloy exhibits highest corrosion resistance with lowest corrosion current density and lowest corrosion. Nickel plated with 0.0005” shows least resistance to corrosion and with increase in thickness of nickel, corrosion rate was observed to decrease. From the above results, it is evident that as coating thickness increases corrosion rate is decreasing. Although the corrosion rate for the sample with highest coating (0.002”) is not as low as Incoloy, still the reduction in corrosion rate with increase in plating thickness is a positive trend. The current density value of 0.002” nickel plated low alloy steel is more compared to that of the other two samples. This clearly indicates that increase in thickness of nickel plating will provide more corrosion resistance. Although the corrosion resistance observed for the nickel plated samples is not as much as that observed for Incoloy 925, the positive trend shows that it can be used as a promising candidate in oil and gas industry.

Further, cost comparison studies has been carried out between Incoloy and nickel plated low alloy steel. Incoloy 925 material is 6 times or more expensive than that of a 110 ksi alloy steel material for the same dimensions. So when an Incoloy part is requested, if we know the exact application then we could just do nickel plating on the 110 ksi alloy steel and manufacture the product which would
reduce the cost of the final product. Nickel plating would provide the required corrosion and wear resistance fairly similar to that of an actual Incoloy 925 part. Cost comparison will be done for tubular and bars for a few dimensions to know the price difference of actual Incoloy 925 material with that of a nickel plated 110 ksi alloy steel.

Table 3: Cost comparison chart

| Sl. No. | Specimen                        | Incoloy 925 ($110 ksi alloy steel ($110 ksi alloy steel with nickel plating in the ID or side ($110 ksi alloy steel with nickel plating on the entire part ($) |
|-------|--------------------------------|---------------------------------|-------------------------------------------------|------------------------------------------------------------------|
| 1     | 3-1/2” 9.2# pipe (3.500” OD and 2.992” ID) 750 mm length | 1920                           | 194                                             | 0.0005 67 134                                                   |
|       |                                 |                                 |                                                 | 0.001 115 230                                                  |
|       |                                 |                                 |                                                 | 0.002 198 396                                                  |
| 2     | 10” OD bar 1.0” length          | 320                             | 18                                              | 0.0005 19 38                                                    |
|       |                                 |                                 |                                                 | 0.001 32 64                                                    |
|       |                                 |                                 |                                                 | 0.002 55 116                                                   |

4. Conclusions:

In the present investigation, it can be concluded that increasing the nickel coating on the low alloy steel will lead to increase in corrosion resistance of materials. Although the corrosion resistance of Incoloy is excellent, nickel plated low alloy steel can be used as replacement material owing to its low cost.

5. Reference

1) Mnasur F A “Microstructural characterization and Electrochemical corrosion behavior of Incoloy 800 in sulphate and chloride solutions”, Belo Horizonte, MG, Brazil, October 24-28, 2011

2) Duncan R N ‘Electroless Nickel: Past, Present and Future’. Proceedings EN 93 Conference, Orlando. November 1993.

3) Bayes M ‘The Physical Properties of Electroless Nickel Coatings’. Proceedings EN 95 Conference, Cincinnati November 1995.