Title	A Comparative Evaluation of ENiCu-7 and ENiCrFe-3 Electrodes for Dissimilar Metal Welding Applications(Materials, Metallurgy & Weldability)
Author(s)	Sadek, Alber A.; Abass, Mahmoud; Elrefaey, Ahmed et al.
Citation	Transactions of JWRI. 2000, 29(2), p. 23-30
Version Type	VoR
URL	https://doi.org/10.18910/12431
rights	
Note	

A Comparative Evaluation of ENiCu-7 and ENiCrFe-3 Electrodes for Dissimilar Metal Welding Applications†

Alber A. SADEK*, Mahmoud ABASS, Ahmed ELREFAEY*** and Masao USHIO******

Abstract

A series of studies were carried out to examine the effect of chemical composition and dilution on the corrosion properties of dissimilar joints between low carbon steel and Monel 400 alloy. Such joints are important parts in oil gasification plants. This kind of joints requires good corrosion resistance and mechanical properties, a stable magnetic permeability besides good weldability. The average chemical composition for weld metals was calculated based on the average dilution of welds. It was shown that the predicted weld analysis more or less agrees with experimentally measured results. The post weld heat treatment (heating at 300°C, holding for 30 min then heating at 650°C holding for 30 min, heating to 900°C, holding for 30 min and then rapid cooling) gives the lowest corrosion rate.

KEY WORDS: (Dissimilar Joints) (Monel 400 Alloy) (Low Carbon Steel) (Post Weld Heat Treatment)(Ni Base Electrode)

1. Introduction

For dissimilar metal joints, it is a common requirement that the mechanical properties of the joints should not be worse than those of the inferior base metal. In addition, the weld should have corrosion resistance at least equal to the resistance of the weaker base metal being joined.

The major and well-known problems encountered in welding dissimilar metal joints are:

- Dilution of the weld metals,
- Carbon migration near the fusion line,
- Formation of a martensitic transition zone across the fusion line between the weld metal and the carbon steel side, and
- The differences in thermal expansion coefficients[1].

The addition of filler materials to the joints makes the situation of dilution and carbon migration in the welding even more complex, but can also bring relief to the problems of weldability and properties of joints. All these factors need to be evaluated before industrial applications can be realized.

Furthermore, welded joints are often subjected to service conditions combining both load and corrosive environment. The mechanical properties of the joints are normally reduced due to these combined effects, which become stronger than any individual effect. Analysis of many failures of welded joints shows that fractures are often not caused by insufficient strength, but by the reduced fracture resistance in a certain corrosive environment. Therefore, both mechanical properties and corrosion resistance should be considered concurrently for a particular joint.

In this study, the welding of Monel 400 alloy to carbon steel is evaluated from the view points of dilution and its effect on the corrosion resistance of the welded joints. In a previous work[2], the weldability and the essential mechanical and metallurgical properties of these type of joints were investigated. These type of joints are exposed to strong corrosive mediums such as H_2S, SO_2, and SO_3. Thus, they should possess good mechanical properties and corrosion resistance. Also, several post weld heat treatment regimes were studied and the proper one will be introduced.

2. Materials and Experimental Procedure

2.1 Base materials

The base metals used in this experimental work were 3 mm sheets of low carbon steel (AISI 1008) and nickel base alloy (AISI Monel 400). The chemical composition of the base metals is listed in **Table 1**.

---

† Received on December 18, 2000

* Associate Prof., CMRDI, Cairo, Egypt
** Professor, Suez Canal Univ., Egypt
*** Graduate Student, CMRDI, Cairo, Egypt
**** Professor

Transactions of JWRI is published by Joining and Welding Research Institute of Osaka University, Ibaraki, Osaka 567-0047, Japan.

Table 1 Chemical composition of base metals

Chemical composition, %	Low carbon steel 1008	Monel 400
Fe	99.33	1.5
Ni	0.228	64.8
Cu	0.059	32.58
Mn	0.218	1
Si	0.047	0.05
C	0.1	0.07
Cr	0.018	---

2.2 Filler materials

According to the results of the previous work[2] nickel-based electrodes were considered suitable for these types of joints. The chemical composition of the used electrodes is listed in **Table 2**.

2.3 Welding procedure

The base metals were prepared as strips with the dimensions of 150×70×3 mm. Shield metal arc welding process was adopted in this work. A short arc and flat bead was maintained during welding. The welding parameters are given in **Table 3**.

2.4 Post weld heat treatment

Four suggested post weld heat treatment cycles were carried out in inert nitrogen atmosphere. The post weld heat treatment parameters are shown in **Fig. 1**.

Table 2 Chemical composition of welding electrodes

Chemical composition, %	EniCu-7	EniCrFe-3
Ni+Co	62	Bal
Cu	Bal	0.1
Mn	4	7.75
Fe	2.5	7.5
Si	1	0.5
C	0.15	0.05
S	0.015	0.008
Al	0.75	---
Ti	1	0.04
Nb+Ta	---	1.75
Cr	---	14

Table 3 Welding Parameters

Current, A	80
Travel speed,(mm/s)	3.75
Voltage, V	12
Polarity)	DCSP
Groove position	Flat

2.5 Chemical analysis

Chemical analysis of the weld metal was carried out by three different methods. First, by using dilution calculations on the measured welded area. The following equation was used[3]

$$X_W=(D_A)(X_A)+(D_B)(X_B)+(1-D_T)(X_F)$$

Where

X_W=the average percentage of element X in the weld metal
X_A=the average percentage of element X in base metal A
X_B= the average percentage of element X in base metal B
X_F=the average percentage of element X in filler metal F
D_A=the percentage of dilution by base metal A
D_B= the percentage of dilution by base metal B
D_T=the percentage of total dilution by base metals A&B

The value of D_A, D_B and D_T are giving in **Table 4** for both electrodes.

The second method was carried out using spectrometer analysis. While, the third method was done by using EDX.

2.6 Corrosion test

Corrosion tests were carried out using potentio dynamic polarization tests (potentiostate/galvanostate model 273 A), at a scan rate of 1 mv/s. The corrosive environment was 10% sulfuric acid solution at room temperature. All samples used in the corrosion tastes were ground and polished through 0.3 micron alumina suspension. The potentioscan operation is schematically shown in **Fig. 2**.

Table 4 Values of dilution calculation

Type of Electrode	Sharing %		Total Dilution %
	Carbon steel D_A	Monel D_B	D_T
ENiCu-7	55	45	40.3
ENiCrFe-3	58	42	35.5

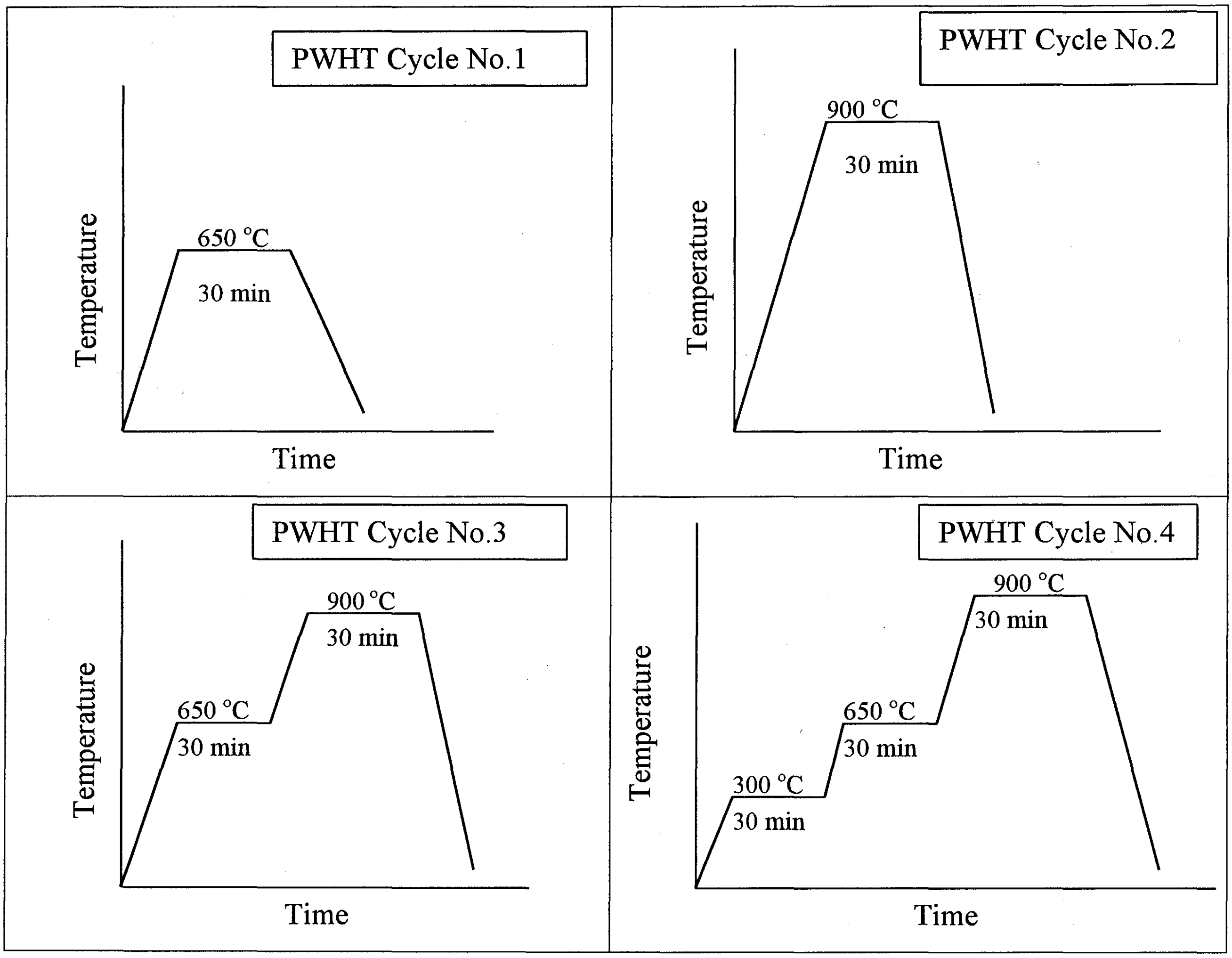


Fig. 1 Schematic illustration of the suggest post weld heat treatment cycles

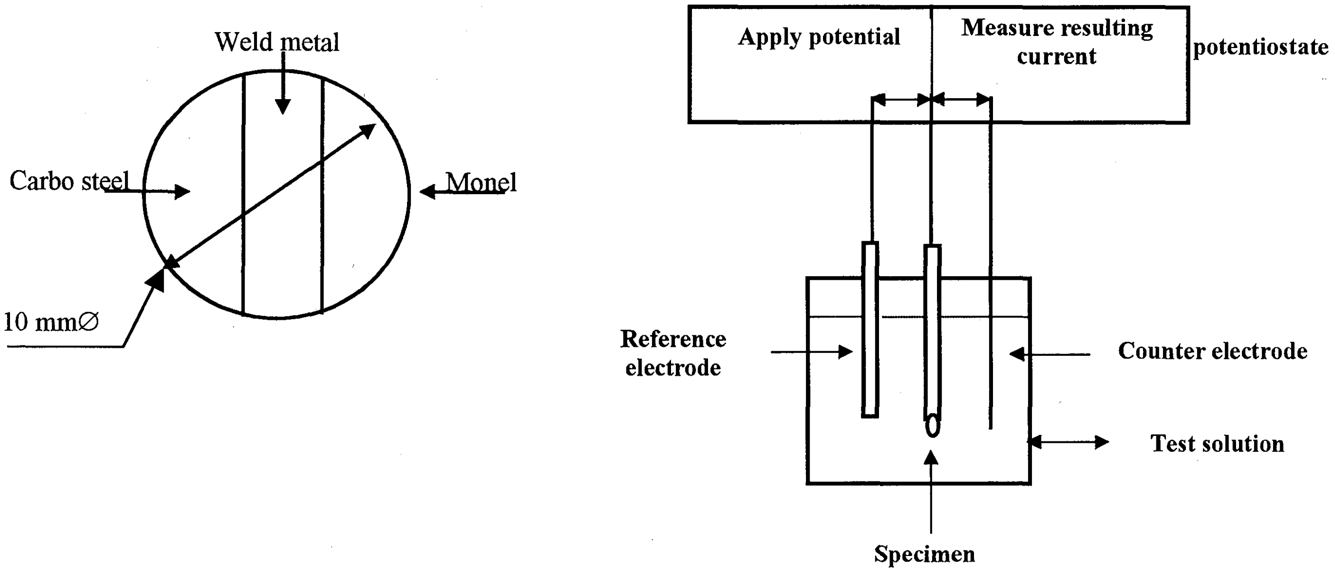


Fig. 2 Schematic diagram showing the potentiostate operation and specimen configuration.

Table 5 Overall results of weld metal composition.

Electrode Type	Analysis method	Chemical composition , wt%				
		Ni	Cu	Fe	Cr	Mn
ENiCu-7	Calculated	50.66	25.49	22.47	---	---
	Spectrometer analysis	51.41	23.2	23.21	---	---
	EDX analysis	52.5	24.1	21.1	---	---
ENiCrFe-3	Calculated	49.65	6.19	33.53	7.5	1.9
	Spectrometer analysis	50.8	7.16	29.12	7.15	2.39
	EDX analysis	49.7	7.8	32.9	6.5	2.77

3. Results and Discussion

3.1 Chemical composition of weld metal

Results of weld metal composition, for both ENiCu-7 and ENiCrFe-3 electrodes, by using the three different methods are shown in **Table 5**. Obviously, the differences between results are so close for the same electrode type.

Accordingly, fully austenitic weld metal could be obtained when using both types of electrodes. The effect of different post weld heat treatment regimes has no significant effect on the chemical composition, but it may affect the formed phases. Therefore, the welded joints were investigated by X-ray diffraction analysis before and after post weld heat treatments to identify the change in phases that may took places after PWHT.

Figure 3 shows the X-ray diffraction pattern for welded joints produced by ENiCu-7 electrode in the as welded condition and after PWHT cycle No.1 and cycle No.4. Cycles No.2&3 did not reflect remarkable change with the result of treatment cycle No.4. Generally, the welded zone is mainly solid solution of nickel base with soluble elements of copper and iron. However, treatment cycle No.1, reflected the formation of α-iron phase. The formation of this phase did not remarkably observed after the other cycles. This may be attributed to the lowest temperature range of the treatment cycle No.1.

In case of welded joints produced by using E-NiCrFe-3 electrode the welded zone is mainly solid solution of nickel base with soluble elements of iron, chromium and copper, as shown in **Fig. 4**. The α (Fe+Cr) phase can be remarkably observed in all weldments before and after post weld heat treatment. However, the presence of α (Fe+Cr) phase drastically decreased with post weld heat treatment. That can be attributed to the increasing of solubility rate of α (Fe+Cr) phase in γ Ni phase with the increase in temperature. Thus, post weld heat treatment cycle No.4 showed the lowest content of α (Fe+Cr) phase as indicated from the decrease in intensity ratio of X-Ray diffraction analysis as shown in Fig. 4.

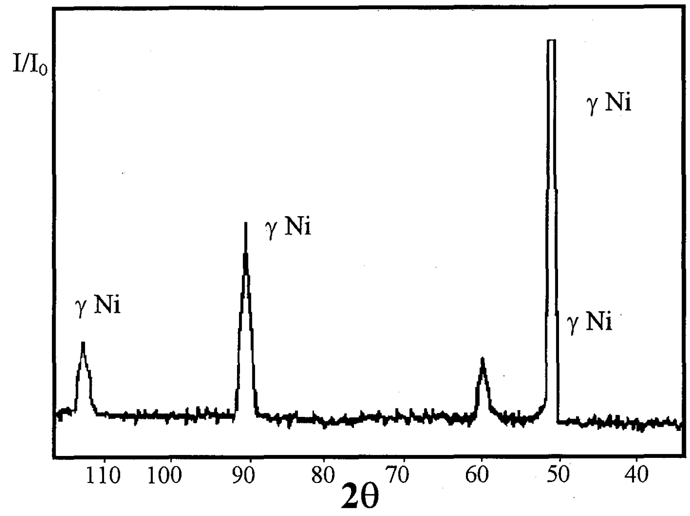
It is worth to note that for both electrodes, the movement of carbon in nickel base alloys is relatively slow and, certainly, at the temperatures likely to be encountered in those PWHT cycles. It is unlikely to cause any difficulty. In fact, the diffusion rate of carbon from a low alloy steel into austenitic materials decreases as the nickel content of the austenitic materials increase[4)]. Based on that, the ENiCrFe-3 electrodes is highly recommended because they will produce single phase welds of high strength that will resist structural changes and have intermediate expansion properties.

Furthermore, these results could explain the previous results of the mechanical properties for both electrodes[2)]. It was found that the PWHT cycle No.1 had a significant effect to increase the values of both UTS and $\sigma_{0.2}$ for the investigated electrodes. While, PWHT cycle No.4 showed the lowest values of UTS and $\sigma_{0.2}$. This may be related to the presence of both α-iron in case of ENiCu-7 electrode and α (Fe+Cr) in case of ENiCrFe-3 electrode. Therefore, the PWHT cycle No.1 can readily be recommended for this type of dissimilar joints.

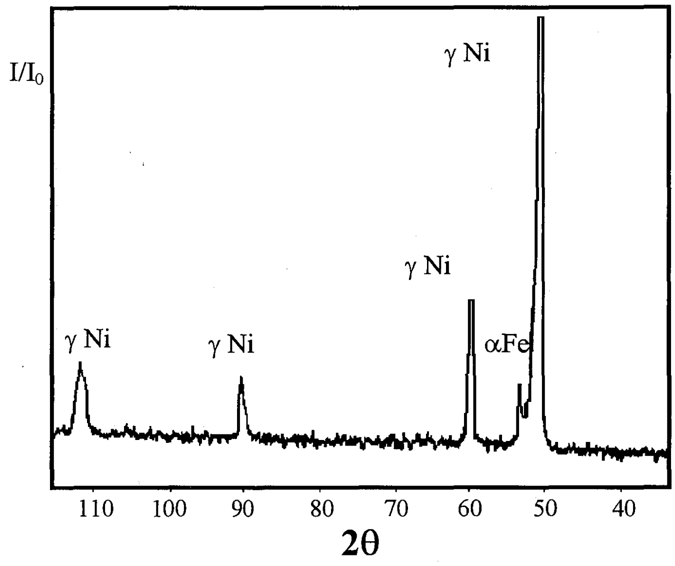
3.2 Corrosion resistance

3.2.1 Polarization curves

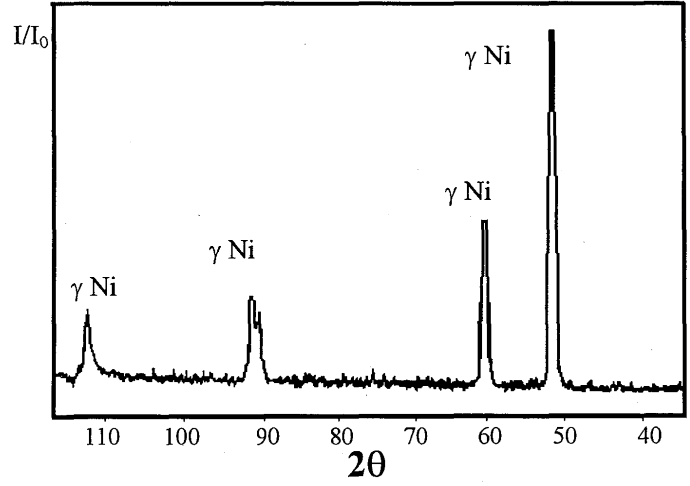
Figure 5 shows the anodic and cathodic polarization curves of the base metal in 0.5 M H_2SO_4 solution. Monel 400 shows passivity due to the formation of a CuO + NiO passive films on the surface while carbon steel shows no passivity. **Figure 6** shows the anodic and cathodic polarization curves of welds before and after different post weld heat treatment cycles, employing ENiCu-7 and ENiCrFe-3. Generally ENiCu-7 electrode is seen to shift the anodic polarization curves to lower current densities indicating a retardation of the anodic dissolution of the weld. For both ENiCu-7 and ENiCrFe-3, post weld heat treatment No.4 also shifts the anodic polarization curves toward the lowest current densities and exhibits passivity.



As Welded

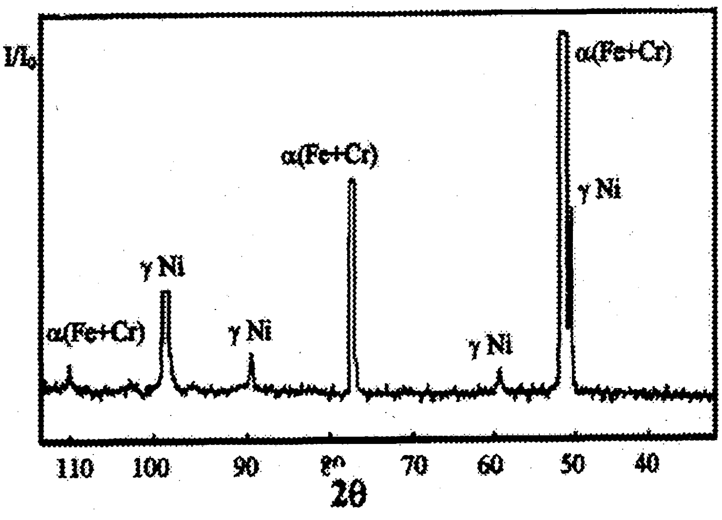


After PWHT Cycle No.1

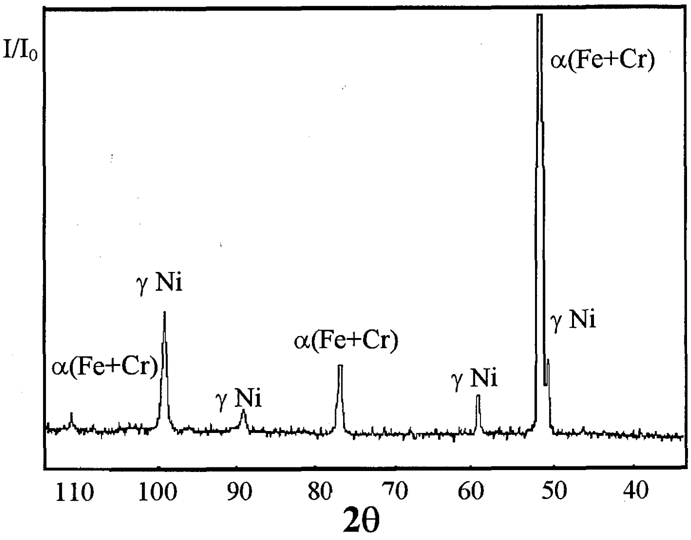


After PWHT cycle No.4

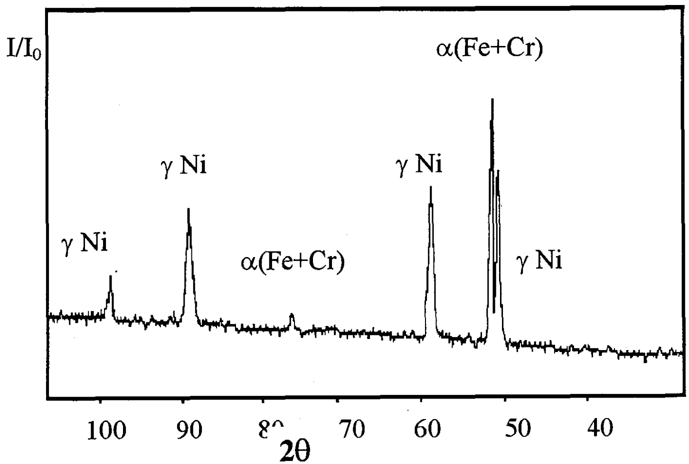
Fig.3 X-Ray diffraction analysis for weldments produced by ENiCu-7.



As Welded



After PWHT Cycle No.1



After PWHT Cycle No.4

Fig.4 X-Ray diffraction analysis for weldments produced by ENiCrFe-3

Table 6 Corrosion Rates of different weldments

	Corrosion rate, mpy	
Condition	ENiCu-7	ENiCrFe-3
Base metal carbon steel	6.01	
Base metal monel alloy	0.06	
As welded	1.38	1.91
Treatment 1	2.2	2.6
Treatment 2	1.05	1.41
Treatment 3	1	1.34
Treatment 4	0.87	1.02

3.2.2 Corrosion intensity

Corrosion rate (Rmpy) corresponding to base metals, as weld, and after different post weld heat treatment cycles were estimated using the linear polarization technique. For both ENiCu-7 and ENiCrFe-3, the obtained results are listed in **Table 6**.

ENiCu-7 exhibits the lowest corrosion rates for the all conditions, i.e. as weld and after different post weld heat treatment cycles. Moreover post weld heat treatment cycle No.4 has the greatest corrosion resistance while the lowest corrosion resistance was accompanied with post weld heat treatment cycle No.1 for both ENiCu-7 and ENiCrFe-3 electrodes. This could be explained by the lowest content of α phase after post weld heat treatment No.4 compared with its content after post weld heat treatment No.1.

3.2.3 Attack Morphology

Figure 7 shows macrographs of the corrosion product formed under controlled dissolution at about 6 mA/cm^2 and holding for 30 min. In this way the comparison of the surface morphology of different cases was made under condition of an equal degree of attack. The percentage corrosion product (darken spots) on the samples could be taken as an indicator of corrosion. It is important that ENiCu-7 electrode provides better corrosion resistance which is in good agreement with corrosion rate measurement.

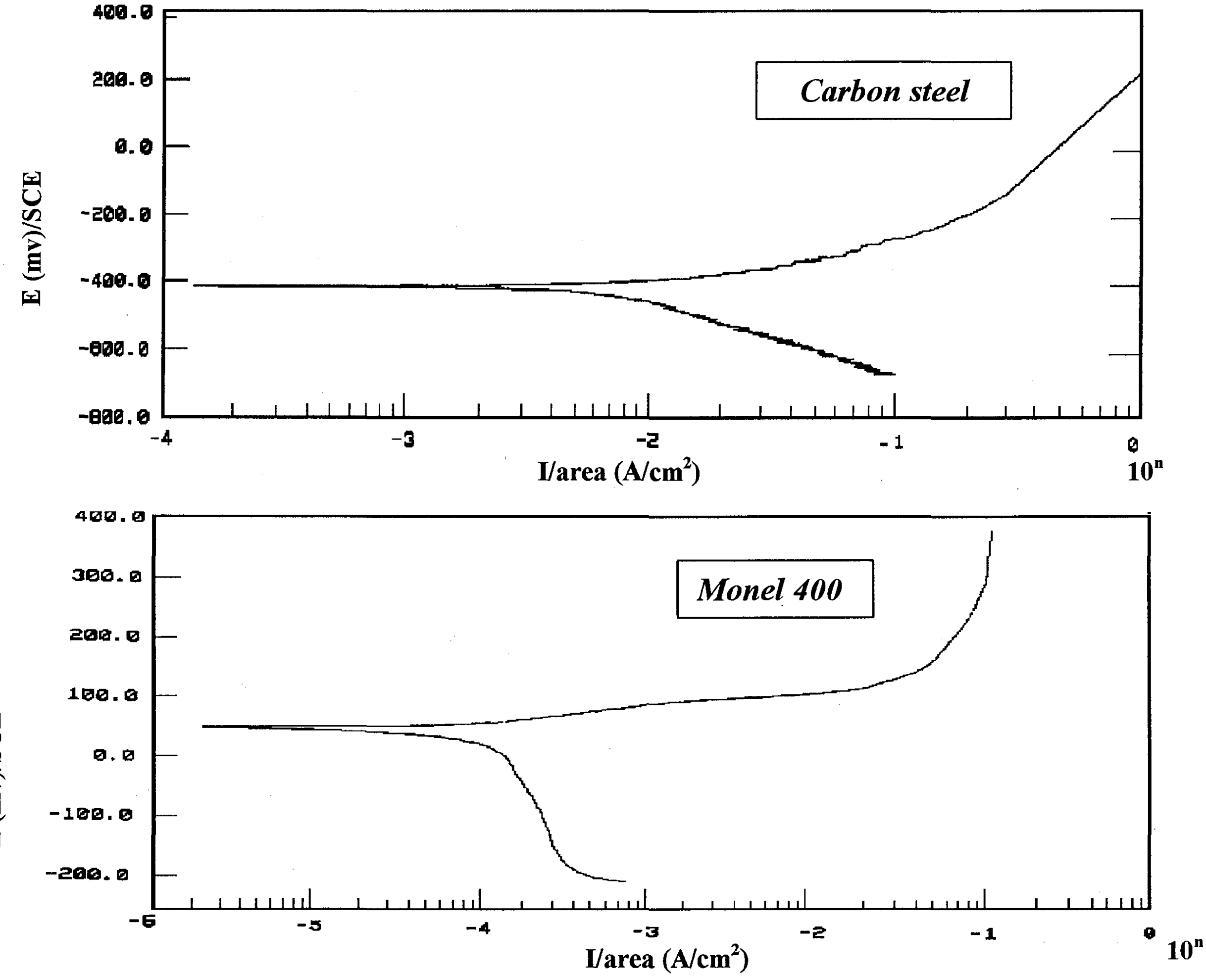


Fig. 5 Anodic and cathodic polarization curves of carbon steel and Monel 400 in 10% H_2SO_4 solution.

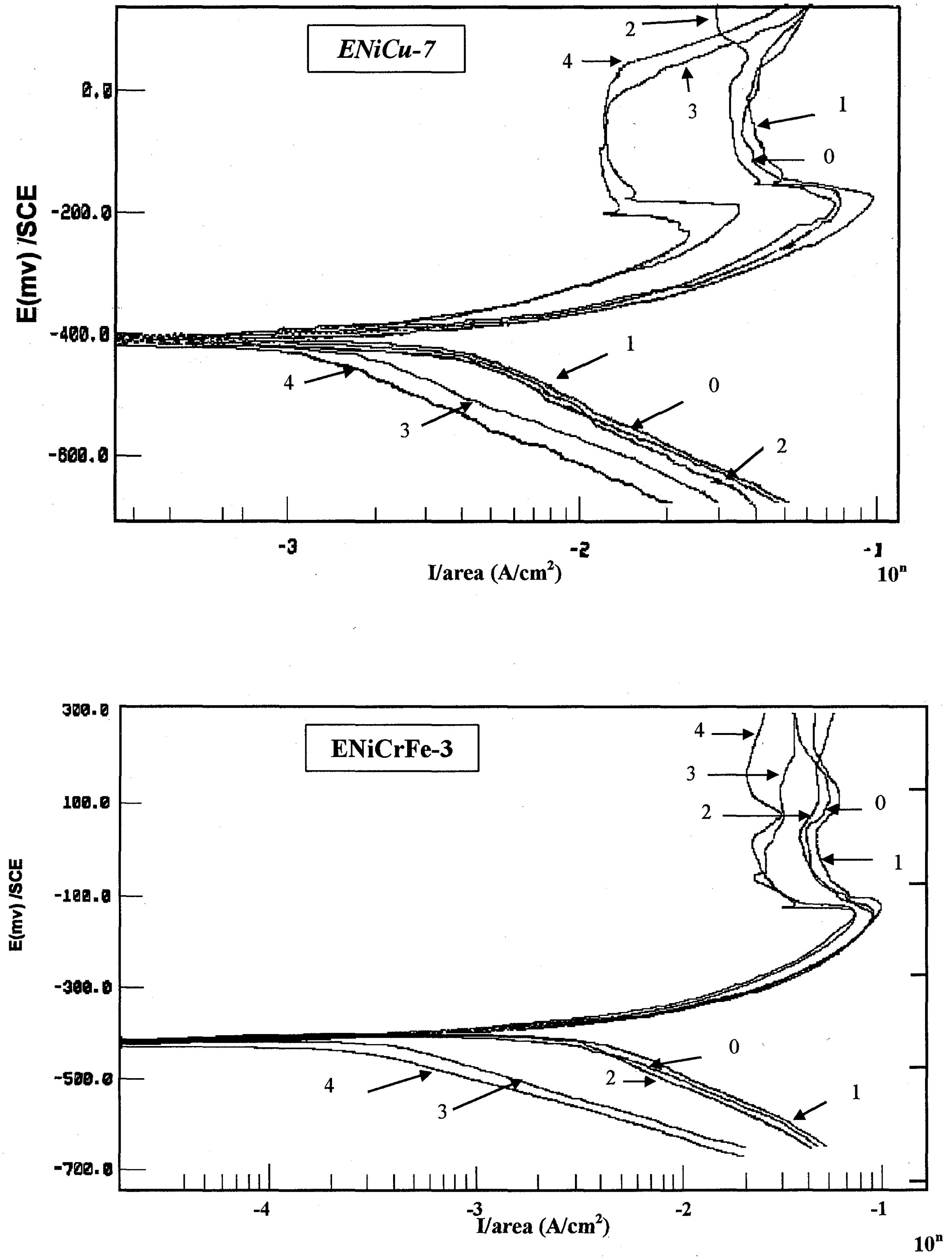
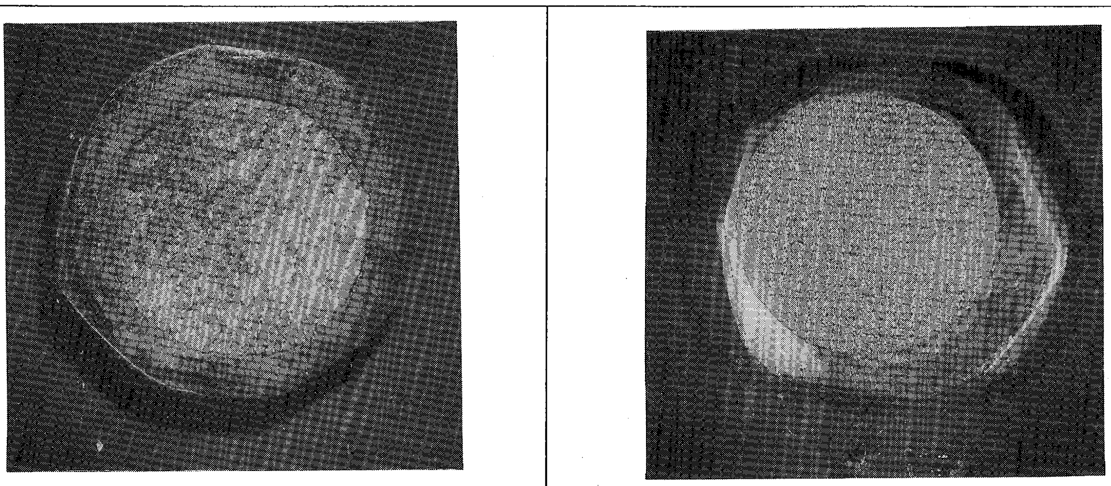
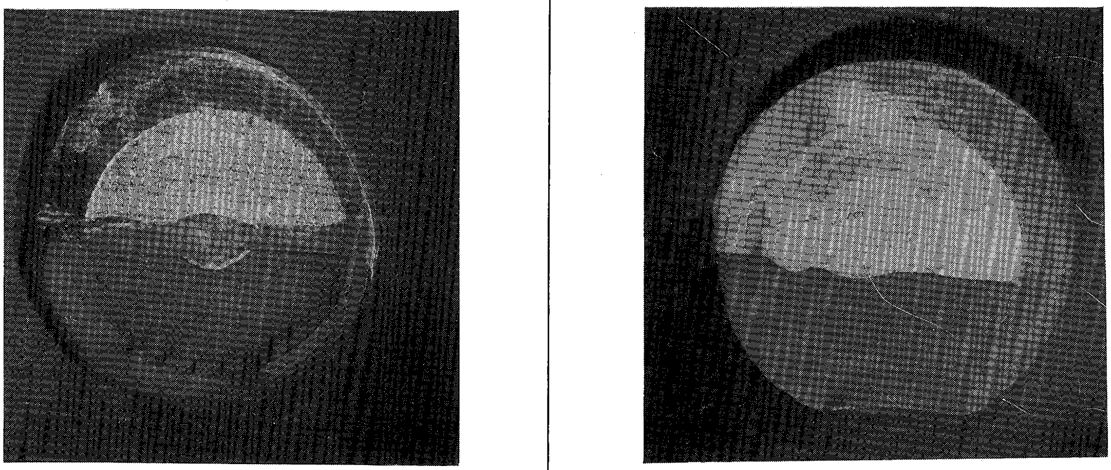


Fig.6 Anodic and cathodic polarization curves of monel-carbon steel weldments, produced by ENiCu-7 and ENiCrFe-3, electrodes before and after different post weld heat treatments in H_2SO_4 solution.



Carbon Steel | Monel



ENiCrFe-3 | ENiCu-7

Fig. 7 Surface morphology of corrosion test samples.

4. Conclusions

Chemical composition, dilution and corrosion resistance of joints between Monel 400 alloy and low carbon steel were investigated. The following conclusions can be drawn from the investigation:

(1) The average chemical composition for weld metals were calculated base on the average dilution of welds. It was shown that the predicted weld analysis more or less agrees with experimentally measured results.

(2) The post weld heat treatment cycle No.4 (heating at 300 °C, holding for 30 min then heating at 650 °C holding for 30 min, heating to 900 °C, holding for 30 min and then rapid cooling) gives the lowest corrosion rate. However, in the previous study, post weld heat treatment cycle No.1 (heating at 650 °C, holding for 30 min then cooling) exhibit the highest ultimate tensile strength and proof strength among the other treatment cycles. Thus, depending on the application conditions the proper post weld heat treatment regime should be selected carefully.

References

1) Castro R. and De cudenet J.J., "Welding Metallurgy of Stainless and Heat Resisting Steel", Cambridge University Press, London, 1972, PP.142-146.
2) Sadek A.A et al, "Investigation of dissimilar Joints Between Low Carbon Steel and Monel 400", To be published in Trans. JWRI.
3) Welding Handbook, Vol.7, 8th edition, American Welding Society, Miami, FL, 1991.
4) Payne B.E., "Nickel-Base Welding Consumables for Dissimilar Metal Welding Applications", Metal Construction, Vol.1, No.125, 1969, PP.79-87.