International Journal of Applied Science and Research

BENCHMARKING THE QUALITY OF 10mm RIBBED REINFORCEMENT STEEL BAR PRODUCED IN A LOCAL MINI-MILL IN NIGERIA

1Ihom, Paul Aondona, 2Uko, Donatus Kaiso, and 1Eleghasim, Chigozie Okwudiri

1 Department 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, IkotAkpaden –Nigeria

IJASR 2020
VOLUME 3
ISSUE 4 JULY – AUGUST **ISSN: 2581-7876**

Abstract – The research work titled "Benchmarking the Quality of 10mm Ribbed Reinforcement Steel Bar Produce in a Local Mini-Mill in Nigeria" has been carried out. 10 mm ribbed reinforcement steel samples were collected from a mini-mill in Lagos. The samples were subjected to tensile tests using a well-calibrated universal strength 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 the mini-mill is not producing structural steel, but constructional steel with carbon content well above 0.3%C. The investigated 10 mm steel bar from Lagos revealed a carbon content of 0.391%, yield strength of 636 MPa, the ultimate tensile strength of 714 MPa, and elongation at fracture of 9.36%. When the result was benchmarked against international standards it was discovered that it is constructional steel and not structural steel for use in buildings. The ribbed steel bars however have chemical and mechanical properties close to St. 60-Mn; a high tensile concrete reinforcement steel bar once produced by former Delta Steel Company, Aladja-Delta State-Nigeria. St.60-Mn rebar steel was produced according to German steel quality standard specifications DIN488 and DIN17100 to also cover RST 37-2 grade for plain round bars and light sections. Standardization is the problem with reinforcement steel bars produced in Nigeria; the tested steel bar did not fit exactly into any of the benchmarked quality standards. Finally, for quality production of reinforcement steel bars in Nigeria; mini-mills should address issues of 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, which is very critical in building collapse.

Keywords: Benchmarking; Local; Nigeria; Collapse buildings; 10 mm reinforcing steel bar.

INTRODUCTION

Quality is thehallmark of functionality; it is that which causes materials to function properly in service throughout their life span without untimely failure. Quality is strict adherence to specifications; this include dimensional and property specifications (Beeley, 1972). The moment these descriptions are lacking in a product we refer to the product as a substandard product; that is the case with many steel rebar for structural reinforcement produced by mini—mills in Nigeria. Most of the mini-mills produce their rolling stock from 100% scraps from scrapped vehicles. In the absence of prior scrap processing and cleaning the final product end up with some level of contamination (Ihom, 2012). Over the years this has affected quality in no small measure. Whenever there is failure in service as a result of substandard products, this is not always without repercussions. The repercussion will be in the form of loss of lives and property as is the case in Nigeria today. Building structures are collapsing occasionally all over the country with attendant losses in the form of lives and property worth billions of Naira (Ihom, 2012).

The efforts of Standard Organization of Nigeria (SON) to checkmating the influx of substandard reinforcing steel bars from China and ensuring mini-mills produce to specification has not availed much (Balogun*et al.,*2009; Ihom, 2012; Adebayo, 2016). Characterization of 10mm, 12mm, and 16 mm steel rebar from different manufacturers in the Nigerian market will give you different values even for the same size of reinforcement steel bar. One notices with nostalgia that even the supposedly sizes vary, that means you don't have to expect a 16 mm bar to be exactly 16mm, but can have a very wide variation. Local benchmark and international benchmark for the production of reinforcement steel bars for structures are in existence unfortunately only few manufacturers comply with these standards and therefore the repeated incidences of building collapse in Nigeria (Champion and Arnold, 1969; Chapman, 1972; Cottrell, 1980; Higgins, 1985; Bolton, 1999; JIS Standard, 2008; Balogun*et al.,* 2009; Ihom, 2013).

According to Cottrell (1980) the choice of a material for a given practical use depends on the effectiveness of the material in that use and on its cost. The property which is really required of materials used in large amounts is mechanical strength. The common structural materials, steel, cement, and timber, all have very high strength to cost ratios and are used in amounts of some 20 to 50 times greater than the next most common materials, plastics and aluminium. According to Higgins (1985) Steel is divided into dead mild steel (0.05-0.15%C), mild steel or low carbon steel (0.15-0.3%C), medium carbon steel (0.3 – 0.7%C) and high carbon steel (0.7-1.7%C).Structural steel composition is from 0.15-0.3%C (sometimes the carbon can be as low as 0.12% since it is a range) this is the grade commonly used for reinforcement in building structures because of the good ductility; as carbon content increases in steel the strength increases, but the ductility decreases (Shrager, 1969; Cottrell, 1980; Higgins, 1985).

Cottrell (1980) revealed that structural steel is used in such large amounts that if its strength could be increased by some 10% to 20%, without losing notch toughness and weldability, and without increasing its cost, there would be immense economic benefits. Great efforts have thus been made to develop improved structural steels. Steels containing 0.15%C, and 1.0 to 1.5%Mn have been developed, with good notch toughness at 0^{O}C. 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 dioxide and so allows a semi-killed steel to be made. JIS (2008), clearly specifies the composition of plain carbon steel and low alloy steel (high tensile steel) used for structural purpose. This standard is the Japanese version of the International Standard Organisation (ISO) and it also agrees with the above discuss.During the 1980s into the early 1990s when Delta Steel Company, Owvian-Aladja, Warri was in production, the steel qualities produced for concrete reinforcement were the ST.60-Mn grade for high tensile ribbed bars and the RST.37-2 grade for plain round bars and light sections. These steels were derived from the German Steel and Iron Quality Standards DIN 488 and DIN 17100. The ladle chemistry employed was as follows: For ST.60-Mn: 0.35-0.42%C, 0.2-0.3%Si, 0.9-1.2%Mn, 0.04%P, 0.04%S, 0.011%N and others traces. For RST37-2: 0.12-0.17%C, 0.18-0.28Si, 0.4-0.5%Mn, 0.04%P, 0.04%S, 0.011%N and others traces (DIN, 1980).

To maintain constant quality products in the Nigerian market, there is need for researchers to constantly benchmark reinforcement steel bars, so as to draw the attention of standard organization institutions for control purpose. Benchmarking is necessary for attaining quality products, and this informs why this work is benchmarking the quality of 10 mm reinforcement steel bar produced by a mini-mill in Nigeria against existing recognized standards.

MATERIALS AND METHOD

Materials and Equipment

The materials used for the research work were ribbed reinforcement steel rod collected from different mini mills across Nigeria. For this work only 10 mm bars were used. Table 1 shows the samplethat was used in the research work. So many equipment were utilized in the quality analysis of the specimens these 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).

Sample Collection

To actualize this project; samples were collected from a mini mill in Lagos- Nigeria. This mill has the capability of producing its own billets or rolling stocks from liquid steel, which was produced using scraps. The mini-mills operating on imported billets were not considered. Table 1 gives details of the location from where samples were collected.

Table 1 Sample of 10 mm Reinforcement Steel Bar Collected from a Mini Mill in Nigeria

S/No.	Sample Label	Location	Ribbed Reinforcement steel rod size (mm)
1	B	Lagos	10

Tensile Test

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

Chemical Composition of Reinforcement Steel Bar from a Selected Mini-Mill in Nigeria.

Samples from a selected mini-mill were sent to Defence Industries Corporation of Nigeria (DICON) for analysis. The essence of the test was to determine the chemical composition of the samples from the mini-mill. The chemical analysis was carried out using spectro-lab metal analyzer (Fe-01-F).The composition obtained was again compared with the ones from Energy Dispersive X-Ray Fluorescent, Minipal4 ED-XRF Model.

Microstructural and EDS Study of selected Ribbed Reinforcement Steel Bars from a Mini-Mill in Nigeria

The samples of 10 mm diameter ribbed reinforcement steel bar from a mini-mill in 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:

Tensile Test Results

Table 2 Tensile Test Result of the 10 mm Ribbed Reinforcement Steel Bar Samples collected from a Mini-Mill in 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}(%)**

Specimen B (T1)	10	78.54	56.10	714	636	1.17	9.36

Figure 1 below shows load-extension curve for specimen B

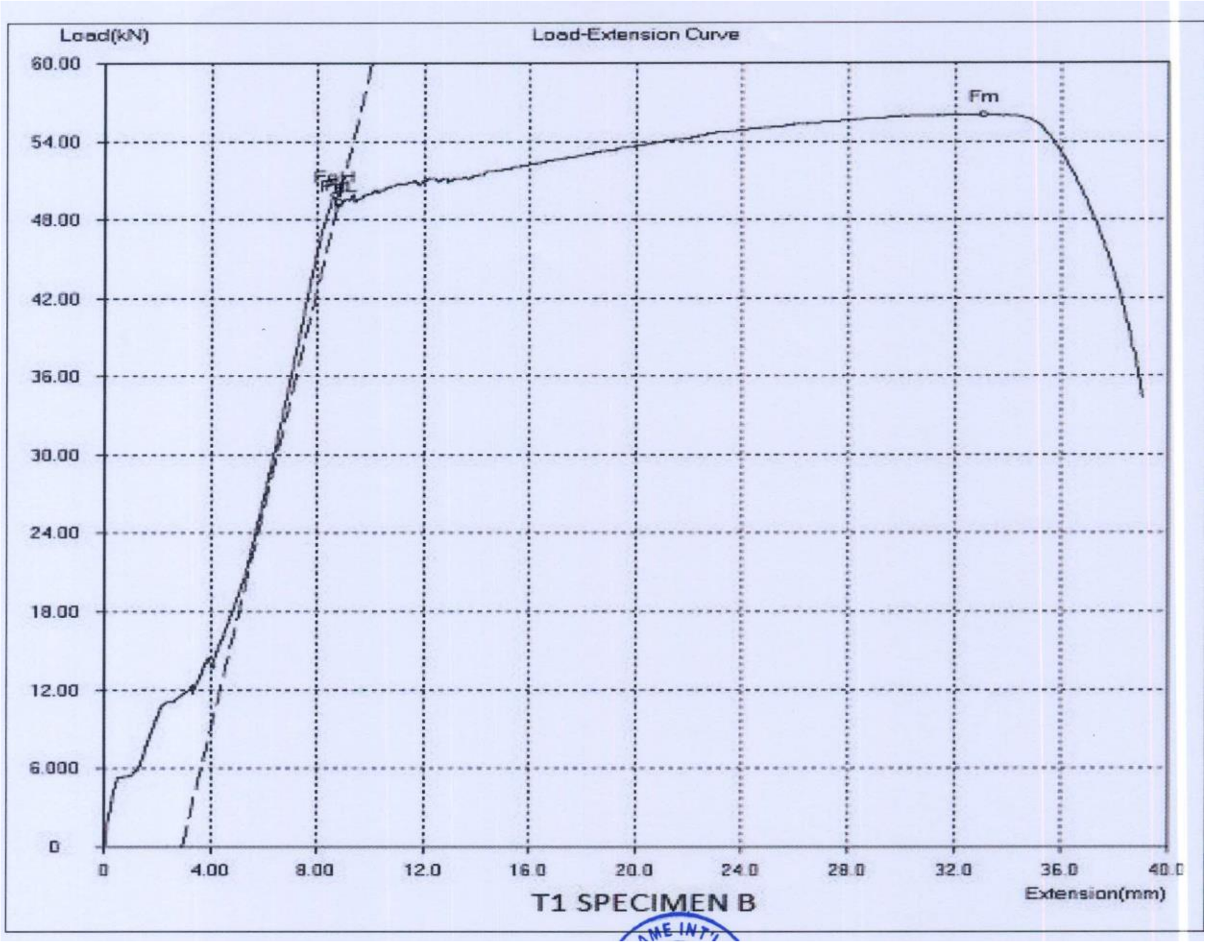


Fig.1 Load-Extension Curve for Specimen B (T1)

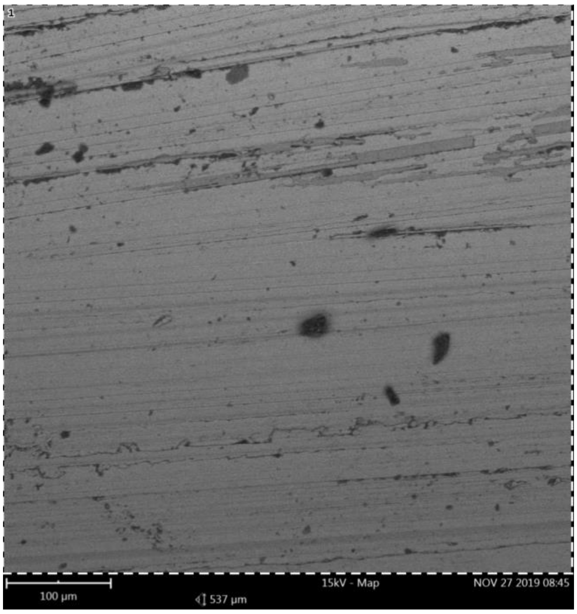
Chemical Composition of 10mm Reinforcement Steel Bar using Spectro-Lab Metal Analyzer

Table 3 Chemical Composition of Specimen B (T1) /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				

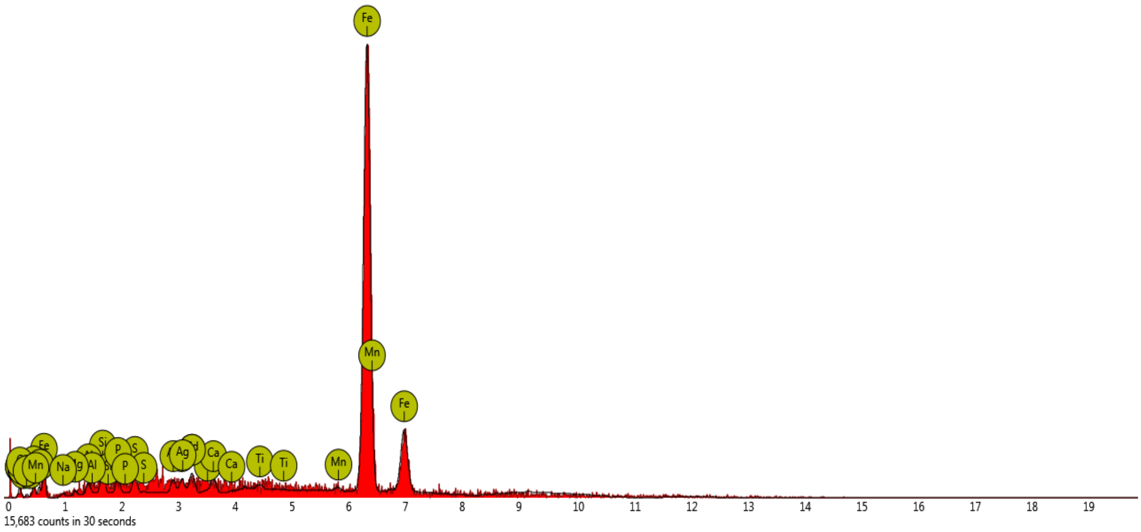
Result ofMicrostructural and EDS Study of 10mm Ribbed Reinforcement Steel Bar from a Mini-Mill in Nigeria

The results below are high resolution morphology of 10 mm reinforcement steel bar from a mini-mill in Nigeria using scanning electron microscope. The microstructures are supported by EDS study of the composition of the structure and elemental distribution. See Fig. 2.

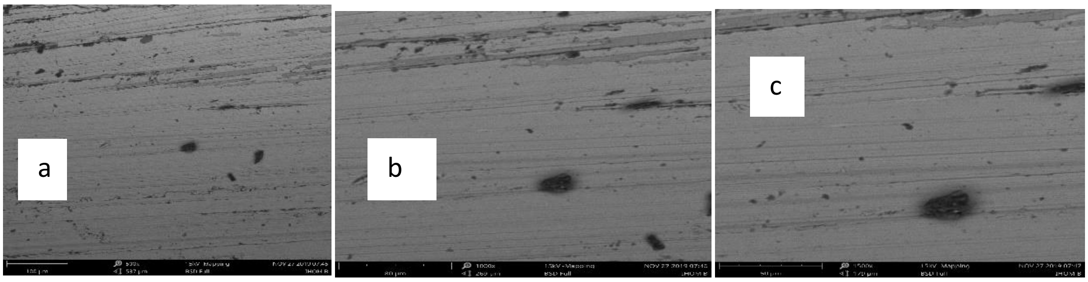


Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
26	Fe	Iron	83.20	89.37
48	Cd	Cadmium	0.97	2.10
47	Ag	Silver	0.82	1.70
6	C	Carbon	5.29	1.22
14	Si	Silicon	1.58	0.85
20	Ca	Calcium	0.90	0.70
19	K	Potassium	0.91	0.69
16	S	Sulfur	1.03	0.63
8	O	Oxygen	1.89	0.58
15	P	Phosphorus	0.94	0.56
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

Electron Microscope

Discussion

Tensile Test

Tensile tests have been applied to test samples from a mini-mill from Nigeria, as a measure of quality; to ascertain the extent of 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 results of Table 2 and figure 1 are here discussed.

Table 2 shows that Specimen B (T1) has a good ultimate tensile strength (Rm) of 714MPa, which correspond to a maximum load of 56.10 kN, a yield strength of 636 MPa, UTS: Y.S ratio of 1.17 and percentage elongation at fracture of 9.36%. The steel has good strength properties at the expense of elongation at fracture which is below specification (Shrager, 1969; Cottrell, 1980; Higgins, 1985; JIS, 2008). The result however, agrees with German iron and steel quality standard specification DIN 488 and DIN 17100 which specifies elongation at fracture of 6-16% for ST.60-Mn high tensile steel rebar, which specimen B has a close composition to. Now comparing the results in Table 2 with the load – extension curves in fig.1, it can be seen that the figure exhibited all the critical points of yield point, ultimate tensile load and necking region until consequent fracture which indicates that the sample tested have a level of ductility. Fig. 1, however, showed serious evidence of grip slip this must have had some effect on the elongation at fracture (Champion and Arnold, 1969; Bolton, 1999; Uko, 2020). The deformation pattern is similar to that of ductile steels. According to Cottrell (1980) mild steel reinforcement bar has a tensile strength of 380 MPa and their low alloy counterpart have a tensile strength of 970MPa. 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%. He further said that the second structural steel used as reinforcement bar comes under relevant specification of B.S 968 with carbon content of 0.20%C and 1.5% Mn; it has yield point of 350N/mm^2,tensile strength of 525N/mm^2, and elongation of 20%.Comparing these standards with the measured parameters; the serious concern is the elongation at fracture of the specimen. The result did not agree with the above standard and no reason for comparison.

According to JIS Standard plain carbon JIS S40C which is equivalent to AISI 1040 with carbon content in the range 0.39-0.43%C has minimum yield strength of 323.4 MPa, tensile strength of 539.55 MPa, and an elongation of 22%. The tested specimen above has yield strength and an ultimate tensile strength that arefar above the minimum specified by JIS standard (JIS Standard, 2008). The Low elongation at fracture which is less than 22% can be explained from the chemical composition and the morphology of the test specimen (Shrager, 1969; Cottrell, 1980; Higgins, 1985; Jain, 2009).

Chemical Composition using Spectro-Lab Metal Analyzer

Table 3 shows the chemical composition of Specimen B (T1), 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). The yield strength and the ultimate tensile strength of this steel is above the minimum of S40C steel, but its elongation at fracture is a far cry from the minimum elongation of 22%. The possible reason may be due to the presence of defects-limiting elongation at fracture or grip slip. These 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. The morphology of the steel as shown by the SEM micrograph did not agree with the chemical composition which indicates that the steel has a carbon content of 0.391%; by this one expects to have seen reasonable amount of pearlite in the morphology of the steel. That's where the problem is, the morphology reveals ferrite matrix, deformed grains, aligned cementite and lines which are obviously from the rolling process. This is an indication that the rolling operation was not properly adjusted for the recovery and recrystallization of deformed grains. This explains partly the reason for the high yield and ultimate tensile strengths, but very poor elongation at fracture (Cottrell, 1980; Higgins, 1985; JIS Standard, 2008).

Scanning Electron Microscope and EDS Study of Reinforcement Steel Bar from a Nigerian Mini-Mill.

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 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 Bdisagrees with the spectro-lab metal analyzer result which says the steel is a plain carbon steel with 0.391%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. 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; of the steel bar also indicate that it is in a work-hardened state. (Cottrell, 1980; Higgins, 1985). 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).

General Observation

From the discussion of results above it can be seen that the investigated reinforcement steel bars from the mini mill did not comply with most of the benchmarked standards for plain carbon steel used as structural steel. Further comparison showed that this steel has close chemical composition and mechanical properties to high tensile strength steel rebar used for concrete reinforcement. This type of steel reinforcement rebar was once produced in Nigeria by Delta Steel Company Aladja-Nigeria. It was produced according to German Iron and Steel Standard Specification DIN 488 and DIN17100. The investigated steel bar did not comply fully with the compositional specification, but the carbon content is within the specified range, likewise the elongation at fracture. If this company is interested in producing high tensile strength grade of steel rebar for concrete reinforcement, it should consult German Iron and Steel Standard specification DIN 488 and DIN17100 for correct implementation of the standard (DIN 1980).

CONCLUSION

The incidences of collapsed building structures in Nigeria have become a common occurrence with the attendant loss of property and lives. Structural quality issues have been raised as being responsible. In this research ''Benchmarking the Quality of 10mm Ribbed Reinforcement Steel Bar produced from a Local Mini-Mill in Nigeria''; the work has focused on the quality status of the reinforcement steel bar from a mini-mill in Lagos-Nigeria. Key findings of interest that needs to be addressed by the mini-mill are here outlined:

1. Chemical Composition of Steel Bar: this mini-mill is not producing structural steel, but constructional steel with carbon content well above 0.3%C.

2. Structural steel with 0.12-0.30%C is commonly used for reinforcement steel bars for building structures; for their high ductility which prevents sudden collapse in buildings and structures.

3. This work notes that the mini-mill is producing plain carbon steel and if this company is interested in producing high tensile strength grade of steel rebar for concrete reinforcement, it should consult German Iron and Steel Standard specification DIN 488 and DIN17100 for correct implementation of the standard

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. The investigated 10 mm steel bar from Lagos has a carbon content of 0.391%C, yield strength of 636 MPa, ultimate tensile strength of 714 MPa, and elongation at fracture of 9.36%. This kind of data is associated with high tensile strength grade of reinforcement bar for concrete reinforcement.

6. 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. The high strength values indicate that the steel bar is in a work-hardened state.

7. Finally, 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, which is very critical in building collapse.

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, AkwaIbom 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 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.
3. Beeley, P.R. (1972) Foundry Technology, First Edition, London: Butterworth Scientific, pp250-259

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 Standard (1980) German Iron and Steel Quality Standard Specification, DIN488 and DIN 17100
10. Higgins R.A. (1985) Properties of Engineering Materials 5th Edition, UK: Hodder and StoughtonEducational, pp178-184
11. Ihom, A.P. (2012) Steel Scrap Recycling in Nigeria: Some Serious Imperativesfor Urgent Consideration, proceedings of the 28th NMSConference, held at National Space Research and
12. Development Agency, Abuja, 2012,pp131-137
13. Ihom, A.P. (2013) Case Hardening of Mild Steel using Cowbone as Energiser, African Journal of Engineering Research, Vol.1 (4), pp99-101
14. Jain, R.K (2009) production Technology, 14th Reprint, New Delhi: Khana Publishers, pp19-27JIS Standard (2008) Japanese Industrial Standard Designation and Specification for metals and metal products
15. Shrager, A.M.(1969)Elementary Metallurgy, and Metallography, third Edition, NewYork: Dover Publications, pp80-203
16. Uko, D.K (2020).Iron-Carbon Phase diagram (a review)MSE 300 Materials Laboratory Procedures Department of Materials Science and Engineering, University of Tennessee.