

## **Investigation of Corrosion Behavior of Low Carbon Steel Oil Pipelines**

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### **Abstract:**

The research aims at investigating the corrosion behavior of low Carbon steel pipelines welds and mechanical properties of weldment. The corrosion behavior was investigated in crude oil and water extraction from oil to study the effect of water chemistry on corrosion employing electrochemical and weight loss measurements.

Corrosion and erosion-corrosion have important role in oil fields especially in oil pipelines. The experimental work tests of erosion- corrosion were done using special device which was designed and manufactured according to (G 73) ASTM. The work tests were achieved using traditional weight loss technique to measure weight loss rates in (mpy) Unit, the tests above were done in pumped media and pumped media had constant pressure of 1 bar, flow rate  $Q = 36 \text{ L/min}$ , temperature  $\approx 25 \text{ }^\circ\text{C}$  and  $\text{pH} = 6.56$  for erosive-corrosive media.

Weight loss method was used in which test specimens of carbon steel, with a known weights, were immersed in the oil for a total exposure time of 60 days. The weight loss was measured at an interval of 10 days, whereas in water specimens immersed for 30 day at an interval 2 days. The corrosion rate was determined using (mpy) unit. Metallographic observations and micro-hardness measurements were also performed on specimens taken from the parent metal, heat affected zone and weld metal. The obtained results clearly indicate a degradation of the mechanical properties of steel welds.

## **1-Introduction:**

Since the fifty cincher the corrosion weldment has been investigated, whoever in today, s corrosion play a major problem to different engineering projects. structure failure of low carbon steel weldment certified to selective attacked as result of different zone of a weldment foe example fusion zone corroded rather than heat effected zone H.A.Z or parent material

The preferential corrosion of weldment can attributed to same factors: the different in composition of metal itself and wire or electrode, microstructure and shape or geometry of weld . in welding process parent material and weld wire mixed to gather by rapidly heating to melting temperature and then cooling to room temperature , the high cyclic of heating and cooling produces ( phase change ) , thus the heat affected zone (HAZ) and the weld metal (WM) may contain one or more of the following structures: ferrite, pearlite, bainite and martensite. It is well known that low transformation temperature products, like martensite and lower bainite , have a higher tendency to corrode than other microstructures , however change in phases produce different in electrochemical potential along the weldment zone ( base metal , H.A.Z and W.Z ) which cause galvanic attack . farther more residual stress development during welding can cause stress corrosion crack [2,3] .

Furthermore, geometrical parameters such as excess root penetration can lead to erosion ( impingement ) corrosion downstream of the weld. In general , the surface discontinuity generated by the weld reinforcement may lead to turbulence in a flowing system .One of the main thread in pipe line transmission crude oil is internal corrosion .crude oil is non corrosive , the presence of water and sediment make it corrosive media . the density different between crude oil and water case that water separate at the bottom and contact the pipe wall [4] .The primary factors that effected the internal corrosion in flow rate When a low flow rate facilitates separation of water droplets and stagnation in the bottom of the tube which facilitates the occurrence of pitting corrosion whereas in the case of higher flow rate cause erosion corrosion due to remove the internal layers of the tube especially in the weld joint ( as a result of excess penetration of root pass ) and areas of impact or change in the flow direction such as the valves [5,9] .

## No.13 Journal of Petroleum Research & Studies (JPR&S)

According to ASTM G205, the corrosivity of crude oil containing water can be understood in terms of three properties : the corrosivity of water in the presence of crude oil, type of the emulsion formed between oil and water, and the wettability of steel surface. It is a widely held view that water and oil are immiscible, but under certain conditions, they can form emulsion, two kinds (O/W and W/O) . O/W emulsion means that oil is the continuous phase (less corrosive and has low conductivity) and vice versa for W/O emulsion [6,7] . Wettability can be characterized by measuring the contact angle . In the contact angle method, the tendency of water to displace hydrocarbon from steel is measured directly by observing the behavior of the three phase system. The contact angle is determined by the surface tensions (surface free energies) of the three phases [8,13] .

### 2-Experimental Work

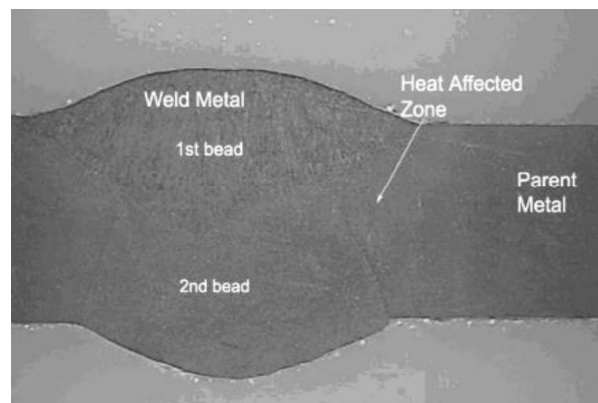
The chemical composition of the mild steel and the filler metal employed in the SAW welding process was carried out using (spectrometer DV.4) in Company General for examination and Rehabilitation Engineering are represented in Table 1 and 2 respectively . The dimensions of the nominee sample working in this research work have the dimensions of (500 mm x 6 mm). Standard V-groove butt configurations an included angle of  $60^\circ$  was employed to weld these similar metals and having root face of 1 mm. Metallographic inspection was carried out on the composite region [parent metal + HAZ+ weld ] of the weldment as shown in Figure(1) [1]. The sample working of the weldments and parent material were polished using the emery sheets of Si C with grit size varying from 220 to 1000 and followed by disc polishing using diamond (grain size  $1\mu\text{m}$ ) to obtain a mirror finish to the sample. Electrolytic etching nital (2%  $\text{HNO}_3$  with 98% alcohol) was employed to study the microstructure of mild steel 1020. Further the samples were cut to different dimensions to achieve various mechanical tests. Hardness studies were conducted on the composite region of the weldment by keeping weld as center using Vicker's Microhardness tester employing a load of 1000g and 10 s dwell time at the regular intervals of 0.25 mm.

**Table (1): Chemical composition (% weight) of base metal.**

C	Si	Mn	P	S	Cr	Mo	Ni	AL	Co	Cu	Fe
0.179	0.009	0.398	0.011	0.01	0.017	0.005	0.025	0.060	0.005	0.019	Bal.

**Table (2): Chemical composition (% weight) of electrode metal.**

Electrode	C	Mn	Si	Pb	S
E6010	0.12	0.48	0.015	0.015	0.015
E7018	0.07	1.38	0.47	0.012	0.01



**Fig.(1) The sample working of the weldments and parent material [1]**

**Table (3): SAW Welding parameters.**

Electrode	Current I (A)	Voltage V (volt)	Heat input (KJ/mm)	Root gab (mm)
First pass E6010	Ac 120	20	1.5	3.5
Second pass E7018	DC 150	50	2.5	

**2.1- immersion corrosion were conducted in crude oil and water extraction from it**

Samples cut from the base metal and welded by CNC laser device to the dimensional ( 30 , 18 , 6 ) mm with a hole diameter of ( 2mm ) using Turning machine to facilitate the process of immersion in corrosive media . the corrosive media are oil and water extracted from the oil .A chemical analysis of both the two mediums has been make .Analysis of water phase present in crude oil chemical composition of the water:

Phase present in the crude oil was determined with the results are given in Table (4). The main ions detected were chloride ( $CL^-$ ) , bicarbonate ( $HCO_3^-$ )and sulphate ( $SO_4^{-2}$ ) where chloride ( $CL^-$ ) has been known as aggressive ion. Water was identified to have pH of 6.34 or basic condition and water content (%)~ 45% .

**Table (4): The main ions detected from analysis of water phase present in crude oil**

<b>Parameter</b>	<b>Water extraction from crude oil (ppm)</b>
<b>TDS</b>	<b>142360</b>
<b>bicarbonate (<math>HCO_3^-</math>)</b>	<b>534</b>
<b>sulphate (<math>SO_4^{-2}</math>)</b>	<b>40</b>
<b>chloride (<math>CL^-</math>)</b>	<b>7742</b>

Analysis of crude oil:

Chemical composition of the crude oil was determined with the results are given in Table (5) . The density of crude oil ( $0.8944$ )  $g/cm^3$  and pH (6.56). Water content (%) ~ 45%.

**Table (5):- The composition of crude oil**

Element composition	Crude oil ( % wt. )
Carbon	85.62
Hydrogen	12.1
Sulfur	0.75

After taking the initial weight and dimension samples ( with and without welding ) submerged in water phase present in crude oil for a one month with period of two days after that Cleaning the previously prepared specimens with acetone and drying them carefully with drying paper. Then they are put in a container containing of a silicon gel bed. On the other hand the sample was immersed in crude oil for a total period of 60 days with six weight measurements taken at an interval of 10 days. The weighting is carried out after the specimens are cleaned with distilled water and brush ,Samples are placed in an oven at a temperature of 80 °C for a period of 15 minutes to dissolve any oils or plankton , and then with acetone . The specimens were dried by using paper.

This expression is readily calculated from the weight loss of the metal specimen during the corrosion test by the equation given below [10,11,12] .

$$\text{Corrosion Rate (mpy)} = 534 \Delta W / \rho A t \dots\dots\dots (1)$$

Where:

$\Delta W$ : different in weight loss (mg)

$\rho$ : density of coupon material (g/cm<sup>3</sup>)

A: area (in<sup>2</sup>), t: time of exposure (h)

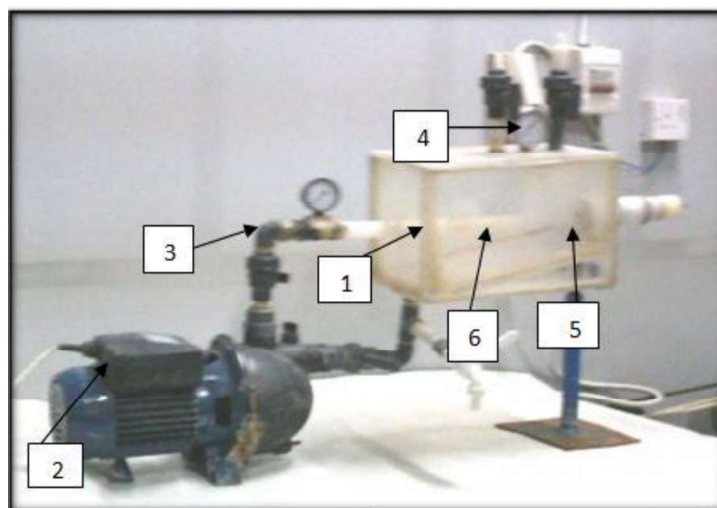
## **2.2 Erosion -corrosion test**

Jet impingement tests were conducted using device which was manufactured and designed according to (G 73) ASTM as show in Figure (2) . the device consist of : 1. Tank

## No.13 Journal of Petroleum Research & Studies (JPR&S)

perspex , 2. 1H.P motor , 3. P.V.C pipe , 4.outlet gas pipe , 5.effective media , 6. Metal specimen , 7. jet nozzle .

The investigational work tests were achieved using traditional weight loss technique to measure weight loss rates in ( MPY ) unit. Nozzle arrangement which impinges onto a flat specimen at an angle of  $90^\circ$ . The nozzle is 4 mm in diameter and positioned at a fixed distance of 5 mm from the specimen. Thickness loss measurements were taken based on the surface area of the sample ( $540\text{mm}^2$ ) exposed to the jet . Tests were conducted for 2 h and specimens were weighed before and after the test to determine the total weight loss. All tests were conducted at flow rate of 36 L/min , medium injection pressure is (1) bar and temperature of  $\approx 60^\circ\text{C}$  . The specimen is weighted again after the specified (10) minutes of exposure to the medium . The weighting is carried out after the specimens are cleaned with distilled water and a brush, Samples are placed in an oven at a temperature of  $80^\circ\text{C}$  for a period of 15 minutes to dissolve any oils or plankton and then with acetone and then with acetone or alcohol. Drying of the specimen carried out using drying paper and specimens driers.



**Fig. (2) Corrosion & erosion-corrosion devise.**

### **2.3 Corrosion rate and passivity of the steel pipeline**

Corrosion rate of the steel pipeline was measured using a three-electrode cell with saturated calomel electrode (SCE) as the reference electrode, platinum ( Pt ) grid as auxiliary electrode

and material as worker electrode were used . To simulate actual corrosion process, the water phase extracted from crude oil was used as the electrolyte.

## **2.4 Open circuit potential measurements**

The potentials of carbon steel electrodes were measured conventional three-electrode electrochemical cell with and saturated calomel electrode (SCE) as reference electrode , platinum ( Pt ) grid as auxiliary electrode and material as worker electrode were used. The measurements of OCP were obtained with a PAR 263 potentiostat .

### **3- Results and discussion**

#### **1.3 Open circuit potential**

The open circuit potential is a parameter which indicates the thermodynamically tendency of a material to electrochemical oxidation in a corrosive medium. After a period of immersion it stabilises around a stationary value. This potential may vary with time because changes in the nature of the surface of the electrode occur (oxidation, formation of the passive layer or immunity). The open circuit potential is used as a criterion for the corrosion behavior. Figures (3, 4) show the OC curves (the relationship between potential (mV) and time (mn.) for all the samples immersed in corrosion solution (water extraction from crude oil) at 25 °C [17].



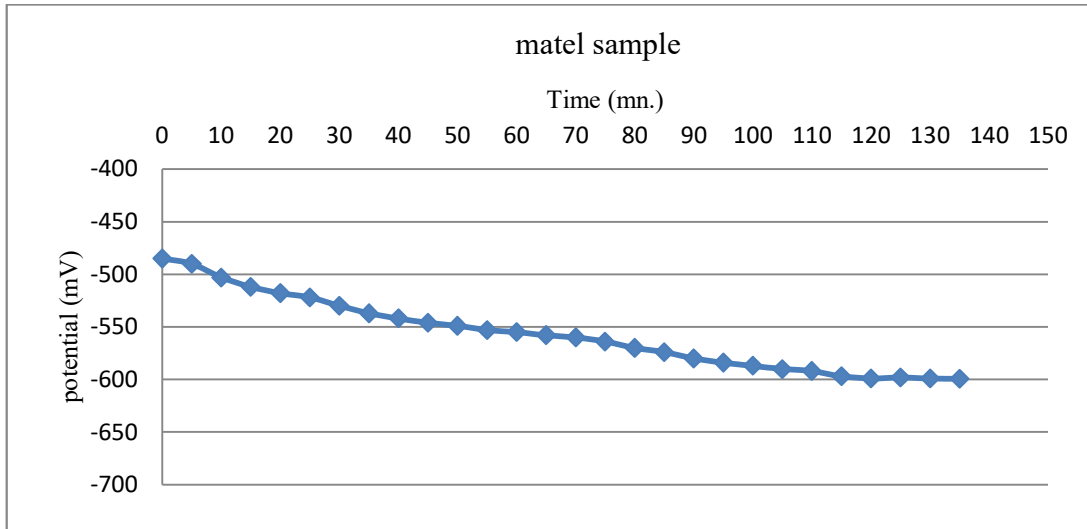


Fig. (3) Shows the OC curves for the samples .

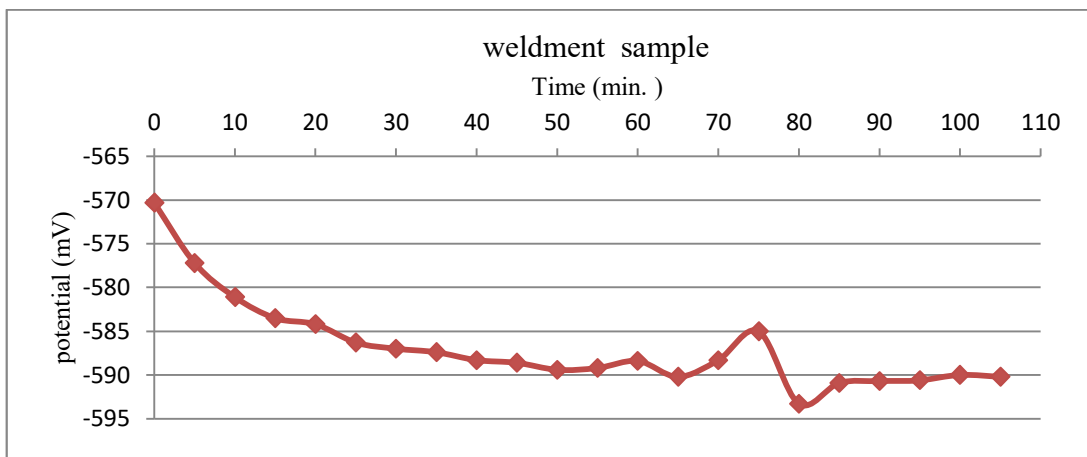


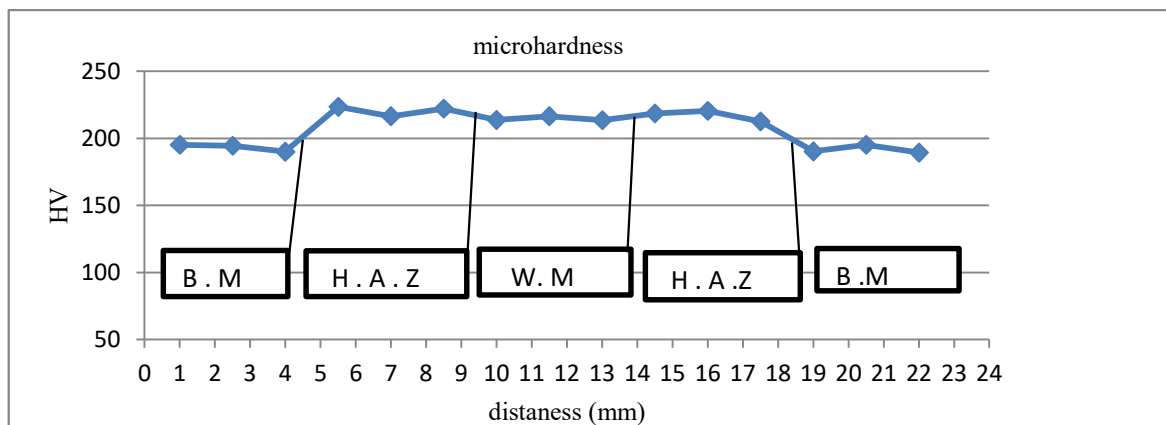
Fig. (4) Shows the OC curves for the samples .

### 2.3 Hardness measurement

The results of Vickers microhardness tests carried out at different regions of the weld cross-section sample with reference to the effect of welding on different regions of sample. The resolute was reported the properties of these various zones, but the information obtained is extremely limited [14]. other researchers, a simple fast way to obtain important information is by hardness testing [16].The hardness values of 189 – 213 HV in Figure ( 3) are observed at location within 1.5 mm from the base metal, through the HAZ across the weld

## No.13 Journal of Petroleum Research & Studies (JPR&S)

metal to the other base plate. These results of hardness s are moderately in good agreement with literature. Indeed, Gul et al. [15], Zakaria ,etal .[3] , the maximum hardness is both in weld metal and heat-affected zones. The variation in properties across the weld can be attributed to several factors, mainly to residual stresses just after welding. However, other factors can contribute to this hardening like phase composition, grain size, and metallic inclusions. Ferrite and colonies of pearlite. We have observed that bands of coarse grains grow along a certain preferred crystallographic directions. Moreover, we have found that maximum hardness values are situated in the area of weld metal and HAZ which indicates its specificity.

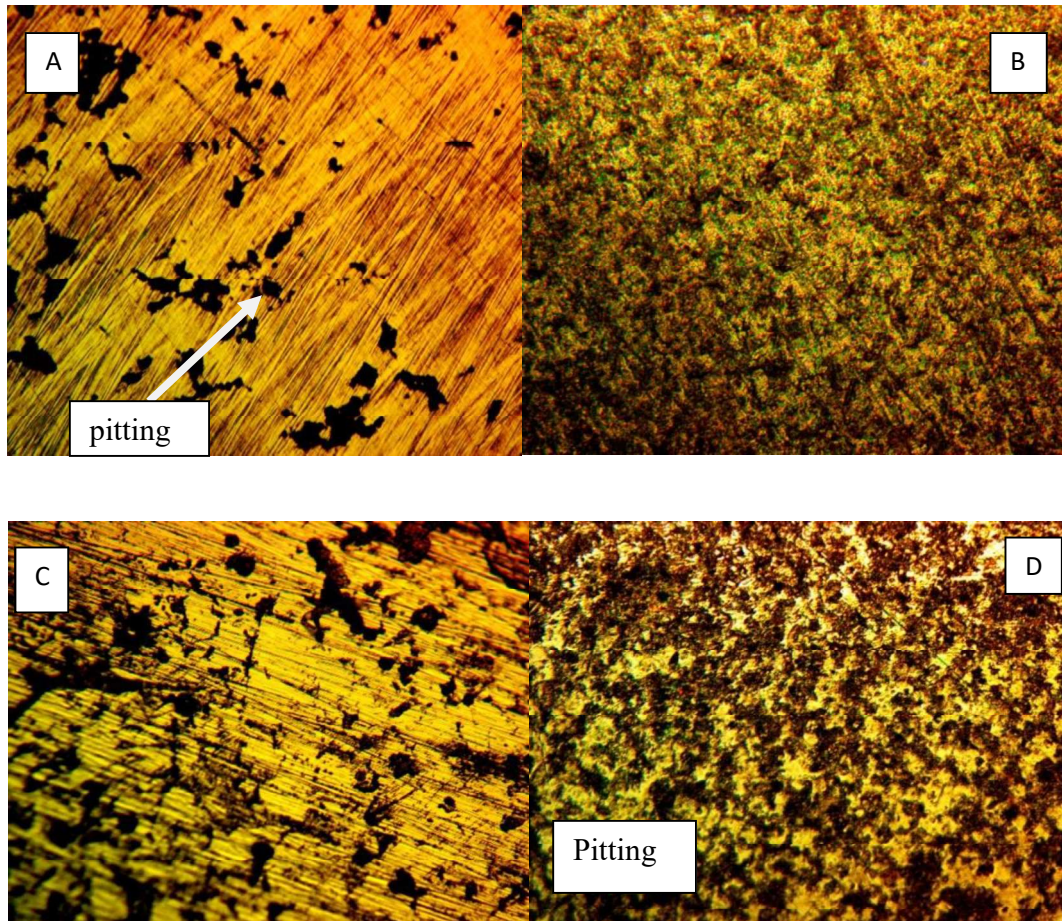


**Fig.(5) Microhardness measurements on surface from the base metal across the weldmet after welding of an industrial low carbon steel (0.179 wt. % C).**

### 3.3 Static corrosion measurement

Uniform corrosion and pitting corrosion was observed in all the test coupons immersed in the media (water extraction from crude oil and crude oil) as shown in Figure (6) (A, B, C and D) for sample. Furthermore the corrosion rate measurements as a function of time are as shown in Figures (9, 10) in crude oil and water extraction from crude oil respectively. Corrosion rate of samples slowly increases due to continuous dissolution of  $Fe^{2+}$  ion in the solution as a result of formation of porous  $FeCO_3$ , which is not protective in nature [12]. When iron carbonate  $FeCO_3$  precipitates at the steel surface, it can slow down the corrosion rate process by: presenting a diffusion barrier for the species involved in the corrosion process

and covering (inhibiting) a portion of the steel surface. The most important one is water chemistry [18, 19, and 22].



**Fig.(6) Microstructure showing (a) Weld - HAZ (b) base metal immersion in crude oil, (C) Weld - HAZ (D) base metal in water extraction from crude oil**

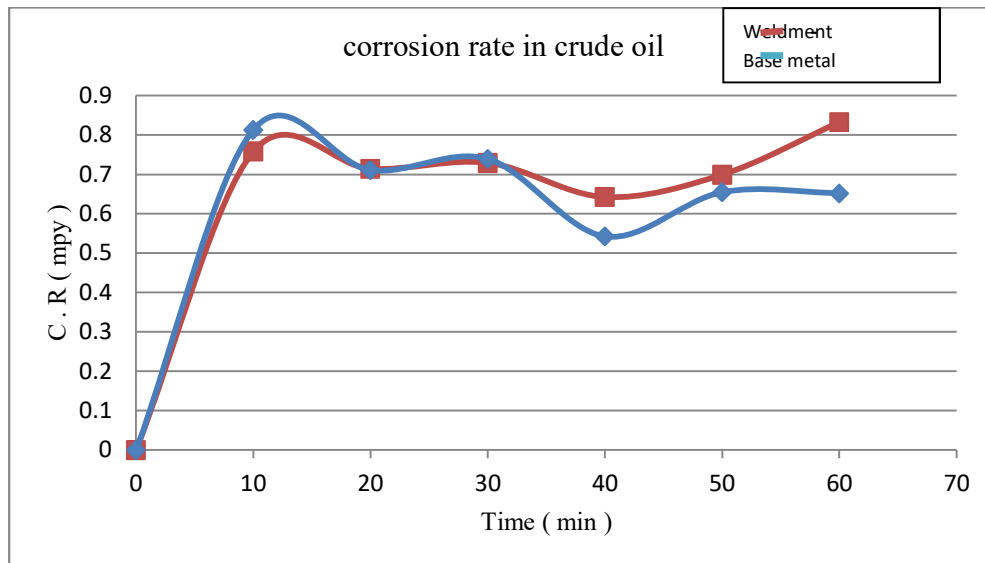


Fig. (7) Are shown the corrosion rate measurements in crude oil and water extraction from crude oil respectively.

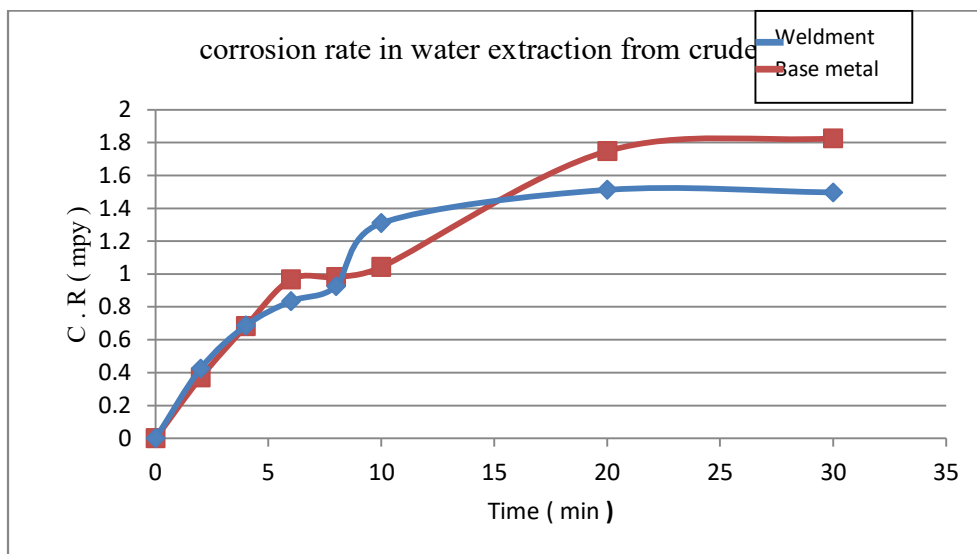
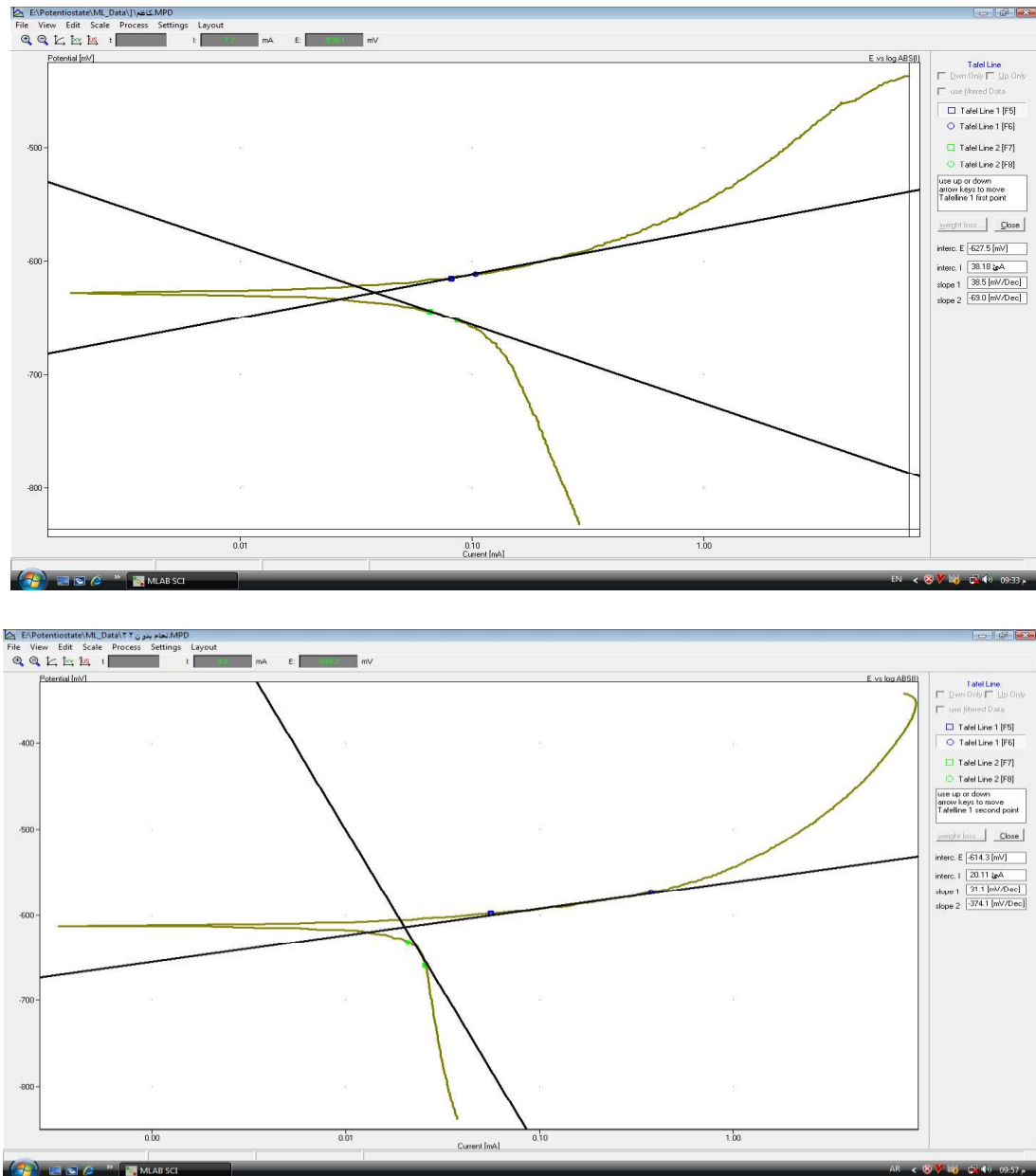


Fig. (8) Are shown the corrosion rate measurements in crude oil and water extraction from crude oil respectively.

Linear polarization was used to calculate corrosion potential ( $E_{corr}$ ) and corrosion current density ( $I_{corr}$ ) for two sample (with and without welding) through point of intersect the both Tafel lines ( $E_{corr}$  and  $I_{corr}$ ) that makes possible the estimation of the corrosion current density by the extrapolation of the Tafel slopes with corrosion potential. This method which

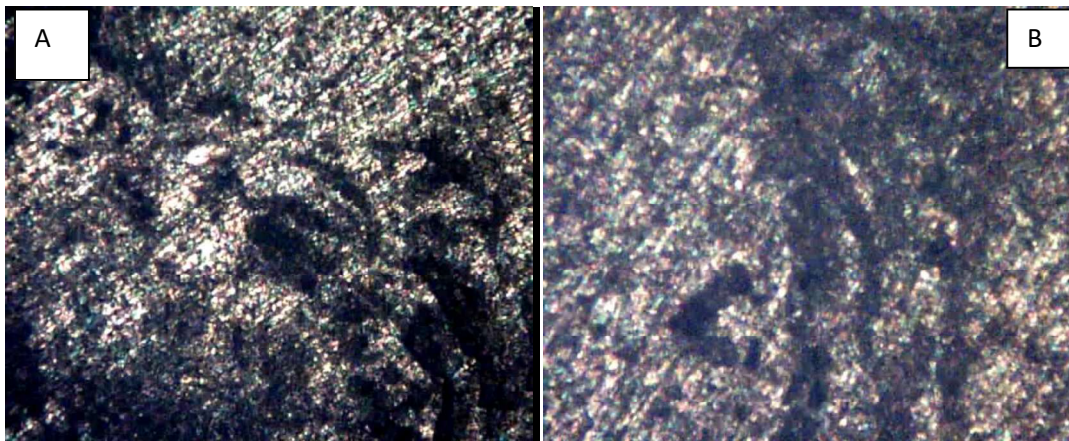
## No.13 Journal of Petroleum Research & Studies (JPR&S)

used to calculate corrosion rates in (water extraction from crude oil) solution. Figure (9) (A & B) for metal and weldment respectively shows that samples in solution. For metal  $I_{corr}$  ( 38.18 )and  $E_{corr}$  ( -627.5) whereas for welding  $I_{corr}$  ( 20.11 ) and  $E_{corr}$  ( -614 ).

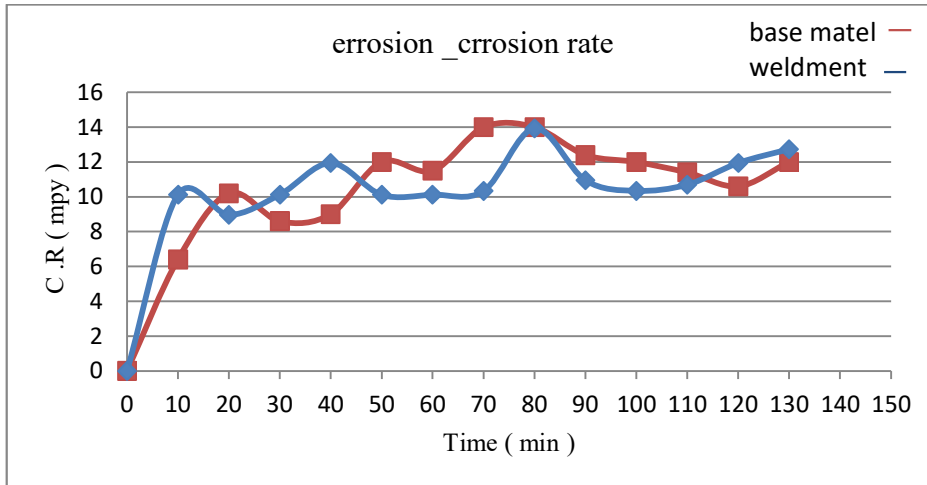


**Fig. (9) (A & B) for metal and weldment respectively shows Linear polarization curve for samples in solution.**

Erosion-corrosion produces the maximum weight loss rate which comes from two effects – one mechanical resulting from the high velocity of the erosive medium with slurry which produces cavitation and impingement [9]. It produces effect like horse-shoe traces which are a distinctive characteristic of erosion- corrosion as show in Figure (10) Microstructure of (A) welding and ( B) metal specimen. The other is electro-chemical resulting from there action between the medium and the specimen. Figure (11) for welding and base matel shows the effect of erosion-corrosion on corrosion rate. This type of corrosion produces great weight loss as a result of removing large and clear-cut metal portions due to impingement erosion and corrosion [21]. The horse-shoe-like areas are dark, distinctive and oriented toward flow direction of the erosive-corrosive medium. The horse-shoe-like areas are typically deep because the metal is soft and easily eroded and spalled by sand grains which are considered erosive matter in the corrosive medium. This is in good agreement with that shown by Stephen M.[20] who studied common features typically observed with erosion-corrosion of horseshoe-shaped and comet tail pitting damage.



**Fig.(10) Microstructure of( A) welding and ( B) metal specimen exposed to the erosive corrosive condition.**



**Fig.(11) Shows the effect of erosion-corrosion on welding and base matel sample.**

**Conclusions:**

This work represents a contribution to the study of the effect of shielded metal arc welding on industrial low carbon steel (0.179 wt. % C). we have found that maximum hardness values are situated in the area of weld metal and HAZ which indicates its specificity. The main corrosion mechanism in oil and gas production pipelines generates pitting damages at different pipelines zones. Weight loss amount by erosion corrosion is greater than the weight loss amount by general pure corrosion for all samples.

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