Corrosion Behavior of Nickel Alloys NiFe and NiCu Welding on Base Metal in Alkalie Solution

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Abstract

Cladding metal weld is a composite product developed to provide effective and economic utilization of expensive materials. The welding layer NiCu and NiFe that will be in contact with the corrosive media is made of the corrosion resistant alloys, whilst the less expensive base carbon steel covers the strength and toughness required to maintain the mechanical integrity. In a nuclear power plant cladding metal weld joints are necessary for joining the different materials chosen for the various parts of the heat transfer circuit. Also Cladding metal welds are utilized in processing pressure vessels, heat exchangers, tanks and storage facilities. Anodic polarization curves for deposited as weld and heat treated Ni alloy weld metal in 3.5% NaCl solution with alkaline pH are studying. Anodic polarization curve for NiFe weld metal on carbon steel heat treated for 50,500 and 1000 hr at 550 oC are recorded. The results indicated that, for example, the anodic polarization curve for NiFe weld metal heat treated for 500 hr at 550 oC in 3.5% NaCl solution, the corrosion current density was 11.23 μ A/cm². The corrosion current density increase at constant rate which indicate a uniform corrosion. The hardness is 205Hv measured at 300 gmload. As for the anodic polarization curve for Ni-Cu weld metal heat treated for 500 hr at 550 °C tested in 3.5% NaCl solution, the corrosion current density was 28.42 μ A/cm². The corrosion current density increases after that with constant rate till and of the experiment. The hardness is 235Hv measured at 300 gm load.

1-Introduction

The weld metal composition is usually not uniform, particularly with multiple pass welds, and a composition gradient is likely to exist in the weld metal adjacent to each base metal. These solidification characteristics of the weld metal are also influenced by the relative dilutions and the composition gradients near each base metal[1,2]. These characteristics are important with respect to hot cracking of the weld metal during solidification. Also specimens from dissimilar metal welds of different types of electrodes between 304L stainless steels and pressure vessel welded joints, were manufactured. Different welding electrodes NiFe, Ni and NiCu nickel base alloy were used[3,4]. These types of cladded-carbon steel and weld joints are widely used in the nuclear power, chemical and petrochemical industries. Investigations of potential degradation mechanisms, integrity assessment methods have been performed in many developments nuclear centers[5]. The weld should have a corrosion / oxidation resistance more that the least resistant base metal being joined. It is fortunate that in most all instances the weld will be of a higher alloy content (better corrosion and oxidation resistance) than the least resistant base metal being joined [6,7].

Some of these specimens were heat treated at temperatures 550°C for various holding times, ranging from 50 to 1000 hours, 550°C is selected because it is within range of nominal operating temperature[8,9]. The experimental investigation included corrosion test and

hardness for weld joints. Nickel alloys are a viable solution for enhancing corrosion properties due to its excellent resistance to aqueous corrosion [10].

For corrosion applications (anodic protection), high density and low oxide content are among the most important properties which the coating has to attain in order to guarantee the high corrosion resistance [11,12]. A fully dense coating forms a physical barrier which in turn, prevents electrolyte penetrating through the coating and reacting with the steel substrate which would otherwise result in the formation of voluminous corrosion products which are likely to cause coating failure. Hence, great effort has been made in order to achieve dense and oxide-free Ni and NiCu coatings. Several studies on the microstructure of cold-sprayed Ni and NiCu coatings have reported high denseness with acceptable bond strengths [13,14].

2-Experimental work

The experimental investigation was carried out to evaluate the corrosion performance of two types of weldments using manual shielded metal arc welding processes. Manual shielded metal arc welding (SMAW) process was used to prepare weldments depositing layers.

2.1 Types of electrodes

Two types of coated electrodes of class AWS (American Welding Society) were used in the welding experiments. The types are E-NiFe and, E-NiCu with diameter $\phi = 4$ mm. The chemical composition of the used electrodes is shown in Table (1)

Table (1) Chemical composition of the electrode

Element	C	Si	Mn	Cr	Cu	Ni	Mo	Ti	Fe
NiFe	1	<2.0	<1.0	-	-	56	-	-	Basis
NiCu	0.05	0.7	3.5	-	29	bal	-	0.4	1.3

2.2 Heat treated procedure

Weld metal specimens were subjected to an heat treated temperature of 550°C for various holding times ranging from 50 to 1000 hours, followed by air-cooling, in order to simulate working conditions. The effect of this isothermal heat treated on microstructure was investigated for weld metal samples. The heat treated process was performed in a muffle furnace, which is automatically controlled with an accuracy of $\pm 5^\circ\text{C}$. An additional Ni-NiCr thermocouple attached to a digital thermal indicator was used to check the temperatures of the furnace throughout the holding time.

2.3 Metallographic examination

Metallographic examination was carried out for the weld deposits. Variations of microstructure in dissimilar metal welds NiFe and NiCu for as weld conditions and after heat treated was examined. The specimens were ground under water on rotating disc, using abrasive paper with grades ranging from 180 to 2000. Then polished to mirrored surface by using diamond paste with grades 3 and 1 micron. Nickel alloys were etched with 30 ml HNO_3 and 70 ml H_2O by immersion at room temperature for 5 to 20 seconds. Specimens were rinsed with alcohol and dried with hot air. The optical microscope (OM) was used for microstructural examination.

2.4 Microhardness test

A Vickers microhardness testing machine was used to measure at least seven hardness values on the weld deposit specimens in the as weld and after heat treatment conditions. The applied load was 300gm and the indentation time was 30 second.

2.5 Electrochemical Corrosion testing

Prior to corrosion behavior studies, the samples were ground on SiC grinding papers from 240 till 1000 grade, followed by polishing on polishing lapped cloth using 1 μm diamond suspension. Then the polished samples were degreased with ethanol before immersion in the test solution. The electrochemical corrosion behavior of the samples was studied by applying the potentiodynamic polarization technique using a potentiostat (Electrochemical Impedance Analyzer, Model 6310) interfaced to a computer and a three-electrode cell with the sample as a working electrode of exposed area 100 mm², a saturated calomel reference electrode (SCE). For testing the performance of the deposited Ni alloys NiFe and NiCu, 3.5% NaCl solution was used, the solution was prepared from reagent NaCl salt, the pH of the solution is nearly alkaline.

3-Results and Discussions

Figure(1) showing the microstructure features of NiFe weld metal deposited on carbon steel (a) as weld (b) heat treated for 50 hr (c) heat treated for 500 hr and (d) heat treated for 1000 hr. These specimens exhibit a complex precipitation behavior at elevated temperatures, during welding, furthermore, the precipitation behavior will depend upon the carbon content and the final temperature [15]. This reveals an almost dendritic morphology structure with a region in the weld metal exhibiting more ferritic-austenitic modes of solidifications. The regions solidified in the ferritic-austenitic mode and consisting of small amount of delta ferrite, segregated in interdendritic (or intercellular) boundaries [16-10].

Figure(2) showing the microstructure features of NiCu weld metal deposited on carbon steel (a) as weld (b) heat treated for 50 hr (c) heat treated for 500 hr and (d) heat treated for 1000 hr. Morphology showed a bi-modal layer formation where white phases showed a transition from small spherical shape to dendritic and cauliflower shape with application of ultrasound [17].

Figure(1) Optical micrograph showing the microstructure features of NiFe weld metal deposited on carbon steel and after heat treated (a) as weld (b) 50 hr (c) 500 hr and (d) 1000 hr

Figure(2) Optical micrograph showing the microstructure features of NiCu weld metal deposited on carbon steel and after heat treated(a) as weld (b) 50 hr (c) 500 hr and (d) 1000hr

The average values of microhardness testing measuring is shown in Table (2) for as-welded condition and after heat treated at 550°C for 50 hr, 500hr and 1000 hr [16]. The highest microhardness values (258 Hv) for as weld condition of NiFe and the smallest (153 Hv) after heat treated for 1000 hr may be attributed to the strain hardening that produces large amount of deformation twins or due to coarsening of precipitates.

For NiCu the lowest microhardness values for as weld condition (170 Hv) and the highest at 500 hr (235 Hv), Shuangqun Zhao et al [18] found that room temperature microhardness of the alloy decreased with an increase in temperature mainly due to the growth of γ' phases. Elevated-temperature microhardness of the alloy for standard heat-treated condition was higher than room temperature microhardness.

Table (2) The average values of microhardness testing measuring (Hv)

	as weld	50hr	500hr	1000hr
NiFe	258	197	205	153
NiCu	170	213	235	217

The corrosion current density I_{corr} and corrosion potential E_{corr} of NiFe and NiCu, which were determined by potentiodynamic technique Table (3). From these data, one may generally evaluate the corrosion performance of NiFe and NiCu at different heat treated conditions.

Table(3)Corrosion potential E_{corr} and corrosion current density I_{corr} for NiFeand NiCu

heat treated condition	NiFe		NiCu	
	E_{corr} (mV)	$I_{corr}(\mu A/cm^2)$	E_{corr} (mV)	$I_{corr} (\mu A/cm^2)$
As weld	-362.1	5.737	-375.8	15.06
50hr	-506.3	6.570	-428.9	17.09
500hr	-436.9	11.23	-484.6	28.42
1000hr	-446.5	6.364	-446.6	21.54

The electrochemical tests were established by using Potentiodynamic technique. Anodic polarization curves for deposited as weld and heat treated for NiFe weld metal in 3.5% NaCl solution having nearly neutral pH are shown in Figures (3-6).

Figure(3) shows the anodic polarization of Ni-Fe as the weld metal in 3.5% NaCl solution, the corrosion current density is $5.737 \mu A/cm$. The current density increases in slow rate till the potential is -300 mV, then it increases a high rate till the end of the experiment. The hardness is 258 Hv measured at load 300 gm load.

Figure (4) shows the anodic polarization of Ni-Fe welds metal heat treated for 50 hr at $550^\circ C$ in 3.5% NaCl solution, the corrosion current density is $6.570 \mu A/cm^2$. The corrosion current density increases with constant rate until -300 mv potential, then the current density increases with higher rate until the end of the experiment. The hardness is 197 Hv measured 300 gm load.

Figure (5) shows the anodic polarization curve of Ni-Fe welds metal heat treated for 500 hr at $550^\circ C$ in 3.5% NaCl solution, the corrosion current density is $11.23 \mu A/cm^2$. The corrosion current density increase at constant rate which may indicate a uniform corrosion. The hardness is 205 Hv measured at 300 gm load.

Figure(6) gives the corrosion behavior of Ni-Fe welds metal heat treated for 1000 hr at $550^\circ C$ tested in 3.5% NaCl solution, the corrosion current density is $6.364 \mu A/cm^2$. The corrosion current density increases smoothly without any change in the rate; this indicates uniform corrosion and no pitting behavior. The hardness is 153 Hv measured at 300 gm load.

Figure(3) Anodic polarization curve of deposit NiFe welds metal for as weld condition

Figure(4) Anodic polarization curve of deposit Ni Fe weld metal heat treated for 50hr at 550°C

Figure (5) Anodic polarization curve of deposit Ni Fe welds metal heat treated for 500 hr at 550°C

Figure (6) Anodic polarization curve of deposit Ni Fe welds metal heat treated for 1000 hr at 550°C

Anodic polarization curves for deposited as weld and heat treated for NiCu weld metal in 3.5% NaCl solution having nearly neutral pH are shown in Figures (7-10)

Figure (7) shows the anodic polarization curve for Ni-Cu welds metal as welded tested in 3.5% NaCl solution, the corrosion current density was $15.06 \mu\text{A}/\text{cm}^2$. The corrosion current density increases at a constant rate of potential higher than corrosion potential till -300 mV, then the corrosion current density increases at the higher rate till -50 mV. After -50 mV the current density increases suddenly from $10^{-3} \text{ A}/\text{cm}^2$ to $10^{-2} \text{ A}/\text{cm}^2$ which may indicate a localized corrosion mechanism. After that the current density increases with regulated behavior which can be due to the presence of pits. Hardness is 170 Hv measured at 300 gm load.

Figure(8) shows the curve of anodic polarization of Ni-Cu weld metal heat treated for 50 hr at 550°C tested in 3.5% NaCl solution, the corrosion current density was $6.364 \mu\text{A}/\text{cm}^2$. The corrosion current density increases smoothly at constant rate up to -300 mV, then increased at higher rate to -100 mV. A sudden increase in current density in the range $3.5 \mu\text{A}/\text{cm}^2$ to $2.5 \mu\text{A}/\text{cm}^2$ which may show formation of localized corrosion, after that current density increases at high rate with irrigation. The hardness is 213 Hv measured at 300 gm load.

Figure (9) shows the anodic polarization curve for Ni-Cu welds metal heat treated for 500 hr at 550°C tested in 3.5% NaCl solution, the corrosion current density was $28.42 \mu\text{A}/\text{cm}^2$. The corrosion current density increases after that with constant rate till and of the experiment. The hardness is 235 Hv measured at 300 gm load.

Figure(10) shows the anodic polarization curve of Ni-Cu weld metal heat treated at 1000 hr tested in 3.5% NaCl solution, the corrosion current density was $21.54 \mu\text{A}/\text{cm}^2$. The corrosion current density increases with constant rate, which indicate uniform corrosion. The hardness is 217 Hv measured 300 gm load.

Figure (7) Anodic polarization curve of deposit NiCu weld metal for as weld condition

Figure (8) Anodic polarization curve of deposit Ni Cu weld metal heat treated for 50 hr at 550°C

Figure(9) Anodic polarization curve of deposit Ni Cu weld metal heat treated for 500 hr at 550°C

Figure (10) Anodic polarization curve of deposit Ni Cu weld metal heat treated for 1000 hr at 550°C

General Conclusion:

The power generation industry uses cladding metal welding extensively to reduce material costs and enhance performance in elevated-temperature applications. Anodic polarization curves for deposited as weld and heat treated Ni alloys NiFe and NiCu weld metal in 3.5% NaCl solution having alkaline pH were studied. Anodic polarization curve for Ni alloys weld metal heat treated for 50, 500 and 1000 hours at 550 °C are recorded. The results indicated that, the corrosion current density of the anodic polarization curve for both NiFe and NiCu alloys decreased at heated treated time 50 hr and 1000 hr, but it increased at 500 hr.

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