Formulation of a Metal Arc Welding Flux with a Potash Enriched Sodium Silicate Binder

Nwigbo Solomon Chukwuka, Atuanya C.U

1Mechanical Engineering Department, Nnamdi Azikiwe University Awka
2Metallurgical and Materials Engineering, Nnamdi Azikiwe University Awka.

Corresponding Author: Nwigbo Solomon Chukwuka

Abstract
A new flux for metal arc welding has been developed. The basic components fall under the category of the rutile electrode. These include: titanium (iv) oxide, iron powder, Cellulose, sodium silicate binder and other additives. In this work, one of the major components was technically and economically substituted. The more popular but expensive potassium silicate binder was replaced by the more readily available sodium silicate. For the newly chosen binder to perform effectively, it was enriched with potassium carbonate (Potash). The flux formulation was not based on the old method of trial and error but some mathematical methods, especially the experimental design approach were applied. The Mc-Cleans and Anderson method was used in the preliminary design to generate the orthogonal array that guided the formulation. Four major components: Titanium dioxide, Iron powder, cellulose and Sodium silicate binder enriched with Potash were considered as the major contributing elements. An electrode made out of the flux was used by some professional welders and their comment on the quality of the electrode was impressive. Tests on the sample of the weldment showed that it could withstand a tensile strength up to 430 N/mm². The Brinell’s harness value gave a maximum of 608 N/mm². Also, the Nick Break revealed a good penetration, no slag inclusion. The micrograph presented an acceptable grain structure.

Keywords: flux, potash, experimental design, sodium silicate, binder

INTRODUCTION
The need to join metals has continued to be an indispensable production operation. Metal arc welding using manually operated equipment is the most widely used fusion welding process in developing economies. In this process, the metal electrode serves both for carrying the arc and as a filler rod which deposits molten metal into the joint. If a bare electrode is used, oxidation of the weld metal becomes imminent. This is not acceptable in metal joining operations and practice. Consequently, there is the need to protect the weld from the adverse effects of this condition. Electrode coating (flux) must be used during welding. The flux generates gases which protect the weld and shield it from harmful atmospheric oxygen, nitrogen, and any other contamination. Fluxes protect, prevent atmospheric oxidation and clean up the joint chemically and reduce impurities in the metal joining processes. Parma (2005). There are over one hundred (100) different raw materials used in the production of welding electrode fluxes. There is a need to combine these components together in the appropriate quantities to for an acceptable blend of flux.

In this work, flux formulation will be designed and optimized. This approach is quite new and different from the old procedure of formulation which was mainly by trial and error. By this optimization, a lot of experimental time and materials are saved. The question of the effects of the interactions of the different components on the flux formulation which seem to be bypassed by this process have been addressed by some authors. Adeyeye and Oyawale (2008). Considerably, the usual problem of searching for the appropriate method of formulation was solved by introducing the multi component analysis and mixture design. This reduces the number of experiments to be carried out without compromising the quality of work (result). Another major input in this work is the substitution of known constituents of the flux with some readily available one in our environment. To this end, the potassium silicate binder could now be replaced with sodium silicate blended with potash from palm bunch. The introduction of this material into the welding system can came through the flux was carefully controlled in quantity. This variation affects the chemical and physical properties of the weldment and contributes to the performance of the three basic functions of the flux; the electrical, physical and metallurgical functions. An interest to use of natural products came as a result of their availability in our
environments, Danbata (2006). It is reported that in Aguata and Orumba local government areas alone, about 1000 tonnes of palm bunch are produced a year as a by-product of palm oil processing. Nwigo (2009). This material is an agricultural waste and constitute problems to our environment thus the need to be properly managed.

As a result of the utilization of these agricultural wastes, there is actually no purchasing cost attached to the raw materials for production. This makes the unit cost of the electrode that will be eventually produced to be affordable.

Achebo and Ibhadode, Achebo and Ibhadode (2008), worked in the area of a New Flux for Aluminium Gas Welding. The major constituents of the new flux was based on NaCl – CaCl2 – CaF2 – Na3AIF6. This was developed for the gas welding of aluminium and its alloys. The flux (formula) was generated by the application of the Hadamard multivariate resolution IV to the chemical composition model. The model uses an 8 x 8 matrix and a full factorial analysis to generate several compositions within given ranges of the constituent flux elements. They carried out mechanical and field tests on the weldments made with the flux. The tensile strength, Izod impact strength and hardness on the materials gave 310MPa, 5.35J and 100BHN respectively. The weld deposition efficiency was 90.3%.

Very close to the idea of flux formulation by design, Adeyeye and Oyawale; Adeyeye and Oyawale (2008) recently proposed the use of mixture design for the design of flux formulation. They concluded that Factorial design is only good enough for some process design and should not be used for mixture analysis. Kanijalal et-al (2004, 2005, 2006) has done several works in experimental design of flux ingredients. He predicted a model for chemical composition in terms of flux ingredients for submerged arc weld arc with the help of statistical experiments for mixture (extreme vertices design).

Flux Mixture Design.

This work will approach the design with a known design methods to reduce the experimentation time. The Mclean and Anderson method for studying the properties of multi component systems in the presence of constraints on the components is one of the suitable methods of building a block of this design. MacLean and Anderson (1966)

This method is for studying multi component systems with two-sided constraints as follows:

\[ 0 \leq X_i \leq b_i \leq 1 ; \sum_{i=1}^{q} X_i = 1 \]  \hspace{1cm} (1)

where \( i = 1, 2, \ldots, q \) and \( X_i \) is the \( i \)-th component of the mixture (multi component).

The above restraints have to be formulated such that

\[ \sum_{i=1}^{q} a_i < 1 \quad \text{and} \quad \sum_{i=1}^{q} b_i > 1 \]

i.e. to exclude degenerate cases;

\[ \sum_{i=1}^{q} a_i \geq 1 \quad \text{and} \quad \sum_{i=1}^{q} b_i \leq 1 \]

If this condition is not met the restraints will become contradictory and there will not exist a sub-region in which the system can be studied. In addition, it is also assumed that the lower and upper limits do not coincide.

If \( \sum_{i=1}^{q} a_i = 1 \) and \( \sum_{i=1}^{q} b_i = 1 \) the sub-region is degenerate and the model cannot be formulated. Equations 1 define a polyhedron space, the shape of this polyhedron depends on the concrete values of the quantities \( a_i \) and \( b_i \).

In experimental design the points are distributed over the polyhedron subject to the conditions of equation 1.

PROBLEM STATEMENT

A welding flux is to be formulated. The major constraints of the flux must be mixed in an appropriate proportion to give optimal (strength) performance. The minimum percentage content of the ingredients are specified below:

1. Titanium oxide (\( X_1 \)) – \hspace{1cm} 40 \leq X_1 \leq 45
2. Iron powder (\( X_2 \)) – \hspace{1cm} 20 \leq X_2 \leq 25
3. Cellulose (\( X_3 \)) – \hspace{1cm} 20 \leq X_3 \leq 25
4. Binder with potash (\( X_4 \)) – \hspace{1cm} 9 \leq X_4 \leq 15

These ranges of the ratio of the components can now be written as:

\[ 0.40 \leq X_1 \leq 0.45 \]
\[ 0.20 \leq X_2 \leq 0.25 \]
\[ 0.20 \leq X_3 \leq 0.25 \]
\[ 0.09 \leq X_4 \leq 0.15 \]

As the next step it is good to check if equation 2 is satisfied. That is

\[ \sum_{i=1}^{4} a_i = 0.40 + 0.20 + 0.20 + 0.09 = 0.89 < 1 \]
\[ \sum_{i=1}^{4} b_i = 0.45 + 0.25 + 0.25 + 0.15 = 1.10 > 1 \]

It is now time to draw up an initial plan of all combinations of levels \( a_i \) and \( b_i \) of the factors; omitting one of the components.
If we represent $a_1$ as $-1$ and $b_1$ as $+1$, we can use the rules for formulating a system matrix. This compositions of welding fluxes could be done using this mathematical experimental design which uses matrix designs to achieve desired result. It generates several flux compositions of flux constituent elements ranges. The positive values of the matrix represents the high values while the negative values represents the lower values of the constrain.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Coded Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$X_{1c}$</td>
</tr>
<tr>
<td>2</td>
<td>$X_{2c}$</td>
</tr>
<tr>
<td>3</td>
<td>$X_{3c}$</td>
</tr>
<tr>
<td>4</td>
<td>$X_{4c}$</td>
</tr>
</tbody>
</table>

Table 1. Mclean – Anderson Design

With this guide, the strength performance of different blends of the flux were observed. Nwigbo (2009). The electrode that was made of this flux was a laboratory sample manually produced. Nwigbo and Atuanya (2005).

**TESTS AND RESULTS**

**Tensile Strength Tests**

The electrode so produced from the flux sample was used to weld some samples of materials and then series of mechanical test were carried out on them. Different samples were prepared to give certain results. Table 3 contain such results of tensile strength test on different diameters of ISI 1020 Mild steel pipe. A similar test carried out on the same mild steel but a plate made in Dog bone shape of throat width 12.7mm gave an average Tensile strength of 430N/mm² at an application of maximum force of 8.4 KN. The fracture occurred in the Heat affected zone.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Pipe Diameter (mm)</th>
<th>Yields Strength (n/mm²)</th>
<th>Tensile Test (n/mm²)</th>
<th>Elongation (%)</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>101mm</td>
<td>377</td>
<td>495</td>
<td>18</td>
<td>Fractured outside the weld</td>
</tr>
<tr>
<td>2</td>
<td>152mm</td>
<td>339</td>
<td>503</td>
<td>28</td>
<td>Fractured outside the weld</td>
</tr>
<tr>
<td>3</td>
<td>504.8m</td>
<td>438</td>
<td>585</td>
<td>24</td>
<td>Fractured outside the weld</td>
</tr>
</tbody>
</table>

**Nick break Test**

The Nick break test was carried out on the same sample of mild steel material used in tensile test to examine the quality of the joint as it cools down from the elevated temperature. The results were recorded in table 4.

<table>
<thead>
<tr>
<th>Pipe Diameter (mm)</th>
<th>Test Energy Absorbed (j)</th>
<th>Result Dimension of Exposed Surfaces after fracture (mm)</th>
<th>Area (cm²)</th>
<th>Fracture Stress (j/cm)</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.8mm</td>
<td>82.5</td>
<td>(19 x 3) mm</td>
<td>0.57</td>
<td>144.7</td>
<td>Good weld fusion</td>
</tr>
<tr>
<td>101.6mm</td>
<td>57</td>
<td>(19 x 4) mm</td>
<td>0.76</td>
<td>75j</td>
<td>Good weld fusion</td>
</tr>
<tr>
<td>152mm</td>
<td>84</td>
<td>(19 x 4) mm</td>
<td>0.76</td>
<td>110</td>
<td>Good weld fusion</td>
</tr>
</tbody>
</table>

**Flux Performance and Rating**

A comparative study was carried out on the produced flux with an existing one. Electrodes produced form each of the flux was used to weld a sample of mild steel plate and the results were recorded. Also the brinell hardness of the samples are also compared. The water absorption rate of the two electrodes was also recorded at an exposure to the atmosphere of a maximum relative humidity of 80% and an average...
The electrode efficiency amounted to 131%, this helped to classify the electrode as E43 00 S 130 3 3.

Table 5 comparative results of performance of the standard and produced flux

<table>
<thead>
<tr>
<th>Sample</th>
<th>Brinell Hardness Value</th>
<th>Tensile Strength Value</th>
<th>Water absorption Value (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diameter of indentation (mm)</td>
<td>Hardness Value</td>
<td>Min</td>
</tr>
<tr>
<td>Sample 1</td>
<td>2.018</td>
<td>147.62</td>
<td>438N/mm²</td>
</tr>
<tr>
<td>Sample 2</td>
<td>2.150</td>
<td>138.82</td>
<td>408N/mm²</td>
</tr>
</tbody>
</table>

*Sample1 is the standard electrode in the market and Sample 2 is the produced electrode.

**Chemical Composition of Weld Metal**

The sample was reduced to small particles to good aid the test, the sample was characterized using atomic absorption spectrometer. The results of the constituents are in Table 5

<table>
<thead>
<tr>
<th>C</th>
<th>Ni</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>Zn</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.015</td>
<td>1.423</td>
<td>1.312</td>
<td>0.0143</td>
<td>0.0021</td>
<td>0.075</td>
<td>0.0012</td>
</tr>
</tbody>
</table>

**Micrographs**

Optical microscope was used to provide basic information about the microstructure of the samples. The samples were cut i.e Parent metal, Heat Affected zone (HAZ) and Weldment (WELD). The cut samples were mechanically ground progressively on grades of SiC impregnated emery paper (80-600 grits) sizes using water as the coolant. The ground samples were polished using one-micron size alumina polishing powder suspended in distilled water. Final polishing was achieved using 0.5-micron alumina polishing powder suspended in distilled water. Following the polishing operation, etching of the polished sample was done using nitric acid reagent. The microstructure obtained was photographically recorded using an optical microscope with built-in camera and the print out was shown in fig 1.

**DISCUSSION**

Generally, the microstructure of the weld deposited by the potash enriched coating shown in fig 1(C) reveals a duplex structure of Acicular Ferrite and cementite. The Heat affected zone in fig 1(b) also showed an almost homogenously distribution of ferrite though with a slight cluster nearer the weld. This is quite close the structure of the parent metal in fig 1(c).

The nick break in table 4 shows that there is good root penetration. There was relatively good fusion between the weld and parent metals. The toe of the
weld was free from under cut. There was no slag inclusion or porosity in the specimen. From the observations on the broken sections of the welded portion it could be concluded that the weld had a good fusion with the parent material. Also observed was homogeneity in the weld bead. It showed very little or no slag inclusion. There was no visible observation of gas pockets.

All the tensile test results showed that the test materials all failed in the Heat affected zone. The result of the analysis carried out on the weld metal as in figure 6, found the sulphur content to be very low.

CONCLUSION
Inclusion of potash in the formulation of a welding flux has proved unharmful. The sodium silicate binder gained some properties as it compared favourably with the potassium silicate binder. The micro properties of the metal upon which the sample was tested on did not show any unusual behavior. The chemical analysis of the weld prepared by the use of the flux was another gain as the poisonous gases was not introduced into the system. Of significance was the very low value of sulphur.

REFERENCES


