International Journal of
Science and Engineering Investigations
vol. 9, issue 102, July 2020
Received on July 6, 2020
ISSN: 2251-8843

Quality Analysis of Locally Produced Reinforcing Steel Bars vis-a-vis the Incidences of Collapse of Buildings in Nigeria

Paul Aondona Ihom[1], Donatus Kaiso Uko[2], Chigozie Okwudiri Eleghasim[3]
[1,3]Dept. of Mechanical Engineering, Faculty of Engineering, University of Uyo, Uyo, PMB 1017 Uyo, Akwa Ibom State, Nigeria
[2]Department of Mechanical Engineering, Faculty of Engineering, Akwa Ibom State University, Ikot Akpaden, Nigeria
([1]ihomaondona@uniuyo.edu.ng)

Abstract-The incidences of collapsed building structures in Nigeria has become a common occurrence with the attendant effects of property loss, and loss of lives. Quality issues have been raised for been responsible. In this research ''Quality Analysis of Locally Produced Reinforcing Steel Bars Vis a Vis the Incidences of the Collapse of Buildings in Nigeria''; the work has focused on the quality status of six (6) reinforcement steel bars from six (6) different mini-mills in Nigeria from different part of the country. The samples were subjected to tensile test using a well calibrated universal testing machine at Mudiame International Limited Port-Harcourt. Key parameters measured were the ultimate tensile strength, the yield strength, and the elongation at fracture. Some of the specimens from the samples were subjected to chemical analysis using Spectro-Lab Metal Analyzer and the morphology of the samples was explored and studied using Scanning Electron Microscope and Energy Dispersive Spectroscopy (EDS), which gave the elemental distribution in the steel bars in terms of weight concentrations with the highest spike indicating the most abundant element present in the sample. The chemical analysis result from Spectro-Lab Metal Analyzer showed that most of these mini-mills are not producing structural steel, but constructional steel with carbon content well above 0.3%C. Only sample E with 0.206%C, sample F with 0.299%C and sample A with 0.256%C qualified as structural steel. All the samples were of plain carbon steel. Sample A had the highest ultimate tensile and yield strength of 732MPa and 630MPa respectively; quite impressive, but had elongation at fracture of 11.5%, which is short of the specified minimum of 25%. The steel is also a structural steel with a chemical composition of 0.256%C. Sample D had the highest elongation at fracture of 15.37%, this was still short of the specified minimum of 25%. Finally, for quality production of reinforcement steel bars in Nigeria; mini-mills should address issues of standardization, chemical composition (all the samples tested had different chemical and mechanical properties), and proper adjustment of their rolling process. This will improve the ultimate tensile and yield strength, as well as the elongation at fracture of the steel bars.

Keywords- *Mini-mills, Quality, Reinforcement Steel Bars, Building Collapse, Incidences*

I. INTRODUCTION

The techno-economic backbone for national development of any developing country such as Nigeria, is related to a sustainable iron and steel production. In order to produce steel for her development, the Nigerian government initiated plans for steel production around 1958 (Adebayo, 2016). In 1972 the discovery of iron ore by the Soviet Union's aero-magnetic survey under the support of Federal Ministry of Industries, led to the formal signing of a global contract between the Nigerian government and the Soviet-owned firm Tiajpromexport for an integrated steel plant in Ajaokuta, the Ajaokuta Steel Project. The Ajaokuta Steel Plant from conceptualization level to completion, was intended to be massive in scale of high quality steel production covering a wide range of steel products from wires to medium steel sections. The umbrella organization for this purpose was the Nigerian Steel Deployment Authority (NSDA). The technology deployed in Ajaokuta is primarily Russian. The plant capacity is 1.3 million tonnes of liquid steel per annum.

By 1983, the Ajaokuta Steel Company (ASC) was reported to have achieved 95% completion. The Delta Steel Project at Ovwian-Aladja, Warri, the construction of which utilized German-Austrian technology, and which commenced at the same period with the Ajaokuta Steel project, went into the production of high quality steel products after it was completed and commissioned in 1982. The plant capacity of Delta Steel is 1.0 million tonnes of liquid steel per annum. The design of the steel plant was integrated in concept with the Inland Rolling Mills of Jos, Oshogbo, and Kastina essentially operating as satellite mills of Delta Steel. This was so in the sense that some 67% of the billet production of Delta Steel was to be shared between these three inland rolling mills, while 33% would be consumed in-house in Delta Steel. Delta Steel tried to stay in production, achieving a peak production of about 250,000 tonnes of liquid steel (25% of capacity) in 1985. Thereafter, production decline commenced and steeped in the 1990s, fizzling out completely by 1995.

Steel production in Delta Steel utilized primarily iron ore concentrates imported from the Lamco mines of neighboring Liberia. The steel products rolled from the billet production of Delta Steel, especially, the high tensile reinforcing steel bars from the St.60-Mn billet grade had overwhelming reception in the Nigerian market. While Ajaokuta Steel has not been able so far to achieve steel production, Delta Steel jointly with its satellite inland rolling mills supplied acclaimed high quality steel products to the Nigerian market between 1982 and 1995. Today, the two major government-owned steel plants of Ajaokuta Steel and Delta Steel are under privatization contracts that have not been able either to bring Ajaokuta into production or rehabilitate and restart commercial production in Delta Steel. For over two decades now, steel consumption in Nigeria have been from a mix of imports and local production based on 100% ferrous scrap by the private mini mills. Taking the Nigerian environment into account, steel production utilizing 100% ferrous scrap is unlikely to be of commendable quality. This is so because the scrap material utilized is primarily of the light melting automobile scrap delivered to the mills without any quality processing (Vlad, 1986).

Plain carbon steels used for reinforcement bars fall within the carbon range of 0.07 to 0.3%C, with greater than 0.2%C as the range for structural steels used for beams, tubes, ship plates etc. However, recent developments, which include Delta Steel Company's St.60 Mn rebar steel, carbon in the range of 0.345-0.42%, with manganese content of 0.90 - 1.52% has been employed in the production of billets used for reinforcement bars. These reinforcement bars are found to have good notch-toughness at 0^oC. A more recent tendency is to add about 0.01% or more of niobium to the steel and to reduce the carbon content still further. The formation of fine NbC particles restricts grain growth and also produces a useful precipitation hardening within the ferrite grains. Niobium is preferred to other strong carbide-forming elements, such as titanium, because it does not deoxidise and so allows a semi-killed steel to be made (Cottrell, 1980; Higgins, 1985; Bolton, 1999; Jain, 2009).

According to Balogun *et al.,* (2009), reinforced steel products produced of mills in Nigeria exhibit terribly low strength characteristics. Since steel in common engineering application is used in allied engineering works as well as in reinforced concrete in building construction, it is therefore of urgent interest and considerable importance to test and compare the qualities of local steel products available in Nigerian market with the Nigerian and International Steel Standards from a wide coverage of the majority of Nigerian private mini steel mills. The intention is to compare the quality of the products with the Nigerian quality code for high tensile reinforcing steel bars as well as with the benchmark provided by international steel standards. The study has in mind the provision of data against which the incidences of building failures may be evaluated.

II. MATERIALS AND METHOD

A. *Materials and Equipment*

The materials used for the research work were ribbed reinforcement steel bars collected from different mini mills across Nigeria. For this work only 12 mm bars were used. Table 1 shows the samples that were used in the research work. The equipment utilized in the quality analysis of the samples included; files, hack saw, lathe machine, Vernier calipers, protractor, universal strength testing machine, scanning electron microscope (SEM), energy dispersive spectroscope (EDS), digital weighing balance, and spectro-lab metal analyzer (Fe-01-F).

B. *Sample Collection*

To actualize this project; samples were collected from different mini mills across Nigeria. Only mills with the capability of producing their own billets or rolling stocks from liquid steel produced using scraps were considered in this research work. The mini-mills operating on imported billets were not considered. Table 1 gives details of the location from where samples were collected.

TABLE I. SAMPLES OF 12 MM REINFORCEMENT STEEL BARS COLLECTED FROM DIFFERENT MINI MILLS ACROSS NIGERIA

S/No.	Sample Label	Location	Ribbed Reinforcement steel rod size (mm)
1	A	Lagos	12
2	C	Abia	12
3	D	Cross-River	12
4	E	Anambra	12
5	F	Kano	12
6	G	Abuja	12

C. *Tensile Test*

The only mechanical test carried out on the samples was tensile test. This was informed by the fact that in service reinforcement rods embedded in the concrete structure handle the tensile component of the stress on the structure. The compressive component of the stress on reinforced structures are mainly handled by the concrete cast. The six (6) samples were sent to Mudiame International Limited, Port-Harcourt-Nigeria for the tensile tests. All the samples were tested according to reference code / standard:BS 4449:2015+A3:2016. The results were plotted on graph and tests results were tabulated.

D. *Chemical Composition Characterization of Reinforcement Steel Bars from Some Selected Mini-Mills across Nigeria.*

Six (6) samples from some selected mini-mills were sent to Defence Industries Corporation of Nigeria (DICON) in Kaduna for analysis. The essence of the test was to determine the chemical composition of the samples from the various mini-mills. The chemical analysis was carried out using spectro-lab metal analyzer (Fe-01-F). The composition obtained was again compared with the one from Energy Dispersive X-Ray Fluorescent, minipal4 ED-XRF Model.

E. *Microstructural and EDS Study of some selected Ribbed Reinforcement Steel Bars from Mini-Mills across Nigeria*

The samples of 12 mm ribbed reinforcement steel bars from mini-mills across the country were sent to Kaduna for HRSEM and EDS study using Phenom SEM Model Pro X and Energy Dispersive X-Ray Fluorescent, mini Pal 4 ED-XRF Model. These tests were carried out to give the morphology of the steel bars alongside their chemical compositions.

III. RESULTS AND DISCUSSION

A. *Results*

The results of this study are presented as follows.

B. *Tensile Test Results*

Figures 1-6 shows the load-elongation graphs for Specimens T1- T6 obtained from the tensile tests.

TABLE II. TENSILE TEST RESULTS OF THE RIBBED REINFORCEMENT STEEL BAR SAMPLES COLLECTED FROM MINI-MILLS ACROSS NIGERIA

Specimen	Nominal Diameter (mm)	Nominal Cross Sectional Area (mm^2)	Maximum Load Fm (kN)	Ultimate Tensile Strength Rm (MPa)	Yield Strength ReH (MPa)	UTS/YS (Rm/ReH)	Percentage elongation at fracture A_{el} (%)
T1 Specimen A	12	113.10	82.75	732	630	1.16	11.50
T2 Specimen G	12	113.10	52.75	466	339	1.37	10.00
T3 Specimen F	12	113.10	72.30	639	451	1.42	10.31
T4 Specimen D	12	113.10	59.30	524	366	1.43	15.37
T5 Specimen E	12	113.10	57.60	509	346	1.47	12.37
T6 Specimen C	12	113.10	44.75	396	303	1.31	11.71

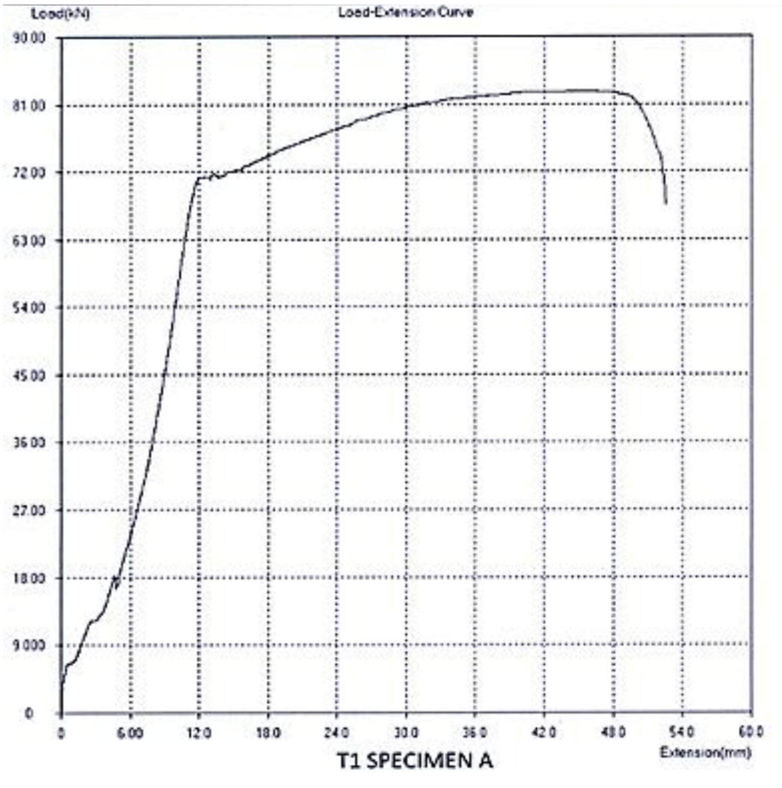


Figure 1. Load-Extension Curve for Specimen A

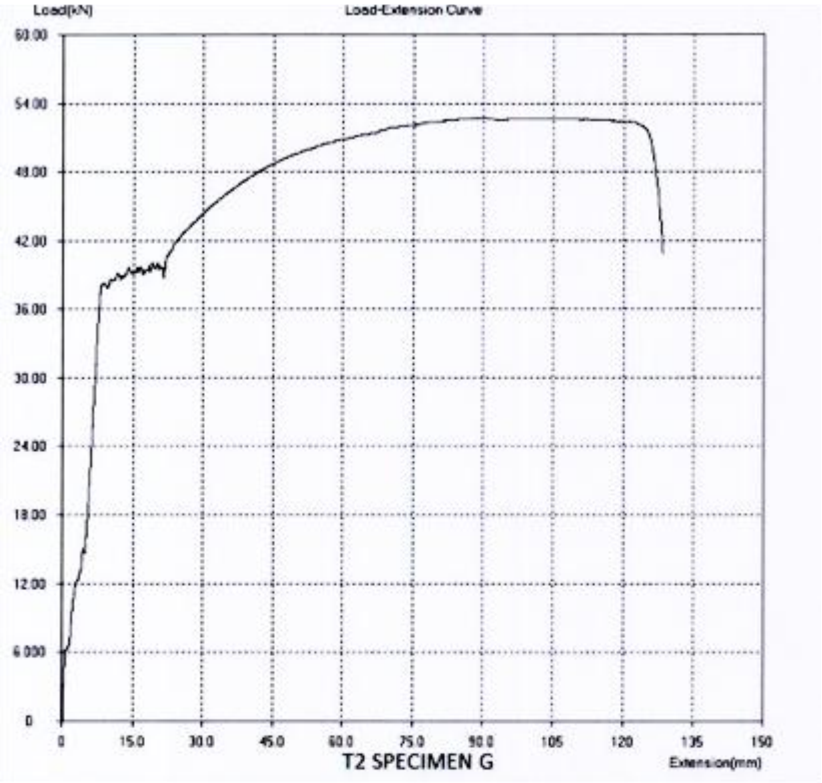


Figure 2. Load-Extension Curve for Specimen G

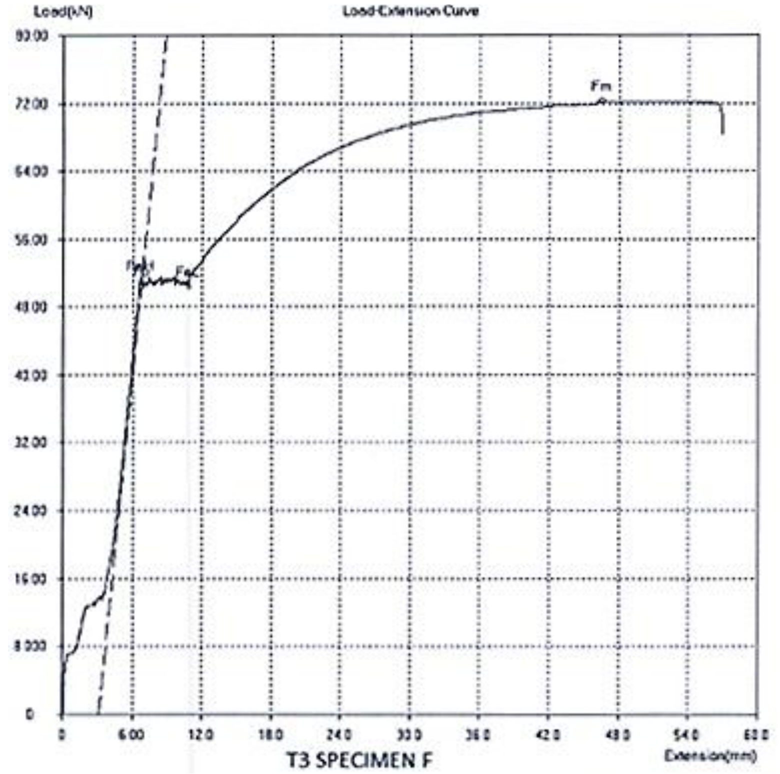


Figure 3. Load-Extension Curve for Specimen F

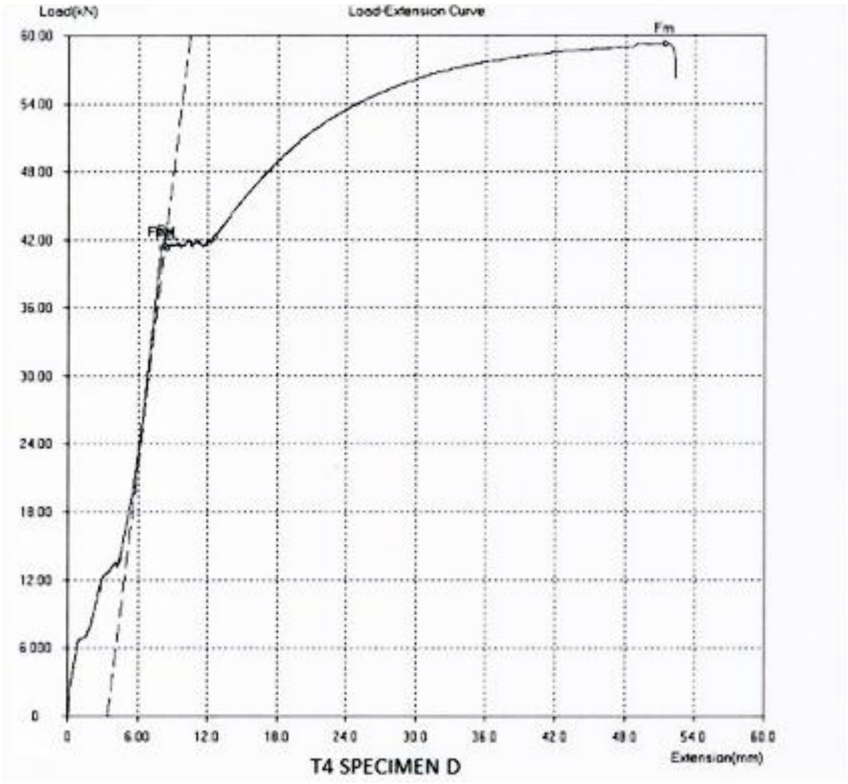


Figure 4. Load-Extension Curve for Specimen D

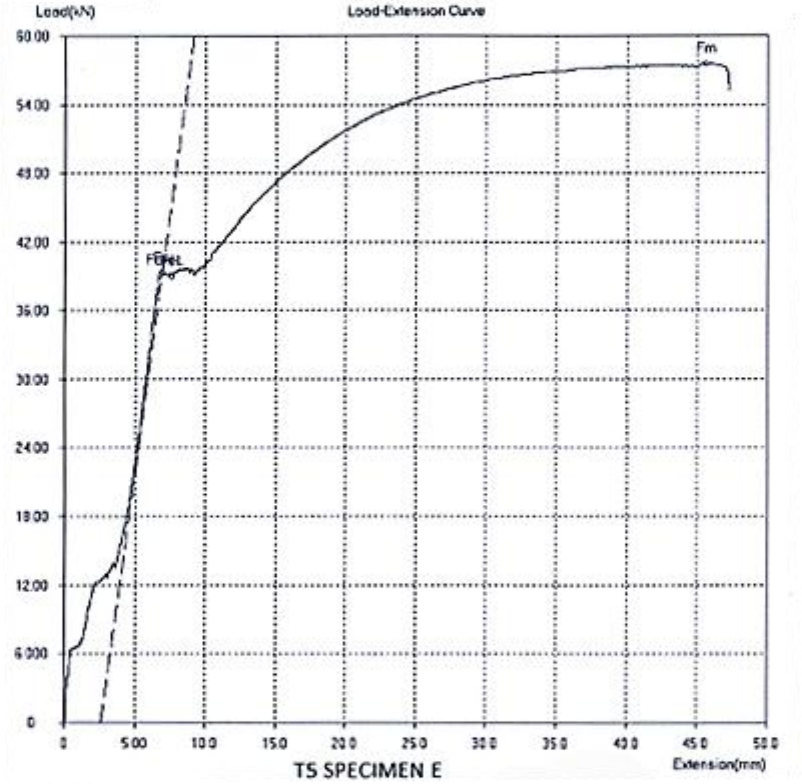


Figure 5. Load-Extension Curve for Specimen E

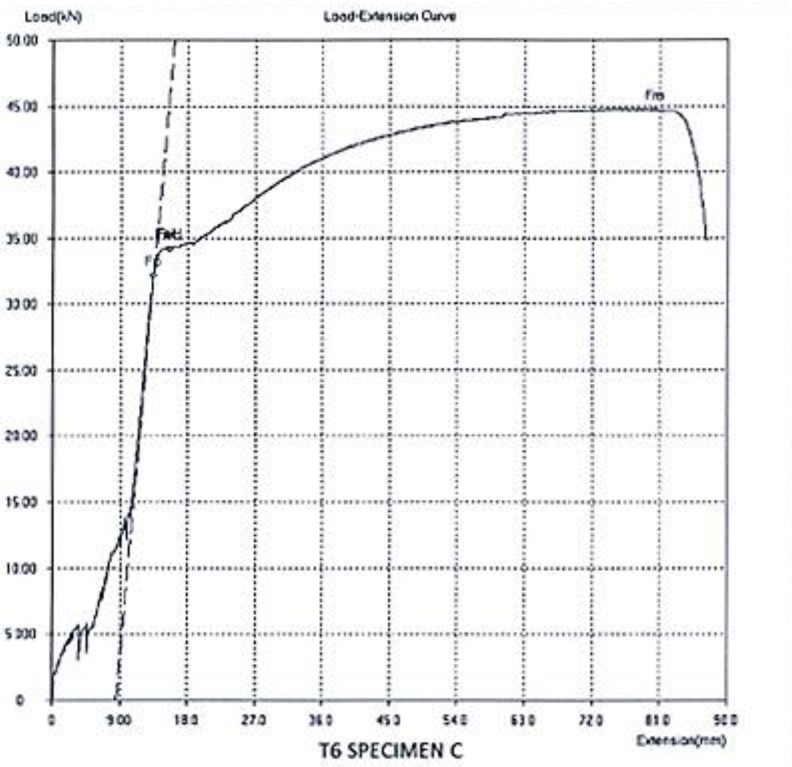


Figure 6. Load-Extension Curve for Specimen C

C. *Chemical Composition of Reinforcement Steel Bars using Spectro-Lab Metal Analyzer*

TABLE III. CHEMICAL COMPOSITION OF SAMPLE 1 FROM SPECIMEN G/QUALITY ANALYSIS (FE-01-F)

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co
%	0.479	0.411	1.08	0.021	0.035	0.102	0.035	0.0099	0.047	0.115	0.0078
Element	Ti	Nb	V	W	Pb	Mg	B	Sn	Zn		
%	0.0044	<0.0040	0.0090	<0.010	<0.0030	<0.0010	0.0035	0.0012	<0.0020		
Element	As	Bi	Ca	Ce	Zr	La	Fe				
%	0.012	0.0032	0.0044	0.0082	0.0033	0.0059	97.6				

TABLE IV. CHEMICAL COMPOSITION OF SAMPLE 3 FROM SPECIMEN A /QUALITY ANALYSIS (FE-01-F)

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co
%	0.475	0.186	0.59	0.025	0.052	0.171	0.072	0.012	0.057	0.238	0.0083
Element	Ti	Nb	V	W	Pb	Mg	B	Sn	Zn		
%	0.0094	<0.0040	0.0065	<0.010	<0.0030	0.0041	0.0031	0.0048	0.0024		
Element	As	Bi	Ca	Ce	Zr	La	Fe				
%	0.012	<0.0020	>0.016	0.0052	0.0017	0.014	<98.0				

TABLE V. Chemical Composition of Sample 3 from Specimen A /Quality Analysis (Fe-01-F)

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co
%	0.256	0.248	0.66	0.036	0.057	0.322	0.100	0.020	0.0006	0.259	0.014
Element	Ti	Nb	V	W	Pb	Mg	B	Sn	Zn		
%	0.0042	<0.0040	0.0093	0.010	<0.0030	<0.0010	0.0043	0.016	<0.0020		
Element	As	Bi	Ca	Ce	Zr	La	Fe				
%	0.012	0.0072	0.0020	0.0078	0.0048	0.0012	97.9				

TABLE VI. Chemical Composition of Sample 4 from Specimen F /Quality Analysis (Fe-01-F)

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co
%	0.299	0.205	0.55	0.029	0.033	0.210	0.061	0.0092	0.0031	0.186	0.0065
Element	Ti	Nb	V	W	Pb	Mg	B	Sn	Zn		
%	0.0024	<0.0040	0.0065	<0.010	<0.0030	<0.0010	0.0036	0.0059	0.018		
Element	As	Bi	Ca	Ce	Zr	La	Fe				
%	0.012	<0.0020	0.0015	<0.0030	0.0025	0.0015	<98.4				

TABLE VII. Chemical Composition of Sample 5 from Specimen C /Quality Analysis (Fe-01-F) Table 1 Chemical Composition of Sample 1 from Specimen G/Quality Analysis (Fe-01-F)

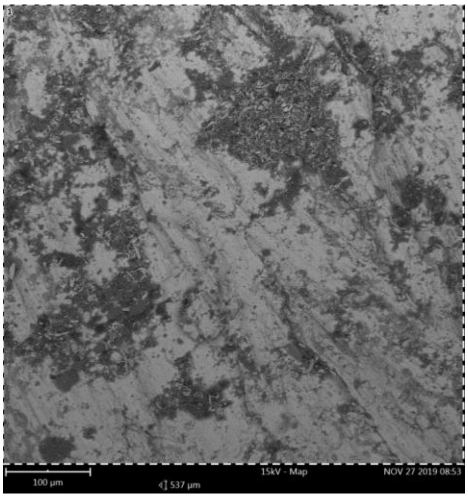
Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co
%	0.361	0.257	0.57	0.027	0.040	0.150	0.044	0.0065	0.0025	0.152	0.0075
Element	Ti	Nb	V	W	Pb	Mg	B	Sn	Zn		
%	0.0032	<0.0040	0.0057	<0.010	<0.0030	<0.0010	0.0039	0.0043	-0.031		
Element	As	Bi	Ca	Ce	Zr	La	Fe				
%	0.014	<0.0020	0.0027	<0.0030	0.0023	0.0033	98.3				

TABLE VIII. Chemical Composition of Sample 6 from Specimen E /Quality Analysis (Fe-01-F)

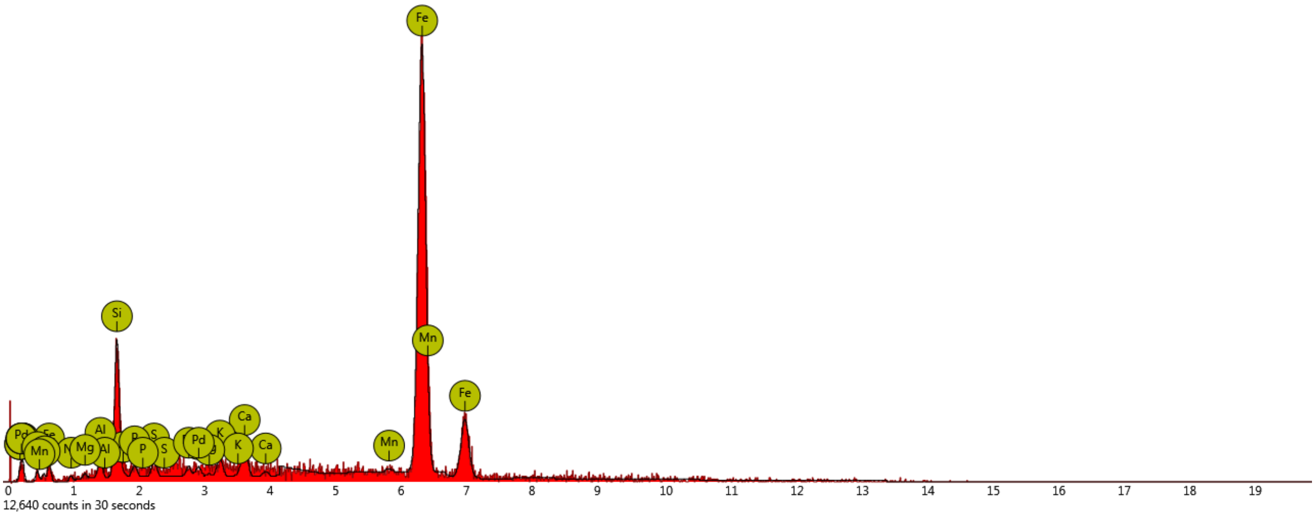
Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co
%	0.206	0.280	0.79	0.033	0.033	0.197	0..052	0.0089	0.0005	0.177	0.0070
Element	Ti	Nb	V	W	Pb	Mg	B	Sn	Zn		
%	0.0025	<0.0040	0.0067	<0.010	<0.0030	<0.0010	0.0044	0.0056	<0.0020		
Element	As	Bi	Ca	Ce	Zr	La	Fe				
%	0.012	<0.0020	0.0018	<0.0030	<0.0015	0.0036	<98.2				

D. *Results of Microstructural and EDS Study of Ribbed Reinforcement Steel Bars from Mini-Mills in Nigeria*

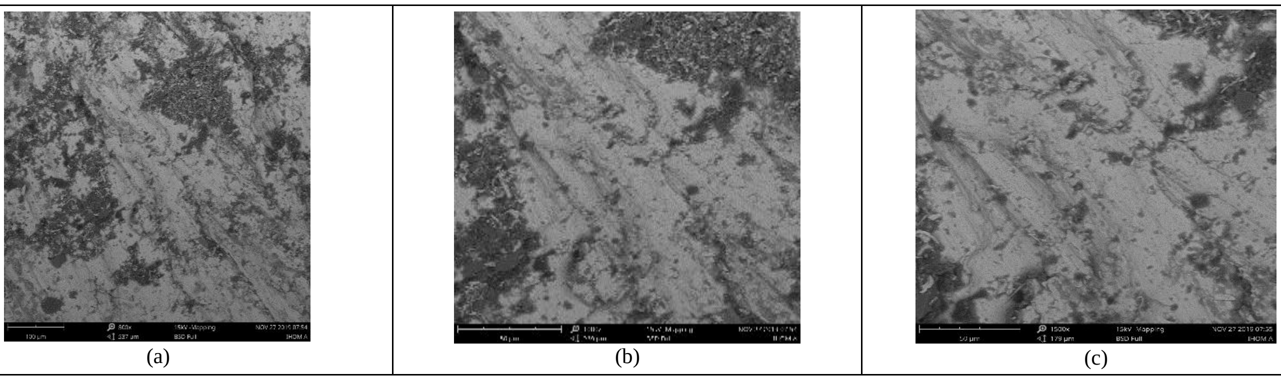
The results below are high resolution morphology of 12mm reinforcement steel bars from six mini-mills in Nigeria using scanning electron microscope. The microstructures are supported by EDX study of the composition of their structures and elemental distribution. See Figs 7-12.



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
26	Fe	Iron	69.65	83.82
14	Si	Silicon	7.66	4.64
6	C	Carbon	12.97	3.36
20	Ca	Calcium	1.87	1.61
47	Ag	Silver	0.55	1.28
46	Pd	Palladium	0.52	1.18
13	Al	Aluminium	1.41	0.82
19	K	Potassium	0.97	0.82
16	S	Sulfur	0.75	0.52
8	O	Oxygen	1.41	0.49
25	Mn	Manganese	0.36	0.42
11	Na	Sodium	0.81	0.40
15	P	Phosphorus	0.57	0.38
12	Mg	Magnesium	0.48	0.25

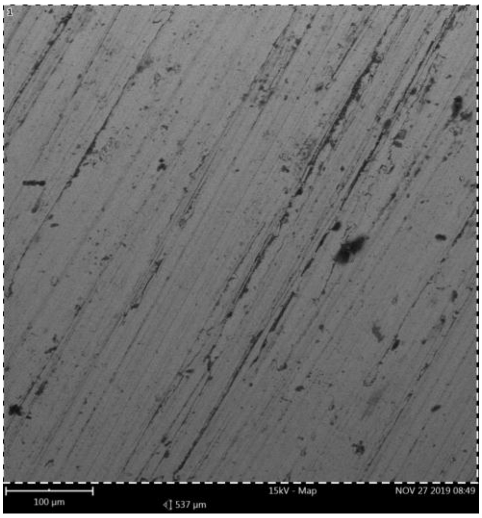


EDS study showing elemental distribution in the structure of the bar. The spikes indicate levels of weight concentration


(a) (b) (c)

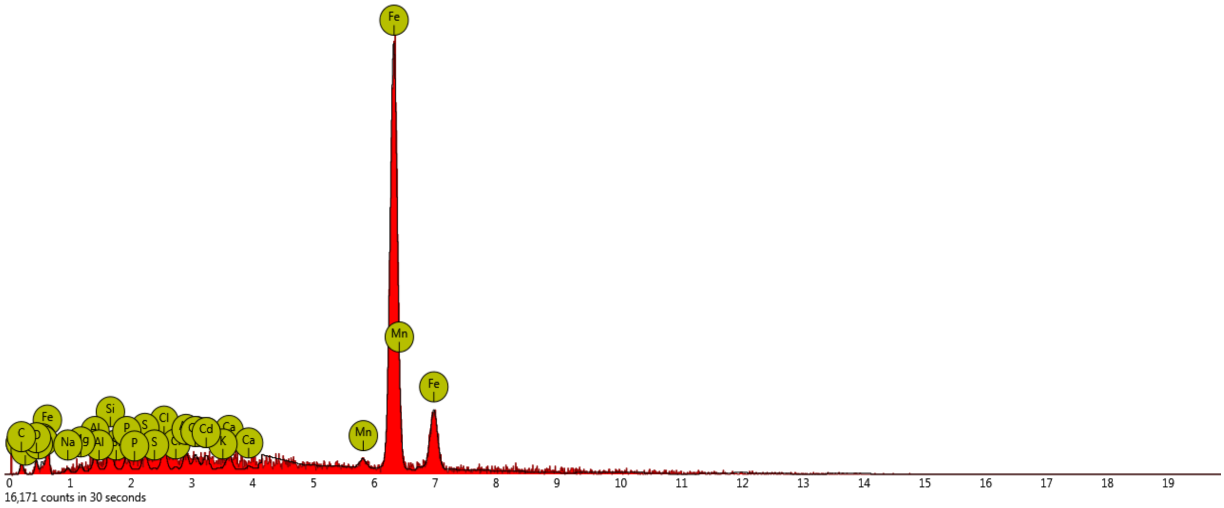
Micrograph (a) is x 500, micrograph (b) is x 1000 and micrograph (c) is x 1500, all the magnifications show a ferrite matrix background and dark areas of pearlite as indicated above

Figure 7. EDS Study of Composition of Sample A supported by various High Resolution Morphology using Scanning Electron Microscope

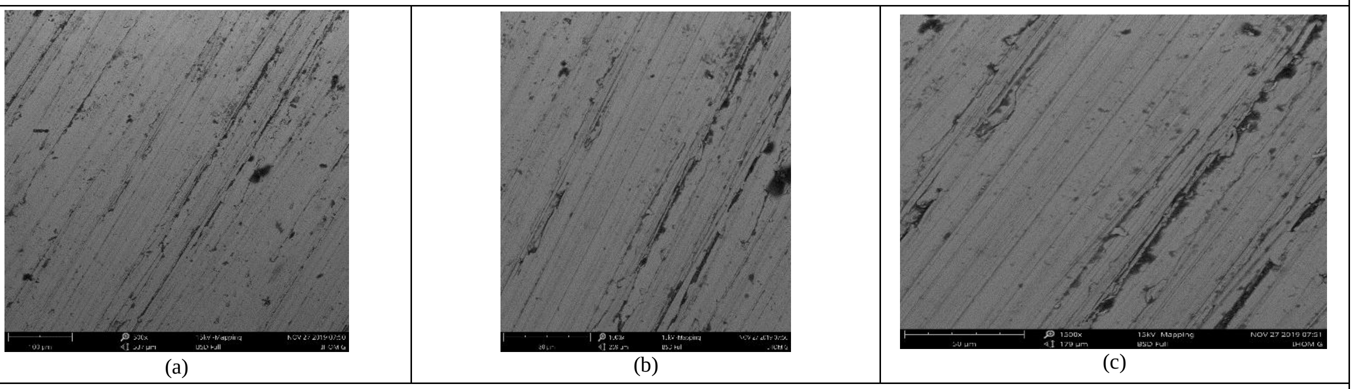


Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
26	Fe	Iron	77.51	86.76
47	Ag	Silver	1.07	2.31
6	C	Carbon	8.35	2.01
25	Mn	Manganese	1.19	1.31
14	Si	Silicon	2.19	1.24
48	Cd	Cadmium	0.51	1.15
17	Cl	Chlorine	1.31	0.93
20	Ca	Calcium	0.96	0.77
16	S	Sulfur	1.04	0.67
8	O	Oxygen	1.99	0.64
13	Al	Aluminium	1.13	0.61
15	P	Phosphorus	0.84	0.52
19	K	Potassium	0.56	0.44
12	Mg	Magnesium	0.67	0.33
11	Na	Sodium	0.67	0.31

FOV: 537 µm, Mode: 15kV - Map, Detector: BSD Full, Time: NOV 27 2019 08:49



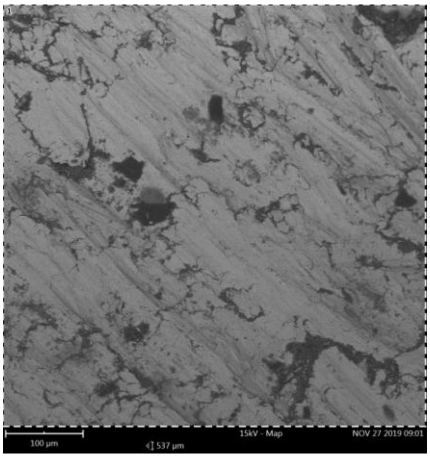
EDX study showing elemental distribution in the structure of the bar. The spikes indicate levels of weight concentration



(a) (b) (c)

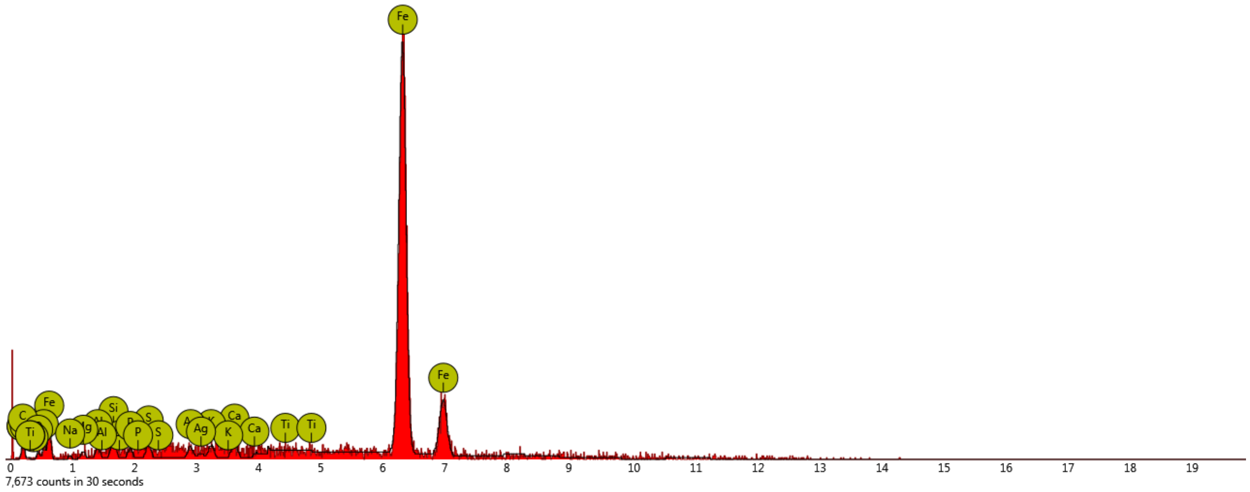
Micrograph (a) is x 500, micrograph (b) is x 1000 and micrograph (c) is x 1500. All the magnifications show a ferrite matrix background, rolling stringers, and dark areas of pearlite as indicated above

Figure 8. EDS Study of Composition of Sample G supported by various High Resolution Morphology using Scanning Electron Microscope

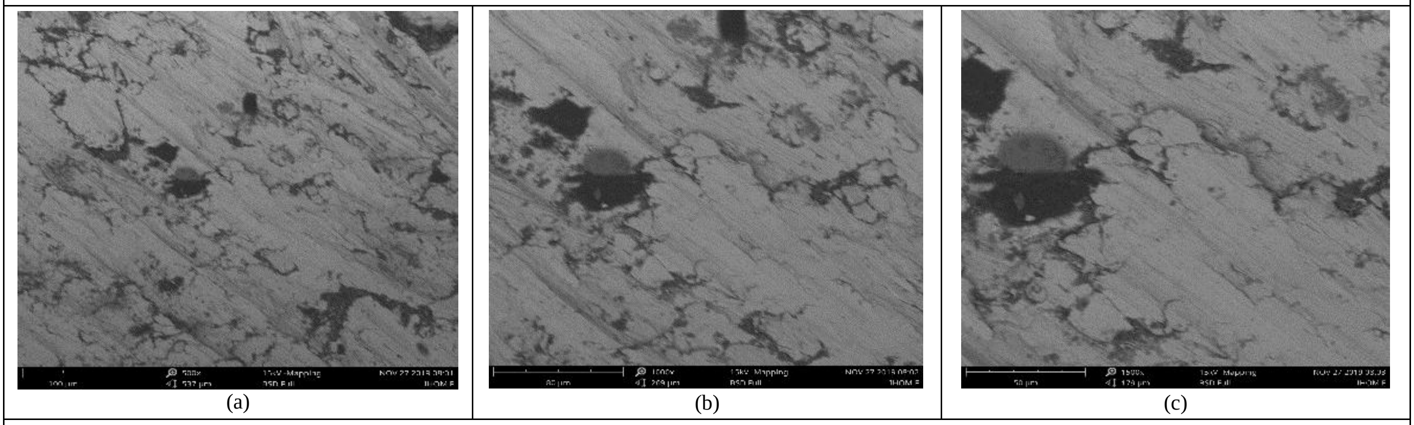


Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
26	Fe	Iron	79.23	90.54
6	C	Carbon	11.67	2.87
47	Ag	Silver	0.74	1.63
14	Si	Silicon	1.70	0.98
20	Ca	Calcium	1.10	0.90
19	K	Potassium	0.82	0.66
16	S	Sulfur	0.86	0.57
13	Al	Aluminium	0.96	0.53
15	P	Phosphorus	0.55	0.35
8	O	Oxygen	1.05	0.34
12	Mg	Magnesium	0.65	0.32
11	Na	Sodium	0.66	0.31
22	Ti	Titanium	0.00	0.00

FOV: 537 µm, Mode: 15kV - Map, Detector: BSD Full, Time: NOV 27 2019 09:01

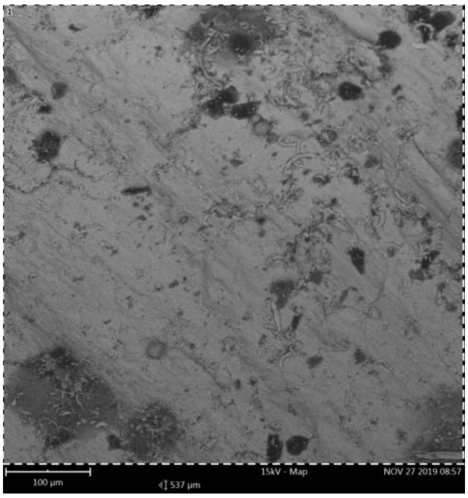


EDX study showing elemental distribution in the structure of the bar. The spikes indicate levels of weight concentration


(a) (b) (c)

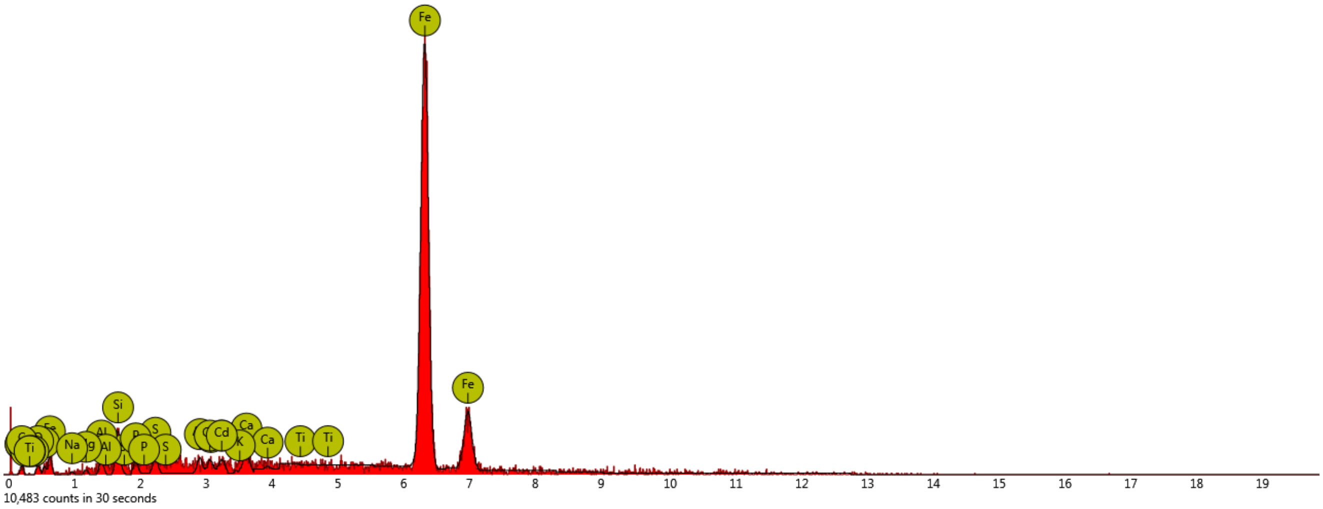
Micrograph (a) is x 500, micrograph (b) is x 1000 and micrograph (c) is x 1500. All the magnifications show a ferrite matrix background and dark areas of pearlite as indicated above

Figure 9. EDS Study of Composition of Sample F supported by various High Resolution Morphology using Scanning Electron Microscope

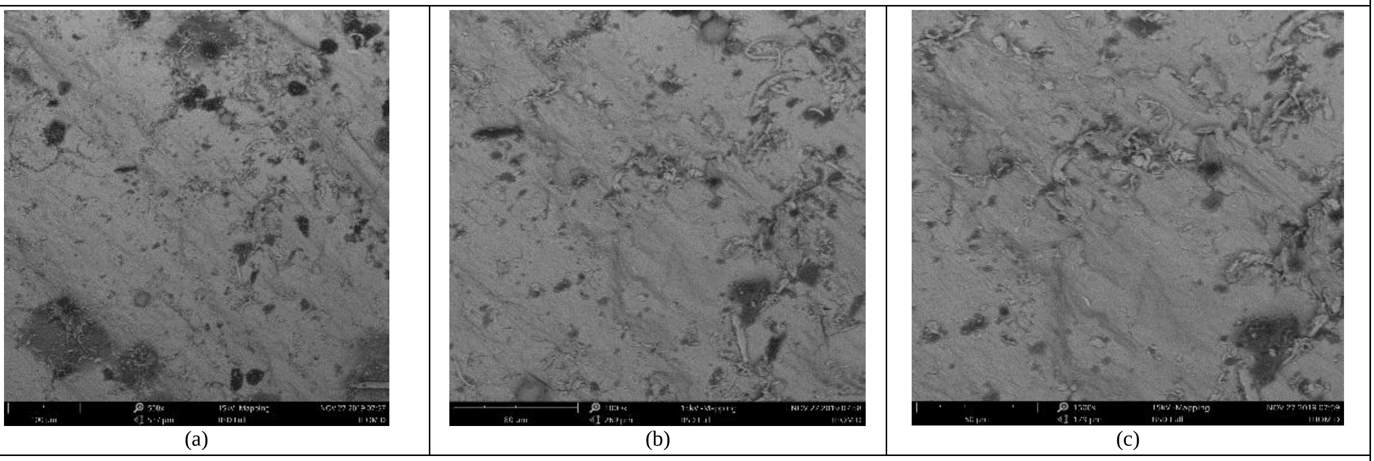


Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
26	Fe	Iron	80.69	88.91
47	Ag	Silver	0.97	2.06
6	C	Carbon	7.08	1.68
14	Si	Silicon	2.96	1.64
48	Cd	Cadmium	0.58	1.29
20	Ca	Calcium	1.38	1.09
13	Al	Aluminium	1.28	0.68
16	S	Sulfur	1.02	0.64
19	K	Potassium	0.83	0.64
8	O	Oxygen	1.53	0.48
15	P	Phosphorus	0.71	0.43
12	Mg	Magnesium	0.56	0.27
11	Na	Sodium	0.42	0.19
22	Ti	Titanium	0.00	0.00

FOV: 537 μm, Mode: 15kV - Map, Detector: BSD Full, Time: NOV 27 2019 08:57



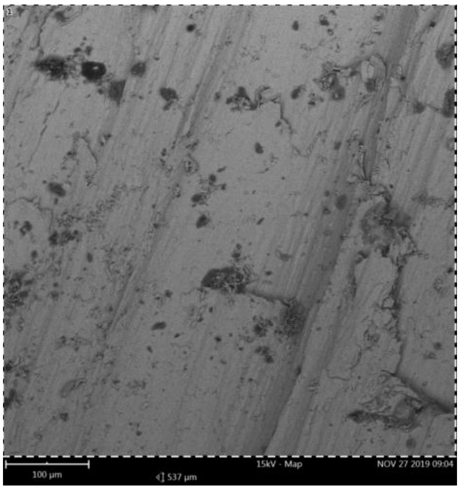
EDX study showing elemental distribution in the structure of the bar. The spikes indicate levels of weight concentration



(a) (b) (c)

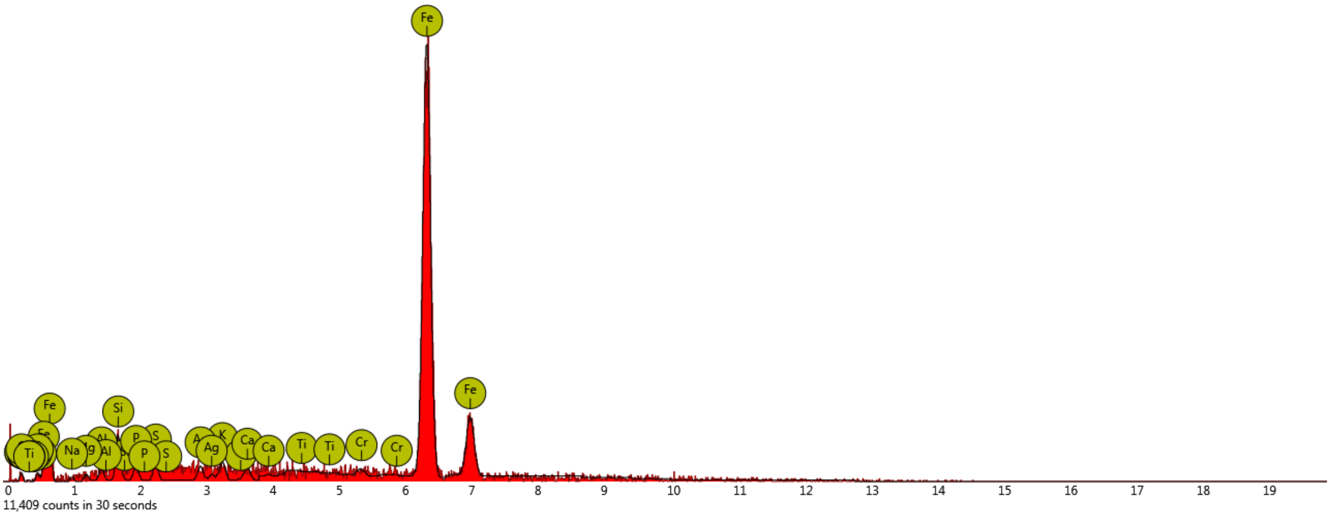
Micrograph (a) is x500, micrograph (b) is x1000 and micrograph (c) is x1500. All the magnifications show a ferrite matrix background and dark areas of pearlite as indicated above

Figure 10. EDS Study of Composition of Sample D supported by various High Resolution Morphology using Scanning Electron Microscope

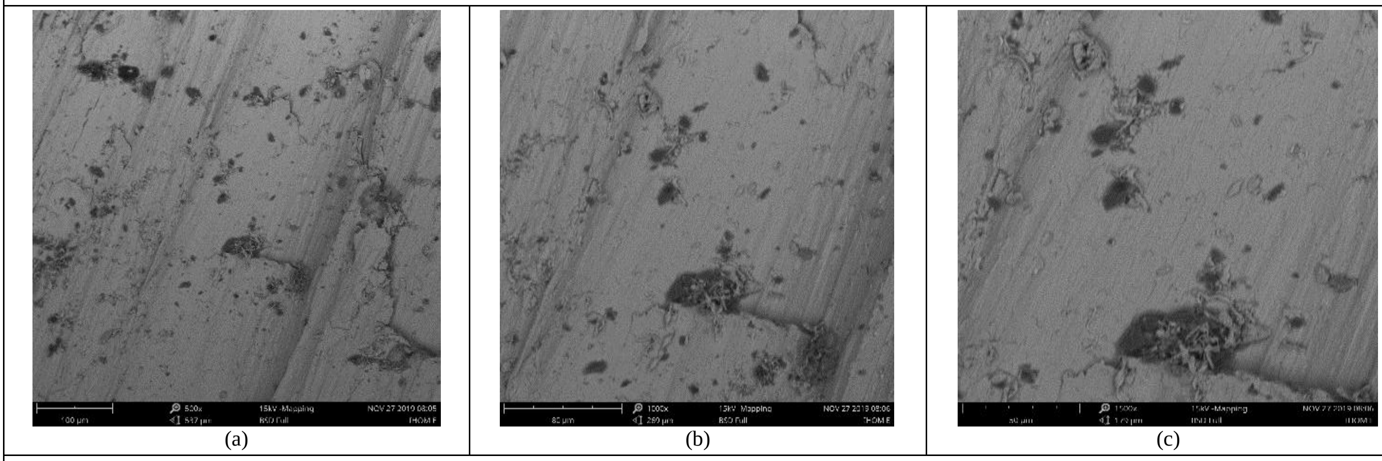


Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
26	Fe	Iron	81.31	89.81
47	Ag	Silver	0.89	1.90
14	Si	Silicon	3.01	1.67
6	C	Carbon	6.37	1.51
19	K	Potassium	1.05	0.81
20	Ca	Calcium	0.86	0.68
24	Cr	Chromium	0.66	0.68
13	Al	Aluminium	1.23	0.66
16	S	Sulfur	1.03	0.66
15	P	Phosphorus	0.91	0.56
8	O	Oxygen	1.21	0.38
11	Na	Sodium	0.76	0.34
12	Mg	Magnesium	0.70	0.34
22	Ti	Titanium	0.00	0.00

FOV: 537 µm, Mode: 15kV - Map, Detector: BSD Full, Time: NOV 27 2019 09:04



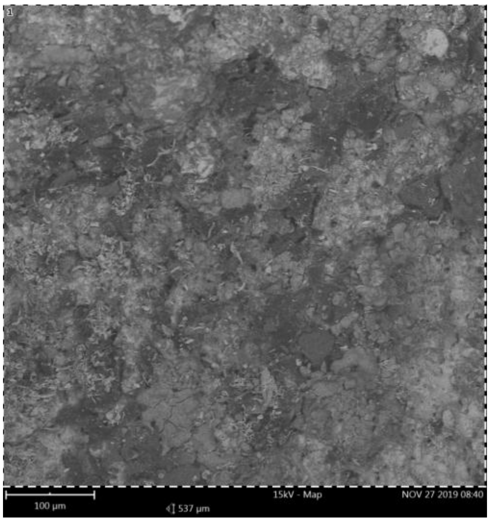
EDX study showing elemental distribution in the structure of the bar. The spikes indicate levels of weight concentration



(a) (b) (c)

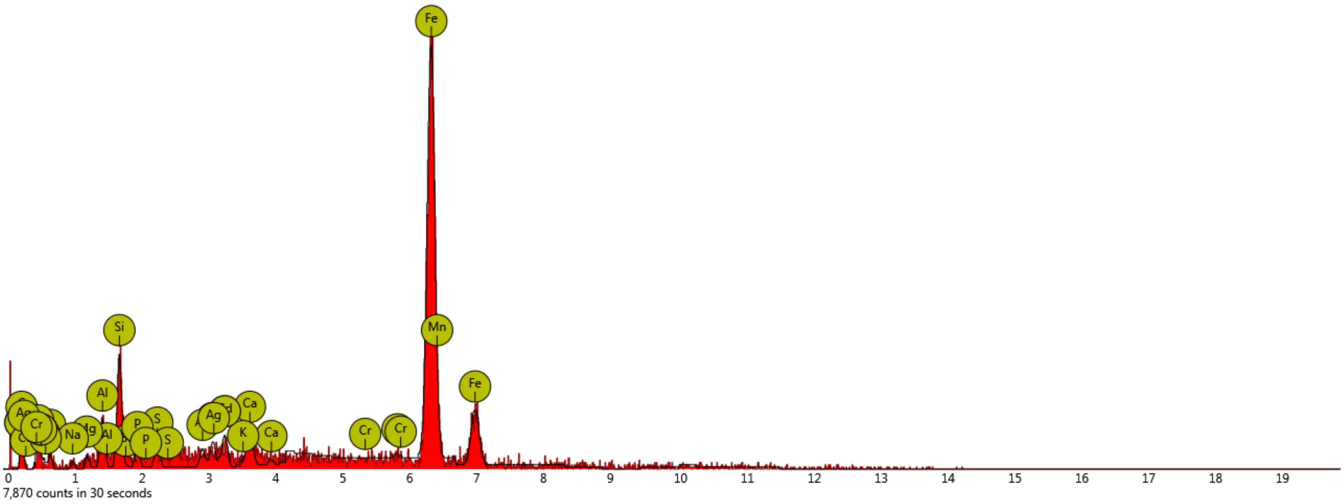
Micrograph (a) is x500, micrograph (b) is x1000 and micrograph (c) is x1500, all the micrographs show a ferrite matrix background and dark areas of pearlite and others as indicated above

Figure 11. EDS Study of Composition of Sample E supported by various High Resolution Morphology using Scanning Electron Microscope

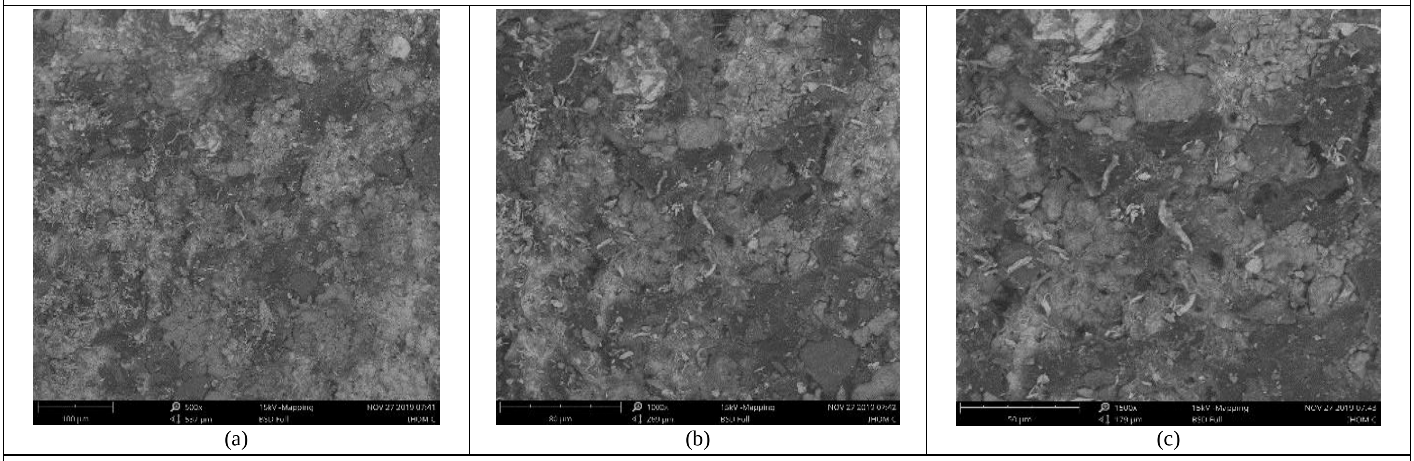


Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
26	Fe	Iron	58.33	77.12
6	C	Carbon	21.59	6.14
14	Si	Silicon	5.39	3.58
48	Cd	Cadmium	0.97	2.58
47	Ag	Silver	0.79	2.03
13	Al	Aluminium	2.78	1.78
20	Ca	Calcium	1.79	1.70
8	O	Oxygen	3.49	1.32
19	K	Potassium	1.12	1.03
16	S	Sulfur	0.91	0.69
25	Mn	Manganese	0.43	0.55
15	P	Phosphorus	0.70	0.51
11	Na	Sodium	0.90	0.49
12	Mg	Magnesium	0.80	0.46
24	Cr	Chromium	0.00	0.00

FOV: 537 µm, Mode: 15kV - Map, Detector: BSD Full, Time: NOV 27 2019 08:40



EDX study showing elemental distribution in the structure of the bar. The spikes indicate levels of weight concentration



(a) (b) (c)

Micrograph (a) is x 500, micrograph (b) is x 1000 and micrograph (c) is x 1500, all the magnifications show light matrix background of ferrite and dark areas of pearlite as indicated above. The pearlite cannot be resolved at this magnification.

Figure 12. EDS Study of Composition of Sample C supported by various High Resolution Morphology using Scanning Electron Microscope

IV. DISCUSSION

A. *Tensile Test*

Tensile tests have been carried out on test samples from mini-mills as a measure of quality; to ascertain the extent of their compliance with existing standards of steels used as reinforcement bars in building structures (Bolton, 1999; Balogun *et al.*, 2009; Adebayo, 2016). Building collapse has become the order of the day and several reasons have been advanced for their occurrence. Some of these include poor quality cement, poor structural design, poor quality of aggregate materials, poor quality of workmanship, improper use of building structure, and poor quality of reinforcement steel bars. This work addresses the last point. The test results in Table 2 and Figures 1-6 are here discussed.

Table 2 shows that Specimen A (T1) has the highest ultimate tensile strength Rm of 732 MPa, which corresponds to a maximum load of 82kN, a yield strength of 630 MPa, UTS : Y.S ratio of 1.16 and percentage elongation at fracture of 11.50%. This specimen has the highest ultimate tensile strength and yield strength among all the specimens, but the elongation at fracture ranks as 4. Specimen F (T3) comes second in terms of ultimate tensile strength and yield strength, it has ultimate strength of 639 MPa and yield strength of 451 MPa. This specimen is followed by Specimen D (T4) with ultimate tensile strength of 524MPa and yield strength of 366MPa; this same specimen equally has the highest elongation at fracture of 15.37%. The specimen with the least values of ultimate tensile strength and yield strength is Specimen C (T6) with ultimate tensile strength of 396 MPa and Yield strength of 303 MPa. Specimen E (T5) follows *Specimen* D (T4) with elongation at fracture of 12.37 %. Specimen G (T2) has the least elongation at fracture of 10%. Now comparing the results in Table 2 with the load – extension curves in Figs. 1-6, it can be seen that all the figures exhibited all the critical points of yield point, ultimate tensile load and necking region until consequent fracture which indicates that all the samples tested have a level of ductility (Champion and Arnold, 1969; Bolton, 1999; Uko, 2020). Their deformation patterns are similar to those of ductile steels. According to Cottrell (1980) mild steel reinforcement bar has a tensile strength of 380 MPa and above. Higgins (1985) said that structural steels used as reinforcement bars under relevant specification B.S 15 with carbon content of 0.20%C have a yield point of 240 N/mm^2, a tensile strength of 450N/mm^2 and an elongation percent of typically 25%. His analysis included second structural steel used as reinforcement bar under relevant specification of B.S 968 with carbon content of 0.20% and 1.5% Mn; for which the yield point of 350N/mm^2, tensile strength of 525N/mm^2, and elongation of 20% are obtainable. Comparing these standards with the measured parameters from the test results of the present work; the serious concern is the elongation at fracture of the specimens.

According to JIS Standard plain carbon JIS S20C which is equivalent of AISI 1020 with carbon content in the range 0.18-0.23%C has a minimum yield strength of 245.25MPa, tensile strength of 402.21MPa, and an elongation of 28%. Most of the tested specimens above have a yield strength that is above the minimum specified by JIS standard (JIS Standard, 2008). All the test results fall short of the specified minimum elongation at fracture for this category of steel. Only Specimen C (T6), did not meet up with the specified minimum standard of 402.21MPa for ultimate tensile strength for this category of steel. This can be explained from the chemical composition as well as the morphology of these steel samples. The Low elongation at fracture which is less than 25% in all the cases can also be explained from the chemical composition and the morphology of the test specimens. A most probable and convincing explanation however, seems to be coming from Figs 1-6 where all the figures showed initial grip slip. This must have affected the final elongation at fracture of some of the specimens. (Shrager, 1969; Cottrell, 1980; Higgins, 1985; Jain, 2009).

B. *Chemical Composition using Spectro-Lab Metal Analyzer*

Table 3 shows the result of the chemical composition of reinforcement steel bar from mini mill labeled sample G (1). The carbon content of 0.479%C indicates that the steel is a medium carbon steel and not mild or low carbon steel that is used for structural purpose. By carbon rating this is supposed to be a constructional steel. The silicon content is above the 0.15-0.35% range for structural steels. The amount of phosphorus and sulphur present is within specified limit of <0.030 and <0.035 respectively. The manganese content of 1.08%Mn and the other elements present are not enough to be regarded as alloying elements. The chemical composition of sample G partly explains why the steel bar has lower than expected mechanical properties of 466MPa ultimate tensile strength, 339MPa yield strength and 10% elongation at failure. This steel has chemical composition similar to Nigeria's St.60-Mn produced by former Delta Steel Company according to German Steel and Iron Quality Standard specification DIN 488 and DIN 17100. The carbon content is however, slightly above 0.42% specified in DIN. Even the mechanical properties of this steel agrees with this standard (Champion and Arnold, 1969; Chapman, 1972; DIN, 1980; Cottrell, 1980; Higgins, 1985; JIS Standard, 2008; Balogun *et al.*, 2009; Ihom, 2013).

Table 4 shows the chemical composition of sample D (2), which is the result of reinforcement steel bar from mini mill. The carbon content of 0.475%C indicates that it is a constructional steel because it is a medium carbon steel and not mild or low carbon steel which is used for structural purpose. The sulphur content is above <0.035%, but tolerable. All the other elements are within specified limits. The chemical composition of sample D steel bar explains why the elongation at fracture is not up to the specified minimum of 25% (JIS Standard, 2008). This sample however, had the highest elongation % of 15.37%. This may be due to the effects of elements like Cu, Mn and Cr which are there which is however, difficult to conclude, since liquid steel final treatment also affect this property. The composition of this steel bar however, agrees with German Iron and Steel Quality Standard specification DIN488 and DIN17100 for reinforcement steel rebar, except that the carbon content is more than 0.42% and the manganese is less than 0.9. The elongation at fracture is however, within the DIN specified range of 6-16% (Champion and Arnold, 1969; Chapman, 1972; DIN, 1980; Cottrell, 1980; Higgins, 1985; JIS Standard, 2008; Balogun *et al.*, 2009; Ihom, 2013)

Table 5 shows the chemical composition of sample A (3), which is the result of reinforcement steel bar from mini mill. The carbon content of 0.256%C qualifies the steel as a low carbon steel used for structural purposes. The silicon content is within limit. The phosphorus content is slightly above limit, as is the sulphur. The Cr and Ni contents are above specification and the other elements are within specifications. The chemical composition of this steel bar is no doubt responsible for the high ultimate tensile strength of 732MPa, and high yield strength of 630MPa exhibited by this steel. Its elongation at fracture is 11.5%, however, this is short of the expected value of a minimum of 28% for steels belonging to this class. The possible cause may be due to impurities or Cr and Ni exceeding specified value of Ni +Cr <0.35 (JIS Standard, 2008).

Table 6 shows the chemical composition of sample F (4) which is the result of reinforcement steel bar from mini-mill. The carbon content of 0.299%C qualifies the steel as a low carbon steel used for structural purpose. The other elements are within specification or just slightly above specification which can be tolerated. The ultimate tensile strength and the yield strength of this steel bar is within specification of steels in this category. However, the elongation at failure which is 10.31% falls short of the 25% minimum. This may be as a result of impurities or defects in the steel bar which tend to limit its elongation before final fracture (Cottrell, 1980; Higgins, 1985; JIS Standard, 2008).

Table 7 shows the chemical composition of sample C (5), which is the result of reinforcement steel bar from mini mill. The carbon content of 0.361%C shows that the steel is slightly above the range for low carbon steel and it is a medium carbon steel that can be considered for constructional purpose. The yield strength and the ultimate tensile strength of this steel is somehow close to that of S30C steel, but its elongation at fracture is a far cry from the minimum elongation of 25%. The possible reason may be due to the presence of defects-limiting elongation at fracture. This defects must have limited the steel bar attaining the maximum elongation by early initiation and propagation of cracks as the load was applied. The defects might even have arisen from the nature of treatment given the liquid steel using deoxidizers before casting. This elongation may have equally been affected by the grip slip experienced at the initial stage of the test. In any case the elongation agrees with German standard specification DIN 17100 which is used for high tensile steel rebar (Cottrell, 1980; DIN, 1980; Higgins, 1985; JIS Standard, 2008).

Table 8 shows the chemical composition of sample E (6), which is the result of reinforcement steel bar from mini mill. The carbon content of 0.206%C shows that the steel is low carbon steel which is used as structural steel in buildings and other structures. The Si, S are within standard specification, the P is just slightly above specification and all the other elements are within specified limits. This specimen has an ultimate tensile strength of 509MPa and yield strength of 346MPa and elongation at fracture of 12.37%. These values agree with the typical values obtainable for this grade of steel however, the elongation of 12.37% is far from the typical minimum elongation value of 28% at fracture for this grade of steel. Defects arising from treatment method may be responsible for the reduced elongation at fracture. It is also most probable that the elongation at fracture must have been affected by the grip slip experienced at the initial period of the testing. This can be seen in Fig.5 (Cottrell, 1980; Higgins, 1985; JIS Standard, 2008).

C. Scanning Electron Microscope and EDS Study of Reinforcement Steel Bars from Nigerian Mini Mills.

Fig. 7 shows Scanning Electron Microscope and EDS study of Sample A. The figure shows SEM micrograph adjacent to EDS compositional analysis, and a graph showing the elemental distribution in the structure of the steel sample. Also captured in the figure are the three different magnifications of the microstructure of the steel bar in the order: X500, X1000, and X1500.

The morphology of the steel bar as revealed by the SEM relates to the EDS compositional analysis and the distribution of the various elements present in the steel bar as shown in the spiked graph. The height of the spikes indicates the relative weight concentration of the elements in the structure of the steel bar. The morphology as revealed by the SEM indicates pearlite (black areas), ferrite matrix (light areas) and defect-like spots. According to Higgins (1983), pearlite areas in plain carbon steel increase as the carbon content increases. When this happens the steel morphology becomes gradually darker. The morphology of sample A agrees with the Spectro-Lab Metal Analyzer result which says the steel is a plain carbon steel with 0.256%C. The SEM and EDS results also confirm why the steel bar has good ultimate tensile strength and yield strength, but reduced elongation at fracture. Defects like segregations, pinholes and inclusions, arising from liquid steel treatment methods are known to reduce the ductility of steel in deformation or loading. The most probable reason for the reduced elongation at fracture remains the observed grip slip at the initial period of the tensile test (Cottrell, 1980; Higgins, 1985; JIS Standard, 2008).

Fig. 8 shows Scanning Electron Microscope and EDS study of Sample G. The figure shows SEM micrograph adjacent to EDS compositional analysis, and a graph showing the elemental distribution in the structure of the steel sample. Also captured in the figure are the three different magnifications of the microstructure of the steel bar in the order: X500, X1000, and X1500.

The morphology of the steel bar as revealed by the SEM relates to the EDS compositional analysis and the distribution of the various elements present in the steel bar as shown in the spiked graph. The height of the spikes indicates the relative weight concentration of the elements in the structure of the steel bar. The morphology as revealed by the SEM indicates deformed pearlite (black areas), ferrite matrix (light areas) and defect-like black spots. Aligned deformation lines can be seen in the SEM morphology of the steel. This must be from the rolling operation which was poorly adjusted and could not allow for normalization and recrystallization to take place for the recovery of the deformed grains. This explanation is no doubt the reason for the low elongation at fracture of 10% of the steel bar. According to Higgins (1983), pearlite areas in plain carbon steel increase as the carbon content increases, when this happens the steel morphology becomes gradually darker. The morphology of Sample G disagrees with the Spectro-Lab Metal Analyzer result, which says the steel is a plain carbon steel with 0.479%C. The SEM and EDS results also confirm why the steel bar has reduced ultimate tensile strength and yield strength, and reduced elongation at fracture. It should however, be noted that under DIN 17100 standard the elongation at fracture for this steel of 10% is still within specification of 6-16%. Defects like segregations, pinholes and inclusions, arising from liquid steel treatment methods are known to reduce the ductility of steel in deformation or loading (Cottrell, 1980; DIN 1980; Higgins, 1985; JIS Standard, 2008).

Fig. 9 shows Scanning Electron Microscope and EDS study of Sample F. The figure shows SEM micrograph adjacent to EDS compositional analysis, and a graph showing the elemental distribution in the structure of the steel sample. Also captured in the figure are the three different magnifications of the microstructure of the steel bar in the order: X500, X1000, and X1500.

The morphology of the steel bar as revealed by the SEM relates to the EDS compositional analysis and the distribution of the various elements present in the steel bar as shown in the spiked graph. The height of the spikes indicates the relative weight concentration of the elements in the structure of the steel bar. The morphology as revealed by the SEM indicates pearlite (black areas), ferrite matrix (light areas), and defect-like spots. According to Higgins (1983), pearlite areas in plain carbon steel increases as the carbon content increases, when this happens the steel morphology becomes gradually darker. The morphology of sample F agrees with the Spectro-Lab Metal Analyzer result which says the steel is a plain carbon steel with 0.299%C. The SEM and EDS results also confirm why the steel bar has good ultimate tensile strength and yield strength, but reduced elongation at fracture. Defects like segregations, pinholes and inclusions, arising from liquid steel treatment methods are known to reduce the ductility of steel in deformation or loading. Equally important is the rolling process which may not have allowed sufficient time for the recovery of all the deformed grains thereby reducing elongation at fracture. It is however, not alright to conclude that the above argument is responsible for the reduced elongation at fracture since initial grip slip was noticed in Fig.3 (Cottrell, 1980; Higgins, 1985; JIS Standard, 2008).

Fig. 10 shows Scanning Electron Microscope and EDS study of Sample D. The figure shows SEM micrograph adjacent to EDS compositional analysis, and a graph showing the elemental distribution in the structure of the steel sample. Also captured in the figure are the three different magnifications of the microstructure of the steel bar in the order: X500, X1000, and X1500.

The morphology of the steel bar as revealed by the SEM relates to the EDS compositional analysis and the distribution of the various elements present in the steel bar as shown in the spiked graph. The height of the spikes indicates the relative weight concentration of the elements in the structure of the steel bar. The morphology as revealed by the SEM indicates pearlite (black areas), ferrite matrix (light areas), and defect-like spots. According to Higgins (1983), pearlite areas in plain carbon steel increases as the carbon content increases, when this happens the steel morphology becomes gradually darker. The morphology of sample D agrees with the Spectro-Lab Metal Analyzer result which says the steel is a plain carbon steel with 0.475%C. The SEM and EDS results also confirm why the steel bar has reduced ultimate tensile strength and yield strength, with reduced elongation at fracture. For DIN 17100 quality standard specification for high tensile reinforcement steel bars the elongation is still within the range of 6-16%. Defects like segregations, pinholes and inclusions, arising from liquid steel treatment methods are known to reduce the ductility of steel in deformation or loading. Poor adjustment of the rolling process does also give rise to reduced mechanical properties of steel bars when grains are not given sufficient temperature and time for recrystallization (Cottrell, 1980; DIN, 1980; Higgins, 1985; JIS Standard, 2008).

Fig. 11 shows Scanning Electron Microscope and EDS study of Sample E. The figure shows SEM micrograph adjacent to EDS compositional analysis, and a graph showing the elemental distribution in the structure of the steel sample. Also captured in the figure are the three different magnifications of the microstructure of the steel bar in the order: X500, X1000, and X1500.

The morphology of the steel bar as revealed by the SEM relates to the EDS compositional analysis and the distribution of the various elements present in the steel bar as shown in the spiked graph. The height of the spikes indicates the relative weight concentration of the elements in the structure of the steel bar. The morphology as revealed by the SEM indicates pearlite (black areas), ferrite matrix (light areas), and defect-like spots. According to Higgins (1983), pearlite areas in plain carbon steel increase as the carbon content increases, when this happens the steel morphology becomes gradually darker. The morphology of sample E agrees with the Spectro-Lab Metal Analyzer result which says the steel is a plain carbon steel with 0.206%C. The SEM and EDS results also confirm why the steel bar has good ultimate tensile strength and yield strength, but reduce elongation at fracture. Defects like segregations, pinholes and inclusions, arising from liquid steel treatment methods are known to reduce the ductility of steel in deformation or loading. Poor adjustment of the rolling process does also give rise to reduced mechanical properties of steel bars when grains are not given sufficient temperature and time for recrystallization, so as to recover from deformation. The reduced elongation at fracture may also be due to grip slip during the tensile test (Cottrell, 1980; DIN, 1980; Higgins, 1985; JIS Standard, 2008).

Fig. 12 shows Scanning Electron Microscope and EDS study of Sample C. The figure shows SEM micrograph adjacent to EDS compositional analysis, and a graph showing the elemental distribution in the structure of the steel sample. Also captured in the figure are the three different magnifications of the microstructure of the steel bar in the order: X500, X1000, and X1500.

The morphology of the steel bar as revealed by the SEM relates to the EDS compositional analysis and the distribution of the various elements present in the steel bar as shown in the spiked graph. The height of the spikes indicates the relative weight concentration of the elements in the structure of the steel bar. The morphology as revealed by the SEM indicates pearlite (black areas), ferrite matrix (light areas), and defect-like spots. According to Higgins (1983), pearlite areas in plain carbon steel increase as the carbon content increases, when this happens the steel morphology becomes gradually darker. The morphology of sample C agrees with the Spectro-Lab Metal Analyzer result which says the steel is a plain carbon steel with 0.361%C. The SEM and EDS results also confirm why the steel bar has reduced ultimate tensile strength and yield strength, and reduced elongation at fracture. For DIN 17100 quality standard specification for high tensile reinforcement steel bars the elongation is still within the range of 6-16%. The SEM micrograph shows that the grains have recovered fully from the rolling operation. Defects like segregations, pinholes and inclusions, arising from liquid steel treatment methods are known to reduce the ductility of steel in deformation or loading (Cottrell, 1980; DIN, 1980; Higgins, 1985; JIS Standard, 2008).

V. CONCLUSION

The incidences of collapsed building structures in Nigeria has become a common occurrence with the attendant loss of property, and lives. Structural quality issues have been raised as being responsible. In this research ‘’Quality Analysis of Locally Produced Reinforcing Steel Bars Vis a Vis the Incidences of the Collapse of Buildings in Nigeria’’; the work has focused on the quality status of six (6) reinforcement steel bars from six (6) different mini-mills in Nigeria from different part of the country. Key findings of interest that needs to be addressed by the mini-mills are here outlined:

1. Chemical Composition of Steel Bars: Most of these mini-mills are not producing structural steel, but constructional steel with carbon content well above 0.3%C. Only sample E with 0.206%C, sample F with 0.299%C and sample A with 0.256%C qualify as structural steel

2. Structural steel with 0.12-0.30%C is commonly used for reinforcement steel bars for structures for their high ductility which prevents sudden collapse in buildings and structures. This work notes that none of the mini-mills is producing high tensile ribbed bars St.60-Mn which was once produced in this country by Delta Steel Company according to German iron and steel quality standard DIN488 and DIN 17100. Sample C, D and G have chemical compositions close to St.60-Mn but did not meet the standard specification for compositional analysis.

3. This work noted that even the samples with correct chemical composition for structural steel do not have the minimum specified elongation at fracture for structural steels. The work also noted that there is no standardization of the products from the mini mills. This makes it difficult for quality assessment.

4. The work noted on close examination of the SEM Micrographs of the steel bars that most of the crystals or grains were deformed and some defects were also sighted in the morphology of the steel bars.

5. Proper adjustment of the rolling process is required to enhance recovery of deformed grains, so as to correct ductility problem and also improve mechanical properties.

6. Ultimate tensile and yield strength were up to specified standard for most of the samples

7. Sample A had the highest ultimate tensile and yield strength of 732MPa and 630MPa respectively; which is quite impressive, but had elongation at fracture of 11.5%, which is short of the specified minimum of 25%. The steel is also a structural steel with a carbon content of 0.256%C. It was observed that grip slip may have affected the elongation at fracture.

8. Sample D had the highest elongation at fracture of 15.37%, which is still short of the specified minimum of 25%. It was however, observed that grip slip may have affected the elongation at fracture.

9. For quality production of reinforcement steel bars in Nigeria; mini-mills should address issues of standardization, chemical composition, and proper adjustment of their rolling process. This will improve the ultimate tensile and yield strength, as well as the elongation at fracture of the steel bars.

10. The mini mills must begin to focus on achieving the required quality of steel for their target market which primarily consists of plain bars, ribbed reinforcement bars and some amounts of light sections. For this purpose, the industry recommends the diligent segregation and standard grading of ferrous scrap into light melting through to heavy melting grades. The grading process in addition permits the separation of nonferrous material from the steelmaking quality scrap.

11. On account of the employment of unsegregated scrap in the steel production program of the mini mills, the presence of various unwanted materials can be seen in the chemistry of the steels selected for this study. The effects of these unwanted constituents which are adjudged to be negative, whether individually or collectively on the properties and performance of the steels easily forms the subject of another study.

12. In addition to the benchmarking the results of this study with Nigerian and international standards, it is considered that the comparison with steels produced using the standard Blast Furnace and Direct Reduction/Electric Arc Furnace processes would be instructive.

ACKNOWLEDGEMENT

This work is made possible by TETFUND Institutional Base Research (IBR) award reference number TETFUND/DESS/UNI/UYO/2018/RP/VOL.1. The research team for this project is highly appreciative of the opportunity given to them to investigate the menace of substandard reinforcement steel bars in the Nigerian market, which has contributed to the collapse of building structures in Nigeria. We are also thankful to the coordinating structure of this TETFUND funds in the University of Uyo, Akwa Ibom State-Nigeria.

REFERENCES

[1] Adebayo, A. (2016). *Nigeria*: *Tackling Challenges in Steel Sector*. Daily Trust, Abuja. www.allafrica.com. Viewed on 22/04/2017.

[2] Balogun, S., Esezobor D., Adeosun S., and Sekunowo O. (2009). *Challenges of Producing*

[3] Quality Construction Steel Bars in West Africa: Case study of Nigeria Steel Industry. Journal of Mineral & Materials Characterization & Engineering, Vol. 8, No. 4, pp 283 – 292, USA.

[4] Bolton, N.C. (1999) Materials for Engineering; 4th Reprint, London: Butterworth-Heinemann, A division of Reed Educational and professional Publishing Ltd, pp27-30

[5] B.S Standard: BSEN1002 Methods of tensile testing of metals (formerlyBS18) Standards specified as BSEN are European standards which are adopted as British standards.

[6] Champion, R.C and Arnold, E.C. (1969) Motor Vehicle Calculations and Science, Part 2, Edward Arnold (Publishers) Ltd, London, pp298-299.

[7] Chapman, W.A.J. (1972) Workshop Technology Part 1 LPE, Edward Arnold (publishers) Ltd. London, pp20-21

[8] Cottrell, A (1980) An Introduction to Metallurgy, 2nd Edition LPE. UK:The English Language Book Society and Edward Arnold (publishers) Ltd, pp509

[9] DIN (1980) German Steel and Iron Quality Standards DIN 488 and DIN 17100.

[10] Higgins R.A. (1985) Properties of Engineering Materials 5th Edition, UK: Hodder and Stoughton Educational, pp178-184

[11] Ihom, A.P. (2013) Case Hardening of Mild Steel using Cowbone as Energizer, African Journal of Engineering Research, Vol.1 (4) pp99-101

[12] Jain, R.K (2009) production Technology, 14th Reprint, New Delhi: Khana Publishers, pp19-27

[13] JIS Standard (2008) Japanese Industrial Standard Designation and Specification for Metals and Metal Products

[14] Shrager, A.M. (1969) Elementary Metallurgy and Metallography, third Edition, New York: Dover Publications, pp80-203

[15] Uko, D.K. *(2020) Iron-Carbon Phase diagram (a review)*. MSE 300 Materials Laboratory Procedures.Department of Materials Science and Engineering, University of Tennessee.

[16] Vlad, C. M. (1986). *A comparison between the Temprimal and Tempcore processes for high strength rebars*. 27th Mechanical Working and Steel Processing Conference Proceedings, Iron and Steel Society, Vol. 23, p. 908 – 912.

How to Cite this Article:

Ihom, P. A., Uko, D. K. & Eleghasim, C. O. (2020). Quality Analysis of Locally Produced Reinforcing Steel Bars vis-a-vis the Incidences of Collapse of Buildings in Nigeria. International Journal of Science and Engineering Investigations (IJSEI), 9(102), 26-43. http://www.ijsei.com/papers/ijsei-910220-04.pdf