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CHEMICAL COMPOSITIONAL STUDY OF SOME REINFORCING STEEL REBARS FOR CONCRETE STRUCTURES PRODUCED BY SELECTED MINI MILLS IN NIGERIA

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ABSTRACT

Chemical Compositional Study of Some Reinforcing Steel Rebars for Concrete Structures Produced by Selected Mini Mills in Nigeria has been carried out. Reinforcement steel bars from seven different mini mills across Nigeria have been investigated for chemical composition amidst the allegations that incidences of collapsed buildings in Nigeria can be linked to chemical compositional issues in reinforcement steel rebars produced in Nigeria from unprocessed steel scraps. This study was only targeted at mini mills which produce their liquid steel from scraps and process it into reinforcement steel rebars. Seven samples of reinforcement steel rebars for concrete structure reinforcement were given chemical compositional and microstructural analysis using spectro-lab metal analyzer (Fe-01-F) and Energy Dispersive X-Ray Fluorescent, miniPal4 ED-XRF Model. Six of the bars were 12mm diameter and only one sample was 10mm; amazedly all of them had different chemical compositions. The carbon content percent of the samples varied as follows: sample A 0.256%; sample B 0.391%; sample C 0.361%; sample D 0.475%; sample E 0.206%; sample F 0.299%; and sample G 0.479%. The same thing applied to their carbon equivalent values which were all completely different indicating that they have different mechanical properties. Samples with carbon equivalent value outside the threshold value were sample D with 0.545 and sample G with 0.623. For different grades of steels the allowable chemical compositional deviation is normally ±0.05, however, most of the samples exceeded this allowable limits. The study therefore based on the above results drew this conclusion, that incidences of collapsed buildings in Nigeria cannot be unconnected with chemical compositional problems in the produced reinforcing steel rebars from Nigerian mini mills given the astounding divergence in the standards of the bars; with every mill producing what they feel like producing. The work has recommended that if sanity is to be restored; Standard Organization of Nigeria should enforce standard in the mini mills. Mills should implement compositional adjustments, controlled rolling, and cooling to improve mechanical properties. Mills should

substitute or complement scraps with direct reduced iron (DRI) to improve compositional control and quality of their produced reinforcement steel rebars.

Keywords: Chemical, Compositional, Incidences of building collapse, Steel rebar, Concrete, Structures, Reinforcing

INTRODUCTION

Engineering materials are manufactured to specification. The specification must conform to accepted standard of the product. Most countries have their industrial standards in addition to the international standard (ISO). Sometimes the local industrial standard is a modification of the international standard as we have in JIS and NIS. Standards specify what the chemical composition of the engineering material should be. It also clearly specifies the physical and mechanical properties of the engineering material. The chemical composition and microstructure of the engineering material however, determines both the physical and the mechanical properties of the engineering material, and dictates the area of application of the engineering material (Ihom *et al.,* 2020a).

When an engineering material is manufactured according to specification as stated in the standard relevant to that engineering product, it is said to be a quality product. It can serve the purpose for which it is produced (Ihom *et al.,* 2020b).

As rightly captured above the importance of chemical compositional specification in engineering materials cannot be over emphasized. It is the hallmark of quality in engineering products. According to Balogun *et al.,* (2009) in common engineering application mild steel 0.1-0.3%C are used in reference to different grades of plain carbon steels. They are mostly produced by hot rolling and constitute the bulk (by weight) of all structural steel profiles commonly used in constructional and allied engineering works. The areas of mild steel application include structural concrete reinforcement and trusses. Other areas are automobiles, plant construction, foundry, agricultural machineries etc. Nigerian reinforcement steel bars are produced by melting automobile scraps in medium frequency induction furnaces, and continuous casting process is used to produce billets. It is this billets that are hot rolled by the mini mills to produce reinforcement steel rebars of various gauge diameter and sizes (Balogun *et al*., 2009; Ihom, 2012).

The inability of Nigerian government to get her integrated steel and mini steel companies running had given rise to the establishment of many local mini mills by privately owned companies. Some of these companies produce rolled products from imported billets; the quality of which cannot be ascertained. There are however; those that process 100% scraps into molten steel using induction furnaces and electric arc furnaces. They produce ingots which they then roll into rebar, smooth rods, angled bars, and other constructional steel shapes. According to Ihom, *et al.,* (2020a), Ajaokuta Steel Company project was conceived as an integrated steel company with an annual capacity of 1.3MT of liquid metal per annum. It was to run on the blast furnace route of steel production; utilizing iron ore from Itakpe Iron Ore Mining Company (NIOMCO). After forty years the project is yet to be completed. Delta Steel Company, Aladja, was conceived as a mini steel plant based on the Midrex process of steel production through the electric arc furnace process of steelmaking using direct reduced iron from the Midrex process. The plant had annual capacity of 1.0MT of metal. This company was built by the Germans using the latest technology as of that time. It was completed and commissioned. It operated on imported iron ore from Liberia and was able to at a point attain 25% installed capacity before it finally shut down in 1995. While in existence the company was able to supply quality billets produced to specification to Jos Steel Rolling Mills, Katsina Steel Rolling Mills, and other rolling mills in the country. The products from this company were of high quality and standard because the technology was German and based on German industrial standard (DIN). Ajaokuta Steel Company also had all the rolling sections completed and commissioned. Some of these sections were producing reinforcing steel rebar and other rolled products using imported billets and billets from Delta Steel Company before it finally shut down (Ihom*, et al.,* (2020). The absence of the two companies made the share of the market for reinforcing steel rebar to be taken over wholly by private mini mills in Nigeria and imported products from China. The local mini mills some of them depend 100% on processed scraps to produce their reinforcing steel rebar.

This has raised a lot of chemical compositional issues leading to quality problems. Substandard reinforcing steel rebar have been alluded to being responsible for collapsed structures in Nigeria today. While this allusion have not been confirmed; these problems persist and also the demand for reinforcement steel rods continue to rise. Gupta (2012) calculates the size of the Nigerian market for steel products at about 2.5MT annually. With economic growth of the past seven years the size of the market can be put at 3.0MT. Of this, 1.77MT are long steel products like rebars. Domestic output in this product group is estimated at 1.2MT. These figures have equally adjusted as a result of the economic growth of the past seven years. The rest is supplied from abroad through importation (Ihom, 2012; Ihom *et al.,* 2020b).

While concerns are being raised about substandard reinforcing steel rebars in the Nigerian market; researchers have observed that the quality of steel scraps obtained today in comparison with thirty years ago is very low. Researchers are of the opinion that for quality of steel products to be maintained less percentage of scraps should be used, and where possible scraps should be substituted with direct reduced iron (DRI). The low quality of scraps utilized by the Nigerian mini mills have led to contamination of steel products, this was observed by Balogun*, et al.,* (2009). According to the authors most of the elements were far in excess of standard compositional specification for the reinforcement steel rebars tested (Balogun *et al.,* 2009; Ihom, 2012).

This paper intends to investigate the chemical composition of several steel rebars from different mini mills across Nigeria in order to correlate the standard of these steel rebars with the incidences of collapsed buildings in the country.

MATERIALS AND METHOD

Materials and Equipment

The materials used for the research work were ribbed reinforcement steel bars (rebar) collected from different mini mills across Nigeria. 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, scanning electron microscope (SEM), energy dispersive spectroscope (EDS), digital weighing balance, and spectrolab metal analyzer (Fe-01-F).

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 1 Samples of Reinforcement steel Bars Across Nigeria (Rebars) Collected from Different Mini Mills

S/No.	Sample Label	Location	Ribbed Reinforcement steel rod size (mm)
1	A	Lagos	12
2	B	Lagos	10
3	C	Abia	12
4	D	Cross-River	12
5	E	Anambra	12
6	F	Kano	12
7	G	Abuja	12

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

Seven (7) 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.

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

The samples of 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.

RESULTS AND DISCUSSION

Results

The results of this study are presented as follows:

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

Table 2 Chemical Composition of 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				
Carbon Equivalent Value (CEV)	0.351										

Table 3 Chemical Composition of Specimen B /Quality Analysis (Fe-01-F)

Element	C Si Mn P S Cr Ni Mo Al Cu Co
%	0.391 0.275 0.60 0.054 0.058 0.162 0.090 0.0070 0.0030 0.289 0.016
Element	Ti Nb V W Pb Mg B Sn Zn
%	0.0012 <0.0040 0.0027 <0.010 <0.0030 <0.0010 0.0064 0.019 0.019
Element	As Bi Ca Ce Zr La Fe
%	0.023 0.0043 0.0038 0.0046 0.0029 0.0036 98.0
Carbon Equivalent Value (CEV)	0.501

Table 4 Chemical Composition of Specimen C /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
Carbon Equivalent Value (CEV)	0.456

Table 5 Chemical Composition of Specimen D /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
Carbon Equivalent Value (CEV)	0.545

Table 6 Chemical Composition of 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				
Carbon Equivalent Value (CEV)	0.310										

Table 7 Chemical Composition of Specimen F /Quality Analysis (Fe-01-F)

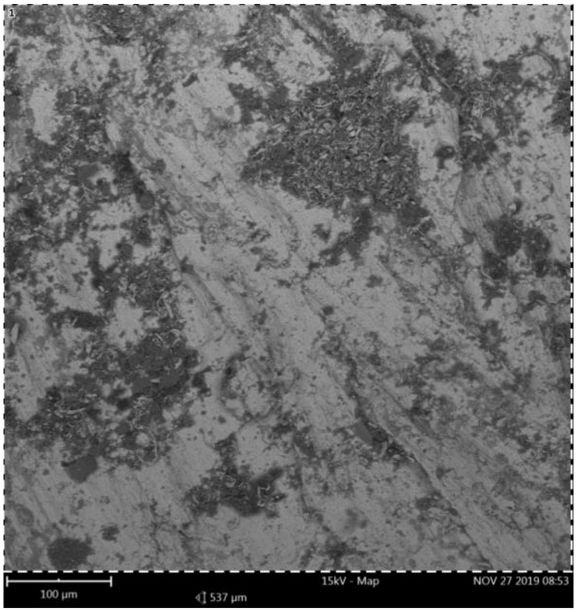
Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co
%	0.299	0.205	0.55	0.029	0.033	0.210	0.061	0.0092	0.0031	0.186	0.0065
Element	Ti	Nb	V	W	Pb	Mg	B	Sn	Zn		
%	0.0024	<0.0040	0.0065	<0.010	<0.0030	<0.0010	0.0036	0.0059	0.018		
Element	As	Bi	Ca	Ce	Zr	La	Fe				
%	0.012	<0.0020	0.0015	<0.0030	0.0025	0.0015	<98.4				
Carbon Equivalent Value (CEV)	0.377										

Table 8 Chemical Composition of Specimen G/Quality Analysis (Fe-01-F)

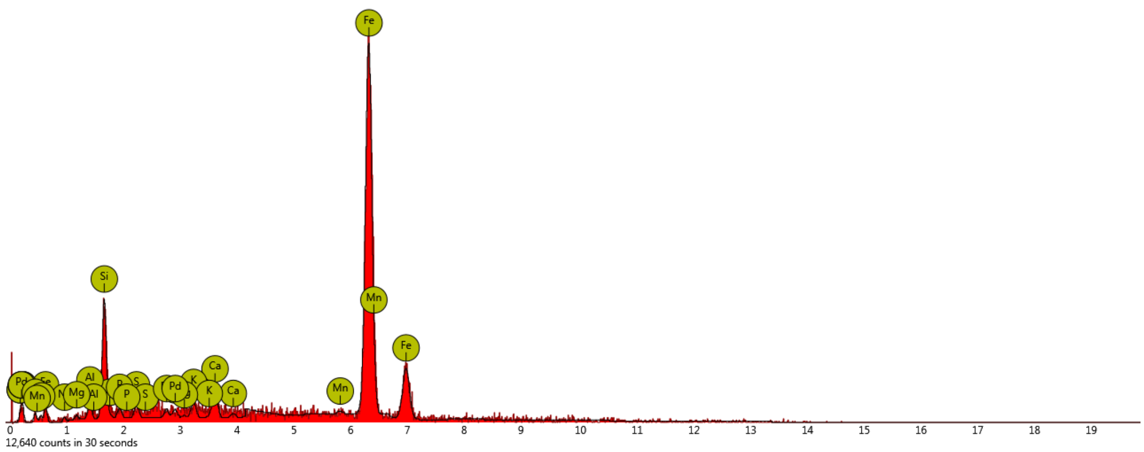
Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co
%	0.479	0.411	1.08	0.021	0.035	0.102	0.035	0.0099	0.047	0.115	0.0078
Element	Ti	Nb	V	W	Pb	Mg	B	Sn	Zn		
%	0.0044	<0.0040	0.0090	<0.010	<0.0030	<0.0010	0.0035	0.0012	<0.0020		
Element	As	Bi	Ca	Ce	Zr	La	Fe				
%	0.012	0.0032	0.0044	0.0082	0.0033	0.0059	97.6				
Carbon Equivalent Value (CEV)	0.623										

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

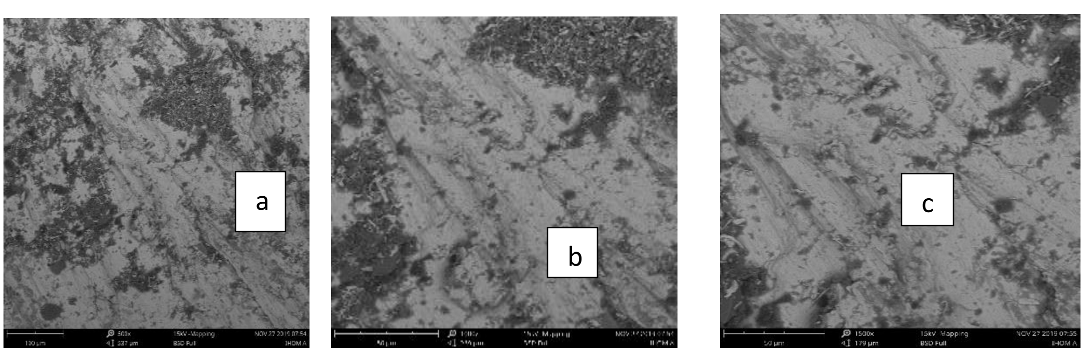
The results below are high resolution morphology of reinforcement steel bars from seven mini-mills in Nigeria using scanning electron microscope. The microstructures are supported by EDX study of the composition of their structures and elemental distribution. See Figs 1-7.



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

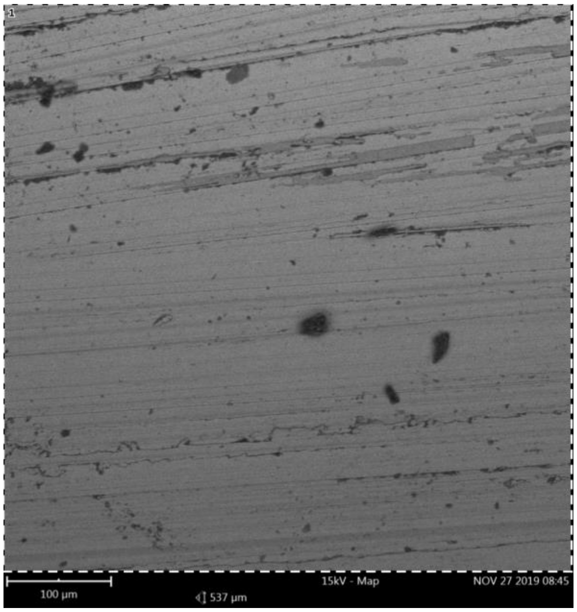


EDS study showing elemental distribution in the structure of the bar. The spikes indicate levels of weight concentration



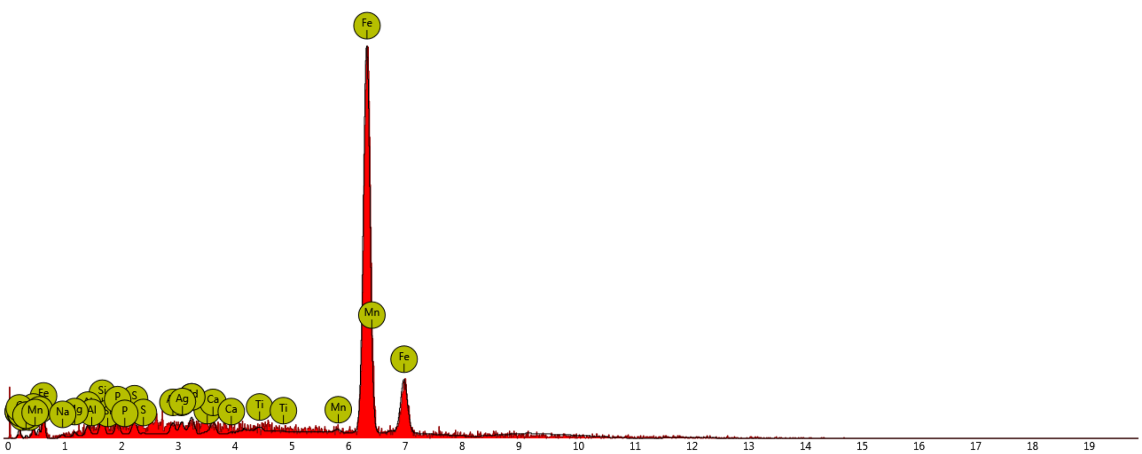
Micrograph (a) is x 500, micrograph (b) is x 1000 and micrograph (c) is x 1500, all the magnifications show a ferrite matrix background and dark areas of pearlite as indicated above

Fig.1 EDS Study of Composition of Sample A supported by various High Resolution Morphology using Scanning Electron Microscope

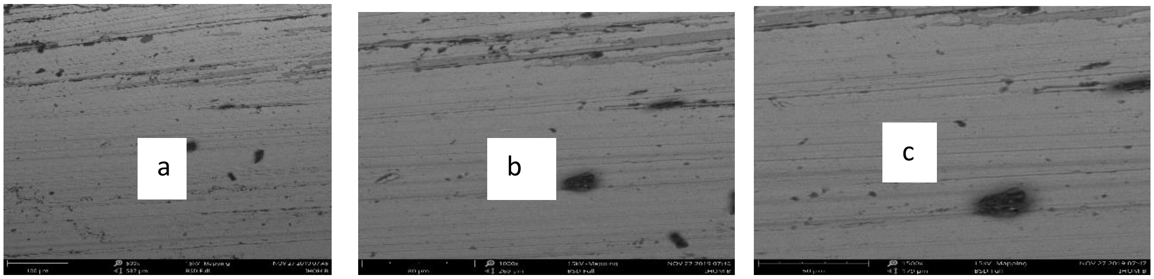


Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
26	Fe	Iron	83.20	89.37
48	Cd	Cadmium	0.97	2.10
47	Ag	Silver	0.82	1.70
6	C	Carbon	5.29	1.22
14	Si	Silicon	1.58	0.85
20	Ca	Calcium	0.90	0.70
19	K	Potassium	0.91	0.69
16	S	Sulfur	1.03	0.63
8	O	Oxygen	1.89	0.58
15	P	Phosphorus	0.94	0.56
25	Mn	Manganese	0.45	0.47
13	Al	Aluminium	0.82	0.43
22	Ti	Titanium	0.34	0.31
12	Mg	Magnesium	0.47	0.22
11	Na	Sodium	0.37	0.16

FOV: 537 µm, Mode: 15kV - Map, Detector: BSD Full, Time: NOV 27 2019 08:45

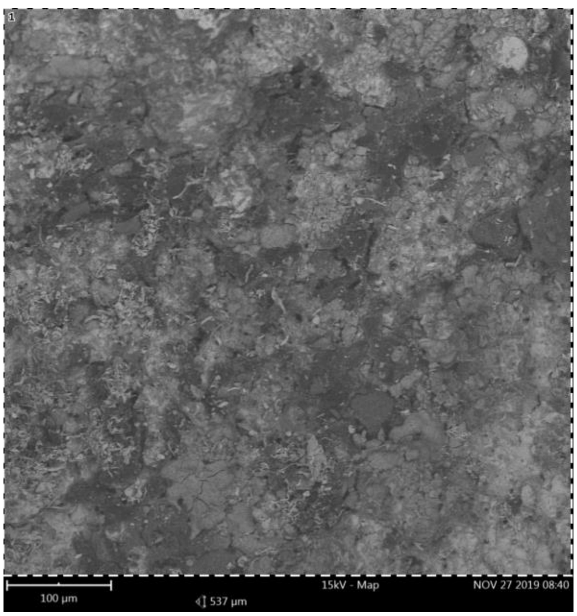


EDS Study showing elemental distribution in the structure of the bar. The spikes indicate levels of weight concentration



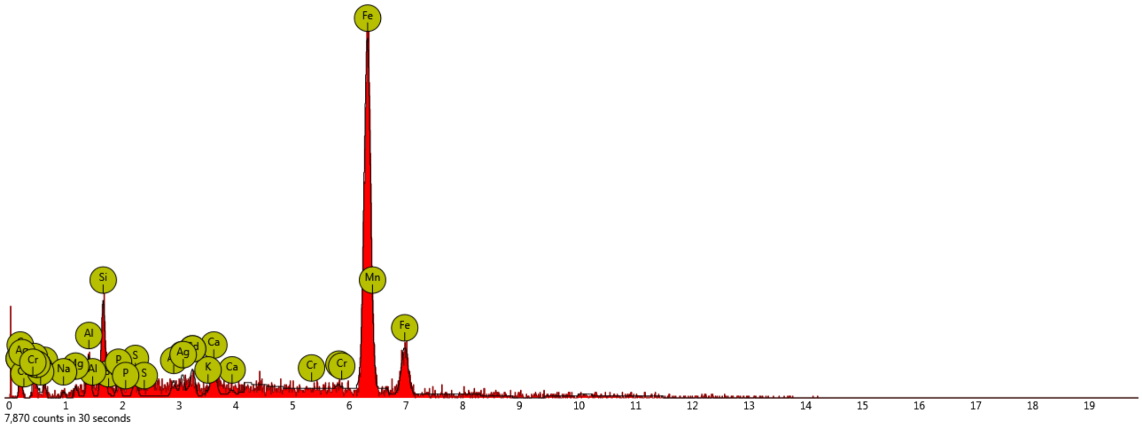
Micrograph (a) is X500, micrograph (b) is X1000 and micrograph (c) is X1500, all the magnifications of the micrograph show a ferrite matrix background and dark areas of pearlite and others as indicated above

Fig.2 EDS Study of Composition of Sample B supported by various High Resolution Morphology using Scanning Electron Microscope

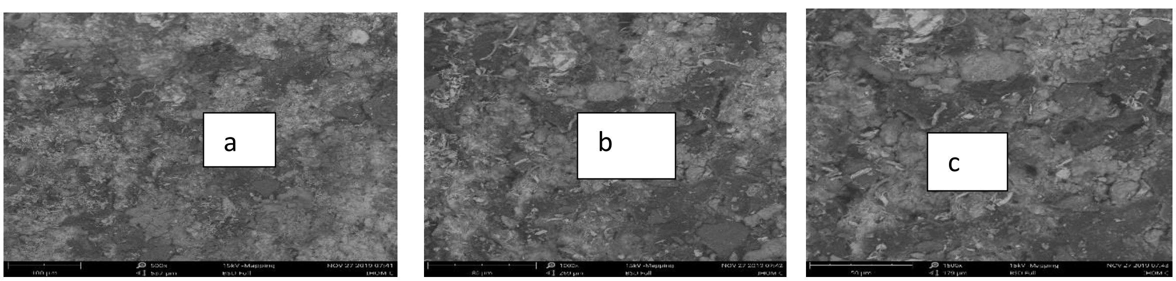


Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
26	Fe	Iron	58.33	77.12
6	C	Carbon	21.59	6.14
14	Si	Silicon	5.39	3.58
48	Cd	Cadmium	0.97	2.58
47	Ag	Silver	0.79	2.03
13	Al	Aluminium	2.78	1.78
20	Ca	Calcium	1.79	1.70
8	O	Oxygen	3.49	1.32
19	K	Potassium	1.12	1.03
16	S	Sulfur	0.91	0.69
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



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



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.

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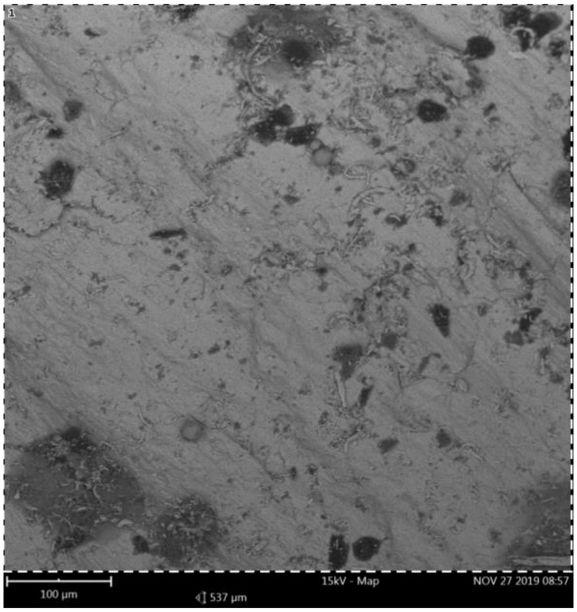
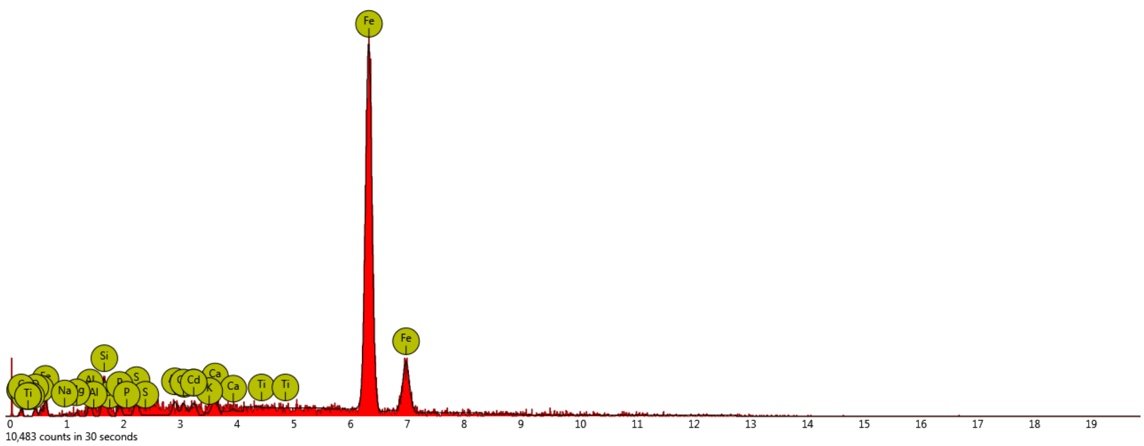
Fig. 3. EDS Study of Composition of Sample C supported by various High Resolution Morphology using Scanning Electron Microscope

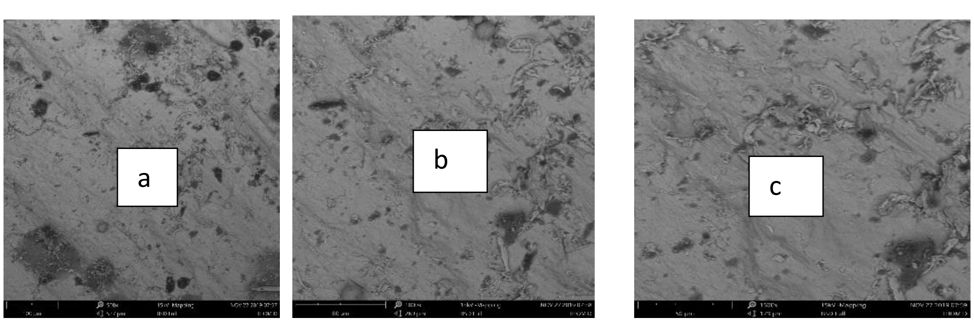


Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
26	Fe	Iron	80.69	88.91
47	Ag	Silver	0.97	2.06
6	C	Carbon	7.08	1.68
14	Si	Silicon	2.96	1.64
48	Cd	Cadmium	0.58	1.29
20	Ca	Calcium	1.38	1.09
13	Al	Aluminium	1.28	0.68
16	S	Sulfur	1.02	0.64
19	K	Potassium	0.83	0.64
8	O	Oxygen	1.53	0.48
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

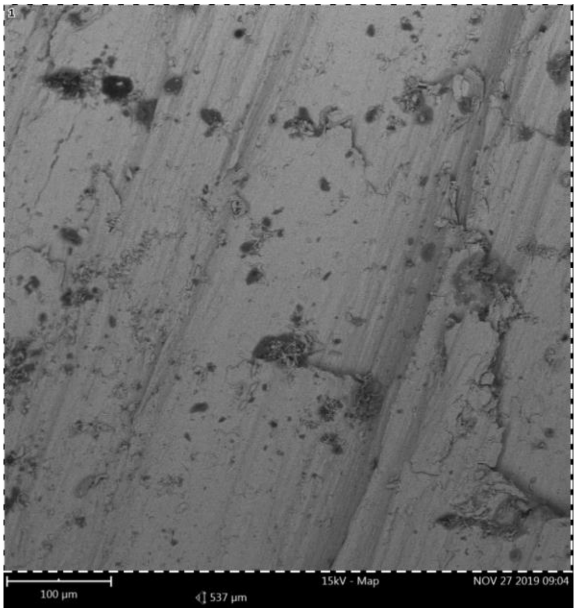


EDS study showing elemental distribution in the structure of the bar. The spikes indicate levels of weight concentration



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

Fig. 4. 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

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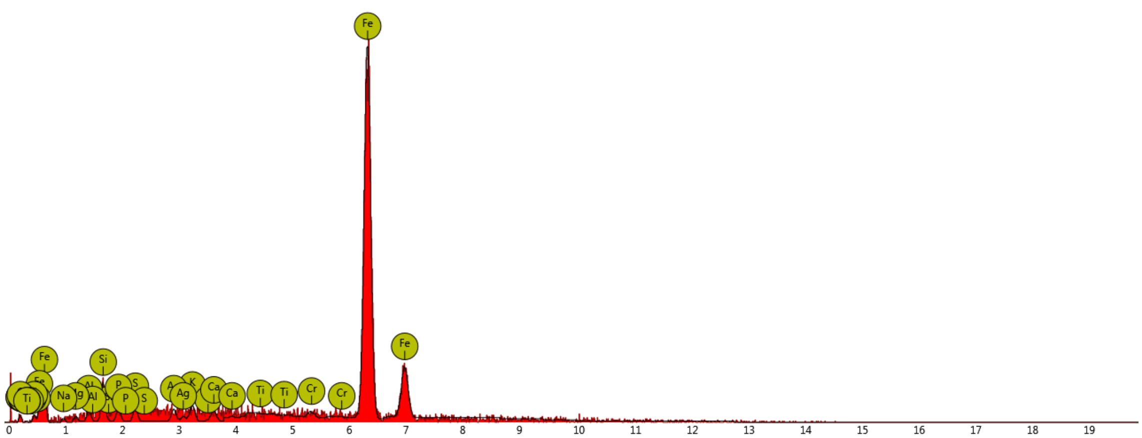
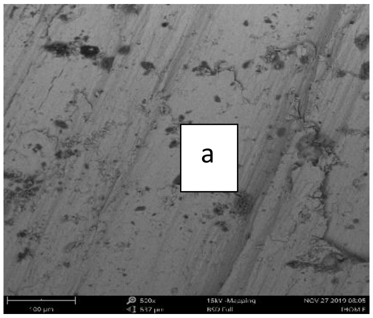
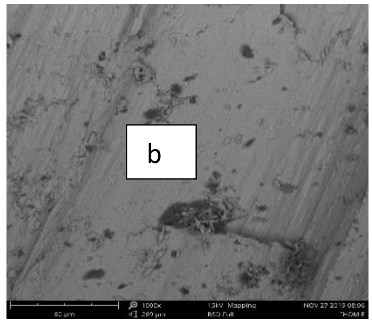
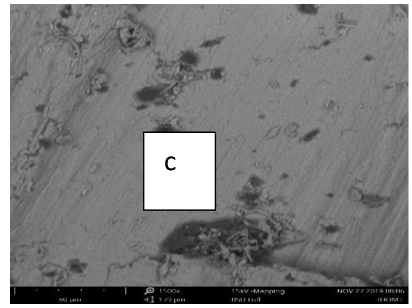


EDS study showing elemental distribution in the structure of the bar. The spikes indicate levels of weight concentration

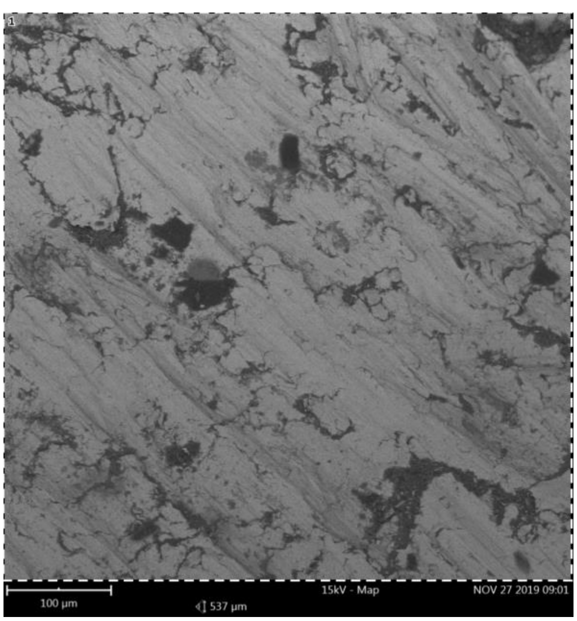






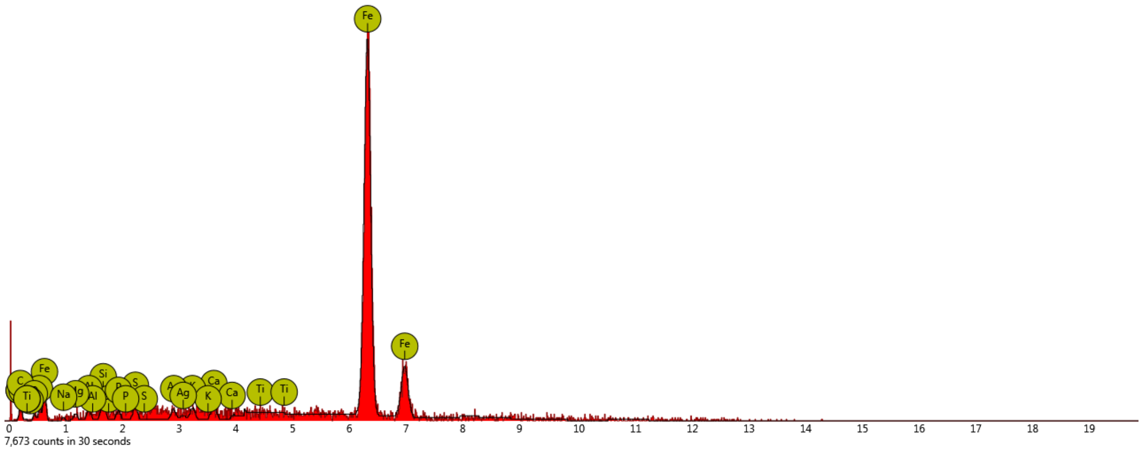
Micrograph (a) is x500, micrograph (b) is x1000 and micrograph (c) is x1500, all the micrographs show a ferrite matrix background and dark areas of pearlite and others as indicated above

Fig. 5. EDS Study of Composition of Sample E supported by various High Resolution Morphology using Scanning Electron Microscope

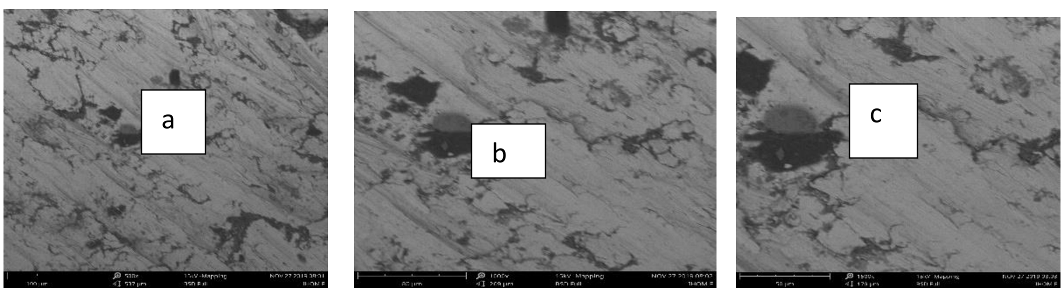


Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
26	Fe	Iron	79.23	90.54
6	C	Carbon	11.67	2.87
47	Ag	Silver	0.74	1.63
14	Si	Silicon	1.70	0.98
20	Ca	Calcium	1.10	0.90
19	K	Potassium	0.82	0.66
16	S	Sulfur	0.86	0.57
13	Al	Aluminium	0.96	0.53
15	P	Phosphorus	0.55	0.35
8	O	Oxygen	1.05	0.34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

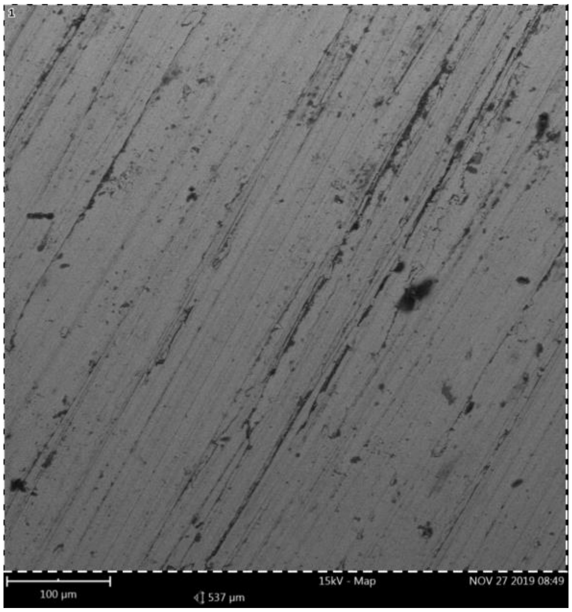


EDS study showing elemental distribution in the structure of the bar. The spikes indicate levels of weight concentration



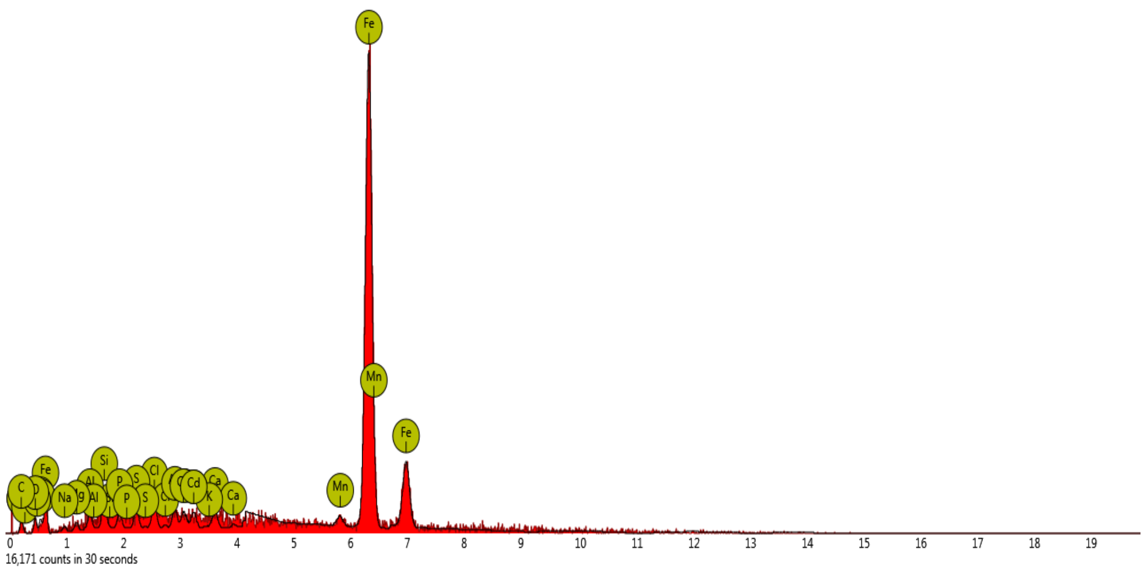
Micrograph (a) is x 500, micrograph (b) is x 1000 and micrograph (c) is x 1500. All the magnifications show a ferrite matrix background and dark areas of pearlite as indicated above

Fig. 6 EDS Study of Composition of Sample F supported by various High Resolution Morphology using Scanning Electron Microscope

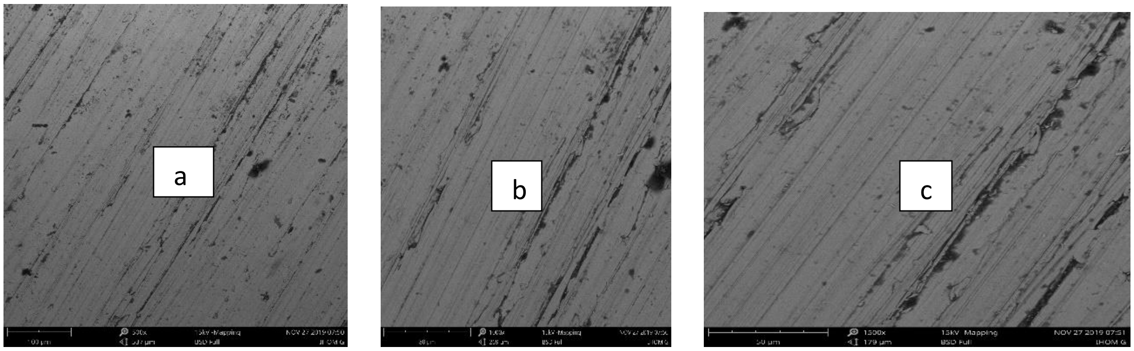


Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
26	Fe	Iron	77.51	86.76
47	Ag	Silver	1.07	2.31
6	C	Carbon	8.35	2.01
25	Mn	Manganese	1.19	1.31
14	Si	Silicon	2.19	1.24
48	Cd	Cadmium	0.51	1.15
17	Cl	Chlorine	1.31	0.93
20	Ca	Calcium	0.96	0.77
16	S	Sulfur	1.04	0.67
8	O	Oxygen	1.99	0.64
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



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

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

Discussion

Chemical Composition using Spectro-Lab Metal Analyzer

Table 2 shows the chemical composition of sample A, 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 carbon equivalent value (CEV) is less than 0.51 and according to Balogun, *et al.,* (2009) the steel can be welded. Impurities or Cr and Ni exceeding specified value of Ni +Cr <0.35 may have effect on the elongation property of the rebar (Bolton, 1999; JIS Standard, 2008; Balogun *et al.,* 2009).

Table 3 shows the chemical composition of Specimen B, which is the result of reinforcement steel bar from a mini-mill in Lagos-Nigeria. The carbon content of 0.391% shows that the steel is far above the range for low carbon steel, and it is a medium carbon steel that can be considered for constructional purpose (Champion and Arnold, 1969; Chapman, 1972; Cottrell, 1980; Higgins, 1985; JIS Standard, 2008; Balogun *et al.,* 2009; Ihom, 2013). According to Balogun *et al.,* (2009) in common engineering application mild steel 0.1-0.3%C are used in reference to different grades of plain carbon steels. These steels are mostly produced by hot rolling, and constitute the bulk (by weight) of all structural steel profiles commonly used in constructional and allied engineering works. Some are also used as structural reinforcement and trusses. This grade has a carbon deviation of more than 0.5. Structural steels with ‘chemical compositional carbon deviation’ of less or equal to 0.5 are accepted, but become unacceptable when it is more than 0.5. Specimen B has a carbon equivalent value of 0.501 which is close to the threshold value of 0.51 for unweldable steels. This rebar will be welded with some difficulties. These type of variations may have effect on the mechanical properties of the rebar (Cottrell, 1980; Higgins, 1985; JIS Standard, 2008; Ihom, 2012; Ihom, 2020).

Table 4 shows the chemical composition of sample C, 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. This grade has a carbon deviation of slightly more than 0.5. Structural steels with 'chemical compositional carbon deviation' of less or equal to 0.5 are accepted, but become unacceptable when it is more than 0.5. Specimen C has a carbon equivalent value of 0.456 which is less than the threshold value of 0.51 for unweldable steels. This rebar will be welded with some ease. These type of variations may have effect on the mechanical properties of the rebar (Cottrell, 1980; Higgins, 1985; JIS Standard, 2008; Balogun *et al.,* 2009; Ihom, 2020).

Table 5 shows the chemical composition of sample D, 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. This grade has a carbon deviation of more than 0.5. Structural steels with 'chemical compositional carbon deviation' of less or equal to 0.5 are accepted, but become unacceptable when it is more than 0.5. Specimen D has a carbon equivalent value of 0.545 which is more than the threshold value of 0.51 for unweldable steels. This rebar will be welded with some difficulties. These type of variations may have effect on the mechanical properties of the rebar. As carbon equivalent value (CEV) of steel increases the strength and hardness of the steel also increases, but the ductility of the steel decreases. This is not good for reinforcement steel bars which are supposed to promote ductile failures in structures and not sudden and catastrophic failure (Cottrell, 1980; Higgins, 1985; JIS Standard, 2008; Ihom, 2020).

The sulphur content is above <0.035%, but tolerable. All the other elements are within specified limits. 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. It is however, clearly established that it does not belong to the grades of steels referred to as mild steels (Champion and Arnold, 1969; Chapman, 1972; DIN, 1980; Cottrell, 1980; Higgins, 1985; JIS Standard, 2008; Balogun *et al.,* 2009; Ihom, 2013; Ihom, 2020)

Table 6 shows the chemical composition of sample E, 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. Structural steels with 'chemical compositional carbon deviation' of less or equal to 0.5 are accepted, but become unacceptable when it is more than 0.5. Specimen E has a carbon equivalent value of 0.310 which is less than the threshold value of 0.51 for un-weldable steels. This rebar will be welded with ease. (Cottrell, 1980; Higgins, 1985; JIS Standard, 2008; Balogun *et al.,* 2009; Ihom, 2012; Ihom, 2020).

Table 7 shows the chemical composition of sample F 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. Structural steels with 'chemical compositional carbon deviation' of less or equal to 0.5 are accepted, but become unacceptable when it is more than 0.5. Specimen F has a carbon equivalent value of 0.377, which is less than the threshold value of 0.51 for un-weldable steels. This rebar will be welded with ease. (Cottrell, 1980; Higgins, 1985; JIS Standard, 2008; Balogun *et al.,* 2009; Ihom, 2012; Ihom. 2020).

Table 8 shows the result of the chemical composition of reinforcement steel bar from mini mill labeled sample G. 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 (B.S Standard, 1980). 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. 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). Structural steels with 'chemical compositional carbon deviation' of less or equal to 0.5 are accepted, but become unacceptable when it is more than 0.5. Specimen G has a carbon equivalent value of 0.623, which is more than the threshold value of 0.51 for un-weldable steels. This rebar will be welded with difficulty. In welded structures these kind of joints become initiators of failure. As carbon equivalent value (CEV) of steel increases the strength and hardness of the steel also increases, but the ductility of the steel decreases. This is not good for reinforcement steel bars which are supposed to promote ductile failures in structures and not sudden and catastrophic failures (Cottrell, 1980; Higgins, 1985; JIS Standard, 2008; Balogun *et al.,* 2009; Ihom, 2020).

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

Fig. 1 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. Balogun *et al.,* (2009) said ''composition and microstructure of a material determines its properties and application (Cottrell, 1980; Higgins, 1985; JIS Standard, 2008; . Balogun *et al.,* 2009).

Fig. 2 shows Scanning Electron Microscope and EDS study of sample B. 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 indicate 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 B disagrees with the spectro-lab metal analyzer result which says the steel is a plain carbon steel with 0.391%C. The SEM morphology reveals a ferrite matrix, deformed cementite and aligned grains, dark spots and lines which are obviously from the rolling operation. The amount of pearlite seen in the morphology did not agree with the carbon content of the steel. The most likely explanation to this anomaly is that the rolling process was poorly adjusted; the microstructure of the steel bar also indicate that it is in a work-hardened state. Balogun *et al.*, (2009) said ‘’composition and microstructure of a material determines its properties and application (Cottrell, 1980; Higgins, 1985; Balogun *et al.*, 2009). 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; Higgins, 1985; JIS Standard, 2008; Ihom, 2012; Ihom, 2020).

Fig. 3 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 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. Balogun *et al.*, (2009) said ‘’composition and microstructure of a material determines its properties and application (Cottrell, 1980; DIN, 1980; Higgins, 1985; JIS Standard, 2008; Balogun *et al.,* 2009; Jain, 2009).

Fig. 4 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. 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. Balogun *et al.*, (2009) said ‘’composition and microstructure of a material determines its properties and application (Cottrell, 1980; DIN, 1980; Higgins, 1985; JIS Standard, 2008; Balogun *et al.,* 2009).

Fig. 5 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.. 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. Balogun *et al.*, (2009) said ‘’composition and microstructure of a material determines its properties and application (Cottrell, 1980; DIN, 1980; Higgins, 1985; JIS Standard, 2008; Balogun *et al.*, 2009).

Fig. 6 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. 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. Balogun *et al.*, (2009) said ‘’composition and microstructure of a material determines its properties and application (Cottrell, 1980; Higgins, 1985; JIS Standard, 2008; Balogun *et al.*, 2009).

Fig. 7 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. 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. Defects like segregations, pinholes and inclusions, arising from liquid steel treatment methods are known to reduce the ductility of steel in deformation or loading. Balogun *et al.*, (2009) said ‘’composition and microstructure of a material determines its properties and application (Shrager, 1969; Cottrell, 1980; DIN 1980; Higgins, 1985; JIS Standard, 2008; Balogun *et al.*, 2009; Ihom 2012).

CONCLUSION

Chemical Compositional Study of Some Reinforcing Steel Rebars for Concrete Structures Produced by Selected Mini Mills in Nigeria has been carried out. Reinforcement steel bars from seven different mini mills across Nigeria have been investigated for chemical composition amidst the allegations that incidences of collapsed buildings in Nigeria can be linked to chemical compositional issues in reinforcement steel rebars produced in Nigeria from unprocessed steel scraps. This study was only targeted at mini mills which produce their liquid steel from scraps and process it to reinforcement steel rebars. From this study the following astounding findings were made:

1. Seven samples from reinforcement steel rebars for concrete structure reinforcement were given chemical compositional and microstructural analysis using spectro-lab metal analyzer (Fe-01-F) and Energy Dispersive X-Ray Fluorescent, miniPal4 ED-XRF Model. Six of the bars were 12mm diameter and only one sample was 10mm; amazedly all of them had different chemical compositions. The carbon content percent of the samples vary as follows: Sample A 0.256%; sample B 0.391%; sample C 0.361%; sample D 0.475%; sample E 0.206%; sample F 0.299%; and sample G 0.479%. The same thing applies to their carbon equivalent values which are all completely different indicating that they have different mechanical properties.

2. The above observation led to the following inferences: there is no sign that the mini mills are regulated by Standard Organization of Nigeria (SON); every mini mill produces any grade of steel for the same size of reinforcement steel rebar; standardization is completely absent; some mills are producing structural steel (0.1-0.3%C), while some are producing constructional steel (0.3-0.5%C) bars or what is referred to under DIN Standard as high tensile reinforcement steel bars.

3. Chemical composition and microstructure of the reinforcement steel bars determines their mechanical properties and their ability to withstand service conditions; the quality of the assessed reinforcement steel bars are therefore doubtful.

4. Different chemical compositions of rebars with the same size diameter and length serving the same application is dangerous

5. Use of unprocessed scraps only for production of reinforcement steel rods makes chemical compositional control difficult

6. Lack of chemical composition testing equipment in some of these facilities makes control during melting difficult

7. Use of direct reduced iron (DRI) will improve chemical compositional control

8. Nigerian mini mills should combine chemical compositional adjustment; controlled rolling and controlled cooling, since higher strengths

are induced in the bars on the basis of better corresponding microstructures developed

9. SON should address the issue of standardization in Nigerian mini mills

10. Even where a particular grade of steel is observed to be produced by a particular mini mill, the allowable deviation from chemical composition of ±0.05 is seen to be exceeded

11. As carbon equivalent value (CEV) of steel increases the strength and hardness of the steel also increases, but the ductility of the steel decreases. This is not good for reinforcement steel bars which are supposed to promote ductile failures in structures and not sudden and catastrophic failures

12. Finally, given the above findings; incidences of collapsed buildings in Nigeria cannot be unconnected with chemical compositional problems in the reinforcement steel rebars from Nigerian mini mills given the astounding divergence in the standards of the bars from the mini mills; with every mill producing what they feel like producing.

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