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Original Research Article

Comparative Evaluation of Some Selected Flux Coated Low Hydrogen Electrodes for Arc Welding of HY-100 Steel

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ABSTRACT

There exist little or no established scientific facts or document on the reason a particular type of low hydrogen electrode (LHE) is given preference to others in usage. Thus, this study presents a comparative analysis of three different brands of flux coated commercial low hydrogen electrodes (LHEs) available in Nigerian market. Shielded metal arc welding (SMAW) of HY-100 steel was carried out using Electrode-A, Electrode-B and Electrode-C respectively. Inspection, chemical analysis, microstructural examination, hardness and tensile strength tests of the resultant weldments of each electrode type were analysed and compared. The results obtained showed the percentage compositions of the weldments constituents, micrographs and values of tensile strength as well as the hardness tests. The results revealed that all the three brands of electrodes investigated gave close conformity with the standard. However, Electrode-B from Sweden exhibited the closest conformity with the expected properties of an ideal LHE weldment, followed by Electrode-A and Electrode-C both from India. This investigation is expected to spur further significant research(es) in quality assurance of welding consumables. Furthermore, it will assist Standard Organization of Nigeria (SON) and other stakeholders in arc welding industry in an effort to evaluate engineering materials available in Nigerian market.

1. INTRODUCTION

Low hydrogen electrode (LHE) is also known as basic electrode, lime-ferrite, or lime-fluorspar electrodes. The flux coating of LHE contains high proportion of limestone ($CaCO_3$) and fluorspar (CaF_2) clays, asbestos and other minerals with combined water are kept to a minimum to ensure very low hydrogen contents in weld deposit (Radhakrishnan, 2005). LHEs are known for good weldability, deep penetration, all position welding. This electrode type is suitable for steel construction, boiler/container fabrication, vehicle construction, ship building and machine construction has 100% metal recovery (Radhakrishnan, 2005).

LHEs are primarily classified in terms of their 'Hydrogen Ratings' which is the amount of diffusible hydrogen (Hd) present in ml. per 100 gm of deposited weld metal. Broadly, there are three classes, namely classes H1, H2 and H3 respectively. Class 1 contained 10- 15 Hd, class 2 contains 5-10 Hd and class 3 contains up to 5 Hd (Padhy *et al*., 2012). The American welding society (AWS) reported that all LHEs as-manufactured or after conditioning, are expected to meet a maximum covering moisture limit of 0.6 percent or less (AWS, 2004). The flux is bound together with a binder of organic silicate (silica) which makes no substantial contribution to the moisture level of the covering, but it makes the covering resistance to hygroscopic (moisture pickup). Meanwhile, it is recommended to bake LHEs before welding (Esab Group, 2000). Thus, this binder minimizes the amount of hydrogen from any moisture in the covering which may be introduced into the weld during welding. Additionally, the flux covering contains a source of barium or caesium in an amount effective to reduce the slag/metal reaction temperature during welding as asserted by Padhy *et al.* (2012) as well as Padhy and Komizo, (2013). Due to this, the amount of hydrogen actually introduced into weld metal from the electrode covering and binder is minimized. This reduction in temperature has been found to have additional advantage of reducing the amount of oxygen in the weld metal, which provides increased impact properties for weld metal (Padhy *et al.*, 2012; Padhy and Komizo, 2013).

The flux coated steel electrodes are the most popular type of filler metal used in arc welding. It is made of material that is compatible with the base material being welded. (Hong *et al.,* 1996). The electrode is coated in a metal oxide mixture called flux, which gives off gases as it decomposes to prevent weld contamination, introduces deoxidizers to purify the weld, causes weld-protecting slag to form, improves the arc stability and provides alloying elements to improve the weld quality (Adeyeye and Oyawale, 2008; Ugoamadi, 2010; and Abdulsalam *et al*., 2020).

Therefore, this research investigates the use of flux coated LHEs for arc welding of HY-100 steel. The investigation covers three different brands of LHEs available in Nigerian market, in order to compare its performance in arc welding of HY-100 steel. To our knowledge, there is no established scientific facts or document on selection of arc welding electrode; particularly the commonly used LHEs in Nigeria. In addition, the development of local content/ standard(s) is needed for welding consumables. Thus, the output of this investigation is expected to assist standard organization of Nigeria (SON) and other stakeholders in arc welding industry.

2. MATERIALS AND METHODS

2.1. Experimental Materials

The materials used in this research include: three different types of low hydrogen electrodes (E7018). Samples of the three different types of low hydrogen electrodes, all of the same diameter size 5 mm are shown in Table 1.

Table 1: Designation of the selected flux coated LHEs used

S/N	Electrode designation	Source
1	Electrode-A	India
2	Electrode-B	Sweden
3	Electrode-C	India

Table 1 show designation and countries were the LHEs used are imported from and readily available in Nigerian market. In addition, other materials used for the experiments include 12 mm thick HY-100 steel plate, nital solution and resin powder. The equipment used in this experiment are: Standard angle grinder, polishing machine, Origo 400 amps' arc welding machine, optical microscope, scan electron microscope (SEM), universal testing machine and hardness testing machine.

2.2. Preparation and Welding of HY-100 Steel

All the weld metals used in this research were given V edge preparation with 60o included angle, 1.5 mm root face and 2 mm root gap; which is in accordance with international institute of welding (IIW) standard, ISO 9692-1 (2003). The specimens were cleaned off rust and dirt to avoid contamination. Three pairs of HY-100 steel specimens for each brand of electrode were butt welded using Origo 400 amps AC/DC arc welding machine which were allowed to cool in air. The weldment carried out by the selected flux coated LHEs were designated after the electrodes used as Electrode-A (Weldment-A), Electrode-B (Weldment-B), and Electrode-C (Weldment-C) respectively.

2.3. Welding Inspection

During and after welding inspections were conducted to examine the arc stability, weld deposition, weld shape and slag removal, porosity and undercut. The welds were inspected for arc stability, metal transfer and weld metal flow. Post welding inspection was conducted to examine the weld quality.

2.4. Chemical Analysis, Microstructural and Hardness Tests of the Weldments

The weldment surfaces were ground and polished with the use of grinding machine and polishing machine to smooth mirror to enhance microstructure examination, hardness test and chemical analysis which were carried out using optical microscope, Brinnel hardness tester and SEM respectively. These analyses were performed as proposed by the AWS A5.1 specification (AWS, 2004). Metallographic of specimens were conducted using optical microscope. The magnification range of the microscope is between 50 and 1000, but higher magnifications are possible with specialized oil immersion lenses. Grinding of the specimen was carried out using emery papers progressively to obtain finer grade. Polishing was carried out carefully to produce mirror like and ridges free surface. The samples were etched with 2% nital solution and then dried. Thereafter, the prepared samples were observed using the metallurgical trinocular microscope (Model MM039BOOM) at the magnification of 400X. Prepared samples for the hardness test were mounted on the machine. The steel ball (indenter) was pressed on the surfaces of the specimen for about 30 seconds to provide impressions. The impressions were not distorted and not too deep so as to avoid too much of plastic deformation which might lead to errors of the hardness values. The diameters of the impression were measured using a low magnification microscope thrice and the average value calculated. The Brinell hardness value for each of the specimens was then calculated using Equation (1), expressed as follows.

$$\mathrm{BHN} = \frac{2p}{\pi D(D-\sqrt{D^2-d^2})} \tag{1}$$

Where *P* = applied force (N), *D* = diameter of indenter (mm) and *d* = diameter of indentation (mm).

2.5. Tensile Test

Specimens were prepared for tensile test. The dog bone rectangular design was adopted as suggested by Parmar, (2010). Three samples were extracted from each coupon for the test. The specimens were slightly grinded and inserted into the chucks of the lower and upper crossheads of the universal testing machine (UTM) and the test was conducted.

3. RESULTS AND DISCUSSION

3.1. Inspection Results

The three brands of electrodes exhibited stable arc, with a spray type metal transfer, and good weld metal flow, except for the Electrode-C which was observed to freeze faster. This could be more suitable for downhill welding (stoving). It was discovered that Electrode-B gave the best in terms of weld shapes, and easy slag removal, followed by Electrode-A. Electrode-C gave reasonable weld shape and fairly easy slag removal. Interestingly, the three electrodes exhibited defect free surfaces which could be as result of the introduction of alloying elements such as caesium, and barium as asserted by (Padhy *et al.*, 2012). The summary of post weld inspection is as shown in Table 2. All the samples were found to be defect free as porosity and undercut were not observed.

Table 2: Summary of post-weld inspection

S/N	Weldment	Weld shape	Slag removal
1	Weldment-A	Very Good	Very Good
2	Weldment-B	Very Good	Good
3	Weldment-C	Good	Fair

3.2. Chemical Analysis of the HY-100 Weldments

The results of the chemical analysis and extract of the alloying elements found in the weldments are shown in Tables 3 and 4.

Table 3: Chemical analysis results of weldments of the three electrode brands

Elemental composition (%)	Brands of weldment		
	Weldment-A	Weldment-B	Weldment-C
Ba	0.242	0.263	0.203
Si	0.458	0.610	0.310
Cl	0.460	0.570	0.360
Mn	0.920	0.970	0.900
Co	0.950	0.990	0.930
C	0.334	0.345	0.304
P	0.047	0.020	0.029
S	0.026	0.019	0.020
Cr	0.150	0.778	0.284
Ni	0.048	0.082	0.046
Mo	0.002	0.020	0.002
Ti	0.028	0.038	0.027
Nb	0.004	0.007	0.008
V	0.019	0.020	0.012
W	0.010	0.010	0.010
Pd	0.007	0.006	0.003
B	0.001	0.001	0.004
Ce	0.058	0.063	0.040
Zn	0.002	0.002	0.002
As	0.001	0.008	0.009
Ca	0.001	0.001	0.001
Zr	0.003	0.002	0.002
Bi	0.002	0.002	0.002
Fe	96.227	95.173	96.492

Table 4: Some Alloying elements in the weldments

Element (%)	Weldment-A	Weldment-B	Weldment-C	Proportion order
Ti	0.028	0.038	0.027	B, A, C
Ba	0.242	0.263	0.203	B, A, C
Ce	0.058	0.063	0.040	B, A, C
C	0.334	0.345	0.304	B, A, C
Cr	0.150	0.778	0.284	B, C, A
Mn	0.920	0.970	0.900	B, A, C
Si	0.458	0.610	0.310	B, A, C
Total of alloying elements (%)	2.162	3.067	2.068	B, A, C

The proportion of the carbon content and total alloying element of the weldments shown in Table 4 were weldment-A (0.334%, 2.34%), weldment-B (0.345%, 3.07%) and weldment-C (0.304%, 2.06%). As asserted by Radhakrishnan (2005), the carbon content of mild steel is between 0.08% and 0.3%. Interestingly, the carbon contents of the three electrodes fell within the range of carbon content of medium carbon steel. This indicates that their usage is expected to cover mild steel and medium carbon steel applications, due to the fact that in practice, medium carbon electrode is generally used in welding ferrous metals except in rear cases of materials like cast iron and stainless steel, and most of the steels for fabrication and construction are either mild or medium carbon steels. In theory, increase in carbon content of steel increases the strength and hardness numerical values as reported by Parmar (2010). Higgins (1993) also asserted that alloying elements generally increase hardenability of steel as well as the strength.

3.3. Hardness and Tensile Test Results

The results of the hardness and tensile test are shown in Tables 5 and 6. The hardness values of the weldments shown in Table 5 are weldment-A (240.8 BHN), weldment-B (244.4 BHN) and weldment-C (242.6 BHN). Similarly, the percentage elongation of the weldments presented in Table 6 shows that weldment-A (13.18%), weldment-B (14.10%) and weldment-C (12.09%). The results of the Tables 5 and 6 agrees with the assertions reported by Parmar (2010) and Higgins (1993) that the effects carbon content and alloying elements is expected to increase the hardness and strength of the weldment accordingly. Therefore, Electrode-B will be selected as the best among the three different electrodes. Then, followed by Electrode-A and then Electrode-C as the least among the three electrodes investigated.

Table 5: Hardness values

Weldment sample	Hardness value (BHN)
Weldment-A	240.8
Weldment-B	244.4
Weldment-C	242.6

Table 6: Tensile test result

Weldment Sample	UTS (N/mm^2)	Yield/Strength (N/mm^2)	Elongation (%)
Weldment-A	559.38	462.01	13.18
Weldment-B	565.24	465.86	14.10
Weldment-C	548.66	461.38	12.09

3.4. Microstructural Examination of the Weldments

The results of the microstructural examination of the mild steel wire electrode and weldments are shown in Plates 1-4. Plate 1 shows the microstructure of mild steel rod which is the control. The formation of acicular ferrite in the weldments could be due to the presence of titanium dioxide (TiO_2) in the coatings. According to Babu *et al.* (1999), this type of oxide favoured the nucleation of acicular ferrite at the interface between austenite matrix and inclusion. A method for promoting the formation of acicular ferrite consists of the additions of oxides into the flux, such as boron oxide, vanadium oxide and titanium oxide (Surian *et al.,* 2010). The oxides in the flux may have contributed to different metallic element dissolution and oxygen into the weld. Plate 2 is the microstructure of Weldment-A. It was observed that the structure has more ferrites than pearlite, assumed to be in the ratio of 55% - 45% as suggested by Ashby and Jones (1998). The presence of polygonal ferrite was also evident, and this could be attributed to the high welding heat input as asserted by Kuldeep, (2009). Plate 3 is the microstructure of Weldment-B, and it was observed to have more acicular ferrite than polygon ferrite. The acicular ferrite could be due to higher percentage of titanium oxide compared to Weldment-A and Weldment-C respectively, while the polygon ferrite could be due to the welding heat as earlier mentioned (Kumar, 2010). It has also been well reported by AWS (2006) that the microstructure of a weld bead deposited by electrode coated basic type E7018 is mainly composed: acicular ferrite (AF), grain boundary ferrite (GBF), and polygonal ferrite (PF). Plate 4 is the microstructure of Weldment-C, and it is clear that it has more polygon ferrite than acicular ferrite and some grain boundary ferrite which could be due to the high welding heat. Also, slight reduction in grains boundaries were observed in the Weldment-A and Weldment-C microstructures. This could be the reason why their strength and hardness values were slightly lower than that of Weldment-B, as asserted by Baham (2010) that reduction in grains boundary as locks for movement of dislocations increases possibility and amount of dislocations movements as line defect in structures which causes reduction in strength and hardness.

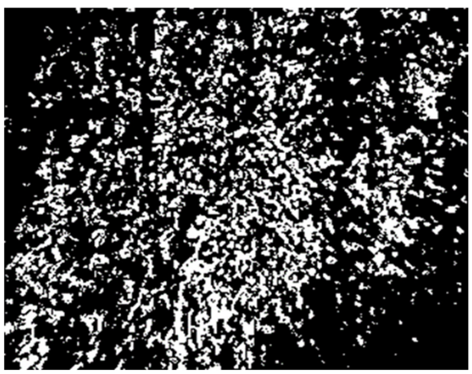

Plate 1: Microstructure of mild steel wire electrode (X 400)

Plate 2: Microstructure of weldment-A (X 400)

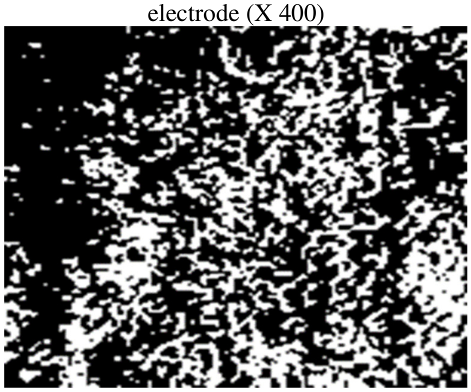

Plate 3: Microstructure of Weldment-B (X 400)

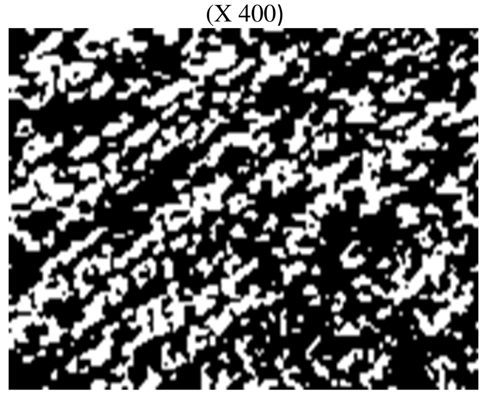

Plate 4: Microstructure of Weldment-C (X 400)

4. CONCLUSION

In conclusion, low hydrogen electrode types in the Nigerian market have been evaluated in this study with reference to elemental composition analysis, hardness test, tensile strength test and microstructure of the weldments. Based on the findings, weldment of electrode-B exhibited the chemical and mechanical properties in line with standard. This study therefore asserted that Electrode-B manufactured from Sweden is the best low hydrogen electrode in Nigerian market followed by Electrode-A and lastly Electrode-C all manufactured in India. This research is expected to spur further significant research in the area of quality assurance of engineering materials and at the same time assist standard organization of Nigeria in her effort to evaluating appropriately engineering materials in Nigerian market for different applications.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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