EVALUATION OF CORROSION BEHAVIOR AND ELECTROCHEMICAL CHARACTRISTIC OF WELDED STEEL ALLOYS

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ABSTRACT

Two types of steel alloys (St.17Mn1Si and st.22MnAl) and their fusion welded parts applying different thermal treatment techniques were tested electrochemically. Their electrochemical characteristic including: the electrochemical potential values and current density of the base metals, heat affected zones and welding pools are estimated. Correlations are developed to express the effect of the electrochemical potential of the heat affected zone as an additional independent variable of the models. Also the evaluation of corrosion resistance behavior of welded alloys used as corrosion medium 3% NaCl solution in presence of air, oxygen and carbon dioxide for 3300 hrs. were investigated visually and experimentally using different techniques. The developed models estimated are candidated to be used to determine the electrochemical characteristics of other related classes of welded steel alloys.

الخلاصة

السبائك الفولاذية (st.1mn si , st.22 mnAl) التي اجري عليها عملية اللحام الانصهاري ، تمت معاملتها حرارياً واختبرت كهروكيمائياً . الخصائص الكهروكميائية تضمنت في الجهد الكهروكميائي وكثافة التيار للمعدن الاساس (B.M.) المنطقة المتاثرة بالحرارة (HAZ) ومنطقة الوصل (اللحام) (W.P) . طورت علاقات لبيان التاثيرات الكهروكيمائية السريعة على المنطقة المتاثرة بالحرارة . اضافة الى دراسة متغيرات اخرى .

لتقييم سلوك مقاومة التاكل للسبائك الملحومة استخدم وسط تاكلي 3 % NaCl مع air ، O_2 و Co_2 لفترة اختبار 3300 hrs . تم الاستقصاء المرئي والتجريبي باستخدام تقنيات مختلفة. النتائج التي تم ايجادها تؤيد الاعتماد عليها لتحديد الخصائص الكهروكيمائية وسلوك التاكل بالنسبة للسبائك الملحومة .

KEY WORDS
Electrochemical potencial, current density, heat affected zone, welding pool, corrosion resistance.

INTRODUCTION

Steel and welded steel alloys are the most important widespread structural engineering materials used in constructions. During service, the constructions are subjected to ecologically hazardous and corrosive media. As a result failures in metalworks occur owing mostly to corrosion damage (O.I Steklov 2001). From practical point of view, the most corrosion failure of steel equipments takes place on welded joints (O.I Steklov2001).

The procedure of welding includes several operations. Deviation of parameters of these operations often result in obtaining the welds of an favorable structural and phase composition (O.I Steklov 1996) which creates high electrochemical heterogeneity providing the chance to corrosion failure of the structure .

On the other hand stress concentration in the welded joints and, in some case low quality of welding are among the reasons causing failures of welded structures; because of that the reliability of the welded equipment is controlled by corrosion protection.

The environmental corrosivity may be attributed to several factors including : temperature . moisture . kind of soil (dry , flooded . frozen , thawed) , saturation by aggressive salt ions such as chloride and sulfate . pH of media and the groundwater level . the presence attendant corrosive components such as hydrogen sulfide , chlorine , carbon dioxide and dissolved ion impurities . Because of that, constructions operated under ecologically hazardous and corrosive conditions need systematic monitoring by which at present. there are unique developed technologies can be used such as ground penetration radar and concentration meters……etc(S. I. Poltayisev 1996).

The present paper concentrates on determination of the electrochemical characteristics of two bimetal – steel alloys welded using different thermal treatment. The work involves development of correlations to express the effect of the most important independent variable of the models. The corrosion behavior of the parent base alloys and the welded ones subjected to a salt solution in presence of different gaseous reagents is also investigated using weight loss method, optical microscopy and penetrating meter method.

The Experimental Part

1- Materials:

a- Carbon steel alloys grades; the chemical compositions and specimens dimensions are listed in table 1.

The steel specimens of each grade were welded using fusion welding (electric arc welding following standard procedure).

b- The corrosive media used for corrosion test was 3% wt. sodium chloride solution. The corrosion test was carried out via pumping air. O_2 and CO_2.

2- Instruments: -

The electrochemical test was carried out using an electrochemical testing device. The details of the test are clarified in plate (1).

3- The Corrosion test:

The main aim of carrying out this test is to measure the corrosion rate of the welded and the unwelded alloys. The test was conducting using the weight loss method following the sequence below:

1- The apparatus is a flask with a capacity of 1000ml with specimens support system.
2- The test solution was 3% by weight NaCl solution.
3- The specimens were firstly cleaned perfectly by removing substantial layer of the alloy with a course abrasive paper No. 50, then stamped with appropriate identifying number . and degreasing by acetone , and then air dried .
4- The dried specimens were weighed and recorded using analytical balance with an accuracy of ± 1×10^{-4}g.
5- The corrosion test was performed at ambient temp. 25±5 °C. the duration of the test was 3300 hr.
6- The specimens were then washed with distilled water and then with ethanol, dried for 5 minutes at 100 °C.

Results and Discussion:

In order to put in advance a reliable tool to analyze the electrochemical characteristics of the steel alloys and the bimetal welded steel alloys , a mathematical model is adopted to represent the variation of these characteristics as best as possible , as well as to activate it for adequate prediction of the electrochemical characteristics of other grades of steel alloys . Correlation were developed using least square method (Stress intensity factors 1987). The correlation were classified as a linear algebraic from. The dependent variables were the electrode potential of the base metals, the electrode potential of the welding pool , Kcm^{φ} (coefficient welding quality) , Kcm^{φ} % and their corresponding current density , while the independent variable was chosen to be the electrode potential of the heat affected zone (HAZ) .

Obviously, the entire models show arising behavior with the electrode potential of HAZ accepts that of Kcm^{φ} which inversely varied with the independent variable.

The best correlated result is referred to the relation of Kcm^{φ} with the electrode potential of HAZ (RSD = 0.0185). while the worse variation is associated with the electrode potential of welding pool (RSD = 0.299).

In ascending task, the best estimated correlation HAZ is denoted as: (Kcm^{φ}, electrode potential of welding pool, current density of base metals, electrode potential coefficient current density of welding pool).

It can be noticed from **Figs. (1,2,3) and (4)** that the observation reading number 3 and number 4 are systematically show the maximum deviations of the experimental values from the corresponding predicted ones , where as figures 5,6,7 and 8 show similar trend but for the first and second reading values .

The high RSD values in **Figs. (6, 7) and (8)** give a sight that a modification upon the model order type may be preferable if one needs to improve the present results, for instant, one can think to extended the present mathematical model from the first degree to second, third,….etc, especially for the former results clarified in **Figs. (6, 7) and (8).**

It is well known that the corrosion resistance of large constructions and their monitoring is considered by the example of oil and gas constructions which are complex, large welded geotechnical system, subjected to the action of natural corrosive media as well as produced and transported hydrocarbon products. On the other hand the processing of welded plates by cold or hot is forming procedures which are defined to preserve the respective properties of the HAZ May creat several types of localized corrosion when the constructions are subjected to aggressive media.

The corrosion resistence test results for the alloys investigated in this study are shown in **Figs. (9,10 , 11)** and **Tablets** (2,3) and (4) the base metals seemed to have similar corrosion behavior as shown in **Figs. (9,10) and (11)** . The corrosion rate increases with time reaching a maximum then reached a steady state. However, the corrosion resistance of St.17Mn1Si is seemed to be higher than that of St.22MnAl. The situation may be attributed to the higher Silicon and Manganese content compared with the steel alloy St.22MnAl.

The effect of the presence of air, O2 and CO2 in the subjected solutions on the corrosion resistance of the alloys is also shown in **Figs. (9, 10, 11)** and **Table (2).** The figures and **Table (2)** show that the corrosion rate increasing with immersion the alloys in 3%wt. NaCl in presence of air rather than in presence of O2 and CO2. The corrosion resistance seemed to increase following the sequence:

in 3% wt. NaCl + CO2 → in 3% wt. NaCl + O2 → in 3% wt. NaCl + air .

Any how the welded bimetals are less corrosion resistant than their parent base metals. The reason is well clarified in the introduction.

On the other hand thermal treatments of constructional steels especially welded joints play a vital role in affecting the corrosion resistance of the steels during service. The thermal – deformation results causes an intense stressed state associated with change in the distribution of interstitial atoms C and O2 in the ferric matrix and partial breakdown of cementite during processing effects and in the course of service. Two types of heating treatments were employed normalizing and hardening

with tempering. The visual test of the welded specimens carried out after coercive nod polarization is well detailed in **Table (3).** The results shown in **Table (2)** and **Table (3)** confirm that welding processes decreases the corrosion resistance. However, welding with hardening plus tempering seemed to have the less negative effect on corrosion resistance compared with normalizing alone.
This situation is well defined in **Table (4)** which clarified the results of measuring the corrosion depth of the steel alloys and their welded part using the mentioned heating treatments.
The common property of all welded joints produced using local energy sources is the presence different types of macro – and micro heterogeneities. The structural physical and also chemical micro heterogeneities is deeply related for the decrease in corrosion resistance of welded joints.
Fig. (12) and (13) shows the micro structural analysis results using optical microscopy. The nature of plastic deformation of the contact zone (weld pool) and the deformation in the structure of of the weld zone is shown. It may clearly be seen that slip lines, formed as a result of plastic deformation in the form of structural transformation and physical heterogeneity.

CONCLUSIONS

Steel alloys grade (St.17Mn1Si and St.22MnAl) are considered to be very capable to be welded to produce welded joints used in the pipe lines for transportations oil and gas, owing to high corrosion resistance steel. 17 posses higher corrosion resistance compared to steel 22. The steel alloys studied can be welded using standard normalizing and hardening plus tempering thermal treatment techniques. However hardening plus tempering technique seemed more favorable because of the resulted welded parts are more corrosion resistant compared with the welded parts made by normalizing heat treatment technique?

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Table (1) Chemical composition of the steel alloys investigated .

	[illegible]					
	C	Mn	Si	S	P	Al
[illegible]	0.18-0.20	1.45-1.60	0.42-0.60	0.021	0.012	0.03
St.22MnAl	0.19-0.25	1.25-1.40	0.16-0.30	≤ 0.01	≤ 0.02	0.015-0.04

Table (2) Effect of different gases on the corrosion rate of steel alloys and welded steels immersed in 3%wt. NaCl solution .

Steel alloys class	[illegible] of metal alloys	Corrosion [illegible] 3% [illegible] NaCl presence		
		CO2	O2	[illegible]
St.17Mn1Si	- Base metal	0.065	0.145	0.3
	-Welding without heating treatment	0.13	0.170	0.39
	-Welding with heating treatment	0.28	0.205	0.47
	-Welding with (hardening + tempering)	0.13	0.16	0.38
	- Base metal	0.29	0.17	0.4
	-Welding without heating treatment	0.22	0.18	0.5
	-Welding with heating treatment	0.2	0.21	0.51
	-Welding with(hardening + tempering)	0.18	0.16	0.48

Table (3) Visual investigation characteristics of welded specimens after coercive mod polarization

No.	Experimental Condition	General state surface specimens	State specimens		
			Base metal	HAZ	Welding zone
1.	St.22MnAl welded with out heat treatment	Damage in welding joint	Uniform corrosion with pitting in different local	Cavity corrosion orientation for welding zone	No striking cavity corrosion
	St.17Mn1Si welded with out heat treatment	Uniform corrosion (welded zone)	Cavity in different local + uniform corrosion	Cavity corrosion	Cavity corrosion
	St.22MnAl welded with heat treatment (normalizing)	Uniform corrosion (welded zone)	Uniform corrosion	Cavity(pitting corrosion)	Pitting corrosion)
4.	St.17Mn1Si welded with heat treatment (normalizing`	Uniform corrosion (welded zone)	Insignificant pitting corrosion	Cavity(pitting corrosion)	In significant corrosion
5.	St.22MnAl welded with heat treatment hardening+tempering	Uniform corrosion (welded zone)	Insignificant pitting corrosion	un revelation or no revelation	No revelation
6.	St.17Mn1Si welded with heat treatment (hardening+tempering)	Uniform corrosion (welded zone)	Insignificant pitting corrosion	Pitting corrosion with local element cavity	In significant corrosion in (welding pool)

Table (4) Metallurgical investigations on welded steel alloys

Welded steel class	Type of heating treatment	Corrosion depth micrometer
St.22MnAl	welded with out heat treatment	-250
	welded with normalizing	-55
	Welded with hardening + tempering	-38
St.17Mn1Si	welded with out heat treatment	-105
	welded with normalizing	-36
	Welded with hardening + tempering	-30

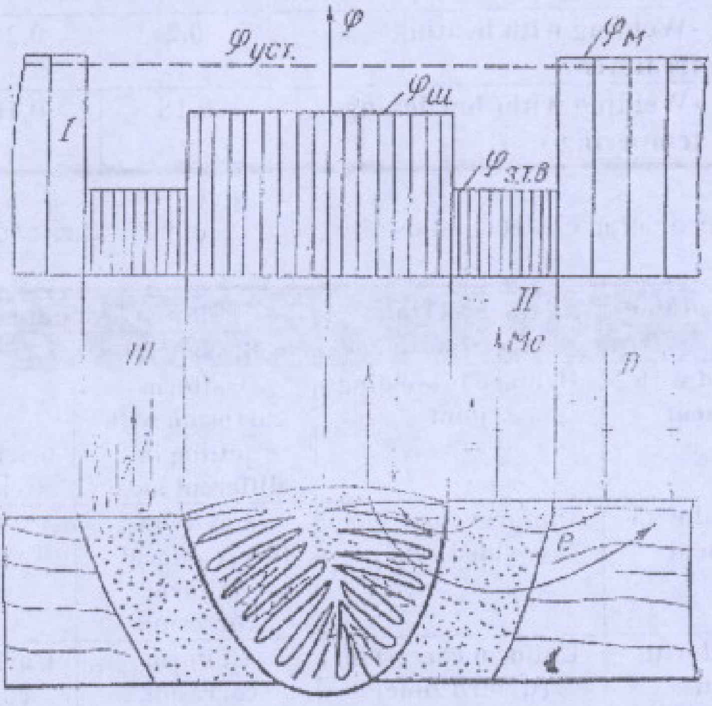

Plate (1) The electrochemical test

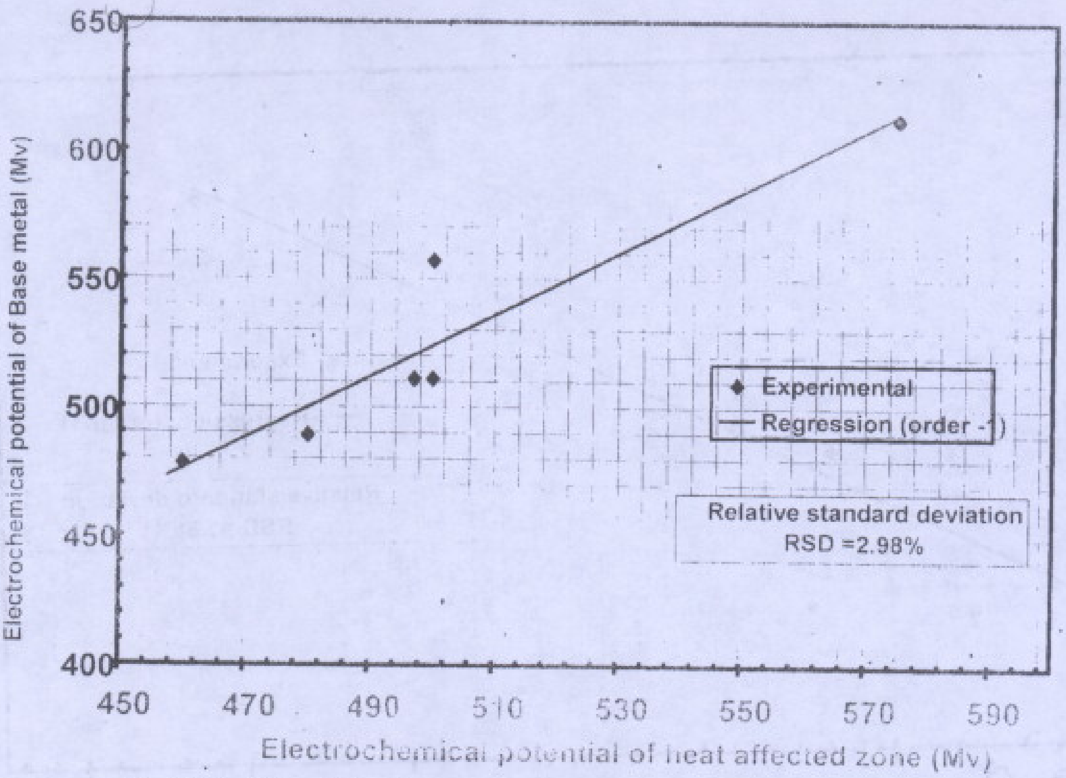

Fig.(1) Variation of the electrod potential level (Mv) of the base metal with that of the heat affective zon, both experimentally and numerically (Regression model of order one).

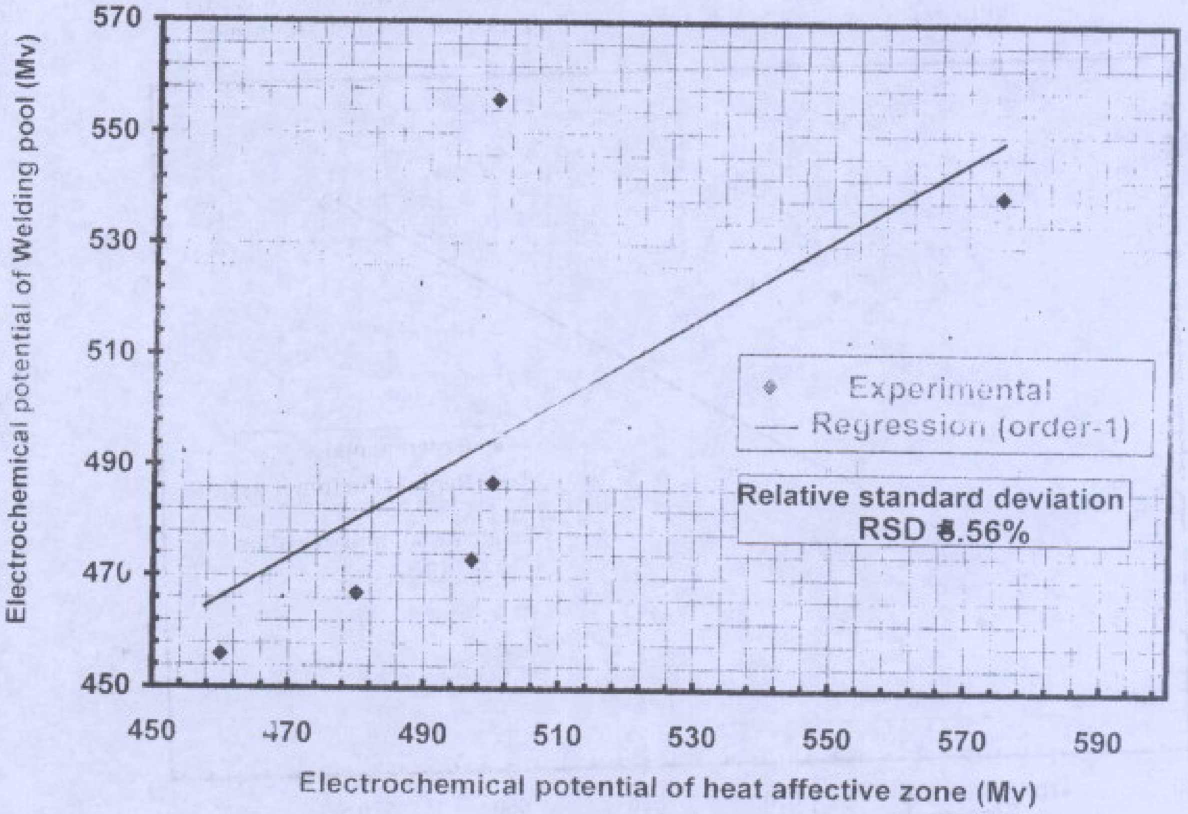

Fig.(2 Variation of the electrod potential level (Mv) of the welding pool with that of the heat affective zon. both experimentally and numerically (Regression model of order one)

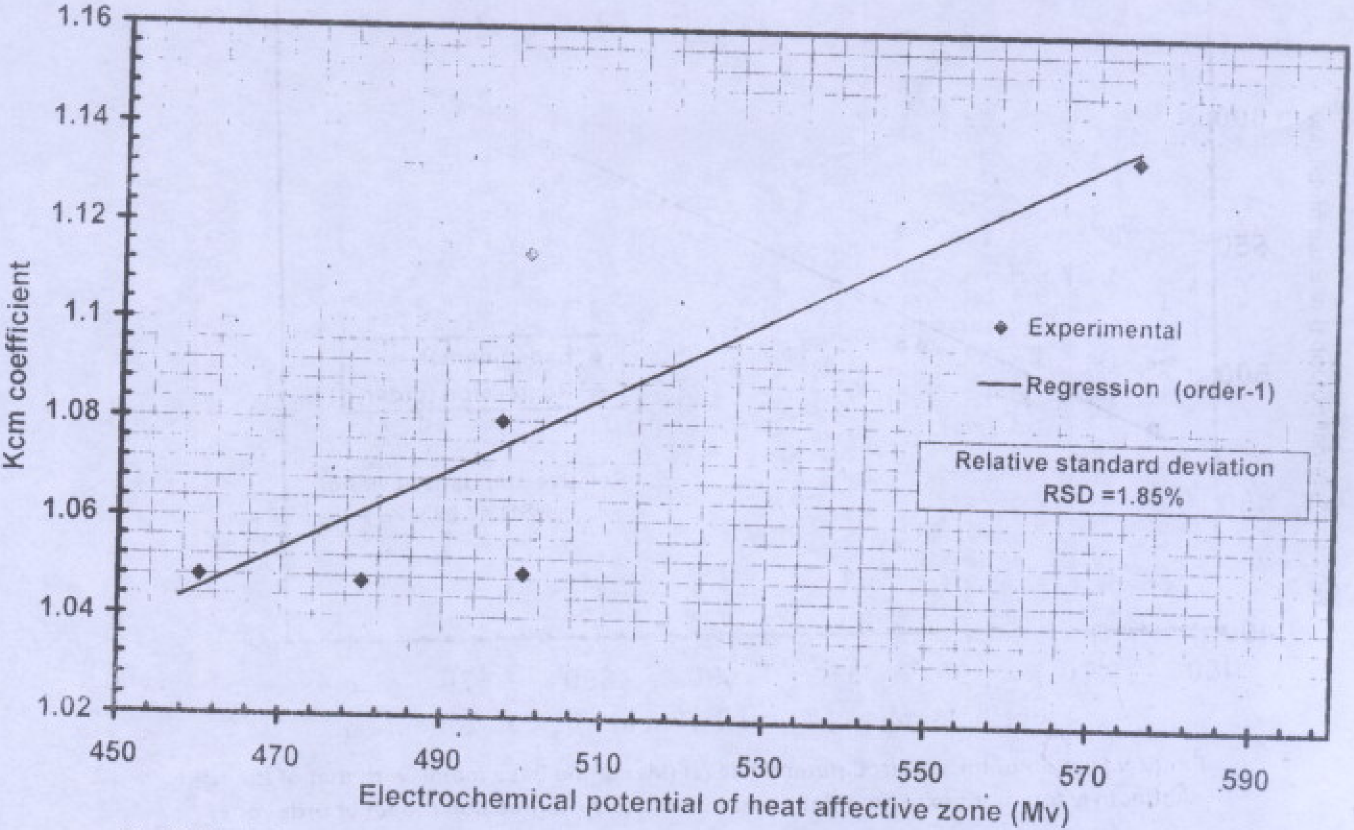

Fig.(3) Variation of the electrod potential level (Mv) of Kcm coefficient with that of the heat affective zon, both experimentally and numerically (Regression model of order one).

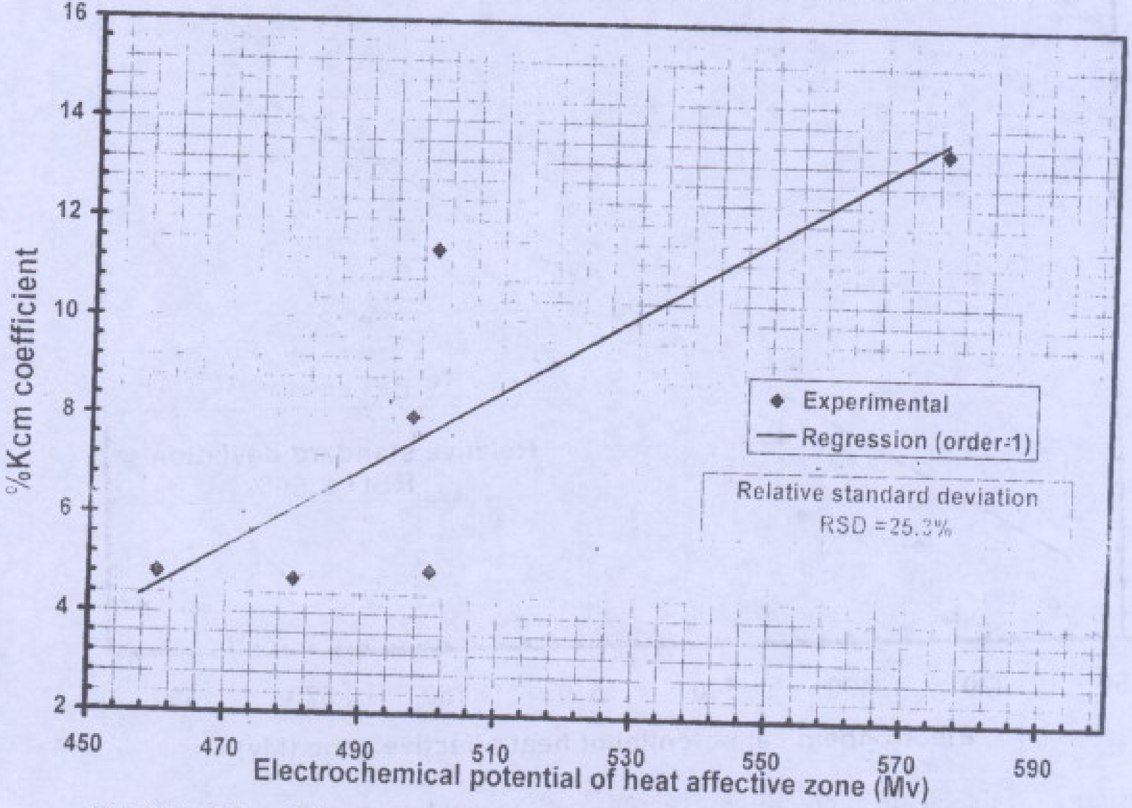

Fig.(4) Variation of the electrod potential level (Mv) of %Kcm coefficient with that of the heat affective zon, both experimentally and numerically (Regression model of order one).

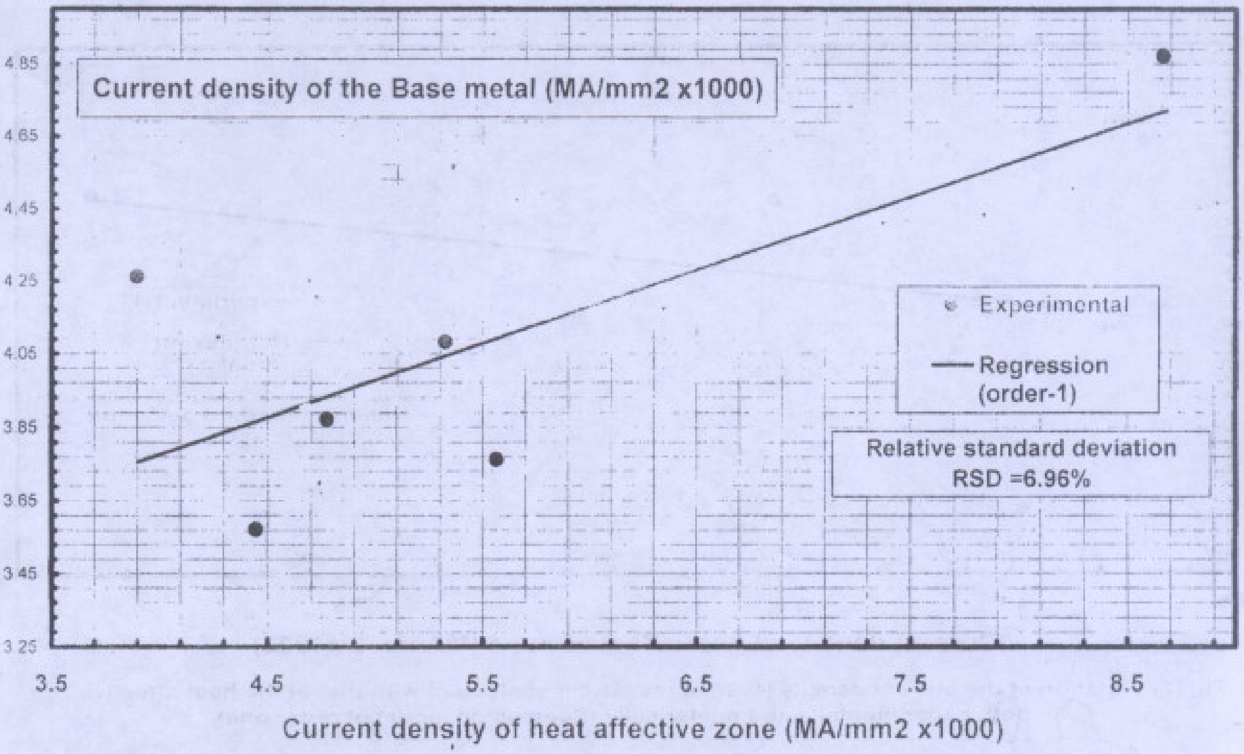

Fig.(5) Variation of the current density level of the base metal with that of the heat affective zon, both experimentally and numerically (Regression model of order one).

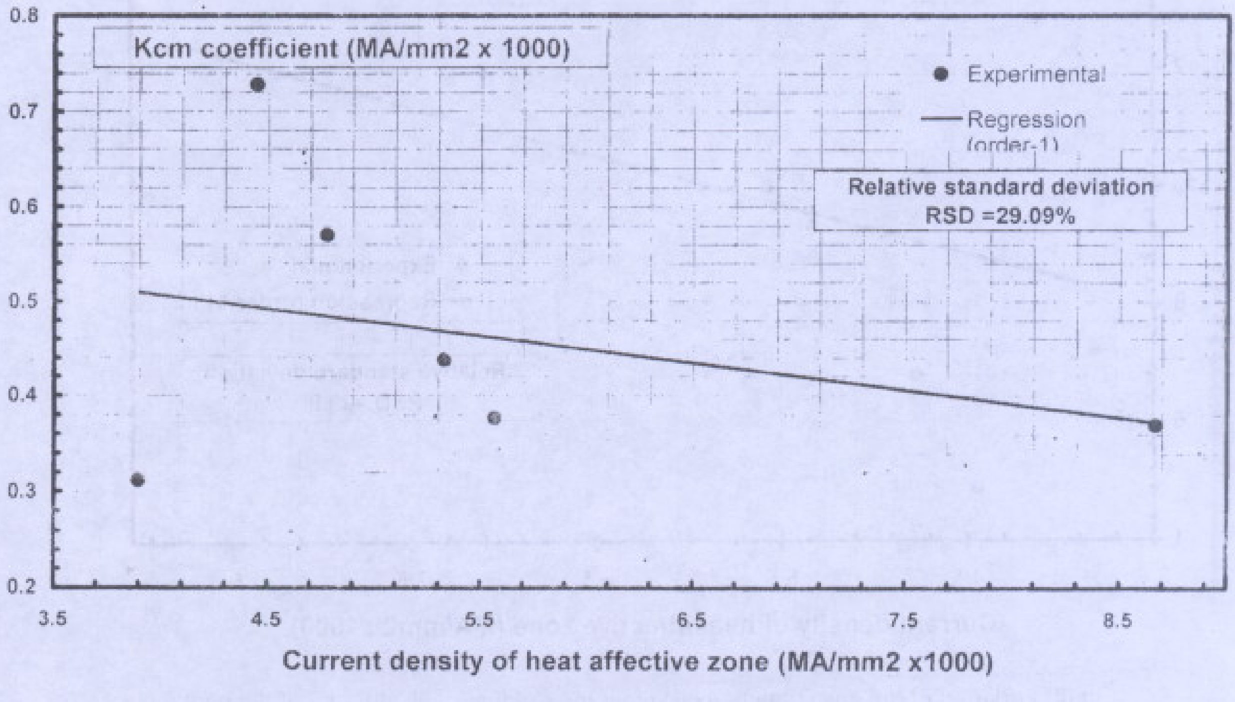

Fig.(6) Variation of the current density level of the Kcm coefficient with that of the heat affective zon, both experimentally and numerically (Regression model of order one).

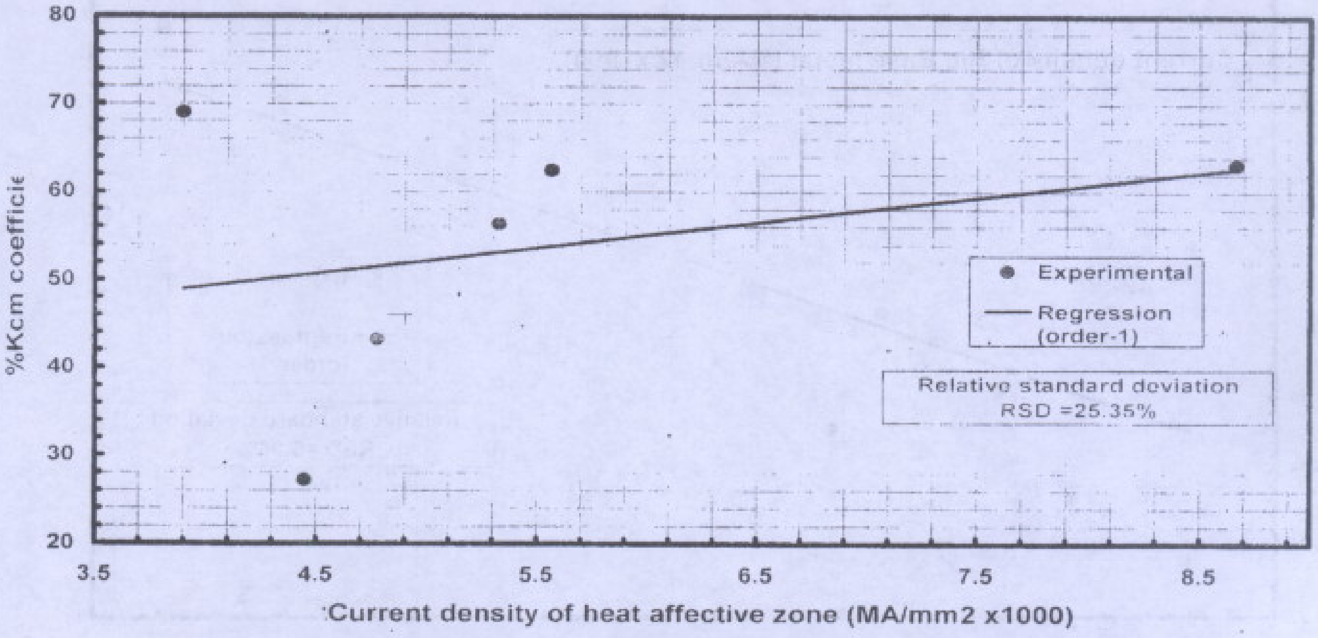

Fig.(7) Variation of the current density level of the %Kcm coefficient with that of the heat affective zon, both experimentally and numerically (Regression model of order one).

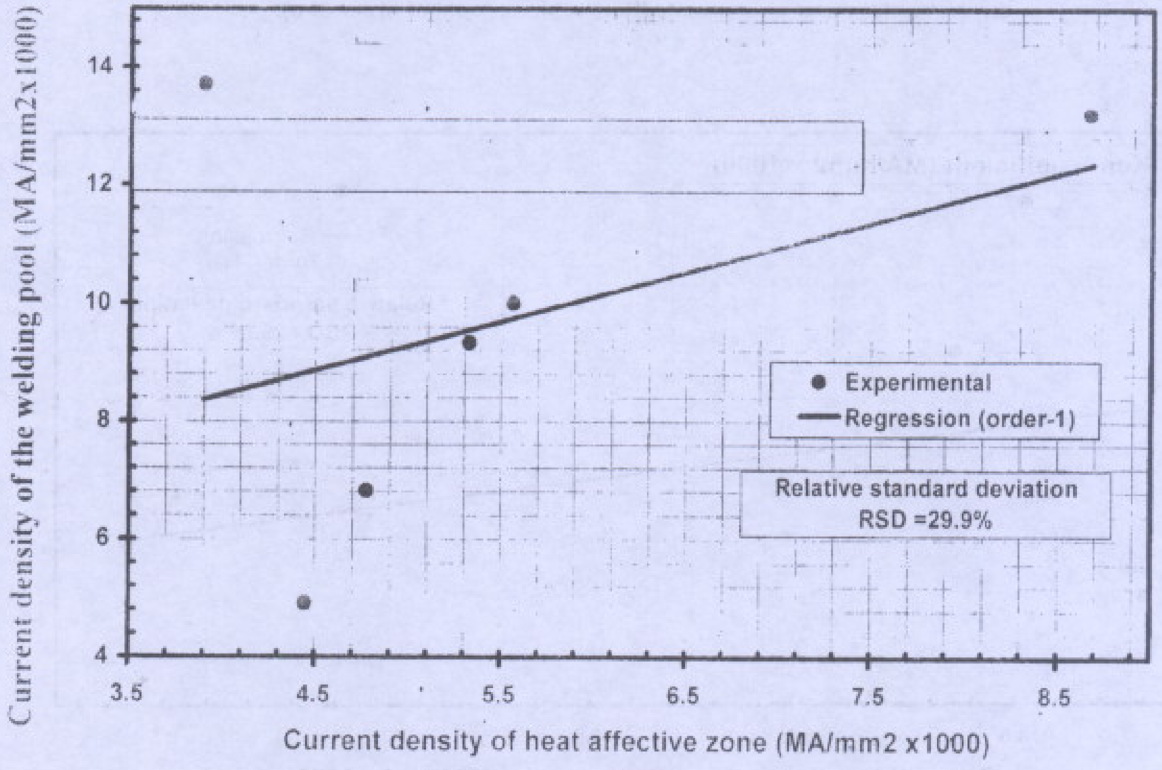

Fig.(8) Variation of the current density level of the welding pool with that of the heat affective zon, both experimentally and numerically (Regression model of order one).

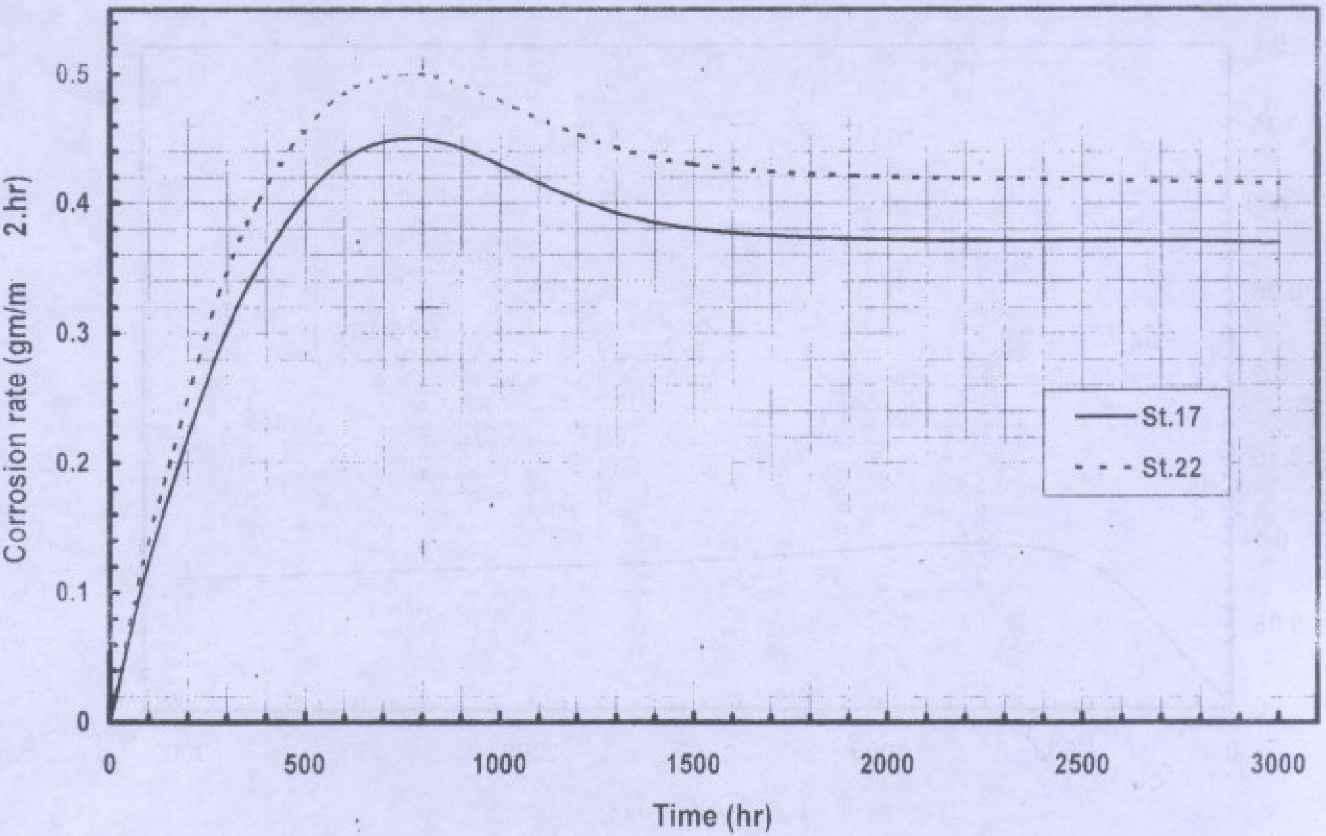

Fig.(9) Corrosion behaviour of steel alloys immersed in (3% NaCl + Air).

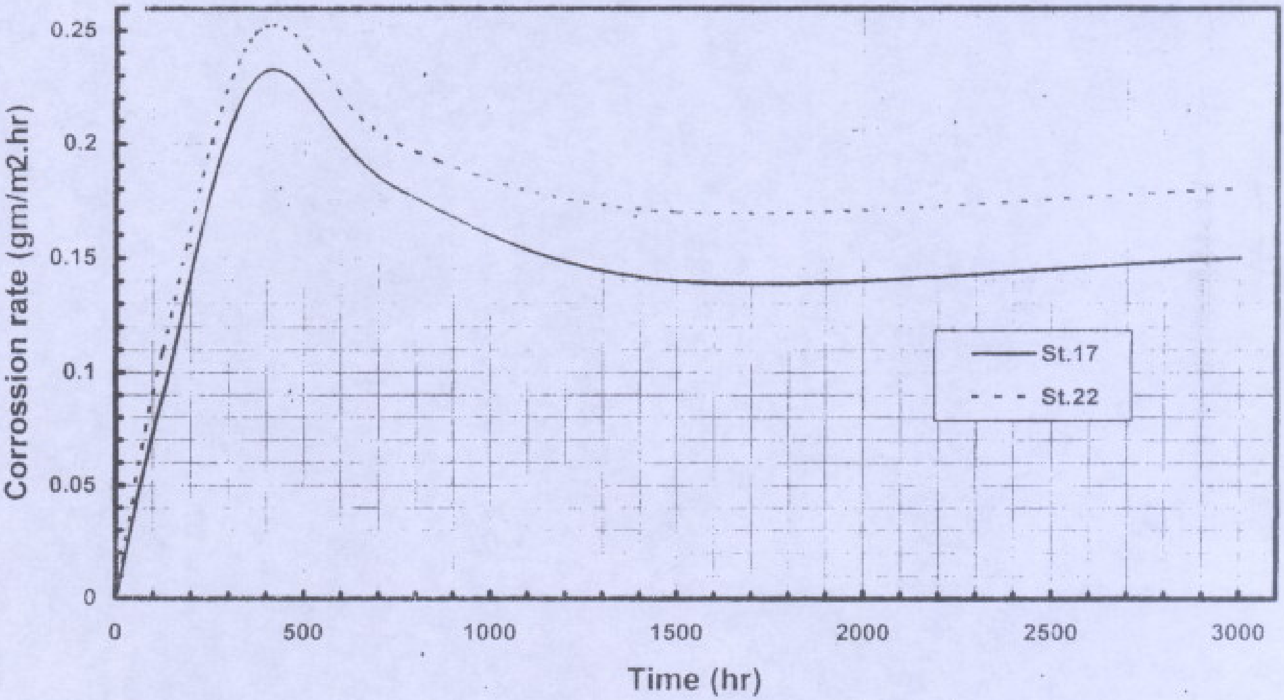

Fig.(11) Corrosion behaviour of steel alloys immersed in (3% NaCl + O2).

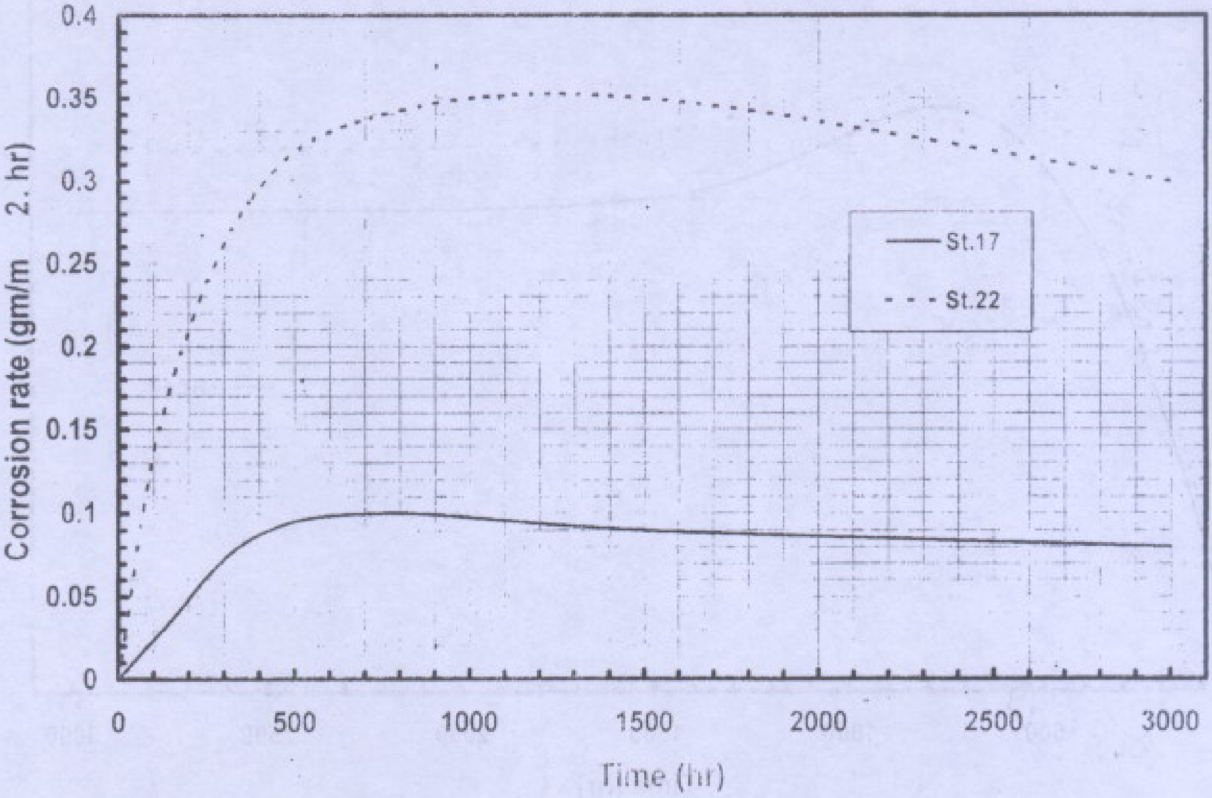

Fig.(10) Corrosion behaviour of steel alloys immersed in (3% NaCl + CO2).

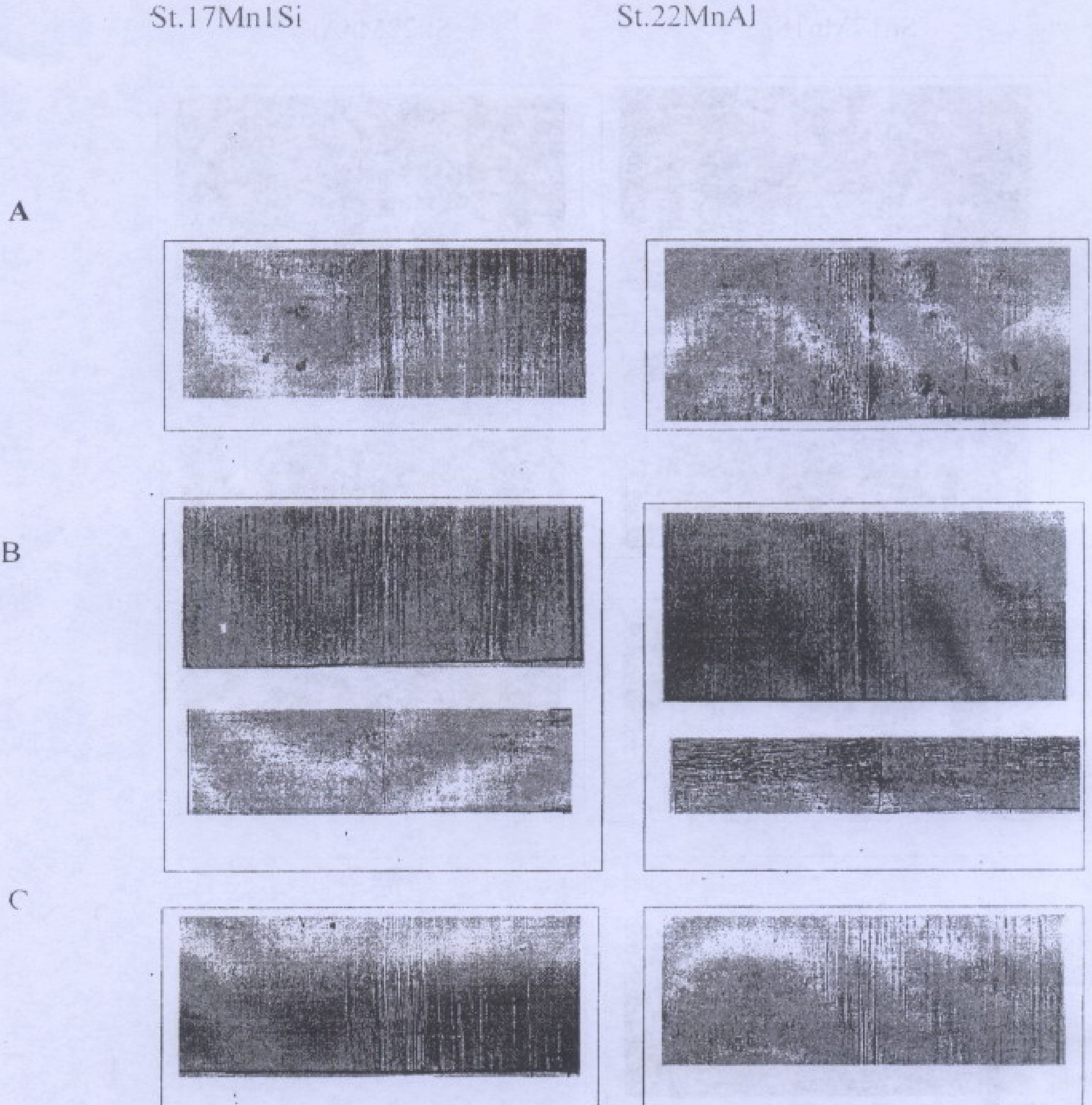

Fig.(12) Microstructures of the contact zone St.17Mn1Si and St.22MnAl (3300hr,3 wt., NaCl + Co2 , T=25C°)

A. Welding without heat treatment ;
B. Welding with heat treatment (normalizing) ;
C. Welding with heat treatment (hardening + tempering) .

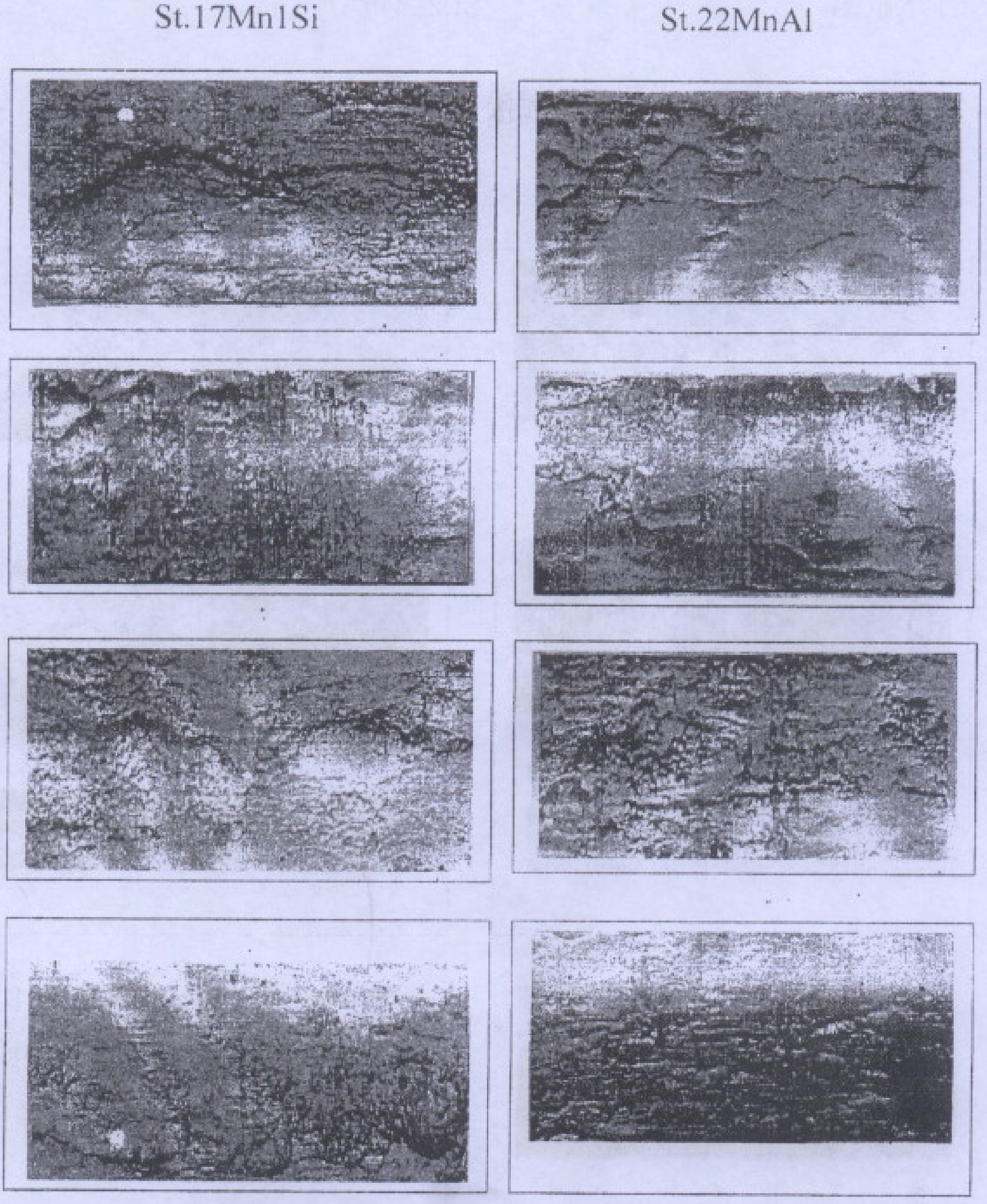

Fig. (13) Microstructure of the Base metal and contact zone of steel St.17Mn1Si and St.22MnAl (3300hr.,3 wt., NaCl + air , T=25C°)

A. Base metal ;
B. Welding without heat treatment ;
C. Welding with heat treatment (normalizing) ;
D. Welding with heat treatment (hardening + tempering) .