Title	Investigation of Dissimilar Joints Between Low Carbon Steel and Monel 400(Materials, Metallurgy & Weldability)
Author(s)	Sadek, Alber A.; Abass, Mahmoud; Zaghloul, Bahaa et al.
Citation	Transactions of JWRI. 2000, 29(1), p. 21-28
Version Type	VoR
URL	https://doi.org/10.18910/5575
rights	
Note	

Investigation of Dissimilar Joints Between Low Carbon Steel and Monel 400[†]

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

Abstract

A series of studies were carried out to examine the weldability and properties of dissimilar joints between low carbon steel and Monel 400 alloy. Such joints are important parts in oil gasification plants. This kind of joint requires good mechanical properties, a stable magnetic permeability besides good weldability. The joints made with the welding procedure that was developed are not susceptible to hot cracking. The joints after post weld heat treatment (heating up to 650oC, holding for 30 min then rapid cooling), exhibit satisfactory mechanical properties. The results of various tests indicated that the quality of the joints is satisfactory for meeting all of the design requirements.

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

1. Introduction

Dissimilar metal joints are widely used in many products in chemical, petrochemical and nuclear engineering. The application of the dissimilar metal joints not only satisfies the different requirements of various service conditions, such as heat resistance, corrosion resistance and magnetic properties, but may also result in large savings of novel and expensive materials, reducing the cost of products. There are even cases for which there is no choice other than to join dissimilar metals together in a single product to meet the design requirements. Dissimilar metal weldments are particularly characterized by compositional gradients and microstructural changes, which produce large variations in chemical, physical and mechanical properties across the weldment. Welding dissimilar metals is therefore normally more complex than joining similar metals. The difficulties encountered when joining dissimilar metals include problems experienced when welding each base metal individually, and problems unique to the range of compositions and properties possible when combining the alloys in various proportions. Further complexity arises with the addition of filler metal, which is a common practice in dissimilar metal welding.

In this study, the welding of Monel 400 to carbon steel is reported. Products made from such joints are designed for application in oil gasification plants at which there is a certain mixture of gases in each zone of the plant. Joints are exposed to strong corrosive mediums such as H2S, SO2 and SO3. Thus, they should possess good mechanical properties and corrosion resistance.

The objective of the present work is to investigate the weldability and essential properties of the above-mentioned dissimilar metal joints. Plate to plate welding was examined. The joint configuration was chosen to simplify the weldability studies. The work was intended to provide sufficient data for manufacturing a real product.

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 are listed in **Table 1**.

2.2 Filler materials

Two types of filler materials were examined in order to compare their suitability for welding the dissimilar steel joint in question. The principles used in choosing filler materials were the following. Firstly, weld metal properties should satisfy the requirements of the product, in particular this concerns the toughness. Secondly, the thermal expansion coefficient should lie in between those of the base materials in order to improve the thermal

---

† Received on May 31, 2000

* Prof., CMRDI, Cairo, Egypt
** Suez Canal Univ., Egypt
*** CMRDI, Cairo, Egypt
**** Student, CMRDI, 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	---

fatigue properties of the joints. Thirdly, hot and cold cracking should not occur. According to these criteria, nickel-based filler was considered superior to other materials in overall performance. In order to make a systematic comparison, two filler materials, listed in **Table 2**, were used.

2.3 Welding procedure

A special welding jig (rigid fixture) was designed and fabricated to hold parts in alignment and to ensure accurate fit-up with no need for tack welding. Meanwhile, by using this jig, which restrains the test strips, the hot cracking tendency can be examined. The base metals were prepared as strips with the dimensions of 150 x 70 x 3 mm. The shielded metal arc welding process was adopted in this work. The joint configuration is shown in **Fig. 1**. A short arc and flat bead was maintained during welding. The joint was kept fixed until it cooled down. After slag removal, the samples were released from the jig. The welding parameters are given in **Table 3**.

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

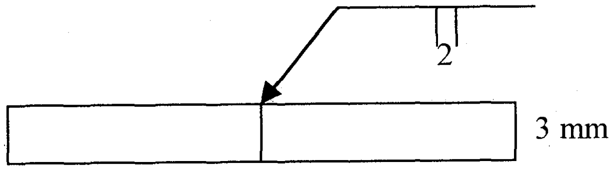


Fig.1 Joint design

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. 2**.

2.5 Metallographic investigation

Metallographic investigations were carried out after etching with two etching solutions, one for carbon steel side and the second for weld metal and Monel alloy side. Both optical and electron microscopy were used to examine the metallographic samples.

2.6 Mechanical testing

Various mechanical tests were conducted for welds employing the parameters given in Table 3. Tensile test specimens were machined from the welded strips, before and after PWHT for both electrodes.

Hardness was measured across the weldments using a Vickers diamond indentor with a load of 10 Kg.

3. Results and Discussion

3.1 Hot cracking tendency

Monel alloys are prone to hot cracking and particularly to solidification cracking. Although the ENiCrFe-3 and ENiCu-7 electrodes show good resistance to hot cracking when welding similar materials or Ni-Cr alloy[1], data is not available on its resistance when welding monel to low carbon steels. This subject needs to be examined in order to ensure the joint quality.

Examination of the restraint test samples by X-Ray and optical microscopy showed that solidification cracks occasionally occurred when using ENiCu-7 electrodes, while no cracks were found when using ENiCrFe-3 electrodes. The reasons may be partly due to the metallurgical effect of the electrodes. Accordingly to the Schaeffler diagram[2], fully austenitic weld metal will be

Table 3 Welding Parameters

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

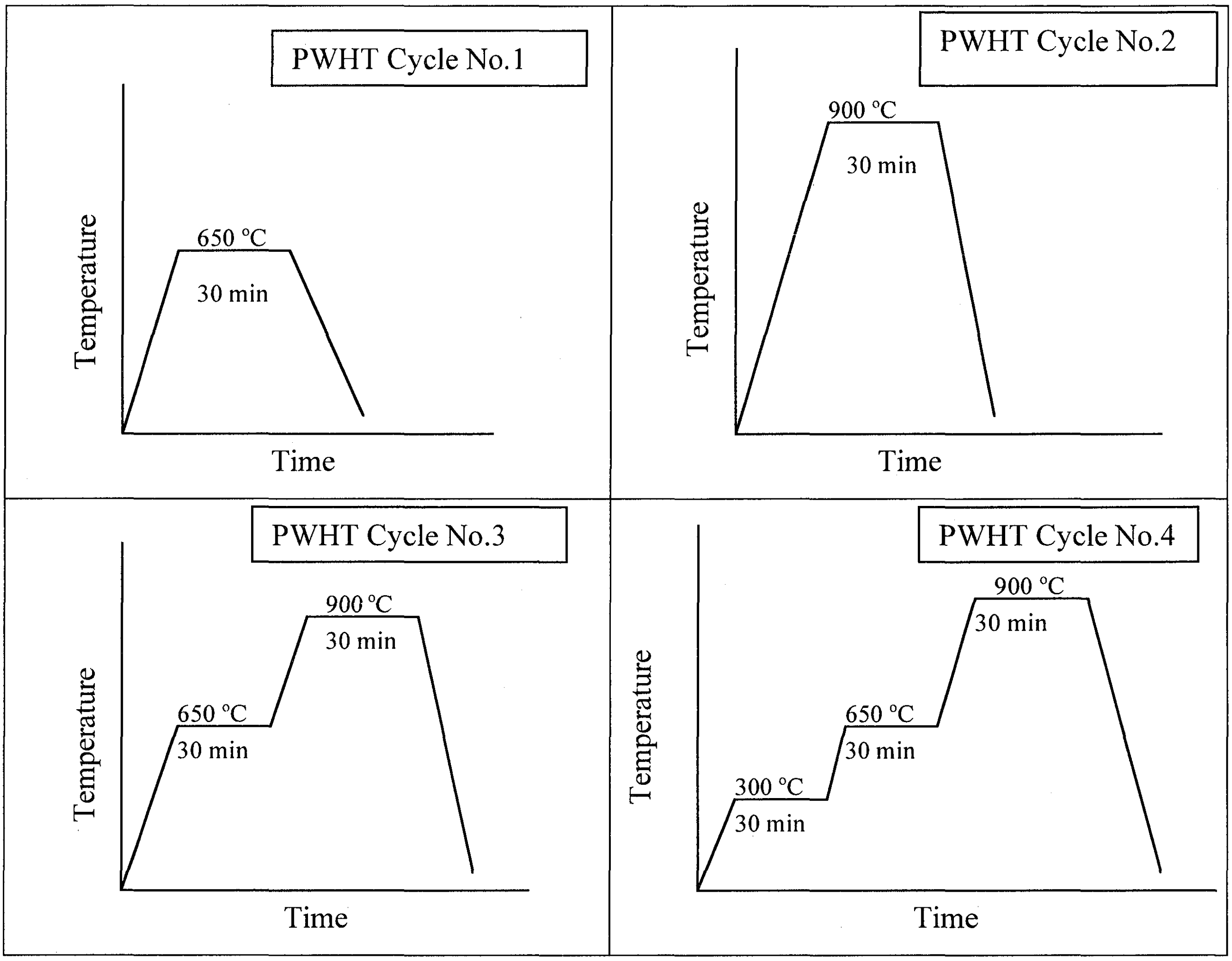


Fig. 2 Schematic illustration of the suggest post weld heat treatment cycles

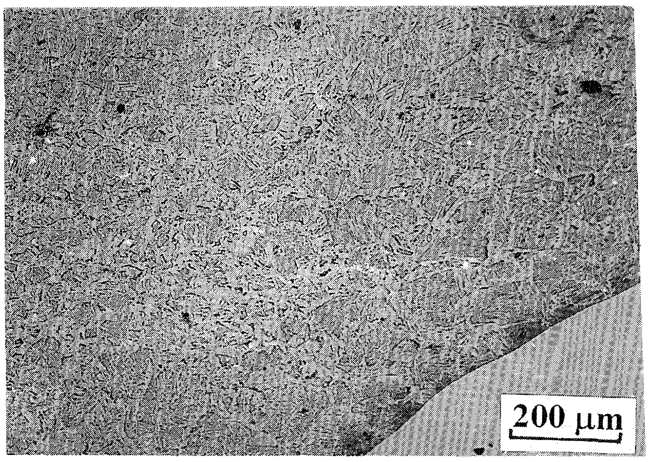


Fig. 3 Microstructure of carbon steel HAZ

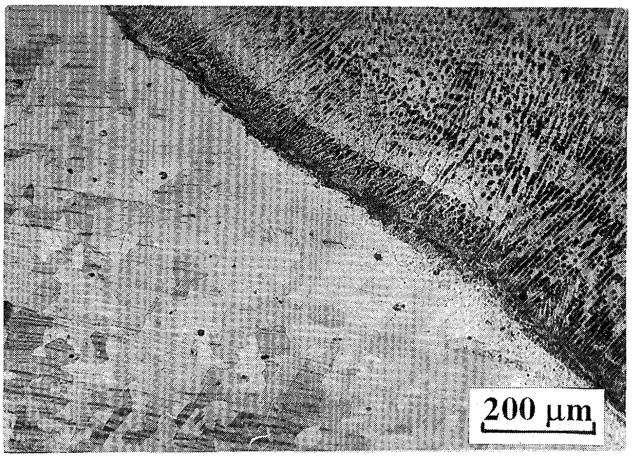


Fig. 4 Microstructure of Monel HAZ

obtained when using both types of electrodes. However, the Nb content is higher in welds using the ENiCrFe-3 electrode. This difference can, at least, partly explain why the hot cracking resistance is better when using the ENiCrFe-3 electrode than when using the ENiCu-7 electrode. In such cases, since a sufficient amount of Nb in the weld has been shown to improve hot cracking resistance, particularly of fully austenitic weld metal[1, 3].

3.2 Microstructure of welded joints

The welding electrodes under consideration are based on compositions involving simple face-center-cubic solid solutions. They readily take into solution nickel, copper, chromium, and iron to the level likely to be encountered in practice by dilution from the parent metals. The weld metal, therefore, will have the normal dendritic structure of single-phase material, for both electrodes. However, in the case of the ENiCrFe-3 electrode, chromium carbides were observed. The presence of these carbides may help to improve the mechanical properties slightly, with a correspondingly slight drop in ductility.

On the other hand, the microstructure of the carbon steel HAZ is bainitic with low amounts of martensite. The HAZ of the Monel alloy revealed grain coarsening at the adjacent area of the weld zone, as shown in **Figs. 3 and 4** for ENiCu-7 and ENiCrFe-3 electrodes respectively.

3.3 Post weld heat treatment

Generally, heating will have little or no effect on the nonmetallic component but it will affect the intermetallics. At intermediate temperatures, if there are any left in solution, carbides will precipitate at grain boundaries and also within the grains. Accordingly, for both ENiCu-7 and ENiCrFe-3 electrodes the result of PWHT showed that there are few differences in structure as a result of treatment cycle No. 1. This may be attributed to the lower heating temperature, which is below the transformation temperature.

In case of treatment cycles No. 2, 3 & 4, phase transformation took place at low carbon steel side, because the temperature was above the transformation temperature. The structure in the carbon steel changed from bainitic structure to ferritic structure with low amounts of pearlite. While at the Monel 400 side, no remarkable changes were observed. **Figs. 5 and 6** show the microstructure after PWHT cycles No.1 and 4 respectively for both electrode types.

On the other hand, the diffusion 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 however 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 material increases[4]. Based on that, the ENiCrFe-3 electrodes are highly recommended because they will produce single phase welds of high strength that will resist structural changes and have intermediate expansion properties.

3.4 Mechanical properties

Tensile test results for all weldments are listed in **Table 4**. It should be noted that both electrodes showed same values of Ultimate Tensile Strength (UTS) and proof strength ($\sigma_{0.2}$) for the original weld.

Also, the bending test results were satisfactory for weldments with both electrode types. All the bending samples, including face bending, root bending were without any crack for 180 degree. This result indicates that the joints have sufficient ductility.

Furthermore, a comparison was made between different post weld heat treatment cycles. It was found that the PWHT cycle No. 1 had a significant effect in increasing the values of both UTS and $\sigma_{0.2}$ for the investigated electrodes. While, PWHR cycle No. 4 showed the lowest values of UTS and $\sigma_{0.2}$. This may be related to the changes in microstructure, which occurred as described above. Therefore, the PWHT cycle No. 1 can readily be recommended for this type of dissimilar joint.

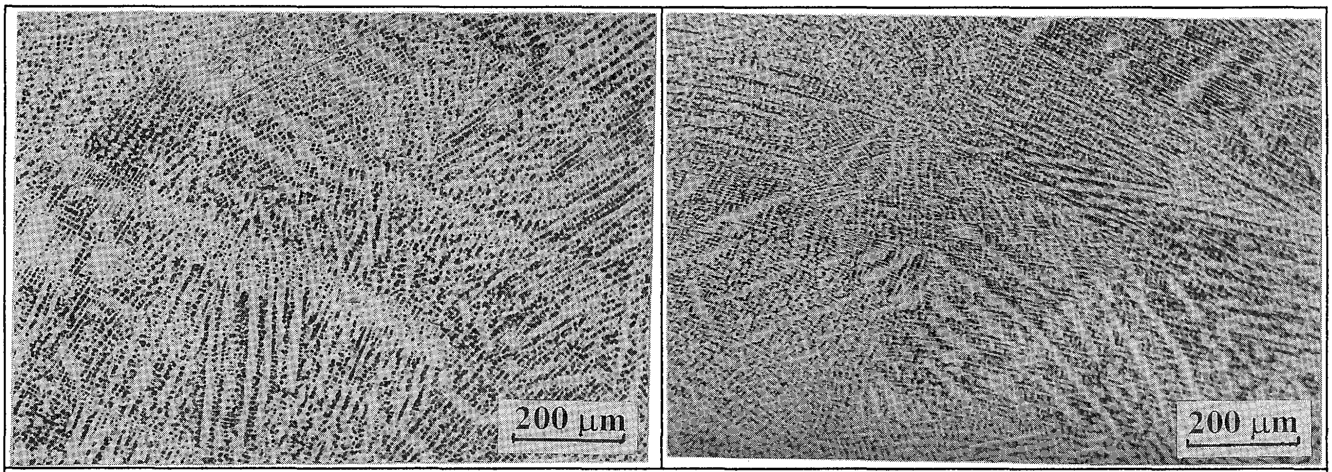
Complete stress versus strain curves were obtained by measuring the strain in the gauge length section of the tensile specimen using an extensometer attached to the specimen. The results obtained are shown in **Figs. 7 and 8** for ENiCu-7 and ENiCrFe-3 electrodes respectively. Again, the PWHT cycle No.1 showed the higher values compared with either the original weld or the other PWHT cycles.

Hardness profiles across the fusion line and HAZ for all joints are given in **Fig. 9**. For both tested electrodes, the hardness profile across the joint cross section showed a peak value at the weld zone compared with that of both base metals and HAZ. It can be seen from Fig. 9 that PWHT generally reduced the hardness, which may improve the toughness of the corresponding regions. However, PWHT cycle No. 1 gave the highest hardness values among other PWHT cycles.

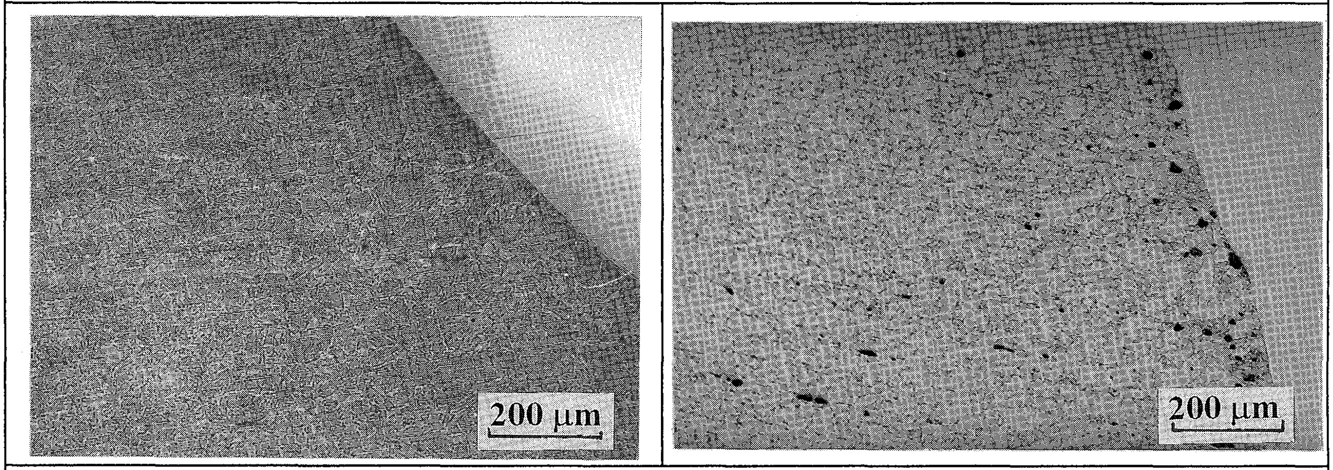
4. Conclusions

Weldability and properties of joints between Monel 400 alloy and low carbon steel were investigated. The following conclusions can be drawn from the investigation:

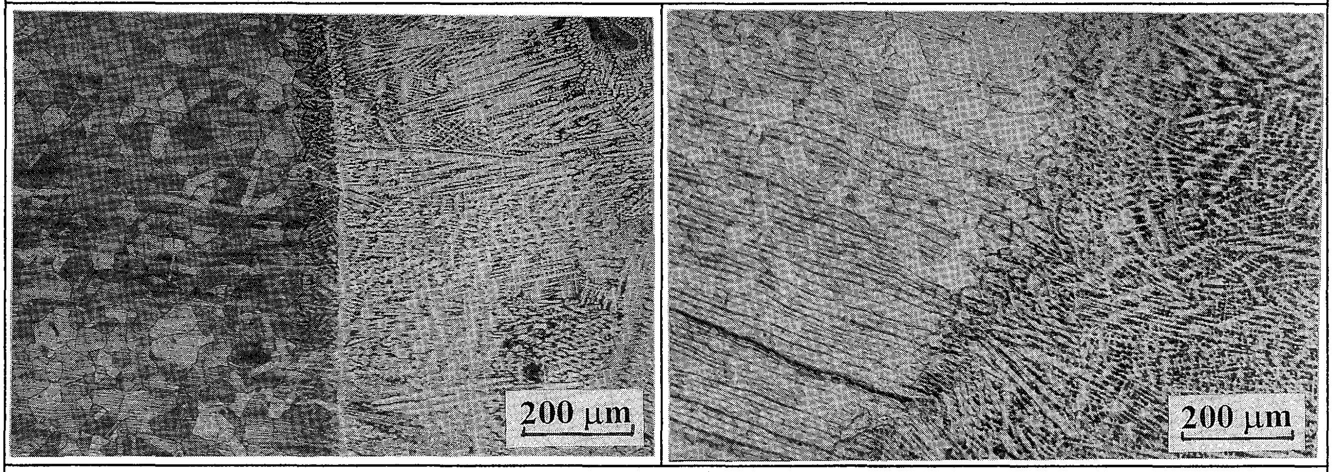
1. Hot cracking resistance of this dissimilar joint is satisfactory when using the ENiCrFe-3 electrode.



Weld metal



Carbon steel HAZ



Monel HAZ

PWHT cycle No.1 | PWHT cycle No.4

Fig. 5 Microstructure of different regions of weldments produced by ENiCu-7 electrode after various PWHT cycles

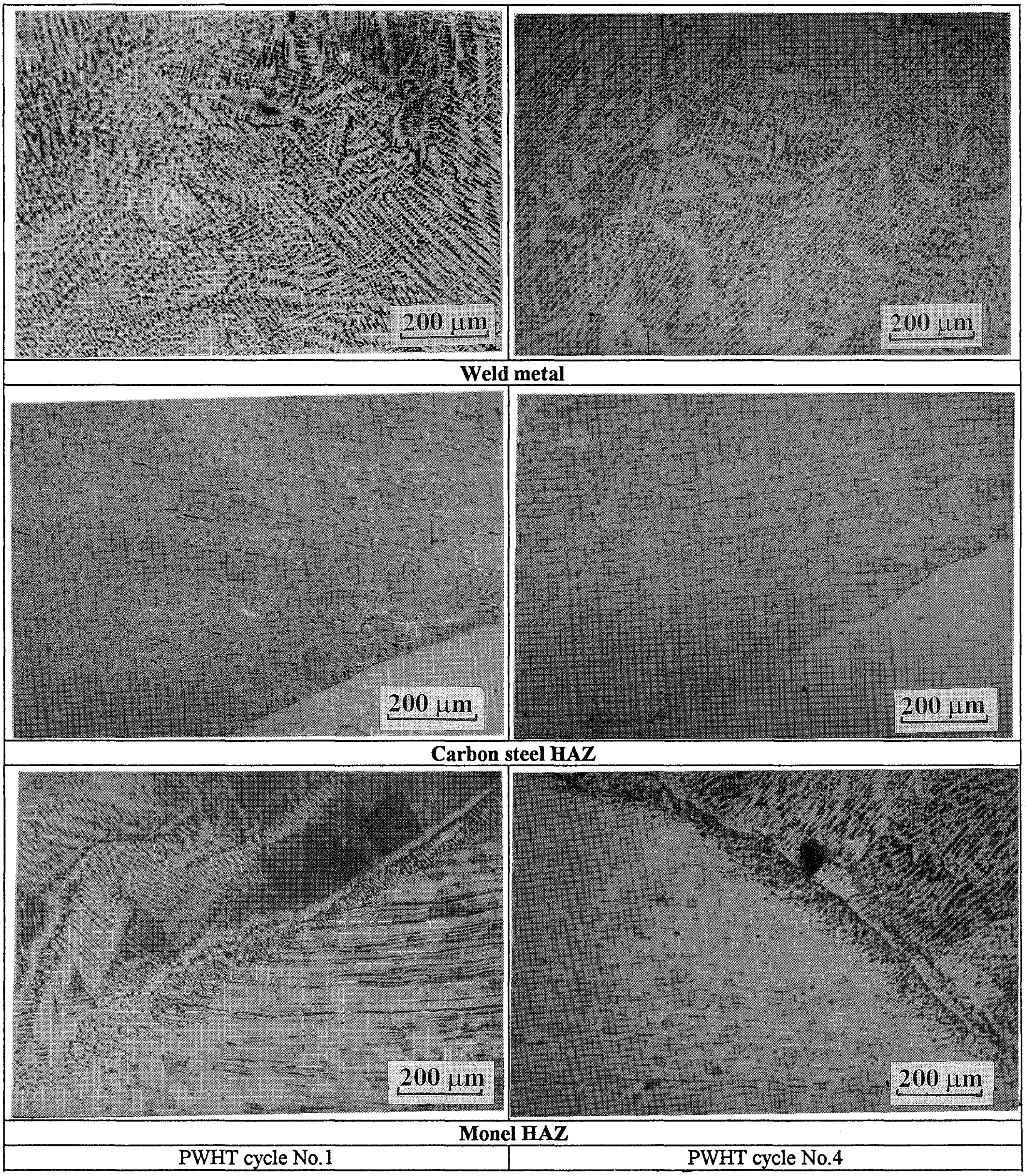


Fig. 6 Microstructure of different regions of weldments produced by ENiCrFe-3 electrode after various PWHT cycles

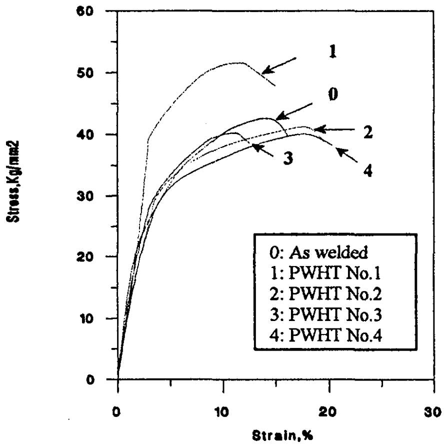


Fig. 7 Stress/Strain diagrams of joints produced by ENiCu-7 before and after post weld heat treatments.

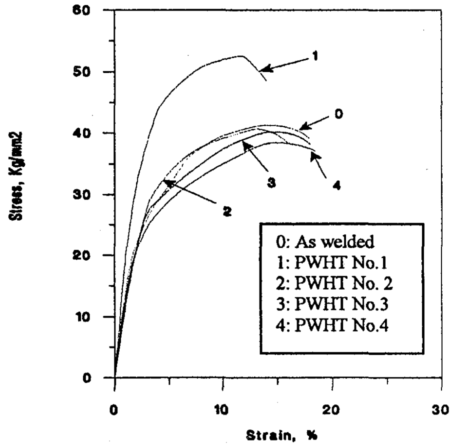
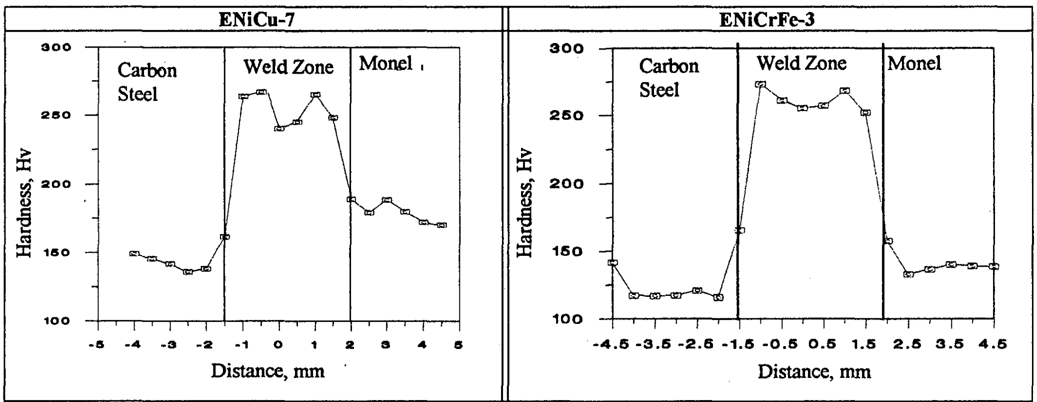
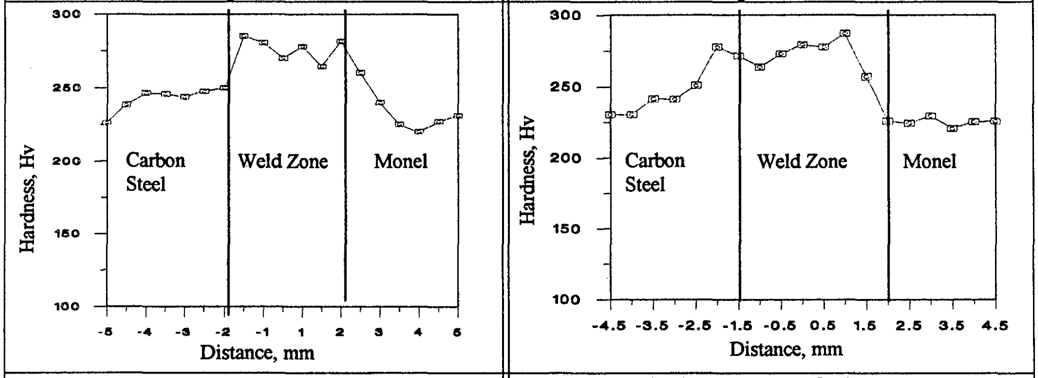


Fig.8 Stress/Strain diagrams of joints produced by ENiCrFe-3 before and after post weld heat treatments.



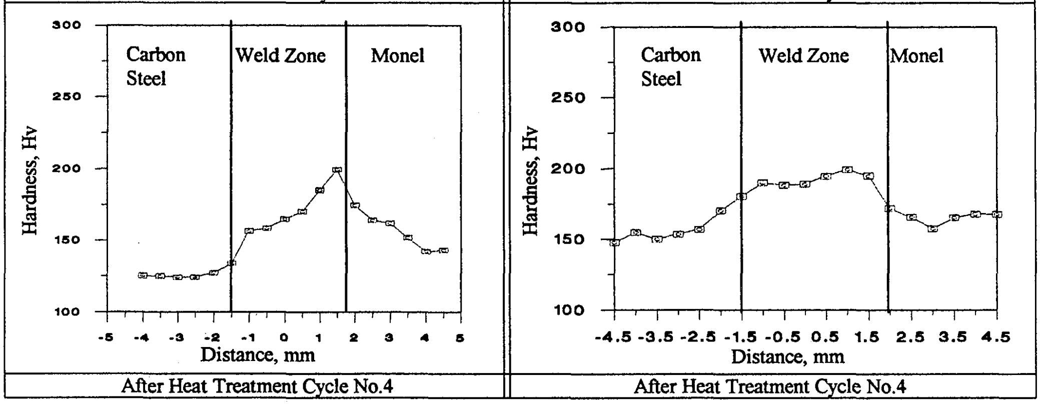
Original Weld

Original Weld



After Heat Treatment Cycle No.1

After Heat Treatment Cycle No.1



After Heat Treatment Cycle No.4

After Heat Treatment Cycle No.4

Fig.9 Hardness distribution along weldments for both electrode types before and after post weld heat treatment

Table 4 Overall results of UTS and $\sigma_{0.2}$

	Electrode type			
Condition	ENiCu-7		ENiCrFe-3	
	UTS	$\sigma_{0.2}$	UTS	$\sigma_{0.2}$
As welded	42.46	31.8	41.2	31.5
PWHT 1	51.85	41.44	52.5	44
PWHT 2	41.71	31.75	40.7	29.4
PWHT 3	41.1	31.6	40.3	29
PWHT 4	39.86	28.18	38.3	27.5

2. The weldments made by both electrodes and with appropriate procedures exhibit satisfactory mechanical properties. It can be said that the tests performed strongly imply that the weld joints exhibit good mechanical properties and can meet the design requirements of low carbon steel/Monel 400 joints.

3. Post weld heat treatment cycle No. 1 (heating at 923 K, holding for 30 min then cooling) exhibits the highest ultimate tensile strength and proof strength among the other treatment cycles. Thus, it can readily be recommended for such types of joint.

4. Tube/tube joints can be welded successfully using the recommended welding procedure based on the plate form joints.

5. As a concluding judgement, the joints produced in the manner recommended in this study, were demonstrated as suitable for application in oil gasification plants.

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. Schaeffler A.L., "Constitutional Diagram for Stainless Steel Weld Metal", Metal Progress, Vol.56, No.5, 1949, PP.680-680B.
3. Sun Z., "A study of Solidification Crack Susceptibility Using the Solidification Cycle Hot Tension Test", Materials Science and Engineering, Vol.A154, 1992, PP.85-92.
4. Payne B.E., "Nickel-Base Welding Consumables for Dissimilar Metal Welding Applications", Metal Construction, Vol.1, No.125, 1969, PP.79-87.