Full Paper

METALLURGICAL INTEGRITY OF AUTO-EXHAUST OXY-ACETYLENE WELDS AND WELDING PRACTICE IN WESTERN NIGERIA: A CASE FOR REGULATION AND QUALITY DEVELOPMENT OF THE ARTISANAL WORKFORCE

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ABSTRACT

Often times, auto-exhaust oxy-acetylene maintenance weld by local artisans hardly serve more than a wet season. The aim here is to study and document why artisanal oxy-acetylene auto-exhaust welds generally have very short service lives, and be able to propose standard practice guide for obtaining durable welds during exhaust repair. The study focus area is Ondo, Ogun and Lagos Southwestern states of Nigeria. A structured questionnaire was developed and administered to respondents, along with field observations, and interviews bothering on practicing standards. Sample artisanal and original auto-exhaust manufacturers (OAM) materials and welds were sourced from welder shops selected randomly. These samples were sectioned and comparative assessment of composition, strength and electrochemical behaviors was carried out. The result showed that virtually all the welders studied do not comply with different basic requirements such as safety and procedural standards covered by ISO 15615:2013 and EN ISO 15609 respectively. Excessive weld bead/excess penetration, pores, weld bead overlap, uneven weld bead, inclusions and spatters were some of the physically observed weld defects in the weld, and these do not bug them. Many of the welders never heard of any standard procedure for post weld quality assessment, heat treatment or basic workshop weld integrity test such as dye penetrant test. The OAM alloys compositions conform closely with standard material specification of AISI 316 stainless steel austenitic for auto exhausts. AISI409 ferritic stainless steel is also a standard material specification in this application, but the compositions of the artisan alloys on the welds deviates clearly from these. The OAM alloys and welds shows more noble electrode potentials compared with the artisan's alloys and welds, while the Rockwell hardness values shows that artisan weld joints are remarkably weak. Artisan oxy-acetylene welds and practices in these focused areas, therefore, show poor compliance to material and procedural standards. Operations and certification of local welders are not well monitored by professional and regulating bodies. Towards improving the quality of this artisanal workforce, relevant welding professional bodies and Standard Organization of Nigeria needs to accept the challenge to organize workshops for these artisans, covering standard operation and quality assessment, and certain standard enforcement measures put in place.

Keywords: *Oxy-acetylene welding, auto-exhausts, weld integrity, standards specification, standard organization.*

1. INTRODUCTION

Repairs of holes, leaks or damaged exhaust system and fabrication of substitute exhaust pipe is usually done in our clime by local artisans using the oxy-acetylene welding. The reliability of the maintenance weld is a function of the welder's skill and combination of metallurgical parameters pre, during and post weld operation (Twi Ltd, 2015). These sum up to the integrity of the welding practice and the weld itself. Common experience is that repaired exhaust hardly last more than a wet season before it fails again, implying frequent revisits to the artisan workshop until the unit has to be junked and replaced with new one. This is obviously with cost implications. Such impaired exhaust systems are also major contributors to carbon emission into the atmosphere (Howard, 2014). In the face of global effort towards minimal emission controls, this is a notable infraction. A definite need for expert assessment of the reliability and integrity of the artisan auto-exhaust welds and practices in this region was identified. In this pursuit, field and laboratory investigations were carried out, with the results and discussions reported herein.

In auto exhaust weld, the focus of weld quality is in reference to strength and seal. The determinants can be summarized under process selection, preparation, procedures, pretesting, personnel (Midwest Metal, 2014). These issues are covered in various international standards and are summarized into standard operating procedure (SOP). Table 1 is a compilation of some standards relevant in this context. The Standard Organization of Nigeria's standard was not obtainable, as they are for sale only to registered companies and not individuals. It is hoped that equivalent SON standards exist in these contexts. Some pertinent issues from a standard gas welding procedure (AS 4839:2001; Andrews, 2013) include: no Personal Protection Equipment (PPE), no work; surface preparation of the components; filler rod selection; gas and flame control procedure; among others.

Table 1: Some International Welding Standards Code and Specification

Standards Title/Code	Specifications
Welding Procedure Specification (EN ISO 15609)	Specification and qualification of welding procedures for metallic materials – (General rules)
Gas Welding Safety Specifications (ISO 15615:2013)	Gas Welding equipment- Acetylene manifold system for welding, cutting and allied processes
Gas Welding Flame Control (BS EN 730-2: 2002)	Gas welding equipment. Safety control
BS EN 730-1:2002	Gas welding equipment. Safety devices
ASTM D7803:5.1.2.3	Surface cleaning step removing oil and grease
ISO 5175: 1987	Equipment used in gas welding, cutting and allied processes

PPE entails coverall, leather gloves, boots, goggles, helmet. Surface preparation of the component parts to be welded must be done. ASTM D6386, D7803 and A780 detail essential steps in surface preparation. The filler material not only adds reinforcement to the weld area, but also adds desired properties to the finished weld. In some cases, a suitable rod with a lower melting point will eliminate possible cracks from expansion and contraction. RG/R45 or R60 is the recommended filler metal for oxyacetylene welding of steel (WeldingWeb, 2010). In manufacturing, Table 2 shows the standard alloy specifications for different parts of the exhaust unit. It follows that, ideal filler rods for different parts of the exhaust should have compositions closest to this alloys (Stifner, 2014). The diameter of the rod used is governed by the thickness of the metal being joined. If the rod is too small, it will not conduct heat away from the puddle rapidly and a burnt weld will result. If the rod is too large, it will chill the weld puddle (Autodesk, 2014).

Table 2: Standard materials specification of auto-exhaust components (Shamsul and Hisyam, 2007).

Components	Standard Materials	Composition	Functions
Exhaust Manifold	AISI 409 Ferritic Stainless Steel	Fe - 11% Cr	Collects gases from combustion chamber to the exhaust pipe
Muffler	S31600 Austenitic Stainless Steel	Fe - 16% Cr	Reduces noise
Tail Pipe	S31600 Austenitic Stainless Steel	Fe - 16% Cr	Discharge exhaust gases to the rear of the vehicle
Catalytic Converter	AISI 409 Stainless Steel	Fe - 11% Cr	Reduce air pollution
Exhaust Pipe	AISI 409 Stainless Steel	Fe - 11% Cr	Connect the exhaust to the catalytic converter
Resonator	S31600 Austenitic Stainless Steel	Fe - 16% Cr	Reduces sound to minimum level

For weld quality testing, physical inspection is the first default step. Certain weld defects such as spatters and uneven weld bead can be seen visually, but fine cracks can be assessed by the dye penetrant inspection (DPI). DPI is a low-cost widely applied workshop inspection technique (Kohan, 1997). ISO 3059 states the procedures for carrying out dye penetrant inspection in a workshop. Towards ensuring the standards, International Standard Organization (ISO) and International Electrotechnical Commission (IEC) are two of the major global regulating and standards' commissions for fabrication and welding related issues. Other standard organizations include, American National Standards Institute (ANSI), British Standard (BS), Standard Organization of Nigeria (SON), International Institute of Welding (IIW), Nigeria Institute of Welding (NIW). NIW is directly empowered by Directive No. 9 of the Nigeria Content Development Policy, Local Content Initiative, to audit and certify all third-party services in the country in welding (NIW newsletter, 2008).

However, it has long been observed that welding standard in Nigeria is at very low ebb and that there was need for stakeholders to be more involved in the drive towards the improvement of welding practice (NIW Conference, 2007). Virtually all the issues observed then are still plaguing the welding industry of today. Making a career out of welding does not require a university degree, yet quality welding demands more than a dropout's devotion. A welder could obtain a certificate within six months, but getting patronage depends on his skills (Ajanaku, 2013). The qualification to become a welder ranges from Ordinary Level School Certificate (OL/SC) to professorship (NIW newsletter, 2008). This implies that some level of formal education is necessary for a promising good welding. A minimum of Technical college qualification is expected. National Business and Technical Examination Board (NABTEB), National Board for Technical Education (NBTE), Nigerian Content Development and Monitoring Board (NCDMB) and Nigerian Institute of Welding (NIW) are some of the bodies set up by the government to regulate technical practices in the country (Ajanaku, 2013). It is hoped that these bodies are looking in this direction.

2. METHODOLOGY

Field investigation was first carried out in form of a structured questionnaire administered to some auto-exhaust weld artisans in Lagos, Ogun and Ondo southwestern states of Nigeria. The questionnaire covers issues to assess compliances levels with standard procedures. Test samples are exhaust alloys and weld joints, both from original exhausts and from artisan worked samples. Table 2 summarizes the designation and description of the samples collected. Rockwell hardness test, alloy composition determination, and electro-chemical response tests were conducted on these samples.

2.1. Hardness Test

Hardness testing used in this research is the Rockwell method which as defined in ASTM E-18 measures the permanent depth of indentation produced by a force/load on an indenter (Mathews, 2001). The Hardness test was done at Federal University of Akure (FUTA) Metallography Lab.

2.2. Chemical Composition

The compositions were obtained via spark spectrometric analysis. The samples were grinded and etched to obtain a mirror-like surface, after then mounted on the spectrometer at Universal Steels Limited Ogba, Lagos state. Model type is Labspark5000 Spark Optical Emission Spectrometer.

Table 3: Samples Designations

Sample Designations	Description
OM (Original Material)	Original Manufacturer's Material for Auto-exhaust
AM (Artisan Material)	Material used Artisans for fabricating Auto-exhaust
OM/AW (Artisan Weld)	Manufacturer's material with artisan weld on it
OM/OW (Original Weld)	Manufacturer's material with Manufacturer's weld on it
AM/AW (Artisan Weld)	Artisan material for exhaust with artisan weld on it

2.3. Electrochemical Response

Samples were put in water and the values of the electrode potentials were taken every 12 hours for 1308 hours using zinc electrode as the reference electrode.

3. RESULTS AND DISCUSSION

3.1. Compliance with Standard Operating Procedure

From the questionnaire responses and observations, extents of compliance and deviation from standards by the artisan welders are summarized in Table 4. The artisans are grossly incompliant with standards in terms of SOPs. Safety consciousness is almost nil. The weld quality is obviously defective. Figure 1a shows a typical expert artisan weld. Welders generally piled up bead until the weld bulge, in essence creating a large heat affected zone with reduced stress corrosion resistance. Excessive weld beads, over penetration, porosities, bead overlap, uneven bead, inclusions and spatters were some defects visible in the welds. A standard weld bead should be visibly of a consistent weld geometry, clean surface without pores and inclusions (Kou, 2003) such as in Figure 1b. Standard Organization of Nigeria (SON) which is the chief regulatory body charged with setting of codes and standards entered into a Mutual Recognition Agreement (MRA) with NIW in 2007. Under the agreement, the Nigerian Institute of Welding is to see to the Standardization/codes implementation and as well Supervision, Surveillance and Control of Welding Activities in Nigeria. It does not appear much has happened in this direction.

Figure 1: Sample artisan welds (a:left) and standard weld (b: right).

Table 4: Issues drawn out from the questionnaires administered on the field.

Issues		Compliance level	Deviation Level
Safety According to Standard Specification ISO 15615:2013	Goggles	Most of the shops visited are compliant with the use of welding goggles	Use of Sun shade and glasses by some of the local artisans and their apprentice
	Boot	No compliance	All weld shops visited never complied with this safety measure as both welders and apprentice either has a rubber or palm slippers on
	Coverall	Some complied, but most had dirty clothes on	
	Hand gloves	No compliance	No compliance at all shops visited
	Helmet	No compliance	No shop visited complied
	Cylinder and regulators	Some shops complied having two different cylinder set with regulators	No compliance with installation of working pressure regulators. Acetylene bottle should be kept upright always (Arcraft, 1995).
	Fire Safety	Extinguishers were rare	Some of them as well has a bottled water which has a perforated head with which they splash water on oily parts that catches fire when welding.
Processes	Filler rod Selection (AWS A5.2/A5.2M:2007)	Low compliance level. Wire hangers/rods was basically the filler material seen at the shops visited.	Generally try to use a corrosion resistant filler, trying to infer from years of work experience, but alloy match cannot be guaranteed. (see composition analysis).
	Post weld treatment (ISO/TR 14745:2015)	None	None of the shops visited carries out either post weld treatment or stress relief annealing despite carrying out cold work activities i.e. hammering, bending etc. while fabricating exhaust replacement
	Surface Preparation (ASTM D7803)	None	Virtually all shops visited don't understand the concept about surface preparation. When asked, one of the respondent said why does he need to waste time when the heat of his gas nozzle will melt the surfaces together irrespective of whether it is rough or smooth.
General	Welder Skill	No standard or Recognized body certification	Poor weld beads. Majority couldn't maintain even weld bead. They do not even see the importance.
	Literacy level		Majority of the respondents (9 out of 10) are of very low literacy level. Modal certificate level is 2 Most of them (7 out of 10) could only communicate in their native language.
	Fluxing material	Some uses a pinkish metallic powder , local named 'bula'	The shops visited understands not what flux is, they simply know 'bula' gives stronger weld .
	Alloy material used in fabrication	The artisans try to use a steel alloy plate; this appears to be a relatively corrosion resistant alloy compared to mild steel.	Standard material for exhaust system is either ferritic or austenitic stainless steel which are corrosion and heat resistant according to ISO/TS 16949:2009(Hannu, 2011; Arlt, 2007)
	Cooling mode	Water quenching and air cooling.	Some respondents said they cool with water when they have large material to weld.

3.2. Alloy and Weld Composition

Table 5 summarize the compositions of the various welds and alloys, with standard alloy compositions. It can be seen that Original Material 1 (OM1) is close to the AISI 316 austenitic stainless steel composition (matweb.com, 2015) which is used for heat exchangers and other heat and corrosion resistant applications. This is also close to the composition of the Society of Automotive Engineers' (SAE) International SAE J2515, which is recommended for high temperature materials used in exhaust manifolds. The chemical composition of the original auto-exhaust manufacturer's welded joint OW is also close to the composition of the OM1 base material. On the contrary, Artisan Material 1(AM1) after welding experiences an increase in the percentage of the alloy elements like with the artisan weld (AW) having 12.872% Cr, 6.741% Ni, 0.850% Mn. It follows that the artisan filler are of a more corrosion resistant alloy than the base material being used in fabricating replacement units such as the muffler. This confirms field observation that the artisan fillers rods sometimes appear to be of stainless steel.

The composition of the artisan fabrication material is close to ASTM A387 alloy steel Grade 9 class 1 (Table 5). ASTM A387 is recommended for general corrosion resistant and high service temperature attributes (matweb.com). This is a costlier alloy compared to mild steel sheet used by some other shops. This is at least commendable that the artisan have chosen such plate. It is should be noted that this is not in all instances; mild steel were found in other instances. It is no use analyzing such obviously in appropriate material. However, this artisan alloy still differs from standard exhaust material specifications (Table 1). The composition contrast between the weld and the base material is also an indication of weakness; the weld relative to the base can set up galvanic cells

3.3. Weld and Material Strength and Corrosion Behavior

Figure 2 shows the Rockwell hardness values of the samples. All the welds show lower hardness relative to the base materials. Some air quenching is expected, but this was not seen here. However, the general differential hardness shows variation of strength across the weld joint. Such strength gradient can allow crack propagation along the weld and base material boundary(Morton et al, 2006). This differential is largest for one of the artisanal welds, and this can explain why such crack is common experience with automobile owners.

Figures 3 and 4 show the electrode potential measurement over time for the different samples. The OAM material shows nobler potentials than the artisan materials. The manufacturers' materials are therefore more corrosion resistant than the artisan materials. From the chemical analysis, higher corrosion resistance of the standard manufacturer material is expected due to the higher chromium and nickel content in the alloy used. The artisan weld gave the least noble electrode potential, even compared to the artisanal alloy. It follows that the artisanal weld is clearly anodic to its base alloy.

This implies that the artisan weld would suffer galvanic corrosion relative to its base material. With such low electrode potential, the artisanal weld will be much more electrochemically unstable under exposure during the cyclic thermal load and moisture in service. A short service life is surely going to result. In fact, visible surface oxidation was noticeable after cutting of the artisan samples during preparation for investigations.

Table 5: Chemical composition of selected original alloy, original weld, artisan weld, artisan alloy, and some standard steel specifications.

Elements	OM1	OW	AM1	AM2	AW	AISI 316	ASTM A387
C	0.052	0.046	0.159	0.130	0.273	≤ 0.080	0.15
Si	0.878	1.089	0.410	0.480	1.061	≤ 1.0	1.0
Mn	1.248	1.566	0.554	0.325	0.850	≤ 2.0	0.30 - 0.60
S	0.055	0.062	0.031	0.029	0.062	≤ 0.030	0.030
P	0.125	0.114	0.070	0.058	0.112	≤ 0.045	0.030
Cr	15.141	16.589	8.093	9.152	12.872	16 - 18	8.0 - 10.0
Ni	8.643	8.719	0.251	0.216	6.741	10 - 14	-
Cu	0.787	0.584	0.151	0.219	0.401	-	-
Nb	0.077	0.057	0.026	0.029	0.050	-	-
Al	0.053	0.047	0.032	0.029	0.039	-	-
B	0.013	0.012	0.004	0.003	0.008	-	-
W	0.090	0.068	0.029	0.021	0.064	-	-
Mo	0.852	0.672	0.213	0.158	0.475	2.0 - 3.0	0.9 - 1.1
V	0.278	0.249	0.072	0.090	0.173	-	-
Ti	0.068	0.111	0.217	0.214	0.800	-	-
Fe	71.190	69.655	89.688	88.847	76.739	61.845 - 72	88.34

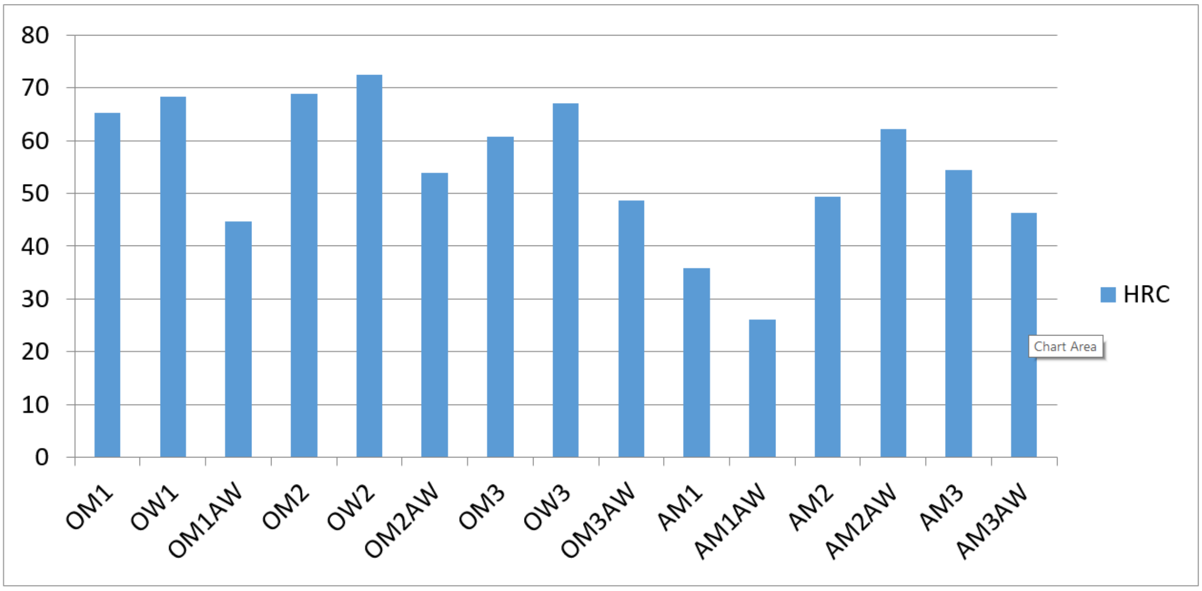

Figure 2: Hardness values for OAM and artisanal weld and alloys

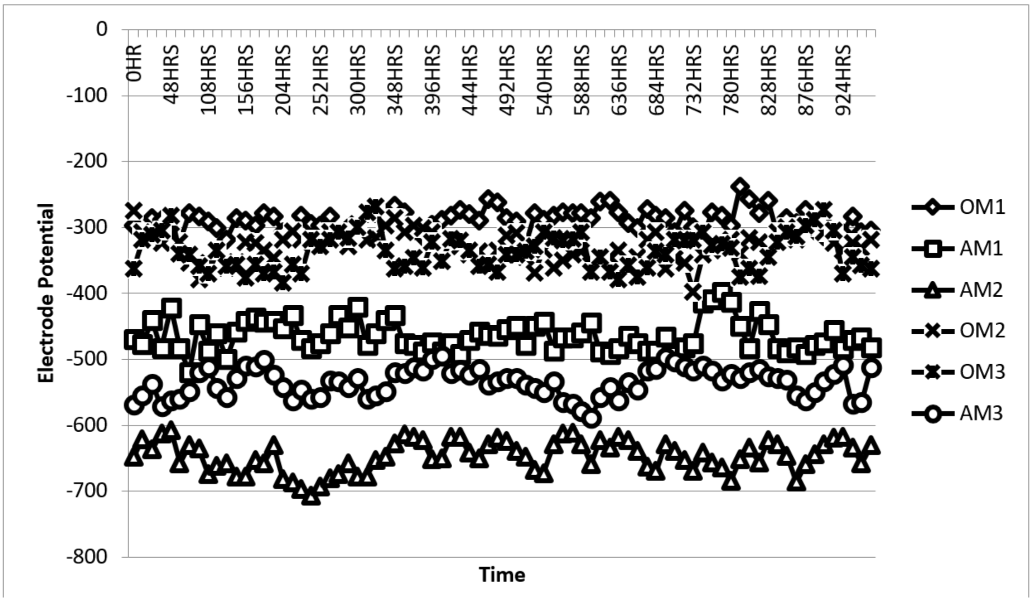

Figure 3: Variation of electrode potentials of artisan and original materials under ordinary water at room temperature over time.

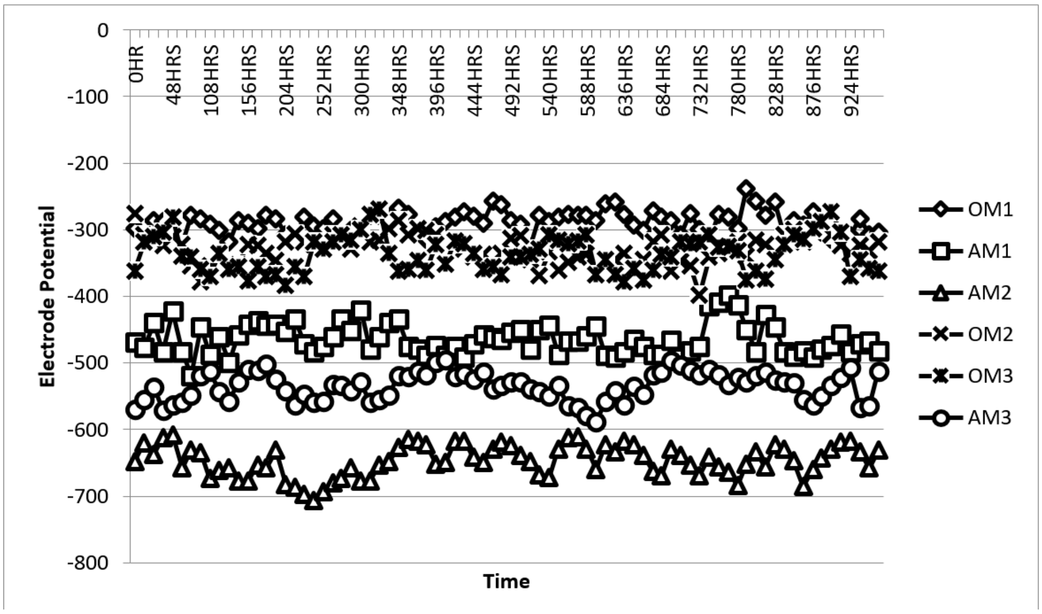

Figure 4: Variation of electrode potentials of artisan and manufacturer welds under ordinary water at room temperature over time

4. CONCLUSION AND RECOMMENDATIONS

Field inspection, strength (hardness) testing and electrochemical investigation shows that artisanal oxy-acetylene auto-exhaust maintenance weld and practices in Western Nigeria does conform to best practicing standards in material, procedure, safety and weld quality. Excessive weld beads, over penetration, open porosity, bead overlap, uneven bead, inclusions and spatters were some defects visible in the welds. Most welds could not produce a consistent bead. Filler rods and alloy material used for some exhaust part fabrication are off specification. No weld integrity check such as the basic dye penetrant nor any post-weld treatment. Weld electrode potential measurement shows the welds are all widely anodic relative to the base alloys. Hardness differential across the joint was also noted. Inferring from these results, the reason these welds have such short service life have been clearly indicated. Literacy level of welders was found to be very low and awareness of any standard is rare. The tendency is to conclude that relevant regulatory agencies such as, SON, NIW, NABTEB, NCDMB, are not attending to this sector. Towards addressing this rot, relevant professional and regulatory agencies should put together a pragmatic and practical training curriculum for this sector of the national workforce, and certification based on such curriculum made mandatory for any artisan to practice. This will amount to a quality human resource development.

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