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Appropriate Technological Procedures for Fusion Welding of Low Alloy Carbon Steel

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A B S T R A C T

Most welding products from unskilled welders in Nigeria have been observed to exhibit low values of mechanical properties, as well as high corrosion rates and incessant failure of the welded joints in service. In this research, unskilled welders in Akure, one of the major capital cities in Nigeria were used as case studies in which low carbon steel plate was made available for the unskilled welders to weld. Three different welding shops within the city were selected while welding of the same material was carried out by skilled welder at the workshop of Metallurgical and Materials Engineering (MME) Department of the Federal University of Technology, Akure; The latter served as a control. Tensile and hardness tests were carried out on the welded samples from where it was observed that the samples welded in the Metallurgical and Materials Engineering Department workshop had better mechanical properties than those welded by the unskilled welders. The best welded samples from among the unskilled welders were used to test for corrosion rates in comparison with the welded control sample. From the result, it was also observed that the welded control sample possessed higher resistance to corrosion in the selected corrosive media than the welded samples from the unskilled welders.

1. Introduction

Welding as a metal joining process has been in use as far back as 1400BC and has been the commonest and most distinct of all known joining methods. As a result of this, the quest for the assessment and improvement on the mechanical properties of welded products is as old as welding itself. Welding is therefore seen as a metal joining process in which coalescence or joining is effected between two similar or dissimilar metals by the application of heat, pressure or combination of both with or without a filler metal (Microsoft Encarta, 2008).

Nigeria like most third world nations is pursuing technological and industrial advancement. Adelabu (2001) in his work titled “Health research in developing countries: challenges and possible solutions for its improvement”, noted that for any meaningful technological advancement, the country must entrench science education in her educational system. Dhamangaonkar (2007) enjoined researchers of the third world countries to always try as much as possible to look inwards rather than outwards for solutions to some of these challenges. For us to achieve this, research and development must be encouraged in Nigeria from the grassroots. A quality or high integrity weld has the same mechanical properties as the parent metal. By mechanical properties, we mean properties such as strength, ductility, hardness, fatigue and creep which determine the material's performance under service condition. The specificity of these properties coupled with the chemical composition of the metal is highly dependent on the welding or fabrication technique(s) adopted by the welder. A little deviation from the specified design lead to failure which is often catastrophic when not detected very early. This is why the oil and gas, marine, aviation, construction and manufacturing industries are keenly interested on the drive for quality welds.

In our various homes, we see most of the common welding products such as iron chairs and gates, kerosene, petrol, diesel and water tanks fail through sudden breakage, bending or rust even at the least expected time. Welders and clients in developed countries have long appreciated the need for modification and diversification of quality welds as a function of welds with improved mechanical properties. Hence there has been a continuous evaluation of their welding products as a way of modifying their welding practices in order to meet up with design specification. But it is paradoxical that such modifications that can improve on the mechanical properties of welding products in Nigeria are still very low. Welders clients (especially those that are not in the field) accept whatever is been given to them by the welders and the welders in their own capacity give out what is within their technical disposal. Therefore, the effect of the assessment and improvement on the mechanical properties of welding products can never be over emphasized. Thus, using electric arc welding process, low alloy steel plate and using Akure as a case study are the scope of the work. This research was carried out to

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Table1: Elemental Composition of the Low Carbon Steel Plate in Wt%

Elements	Fe	C	Si	S	P	Mn	Ni	Cr	Mo	Cu	Zn	Al
% Composition	99.55	0.0489	0.008	0.0285	0.0132	0.262	0.016	0.0004	0.0035	0.004	0.0269	0.0373

ascertain the mechanical properties of unskilled/local welded products and improve on it so that such improvement could be standardized.

2. Materials and Methods

22.1 Materials

The low alloy carbon steel plate (800mm x 800mm x 3mm) used for this project was obtained from Universal Steels Nigeria Limited, Ogba-Ikeja, Lagos State. Its chemical composition is as shown in Table1. Other materials used include emery papers of grades 60 and 80µm, low carbon steel electrode with electrode diameter of 2.5mm, filler metal, brush and ash etchant (Nital).

2.2 Equipment

Electric arc welding machine (ESAB MEDIUM), Rockwell hardness testing machine (with square-based diamond indenter) hardness testing machine, Grinding machine, Mounting press, Digital metallurgical microscope, Computer-aided metallurgical spectrometer, Table vice, Polishing machine, Monsanto Tensiometer and hand hack-saw, were the basic facilities used.

2.3 Methods

The 800mm x 800mm x 3mm low carbon steel plate was sectioned into eight pieces measuring 100mm x 800mm x 3mm of which two pieces were welded together by the four different welding groups to give four samples. Samples were made available for the unskilled welders to weld while the control sample known as the improved weld sample was welded by the skilled welders in MME workshop . Samples A, B and C represents the sample from the first, second and third unskilled welders weld respectively while sample D represent the improved welded sample from the Metallurgical and Materials Engineering Department, Federal University of Technology, Akure (MME, FUTA) welding workshop. The welded samples were machined into tensile, hardness and micro structural examination tests samples. Sample with the best mechanical properties from unskilled weld, and the improved weld sample were then tested for corrosion resistance.

2.3.1 Unskilled Welding Approach

This was carried out in three different welding shops by three different welders in Akure. The welding was carried out by setting the butt edges together with a little root gap between them. Though the work pieces were not clamped down, it was held together such that it was firm and the tong was used to "tack" the sample pieces together before the full welding was carried out. The welders were allowed to weld in their usual way using electric arc welding process.

2.3.2 Improved Welding Approach

Surface cleaning was first carried out on the samples by grinding the edges to be welded. The butt edges were set together with a little root gap left between them after which the plates were clamped down on a sheet with the help of a G-clamp to facilitate stability, and proper handling of the samples to prevent contamination. The steel was welded by first using the tong to "tack" the uppermost part of the halves of each of the samples together before the final welding was carefully carried out. Proper handling was ensured during solidification.

2.4 Samples Preparation

The samples for tensile test were prepared using the lathe machine while hand hack-saw was used for cutting the samples into hardness, micro-structural and corrosion specimens.

3. Mechanical and Corrosion Tests of Specimens

3.1 Tensile Test

This test was carried out using the Monsanto Tensiometer which has a graph plotter that automatically plots the graph of load against extension as the load increases. Before the specimen was inserted into the machine, the appropriate load range and the pointer was set to zero. Also, the gauge length of the specimen was first measured before they were inserted one after the other within the tension space of the machine with a small load being applied to just grip the specimen. Maintaining the load pointer at zero, the specimen was subjected to slow gradual loading thereby plotting points on the graph sheet with the help of the graph plotter. This process continued until the specimen fractured. This was prepared in accordance with Oyetunji (2007). Figure 1 show a typical tensile test specimen

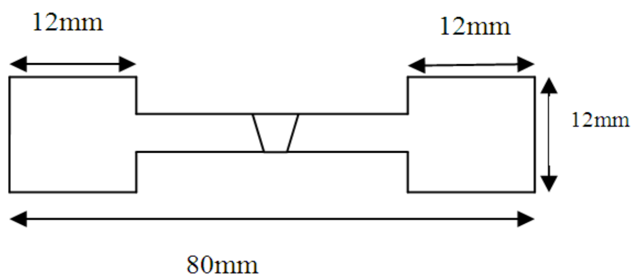

Figure 1: Tensile Specimen

3.2 Hardness Test

Rockwell hardness testing machine and their accessories were used for this test. The surfaces of the specimens were smoothened by filling them before they are placed in the holding fixture of the hardness testing machine and indentation was made in line with Oyinlola (1997). The hardness values were measured and

Table 2: Results of The Welding Variables and The Mechanical Properties Obtained.

Sample	Current (A)	Voltage (V)	Low Carbon Steel Electrode Gauge	Mean time (s)	Speed (mm/s)	Heat input (KJ)	Power input (kW)	Mean Hardness (BHN)	Mean UTS (N/mm^2)
A	150	200	12	47.50	2.10	5.40	30.00	15.70	48.66
B	150	220	12	53.50	1.87	5.94	33.00	4.20	34.70
C	75	180	12	52.50	1.90	2.43	13.50	4.00	21.38
D	100	195	12	49.50	2.00	3.50	19.50	17.90	64.00

read with the help of a computer aided machine.

3.3 Corrosion Test

Two samples each from the unskilled welders with the best mechanical properties and the control weld were used. One sample from each set was subjected to kerosene medium and the others to diesel for thirty days since the tanks were mostly used to transport and store kerosene and diesel. Readings were taken at three days interval and the corrosion rate was determined.

$$\text{Corrosion rate} = \text{Weight Loss(g)} / DAT \qquad 1$$

Where,

D = Density of steel

T = Exposure time in year

A = Surface Area

3.4 Microstructural Examination

A sample each from the unskilled welded part with the best mechanical properties and the improved welded part from MME FUTA workshop were used. The specimens were further prepared by mounting, grinding, polishing and etching before they were viewed using the digital metallurgical microscope. They were prepared in accordance with Oyetunji and Alaneme (2005).

4. Results and Discussion

The data on the welding variables and the results of the mechanical properties of the samples are shown in Table 2. Figures 2-6 are the plots of the mechanical properties and welding variables. The microstructures of the welded samples are shown in plates 1-2 and the corrosion rates are shown in Figures 7-8.

4.1 Effects of the Welding Variables on the Mechanical Properties of the Welded Samples.

Figure 2 shows the variation of the ultimate tensile strength with weld sample. From this figure, it was observed that, sample D (improved welded sample) had the highest ultimate tensile strength (UTS) of 64 N/mm2 while sample A from one of the unskilled welded samples recorded the next UTS value of 48.66 N/mm2. This variation in UTS values could be attributed to the better choice of some of the welding variables adopted by the skilled welders in MME workshop compared to the unskilled welders in town.

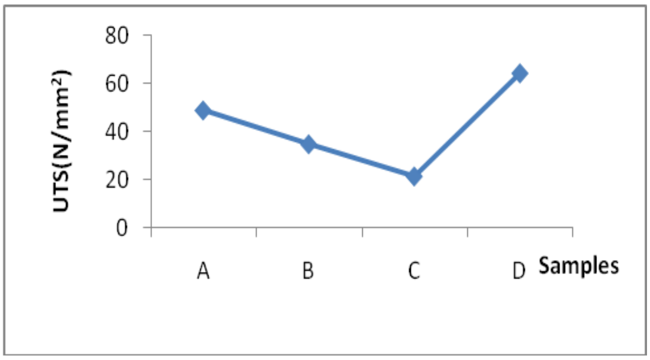

Figure 2. Variation of Ultimate Tensile Strength (UTS) with various Welded Samples.

The variation of hardness with welded samples is shown in Figure 3. It was observed in Figure 3 that sample D had the highest hardness value of 17.9 HBN while the unskilled welded sample A was next with a value of 15.7 HBN. This variation in hardness values was also attributed to the better choice of the welding variables by the skilled welders compared to the unskilled welders which were in accordance with Khurmi (2006), that improvement in the mechanical properties of welded structures is a function of the welding variables.

4.2 Effects of Power Input on the Welding Process

For every welding condition, there is a limiting power input at which the welding arc becomes stable, unstable or spontaneous, (Polukin, 1977). In arc welding, the length of the arc is directly related to the voltage, and the amount of heat input is related to the current, (ASM Inter., 2003). Figure 4 shows the power inputs from the unskilled welders. From the result, it was observed that, the value obtained from the welded sample from Metallurgical and Materials Engineering Department was within the values obtained from the unskilled welders. The values range from 13.5 kW to 33 kW. By relating the values to the mechanical properties in Figures 2 and 3, it

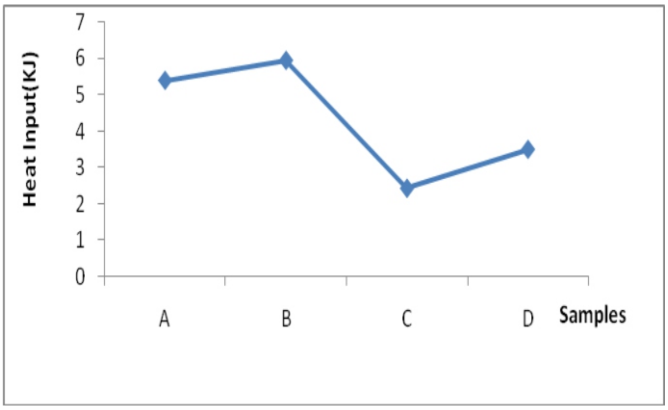

Figure 5: Heat Input for the Welded Samples.

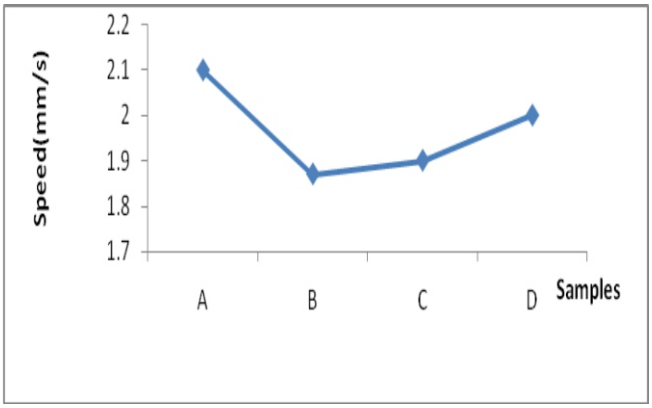

Figure 6: Welding Speed for the Welded Samples

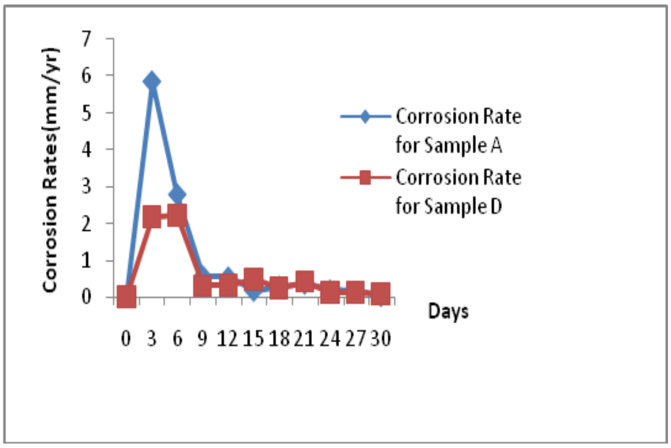

Figure 7: Corrosion Rate of Welded Samples Immersed in Kerosene Medium

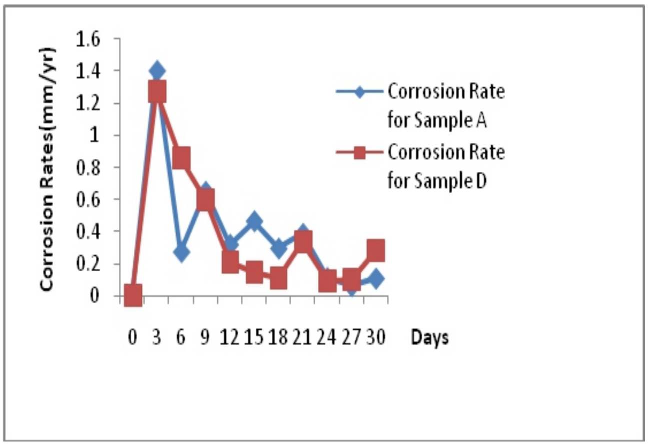

Figure 8: Corrosion Rate of Welded Samples Immersed in Diesel Medium

is implied that the power input of 13.5 kW is too low, while 33 kW is too high. Consequently, 19.5 kW and 30 kW are the two values that fall within the domain of stable arc.

4.3 Effects of Heat Input and Welding Speed on the Welding Process

The variations of heat input and weld speed on the four welding cases are shown in Figures 5 and 6 respectively. The time taken to weld the same length of the samples was used in determining the welding speed of the steel. It was observed that the welding speed varied inversely as the time taken to weld the samples.

During welding, the rate of penetration, melting and deposition as well as solidification of the welds all depends on the heat input and the welding speed. The combination of these two parameters contributed to the best mechanical properties obtained in sample D which was carried out at a welding speed of 2 mm/s for a heat input of 3.5 KJ followed by that of sample A which was welded at a welding speed of 2.1 mm/s for a heat input of 5.4 KJ. It was observed that sample A followed by sample D had the highest welding speed. Sample B that had the highest heat input of 5.94 KJ was welded at the slowest rate of 1.89 mm/s followed by sample C with the least heat input of 2.43 KJ and welding speed of 1.90 mm/s. These combinations show that, *4* sample B is likely to have burnt due to its high heat input while sample C is likely not to have good penetration due to its low heat input.

4.4 Corrosion Properties

Figures 7 and 8 show the corrosion rates of the welded samples in kerosene and diesel media respectively. These media are some of the environments where these products are being utilized. It was observed that in kerosene medium, sample D was more resistant to corrosion with a value of 2.1818 mm/yr compared to the welded sample A with a value of 5.8571 mm/yr. But in diesel medium, both welds corroded almost at the same rate. However, sample D still corroded at a lesser rate compared to sample A with values 1.2727 mm/yr and 1.4 mm/yr corrosion rate respectively. Both kerosene and diesel are mild corrosive media. The observed corrosion rates could be attributed to the effect of the high temperature generated during the welding process. The cycle of heating and cooling that occurs during the welding process affects the microstructure and surface composition of welds and adjacent base metal. Micro segregation, precipitation of secondary phases, contamination of the solidifying weld pool and formation of unmixed zones are some of the factors that have been identified by Davis (2006) to affect the corrosion of weldments and base metals. These factors could be responsible for the higher corrosion rates observed in the samples welded by the unskilled welders.

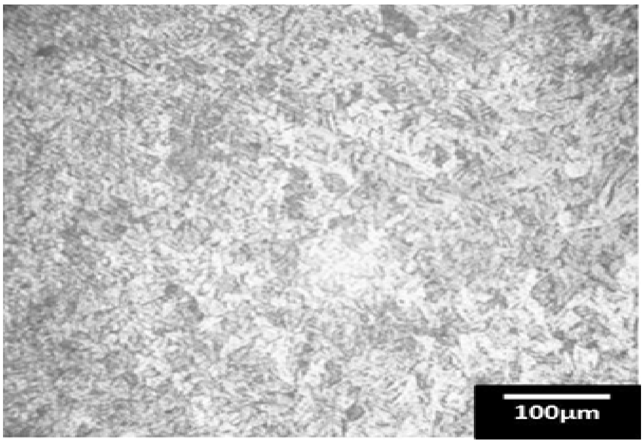

Plate 1: Microstructure of Welded Sample A (100X). Etched in 2%Nital

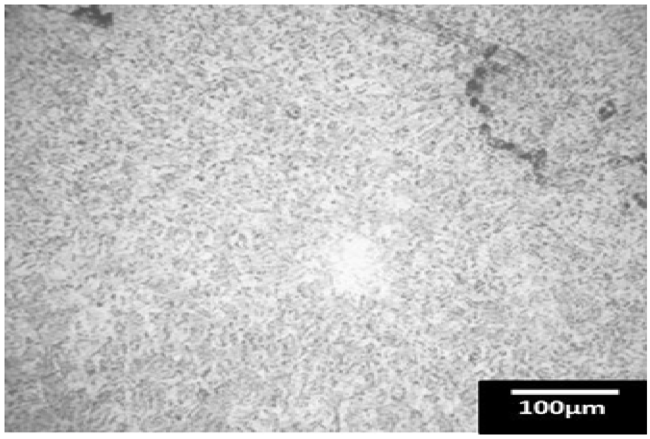

Plate 2: Microstructure of Welded Sample D (100X). Etched in 2%Nital

4.5 Microstructures

From plate 1, it was observed that the unskilled welded sample A consist of pearlite distributed in the ferrite matrix in a non uniform pattern due to arc blows. This could be some of the reasons why its mechanical properties were not as good as that of the control sample D Plate 2 showed the welded sample from Metallurgical and Materials Engineering Department, Federal University of Technology, Akure welding workshop. The structure shows a uniform distribution of pearlite in the ferrite matrix . This is responsible for the good mechanical properties obtained from the results.

As part of our observations during the welding processes adopted by the local/ unskilled welders, special and technical attention should be given to surface cleaning, material handling, welding speed, power and heat input. These parameters have not been given any special attention by these welders and these have contributed to the weak mechanical properties observed in comparison with the welded sample from Metallurgical and Materials Engineering Department, Federal University of Technology, Akure.

5.0 Conclusion

From the results, it was concluded that;

i. The improved and controlled welding procedure adopted at the Metallurgical and Materials Engineering Department of the Federal University of Technology, Akure welding workshop gave better mechanical properties than the method adopted by unskilled welders.

ii. Power input of 13.5kW was too low, while 33kW was too high. Consequently, 19.5 kW and 30kW were the two values that fall within the domain of stable arc.

iii. The combination of heat input and the welding speed contributed to the best mechanical properties obtained in sample D which was carried out at a welding speed of 2mm/s for a heat input of 3.5KJ

iv. The welded sheet samples corroded faster in kerosene medium than in diesel medium, this may be attributed to the relatively more corrosive nature of kerosene when compared with diesel.

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