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INFLUENCE OF NANO-FLUX POWDER ON THE HARDNESS AND TENSILE STRENGTH OF STEEL WELDED JOINTS

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ABSTRACT

The use of flux during welding is important because it prevents the formation of oxides thereby giving a better profile to the weld. In this study, nano- flux powder (CaO) developed from agrowastes (eggshell) and commercial flux powder were used during Metal Inert Gas (MIG) Welding. Materials prepared and welded were galvanized, stainless and mild steel plates and rods of 50 x 50 x 10 mm. The SEM and EDX of the fluxes were carried out while the welded joints of each samples were subjected to tensile, hardness and surface morphology tests using SEM. The high volume of 57.10% Iron and 29.45% Calcium respectively confirmed that the fluxes were Iron and Calcium Oxides suitable as fluxes for the welding. The mechanical properties of the joints proved better in Nano flux than the commercial and when no flux applied.

Keywords: nanoparticles, nano-flux, powder, welding; MIG, morphology, characterization.

1. INTRODUCTION

The process of joining metals with heat or pressure (or both) is referred to as welding. This technology has found high relevance in building ships, roads, pipelines, aircrafts, automobiles and in many other sectors of the industry [1]. The need for a constant upgrade in this technology resulted in the development of various types of welding include Gas Tungsten Arc Welding, Shielded Metal Arc Welding, Flux Core Arc Welding, Submerged Arc Welding, Plasma Arc Welding etc [2].

Metal Inert Gas (MIG) or GMAW is a welding procedure that has been existing industrially since the 1950s, with the fundamental principle of the GMAW procedure remaining the same. This principle is to use an arc electrically created by the disposable metal electrode to melt the electrode and weld two pieces of metal together, protected by an inert gas (mostly Argon) from atmospheric contamination. MIG which can equally be called gas metal arc welding (GMAW) has properties like simplicity, versatility, speed and adaptation which makes it one of the most widely used welding methods in the industry [3]. This process has attained widespread use in industry, and the weld joint quality is determined by the parameters of its input. The GMAW input parameters being the most important factors have a great effect on the cost, quality and productivity of the weld. Moreover, the parameters influencing the weld should be estimated and the conditions that differ during this process should be acknowledged in order to get conformity for a perfect arc. The welding process variables could further be augmented to yield improved weld bead and geometry [4]. Inert gases due to their cost are not often used which limits their application until gases such as CO2 were recognized. This procedure can be automatic or semi-automatic. Argon with 3 to 25% CO2, Argon with 1 to 5% O2, Argon/Helium and pure Argon are the shielding gases which are often used. The weld properties are being improved through the utilization of pure CO2. However, deterioration in the weld's mechanical properties occurs due to the presence of CO2. Shielding Gas, Current, Electrode Size, Arc Travel Speed, Arc Travel Speed, Voltage are some of the MIG welding parameters [5-6].

Several researchers have investigated the use and effect of MIG in welding. Miao *et al.* [7] investigated the experimental study on AA606/Ti-6AL-4V joints whereby the mechanical properties and microstructure of bypass current BC-MIG welding joints were analyzed and assessed. There was a decrement of the heat source acting on the base metal, this occurred as a result of bypass current. However, to create an improvement in the characteristics and wettability of the weld, there had to be an increment in the efficiency of the melting of filler and the mode of transfer of the metal had to be moved to projected transfer from short circuiting transfer. The intermetallic compounds consisted of TiAl3 and TiAl2. There was a continuous reaction layer due to the bonding between Titanium alloy and aluminum alloy. BC-MIG welding brazing obtained dependable Al/Ti joints (Miao *et al*., 2014). A maximum of 190 MPa could be reached of tensile shear strength of as received joint which was 96% of the base metal of AA6061. They reported that melt flow aided in the formation and growth of interface. Muzakki *et al*. [8] investigated the mechanical properties of Stainless Steel and Aluminum Alloy with zinc sheet insertions. Zakharov *et al.* [9] investigated the possibility of a weldable corrosion resistant alloy using Aluminium, Zinc and Magnesium. They reported that the welded alloy displayed a high strength characteristic and can be welded easily.

As opined by Mishra *et al.* [10], when they investigated the strength of the welded joints between a mild steel and stainless steel, when joints are being made between different metals it is beneficial because it prevents corrosion and enhances strength of the welded joints [11].

The use of galvanized, mild and stainless steels in various sectors of the industries cannot be overemphasized and one of such use is in MIG welding [12]. This welding type is limited by low weld penetration and weld bead

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shape of the weld joint [13]. However, this research is aimed at increasing weld penetration and increase the quality of weld bead shape of a welded joint using MIG welding through the use of flux powders [14]. The approach will involve a comparative analysis and performance evaluation of the commercial flux powder and the developed Nano-flux powder (eggshell) from agrowaste.

2. METHODOLOGY

2.1 Preparation of the Metals

The metals used for this study were galvanized, mild and stainless steel. These steel types were selected because of their frequent use in the metal manufacturing industries. To prepare the samples, eight (8) pieces each of the metal sheets and plates were cut into dimensions 50 x 50 x 10 mm. Galvanized steel plate having a thickness of 6mm, mild steel plate having a thickness of 10mm, and stainless-steel plate having a thickness of 8mm, stainless steel and mild steel rods having a thickness of 9mm were all cut with a disc steel cutter. The stainless and mild steel rods were cut to 50 mm long 16 mm diameter rods and machined into 5mm bell shape respectively as shown in figure 1 (a and b) for the purpose of tensile test.

Figure-1. (a) Stainless steel rod (b) Mild steel rod.

2.2 Flux Powder Application

The Flux types used were the Easy-Flo flux powder and the calcium oxide flux powder which has been developed. The Easy-Flo flux powder is a silver brazing flux. It is intended for use with silver brazing filler metals that melt below 750^{o}C. The flux was operated within a working range of 550-800^{o} C and weighed 250g with batch number 151050. This flux was manufactured by Johnson Matthey Metal Joining in York Way, Royston, Hertfordshire SG8 5HJ, UK. The developed Nano-flux powder was made from eggshell which is an agrowaste.

2.3 Welding Parameters

The welding type used in this experiment was Metal Inert Gas Welding (MIG) (see Figure-2a) and the mild steel rod and the welded mild steel plate are shown in Figure 2b and c respectively. The welding parameters considered during this study were Current (30 - 36 A), Voltage (36 - 51 V), Arc gap (4 -5 mm) and Gas flow rate (7-8). Details of the parameter spread across welding conditions is as shown in Table-1.

Table-1. MIG welding parameters for the experiment.

METALS	CURRENT (A)	VOLTAGE (V)	ARC GAP	GAS-FLOW RATE
STAINLESS STEEL	36	20	5	8
GALVANIZED STEEL	32	15	5	8
MILD STEEL	36	20	5	8
STAINLESS ROD	31	12	4	7
MILD ROD	30	12	4	7

Figure-2a. MIG welding machine.

Figure-2b. Mild rod.

Figure-2c. Mild steel plate.

2.4 Experimental Analysis

Compositional analysis of the flux powder was carried out using a Scanning Electron Microscope (SEM) and Elemental Dispersive X-ray (EDX) as shown in Figure-3a.

Tensile test was also carried out on the welded joints using a Universal Testing Machine (UTM). Finally, Hardness test was carried out using a Monsanto hardness testing machine shown in Figure 3b. The hardness test was carried out to determine the welds resistance to indentation of the three zones under investigation [15-17]; base metal, weld joint and heat affected zone.

Figure-3a. JOEL JSM-7600F scanning electron microscope.

Figure-3b. Monsanto hardness testing machine.

3. RESULTS AND DISCUSSIONS

3.1 Hardness Test

The Brinell hardness results taken during the experiment has been presented in Table-2 for the welded joint for galvanized steel as well as mild steel plates carried out during MIG welding. Figure-4 depicts the values of hardness at different zones.

The results above show the hardness between of the three zones, that is, base metal, weld joint and heat affected zone when MIG welding was used for Specimen galvanized steel and mild steel.

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Table-2. Hardness test for MIG for galvanized plates.

Samples	Base metal (BHN)	Welded joint (BHN)	Heat affected zone (BHN)
Developed Flux	131.58	100.93	109.61
Imported Flux	125.76	112.75	120.50
Control	83.7	86.89	156.74

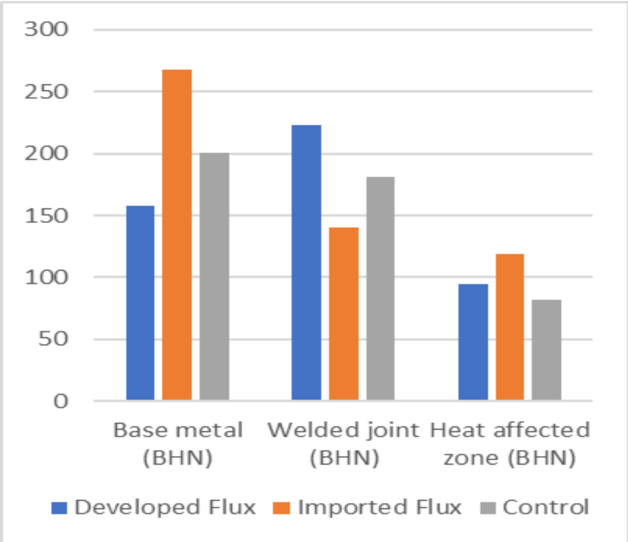

Figure-4. Hardness test for mild steel.

The hardness in the galvanized plates of the base metal for when calcium oxide was used for the developed, imported flux and control resulted as 131.58, 125.76, 83.7 BHN respectively. The hardness in the welded joint for the developed, imported flux and control resulted as 100.93, 112.75, 86.89 BHN respectively. The hardness in the heat affected zone for the developed, imported flux and control resulted as 109.61, 120.50, 156.74 BHN respectively (Table-2). Figure-8 shows that the developed flux at the base metal has higher hardness compared to the imported flux and control. The mechanical properties of this weld would have low ductility, elasticity, malleability and high brittleness, resilience and stiffness with the application of the developed flux [17-19]. The hardness in the mild steel plates for when calcium oxide was used for the base metal of the developed, imported flux and control resulted as 158.05, 222.73, 94.45 BHN respectively. The hardness in the welded joint for the developed, imported flux and control resulted as 267.90, 139.99, 118.56 BHN.

Table-3. Hardness test for MIG for mild steel plates.

Samples	Base metal (BHN)	Welded joint (BHN)	Heat affected zone (BHN)
Developed Flux	158.05	222.73	94.45
Imported Flux	267.90	139.99	118.56
Control	200.48	181.36	81.67

The hardness in the heat affected zone for the developed, imported flux and control resulted as 200.48, 181.36, 81.67 BHN. The developed flux has higher hardness at the heat affected zone compared to the imported flux and control. The mechanical properties of this weld would have low ductility, elasticity, malleability and high brittleness, resilience and stiffness with the application of the developed flux.

3.2 Scanning Electron Microscopy Test

The Figure-5 (a and b) shows the micrograph of the commercial flux and developed Nano flux and powder welding respectively. This Microstructure analysis indicates an appearance of lamellar alternating structure characteristic in which the SEM Micrograph of the developed flux has a radial pattern and a homogenous structural surface. The heat caused by friction could induce different structure in the surface of the developed flux. Evidently, the microstructure has an effect which is termed to play an important role in the mechanical properties of the joints. A mixed structure characteristic occurred between the welds whereby there is an induction which occurred on different sides of the metal structure. In this experiment, the metal experienced recrystallization which caused a refinement in the grain boundaries.

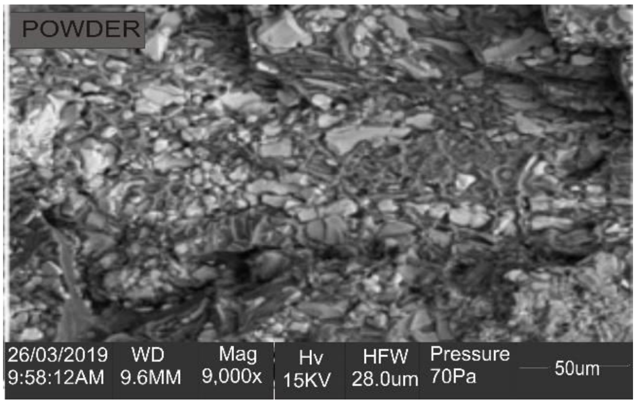

Figure-5a. SEM micrograph of imported flux.

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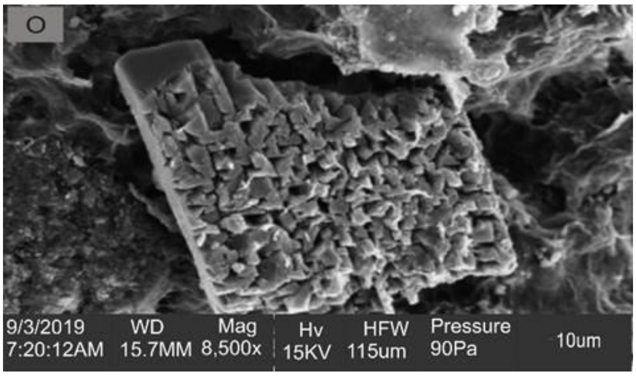

Figure-5b. SEM micrograph of developed flux.

3.3 Elemental Dispersive X-ray

As displayed in Figure 6 on the micrograph, the major constituents of the calcium flux powder include Calcium (Ca) with a concentration of 57.30%, Oxygen (O) with a concentration of 18.4% and Sodium (Na) with a concentration of 12.31%. Minor constituents include Carbon (C), Magnesium (Mg), Aluminum (Al) with compositions 6.86%, 3.90%, and 1.23% respectively. The powder is enriched with Calcium highly due to the high percentage of Calcium found in eggshells and salt used during the synthesis process. Calcium has its peak between 1.70KeV and 1.80KeV and lower composition in 0.3KeV, 3.8KeV and 4.0K.eV. The analysis show composition high in Carbon with insignificant wt% due to the ashes used in the carrying out of the synthesis process of the experiment.

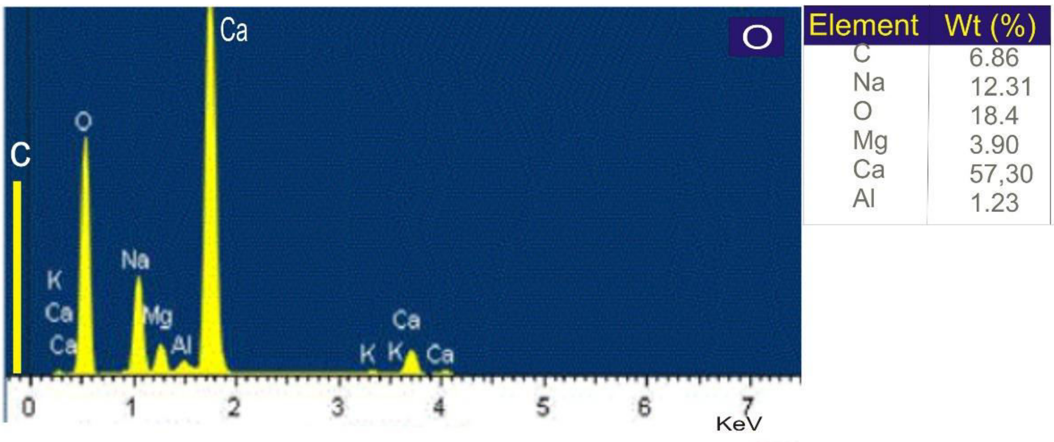

Figure-6. EDX micrograph of developed flux powder.

3.4 Tensile Test

As seen in Tables 4 and 5, Results of tensile tests carried out on the welded joints Metal using MIG reveals that the developed flux powder displayed a maximum tensile stress of 4393.541 and 525.898Mpa respectively, whereas for the stainless and mild steel rods without the application of any flux which withheld a maximum tensile stress of 252.141 and 372.584MPa respectively. Furthermore, for the imported flux powder mild steel and stainless-steel rods appeared to be 125.95 and 252.612Mpa respectively.

Table-4. Tensile test result for MIG welds for mild steel rods.

Parameters	Developed flux powder	Imported flux powder	Control
Load at Maximum Tensile Stress (N)	5964.289	1428.419	4225.539
Maximum Tensile Stress (MPa)	525.898	125.95	372.5847
Maximum Tensile Strain (mm/mm)	0.03215	0.01785	0.02323

Table-5. Tensile test result for MIG welds for stainless-steel rods.

Parameters	Developed flux powder	Imported flux powder	Control
Load at Maximum Tensile Stress (N)	4393.541	1028.341	2859.563
Maximum Tensile Stress (MPa)	387.398	252.612	252.1405
Maximum Tensile Strain (mm/mm)	0.03245	0.01456	0.02262

Figure-7(a and b) revealed that the developed flux powder in the MIG welding process results in increased load bearing capacity, higher tensile stress and lowest tensile strain. It can be seen that for both the mild steel and stainless-steel welds, those produced with the developed flux had highest values of Load at maximum stress, Maximum Tensile stress and Maximum tensile strain with those produced without flux having the second highest values and the welds produced with imported flux had the lowest tensile values.

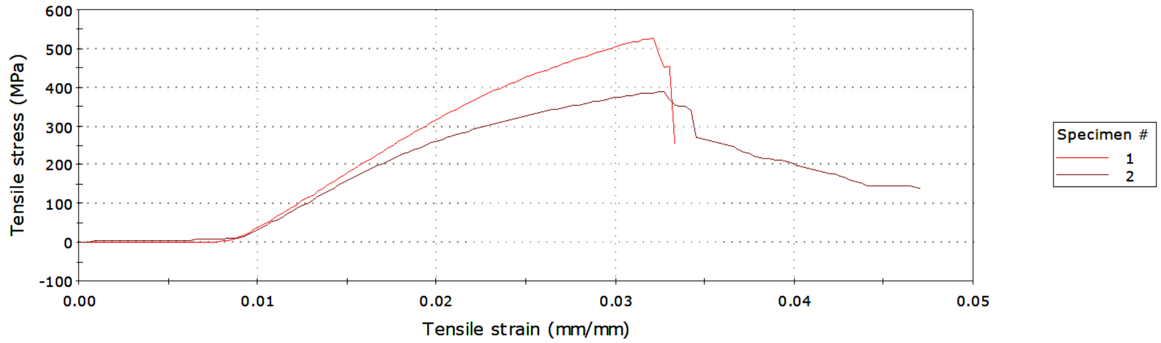

Figure-7a. Stress-Strain curve of MIG welding with imported flux.

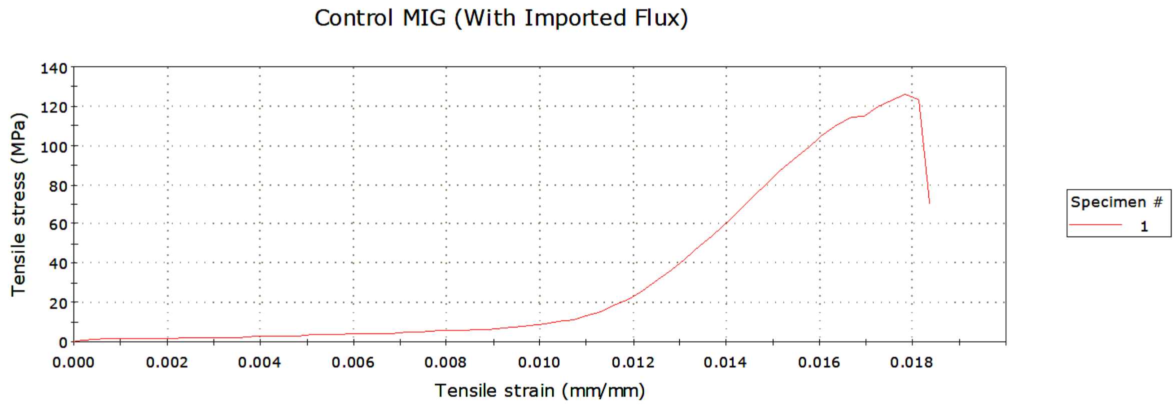

Figure-7b. Stress-Strain curve of MIG welding with imported flux.

CONCLUSIONS

Based on results obtained after analysis, the following conclusions have been reached.

- Microstructural analysis carried out on the two flux powders (developed Nano flux and commercial flux powder) using a Scanning Electron Microscope showed some dispersed quartz sum of Calcium, Sodium and Oxygen respectively. Hence confirming the suitability of the sample developed Nano powder as a flux for the MIG welding.
- EDX analysis has proven that Calcium(Ca) is responsible for the improvements in the weld having the highest constituent of 57.30% in the composition of oxygen(O), Sodium(Na), Carbon(C), Magnesium (Mg), Aluminum(Al) forming the salt being produced which was derived from the synthesis of Calcium Carbonate salt and ashes of the egg shell.
- The Microstructural analysis results with the use of Scanning Electron Microscope revealed the microstructural properties of the weld with the

application of the developed flux to have improved the structure, surface and pattern of the welds as compared to the imported flux.

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