Investigation of Shielded Metal Arc Welding (SMAW)Weld Integrity on a Low- Carbon Steel Pipeline using Destructive Mechanical Testing Technique

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Abstract
Welding is a major application in industries particularly for engineering, and is a typical process that involves joining two or more metals, either similar or dissimilar, through heat energy. Pipeline welded joint failed due to lack of weld integrity. This research aims to investigate weld integrity using destructive techniques by evaluating mechanical properties of shielded metal arc welding (SMAW) weld on low-carbon steel pipeline. Welded joint integrity was evaluated through destructive tests such as, hardness tests, impact-charpy test, tensile testing, bend test, mic & macro hardness. The average Hardness of the WM at 12 o'clock is 211.1 HV, HAZ is 208.6 HV, and BM is 208.6 HV, and at 6 o'clock, the WM is 199.0 HV, HAZ is 216.8 HV, and BM is 178.9 HV, respectively. Tensile tests of welded sample 1 and sample 2 were evaluated and the UTS (N/mm^2) are 569.26 and 566.52, Yield stress (N/mm^2) are 468.43 and 456.1, and breaking stress (N/mm^2) are 380.12 and 382.4, respectively. Impact charpy test were performed on WM, HAZ and BM. The WM has average of 132.9 joules, HAZ with average of 237.1 joules and the BM average of 247.4, characteristically shows the highest value of toughness due to unchanged by welding process. Macro hardness was carried out; the weld penetration was adequate, with a penetration depth of approximately 5.8mm, weld reinforcement approximately 3mm and width approximately 2mm. The bend test showed that the samples could withstand bending without cracking or breaking. This research shows that SMAW can produce a good quality weld on a low-carbon steel pipeline with reasonable mechanical properties.

Keywords: *Low carbon steel, SMAW, Mechanical properties*

1.0 INTRODUCTION

A pipeline is used economically to transport oil and gas over lengthy distances to various locations of demand, such as flows stations and refineries [1] and [2]. Pipeline has continually failed due to welds failure, and this can be prevented in part by the quality of the weld. Weld discontinuities are thus measured as the primary stress raiser in a pipeline. [3] and [4].

Welding is a method of connecting two(2) or more sections of metal together by applying heat to the appropriate melting point, and initiating the melted metal to solidify together. Welding is the metallurgical joining of two members to form a single member (metal). The advantages of using the SMAW process are that it is the simplest among arc welding processes, the equipment is small in magnitude/size and easy to move from location to different locations, the equipment is not too expensive compared to other arc welding equipment. This welding process (Shielded metal arc welding) is used for many applications due to the availability of wide-ranging electrodes that make it conceivable to weld the metal and its alloy. The Shielded metal arc welding (SMAW) find common application in virtually all divisions of industries and fabrication. Welding is tremendously active in manufacturing, construction of steel structures in manufacture, industrial and civil industrial, e.g, building and bridge structural member etc.; welded plates construction of vessel (steels reservoir, boiler, and pipeline etc.), and concrete reinforcements [5]. Stick welding also called SMAW which is commonly used in the fabrication industries and also suitable for repairing, it is flexible and portable. The electrode always covered by flux, coating for protective, to protect the joints. Shielding gas always release when flux coating on electrode begin to burn during welding process, shielding the BM and weld metal from flying contaminant. Inference to [6], welding defects such as crack and porosities are oxygen and hydrogen. The SMAW is among the easiest and most flexible arc weld process in which the welding heat is generate an electric arc amongst cover metal electrodes and the work pieces. The filler metals are deposit from electrodes, and electrode cover offers for protection [7]. The welder controls the arc. During welding activities, the slags are always on the surfaces of the weld beads which is very important to clean it off to avoid inclusion. Welding mild and low alloy steel are frequently used in this welding process. The equipment’s easy, and welding process easy that welders needed to carry electrode’s holder, work cables to welding operating location [8]. Weld circuit contains an electrode holder, welding cable, power source, a work-clamp and an electrode and after connection of the accessories, and welder initiates the welding arc by temporarily sparking electrode to BM in which the electric-circuit is completed. Electrode is guided manually by welder, control the speed and the travel direction. Welder maintain arc, control space between work piece and electrode tip (arc-length) [9]. SMAW is frequently use to weld low, high alloy steels, cast iron, Stainless steels & ductile irons. Whereas small widespread for Non-Ferrous material, SMAW can performed on a copper, nickels and their alloy but, occasional cases on aluminium [10]. According to [20], Carbon content of low carbon steels are less than 0.29 % and commonly use. It contains Low Tensile Strength but with High ductility that make exceptional welding operation and good machining. It cannot harden by carrying out heat treatment, as a substitute for cold working. The application of low carbon steel are; parts of automotive body, beams for structural, channel, angle iron, pipelines and in fabrication work [11]. In reference to Jha & Jha A., Welding speed is rate of distance cover by electrode alongside the joint. Increasing speed and maintaining welding arc voltage, width of weld bead will reduce. This is optimum point where penetration of welds will get to maximum and go beyond the optimum point will reduce penetration [12]. As reported by [12], welding current is an important Parameter in the welding process that have excessive effect on Fusion depth, Penetration depth and rate of Feed. Heat generated for the period of welding depend on current usage for sizes of electrode. Hence, accurate current needed for good quality welds [12]. Effect of some parameters are welding speed, voltage and current.

Voltage is Potential difference amongst tip of the welding wires and the surface of the molten welding pool. It defines shapes of the Fusion zone (FZ) and reinforcement of the WM. The high welding voltage produce the wider it is, less and flatter extremely penetrating weld than low Welding voltage, and penetration depth remains maximum at the optimum voltage.

As reported by [13] [20], Heat inputs are measure of energy moved Per Unit Length of the weld. It’s significant for the reason that it influences the Cooling rate, that may affect mechanical Properties and the metallurgical structures of WM and HAZ. Heat input is determining by equation (1)

$$H = \frac{60EI}{1000S} \tag{1}$$

Where H=heat input(kJ/mm), E = voltage(V), I=current (A) and S=travel speed (mm/s)

2.0 METHODS

2.1 Materials and Equipment

In this study, the ASTM A106 Gr B material pipe was used as a test coupon as presented in Figure 1-c and Table 1. This material was carefully chosen due to its wide application in the construction industry. The carbon steel material was subjected to a chemical analysis test using an optical emission spectrometer machine as presented in Figure 1. The chemical compositions are presented in Table 1. The Positive Material Identification (PMI) analysis was performed to determine chemical composition material selected.

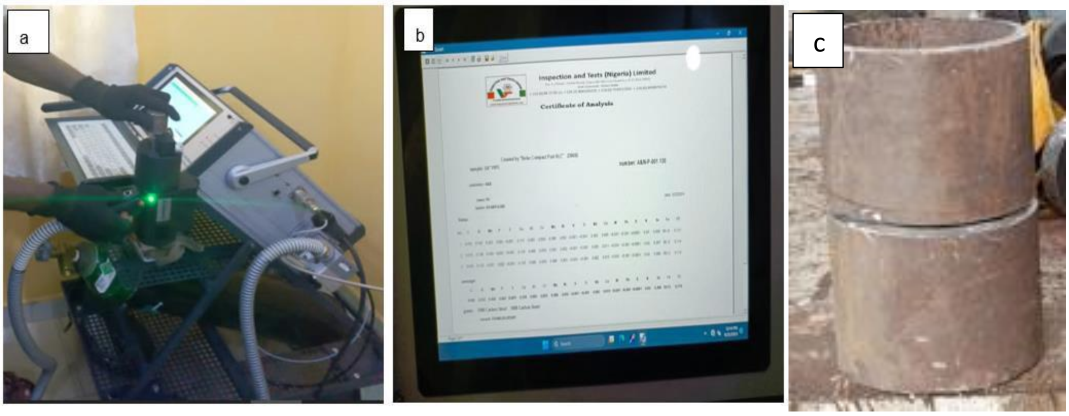

Figure 1: (a) Optical emission spectrometers machine (b) Certificate of chemical analysis and (c) Base metal

Table 1: Chemical composition of base metal (BM) (wt%)

Element	C	Si	Mn	P	S	Cu	Al	Cr	Mo	Ni	V	Ti
	0.122	0.236	1.306	0.011	0.005	0.005	0.018	0.144	0.066	0.038	<0.001	0.003
	0.133	0.243	1.347	0.012	0.004	0.006	0.018	0.156	0.07	0.043	<0.001	0.003
	0.132	0.242	1.325	0.01	0.005	0.006	0.018	0.142	0.066	0.038	<0.001	0.003
Average	**C**	**Si**	**Mn**	**P**	**S**	**Cu**	**Al**	**Cr**	**Mo**	**Ni**	**V**	**Ti**
Wt%	0.129	0.24	1.326	0.011	0.005	0.006	0.018	0.147	0.067	0.04	<0.001	0.003

Element	Nb	Co	W	Pb	B	As	Bi	N2	Sn	Sb	Ca	CE
	0.025	0.002	<0.001	0.006	<0.0002	<0.001	0.004	0.01	0.004	<0.001	0.0065	0.38
	0.03	0.003	<0.001	0.006	<0.0002	<0.001	0.003	0.002	0.003	<0.001	0.0052	0.42
	0.026	<0.001	<0.001	0.006	<0.0002	<0.001	0.003	<0.001	0.004	<0.001	0.0066	0.4
Average	**Nb**	**Co**	**W**	**Pb**	**B**	**As**	**Bi**	**N2**	**Sn**	**Sb**	**Ca**	**CE**
Wt%	0.027	0.002	<0.001	0.006	<0.0002	<0.001	0.003	0.004	0.004	<0.001	0.0061	0.4

Manganese (Mn), Carbon (C), Niobium (Nb), Cobalt(Co), Silicon (Si), Tungtem (W), Lead (Pb), Boron (B), Arsenic (As), Bismuth (Bi) Molybdenum(Mo), Chromium(Cr), Aluminium (Al) Nickel(Ni), Titanium (Ti), Vanadium(V), Copper (Cu), Sulfur (S), Tin (Sn), Antimony (Sb), Phosphorus (P), and Nitrogen (N).

Low hydrogen electrode ESAB 55.00 E7018 was used for root pass, hot pass, filling and capping as a consumable as presented in Table 3. E7018 electrode is good for penetration, high deposition rate and suitable for welding different kinds of steel thickness.

Table 2: Base Metal Identification

Pipe Identification	Wall thickness (mm)	Nominal Pipe size	Material Type
Low Carbon Steel	14.27mm	6''Sch 120	ASTM A106 GR B

Table 3: Experimental Electrode used

Manufacturer	Classification	Group	Sizes	Batch No
Esab 55.00	AWS E7018-1H4R	A5.1	2.5	EC229532566Rev0
Esab 55.00	AWS E7018-1H4R	A5.1	3.2	EC24826988Rev0

The equipment used in this research were: Super Arc-4000 electrical welding machine, Optical emission spectrometer machine, ENKAY Tensile universal test machine, Charpy impact test machine, Hardness test (model HVS-30), Bend test machine (model-FISCHER), Micro examination test machine and macro examination test machine.

Figure 2: Photograph of Electrical welding machine (Super Arc 4000)

2.2 Methods

This research, the welding process of SMAW was used to weld the base metal by utilized E7018 electrode, 2.5mm diameter for the root pass and 3.2mm diameter for hot pass, filling and capping. The weld parameters that was used as presented in Table (4) and steps of this experimental work has been considered as specified below.

Table 4 Weld parameters

Welding current (A)	Voltage (V)	Electrode dia (mm)
115	28	2.5/3.2mm

The test coupon was 160 mm in length with thickness of14.27mm and longitudinally cut with single-v-joint, prepared with bevel-angle between 50°- 60°, and with root-gap equal to 3mm and root face equal to 2 mm. The weld position was 60-degree angle (6G POSITON) as seen in Figure 3-a, the test coupon was welded in accordance with Table 4 by qualified welder and also qualified to weld the same process (SMAW). Weld direction (Vertical-uphill) and bead sequences were maintained, and Figure 3 shows test coupon before and after welding. Prior to start, it was preheated to dry of the moisture, because; to reduce rate of cracking, improve weld penetration, reduce distortion and improve quality of weld by reduce porosity and lack of fusion. Inter pass temperature was measured on the test coupon 2.6mm from weld toe for all the welding passes using Infrared-thermometer. Immediately after the completion of the welding operation, the weld beads and weld toe at the capping surface were cleaned with wire brush and the pipes (tested coupon) was subjected for mechanical: tensile, bend, impact, hardness test, micro and macro examination test.

Figure 3: Photograph of test coupon (a) before and (b) after weld

2.2.1 Mechanical Test

(i) Tensile Test

This test was carried out according to ASTM A 370 Standard using ENKAY Universal testing machine of 1000KN capacity. The specimens were machined into 230mm x 20mm size of two numbers along the transverse direction of the welded coupon as seen in Figure 5 (a & b). Two specimens were conducted to enable comparison.

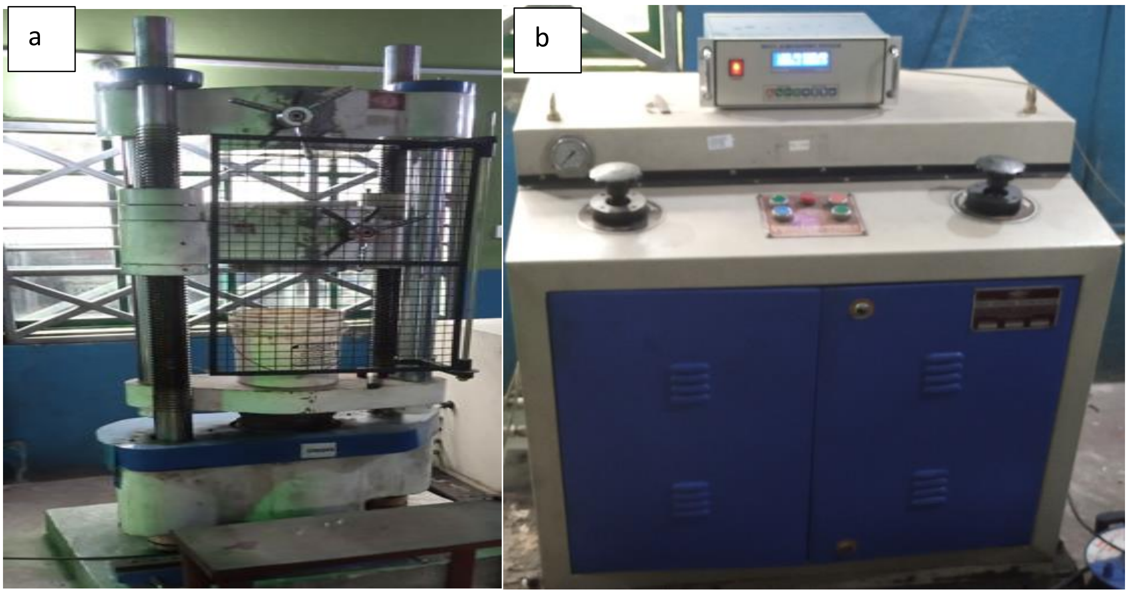

Figure 4: Photograph of (a) ENKAY Universal testing machine and its (b)unit

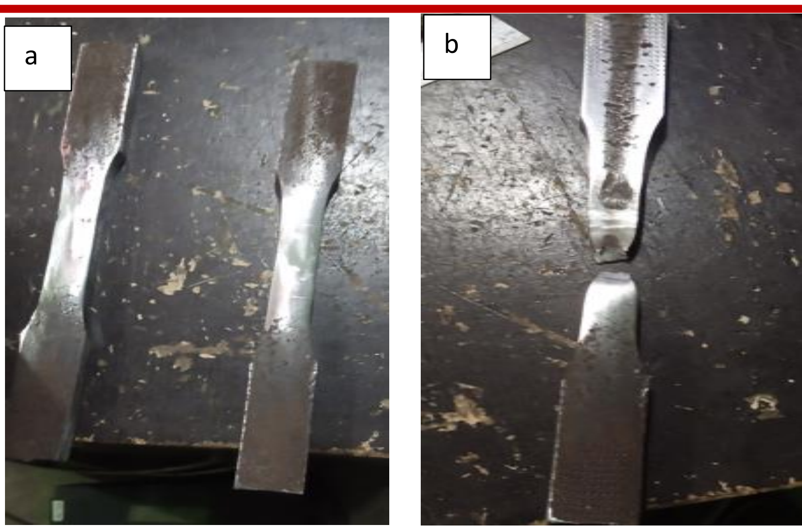

Figure 5: Photograph of tensile test (a) Before test and (b) After test

(ii) Impact charpy test

Impact charpy test were carried out according to ASTM E 23-02. Three specimens each were cut from WM, HAZ and BM, amount to total numbers of nine specimens into 60mm x 10mm sizes. The specimens were prepared by means of milling machine (model; parkson) and etched with Nitric acid and ethanol, and the specimens were inserted in the cooling chamber unit and allow to cooled for 15 minutes at temperature of -20^{o}C. Thereafter, the impact strength specimens were tested at -20^{o}C. Anvil (pendulum-arm) was carried up toward the lock location and released using release lever. Anvil swing in Pendulum motion breaking the metal specimen and Impact strength were documented for further analysis as presented in Figure 6 - 7 (a and b).

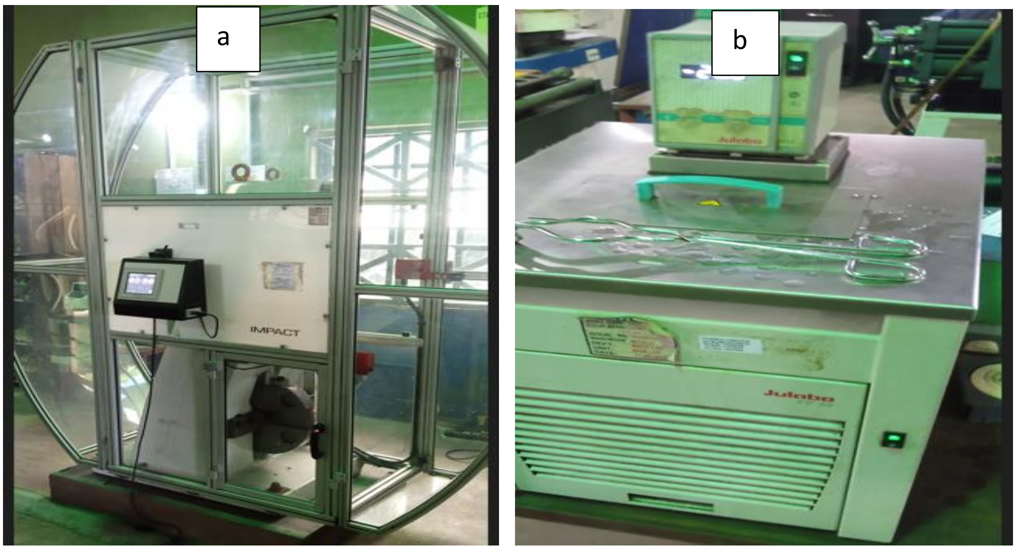

Figure 6: Photograph (a) Impact test machine and (b) its Cooling chamber unit

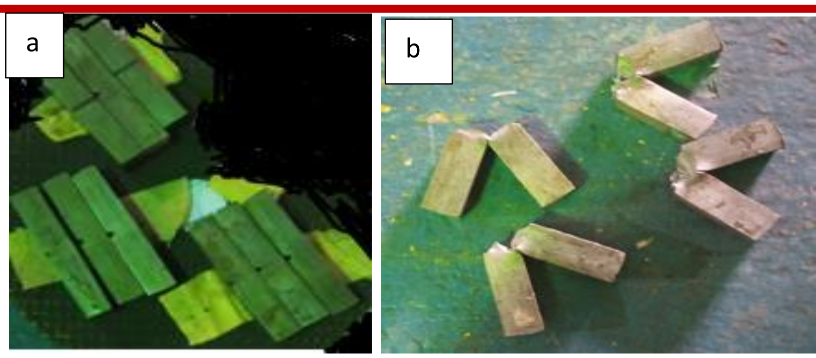

Figure 7: Photograph of Charpy impact test (a) Before test and (b) After test

(iii) Hardness Test

Hardness test were carried out using Digital display Vivtorinox hardness tester (model; HVS-30) at 6 o'clock and 12 o'clock on WM, HAZ and BM according to ASTM E384 standard. The specimens were machined using milling machine and thereafter, they were etched using Nitric acid and ethanol. The Digital display vivtorinox hardness tester was set at 10kg, and the procedure were followed to avoid errors. Twenty-four measurements were taken on each specimen to determine the average hardness value for specimens.

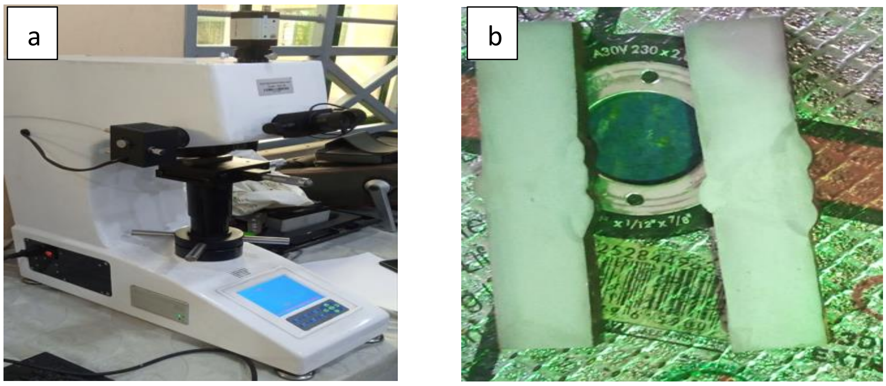

Figure 8: Photograph (a) Digital display Vivtorinox hardness tester (HVS-30) and (b) test samples

(iv) Bend Test

Bend test was performed to ascertain the weld quality, using bend-test machine (model; FISCHER Bt3 with mandrel diameter 1.5 inches. The specimens were machined into 230mm x 10mm size of four numbers and etched. The roller of bend machine moved and specimen were inserted between the rollers and the screw was tight. The specimens were bent up to 180 degrees. Thereafter, the specimens were removed and inspected. See Figure 9 b.

Figure 9: Photograph of (a) bend test machine (model; FISCHER Bt3) and (b) test samples

(v) **Micro examination test**

A micro examination test was carried out in accordance with ASTM 370, ASTM E3, ASTM E407 & ASTM 1268 using a pax cam micro tester. The specimen was machined and etched with Nitric acid and ethanol. The specimen was placed on the tester, as shown in Figure 10 b. The specimen was prepared, and examined according to the standard of metallographic technique, and the microstructure result shows ferrite and pearlite.

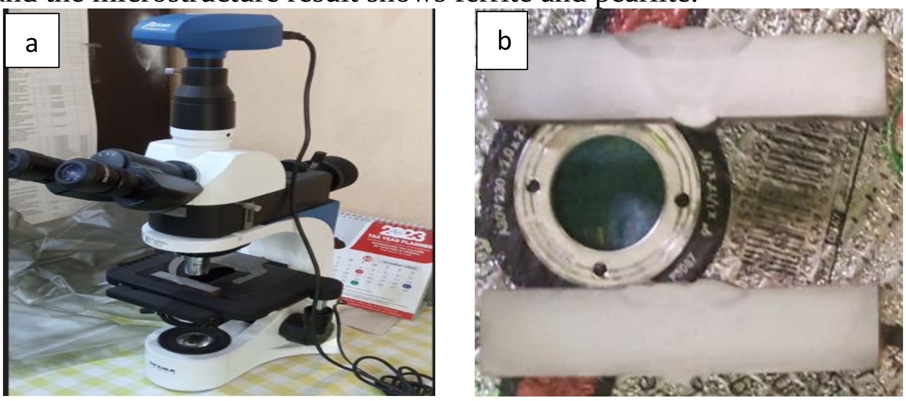

Figure 10: Photograph of (a) pax cam micro tester and (b) test samples

(vi) Macro Examination test

Macro examination test was performed in accordance with ASTM 370 & ASTM 1268 using scienscope macro tester. The specimen was machined and etched with Nitric acid and ethanol. The specimen was placed on the tester as shown in Figure 11. The specimen was prepared and examined.

Figure 11: Photograph of scienscope macro tester

3.0: RESULTS AND DISCUSSIONS

3.1 Electrode travel speed and heat Inputs

The different Electrode travel speeds and heat inputs for root pass, hot pass, filling and capping

Table 5: Welding control parameter

Pass Number	Length (mm)	Time (s)	Travel speed (mm/s)	Heat input (kJ/mm)
Root	509	352	1.4460	2.2268
Hot Pass	515	319	1.6144	1.9945
Filling	531	307	1.7296	1.8617
Filling	531	309	1.7184	1.8738
Average Filling	531	308	1.7240	1.8677
Capping	549	234	2.3462	1.3725
Capping	549	239	2.2971	1.4018
Capping	549	241	2.2780	1.4135
Average Capping	549	238	2.3071	1.3959

3.2: **Tensile Test**

This test, is a mechanical test to determine the strength and ductility of a welded joint under a tensile load. Failure can occur in base metal (BM), weld metal (WM) or heat affected zone (HAZ). Tensile test of the welded sample 1 and sample 2 were evaluated and as presented in Table 6 the Ultimate Tensile Stress(N/mm^2) are 569.26 and 566.52, Yield stress (N/mm^2) are 468.43 and 456.1, Breaking stress (N/mm^2) are 380.12 and 382.4 respectively.

Table 6 shows the results of the tensile test carried out, and it is obvious from results that all process input parameters, current, preheat temperature and electrode temperature have a significant effect on the tensile strength of the welded joint. Nevertheless, Figure 12 (a and b) shows the tensile strength graphs for the two specimens at 12 o'clock and 6 o'clock. The current influences the heat generated at the weld interface and microstructure of steel, which affect the tensile strength of the welded joint. Higher currents generally lead to coarser grains in the HAZ, which can reduce Strength by causing the material to be more prone to failure under stress. Higher current tends to decrease the ductility of steel in the HAZ, as too much heat can cause the material to become brittle. This reduction in ductility makes the material more prone to cracking during the tensile test.

The electrode temperature plays a substantial role; it influences the heat distribution during the weld process and the final properties of the welded joint. However, too high a temperature may cause overheating, leading to grain growth and decreasing the tensile Strength. Preheated temperature prevents cracking and controls the cooling rate. Preheating minimizes the risk of forming cracks or weak regions that could lead to premature tensile failure.

The interaction between current, electrode, and preheat temperature is crucial in determining the outcome of the tensile test. However, the breaking point of tensile test performed on specimens, break at the base metal (BM) location as seen in Figure 5-b, show that the tensile Strength of welded joint (WM) greater than the base metal (BM), which shows that the test is acceptable and in line with [14] [26] and also in accordance with ASTM A370 and ASTM E8/E8M.

Table 6: Experimental result (Tensile test) (ASTM A106 GR B)

Specimen	Ultimate Tensile stress (N/mm^2)	Yield Stress (N/mm^2)	Breaking Stress (N/mm^2)
Specimen 1	569.26	468.43	380.12
Specimen 2	566.52	456.1	382.4

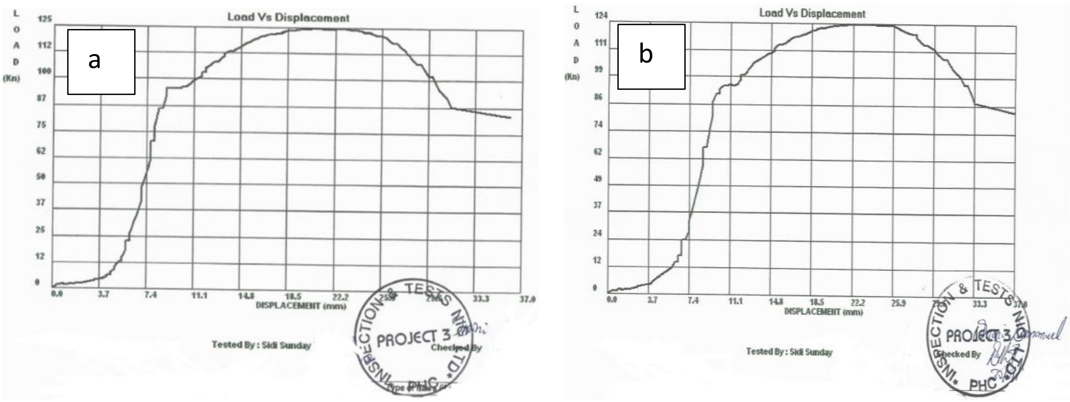

Figure 12: Tensile strength graphs for: (a) at 12 o'clock (b) at 6 o'clock

3.3 Impact - Charpy test

Impact - Charpy test is the usual test used to estimate the toughness of the welded joint, particularly its resistance to fracture under impact loading, and it measures the material's ability to absorb energy during sudden impact. Results demonstrate all input parameters have significant influence on impact Strength. it is clear that impact strength increases as welding current, preheat temperature and electrode temperature increase, and as the high temperature is achieved, the weld pool will lead to an annealing and HAZ improve their toughness. The impact Strength reduces as welding speed increases due to comparatively lesser weld pool magnitude obtained as the outcome of high cooling rate that decreases weld toughness and causes the weld to be more brittle.

The impact - Charpy test was carried out in three locations: at WM, HAZ and BM as results were presented in Table 7. The WM has average equal to 132.9 joules which is the area of welded joint formed by welding electrode and toughness can be similar to or a little lesser than base metal, depending of filler material and the welding process. The HAZ with average of 237.1 joules often shows reduced toughness due to the heat treatment during the welding. Grain coarsening and phase transformations from ferrite to martensite can make the material more brittle; the result will show lower absorbed energy in this region compared to base metal. The BM that is the parent material has an average of 247.4, typically exhibiting the highest toughness due to unaltered by the welding process. The experimental results of the impact charpy test presented is in line with [15] [22] [25]and also in accordance with American Society for Testing and Materials (ASTM) 2016, Standard Test Methods for notched bar impact test of metallic-materials. And International institute of welding, 2018. Figure 13 shows the comparison for WM, HAZ and BM.

Table 7: Experimental result (Impact- Charpy test)

Location	Specimens	Impact value (Joules)	Average Value (Joules)
WM	WM-A	131	132.9
	WM-B	110	
	WM-C	157.7	
HAZ	HAZ-A	219.2	237.1
	HAZ-B	240.1	
	HAZ-C	252	
BM	BM-A	248	247.4
	BM-B	247.4	
	BM-C	246.7	

3.4: **Hardness investigation**

Figure 13 reveals the microstructure of the sample grains. The microstructure of the sample consist of two phases which are ferrite (white/light area) and pearlite (dark area), which is the combination of ferrite & cementite (Fe_3C). The hardness average of WM at 12 o'clock is about 211.1 HV, heat affected zone is 208.6 HV and base metal is 167.4 HV, and at 6 o'clock, the weld metal is 199.0 HV, heat affected zone is 216.8 HV and base metal is 178.9 HV respectively as presented in Table 8, the grains at weld metal are longer and larger than the heat affected zone. Heat input increases the microstructures of the weld area, which come to be coarser (i.e grain sizes becomes bigger) due to the greater the quantity of heat, the faster the grains grow and the bigger/larger the grains. Change amount of the second phase (i.e. decreasing the amount of the pearlite as heat input increase) mostly ferrite-matrix has strong effect on strength of steel, particularly the yield Strength, as the neighboring ferrite is more-ductile, according to [16]. Hence, as the amount of the second phase increases and becomes finer, it is expected to have higher strength, inference to [17] [18] [21] [27-30]. Figure 14 shows the effect of heat input on the microhardness average of weld zone; as heat input increases, the microhardness decreases. This may possibly attribute to two (2) factors ; the increases in grain sizes that take place as heat input increase and coarser second (2^{nd}) phase due to relation slow cooling speed. Hence, samples that have a lesser amount of heat input and a faster cooling rate/speed due to volume of molten metal being less will have finer-pearlite and higher micro-hardness. This result agreement with [18] [23-24].

Table 8: Experimental result (Macro hardness test)

Test points	**Hardness valve (HV10)**					
	12 O'Clock			**6 O'Clock**		
S/N	WM	HAZ	BM	WM	HAZ	BM
1	200.7	-	-	201.2	-	-
2	217.6	-	-	150.6	-	-
3	208.6	-	-	163.7	-	-
4	204.2	-	-	222.6	-	-
5	224.6	-	-	232.9	-	-
6	210.9	-	-	223.2	-	-
7	-	190.2	-	-	257.8	-
8	-	194.8	-	-	244.6	-
9	-	216.1	-	-	239.7	-
10	-	236.5	-	-	206.9	-
11	-	230.5	-	-	220.4	-
12	-	212.4	-	-	232.5	-
13	-	206.7	-	-	191.2	-
14	-	206.9	-	-	196.1	-
15	-	206.1	-	-	177.8	-
16	-	220.9	-	-	209.4	-
17	-	193.5	-	-	218	-
18	-	189.1	-	-	207.7	-
19	-	-	177.4	-	-	191
20	-	-	168	-	-	202.4
21	-	-	169.2	-	-	202.6
22	-	-	165	-	-	159.8
23	-	-	161.5	-	-	165.1
24	-	-	163.3	-	-	152.6
AVERAGE	211.1	208.6	167.4	199	216.8	178.9
OVERALL AVERAGE			197			

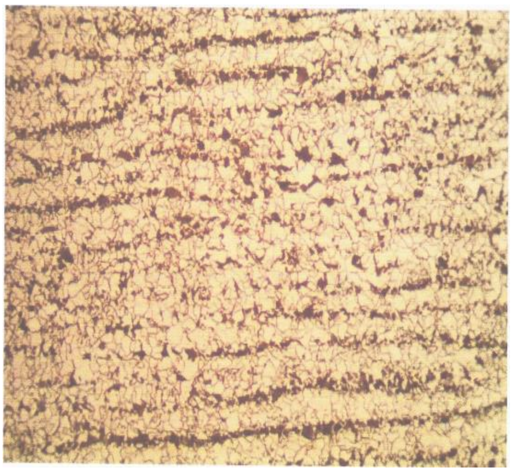

Figure13: Micrograph shows the microstructure of Ferrite and Pearlite for Magnification X200.

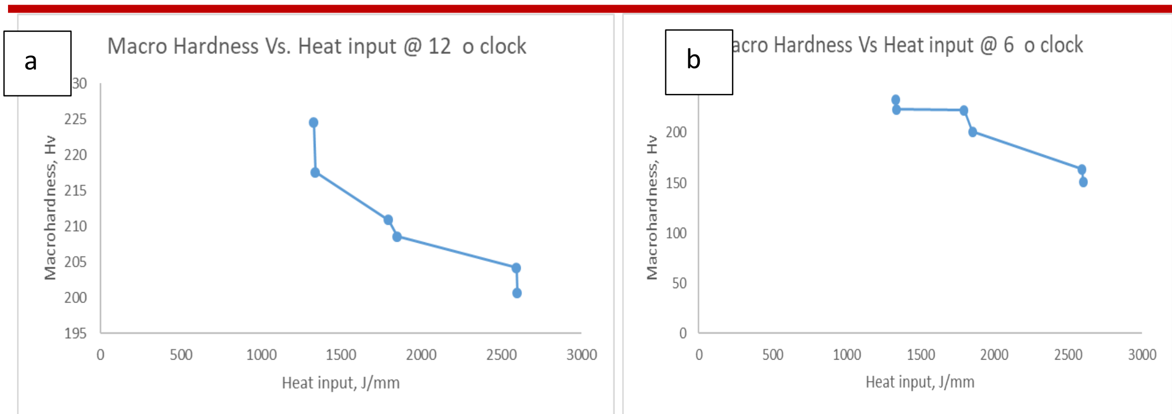

Figure 14: Macrohardness Vs. Heat input; (a) @12 o'clock and (b) @6 o'clock

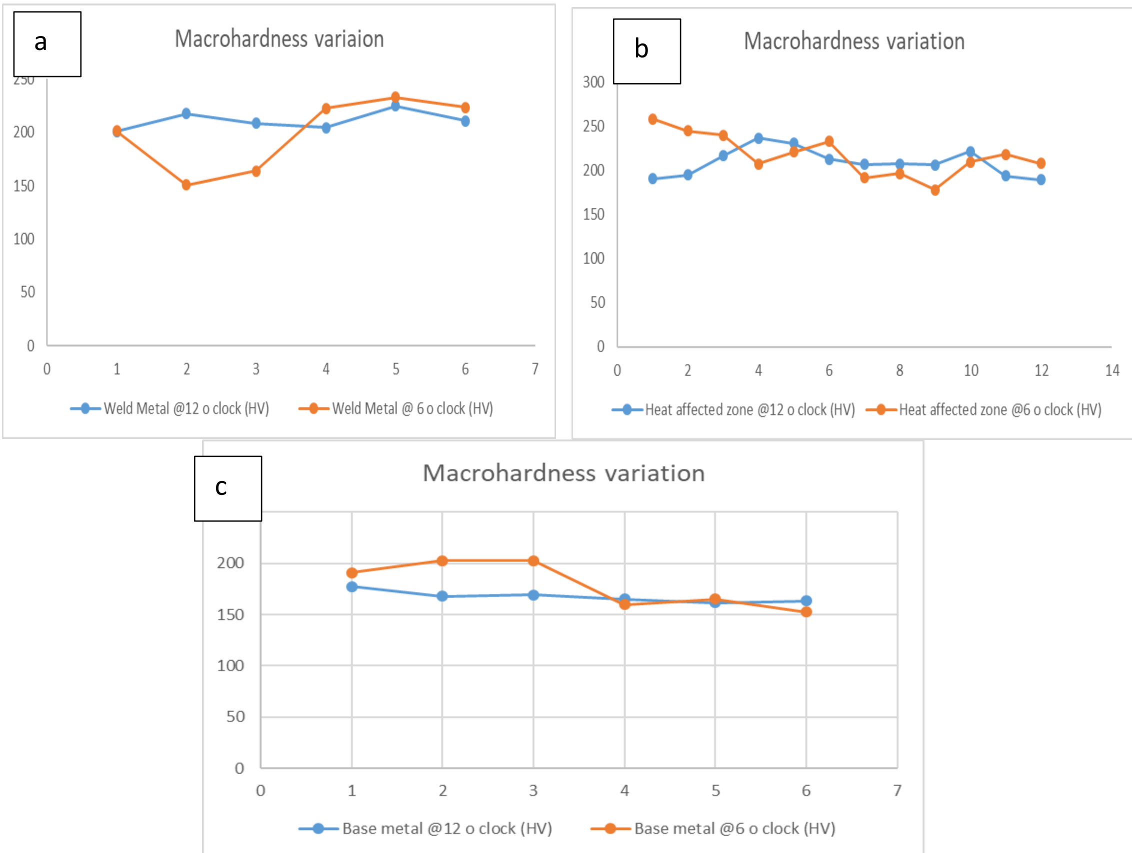

Figure 15: Macrohardness variation; (a) WM @ 12 and 6 o'clock and (b) HAZ @ 12 and 6 o'clock(c) BM at 12 and 6 o'clock

3.5 Bend Test

This test is used to evaluate ductility, strength, and overall quality of a welded joint. The aim of this test is to assess the welded joint ductility and its ability to withstand deformation without cracking or breaking. The test was carried out as seen in Figure 9-b. The specimens were machined into 230mm x 10mm size of four numbers at 2, 4, 8 &10 o'clock, and all were bent up to 180 degrees. The samples were able to withstand bending without cracking or breaking. The results indicate that the welded joint showed good ductility and flexibility as per [19] and in accordance with American Society for Testing and Materials (ASTM) 2014, Standard Test Methods for bend test of material.

3.6 Macroscopic Examination

Figure 16 shows the macro view of the welded pipe at 10X magnification. The test aimed to evaluate the quality of the weld and identify any defects or discontinuities. In accordance with [19], the weld penetration was adequate, with a penetration depth of approximately 5.8mm the weld reinforcement was moderate, with a height of approximately 3mm and the HAZ was narrow, with width of approximately 2mm.

Figure 16: Macro Photo of weld at 10X

4.0 CONCLUSION

The integrity of the welded pipeline was carried out using destructive (Mechanical test) such as hardness tensile, impact charpy test, bend test, macro hardness/macroscopic examination.

- The average Hardness of the weld metal at 12 o'clock is about 211.1 HV, heat affected zone is 208.6 HV and base metal is 208.6 HV, and at 6 o'clock, the weld metal is 199.0 HV, heat affected zone is 216.8 HV and base metal is 178.9 HV respectively as presented in Table 8 . The grains at weld metal are (longer & bigger) than the heat affected zone. Heat input increase microstructure of weld area which become coarser (i.e grain sizes becomes bigger) due to the bigger the quantity of heat, the faster grains growth and larger/bigger the grain. Also increase in heat input resulted to decreases in hardness.
- Tensile test of the welded sample 1 and sample 2 were evaluated and the Ultimate Tensile Stress(N/mm^2) are 569.26 and 566.52, Yield stress (N/mm^2) are 468.43 and 456.1, Breaking stress (N/mm^2) are 380.12 and 382.4 respectively as indicated in Table 6.
- Impact charpy test were performed on WM, HAZ and BM, as presented in Table 7. it was observed that, impact Strength increase as welding current, preheat temperature and electrode temperature increase. Also, at high temperature the weld pool and HAZ will lead to an annealing. The weld metal (WM) has average of 132.9 joules which is the area of the joint formed by the welding filler composition and the toughness can be comparable to or slightly lower than the BM, depending on filler material and welding process. The HAZ with average of 237.1 joules often shows reduced toughness due to the heat treatment during the welding. And grain coarsening and phase transformations from ferrite to martensite can make the material more brittle, the result of the charpy test will show lower absorbed energy in this region compared

to base metal. The BM that is the parent material has average of 247.4, typically exhibits the highest toughness due to unaltered by welding process.

- Macrohardness was carried out, the weld penetration was adequate, with a penetration depth of approximately 5.8mm the weld reinforcement was moderate, with a height of approximately 3mm and the HAZ was narrow, with width of approximately 2mm.
- The bend test, the samples were able to withstand bending without cracking or breaking and the results indicate that the welded joint showed good ductility and flexibility.

REFERENCES

[1] Hansen, M.E. and Dursteler, E. "Pipeline, rail & trucks: Economic, environmental, and safety impacts of transporting oil and gas in the U.S, Strata" 2017, 1–6.

[2] C.F. Mason, A comparison of the risk of transporting crude oil: Rail vs. pipeline, IAEE Energy Forum. (2018) 5–7.

[3] Vervynckt, S. Verbeken, K., Lopez, B. and Jonas, J.J, "Modern HSLA steels and role of non-recrystallisation temperature," International Materials Reviews. 57, 2012, 187– 207.

[4] Baker, T.N. "Microalloyed steels, Ironmaking and Steelmaking" 43, 2016, 264–307.

[5] P C Sharma, A text book of Production Technology, S Chand and company2004

[6] Haider, S. F., Quazi, M. M., Bhatti, J., Nasir Bashir, M., & Ali, I. (2019). Effect of Shielded Metal Arc Welding (SMAW) parameters on mechanical properties of low-carbon, mild, and stainless-steel welded joints: A review. *Journal of Advances in Technology and Engineering Research, 5(5). https://doi.org/10.20474/jater-5.5.1

[7] Vijayesh Rathi, Hunny 'Analyzing the effect of parameters on SMAW processes. International journal of emerging research in management and technology. ISSN: 2278-9359, Volume 4, Issue 6, June 2015

[8] Prakash M, Robert Henry. 'An experimental investigation of weld defects in shielded metal arc welding'. International journal of research in engineering, science and technologies ISSN:2454-5392, Volume 1, Issue 8, April 2016.

[9] Gurpreet Singh Sidhu, Sukhpal Singh Chatha 'Role of shielded metal arc welding consumables on pipe weld joint' International Journal of Emerging technology and Advanced Engineering , Volume 2, Issue 12, 2012.

[10] S. Murugan, P. V. Kumar, B. Raj, M. S. C. Bose. 'Temperature distribution during multi-pass welding of plates'. International journal of pressure vessels and piping, Volume 75, Issue 12, October 1998, Pages 891-905

[11] M. A. Gaodi and D. Sangotra, ``A review paper on effect of varying welding heat inputs on microstructure, mechanical properties and corrosion behaviours of ferritic stainless steel & mild steel," International Journal of Modelling Engi- neering Resolution, vol. 4, no. 1, pp. 105-109, 2014.

[12] R. Jha and A. Jha, ``Inluence of welding current and joint design on the tensile properties of SMAW welded mild steel joints," International Journal of Engineering Research and Applications, vol. 4, no. 6, pp. 106-111, 2014.

[13] Thornton, C. E., and Webster, D. J. (1990). Progress in the use of metal powder additions for the welding of offshore structures. In Proceeding of the Ninth International Conference on offshore mechanics and arctic Engineering. 3, 399-408).

[14] Callister, W.D and John Wiley & Sons, (2014), Materials Science and Engineering, An Introduction, 9th Edition,

[15] Devendrnath K. R. and Suresh K.S, (2019) Department of metallurgical and materials Engineering, Ntional institute of Technology, warngal, India.

[16] Askeland, D. R. (1996) The Science and Engineering of materials, 3rd Edition, Chapman & Hall, pp. 352-400.

[17] Connor, L. P. (1991) Welding Handbook-welding processes, Vol. 2, 8th Ed, American welding Society.

[18] Hrivak, I. (1992) Theory of weldability of metals and alloys, Materials Science Monographs 74, Elsevier.

[19] Devendrnath, K. R. (2017) Department of metallurgical and materials Engineering, Ntional institute of Technology, warngal, India.

[20] M. A. Gaodi and D. Sangotra, ``A review paper on effect of varying welding heat inputs on microstructure, mechanical properties and corrosion behaviours of ferritic stainless

steel & mild steel," International Journal of Modelling Engi- neering Resolution, vol. 4, no. 1, pp. 105-109, 2014.

[21] Abson, D. J., and Pargeter, R. J. "Factors influencing as-deposited strength, microstructure, and toughness of manual metal arc welds suitable for C-Mn steel fabrications", International Metals Reviews, 31(1), 1986,141-196.

[22] Abson, D. J., Dolby, R. E., and Hart, P. H. M. "The role of non-metallic inclusions in ferrite nucleation in carbon steel weld metals", Trends in Steel and Consumables for Welding, 1, 1978, 75-101.

[23] Agilan, M., Venkateswaran, T., Sivakumar, D. and Pant, B. "Effect of heat input on microstructure and mechanical properties of inconel-718 EB Welds", Procedia Materials Science, 5, 2014, 656-662.

[24] Dutta, J., and Narendranath, S. "Estimation of cooling rate and its effect on temperature dependent properties in welded high carbon steel joints", 2014.

[25] Grong, O. and Matlock, D. K. "Microstructural development in mild and low-alloy steel weld metals", International Metals Reviews, 31(1), 1986, 27-48.

[26] Lee, C. S., Chandel, R. S., and Seow, H. P. "Effect of welding parameters on the size of heat affected zone of submerged arc welding", Materials and Manufacturing Processes, 15(5), 2000, 649-666.

[27] Beachem, C.D. "A new model for hydrogen-assisted cracking (hydrogen "embrittlement")", Metallurgical Transactions. 3, 1972, 441–455.

[28] Chattoraj, I. "The effect of hydrogen induced cracking on the integrity of steel components", Sadhana, 20, 1995, 199–211.

[29] Dong, C. F., Liu, Z. Y., Li, X. G., and Cheng, Y. F. "Effects of hydrogen-charging on the susceptibility of X100 pipeline steel to hydrogen-induced cracking", International journal of hydrogen energy, 34(24), 2009, 9879-9884

[30] Dong, C.F. Xiao, K. Liu, Z.Y. Yang, W.J. Li, X.G. "Hydrogen induced cracking of X80 pipeline steel", International Journal of Minerals, Metallurgy and Material, 17, 2010, 579–586.