

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/310968177>

Assessment of Suitability of Nigerian Made Steel Bars for Structural Applications

Article · November 2016

CITATIONS

16

READS

942

6 authors, including:



Abdul Ganiyu Funsho Alabi
Kwara State University

31 PUBLICATIONS 198 CITATIONS

SEE PROFILE



Akintunde Olayinka Ayoade
University of Ilorin

1 PUBLICATION 16 CITATIONS

SEE PROFILE



Jamiu Odusote
University of Ilorin

115 PUBLICATIONS 1,589 CITATIONS

SEE PROFILE



Adekunle Adeleke
Nile University of Nigeria

223 PUBLICATIONS 2,255 CITATIONS

SEE PROFILE

Assessment of Suitability of Nigerian Made Steel Bars for Structural Applications

Abdul Ganiyu F. Alabi^a, Akintunde O. Ayoade^b, Jamiu K. Odusote^{c,Ψ} and Adeleke A. Akanni^d

^aDepartment of Material Science and Engineering, Kwara State University, Malete, Ilorin, Nigeria; E-mails: agfalabi@gmail.com; abdulganiyu.alabi@kwasu.edu.ng

^{b,d}Department of Mechanical Engineering, University of Ilorin, Ilorin, Nigeria; E-mails: ^bayoadeakintunde@gmail.com; ^dadeleke.kunle@gmail.com

^cDepartment of Materials and Metallurgical Engineering, University of Ilorin, Ilorin, Nigeria; E-mail: jamiukolawole@gmail.com

^Ψ Corresponding Author

(Received 16 May 2016; Revised 22 June 2016; Accepted 10 August 2016)

Abstract: The mechanical properties of selected reinforcing steel bars produced from two rolling mills in Osun State, Nigeria were studied. An optical emission spectrometer was used for chemical composition analysis while the tensile test was carried out using a Universal Testing Machine. Izod v-notched was used for impact test, while the hardness values were obtained from Brinell hardness tester. Scanning Electron Microscope was used for the fractured surface fractography. The Ultimate Tensile Strengths (UTS) of all the samples are higher than BSS4449:2005+A2:2005 standard and are also in close proximity to A707M-15 standard. Samples A12, B10 and B12 possessed higher yield strengths than samples A16 and B16 but lower than those of BSS4449:2005+A2:2005 and A707M-15 standards. Ductile property of the samples doubled the recommended Nst-65-Mn standard values while the hardness and ductility properties are higher than the recommended A707M-15 and BS4449 standards. The results showed that the investigated reinforcing bar samples possessed reasonably high strength and ductility when compared with available standards. Consequently, these bars would be suitable for structural applications where strength and ductility are critical properties. They would also be used in steel reinforcement applications that would require continuous and repetitive loading such as in buildings and bridges.

Keywords: Nigerian steel bars, Tensile strength, Fractography, Hardness, Construction, Ductility

1. Introduction

Regardless of the strong competition from other engineering materials, steel is still one of the most important engineering materials in use today for structural works (Sambo et al., 2009), such as concrete reinforcement, bridge trusses, military hardwares, and automobile components. Steel is also found applications in power generation plants, telecommunications, aviation, drilling, medical equipment, as well as oil and gas sectors.

Concrete has high compressive strength, but is weak in tension. As a result of shrinkage and temperature gradient, concrete often times develops cracks. There is a need to accommodate the tensile stresses in order to minimise crack widths which makes reinforcement of concrete matrix indispensable (Serope and Schmid, 1993). Reinforcement also reduces creep in concrete structures (Alabi and Onyeji, 2010). Concrete could be reinforced with several materials among which is fibre reinforced polymers, bamboo, plastic filament, ceramic composites and steel rods (Alabi and Onyeji, 2010; Adeleke and Odusote, 2013).

The fact that steel and concrete act together to withstand induced forces forms the basis for the design of reinforced concrete structures (Prabir et al., 2004).

Also, the closeness in the co-efficient of thermal expansion of steel and concrete reduces the relative movement between the embedded bars and concrete in the reinforced concrete work due to temperature changes to a minimum (Alabi and Onyeji, 2010). In addition, steel has excellent bendability and bond effectively with concrete for reinforcement. Steel rods are indented on the surface during rolling process to enhance bonding with concrete by mechanical interlocking (Prabir et al., 2004, Alabi and Yahaya, 2012). It is also known that steel does not corrode in cement and sand environment (Vlack, 1982).

In Nigeria, cases of structural failure have in recent time become a frequent report especially for buildings and many lives and properties have been lost. According to National Building and Road Research Institute (NBRRI, 2016), building collapses are more common in cities such as Lagos, Enugu, Abuja and Port Harcourt, with about 60% of the collapses occurring in Lagos. As reported by Ede, not less than 264 deaths were recorded from about 25 cases of building collapses between 2005 and 2010 (Ede, 2010). On September 12, 2014, a guest house under construction within the premises of Synagogue Church of All Nations (SCOAN) in the Ikotun area of Lagos collapsed and 116 people died

(Gabriel, et al., 2014). A five-storey building recently collapsed in Lekki Gardens, Lagos State where more than 30 people were declared dead (Adegboyega, 2016).

A number of factors have been identified to be responsible for the incessant building collapse, some of which are structural failures, use of incompetent manpower, unauthorised conversion of bungalow to high-rise buildings, faulty design/implementation, use of substandard materials, among other factors (Arum, 2008; Fagbenle and Olawunmi, 2010; Ede, 2010; Alabi and Onyeji, 2010; Alabi and Yahaya, 2012; Adeleke and Odusote, 2013; Odusote and Adeleke, 2012).

However, since the incident of building collapses in Nigeria is persisting, it has become very important to examine the mechanical properties of reinforcing bars being produced in newly established indigenous steel mills in Osun state, Nigeria. This will assist in determining their suitability and conformity with standards. Thus, the objective of the present work is to evaluate the mechanical properties of selected reinforcing steel bars from two new indigenous steel mills in Osun State, Nigeria, to assess their suitability for structural applications.

2. Experimental Procedures

2.1 Sample collection

Five samples of reinforcing steel bars were obtained from two steel mills in Osun State, Nigeria. 12 mm and 16 mm diameters were collected from product source A and identified as A12 and A16, respectively, while 10 mm, 12 mm and 16 mm were collected from product source B and identified as B10, B12 and B16, respectively. The various samples are shown in Figure 1. Three (3) samples of each were used for assessment to ascertain the reproducibility of results. The mean values of the results were recorded along with the error bars, which show the upper and lower limits of the data.

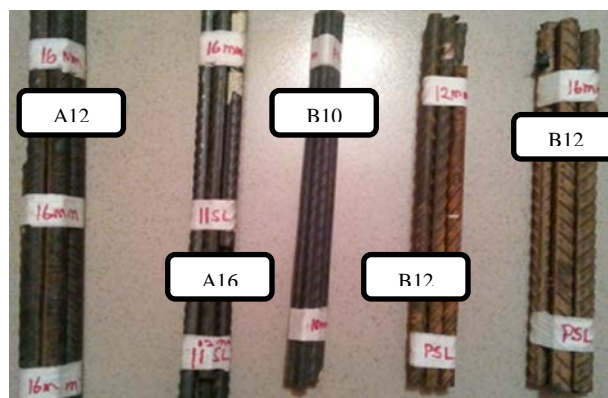


Figure 1: Steel bar Samples

2.2 Chemical Composition

Analysis of the chemical composition of the samples was carried using Labspark Optical Emission Spectrometer (Model Number 7600). Two specimens of each of the samples were grounded for 3 seconds on a metallographic abrasive grinding machine to reveal the cores of the samples after which the flat surface was rinsed with methanol in order to eliminate contaminants. The samples were mounted one after the other on the Optical Emission Spectrometer. The average percentage chemical composition of each steel rod samples was displayed on a monitor connected to the equipment.

2.3 Tensile Test

Instron Universal Tensile Testing Machine (Model Number 5569) was used to determine the tensile properties of the steel samples. The machined specimen as shown in Figure 2 was firmly gripped between the jaws of the machine. The jaws were pulled apart at strain rate of 3 mm/minute until the specimens are fractured.

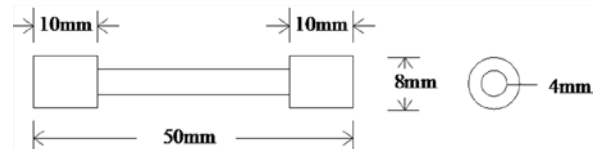


Figure 2: Geometry of tensile test specimen

2.4 Fractography

The fractured surfaces from tensile test were examined on Scanning Electron Microscope. Pairs of the fractured tensile test specimens were collected and preserved in desiccators to protect their surfaces from reacting with the environment. The surfaces were thoroughly rinsed in methanol and properly air-dried to get rid of moisture. Specimens were carefully gripped onto the specimen holder to avoid sliding off in the vacuum chamber. The fractured surfaces of the samples were then observed under Scanning Electron Microscope to reveal their microstructures.

2.5 Hardness Test

The steel samples were placed on the anvil of Brinell hardness testing machine one after the other and the capstan hand-wheel was turned until the samples touch the indenter. A load of 3000 kg was gradually applied perpendicular to the surface of the steel specimens through a steel ball indenter of 5mm diameter. This load was maintained for 15 seconds on each specimen. The diameter of the indentations were viewed and measured with a graduated low power Brinell microscope. The values thus obtained were converted to Brinell hardness number (BHN) using a Brinell hardness number chart. Theoretical hardness values were obtained by linear

interpolations from standard strength-hardness conversion table (EHB, 2014).

2.6 Impact Test

Izod v-notched impact test was carried out on the samples. A weighted pendulum hammer of 21.25 kg that was released from a height of 0.825m at a speed of 3.844 m/sec was used. The magnitude of energy absorbed was read from the dial on the instrument and recorded in Joules. The geometry of the specimen is illustrated in Figure 3. The volume of the standard Izod test samples is $1.1781 \times 10^{-6} \text{m}^3$.

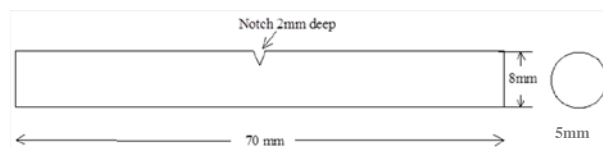


Figure 3: Standard izod impact test specimen

3. Results and Discussion

3.1 Chemical Composition

The chemical composition of the specimens is presented in Table 1. It has been prepared along with BS 4449:2005+A2:2005 (BSI 2005), A707M-15 (ASTM 2009) and Nst.-65-Mn standards for construction steel bars. The results obtained for the specimens B10 and A16 shows that they are medium carbon steel as the carbon content is between 0.30-0.60 % as prescribed by Serope and Schmid (2006). The results of the other specimens show that they are mild steels as their carbon contents are less than 0.30%, which is the benchmark for mild steel. However, Specimen B12 contains lower carbon content compared with the standards. The sulphur and phosphorus contents of the present study are lower than the recommended values. The production of

steel bar will be desired to contain lesser percentage of these elements as they impact more negatively on their properties. For example, Odusote and Adeleke (2012) reported a negative havoc of the excessive sulphur content during their examination of steel bars collected from collapsed building sites. As reported, sulphur lowers ductility and increase hardness if present in excess alongside silicon, manganese and phosphorus. Nickel, chromium and copper are known to increase strength of steel generally (Serope and Schmid, 2006). The substantial amount of nickel, chromium and copper in the specimens alongside their carbon contents accounts for a relatively close ultimate tensile strength with standards as shown in Table 2 and Figure 4.

3.2 Yield Strength and Ultimate Tensile Strength

The yield strengths obtained ranges from 410 MPa to 373 MPa with B10 having the highest and B16 has the lowest. These values are lesser than 500 MPa recommended by BS4449, A707M-15 and Nst-65-Mn as shown in Figure 4. The low yield strength is in consonant with the result of Alabi and Onyeji (2010) as shown in Table 3. Chukwudi (2010) worked on steel rods from Onitsha market and they also reported low yield strength of steel rods in Eastern Nigerian markets. The low yield strengths could be as a result of significantly low amount of silicon and manganese in the steels. Silicon and manganese are very good deoxidizers in steels (Kutz, 2002) which assist reducing casting defects by removing undesirable oxygen in the melt and also, improve mechanical properties in specific amount

Manganese also have very strong refining action which produces fine pearlite structures, which increases strength and hardness of steel. Odusote and Adeleke (2012; 2013) however reported yield and tensile strengths that are higher than those in this work as shown in Table 3.

Table 1. Chemical composition of the samples (wt. %)

	C	Si	Mn	S	P	Cr	Ni	Cu	Al	Fe
A12	0.259	0.179	0.519	0.038	0.043	0.154	0.100	0.342	0.021	Bal.*
A16	0.329	0.176	0.555	0.036	0.042	0.164	0.112	0.261	0.021	Bal.
B10	0.330	0.307	0.727	0.040	0.045	0.163	0.091	0.245	0.021	Bal.
B12	0.169	0.228	0.579	0.047	0.056	0.204	0.085	0.292	0.020	Bal.
B16	0.291	0.193	0.579	0.042	0.054	0.271	0.105	0.308	0.021	Bal.
BS4449	0.240 ¹	0.400 ²	1.000 ²	0.055 ¹	0.055 ¹	-	0.012 ²	0.850 ¹	0.100 ²	-
A707M-15	0.250	0.400	1.000	0.050	0.050	-	-	-	-	-
Nst-65-Mn	0.350	0.300	1.200	0.040	0.040	-	-	0.250	-	-

Remarks: ¹ BSI (2005), ² BSI (1997)

Table 2. Mechanical properties of the steel samples compared with standards

	A12	A16	B10	B12	B16	BSS449	A707M-15	Nst.-65-Mn
UTS(MPa)	582.44±6.38	591.01±36.78	667.73±24.14	544.80±17.52	556.14±0.93	540.00	590.00	-
YS(MPa)	405.14±11.68	389.12±13.32	410.73±5.13	404.60±13.73	373.14±3.07	500.00	500.00	500.00
Strain(mm/mm)	0.3142	0.2795	0.2711	0.3154	0.3042	0.1400	0.1600	0.1200
S.H.R	1.4360	1.5188	1.6258	1.3464	1.4905	1.0800	-	-
BS (MPa)	445.99±3.91	400.32±26.47	529.95±18.86	385.60±15.46	436.59±4.81	-	-	-

Remarks: *UTS- ultimate tensile strength *YS- yield strength * S.H.R- strain hardening ratio *BS- breaking strength

Table 3. Specimens’ properties compared with previous studies

Samples Denotations	%C	CEV	Y/S (MPa)	UTS (MPa)	Elong. (%)	Hardness		Sources
						BHN	HRC	
A12	0.259	0.4058	405.64	582.44	31.42	210.08	18.04	(P/W*)
A16	0.329	0.4732	389.12	591.01	27.95	215.11	18.21	(P/W)
B10	0.330	0.5062	410.73	667.73	27.11	226.83	20.71	(P/W)
B12	0.169	0.3315	404.64	544.80	31.54	206.16	16.83	(P/W)
B16	0.291	0.4693	373.14	556.14	30.42	211.34	17.05	(P/W)
SF	0.530	-	400.00	692.73	18.00	-	48.00	(AO2010)
US	0.398	-	400.00	651.58	28.00	-	44.00	(AO2010)
NS	0.383	-	400.00	610.79	28.00	-	47.83	(AO2010)
AS	0.483	-	325.00	660.17	25.00	-	45.00	(AO2010)
EC	0.339	0.6180	460.14	597.21	9.02	-	21.19	(ODAD,2012)
IC	0.311	0.5910	486.31	585.71	11.72	-	20.22	(ODAD,2012)
SC	0.345	0.5920	551.50	625.75	9.80	-	19.63	(ODAD,2012)
ST66-2	0.240	-	448.06	667.19	21.11	-	-	(C2010)
ST44-2	0.170	-	317.38	485.40	27.24	-	-	(C2010)
Kogi Steel 10mm	-	-	441.00	684.00	23.00	187.00	-	(K2002)
Kogi Steel 12mm	-	-	399.00	648.00	22.20	170.00	-	(K2002)
Lagos Steel 10mm	-	-	479.00	729.00	19.00	217.00	-	(K2002)
Lagos Steel 12mm	-	-	449.00	748.00	21.50	207.00	-	(K2002)
Universal Steel	-	-	418.00	590.00	28.60	-	43	(OA2013)
African Steel	-	-	380.00	410.00	18.70	-	56	(OA2013)

Remarks: *P/W-Present work; AO2010- Alabi and Onyeji (2010); ODAD2012- Odusote and Adeleke,(2012); C2010-Chukwudi (2010); K2002-Kutz (2002); OA2013-Osarenwida and Amuchi (2013)

This was attributed to the presence higher chromium, silicon and manganese contents in the investigated steel bars. The greater hardness and strength exhibited by B10 than A16 despite their very close carbon content is possibly a result of higher silicon and manganese as contained in Table 1 and Figure 4. The UTS which is the stress at which plastic failure terminates and necking begins for the steel samples are in close proximity with BS4449 and A707M-15.

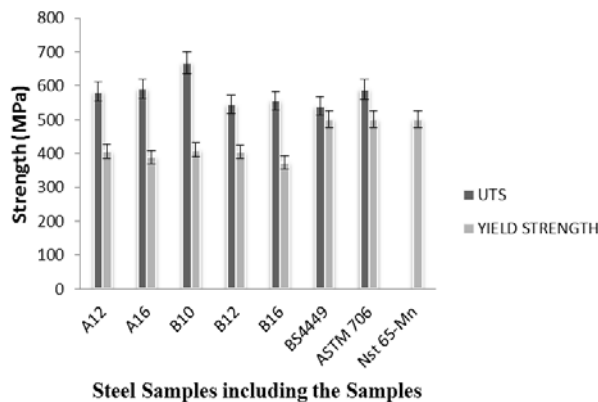


Figure 4. Ultimate tensile strengths and yield strengths of the samples compared with standard

3.3. Ductility

The steel samples from the two mills are more ductile by about 200% of the values recommended by Nst-65-Mn and well above 150% of the A707M-15 and BS4449 as shown in Figure 5. Ductility of steel bars used for concrete reinforcement (rebar) is its ability to dissipate

energy and plastically deform without brittle or catastrophic failure. Insufficient ductility of reinforcing steel bars has direct influence on the ductility of RC structural members. This often results in reduced and unfavourable distribution of plastic deformations and premature tensile fracture and buckling of reinforcing bars (Bachmann and Wenk, 1998). Generally, sulphur and phosphorus are detrimental to effective ductility (William, 2010; Adeleke and Odusote, 2013). A12 contains 34% more carbon than B12, yet they have the same percentage elongations. This is possibly because B12 is richer in sulphur and phosphorus which are deleterious elements that affects the ductility. The presence of higher chromium content in sample B12 compared with sample A12 is also responsible for the low ductility since chromium is carbide former.

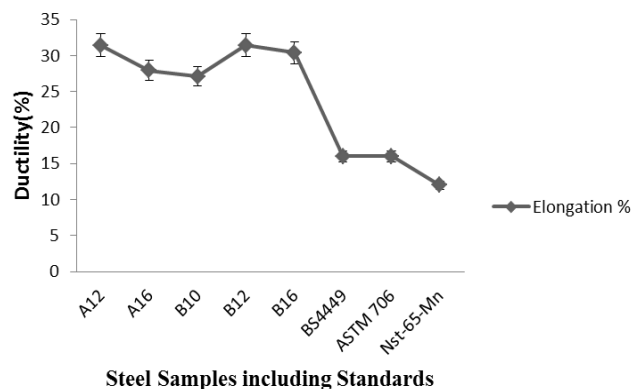


Figure 5. Percentage elongations of the steel samples compared with standards.

3.4 Hardness

The hardness values in the present study is far lower than that of Alabi and Onyeji (2010) and Sambo et al. (2009) due to the lower carbon content as shown in Table 3. They are however relatively close to that obtain by Odusote and Adeleke (2013). Figure 6 compared the experimental hardness results of the specimens with the theoretical values. The values are compared with A707M-15 standard and were found to be higher than the standards. For each of the samples, the experimental values surpassed the theoretical values. The present study possesses nearly an equivalent values with that of Odusote and Adeleke (2012) yet they thrive in ductility which might be as a result of lower values of sulphur and phosphorous.

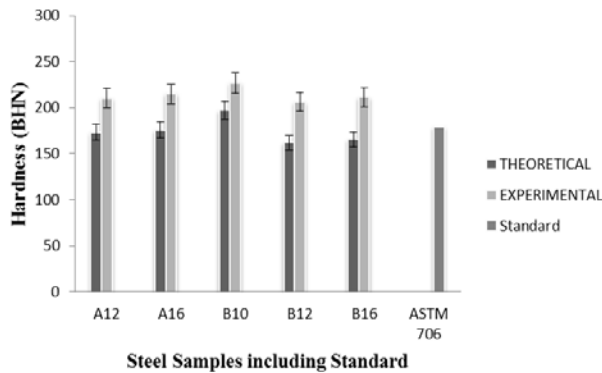


Figure 6. Theoretical and experimental Brinell hardness values of the steel samples compared with A707M-15

3.5 Toughness

Figure 7 shows the specific theoretical toughness, specific theoretical resilience and specific experimental toughness. Resilience is a material’s ability to absorb energy per unit volume within the elastic region without causing permanent deformation (Serope and Schmid, 1993). A12 and B10 as well as B12 and B16 behave in similar manner in term of resilience. This is because of the similarity in the distribution of their strengths and ductility because resilience as well as toughness is a combination of strength and ductility (William, 2010). Sample A16 has the least specific resilience and toughness property among the samples because it has low yield and percentage elongation. Specific theoretical toughness and those obtained experimentally through izod impact test are not the same but the trend is similar. A12 and B12 are better in term of toughness among the samples followed by B10 and B16 which have close specific toughness.

The behaviours reflect the respective ultimate tensile strength and ductility of the samples. Low toughness exhibited by A16 and B10 may also be

attributed to the high carbon contents because carbon is a strong pearlite former that significantly increases strength but strongly reduces toughness as pearlite structures cannot absorb much impact energy due to formation of interfaces for crack nucleation (Higgins, 1993). It can also be inferred from the result that toughness and resilience varies proportionately.

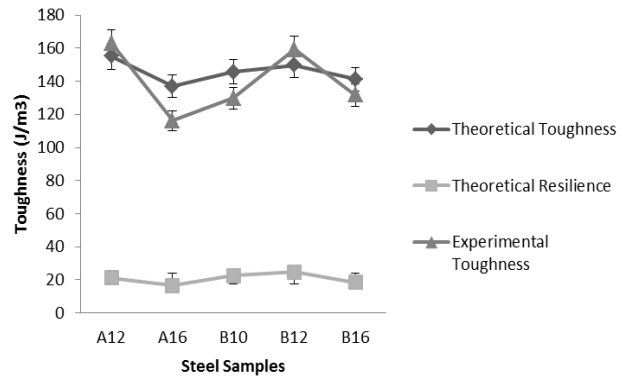


Figure 7. Specific theoretical toughness, theoretical resilience and experimental toughness of the samples X10⁶

3.6 Fractography

The fractography of the tensile fractured samples are presented in Figure 8. The fractography examination reveals the failure mechanism and mechanical behaviours of the steel bars as reported in Table 2.

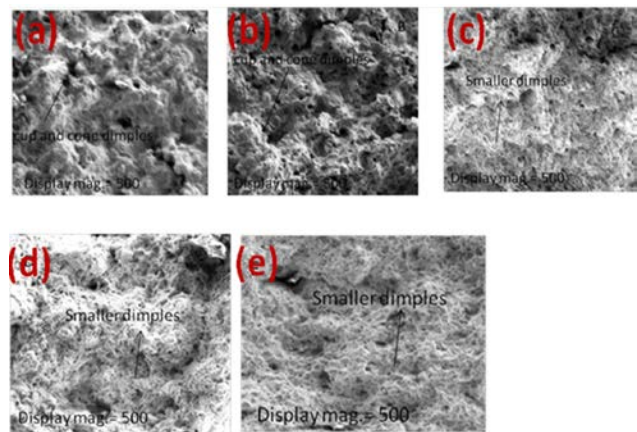


Figure 8. SEM fractographs of fractured surfaces of samples A12 (a), B12 (b), A16(c), B16 (d) and B10 (e)

A number of cup and cone shaped dimples were observed all over the fractured surface of the specimens which are believed to have nucleated from inclusions or coarser precipitates. This is an indication that the steel bars behaved in a ductile manner. The size, depth and

distribution of dimples are measures of ductility of the test samples (Hani et al., 2004). A12 and B12 comprise large and deep dimples whereas A16, B10 and B16 comprise many small, shallow dimples. This confirms that A12 and B12 are more ductile than A16, B10 and B16.

4. Conclusion

The tensile analysis shows that the ultimate tensile strengths (UTS) of the samples are close to the specifications of the BS4449:2005+A2:2005, A707M-15, and Nst.-65-Mn standards. However, the yield strengths are substantially lower compared with these standards. Ductile property of the samples doubled the values recommended by Nst-65-Mn and 150% higher than the A707M-15 and BS4449 standards. The hardness values of the steel products are higher than BS4449 and A707M-15 standards are just about 50% of the hardness value recommended by Nst-65-Mn. Conclusively, samples A16 and B10 would be materials of interest in applications where strength and ductility are critical properties of interest while samples A12, B12 and B16 would be suitable in situations where the steel reinforcement would require continuous and repetitive loading.

References:

- Adeleke A.A. and Odusote J.K. (2013), "Evaluation of mechanical properties of reinforcing steel bars from collapsed buildings sites", *Journal of Failure Analysis and Prevention*, Vol. 13, pp. 737-743.
- Adegboyega, K. (2016), *Lekki Gardens: Many Posers Begging for Answers*, Accessed 22nd March, 2016, from <http://www.vanguardngr.com/2016/03/lekki-gardens-many-posers-begging-answers/>
- Alabi, A.G.F and Onyeji, L.I. (2010), "Analysis and comparative assessment of locally produced reinforcing steel bars for structural purposes", *USEP: Journal of Research in Civil Engineering*, Vol. 7, pp. 49-60.
- Alabi, A.G.F. and Yahaya, R.A. (2012), "Comparative assessment of some commercial steel bars with standards", *Journal of Research Information in Civil Engineering (RICE)*, Vol.9, No. 1, pp.73-83 (Website: www.usep-rice.com, ISSN 0189-8787).
- Arum, C. (2008), "Verification of properties of concrete reinforcement bars: Nigeria as case study", *Indoor Built Environment*, Vol. 17, No 4, pp. 370-376.
- ASTM (2009), *Standards A707M-15: Metals, Test Methods and Analytical Procedures* (Metals, Mechanical Testing; Elevated and Low-Temperature Tests; Metallography; Section 03: (Reviewed)), ASTM Standards
- Bachmann, H. and Wenk, T. (1998), "Ungenügende Duktilität beim Bewehrungsstahl (Insufficient ductility of reinforcing steel)", *Schweizer Ingenieur und Architekt Journal*, No 29, July, pp.544-551.
- BSI (1997), *BS 4449: Carbon Steel Bars for the Reinforcement of Concrete*, British Standards Institution, London.
- BSI (2005), *BS 4449: Carbon Steel Bars for the Reinforcement of Concrete*, British Standards Institution, London, p.1-17.
- Chukwudi, B.C. (2010). "Assessment of the quality of steel rods available in Onitcha market: In view of the role of poor quality rods in building failures in Nigeria", *Pacific Journal of Science and Technology*, Vol. 11, No 1, pp.55-59.
- Ede, A.N. (2010). "Building collapse in Nigeria: The trend of Casualties in the last decade (2000-2010)", *International Journal of Civil and Environmental Engineering*, Vol.10, pp. 32-42.
- EHB (2014), *Standard Table Correlating Tensile Strength and Hardness of Steel*, Assessed October 23rd, 2014, from <http://www.engineershandbook.com>
- Fagbenle, O.I. and Olawumi, A.O. (2010), "Building failure and collapse in Nigeria: The influence of informal sector", *Journal of Sustainable Development*, Vol.3, No.4, pp. 268-276.
- Gabriel, C., Usman, E. and Latona, Y. (2014), *Tragedy Scores Die-synagogue Church Building Collapses*, Assessed 22nd March, 2016, from <http://www.vanguardngr.com/2014/09/tragedy-scores-die-synagogue-church-building-collapses/>
- Hani T.M., Ul-Hamid, A. and Abbas, N.M. (2004), *Practical Engineering Failure Analysis: Metallurgical Aspects of Fracture and Fractography*, CRC Press, Florida, p.401.
- Higgins, R.A. (1993), *Engineering Metallurgy Part 1*, Physical Metallurgy Edward Arnold Bodmin, Cornwall, p.55.
- NIBRI (2016), Analysis of Properties of Reinforcing Steel Bars: Case Study of Collapsed Building in Lagos, Nigeria, Accessed 22nd, March 2016, from <http://www.nibri.gov.ng/doc/building-collapse-maryland.pdf>.
- Kutz, M. (2002), "Role of Alloying Elements in Steel", In: *Hand Book of Materials Selections*, Kutz Myer Associates, John Wiley and Sons Inc.
- Nigerian Standard (2004), *NST-65-Mn: Raw Materials and Specifications for Federal Government Steel Companies (Reviewed)*, Nigerian Standard, pp 3-19.
- Odusote, J.K. and Adeleke, A.A. (2012), "Analysis of properties of reinforcing steel bars: Case study of collapsed buildings in Lagos, Nigeria", *Applied Mechanics and Materials*, Vol.204-208, pp.3052-3056.
- Osarenwindu, J.O. and Amuchi, E.C. (2013), "Quality assessment of commercially available reinforced steel rods in Nigeria markets", *Journal of Emerging Trends in Engineering and Applied Sciences*, Vol. 4 No 4, pp. 562-565.
- Prabir, C.B., Shylamoni, P. and Roshan, A.D. (2004), "Characterisation of steel reinforcement for RC structures: An overview and related issues", *Indian Concrete Journal*, Vol.78, pp.19-30.
- Sambo, B., David, E., Samson, A., and Olatunde, A. (2009), "Challenges of producing quality construction steel bars in West Africa: Case study of Nigeria steel industry", *Journal of Minerals Characterisation and Engineering*, Vol. 8, pp.283-292.
- Serope, K and Schmid, R. (1993), *Manufacturing Engineering and Technology*, 2nd Edition, Pearson Education South Asia Pte Ltd, Singapore.
- Vlack, L.H (1982), *Materials for the Engineer, Materials, Concept and Application*, Addition Wesley Publishing Company, Reading.
- William C.D. Jr. (2010), *Callister's Materials Science and Engineering*, 7th Edition, (Adapted by R. Balasubramaniam), Wiley Indian (P) Ltd, New Delhi.

Authors' Biographical Notes:

Abdul Ganiyu Funsho Alabi is presently at the Material Science and Engineering Department of Kwara State University, Malete and an Adjunct Professor at the Department of Materials and Metallurgical Engineering, University of Ilorin, both in Kwara State, Nigeria. His areas of interest are in the Materials Development, Corrosion processes and Extractive Metallurgy. Professor Alabi had a B.Sc. in Chemistry from the University of Ife (Now Obafemi Awolowo University), Ile Ife, an M.Sc/DIC from

Imperial College, London in Extractive Metallurgy of Primary and Secondary Metals and a Ph.D. from the School of Engineering, University of Pittsburgh in USA. He is a Fellow of the Nigerian Society of Engineers.

Akintunde Olayinka Ayoade received his B.Eng and M.Eng degrees in Mechanical Engineering from University of Ilorin, Ilorin, Nigeria in 2012 and 2015, respectively. His current research interests include Materials Selections and Applications, Microstructural Characterisation and Fracture Behaviours of Materials. He is currently a PhD student in the department of Mechanical Engineering, University of Ibadan, Ibadan, Nigeria. His current research interests include Materials Selections and Applications and Manufacturing Process.

Jamiu Kolawole Odusote got his Ph.D degree from University of the Witwatersrand, Johannesburg, South Africa, in 2011. He is a Registered Engineer with Council for Regulation of Engineering in

Nigeria (COREN). He is also a member of Nigeria Society of Engineer (NSE) and International Association of Engineers (IAEng). Dr. Odusote is currently a Senior Lecturer in the Department of Materials and Metallurgical Engineering, University of Ilorin, Ilorin, Nigeria. His major research Interests are in materials selection and characterisation, Corrosion and High temperature oxidation as well as materials/product design and development.

Adekunle Akanni Adeleke obtained his B.Eng. and M.Eng. degrees in Mechanical Engineering from University of Ilorin, Ilorin, Nigeria in year 2009 and 2013, respectively. He is currently a PhD student in the same department. His area of interest is Iron and steel development, Renewable energy and Materials development.

■