

Formulation and Production of Arc Welding Electrode Coated with Mill Scale Based Flux Locally Sourced from Ajaokuta Steel Company Limited in Nigeria

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Abstract— This research is targeted at locally produced iron (Fe) based arc welding electrodes, using mill scales from Ajaokuta Steel Company Limited (ASCL). Mill scale was collected, prepared into pulverized form and analyzed using X-ray fluorescence spectrometer machine. The result of the analysis showed predominantly (more than 96%) iron, which is an important constituent of iron oxide electrode coatings. The flux compositions were generated using Hadamard multivariate chemical model, by which fifteen different flux compositions were formulated within given trial ranges of the constituent flux elements. Three of the flux compositions formulated were used for the coatings of the electrodes. The percentage compositions of the three different fluxes were A(X1=40%, X2=25%, X3=15%, X4=8%, X5=5%, X6=3%, X7=4%), B(X1=43%, X2=25%, X3=10%, X4=10%, X5=5%, X6=3%, X7=4%) and C(X1=44%, X2=30%, X3=10%, X4=8%, X5=3%, X6=3%, X7=2%). Where X1=mill scales, X2=sodium silicate, X3=calcium carbonate, X4=manganese dioxide, X5=silica, X6=calcium fluoride and X7=feldspar. The elemental composition of the mill scale, using the modern XRF machine shows that Fe, Ti and Mn were found to be major constituent elements, with Fe constituting more than 96% of the total contents. Other elements such as P, Cu, Ni and Cr were found to be present in traces. Also the elemental compositions of the steel core wire used for the research was found to be within the specification of mild steel, according to ASTM standard which states the percentage of carbon for mild steel as 0.05 – 0.25%, Manganese not to be more than 1.65% while Silicon should not be more than 0.6%

Keywords— Arc welding, Electrodes, Flux, Iron, Mill Scale.

I. INTRODUCTION

Arc welding electrodes play an important role in most engineering firm such as fabrication industries. Electrodes are usually coated with chemical constituents known as flux, which melts along with the core wire during welding, to protect the welded joint from oxidation. In some situations, alloying elements could be introduced into the welding through fluxes to improve some of the properties of the parent metals. The importance of flux in electrode cannot be overemphasized, as it shielded the welding pool from atmospheric oxygen or nitrogen, which is detrimental to the strength and chemical/physical properties of the welded joints.

In this work, mill scales from Ajaokuta Steel Company Limited (ASCL) was used to formulate flux along with

other constituents. Hadarmart multivariate matrix was adopted in formulating the percentage weight composition of each constituent in the flux for producing electrodes.

II. MATERIALS AND METHODS

MATERIALS

The following materials were used in the production of the Electrodes: Mild steel wire (3mm diameter), Mill scales, Sodium silicate, Calcium carbonate, Manganese dioxide, Silica, Calcium fluoride, Feldspar, weighing balance, sieve (75 microns aperture), oven, wooden mould and spatula.

METHODS

In this research, the Hadamard multivariate analysis was adopted. The model as shown in Table 2.1 was used to generate different flux compositions. The proposed chemical composition range for the coating flux of the locally produced electrode is shown in Table 2.2. These ranges for the flux formulation process were chosen base on trial.

Table 2.1: Hadamard matrix layout for formulation of the flux (Source: Achebo and Ibhadode, 2008)

Trial	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
1	+	-	-	+	+	-	+
2	+	+	-	-	-	+	+
3	+	+	+	+	-	-	-
4	-	+	+	-	+	-	+
5	+	-	+	-	+	+	-
6	-	+	-	+	+	+	-
7	-	-	+	+	-	+	+
8	-	-	-	-	-	-	-

This is a standard table adapted in formulating flux compositions. As each of the constituent is confined between a trial range of upper and lower value as revealed in table 2.2, when filling the matrix table, the lower range was entered on the negative column while the upper range was entered on the positive column.

Table 2.2: Proposed chemical composition ranges for flux coatings of the locally produced welding electrode

Constituent elements	Composition ranges (%)
Mill scales	40 ≤ X ₁ ≤ 50
Sodium silicate	25 ≤ X ₂ ≤ 30
Calcium carbonate	10 ≤ X ₃ ≤ 15
Manganese dioxide	8 ≤ X ₄ ≤ 10
Silica	3 ≤ X ₅ ≤ 5
Calcium fluoride	3 ≤ X ₆ ≤ 5
Feldspar	2 ≤ X ₇ ≤ 4

where X₁= Mill scales, X₂= Sodium silicate, X₃= Calcium carbonate, X₄= Manganese dioxide, X₅= Silica, X₆= Calcium fluoride and X₇= Feldspar.

These ranges were chosen base on trial for the formulation of the flux for this research. During the formulation, the lower values were entered on the

negative boxes and the higher values on the positive boxes in table 2.1.

FLUX COMPOSITION FORMULATION PROCEDURE

Tables 2.3-2.9 show the steps involved in arriving at the flux compositions. The composition ranges in Table 2.2 were used for these steps. The matrices of variables X₁, X₂, X₃, X₄, X₅, X₆, X₇ were extracted from the Hadamard matrix layout Table 1.1 and the composition ranges in Table 2.2 were used to fill the matrices of the extracted variables bearing in mind that by standard, the positive (+) signifies high value and negative (-) signifies a low value of the composition ranges. In this case X₁ is being considered first in the formulation process as mill scales constitute highest percentage. The other variables X₂-X₇ were filled and X₁ was left blank in table 2.3. The condition of this formulation process required that each composition or trial must add up to hundred percent by weight. To make a complete composition therefore, the variables X₂-X₇ were added up and the remaining value to sum it up to hundred percent by weight were entered in the X₁ column. If the value fell within the range set for variable X₁ as specified in Table 2.2, it was entered in the column X₁, but if the value was above or below the range, it was skipped because it was not within the trial range. This procedure was repeated for X₂, X₃, X₄, X₅, X₆ and X₇ as shown from Table 2.4 to Table 2.9 All formulated flux compositions generated from the procedure is tabulated in Table 2.10 and Table 2.11 shows the three (3) compositions range selected for this research based on the differences in percentage values of the mill scale and other constituents.

Table 2.3: Mill scales, 40-50% of flux composition ranges by weight

Trial	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
1	43	25	10	10	5	3	4
2	40	30	10	8	3	5	4
3	-	30	15	10	3	3	2
4	-	30	15	8	5	3	4
5	40	25	15	8	5	5	2
6	-	30	10	10	5	5	2
7	-	25	15	10	3	5	4
8	44	30	10	8	3	3	2

Table 2.4: Sodium silicate, 25-30% of flux composition ranges by weight

Trial	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
1	50	–	10	10	5	3	4
2	50	–	10	8	3	5	4
3	50	–	15	10	3	3	2
4	40	25	15	8	5	3	4
5	50	–	15	8	5	5	2
6	40	28	10	10	5	5	2
7	40	–	15	10	3	5	4
8	40	–	10	8	3	3	2

Table 2.5: Calcium carbonate, 10-15% of flux composition ranges by weight

Trial	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
1	50	25	–	10	5	3	4
2	50	30	–	8	3	5	4
3	50	30	–	10	3	3	2
4	40	30	10	8	5	3	4
5	50	25	–	8	5	5	2
6	40	30	–	10	5	5	2
7	40	25	13	10	3	5	4
8	40	30	14	8	3	3	2

Table 2.6: Manganese dioxide, 8-10% of flux composition ranges by weight

Trial	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
1	50	25	10	–	5	3	4
2	50	30	10	–	3	5	4
3	50	30	15	–	3	3	2
4	40	30	15	–	5	3	4
5	50	25	15	–	5	5	2
6	40	30	10	8	5	5	2
7	40	25	15	8	3	5	4
8	40	30	10	–	3	3	2

Table 2.7: Silica, 3-5% of flux composition ranges by weight

Trial	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
1	50	25	10	10	–	3	4
2	50	30	10	8	–	5	4
3	50	30	15	10	–	3	2
4	40	30	15	8	–	3	4
5	50	25	15	8	–	5	2
6	40	30	10	10	3	5	2
7	40	25	15	10	–	5	4
8	40	30	10	8	–	3	2

Table 2.8: Calcium fluoride, 3-5% of flux composition ranges by weight

Trial	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
1	50	25	10	10	5	–	4
2	50	30	10	8	3	–	4
3	50	30	15	10	3	–	2
4	40	30	15	8	5	–	4
5	50	25	15	8	5	–	2
6	40	30	10	10	5	3	2
7	40	25	15	10	3	3	4
8	40	30	10	8	3	–	2

Table 2.9: Feldspar, 2-4% of flux composition ranges by weight

Trial	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
1	50	25	10	10	5	3	–
2	50	30	10	8	3	5	–
3	50	30	15	10	3	3	–
4	40	30	15	8	5	3	–
5	50	25	15	8	5	5	–
6	40	30	10	10	5	5	–
7	40	25	15	10	3	5	2
8	40	30	10	8	3	3	–

Table 2.10: Some formulated sample flux compositions in (%) weight

S/N	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
1	40	30	10	8	3	5	4
2	40	25	15	8	5	5	2
3	40	25	15	8	5	3	4
4	40	30	10	8	5	3	4
5	40	30	10	8	5	5	2
6	40	30	10	10	3	5	2
7	40	30	10	10	5	3	2
8	40	25	15	10	3	5	2
9	40	25	15	10	3	3	4
10	40	25	15	8	3	5	4
11	40	25	13	10	3	5	4
12	40	30	14	8	3	3	2
13	40	28	10	10	5	5	2
14	43	25	10	10	5	3	4
15	44	30	10	8	3	3	2

Table 2.11: Flux compositions (%) used in production of sample electrodes

S/N	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇
1	40	25	15	8	5	3	4
2	43	25	10	10	5	3	4
3	44	30	10	8	3	3	2

PRODUCTION PROCESS OF THE ELECTRODES

Each of the formulating minerals, mill scales, calcium carbonate, manganese dioxide, silica, calcium fluoride and feldspar were sieved with a 75µm aperture sieve so as to ensure uniformity of particle size for effecting coating onto the core wire. Thereafter, the minerals were weighed in proportions indicated in Table 2.11 and mixed thoroughly for about 15 minutes until a homogenous mixture was obtained. A measured quantity of sodium silicate was added to the homogenous dry compound and thoroughly mixed for another 5 minutes until a thick paste was formed. The 3mm mild steel core wire was

thoroughly polished using silicon carbide grit paper to remove rust and impurities. The thick paste was then deposited on the groove of the mould which was of same size as the electrode to be produced. A core wire was then dipped in the paste in the groove. The core wire was left in the paste for 5 minutes to enable sticking of about 2mm of the paste to the core wire. The core wire coated with the flux paste was then removed from the groove and a spatula was used to smoothen the coatings, to achieve a better finishing surface of the electrode. The electrodes were left in the atmosphere (at room temperature) for 5 minutes for curing. Hence, the electrode formed was dried at a well regulated temperature of 600C in an oven for an hour. The drying process was done so as to eliminate the moisture content of the electrode coating, and while drying the electrodes in the oven, adequate care was taken not to overheat it to prevent cracking of the coating. After an hour the electrodes were removed from the oven.

III. RESULT AND DISCUSSION

RESULTS

The results obtained from each test conducted during the investigation are presented in tables. Table 3.1(i) present the percentage chemical composition of the mill scale as obtained from the XRF analysis. Similarly, Table 3.1(ii) shows the percentage chemical composition of the core wire and the mild steel plate as received.

Table 3.1(i): Percentage Chemical Composition of the Mill Scales Using XRF Analysis

Element	O	P	Ti	Cr	Mn	Fe	Ni	Cu	As	S
Composition (%)	0.0062	0.0054	1.3208	0.0986	1.1826	96.9362	0.0692	0.323	0.0083	0.0039

Table 3.1(ii): Percentage Chemical Composition of the Mild Steel Core Wire

Element	C	Si	Mn	P	S	Cr	Ni	Fe
Core wire	0.120	0.040	0.541	-	0.051	0.030	0.016	88.065

DISCUSSIONS

The elemental composition of the mill scale, using the modern XRF machine was presented in Table 3.1(i). It could be observed that Fe, Ti and Mn were found to be major constituent elements, with Fe constituting more than 96% of the total contents. Ferrite (Fe) being the major constituent in high iron oxide electrode covering (Davies, 2008), suggests that mill scales obtained from ASCL can be used in electrode production. Other elements such as P, Cu, Ni and Cr were found to be present in traces. Table 3.1(ii) also presented the elemental compositions of the steel core wire used for the research. It was found to be within the specification of mild steel, according to ASTM standard which states the percentage of carbon for mild steel as 0.05 – 0.25%, Manganese not to be more than 1.65% while Silicon should not be more than 0.6%.

IV. CONCLUSION

In this research, iron based arc welding electrodes were produced using mill scales (an industrial waste). The analyzed mill scales from ASCL showed the presence of predominantly iron. Iron oxide is one of the important constituents of covering on high iron oxide electrode coatings. Therefore, mill scales from ASCL can be used in the production of iron oxide electrodes for welding.

V. RECOMMENDATION

Mechanized production process, such as extrusion, should be adopted so as to have electrodes with smooth appearance, and to increase efficiency and productivity.

Future research should be carried out on the performance evaluation of the electrodes produced from mill Scale based flux sourced from Ajaokuta Steel Company Limited in Nigeria. The produced electrodes thus should be used to weld and its welded part be tested for some mechanical properties such as tensile strength, hardness strength and microstructural analysis to ascertain its use for industrial applications.

APPENDIX



Plate I: Materials used for the production of electrodes



Plate II: Weighing balance at the Civil Engineering Lab (FUT, Minna)



Plate III: Oven used for curing of the produced electrodes at Civil Engineering Lab. (FUT, Minna)



Plate IV: Mild steel core dipped in the mill scale paste in the mould groove



Plate V: Produced welding electrodes prior to curing in the oven

REFERENCES

- [1] Abu, J. O. (2011). Manufacturing Engineering and Production Management: Aboki Publishers Makurdi, Benue State, Nigeria, pg 46.
- [2] Achebo, J.I. and Ibadode, A.O.A. (2008). Development of a New Flux for Aluminum Gas Weldin: Advanced Materials Research, Switzerland Vol. 44-46, pp 677-684.
- [3] Achebo, J.I. and Ibadode, A.O.A. (2009). Determination of Optimum Welding Flux Compositions Using the Bend Strength Test Technique: Advanced Materials Research, Switzerland Vol. 62-64, pp 393-397.
- [4] Annual Group of ASTM standard Vol. 0101 to 14.2 and updated as ASME 345E 47th series N.Y. 1001 from standard document N.Y. General Specification for general requirement for steel plate and pressure vessel October 1998 reviewed year 2002
- [5] Bruce, B (2008). A Basic Guide of Arc Welding Electrode: Peterson Press, Indiana.
- [6] Cary, H.B. and Helzer, S.C. (2005). Modern Welding Technology: Pearson Education New Jersey.
- [7] Davies, A.C. (1972). Science and Practice of Welding: Seventh Edition, Cambridge University press, London.
- [8] Davies, A. C (2008). The Science and Practice of Welding: Twelfth edition, Cambridge University Press, England.
- [9] Folayan, C.O, Adebisi, O. and Tuleun, L.T. (1992). Production of E6020 Arc Welding Electrodes: A research proposal submitted to Raw Materials Research and Development Council.
- [10] George, V. V. (2008). Technical Notes on Welding: Buehler Journal, Vol. 4. No.3.
- [11] Hwaiyu, G. (2004). Manufacturing Engineering Handbook: McGraw Hill, Chapter 21 (21.3).
- [12] Ibadode, A.O.A. (2001). Introduction to Manufacturing Technology: Second Edition, published by Ambik Press, Benin City, pp 505-509.
- [13] Jain, R.K. (2008). Production Technology: Sixteenth Edition, Khanna Publishers. New Delhi, India, pp 427-465.
- [14] Kay, T., Gao, G. and Naing, T. S. (2010). Current Welding Technology on Myanmar: Journal of American science 6(1), pg 99-204.
- [15] Kenyon, W. (1979). Basic Welding and Fabrication: 1st Edition, B.O.C Limited.
- [16] Khan, R. H. (2015). MEE 614 Welding Engineering: Lecture Note.
- [17] Kou, S. (2003). Welding Metallurgy: Second Edition. A John Willey and Sons Inc, USA, pp 13-30.
- [18] Lincoln Electric. (2006). The Procedure Hand Book of Arc Welding: Revised Third Edition, Cleaveland Press US.
- [19] Nwigbo, S.C. and Atuanya, C.U. (2012). Formulation of a Metal Arc Welding Flux with a Potash Enriched Sodium Silicate Binder: Journal of Emerging Trends in Engineering and Applied Sciences. Vol. 3 (3) pp 497-501.
- [20] Parking, N. and Flood, C.R. (1974). Welding Craft Practice: Part1 Vol. 2 Electric arc welding and related studies, Pergamon Press, Oxford.
- [21] Parma, R.S. (2005). Welding Technology: Khanna Publishers New Delhi India.
- [22] Radhakrishnan, V.M. (2005). Welding Technology and Design: Second Edition, New Age Publishers, U.S.A.
- [23] Rossi, B.E (1954). Welding Engineering: McGraw-Hill. New York.
- [24] Serope, K and Steven, S. (2006). Manufacturing Engineering and Technology: Fifth Edition, Pearson Education, pp 951-964.
- [25] Schematic diagrams of different types of arc welding. Retrieved from <http://me-mechanicalengineering.com/wp-content/uploads/24-9-2016>
- [26] Somksy, P. (1986). Basic Welding: The Macmillan Press Limited, London.
- [27] Ugoamadi, C.C. (2010). Production of Arc Welding Electrodes with Local Raw Materials: Nigerian Journal of Technology. Vol. 29 No.1, pp 98-101.