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Prediction of Ultimate Tensile Strength of Shipbuilding Steel Plate LR Grade-A (S235JRG2) for One-Sided Butt-Welding Joint

R. Ramadan[1], *M. R. Abou Elsayed*[2]

[1]*Lecturer, Naval Architecture, and Marine Engineering Department, Faculty of Engineering, Port Said University, Port Said, Egypt,*
E-mail: randa.ramadan@eng.psu.edu.eg
[2]*B.Sc., Naval Architecture, and Marine Engineering, Department, Faculty of Engineering, Port Said University, Port Said, Egypt,*
E-mail: mohamed.ragab@suezcanal.gov.eg
* *M. R. Abou Elsayed, mohamed.ragab@suezcanal.gov.eg,* *DOI: 10.21608/pserj.2021.99551.1148*

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ABSTRACT

This work presents an evaluation of the Ultimate Tensile Strength (UTS) of One-sided butt-welding joints in the marine field, using the technique of the rootArc® program. The study was conducted using a semi-automatic welding machine model; EWM-Taurus 505 Basic S. In this study, due to the developments of welding technology and the improvements in welding machines, the one-sided welding technique was adopted to weld two (S235JRG2) steel plates of 8 mm, by means of Gas Metal Arc Welding (GMAW) process. Through the experiments, six samples were evaluated. All welding passes of welded joints were welded using a welding machine (EWM) with the same program rootArc®, using 100% commercial Carbon Dioxide (Co_2) as shielding gas. In addition to implementing a range of current intensity from 90 to 180 Amp and voltages from 15 to 25 Volt were used. Two different types of welding consumables electrodes were used in this work, first flux-cored wire, AWS A5.20/ASME SFA5.20 E71T-1C, and second solid wire, AWS/ASME A-5.18 ER70S-6. The experimental results were verified by Destructive Tests (DT) in the International Pipe Industry Company (IPIC) laboratory as well as Non-destructive tests (NDT), magnetic particles, Ultrasonic and X-ray, done in Port-Said Shipyard. The results have shown that the accepted joint with selected parameters was able to predict the ultimate tensile strength. Moreover, the specimen shows that the rapture due to the transverse tensile test occurs in the base metal, not in the welding seam.

Keywords: Gas Metal Arc Welding (GMAW), Ultimate tensile strength (UTS), rootArc® program, Steel plates S235JRG2, Non- destructive Test (NDT), Destructive Test (DT).

1.INTRODUCTION

Welding is defined as “a jumping process that produces coalescence of materials by heating them to the welding temperature, with or without the application of pressure alone, and with or without the use of filler metal [1].

Gas Metal Arc Welding (GMAW) is a welding process where an electrode wire is continuously fed from an automatic wire feeder through a conduit and welding gun to the base metal, where a weld pool is created. If a welder is controlling the direction of travel and travel speed, the process is considered semi-automatic. The process is fully automated when a machine controls the direction of travel and travel speed, such as in the case of robotics [2].

In 1948, the first inert gas metal arc welding (GMAW) process shown in **Error! Reference source not found.**, as it is known today, was developed and became commercially available. In the beginning, the GMAW process was used to weld aluminum using argon (Ar) gas for shielding. As a result,

The process was known as MIG, which stands for metal inert gas welding. The later introduction of CO_2 and O_2 to the shielding gas has resulted in the American Welding Society’s preferred term gas metal arc welding (GMAW) [3].

Gas metal arc welding (GMAW) is also referred to as MIG (metal inert gas) welding if the shielding gas is inert (e.g., argon) or MAG (metal active gas) welding if the gas has a content of an active gas (such as CO_2) [4].

Metal Active Gas (MAG) welding process, a subtype of Gas Metal Arc Welding (GMAW), has been used in the welding industry for many decades due to its significant advantages, including high productivity, simple mechanism, good quality and mechanical properties of the weld joint, and a wide range of weldable materials and filler metals [5].

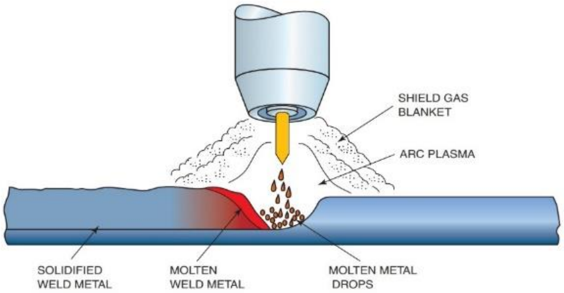


Figure 1: Gas-shielded metal arc welding (GMAW)

In this work, the authors propose a welding method that could achieve the requirements of the classification society during the special survey of a floating unit owned by the Suez Canal Authority. Moreover, it may overcome the problem of cutting and renewal damaged plates in the superstructure area, which might be more difficult to be fulfilled due to the constraints of implementation as (piping systems - insulation systems Cables-trays).

Due to the development of welding systems which are being transformed by the advent of modern information technologies such as the internet of things (IoT), big data, artificial intelligence (AI), cloud computing, and intelligent manufacturing. The intelligent welding systems (IWS) as multi-functional welding machines which have many programs as rootArc® program [6].

This program solves the problem of the renewal of damaged plates in the superstructure area. Firstly, using the One-Sided welding technique, designing welding connection, writing welding procedure specification (WPS), and setting the rootArc® program parameters in the welding machine. Thereafter, the welding joint subjects to two types of tests, Non-destructive (NDT) and Destructive tests [7].

The accepted joint gets approval from classification societies for Procedure Qualification Record (PQR) and Welding Procedure Specification (WPS).

2. EXPERIMENTAL DETAILS

In this paper, the ultimate tensile strength (UTS) is predicted by evaluating six chosen welding joints using the same welding technique rootArc®, and two different types of welding consumable electrodes include.

2.1. Welding Joints Preparation

A shipbuilding mild steel (S235JRG2) plate 8mm thick is used as the base metal of welding joints, with a yield strength of 268 MPa and ultimate tensile strength of 402 Mpa [8].

The chemical composition of base metal (S235GRG2) in addition to the chemical composition of Consumables, according to AWS A5.20/ASME SFA5.20 E71T-1C and AWS A5.18: ER70S-6, are shown in Table 1 [9].

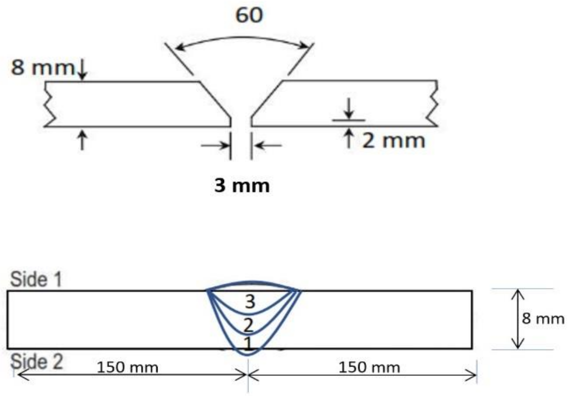


Figure 2: Welding joint specification

The dimensions of the welding joints are 150 mm wide, 300 mm long, according to the International Association

Table 1: Chemical compositions of base metal and consumables

Contents	Flux cored wire (E71T-1C)	Solid wire (ER 70S-6)	Base metal (S235JRG2)
C	0.030	0.070	0.170
Si	0.560	0.860	0.200
Mn	1.290	1.440	0.800
P	0.011	0.014	0.025
S	0.005	0.008	0.015
Cr	0.040	0.025	0.040
NI	0.020	0.014	0.020
Mo	0.010	0.002	0.002
V	0.020	0.002	0.002
Nb	N/A	N/A	0.002
Cu	0.010	0.150	0.030

of Classification Societies (IACS: Unified Requirements UR/W28), as shown in Figure 2[10],[11].

The welding joints were cleaned and prepared with a mechanical tools brush for better weld quality and to prevent any inclusion in the welding seam during the welding process. A 3 mm-gap butt joint was formed in three passes by means of the Metal Active Gas welding process (MAG), as shown in Figure 2 [12]

2.2. Equipment’s

An EWM-Taurus 505 Basic S (Mundersbach, Germany) as a welding machine is shown in Figure 3.

A consumable electrodes flux-cored wire, AWS A5.20/ASME SFA5.20 E71T-1C, and solid wire, AWS A5.18, ER 70S-6 with 1.2 mm rod diameter were the welding consumable [13],[14].

Commercial carbon dioxide (CO_2) bottles were used as the shielding gas in order to prevent chemical reactions between the spacemen’s surface and the atmosphere.

Figure 3: Welding machine EWM-Taurus 505

2.3. Selection of Welding Parameters

The welding processes Handbook 2nd edition recommended an advisable range for input parameters used which has been used in the welding machine shown in Table 2 [4].

The welding procedure specifications define the six parameters which are investigated in the study shown in **Error! Reference source not found.**.

As for the welding machine by selecting the rootArc® job using machine control shown in Figure 4 and recommended job list shown in **Error! Reference source not found.**.

rootArc® job produces a short arc with perfect weld modeling capabilities for effortless gap bridging, especially for positional welding [15].

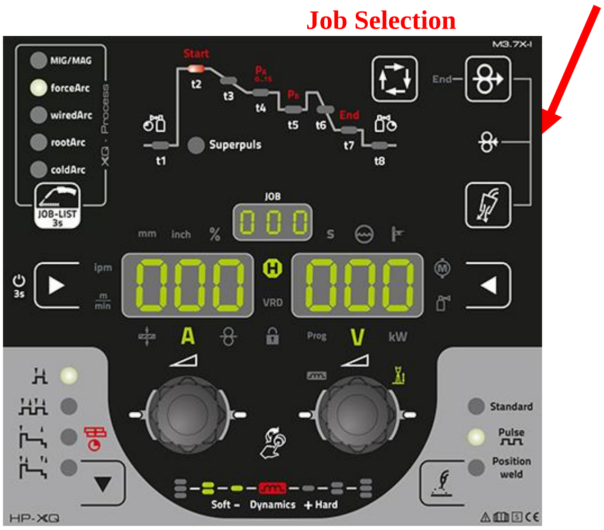
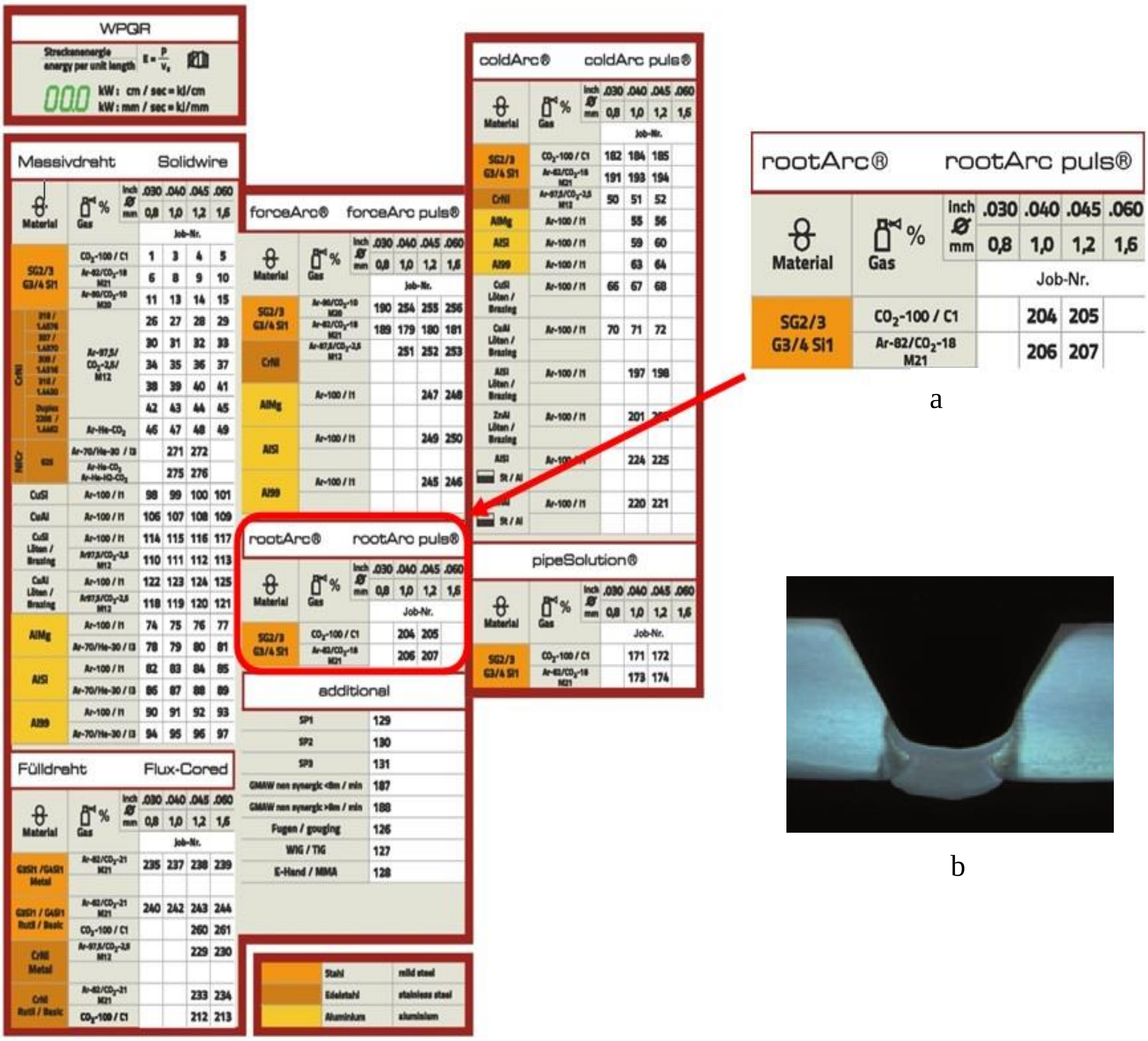

Job Selection

Figure 4: Machine control of Taurus 505 Basic S

Table 2: Six input parameters

Number	Parameter	Unit	Notation
1	Wire feed rate	m/min	*F*
2	Welding voltage	Volt	*V*
3	Travel angle	Degree	*S*
4	Welding speed	mm/min	*A*
5	Travel-to-work distance	mm	*D*
6	Shield gas flow rate	Litter/min	*G*



WPQR

Streckenenergie energy per unit length $E = \frac{P}{v_s}$

000 kW : cm / sec = kJ/cm
kW : mm / sec = kJ/mm

Massivdraht Solidwire

Material	Gas %	.030 / 0,8	.040 / 1,0	.045 / 1,2	.060 / 1,6
SG2/3 G3/4 Si1	CO_2-100 / C1	1	3	4	5
	Ar-82/CO_2-18 M21	6	8	9	10
	Ar-90/CO_2-10 M20	11	13	14	15
CrNi 318 / 1.4576	Ar-97,5/ CO_2-2,5/ M12	26	27	28	29
CrNi 307 / 1.4370		30	31	32	33
CrNi 308 / 1.4316		34	35	36	37
CrNi 316 / 1.4430		38	39	40	41
CrNi Duplex 2209 / 1.4462		42	43	44	45
	Ar-He-CO_2	46	47	48	49
NiCr 625	Ar-70/He-30 / I3		271	272	
	Ar-He-CO_2 Ar-He-H_2-CO_2		275	276	
CuSi	Ar-100 / I1	98	99	100	101
CuAl	Ar-100 / I1	106	107	108	109
CuSi Löten / Brazing	Ar-100 / I1	114	115	116	117
	Ar97,5/CO_2-2,5 M12	110	111	112	113
CuAl Löten / Brazing	Ar-100 / I1	122	123	124	125
	Ar97,5/CO_2-2,5 M12	118	119	120	121
AlMg	Ar-100 / I1	74	75	76	77
	Ar-70/He-30 / I3	78	79	80	81
AlSi	Ar-100 / I1	82	83	84	85
	Ar-70/He-30 / I3	86	87	88	89
Al99	Ar-100 / I1	90	91	92	93
	Ar-70/He-30 / I3	94	95	96	97

Fülldraht Flux-Cored

Material	Gas %	.030 / 0,8	.040 / 1,0	.045 / 1,2	.060 / 1,6
G3Si1 / G4Si1 Metal	Ar-82/CO_2-21 M21	235	237	238	239
G3Si1 / G4Si1 Rutil / Basic	Ar-82/CO_2-21 M21	240	242	243	244
	CO_2-100 / C1			260	261
CrNi Metal	Ar-97,5/CO_2-2,5 M12			229	230
CrNi Rutil / Basic	Ar-82/CO_2-21 M21			233	234
	CO_2-100 / C1			212	213

forceArc® forceArc puls®

Material	Gas %	.030 / 0,8	.040 / 1,0	.045 / 1,2	.060 / 1,6
SG2/3 G3/4 Si1	Ar-90/CO_2-10 M20	190	254	255	256
	Ar-82/CO_2-18 M21	189	179	180	181
CrNi	Ar-97,5/CO_2-2,5 M12		251	252	253
AlMg	Ar-100 / I1			247	248
AlSi	Ar-100 / I1			249	250
Al99	Ar-100 / I1			245	246

rootArc® rootArc puls®

Material	Gas %	.030 / 0,8	.040 / 1,0	.045 / 1,2	.060 / 1,6
SG2/3 G3/4 Si1	CO_2-100 / C1		204	205	
	Ar-82/CO_2-18 M21		206	207	

additional

SP1	129
SP2	130
SP3	131
GMAW non synergic <8m / min	187
GMAW non synergic >8m / min	188
Fugen / gouging	126
WIG / TIG	127
E-Hand / MMA	128

Stahl	mild steel
Edelstahl	stainless steel
Aluminium	aluminium

coldArc® coldArc puls®

Material	Gas %	.030 / 0,8	.040 / 1,0	.045 / 1,2	.060 / 1,6
SG2/3 G3/4 Si1	CO_2-100 / C1	182	184	185	
	Ar-82/CO_2-18 M21	191	193	194	
CrNi	Ar-97,5/CO_2-2,5 M12	50	51	52	
AlMg	Ar-100 / I1		55	56	
AlSi	Ar-100 / I1		59	60	
Al99	Ar-100 / I1		63	64	
CuSi Löten / Brazing	Ar-100 / I1	66	67	68	
CuAl Löten / Brazing	Ar-100 / I1	70	71	72	
AlSi Löten / Brazing	Ar-100 / I1		197	198	
ZnAl Löten / Brazing	Ar-100 / I1		201	[illegible]	
AlSi St / Al	Ar-100 / I1		224	225	
[illegible] St / Al	Ar-100 / I1		220	221	

pipeSolution®

Material	Gas %	.030 / 0,8	.040 / 1,0	.045 / 1,2	.060 / 1,6
SG2/3 G3/4 Si1	CO_2-100 / C1		171	172	
	Ar-82/CO_2-18 M21		173	174	

rootArc® rootArc puls®

Material	Gas %	Inch .030 / mm 0,8	.040 / 1,0	.045 / 1,2	.060 / 1,6
SG2/3 G3/4 Si1	CO_2-100 / C1		204	205	
	Ar-82/CO_2-18 M21		206	207	

a

b

welding

Table 3: Welding procedure specification

Run	Process	Size of Filler Metal	Current Amp	Voltage Volt	Type of Current/Polarity	Wire Feed Speed	Travel speed	Heat Input KJ/mm
1	GMAW	1.2 mm	90-120	15-20	DC+	3.5-5	150-200	..
2	GMAW	1.2 mm	165-180	18-24	DC+	3.5-5	200-400	..
3	GMAW	1.2 mm	165-180	18-24	DC+	3.5-5	200-400	..

3. EXPERIMENTAL PROCEDURE

Firstly, the experimental works were carried out using a flux-cored wire, AWS A5.20/ASME SFA5.20 E71T-1C used as a consumable electrode, with constant current intensity and Voltage 180 Amp/22.9 V shown in Table 4. The welding joint shown in Figure 7 expresses the face pass in good quality. The root pass did not give adequate quality, with many discontinues as root lack of penetration. Therefore, the first welding joints were rejected.

Table 4: Welding parameters for First welding joint using flux-cored electrode

Run	Process (Job)	Size of Filler Metal Ø(mm)	Current Amp	Voltage V	Type of Current/ Polarity	Wire Feed Speed m/min	Travel Speed mm/min	Heat Input KJ/mm
1	205	1.2	180	22.9	DC +ve	..	..	..
2	205	1.2	180	22.9	DC +ve	..	..	..
3	205	1.2	180	22.9	DC +ve	..	..	..

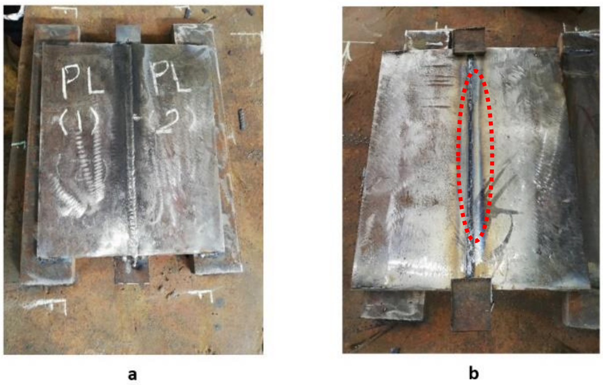


Figure 7: First welding joints: a) Face pass. b) Root pass

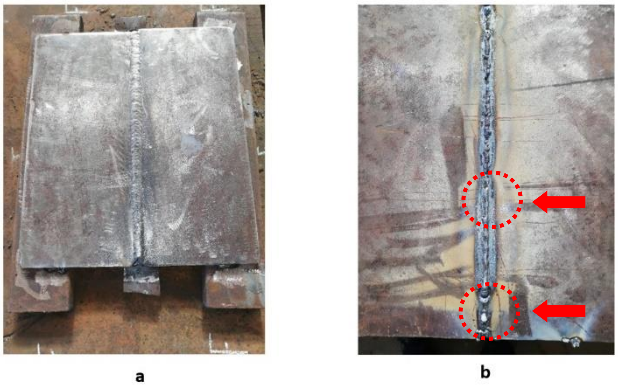


Figure 6: Second welding joints: a) Face pass. b) Root

In the second stage, using a flux-cored wire, AWS A5.20/ASME SFA5.20 E71T-1C was used as a consumable electrode, with constant Voltage and current intensity 171 Amp/22.5 V shown in Table 5.

The decreasing of current intensity and Voltage give an optimized choice in welding joint root pass but Figure 6

The following stage using the same consumable electrode, with constant Voltage and current intensity 112 Amp/18.3 V shown in Table 6. Also, decreasing of current intensity and Voltage did not give adequate root pass shown in Figure 8.

Table 5: Welding parameters for Second welding joint using flux-cored electrode

Run	Process (Job)	Size of Filler Metal Ø(mm)	Current Amp	Voltage V	Type of Current/ Polarity	Wire Feed Speed m/min	Travel Speed mm/min	Heat Input KJ/mm
1	205	1.2	171	22.5	DC +ve	..	..	..
2	205	1.2	171	22.5	DC +ve	..	..	..
3	205	1.2	171	22.5	DC +ve	..	..	..

Table 6: Welding parameters for Third welding joint using flux-cored electrode

Run	Process (Job)	Size of Filler Metal Ø(mm)	Current Amp	Voltage V	Type of Current/ Polarity	Wire Feed Speed m/min	Travel Speed mm/min	Heat Input KJ/mm
1	205	1.2	112	18.3	DC +ve	..	..	..
2	205	1.2	112	18.3	DC +ve	..	..	..
3	205	1.2	112	18.3	DC +ve	..	..	..

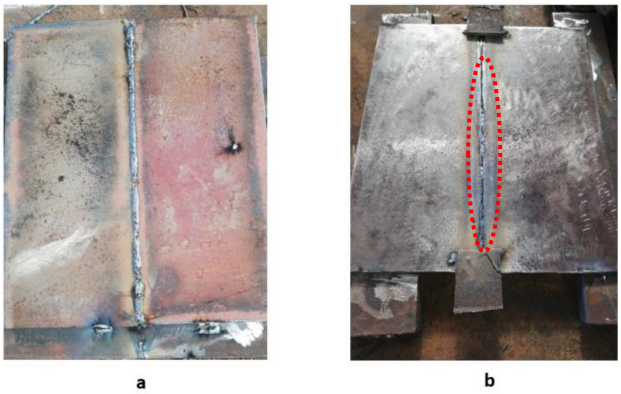


Figure 8:Third welding joints: a) Face pass. b) Root pass

Adopting the second type of welding consumable, solid wire AWS/ASME A-5.18 ER70S-6, with a constant of current intensity and Voltage 165 Amp/ 22.2 V shown in Table 7.

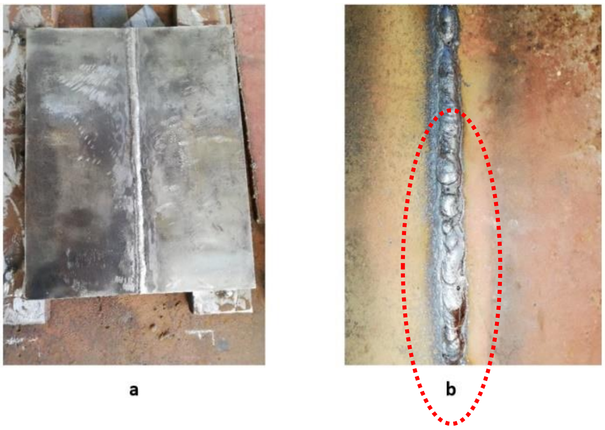


Figure 9: Fourth welding joints: a) Face pass. b) Root pass

The welding joint gives an improvement in face welding pass, but with excess in welding root pass shown in Figure 9, the welding joint also is rejected.

Table 7: Welding parameters for Forth welding joint using solid wire electrode

Run	Process (Job)	Size of Filler Metal Ø(mm)	Current Amp	Voltage V	Type of Current/ Polarity	Wire Feed Speed m/min	Travel Speed mm/min	Heat Input KJ/mm
1	205	1.2	165	22.2	DC +ve	5.7	260	0.65
2	205	1.2	165	22.2	DC +ve	5.7	260	0.65
3	205	1.2	165	22.2	DC +ve	5.7	260	0.65

Starting the first run with a low current intensity of 150 Amp and Voltage 41.4 V and by using the same current intensity and Voltage in the second and third run passes 165 Amp/22.2 V shown in Table 8.

The welding joint shown in Figure 10 gives an adequate face and root pass with a lack of penetration in a small area.

Finally, after five trials, the selection of the optimal welding parameters in the control of the welding machine is shown in Table 9.

The joint shown in Figure 11 did not express any defects and produced the adequate quality of Cap and Root reinforcement. Consequently, the welding joint was accepted.

Table 8: Welding parameters for Fifth welding joint using solid wire electrode

Run	Process (Job)	Size of Filler Metal Ø(mm)	Current Amp	Voltage V	Type of Current/ Polarity	Wire Feed Speed m/min	Travel Speed mm/min	Heat Input KJ/mm
1	205	1.2	150	21.4	DC +ve	5.1	230	0.61
2	205	1.2	165	22.2	DC +ve	5.7	260	0.65
3	205	1.2	165	22.2	DC +ve	5.7	260	0.65

a b

Figure 10: Fifth welding joints: a) Face pass. b) Root pass

a b

Figure 11: Sixth welding joints: a) Face pass. b) Root pass

Table 9: Welding parameters for Sixth welding joint using solid wire electrode

Run	Process (Job)	Size of Filler Metal Ø(mm)	Current Amp	Voltage V	Type of Current/ Polarity	Wire Feed Speed m/min	Travel Speed mm/min	Heat Input KJ/mm
1	205	1.2	107	18.1	DC +ve	3.1	140	0.65
2	205	1.2	168	22.3	DC +ve	5.8	260	0.67
3	205	1.2	168	22.3	DC +ve	5.8	260	0.67

4.RESULTS AND DISCUSSIONS

After six welding trials, by visual inspection, the results of the accepted welding joint show that the root pass made over the welding machine using solid wire electrode ESAB AWS A5.18 ER 70S-6 with specified optimal Current intensity and Voltage provided adequate quality of welding joint free from discontinuities.

The next stage, the accepted welding joint subjected to Non-destructive tests (NDT) according to (IACS: Unified Requirements UR/W28) [10]. Firstly, surface test magnetic test (MT) is using the evaluation done using IACS: Rec No.20; the results did not express any cracks and defects. Then the welding joint was subjected to Ultrasonic Test (UT) and X-ray test as shown in Figure 12 and Figure 13; results did not express any internal cracks or defects; the results were supported with an NDT report from Port Said Shipyard [16].

Finally, the welding joint subjected to Destructive Tests (DT) was done in the International Pipe Industry Company (IPIC) laboratory. The accepted welding joints were cutting to samples according to IACS: Unified Requirements UR/W28, as shown in Figure 14.

Figure 12: Ultrasonic Test (UT) for accepted welding joint

Once cutting the samples, each was subjected to a transverse tensile test using 10 Ton universal tensile test machine, as shown in Figure 15. The welding passes have adequate penetration in the edges of the groove and adequate reinforcement shown in Figure 16. The tensile test has not shown any discontinuities. The rupture showed in Figure 17 occurred in the base metal, indicating that the welding procedure was accepted. The Ultimate tensile strength is predicted from the stress-strain curve, as shown in Figure 18.

Figure 13: X-ray test for accepted welding joint

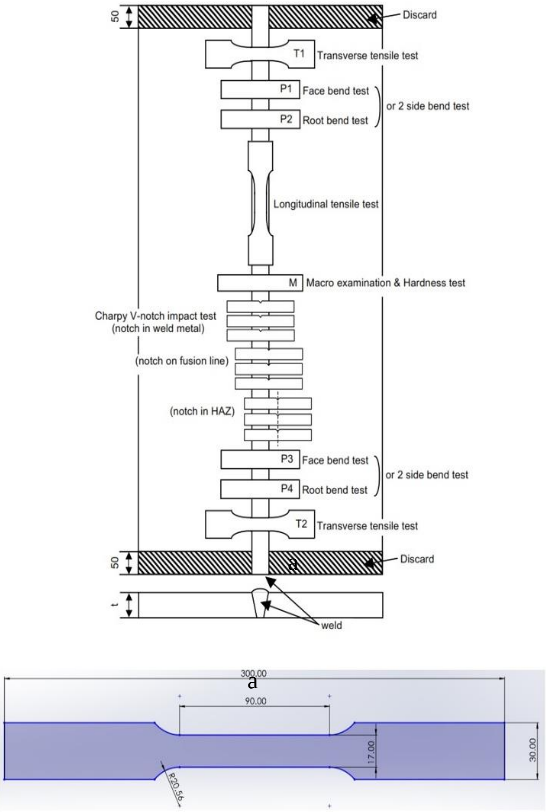


Figure 14: Specimen preparation for the tests: a) IACS w/28 Standard b) Specimen scheme dimension

Figure 15: Universal tensile test machine 10-Ton

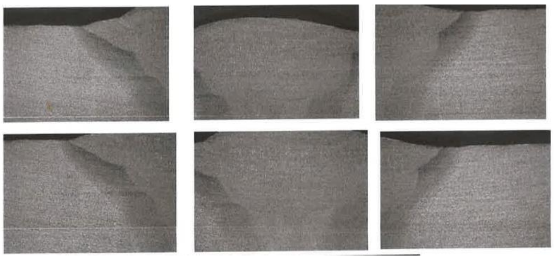
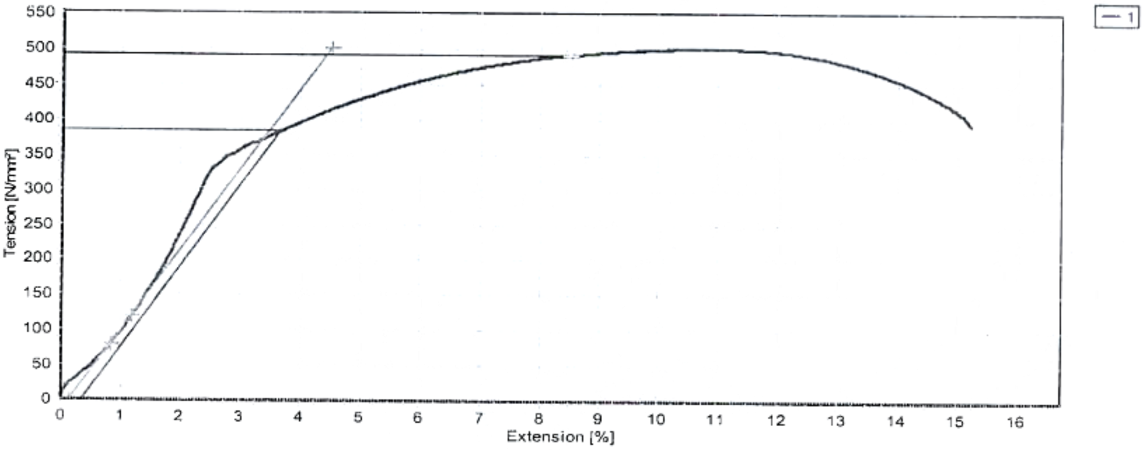


Figure 16: Microstructure of accepted welding joints

Figure 17: Welding joint after tensile test



RM : Ultimate Tensile Strength

Figure 18: Stress-strain curve of transverse tensile test of welding join

5. CONCLUSION

RM

The study focuses on the effect of welding parameters for predicting the ultimate tensile strength (UTS) of the welded joint and the optimal welding conditions for maximum UTS.

The experiments are carried out for predicted Ultimate Tensile Strength (UTS) for variation of current, Voltage, and different types of electrodes and with constant angles of joint and shielding gas type.

The experimental results show that with decreasing current intensity and voltages, the welding joints give adequate quality.

The use of the One-Sided welding technique solves some problems in the ship repair industry. The result has shown that the use of solid wire electrodes gives the best welding joints.

The use of solid wire electrodes is preferred that during use one-sided welding joint the result were optimum than using flux-cored electrodes.

Credit Authorship Contribution Statement:
M. R. AbouElsayed: Joints Preparation, Resources, Investigation, Data Curation &Writing.
R. Ramadan: Validation, Writing, supervision, Review & Editing.
Declaration of competing interest
The authors declare that there is no conflict of interest regarding the publication of this paper.

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[15] EWM, "Operating instructions " in wire feed unit drive 4x HP-drive 4x HP MMA, ed, 2016.
[16] No.20 Non-destructive testing of ship hull steel welds, 2007.