Performance Evaluation and Cost Analysis of Selected Shielded Manual Metal Arc Welding (SMMAW) Steel Electrodes

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ABSTRACT

The work investigated the effect of electrodes on consumption rate and mechanical behavior of welded mild-steel and galvanized-steel joints, to ascertain their performance level under service conditions, which has increased joint failure and increased equipment cost of maintenance. 20 welded mild-steel and galvanized-steel flat bars (¾” x ¼ “) produced from shielded manual metal arc welding (SMMAW) were prepared using mild steel electrodes, gauge 12 of four selected different brands from local hardware market. Standard methods were applied for tensile properties using Ultimate tensile test machine. Also, the consumption rate of each brand of electrode in joining specified metal types were ascertained through 5 replications within specified time frame (6 seconds) for each metal type. Results obtained from tensile tests in respect to allowable maximum load, breaking point and yield point. The result showed allowable maximum load at tensile strength of 5524.767 N and 5131.088N attained for mild steel welded with Zika electrode and galvanized steel welded with Oerlikon electrode respectively. Changes were noticed in the modulus of elasticity at yield point for galvanized steel welded with Fed electrode, and mild steel welded with China electrode. The consumption rate with equivalent price value was projected to 8 working hours, this gave maximum consumption rate of 528.4 sticks of electrodes (2.11 packs), corresponded to price value of 4,227naira in respect to galvanized steel welded with Zika. It was therefore recommended that Zika electrode brand are in no-way fit to be used on galvanized steel based on tensile properties test and consumption rate. Zika electrode brand is most suitable for mild steel joints for tensile properties, while Oerlikon electrode brand is best suited for galvanized steel joints when the same property is desired. All specified electrode brands are found to be more cost effective when used on mild steel compared to galvanized steel.

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I. Introduction

In manufacturing, welds are used to join two or more metal surfaces. Because these connections may encounter loads and fatigue during product lifetime, there is a chance they may fail if not created to proper specification.

Manufacturing technology techniques are of immense importance to modern industries where inconceivable machines are produced from elementary materials such as blanks using basic and specific manufacturing processes. In conjunction with engineering management techniques, it ensures the most efficient use of materials and labour. It curtails wastes and ensures the use of the right processes for each operation in the production of a product or component. It also ensures the most effective method of handling and assembly of components to form specific product [1].

Arc welding may be defined as a process whereby the heat generated by an electric arc is maintained in most cases between the electrode and the work piece [2], [3]. The arc supplies sufficient heat to melt the base metal in the vicinity of the arc and usually the electrode. In arc welding, some of the processes utilize consumable electrodes, which serve to strike an arc unto the work pieces, and melted to provide the weld metal [3]. Welding electrodes are metal wires with chemical coatings. The rod is used to sustain the welding arc to provide filler metal required for the join to be welded. The coating protects the metal from damage, stabilizing the arc and improves the welds. The diameter of the wire, less the coating determines the size of the welding rods .This is expressed in fractions of inches such as:3/32,1/8 or 5/32.The smaller the diameter the less current required and the smaller the amount of filler metal deposited[4].

The primary functions of coated electrode in shielded manual metal arc welding (SMMAW) are to provide (i) the electric arc which supplies the heat energy required for melting the metals to be joined, and (ii) the filler metal required for the weld joint.

[5] Put forward the classification of defects being made by International Institute of Welding which would cause weakness in a welded structure as follows:

- Incomplete penetration – the weld fails to penetrate to the root of the groove.
- Overlap – infused weld metal piling on the base metal.
- Porosity – weld contains gas pockets and globular voids.
- Undercutting – excessive current causing a burning off of the base metal.
- Slag inclusion – slag is trapped in the weld.
- Cracking – tearing of weld as it cools.
- Lack of fusion – failure to properly fuse.

There are many SMMAW steel electrodes available in the local technical hardware markets in the country, many of which are being used by local welders on both galvanized steel metal and mild steel metal during fabrications and constructions of, mechanical equipment, agricultural machinery and some others. However, the compatibility modes are not established for the best fit in terms of strength and consumption rate.

II. Materials and Methods

The materials used for the research work were obtained from one of the technical hardware markets in South Western Nigeria. Four different types of Gauge 12 electrodes and two types of steels [mild steel (MS) and galvanized steel (GS)] flat bars were used for the experiments. Metal tape rule is used to measure and determine the length of each type of electrode by measuring through both ends, while micrometer screw gauge was used to measure the thickness of core wire and the whole electrodes (flux inclusive). Deposition rate and welding speed of electrodes were determined by welded together GS to GS and MS to MS flat bars with the different electrode, five (5) replicates per each of the samples for the duration of 6seconds on each specimen for each welded metal seam. The current of the welding machine is set to 130A. Eight welded specimens were prepared to have uniform thickness (t) of 2.75mm, minimum parallel length L1 of 36mm, average minimum length L2 of 35mm and minimum total length L3 of 70mm (Fig. 1). These were subjected to tensile test by the Ultimate tensile test machine. The collected data were subjected to statistical analysis and discussed.

Nomenclature

GC = galvanize steel welded with China electrode
GF = galvanize steel welded with Fed electrode
GO = galvanize steel welded with Oerlikon electrode
GZ = galvanize steel welded with Zika electrode
MC = mild steel welded with China electrode
MF = mild steel welded with Fed electrode
MO = mild steel welded with Oerlikon electrode
MZ = mild steel welded with Zika electrode

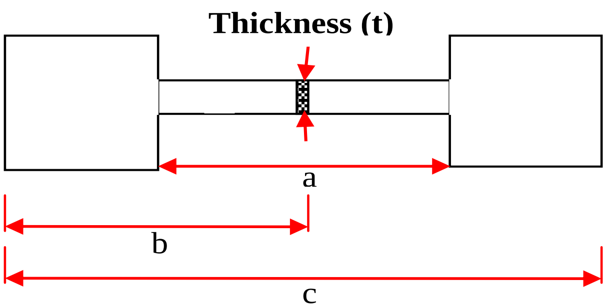

Fig.1: Schematic Diagram of Prepared Specimen

Legends

a= minimum parallel length (L_1)
b= average minimum length (L_2)
c= total minimum length (L_3)

III. Results and Discussion

Table 1 presents the characteristics and relative naira values of the four selected brand of electrodes for the study. Tables 2, and 3 displays consumption rate, and projected quantity of each electrode brand used on each steel type and cost analysis. The tensile test results are presented in Tables 4 through to 6. Figs. 2a & 2b, 3a & 3b, 4a & 4b and 5a & 5b show machine plotted stress-strain graphs of tensile stress analyses. Plates 1, 2 and 3 show sample specimens before preparation, after preparation and after test respectively. The stress-strain curves plotted by the machine in respect to the test results are presented in figs. 2a;2b, 3a;3b, 4a;4b, and 5a;5b in the Appendix 1. The curves show each electrode brand as related to base engineering materials when subjected to tensile test.

Table 1: Characteristics of Selected Electrode Brands

S/N	Electrode Brand	Manuf-acturer	No of stick per pack	Price per Stick (₦)	Price per Pack (₦)	Length (mm)	Electrode Thickness (mm)
1	Fed	Nigeria	260	7.5	1,100	347	4.10
2	Oerlikon	Nigeria	280	10	2,100	346	3.99
3	China First	China	240	5	1,100	347	4.30
4	Zika	Israel	250	10	2,000	357	4.60

Table 1 presents the characteristics of the four selected brand of electrodes for the study. As shown in the table, two brands of electrodes are produced locally (Fed and Oerlikon), while other two (China first and Zika) are trade maked China and Israel respectively. Number of electrode stick per pack ranged from 240; China first to 280; Oerlikon, corresponded to price values of ^ 1,100 to ^2,100, with equal length of electrode stick. Cost per stick per electrode brand shows that Oerlikon and Zika has the highest value of ^10, followed by Fed which is ^ 7.5, with the minimum, equals the half of the highest cost value (Table 1).

Table 2: Average Consumed Lengths and Standard Deviations (SD) of Electrodes with Consumption Rate (CR) on Selected Steel Types

Steel Material		Brand of Electrode China	Fed	Oerlikon	Zilka
Mild Steel	Mean (mm)	27.4	32.4	32.4	35.1
	SD	0.20	2.18	1.18	1.18
	CR (mm/s)	4.57	5.40	5.40	5.85
Galvanized Steel	Mean (mm)	33.9	35.6	38.8	39.3
	SD	0.71	0.95	0.99	0.65
	CR (mm/s)	5.65	5.93	6.47	6.55

Replication = 5times Duration/Replicate = 6seconds

steel metals on the selected electrode brands. The results indicate that there is a constant consumption rate of 5.4mm/s for Fed and Oerlikon when working on mild-steel, compared to the consumption rate on galvanized-steel, with Oerlikon, 6.47mm/s faster than Fed with 5.93mm/s. China electrode showed lowest burning rate on both steel metals, it has the consumption rates of 4.57mm/s and 5.65mm/s respectively for mild-steel and galvanized-steel, while Zilka on the other hand has highest consumption rate of 5.85mm/s on mild-steel and 6.55mm/s on galvanized-steel. Generally, all brands of electrode have lower consumption rate on mild-steel compared to galvanized-steel (Table 2).

The projection of the expected quantity of each electrode brand to be used on each metal type in 8hrs duration and the corresponded naira value is as presented in Table 3. In respect to the number of electrode stick used, Oerlikon on galvanized steel has the highest with total number of 538.5 electrodes approximately, this is followed by Zika, also on galvanize steel with the value of 528.4 approximately. In all electrodes – steel combinations, it is observed that the quantity of electrodes used on galvanize steel are more than that on mild steel, and this is directly proportional to naira value (Table 3). By considering tensile strength result on allowable maximum load (Table 4), it could be deduced that it is better fit and would be cost effective to use Zika on mild steel than on galvanized steel with the corresponded naira values of ^ 3,774 ^ 4,227 respectively for duration of 8hrs work (Table 3).

For galvanized dependent specimens, it is observed from Table 4 that Galvanized steel welded with Oerlikon electrode has highest energy of 7.89J at breaking point which is corresponded to tensile stress and strain of 172.354MPa and 0.0607mm/mm respectively. Throughout the prepared specimens, mild steel welded with Zika has the highest energy of 13.71J at breaking point with tensile stress and strain of 139.469MPa and 0.1079mm/mm respectively (Table 4).

Table 3: The Projected Quantity of Electrodes Consumed and Correspondent Cost Implication in 30s, 60s, 1hr & 8 hr

	Duration	Quantity Consumed China GS	China MS	Fed GS	Fed MS	Oerlikon GS	Oerlikon MS	Zika GS	Zika MS
	1s	5.65	4.57	5.93	5.4	6.47	5.4	6.55	5.85
	6s	33.9	27.42	35.58	32.4	38.82	32.4	39.3	35.1
	30s	169.5	137.1	177.9	162	194.1	162	196.5	175.5
	60s	339	274.2	355.8	324	388.2	324	393	351
	1hr	20340	16452	21348	19440	23292	19440	23580	21060
	8hr	162720	131616	170784	155520	186336	155520	188640	168480
No of Electrode Sticks/8hr		468.93	379.30	492.17	448.18	538.54	449.48	528.40	471.93
No of Packs		1.95	1.58	1.89	1.72	1.92	1.61	2.11	1.89
Cost Equivalent (₦)		2,150	1,738	2,082	1,896	4,039	3,371	4,227	3,775

Table 4: Tensile Properties of the Samples at Breaking Point (Standard)

Brand of Electrode		Load (N)	Extension (mm)	Tensile stress (MPa)	Tensile strain (mm/mm)	Energy (J)
G	CHINA	2028	1.10	1.75384	0.0306	1.11
	FED	1880	0.45	131.458	0.0125	0.609
	ZIKA	673	0.48	47.0621	0.0134	0.238
	OERLIKON	2465	2.18	172.354	0.0607	7.839
M	CHINA	652	1.59	45.5959	0.0442	4.089
	FED	-0.23 9	1.80	-0.0167	0.0501	4.31
	ZIKA	1994	3.88	139.469	0.1079	13.71
	OERLIKON	1115	1.09	77.9857	0.0303	2.172

Galvanized steel welded with Oerlikon has the highest allowable maximum load at tensile strength (5131.088N), with the overall lowest allowable maximum load at tensile strength (605.2245N) across the specimens corresponded to Zika electrode. On the other hand, mild steel welded with Zika electrode has the overall highest allowable maximum load at tensile strength (5524.767N) across the specimens, while mild steel welded with Oerlikon has the least allowable maximum load of 2634.588N at tensile strength (Table 5). It could be generally deduced that, all electrode brands give better tensile strength when used with mild steel, compared to when used with galvanize steel, except for Oerlikon (Table 5).

The tensile properties at yield point for the prepared specimens are presented in Table 6. The result shows that Fed and China electrodes have highest modulus of elasticity on galvanized steel and mild steel respectively with the values of 33255.73MPa and 32386.9MPa. It could be inferred that the either galvanize or mild steel welded with Zika electrode brand will deform elastically and plastically when the applied

Table 5: Tensile Properties of the Samples at Allowable Maximum Load

	Brand of Electrode	Maximum Load (N)	Tensile stress (MPa)	Tensile strain (mm/mm)	True strain (mm/mm)	True stress (MPa)	Energy (J)	Load at Tensile Strength(N)
G	CHINA	2277.67	159.27754	0.01782	0.61275	162116602	0.61275	2243.346
	FED	2729.8	190.89543	0.00971	0.00967	192749699	0.37029	1820.659
	ZIKA	1253.29	87.64237	0.01088	0.01082	88596243	0.13913	605.2245
	OERLIKON	5136.54	359.1989	0.05348	0.0521	378409802	6.56633	5131.088
M	CHINA	3595.93	251.46361	0.02107	0.01767	256760932	1.73337	3575.011
	FED	3564.43	249.26087	0.02362	0.02334	255147923	1.82513	3524.099
	ZIKA	5537.59	387.2444	0.09259	0.08855	423099456	10.9943	5524.767
	OERLIKON	2643.77	184.87916	0.02385	0.02357	189288338	1.60749	2634.588

M = Mild Steel G = Galvanized steel

Table 6: Tensile Properties of the Samples at Yield point

	Brand of Electrode	Tensile stress) (MPa)	Tensile strain (mm/mm)	Energy (J)	Load (N)	Extension (mm)	Modulus (E-modulus) (MPa)
G	CHINA	159.28	0.02	0.61	2277.7	0.642	24949.08
	FED						33255.73
	ZIKA						21606.37
	OERLIKON	359.2	0.05	6.57	5136.5	1.925	24082.9
M	CHINA	251.46	0.02	1.73	3595.9	0.758	32386.9
	FED	249.26	0.02	1.83	3564.4	0.85	29389.17
	ZIKA	387.24	0.09	11	5537.6	3.333	20941.34
	OERLIKON	184.88	0.02	1.61	2634.6	0.859	23895.34

M = Mild Steel G = Galvanized steel

stress is not removed which leads to permanent and non-reversible deformation compared to other electrode brands (Table 6). Knowledge of the yield point is vital when choosing electrode brand in construction and fabrication of some components since it generally represents an upper limit to the load that can be applied.

Plate 1: A Welded Sample Work Piece before Machining

Plate 2: Prepared Sample for Testing After Machining

Plate 3: Some Sample After Tensile Stress Test

Plate 1 shows a sample of welded unprepared specimen, while Plate 2 presents a well prepared sample specimen before tensile test. The samples of broken parts of the specimens after tensile test are as displayed in Plate 3.

IV. Conclusion and Recommendation

It can be concluded that the best combination of cost effectiveness and tensile strength for the two studied types of steel (mild and galvanized steel) were obtained for mild steel welded with Zika electrode. All electrode brands were discovered to have measurable effect on mild steel compared to galvanized steel, while Oerlikon electrode is most suitable for galvanized steel. With respect to analysis results, one can deduced that it is not advisable to use Zika electrode on galvanized steel, as it has the least tensile strength with highest consumption rate.

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APPENDIX

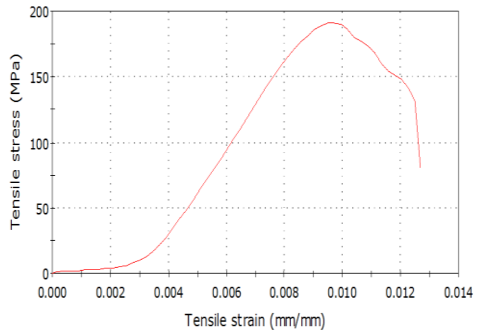

Fig.3a: Galvanized steel welded with Fed electrode

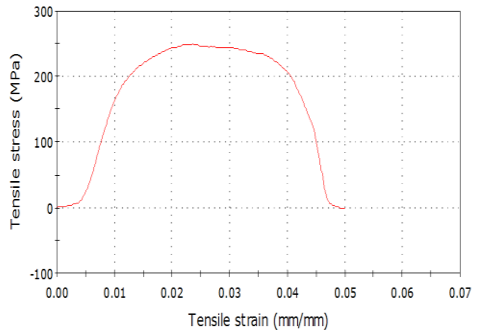

Fig.3a: Mild steel welded with Fed electrode

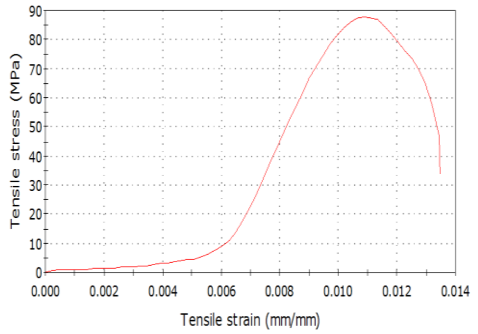

Fig.4a: Galvanized steel welded with Zika electrode

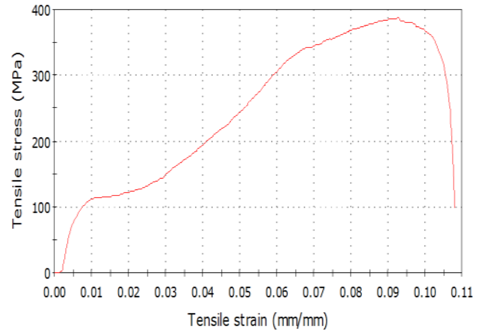

Fig.4a: Mild steel welded with Zika electrode

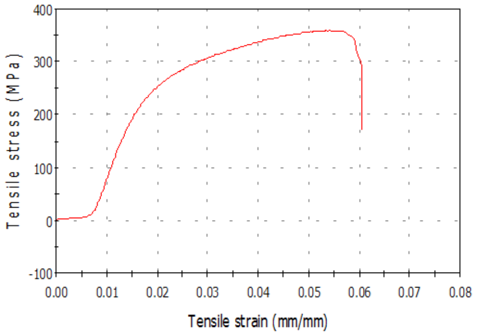

Fig.5a: Galvanized steel welded with Oerlikon electrode

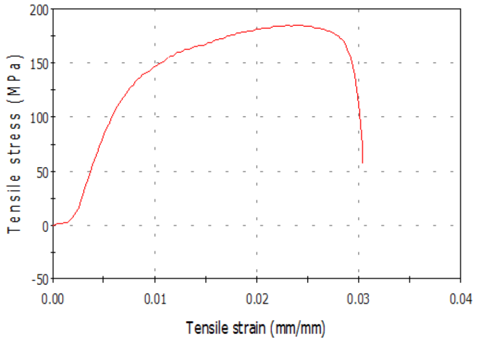

Fig.5a: Mild steel welded with Oerlikon electrode