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DEVELOPMENT OF FeO.TiO$_2$-SiO$_2$-CaCO$_3$ SYSTEM AS A WELDING FLUX

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ABSTRACT

Using local raw materials, various metal-arc welding fluxes were formulated. A ternary system of FeO.TiO$_2$-SiO$_2$-CaCO$_3$ gave satisfactory results. Average values of 546 N/mm^2 ultimate tensile strength and 10% elongation were obtained from all-weld metal tensile specimens. The formulation also gave a metal deposition efficiency of 88.9%.

Key words: Flux, Welding flux, Flux system

1.0 INTRODUCTION

A welding flux is a granulated fusible mineral normally made of oxides that are physically and or chemically active both in shielding the metal from oxidation and in disposing of any oxide that forms in shielded manual metal-arc welding (SMMAW) [Ferrera and Olson, 1975]. Kjelberg [1995] got the first patent for applying protective coatings to the electrode. During the period 1936 to 1950 there was rapid development in the field of welding of structural steel. Many new welding processes made their appearance and a wide range of welding electrodes suitable for manual metal arc welding were developed. This period saw the first appearance of solid extruded electrodes.

Despite the fact that welding electrodes are needed by key industries, maintenance shops and roadside welders, manufacturers of SMMAW electrodes in Nigeria import all their raw materials [MAN, 1999]. Some attempt have been me to find local substitutes for the imported flux and wire used for the manufacture of welding electrodes as exemplified by the work of Okoh and Ibhadode [1993] in which starch was used as the binder. This work is in furtherance of that attempt.

In this paper, ilmenite, a waste by-product of tin processing, is used as a base mineral. Other minerals and raw materials were selected according to their contribution to the desired performance of the welding electrodes.

2.0 THEORETICAL BACKGROUND

2.1 Arc Stability

Arc stability affects the initiation and maintenance of the welding arc and even the weld bead morphology [Schwemmer et al, 1979]. The arc should ignite easily and be able to maintain itself under a varying length. The arc voltage should not fluctuate a great deal thus producing a constant heat input and uniform weld bead. Arc stability has been defined by Sparagen and Claussen [1939] as the ratio of the distance that the arc can be lengthened before being extinguished to the given length. The stability of an arc at any given voltage and current has been related to the ionization potential of the material from which the plasma is produced [Butler and Jackson, 1967]. Potassium is usually used as ionizers in metal-arc welding fluxes.

2.2 Viscosity

Viscosity of a molten flux plays an important role in production of an acceptable welded joint. Viscosity is not only a measure of the resistance to flow, it is also related directly to the rte coefficient of mass and heat transport in the flux which affect the weld metal protection and refinability and heat transfer during welding.

A flux must remove elements and gasses away from the weld metal by first absorbing atoms or molecules into the flux at the liquid metal slag interface and diffusing same way from the interface.

A flux with low viscosity will have a greater bulk diffusion rate and therefore a greater reaction rate at the metal slag interface. On the other hand, a high enough viscosity is necessary to protect the weld metal from atmospheric gases. Silica additions to both acid and basic fluxes have been shown to increase the viscosity. A close examination of the molten silica network reveals that a basic unit of the network is the silicate tetrahedron which consists of four nearly close-packed oxygen atoms surrounding a small silicon atom [Ferrera and Olson, 1975].

3.0 RAW MATERIALS AND THEIR LOCAL SOURCES

3.1 Rutile And Ilmenite

Of all the naturally occurring minerals containing titanium as a major constituent, only two have been seriously considered as suitable feedstock for either the metal producing or pigment industries. The mineral rutile, when pure, consists essentially of TiO_2 with very small quantities of iron. Ilmenite on the other hand has a composition $FeO.TiO_2$ with ordinarily between 40% and 60% TiO_2, depending on the relative amount of ferrous and ferric ions. The major deposits of the titanium ore mineral are located in Australia, and Sierra Leone. Ilmenite deposits are more widely distributed and are located in Australia, Canada, Finland, India, Norway, Malaysia and in the United States [Dooley, 1975]. In Nigeria, very large deposits in commercial quantities are found in Kaduna and Plateau States. The mineral is presently dumped as a waste product in tin mining.

3.2 Silica

This compound occurs naturally as quartz and sand and also as flint, opal or agate. Pure silica is colourless but sand is usually coloured yellow or brown by ferric oxide impurity. Quartz, like graphite and diamond has high melting point – about 1700°C. Unlike most solids, however it does not melt sharply to a liquid but turns to a viscous mass over a reasonably wide temperature range first softening at about 1400°C. Silica combines with lime formed by decomposition of limestone to produce slag. Silicon dioxide is widely distributed in Nigeria as may be seen in the location of glass factories at Lagos, Ondo, Oyo, Delta and Rivers States [RMRDC, 1997].

3.3 Limestone

Limestone decomposes thermally to form calcium oxide and carbon dioxide:

$CaCO_3 = CaO + CO_2$

The limestone combines with silica to produce calcium silicate slag:

$CaO + SiO_2 = CaoSiO_3$

Limestone occurs naturally and is available extensively in deposits in Edo, Enugu, Bauchi, Ogun and Benue States [RMRDC, 1997].

3.4 Wood Flour

This is wood that has been finely divided by mechanical means to desired particle sizes. The finest grinds resemble wheat flour. It is the major source of cellulose for electrode production. It occurs extensively in the woodlands of Nigeria. In particular, large quantities can be obtained from the numerous sawmills in Nigeria.

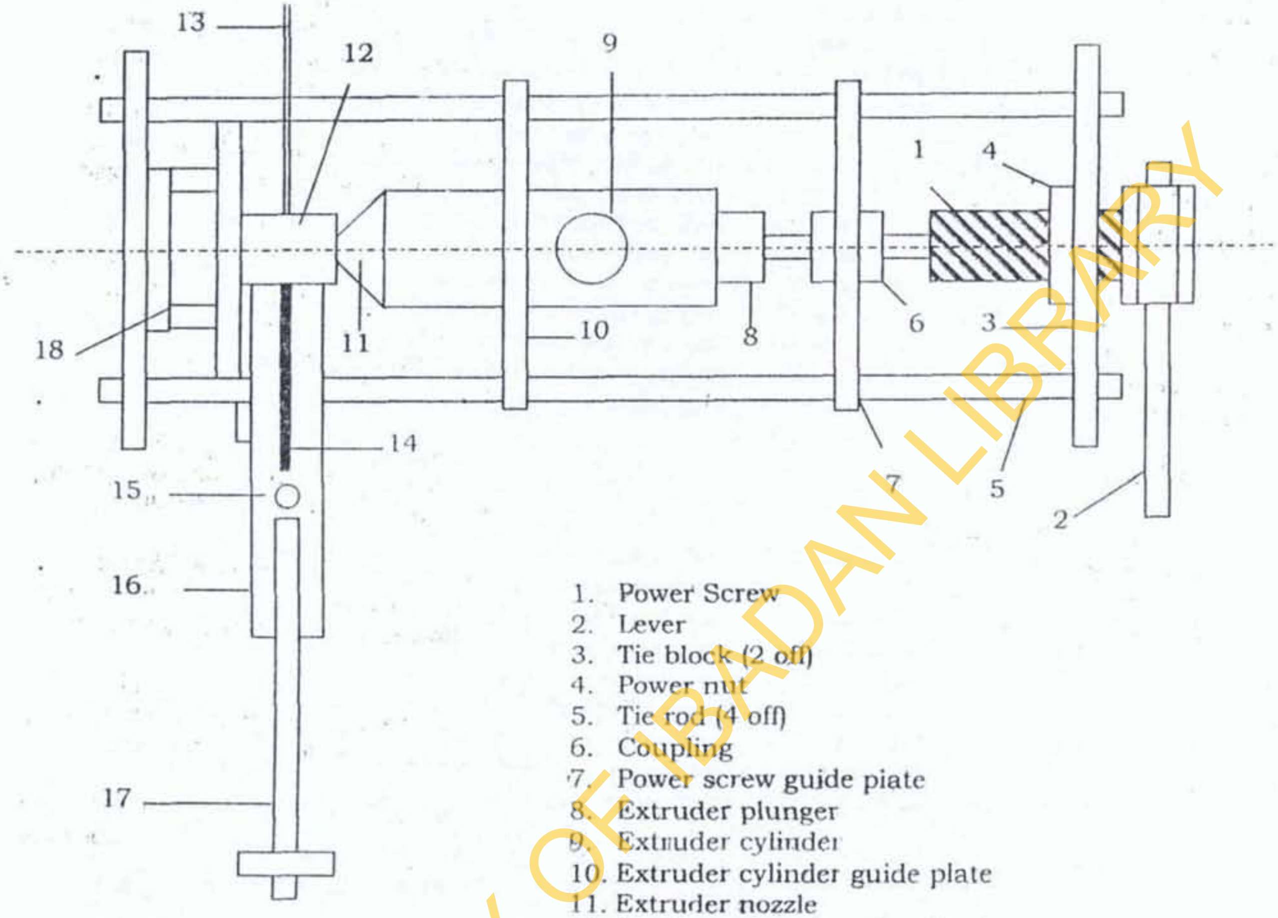
4.0 EXPERIMENTS

4.1 Equipment

A laboratory screw-extruder shown in Fig 1 [Ibhadode, 1997], was used for coating the core wire with flux. The extrusion barrel had a volumetric capacity of 50 cm^3. The extrusion block had an extrusion hole of 5.0 mm diameter through which the electrodes were extruded. A Triton oven was used for baking the extruded electrodes at 120°C. An Avery weigh scale of accuracy 0.1g was used for weighing out the various materials used for flux formulation. A 600 kN Avery hydraulic testing machine was used for testing the strength of the welded joints. A Monsanto Swindon tensometer was used for carrying out the tensile tests. An ESAB 175 ampere oil-cooled welding machine set at 90 amps was used for welding test pieces.

4.2 Materials

Assorted minerals and organic materials adequately beneficiated and prepared into powders were used for the coating formulation. These were silica, ilmenite, limestone, wood flour, oil palm bunch ash, sodium silicate, starch, feldspar, mica manganese oxide and ferro-silicon. A 2.5 mm diameter core wire of chemical composition 0.12 – 0.17% C, 0.18 – 0.28% S and 0.40 – 0.60% Mn was used. It was obtained from a wire drawing factory in Oshogho, Osun state, Nigeria. Mild steel pieces measuring 60mm x 25mm x 5mm were used as weld test pieces. Welded joints were made on length 60mm of test pieces.



1. Power Screw
2. Lever
3. Tie block (2 off)
4. Power nut
5. Tie rod (4 off)
6. Coupling
7. Power screw guide plate
8. Extruder plunger
9. Extruder cylinder
10. Extruder cylinder guide plate
11. Extruder nozzle
12. 90° Extrusion chamber block
13. Uncoated electrode wire 2.7mm
14. Coated electrode wire 4.5mm
15. Electrode guide head
16. Electrode withdrawal cylinder
17. Electrode holder/withdrawal plunger
18. Support

Fig 1: Schematic of the Manual Electrode Coating Machine

3 Formulation

Various flux formulations were made. For each formulation, ingredients were sieved, weighed and properly mixed in a bowl. The electrodes were then extruded using the laboratory extruder. After air-drying for at least two hours, the electrodes were baked in the oven at 120°C for one hour. On the average, the final coated diameter of the electrode was 4.6mm.

5.0 TESTS

5.1 Welding Tests

For each electrode flux formulation, welded joints were made at a current setting of 90 amps. The mild steel plates to be welded were ground and double V-butt welds made. For each welding test, the following were noted qualitatively in order to assess the electrode performance: ease or difficulty of arc ignition, arc stability, quietness of arc, spatter generated, quality of slag cover, slag removability and smoothness of weld bead.

5.2 Strength Tests

For those formulations, which showed good welding performance, the weld test pieces were subjected to bend tests in order to determine their breaking strengths. The test pieces were mounted on a vee-block and breaking loads were applied with the hydraulic testing machine. Three bend tests were performed for each electrode formulation. Two different commercial electrodes were used as controls for these bend tests and others. Commercial electrode A is a popular brand and is generally regarded as the best in the market. Commercial electrode B is an Asian brand, which enjoys a wide patronage due to it relative lower cost vis-à-vis performance.

5.3 All-Weld Metal Tensile Tests

All-weld metal tensile test pieces were prepared from the electrode under test. The groove formed by this arrangement was built up with the electrode weld metal under test, with a top reinforcement of about 3mm [B4 Committee, 1987]. The welded portion was then cut out at about 10mm on each side of the weld line. The cut out piece was then machined to the appropriate dimensions for a tensile test piece. Tensile tests were then carried out on the tensometer.

5.4 Electrode Deposition Efficiency

Clean mild steel plates measuring 60mm x 25mm x 5mm were weighed (W_1). Each electrode type under test was deposited on each steel plate. The steel plate was then de-slagged and cleaned. The leftover electrode stub was then stripped and cleaned of the flux coating. The total weight of the steel plate on which the electrode had been deposited and stub was then taken (W_2). The weight of bare electrode wire was also taken (W_3). The electrode deposition efficiency was obtained from the equation

Electrode efficiency (%) = $100(W_2 - W_1) / W_3$

6.0 RESULTS AND DISCUSSION

6.1 Electrode Flux Formulations

6.1.1 Single Component Fluxes

Single component fluxes were first made to establish their individual performance. These single-component fluxes were made separately from sodium silicate, potassium silicate, quartz, limestone, ilmenite, wood flour, starch and palm bunch ash. The separate single-components were crushed into fine powder and sieved to have a maximum grain size of 0.15mm. Sodium silicate was used as the binder for these single component fluxes except for the starch flux and sodium silicate flux. These two fluxes were self-binding. Qualitative welding tests were carried out with the electrodes made from these single components as previously outlined. The results obtained are summarized as follows:

Sodium Silicate: As a control, the silicate was used to establish its contribution to ignition and arc stability. The welding was poor and the arc was very unstable. The electrode overheated and the welding could not continue.

Silica: The welding was very noisy with a lot of spatter. The arc was unstable and extinguished periodically. Re-ignition was rather difficult.

Limestone: The electrode fired easily and burned with very quiet arc. The arc was very stable and the weld and the weld bead were reasonably smooth.

Ilmenite: The electrode burned quietly and the arc was very stable. The electrode burned continuously to the end and gave a reasonably smooth weld.

Wood Flour: The starting was easy. The burning was continuous but noisy. The spark was good but there was spatter.

Starch: The electrode started and burned well. Arc was very noisy and extinguished from time to time. Re-ignition was rather difficult.

Potassium Silicate: The ignition was easy. The burning was noisy with spatter. The arc extinguished from time to time but was not difficult to re-ignite.

Palm Bunch Ash: The electrode ignited and burned well with a fairly quiet arc and little spatter.

6.1.2 Multi-Component Fluxes

Multi-component fluxes were made in order to obtain higher performance electrodes by combining the above properties of the single-component fluxes. The various compositions and the test results are summarized in Tables 1-5, Series 1 Fluxes (Table 1 were made with starch as binder. The starch was made from a 25g starch powder and 150gm^3 of boiling water. The other fluxes were made with 30cm^3 of sodium silicate, which was supplied by Drury Industries, Lagos. Formulation 16 containing 60% ilmenite (FeO.TiO$_2$), 15% limestone (CaCO$_3$), 10% silica (SiO$_2$) and traces of palm-bunch ash, wood flour and potassium silicate (Table 5) performed very well and had a good slag cover. The slag was also easy to remove exposing a very smooth weld bead.

6.2 Strength Tests

Table 6 shows the average breaking strengths of the welded joints made by electrode flux formulation 16 and the commercial electrodes tested. The laboratory electrode had about 82 percent $W_2 - W_1$ the breaking strength of commercial electrode A and about 186 percent of that of commercial electrode B. This shows that the laboratory electrode has the potential for commercial exploitation.

Table 7 shows the tensile test results for the all-weld tensile specimen made from the laboratory electrode No. 16. Thr average ultimate tensile strength and the average percent elongation are 546N/mm^2 and 10.42 respectively. The tensile strength falls within the published results for mild steel electrode ISO 2560: E432R11 whose value is given as 450-550 N/mm^2. The elongation for this particular electrode is quoted as > 22%. This shows that the laboratory made electrode is about half as ductile as that of Primafixe of Oerlikon. It is expected that the higher the tensile strength, the less ductile will be the material. The strength of the laboratory electrode is in the upper range of the Primafixe electrode. The low value of percent elongation of the laboratory electrode may be due to the type of electrode wire used which has higher alloying elements compared to 0.10%C, 0.3-0.5% Mn and 0.02% Max Si core wire conventionally used. This needs further investigation.

Table 1: Series 1 Welding Flux (percent composition by weight)

Experiment No.	Silica	Limestone	Wood Flour	Iron Powder	COMMENTS
1	59	10	02	29	Arc was easy to strike, and was fairly stable. Arc extinguishes and re-ignition was poor
2	48	25	02	25	Arc starts with ease, but rather unstable. Coating burned ahead of core wire
3	59	10	01	30	Fair burning with flush tip. Poor bead formation

Table 2: Series 2 Welding Flux (percent composition by weight)

Experiment No.	Silica	Limestone	Clay	Potassium silicate	Iron powder	Wood Flour	Starch	COMMENTS
4	20	40	09	03	20	04	04	Arc was easy to start and fairly stable. Good bead but discontinuous. Poor slag.
5	45	15	-	-	30	05	05	Very easy to start, good burning with flush tip. Does not extinguish. Poor bead with slag inclusion.
6	46	25	-	-	23	02	06	Very easy to start. Fairly stable arc. Coating burned ahead of core. Poor joint.

Table 3: Series 3 welding Flux (percent composition by weight)

Experiment No	Wood flour	Potassium silicate	Clay	Iron Powder	Limestone	Starch	Silica	COMMENTS
7	04	04	10	20	38	04	20	Easy to start, good arc, deep conical tip, fair performance
8	04	04	09	20	20	04	39	Easy to start, good arc, slight flagging of tip, fair performance
9	03	03	08	33	33	03	33	Easy to start, good arc, slight flagging of tip, fair performance
10	03	03	09	24	24	03	30	Easy to start, fairly stable arc, fairly large amount of spatter. Fair performance.
11	03	03	08	21	21	03	25	Easy to start, fairly stable arc, flagging of tip, good bead and slag

Table 4: Series 4 Welding Flux (percent composition by weight

Experiment No.	Ilmenite	Starch	Potassium Silicate	Felspar	Mica	Clay	Ferro-silicon	COMMENTS
12	41	26	10	08	05	05	05	Very good starting stable arc, very good weld bead, very little spatter. Easily detachable slag
13	56	10	10	08	05	05	05	Easy to start, fairly stable arc, fir slag cover
14	60	07	10	08	05	05	05	Easy to start, no spatter, stable arc fair weld bead and slag cover

Table 5: Series 5 Welding Flux (percent composition by weight

Experiment No	Ilmenite	Limestone	Silica	Palm Bunch ash	Wood flour	Potassium silicate	COMMENTS
15	68	13	5	5	5	5	Ignition was easy, arc was very quiet and stable, no spatter, the bead was smooth. Slag cover was thin and difficult to remove
16	60	15	10	5	5	5	Starting was very easy. Arc was quiet and stable. No spatter, good slag cover, easy to remove. Smooth bead.

Table 6: Breaking Strength for Welded Joint

Electrode	Breaking strength (kN)
Laboratory electrode (No 16)	28
Commercial A	34
Commercial B	15

Table 7: Tensile Test Results

Factor	Tensile Sample				Average Value
	1.	2	3	4	
Area of cross section (mm^2)	19.63	19.63	19.63	19.63	19.63
Gauge length (mm)	60.00	60.00	60.00	60.00	60.00
Final length (mm)	67.00	65.00	68.00	65.00	66.25
Maximum Load (N)	10671	10800	10714	10713	10724.5
UTS (N/mm^2)	543.45	550.05	545.68	545.65	546.21
Percent Elongation	11.67	8.33	13.33	8.33	10.42

6.3 Deposition Efficiency

Table 8 shows the deposition efficiencies of the laboratory-made electrode and the two commercial electrodes A and B. The table shows that the laboratory electrode has a deposition efficiency of about 90 percent of that of commercial electrode A and about 108 percent of commercial electrode B.

Table 8: Deposition Efficiency

Electrode	Efficiency (%)
Laboratory No. 16	88.9
Commercial A	98.6
Commercial B	82.5

6.4 Potential of Electrode Manufacture from Local Raw Materials

The formulated laboratory electrode possesses properties that recommend it for commercial exploitation. Its properties are clearly superior to commercial electrode B (which is already enjoying a wide patronage in the market), as shown by higher breaking strength tensile, strength and deposition efficiency of the former over the latter. With the exception of the potassium silicate, all the other raw materials for its formulation are obtained locally. Thus the foreign content of about 5 percent is negligible.

The advantage of local sourcing of raw materials include: (i) lower production cost, (ii) lower electrode prices, (iii) higher capacity utilization of electrode manufacturers, (iv) generation of employment opportunities in the raw materials sector of the industry, and (v) boosting of gross national product of the economy. Further work is in progress to perfect the system for commercial exploitation, so that the nation can avail herself of the above gains.

7.0 CONCLUSION

A suitable metal-arc welding flux has been formulated from local raw materials comprising ilmenite, limestone, silica, wood flour, palm bunch ash and potassium/sodium silicate as the binder. The only foreign content that cannot be produced locally is potassium silicate, which constitutes only 5% by weight. The performance indices of the electrode compare well with ISO 2560:E432R11 for mild steel electrodes.

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