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INVESTIGATION CORROSION BEHAVIOUR OF DUCTILE CAST IRON WELD JOINT IN SEA WATER

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ABSTRACT

Manual metal-arc welding was carried out for ductile cast iron under welding conditions of (90) A DC current (DCEN) and 20 volts. Welding wire type E- Ni -Fe- CI in diameter of 3.2mm was used and travel speed of 7 inch /min and welded through two passes. The weld joined are examined using X-ray radiography, broken down joint are excepted. Corrosion specimens prepared from free defects joints having measurements of (15*15*3) mm agreeing to ASTM G71-31. Then Optical microscopy was employed to detect the welded joint microstructure and base metal. Micro hardness was implemented using Vickers test. Corrosion examinations are conducted using electrochemical potential state chamber in equipped (sea water 3.5% NaCl),Corrosion examination is achieved using potentiostatic polarization dimensions in saltwater 3.5%NaCl at potential scan rate (+100-100 mv/sec) to estimate corrosion parameters by extrapolating. The corrosion rate was calculated by Tafel equation. The results of corrosion rate can be predicted using a mathematical model using data achieved from practical method and compare these results with the theoretical one, results show that corrosion rate for welded joint is more than the base metal because of the change in metal microstructure during welding process.

KEYWORDS :- ductile cast iron, shield welding, corrosion rate, sea water

التحقيق من سلوك التاكل لملحومات سبائك الحديد الطرية في ماء البحر

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الخلاصة :-

يتضمن البحث دراسة سلوك التاكل لوصلات لحام انابيب من حديد الزهر المطيلي في ماء البحر تم اللحام بواسطة لحام القوس الكهربائي المحمي بالصهيرة عند ظروف لحام من تيار90 امبير و فولتية 20 فولت وسرعة 7 انج/دقيقة باستخدام سلك لحام نوع ENi Fe- CI وقطر 3.2 ملم و بعدد اثنان من التمريرات باستخدام تيار (DCEN) للحصول على وصلة لحام تناكبية ،وبعد عملية اللحام والتاكد من خلوها من العيوب من خلال فحصها بواسطة جهاز X-ray radiography تم تحضير عينات اختبار التاكل بابعاد 3×15×15ملم وفق المواصفة القياسية ASTM G71-31 اتبعتها عمليات تحضير من تنعيم وصقل لاجراء فحص البنية المجهرية باستخدام المجهر الضوئي ذو كاميرا للملحومات والمعدن الاساس واختبار الصلادة الماكروية.اجري اختبار تاكل كهروكيمياوي بطريقة المجهاد الساكن عند جهد محدد وفق موقع المعدن في السلسلة الكهوكيمياوية وبعدها تم زيادة الجهد ب (±100) ملي فولت عند كل 10 ملي فولت يزداد التيار ، وأن التيار الذي يؤدي الى زيادة في الجهد يمثل تيار التآكل ، وتم حساب معدل التآكل اعتمادا على معادلة تافل .وقد تم التنبأ بمعدل التآكل عن طريق بناء نموذج رياضي اعتمادا على البيانات المحصلة عمليا ومقارنة تلك النتائج مع النتائج النظرية ومن النتائج التي تم الحصول عليها وجد ان معدل التآكل للملحومات اكثر من معدل التآكل للمعدن الاساس بسبب التغيرات التي تحدث بالبنيه المجهريه خلال عملية اللحام .

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INTODUCTION

Ductile cast iron has main graphite in contractual or global shape. The variation in the graphite shape is achieved due to added an alloying element, generally magnesium, to melted iron of suitable conformation. Appropriately cured iron will solidify by means of the graphite in the shape of contractual or global. The allotment and form of the graphite contractual are fixed when the metal hardens in the template and will stay fundamentally unaffected through consequent treating.[Richard w. bonds 1998 , R. Grundy 1979] Because of their great carbon contents, the whole thing in cast irons have a common divisor influential their join aptitude. Through joining of cast irons, the iron directly close to the join metal is heated to its melting point [M. Pascual.et al, 2009] subsequently joining, the whole heat-affected region cools off greatly quickly. Through this heating and cooling, a number of the graphitic carbon melts and disperses into the iron, and, as a consequence, carbides be disposed to shape at the end of the melt region. High-carbon marten site or binate be disposed to shape in the remnants of the heat-affected region.[M. Pascual.et al, 2009] .Ductile cast Iron tube, having a mostly ferrite matrix, is capable of indigenous ductile distortion to adapt the thermal joining stresses and is as a result improved appropriate to absorb joining stresses than is gray cast iron. Effective joins be able finished by reducing the stress from shrinkage of the weld .For the reason that of the template chilling and quick iron solidification the tube ought to be annealed (heat-treated) to manufacturing the required percentage of ferrite that conveys strength, ductility, and impact quality requisite using allocations water favor Protected metal-arc joining is the greatest public joining method adopted on malleable cast iron tube in terrain. The essential tools for sheltered metal-arc joining is as next:1. D.C. arc welder by means of inverted polarity. Certain electrodes devised for joining ductile iron are numbering 44- and 55 nickel-iron percentage electrodes.. These electrodes offer join metal strength and stiffness qualities that are analogous to those of the parent iron. The 44- and 55-percent nickel-iron electrodes ought to be in agreeing with (E-R-Ni-CI) and (E-Ni-Fe-CI) correspondingly. These electrodes are talented of manufacturing appropriate joins devoid of preheating or post heating the tube or connecting section. Such as a supple tube, ductile iron has numerous benefits to account through fresh water and wastewater tube projects. Several of tubs have denser fence, abound, and usefulness and entrepreneur knowledge – supplied the precise corrosion predominance ways are adopted. As with all metallic pipes, however, failing will happen if corrosion is not effectively give a talk. It is fair a matter of time [Olasupo ogundare1 2012].The main worsening way on the peripheral of gray and ductile cast iron tubing is electrochemical corrosion with destruction happening in the shape of pits. The destruction to gray cast iron is regularly disguised by the being there "graphitization ."Graphitization is a word used to define the grid of graphite flakes that stay after the iron in the tube has been filtered away using corrosion. Either shape of metal lack exemplifies a corrosion pit that will propagate with time and finally lead to a water chief break. The physical surroundings of the tube has a important influence on the weakening rate . Elements that Hurry corrosion of metallic tubing are wandering.electrical currents, soil qualities like dampness meaning, chemical and microbiological meaning, electrical resistivity, a response, redox potential [N,rajani b. et al ,2001] .The inner of a metal tube perhaps be exposed to tuberculation, erosion, and crevice corrosion subsequent in lowered the active of inner diameter. Violent inside corrosion perhaps as well influence tube structural perversion .The source water affects the interior corrosion in tubes during its chemical qualities, e.g. pH, solute oxygen, free chlorine remaining, alkalinity[Chariton,r.s . p.eng et al,1989]**.**The form of the graphite existent in an alloy impacted on the mechanical qualities of the material .Flake graphite performances as a hard stress while the spheroidal graphite does not Admirable instance of this influence is the variance among

gray and ductile cast iron [ASTM annual book2000] .Many studies concerned this subject as [Olasupo Ogundare1 2012] studied the corrosion qualities and the inseparable variations in the microstructure of unalloyed ductile iron (DI) and austenitic stainless steel (ASS) in salt medium using immersion test technique. The discrete corrosion rates of DI and ASS is calculated for the extreme epoch of 1200 hr., the corrosion rate of DI is calculated and existing it is larger four-orders of amount than of ASS. The corrosion generative morphologies of the DI indicated that the nodular matrix is regularly protected up as inundation period advanced while the corrosion canals and size of pits that originally shaped in ASS consecutively excavated and increased with increased exposure time. DI and at that time show that microstructures of the rusted specimens exhibited corrosion start and step by step accretion of corrosion crops. [Ukoba ,et al ,2012] studied the corrosion rate of ductile iron in diverse consistent to zones of practice and storing for a time of six (6) months. The surroundings are outside, air conditioned, (salty) and alkaline. He show that when the period is rising the corrosion rate reduce . And find a shrill corrosion rate at the first little months for the whole surroundings on the other hand as the month rises the corrosion decelerates down. Brackish (NaCl) surroundings had the uppermost weight wasting with a variance (last month – initial month) of 1.1456g followed by outside with a variance of 1.0284g while A/C had the lowest with zero. The results obtained will assist the engineers, scientists, materials sellers and users, policy makers particularly in the zone this manufactured goods exercise and stockpile.
[T. J. KELLY et al, 1985] studied the tensile strength of unalloyed ductile iron weld joint using Ni-Fe-Mn as filler metal for arc welding it is found (552 MPa) without pre heat Ni-Fe-Mn. This recently developed filler metal system has several metallurgical characteristics that provide advantages over other systems for joining ductile iron (and other cast irons) The Ni-Fe-Mn scheme has been exist to be valuable with a diversity of joining methods, present the potential for augmented usefulness and cheap in joining of ductile iron. Evaluations of weldment structures and tensile properties are presented. Finally, the effects of heat-affected zone microstructural features are assessed .The results indicate that satisfactory weld meant properties do not depend solely on HAZ microstructure. [A. Al-Hashem, 2001] says that an exploration was implement to define the result of microstructure of nodular cast iron (NCI) on its super cavitation torpedo corrosion conduct in normal saltwater. The cavitation examinations are conducted by a cavitation-induced facility at a frequency of 20 kHz on detached samples. Morphological test on activated samples referred that the surface of NCI turns into very hard by great volume hole pits. Test using optical microscopy of cross-sectioned samples exposed the existence of micro cracks in the bottom of hole pits centering material exclusion on the NCI surface is because of ductile ripping and stiff modes of miss.
The aim of this study to establish a applied electrochemical method for the quick calculation of corrosively of ductile cast iron in sea water, founded on potentiodynamic polarization in the weak polarization area.

TENTATIVE WORK

Metal selection

Ductile cast irons (ductile iron pipe).(ASME IX-AWS D1.1) was chosen and its chemical examination is shown in Table1 which is carry out using ARL Spectrometer .

Welding process.

Manual metal arc welding is used to weld the ductile cast iron pipe which is used in sewage network. The standard length of this pipe is (6) meter with 0. 250m diameter and 5.3mm thickness. Sample shown in figure(1) with dimensions of (200*150*5.3) mm was used in this work.

After cleaning with a scraper and acetone the plates prepared to the dimensions (100*50*4) mm manufacture of single V- butt combined with angle of 45° as shown in Figure(2).

In welding process, welding machine type smart was used with [Ni-Fe-C1] as filler metal its chemical compassion is shown in Table 2., the other parameters are shown in Table 3 .

When joining method actualizes the joints are examined using X-ray radiography. Broken down and are poor joined parts are disqualified as of the group, the joined deprived of faults used to prepare the corrosion specimens test in the dimensions of (1.5*1.5*3) cm agreeing to the ASTM G 71 -31

Categorization of specimens

After completing the preparation of specimens, it is categorized by giving symbol (A) to base metal specimens and symbols (B) for weld specimens

Microstructure test

As of a cross section of the joins and parent alloy many specimens are equipped for Microstructure examination according to the following procedure . grinding process with water by SiC emery paper at diverse grits of (220,320,500, and 1000) .polishing process using diamond paste of size (0.3µm) with special polishing cloth. And the samples are washed by water and alcohol then dehydrated. Engraving operation is complete to the samples using engraving solution (Nital) consisting of 98 ml methanol of alcohol and 2%, ml HNO_3, then wash away with water and alcohol and parched in furnace.

The joint samples are inspected using Nikon ME-600 optical microscope supplied with a NIKON camera, DXM-1200F.the microstructure consequences are exposed in Fig. 3.4

Micro Hardness Examination

Using Vickers hardness device at a 200 g weight for 15 sec to measure the hardness across the weld joint section and determined weld zone to the base metal Fig. 5 shows the hardness profile result.

Corrosion examination

Corrosion examination performed as sequent

A-preparing of the Corrosion Solution

The corrosion solution was 3.5 wt %NaCl which was by dissolve in 35 gm of sodium chloride (NaCl) in1000ml of distilled water. The pH was quantify using pH measure and it was read to be 6.9.

B-Electrochemical Examinations

Equipped sample was immobile within the possessor; the authority electrode was immobile around (1 mm) than the face of the sample to be examined. The authority electrode applies in this examination was Calomel Electrode (SCE). The helpful electrode apply in the electrochemical test was platinum. The sample immobile (working electrode), together with the authority and helpful electrode was injected in their individual location in the electrochemical cell apply for this object then all electrodes were fitted as exposed in **Fig. 6.**

Fixed potentials (anodic or catholic) was be compulsory on the sample, with the Potentiostat (Mlab200)"from of Bank Eleck. Germany). This potentiostat can be to persuade a fixed potentials varying (-1 + lv).

The potential difference between the working and helpful authority electrodes and some current transient in the circuit of employed electrode was helpful electrode and could be measured using the SCI Computer Software. The consequence and plans are note down by window XP. The poll modifier was choices also.
Polarized confrontation examinations are employed to get the micro cell corrosion modifiers. In the examinations, cell current evaluation is getting through a dumpy scavenge of the potential. The scavenge is in use starting (-700 to +700) mv imputation to (OCP).
survey average describes the rapidity of potential scavenge, a linear information fitting of the analogue model offers an (icorr) and corrosion rate .at scan rate (10 mv/sec) where the test conditions are the temperature at 25ºC and media velocity 1m/min

Mathematical model

Depending on mathematical model used in research **Xianming Shi et.1985** .For weak polarization of ductile cast iron in sea water, the polarization because of quantity relocation or Ohmic fall is either one insignificant or manage to remunerated correlation among current density (i) and potential (E) on the polarization curve was dominate through the subsequent following equation (1)

$$i = i_{corr}\left\{\exp\frac{2.3(E-E_{corr})}{b_a} - \exp\frac{2.3(E-E_{corr})}{b_k}\right\} \qquad (1)$$

where
Icorr . corrosion current
Ecoor corrosion voltage
E instance voltage
I instance current
b_a,b_k slop of polarization curve

While the gravimetric way offers the mediocre corrosion improved above a period of time. The corrosion electrochemical factors containing E_{corr} i_{corr} b_a and b_k be capable of applied not only to define the immediate corrosion average in order to get such data from potentiodynamic polarization curves; this study introduces an approaching way in place of the mathematical resolution. First, E_{corr} is inserted as the potential where the current density is zero on the CSV curve. As proved in Fig.6, the anodic and cathodic polarization curves are then plotted as over potential (ΔE) versus the logarithm of current density (Lgi), in the polarization range of ± 80 for sample A and ±100 mV (weak polarization region). The anodic and cathodic bows are at that time arranged to two polynomials, continually. In Fig. 6 for samples A, B, the importance of R-square designate in what way well the bows were arranged, with (1) as finest appropriate and (0) as poorest appropriate. At times the bows are fitted, the Tafel slopes, b_a and b_k, can be approximated by taking the derivatives of the linear at over potential of ±80 mV and ±100 mV, respectively. Based on $b_{a \text{ and }}$ b_k, the value of Tafel constant B can be calculated.

$$\Delta E_{a.} = A_a + b_a \log i_a \qquad (2)$$

$$\Delta E_k = A_k + b_k \log i_k \qquad (3)$$

Where ΔE_a and ΔE_k are anodic and cathodic over potential, and i_a and i_k are anodic and cathodic current density, respectively. Replacing ΔE_a and ΔE_k with and -80 and +80 mV for sample A and +100 and -100 for sample B in equations (2) and (3) respectively, we can obtain the values of A_a and A_k. Then, replacing ΔE_a and ΔE_k with (0), we can obtain the values of lgi_a and lgi_k at E_{corr}. As shown in Table 3. If the values of lgi_a and lgi_k at E_{corr} are very close to each other, their average gives the logarithm of i_{corr}.

DISCUSSION

Fig. 3 Shows the microstructure of ductile cast iron sample (A) consists of spherical graphite in matrix of full ferrite and Fig. 4 displays a photomicrograph for joined (sample B) gained by a Ni- Fe -C electrode deprived of heat up and chilled in air it shows three areas, First the HAZ region is witnessed to be knot graphite and ferrite, pearlitic structure (dark matrix) greatly alike to the original metal structure counting too martins ate and carbide this is goes with researcher[M. Pascual et al,2009]. The second is fusion zone (M.R.) is the consequence of fusing which melt the original alloy and padding alloy to fabricate a region using a conformation that is most a lot diverse as of that of the original metal. When liquid phase of the MR cools there will be a formation of marten site and carbide in fusion zone ,it can be controlled via controlling of cooling rate and chemical composition of fusion zone by nickel original padding material, take shape of brittle martensite and carbide in weld zone is hindered . The third is base metal region which does not affected by welding, Fig. 5 demonstrations the hardness sketch of the join region along the distance from welding zone, the highest hardness value is 430 Hv in HAZ region because of the martinsite and carbide exist in microstructure while the lowest one is 180 Hv at base metal region . This is because of the heating conductivity and slow cooling and the hardness of fusion zone was 300 Hv this decreasing because of high heat input and low cooling rate producing ferrite phases and pearlite by dissolving martensite. Electrochemical corrosion examination using Tafel extrapolation process is performed on the whole specimens of original iron alloys and weld joint of ductile cast in sodium chloride solution of 3.5% NaCl to define corrosion Factors, like corrosion potential (Ecorr) and corrosion current (Icorr) as exposed in Table. 4. These factors will give information to compute the corrosion average agreeing to the equation (4) [Annual book of ASTM Standards, 2004].

$$C.R\ (m.p.y) = 0.13 * Icorr * eq.wt / \rho \qquad (4)$$

where
m.p.y= mille-inches per year
I_{corr}=corrosion current density (μAcm2)
Eq.wt=the same weight of the corroding sort,
ρ= density of the corroding kinds, (g/cm3).

Figure. 7 shows the predicted polarization curves, Fig. 8 shows the practical polarization curves of the ductile cast irons sample in sea water .these curvatures demonstration the cathodic and anodic areas which indicate that, there is in sample (A) is an decreases in corrosion current density (Icorr) then corrosion rate , welding process in sample (B) produce different Compositional area because of the effect of filler metal and the major item in it is ferrite which will produce galvanic couple, which can influence the corrosion

process in the vicinity of the weld. This is obvious in Fig. 9 that shows the corrosion photos.
In mathematical model all reckoning of corrosion electrochemical factors are completed in a spreadsheet deprived of program design. The R-square for feeble polarization curve fitting is originate generally greater not to 0.90, and the constant of difference for lgia and lgik is present generally lesser not to 2%. These results circuitously authenticate the suggested method to finding corrosion electrochemical factors as of feeble polarity arcs. For that after comparing corrosion rate measuring value achieved directly from the Potentiostat device with the predicate one there is a slight difference between these values.

CONCLUSIONS

From the results obtained in the present work, the following conclusions can be drawn

1. The electrochemical method is able to quickly calculate the corrosively of metals in sea water and (corrosion current density) are find valuable near forecast the consequence of gravimetric examination in equitable precisions.
2. The ability to form barrier film on base ductile iron is better than for the welded one.
3. These results show that, HAZ, microstructure gives the highest hardness value in weld region and improve by that the mechanical properties.
4. Choosing Welding filler metal effect on corrosion rate in weld metals.

Table 1 chemical analyses of ductile cast Iron [Metals handbook 1985]

Element %wt	C	Si	Mn	Cr	Cu	Mg	Mo	Ni	Fe
Nominal value	3-3.9	2.25-2.75	0.3-1	0.8	0.15-0.4	0.03-0.05	0.01-0.1	0.05-.0.2	Rem.
Actual value	3.6	2.3	0.65	0.05	0.05	0.02	-	0.06	Rem.

Table 2 chemical composition of wire electrode (Ni-Fe-C_l)

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu
Wight %	2.0	4.0	1.5	-	0.03	-	6-4.5	-	1.0	2.5

Table 3 welding conditions

No.of pass	Current(amp(	Voltage (volt(	Travel speed inch /min	Filler metal diameter (mm)
Pass (1)	DCEN 90	20	7	3.2
Pass(2)	DCE 78	20	8	3.2

Table 4 The corrosion electrochemical paramete r

Sample	E_{corr}	b_a	b_k	i_{corr})µA/cm(2	PCR measured (m.p.y)	PCR predicated (m.p.y)	Error
A	-738.6	49.577	-51.78	25.68	11.62	11.3	2.5%
B	-780.3	0.468	-0.477	40.8	17.18	17.9	4%

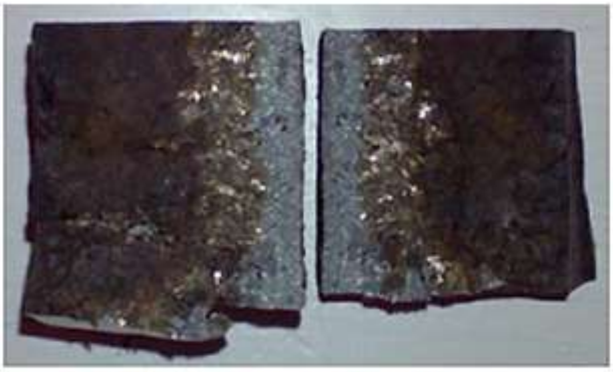


Fig. 1 a photograph of the cutting pieces from the pipe

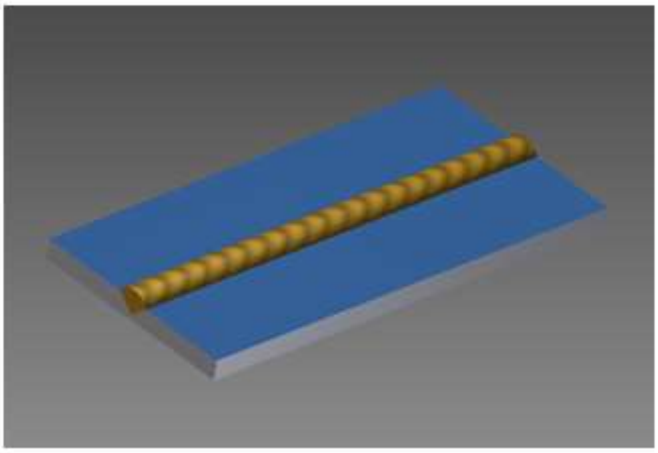


Fig. 2 butt weld join

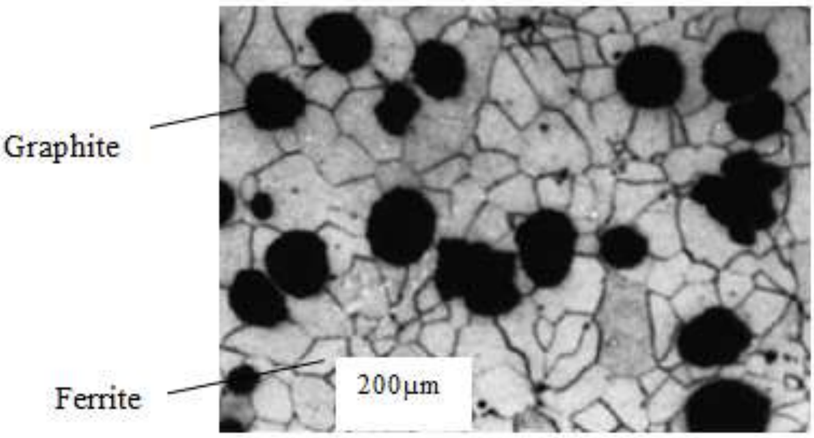
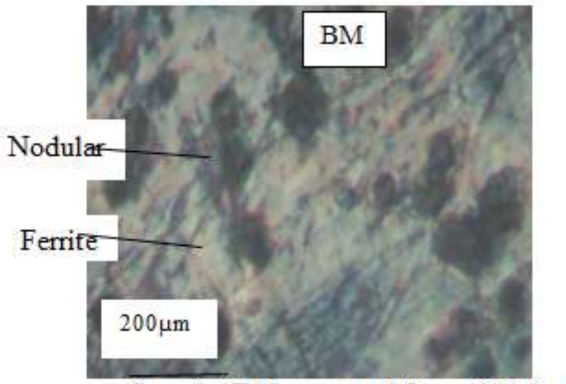
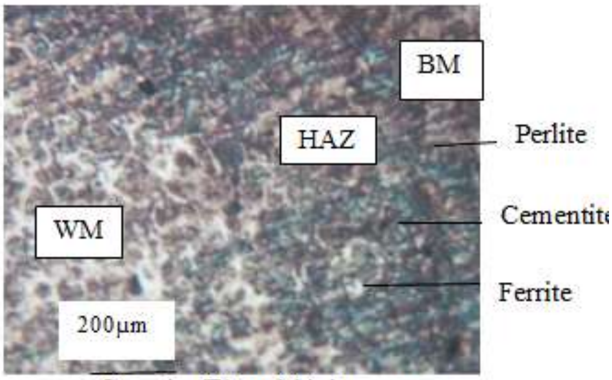


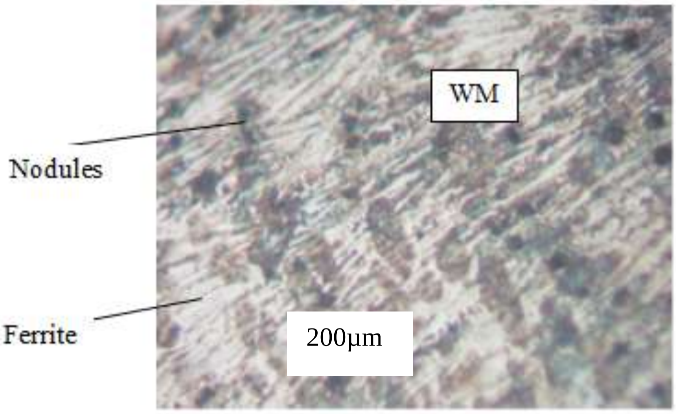
Fig. 3 micro structure for sample (A) Base metal



Sample (B) base metal for weld joint



Sample (B) weld joint zone



Sample (B) at fusion zone

Fig.4 Microstruture of sample(B) **after welding.**

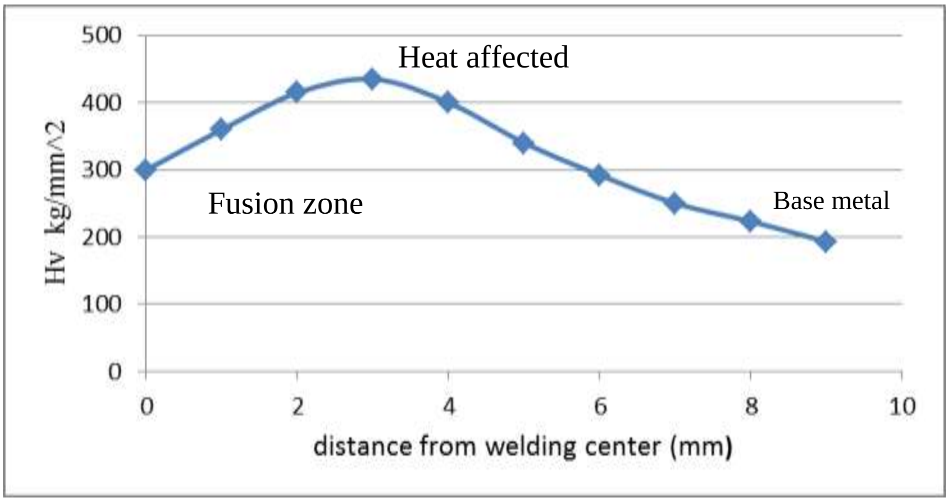


Fig 5 micro hardness profile for weld joint specimens

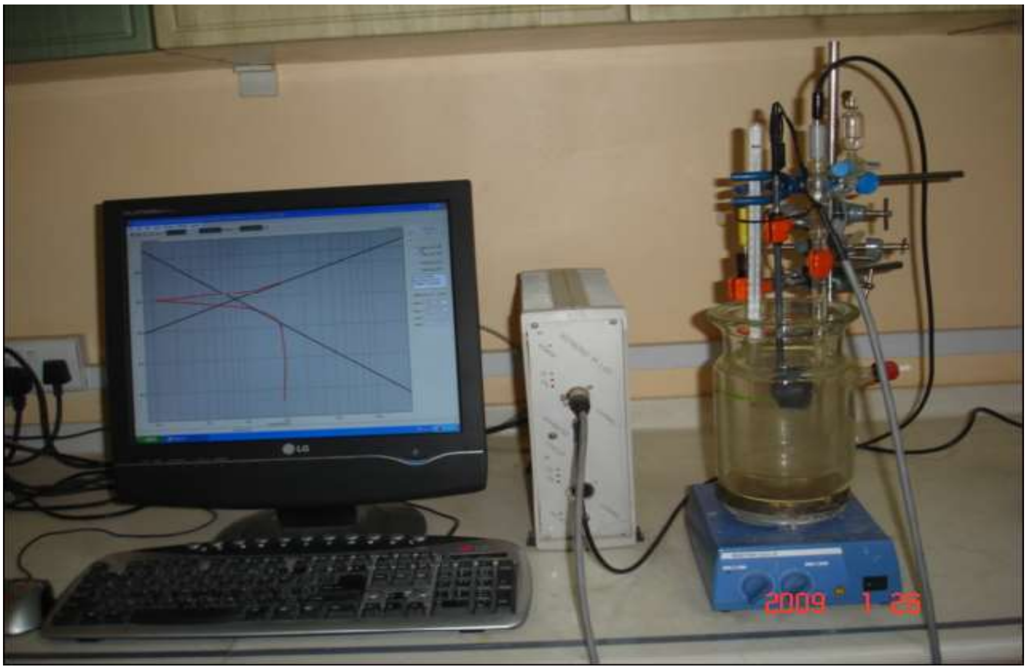
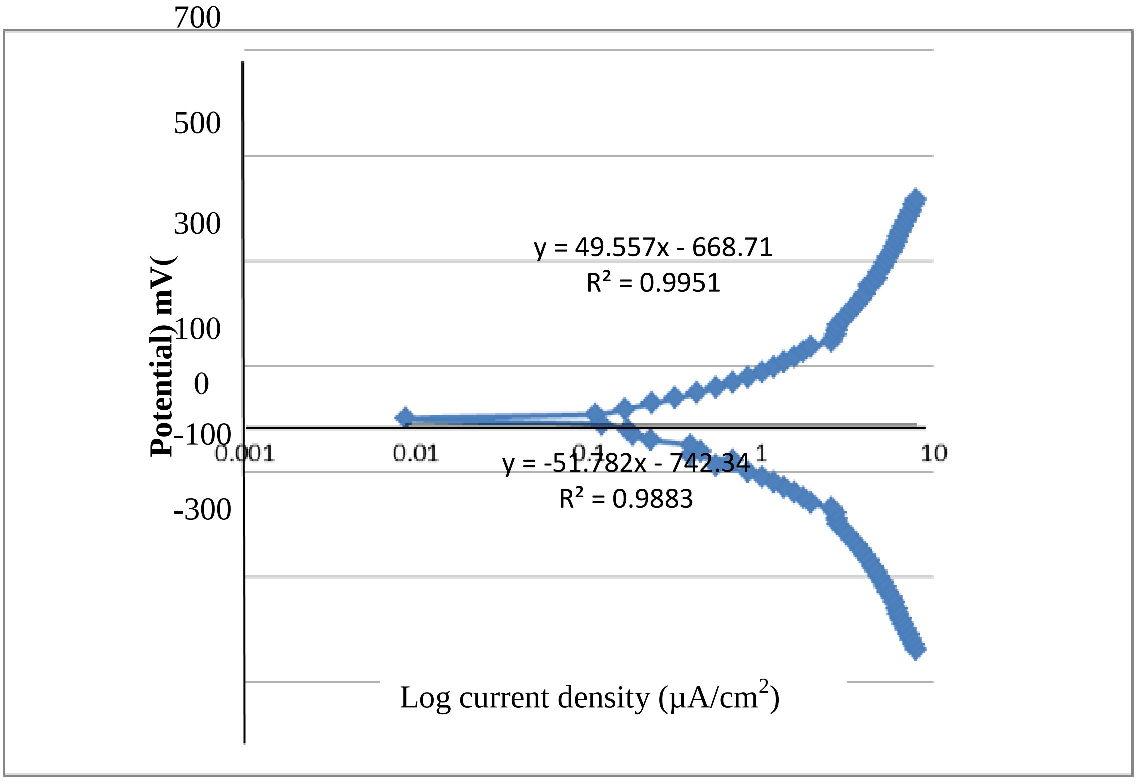
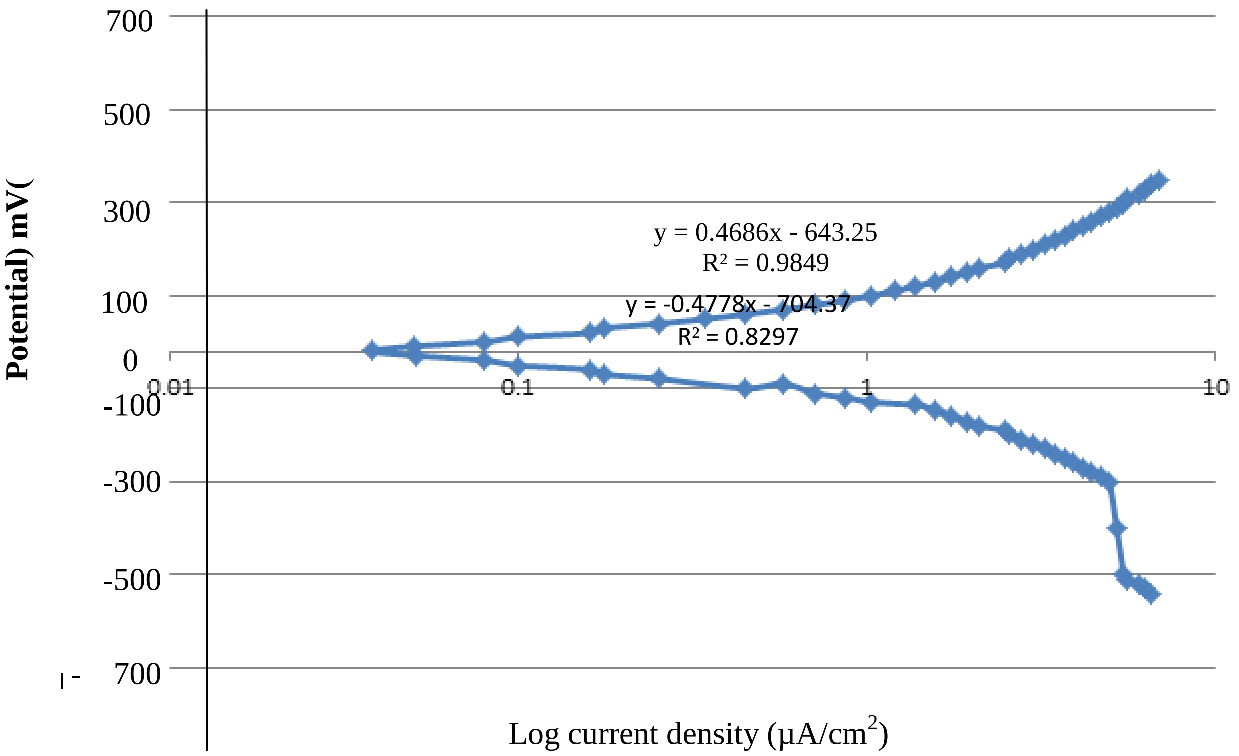


Fig. 6 The electrochemical corrosion unit and its cell.

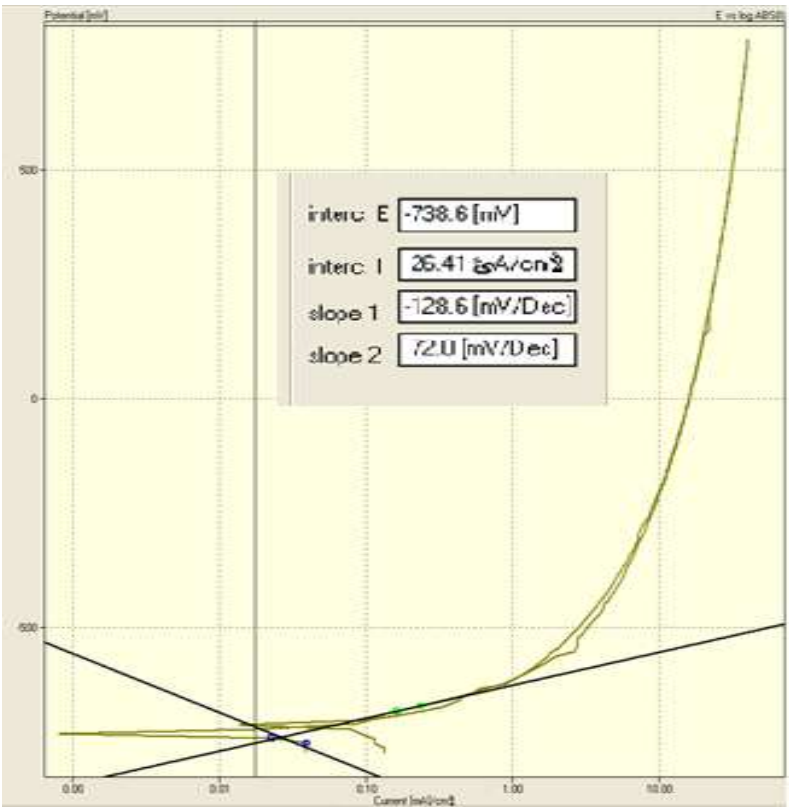


Sample (A)

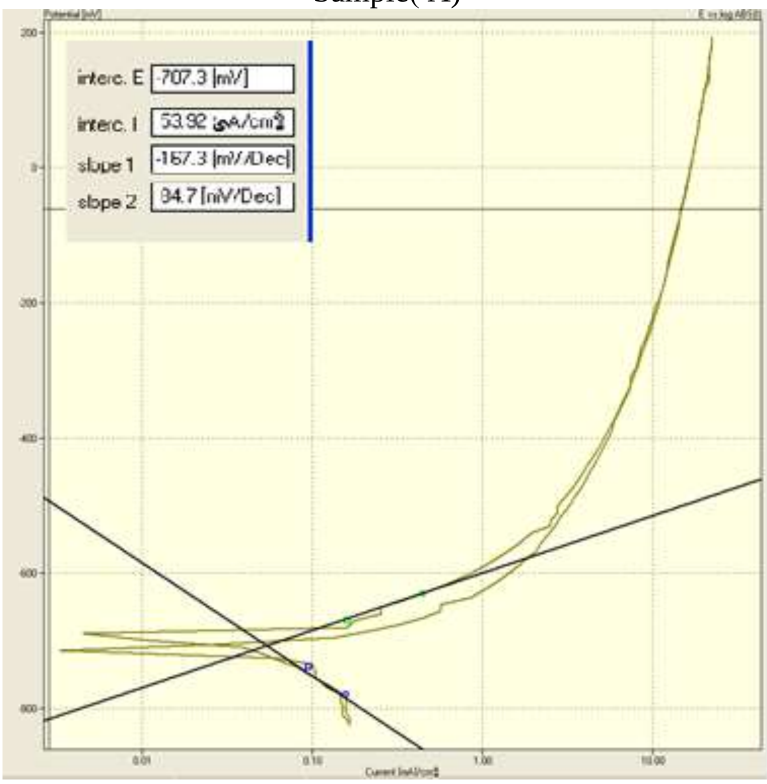


Sample (B)

Fig.(7) The relationship between current density and potential



Sample(A)



Sample (B)

Fig. 8 **predicted** relationship between current density and potential

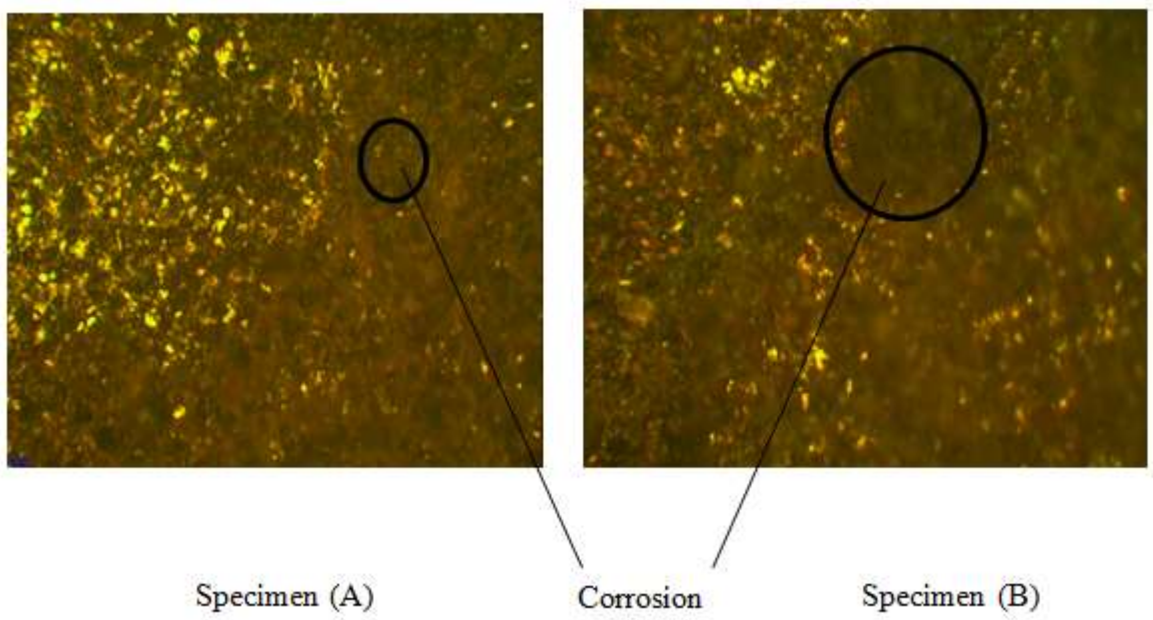


Fig. 9 Corrosion photos

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