Asian Journal of Advances in Research

5(1): 808-816, 2022

STUDY OF THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF STEEL REBARS LOCALLY PRODUCED IN GHANA

EBENEZER ANNAN [a], LUCAS NANA WIREDU DAMOAH [a], YAW DELALI BENSAH [a], DAVID SASU KONADU [a*] AND JONATHAN SELORM DEGBEZUI [a]

[a] Department of Materials Science and Engineering, University of Ghana, School of Engineering Sciences, P.O. Box LG 77, Legon, Accra, Ghana.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Received: 18 February 2022
Accepted: 21 April 2022
Published: 30 April 2022

Original Research Article

ABSTRACT

The structural integrity of engineered structures depends highly on the materials used. In recent times, increase in the collapse of buildings in Ghana has allegedly been attributed to the poor engineering properties of locally produced steel rebars, an indication that they do not meet the requirements set by the Ghana Standards Authority (GSA). This project studied the metallurgy of different rebars randomly sourced in Ghana, with a view to determine their suitability for structural applications. The study involved determining the chemical composition of the various diameters of rebars, analyzing microstructure and mechanical properties of the rebars and the obtained results compared with GSA values. The diameters measured gave average values which were close to that of the standard values. The chemical compositions of the rebars were good as they were all within the mild steel range but a few noticeable inconsistencies were observed in the chemical composition. The average tensile and yield strength for the samples were 545.11 MPa and 453.55 MPa which were above the GSA values of 400 MPa and 300 MPa minimum respectively. The rebars were quite ductile as standards for both elongation and area reduction were exceeded. This showed that the selected rebars met the GSA standards.

Keywords: Steel rebars; mechanical properties; microstructure; yield strength; mild steel.

1. INTRODUCTION

The iron age was an important period in the history of humanity, where man studied and began producing tools from iron and steel [1]. Iron in its abundance in the earth's crust make about 80% mass of the inner and outer cores of the earth [2]. Steels are a family of materials derived from iron rich ore deposits (or steel scrap) which contains iron and carbon. Steel has a weight percentage of carbon ranging from 0.008-2.1. Steels are very versatile; formed into desired shape by plastic deformation through rolling and forging. It may be treated to provide a wide range of mechanical properties and be used for enormous applications [2-4].

In the iron–carbon alloy system, pure iron melts at a temperature of 1539°C. During the rise in temperature from ambient conditions, it undergoes several solid-state phase transformations. The alpha (α) ferrite

**Corresponding author: Email: dskonadu@ug.edu.gh;*

phase is present from room temperature. At 912°C, ferrite transforms to gamma (γ) iron, which is known as austenite. This then transforms at 1394°C to delta (δ) ferrite, which remains until melting at 1539°C [5]. Alpha and delta ferrites have body-centred cubic (BCC) lattice structures, while gamma has a face-cantered cubic (FCC) lattice structure. Another phase Fe_3C, often known as cementite, is an intermediate phase. It is a hard and brittle intermetallic compound of iron and carbon [5].

To produce steel rebar, after melting the raw material from either iron ore or steel scrap, the molten steel is delivered into a tundish which feeds into a caster to form billets. Large billets are then reduced continuously into smaller shapes at the roughing mill through round openings. At this point, the billet begins to take shape into rebars. The bars then undergo finishing which includes coating, twists/ribs and grooves that gives them the ideal reinforcing application appearance [4–6]. Steel rebars will remain the most widely utilized constructional material in terms of volume in the future since this is a product that is constantly in great demand [7–9].

Concrete, on the other hand, is the most widely used construction material in the world and is mostly used with steel reinforcements, giving rise to reinforced concrete material. This composite material uses cement as a matrix to absorb compressive stresses, protect reinforcing steel bars, and shift loads inside the embedded steel bars to absorb tensile stresses. The steel rods that are installed within concrete and brick to assist them preserve their shape and qualities are known as rebar or "reinforcement bar." In reinforced concrete and reinforced masonry constructions, rebar is widely employed as a tensioning system to keep the concrete in compression [9]. Rebar is essential to building constructions that are secure, long-lasting, and reliable. Without them, the natural expansion and contraction of the concrete will result in the formation of weak regions, which will eventually collapse. Even though concrete is a resilient material capable of carrying a significant amount of weight, it lacks the required tensile strength [8–10].

Steel rebars are usually made of mild steels, but can also be made from heat treated medium carbon steel, stainless steel, etc. [3]. Rebars are available in different grades and specifications that vary in mechanical and chemical properties [9]. Plain carbon steels are the type that include only trace amounts of impurities other than carbon, as well as a little amount of manganese and silicon. Mild steel rebars have a carbon content of less than 0.25 wt% and do not respond to heat treatments. As a consequence, these alloys are rather soft but have great ductility and toughness. Also, they are machinable, weldable, and most importantly, they are the least expensive to make, saving money during construction [1].

The construction industry over the past decades has been one of the fastest growing sectors of the Ghanaian economy [11]. At present, most contractors or engineers are only interested in the mechanical properties of steel rebars. There is inadequate information on the actual behavior of these reinforcing steel bars locally manufactured in Ghana, which are already in use in structural concrete for construction works [12]. Failure may occur due to different reasons, including the chemical composition of a material. The chemical composition of a material must therefore be analyzed to determine its inherent properties, as it will invariably affect its mechanical properties [12,13]. Boateng and Danso [14] reported that in Ghana, more than 10 different cases of building collapse have claimed thirty-nine (39) lives and caused ninety-one (91) injuries between 2009 and 2013. They recommended further studies for identification of sub-standard materials that contribute to building collapses in Ghana after they had concluded that cement produced in Ghana is not the real cause of collapse of buildings. They reiterated the call that poor quality construction materials are the major causes of collapse of buildings in Ghana. They also noted that among the main materials identified as sub-standard included reinforcing rebars.

Even with this wake-up call, the recent collapse of the Dzorwulu Primary School at Ayawaso West Municipality, Accra - Ghana on 29th September, 2019 calls for a thorough investigation on the actual causes of collapse of buildings to determine the tests needed to be carried out on the buildings and the possible solutions [15]. Adequate knowledge on both the physical and chemical properties of steels available in the market is therefore essential to guide engineers in choosing the right materials for the right job. This will help ensure more safe and durable structures in the near future [16].

The GSA has provided standard values for the mechanical properties and chemical composition for the various rebars [17]. Material specifications set the requirements for grades as well as additional properties such as, chemical composition, minimum elongation, physical tolerances, etc. Fabricated rebar must exceed the minimum yield strength of a particular grade and any other material specification requirements when inspected and tested. This project seeks to study the mechanical properties of some randomly sourced steel rebars.

2. MATERIALS AND METHODS

2.1 Materials and Diameter

The steel rebar samples were obtained from five different construction sites in Accra, the capital city of Ghana (Fig. 1). The samples were cut and machined to standard dimensions according to ASTM A370/EN 10002 standard. The Samples were labeled as TM1, TM2, TM3, TM4, TM5 and TM6 as presented in Table 1 with their theoretical diameters. The diameters of the various samples were measured with a vernier calliper. For each sample, at least thirty diameters were measured at different portions.

2.2 Chemical and Mechanical Analysis

The collected samples were sectioned using a precision hacksaw to a thickness of 5 mm and then labelled as shown in Table 1. The sample surfaces were then ground on an automatic polisher with silicon carbide abrasive papers of grade 180, 240, 400 and 600 grits and washed with ethanol for the chemical analysis. They were then placed into an Angstrom V-950 Spectrometer for the analysis. The tensile test was done in accordance with ASTM A370/EN 10002. Three specimen each of the 6 mm sized steel rebar herein labelled TM1, 12 mm sized steel rebar herein labelled TM3 and the 16 mm sized steel rebar herein labelled TM4 were tested. The other diameters sourced could not meet the required dimensions for the tensile testing. Each sample was placed into a marker machine to a graduation of 10 mm interval on the steel rod as required by the Tinius Olsen Materials Testing Machine H50KT. Thus, the mechanical characteristics (the average yield strength (YS), average ultimate tensile strength (UTS), and percentage elongation (%EL)) of the specimens were determined using the universal testing machine (UTM). Percent elongation (%EL) is a measure of the plastic strain at fracture (Egn 1).

$$\%EL = \frac{l_f - l_o}{l_o}\ x\ 100 \qquad 1$$

Where l_f is the fracture length and l_o is the original gauge length.

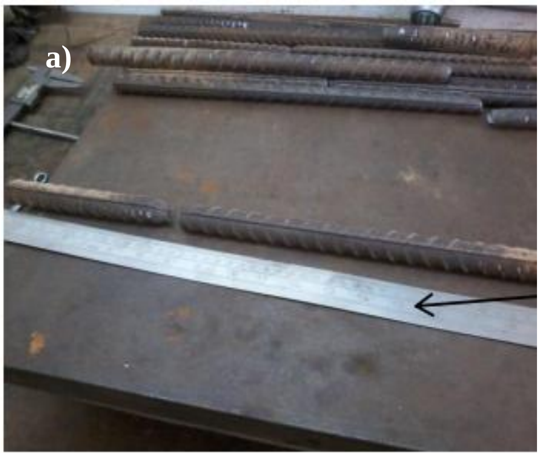
Percent reduction in area (%RA) may be calculated according to (Eqn 2)

$$\%RA = \frac{A_o - A_f}{A_o}\ x\ 100\% \qquad 2$$

Where A_0 is the original cross-sectional area and A_f is the cross-sectional area at the point of fracture (Ref 4).

2.3 Microstructural and Hardness Tests

For the hardness measurements, a portable hardness tester phase II (PHT-1700) was used. The samples were cut such that both sides were parallel. Five readings were taken along the diameter of each sample and an average was calculated. The samples were then sectioned and cold mounted in cups; using a 2:1 ratio of PELCO epoxy resin and PELCO fast curing epoxy hardener. The mixture was poured into removable cups and left for 24 hours to harden. The mounted samples were ground by using silicon carbide papers of grade 180, 240, 400, 600, 800/3000 and 1200/4000 grits. The samples were placed on the SBT Model 900 grinder/polisher once more, while water was poured on at regular intervals to dissipate heat and allow for faster grinding. The samples were further polished to a 1 µm surface



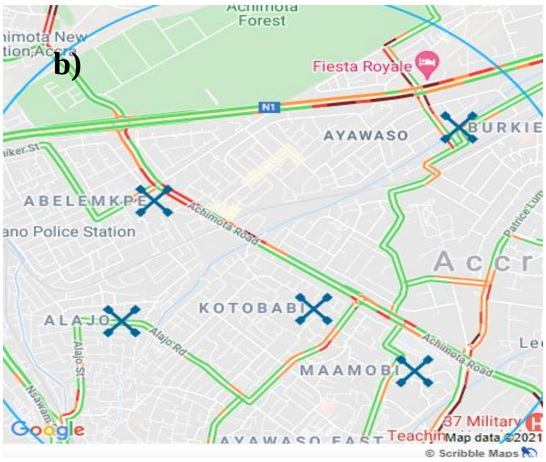


Fig. 1. a) Measuring length of sample steel rebar, b) map of the construction site locations in Accra, Ghana

finish using diamond spray and diamond extender (lubricant). The samples were then etched for microstructural analysis using 2% HNO_3 and 98% ethanol for about 15 seconds and quickly washed in distilled water to stop the etchant from attacking more of the phases. Finally, they were rinsed in ethanol and dried. The etched samples were imaged using a metallurgical microscope model MT8100.

3. RESULTS AND DISCUSSION

3.1 Diameter

The measured average diameter values are shown in Table 1. These values are approximately equal to the standard required. This showed that the companies produced steel rebars which have the right diameter and is not in agreement to the allegation given by the GSA as reported by Domfeh [18].

3.2 Chemical Analysis of Samples

Table 2 shows the chemical composition of the samples obtained. Standard values obtained from the GSA are also presented in Table 3. The results presented in Table 2 showed that the samples were mainly made of iron between 99.07 wt% - 97.89 wt% and other constituents such as Ni, Si, Mn, P, Cu, Cr, Al, etc. in infinitesimal amounts. The carbon contents were observed to be below the 0.25 wt% benchmark, which meant that the rebars were mild steels. The strength of iron increases as carbon content increases but reduces the ductility [12].

The TM4 sample recorded the highest amount of carbon content of 0.204 wt% and the least was TM5 sample of 0.168 wt%. Alloying elements such as nickel, manganese, molybdenum, and chromium help increase the strength and toughness of each sample. Chromium content also helps in wear and corrosion resistance [19].

The phosphorus content did not fall within the standard, for instance, TM1, TM2, TM3, and TM4 phosphorus levels ranged between 0.054 wt% - 0.061 wt% which was greater than both GS 788 and BS 4449 standards of 0.05 wt%. The sulphur content in the rebars was generally far below (between 0.0240-0.039 wt%) the GS 788 and BS 4449 standards of 0.05 wt% except TM1 which recorded sulphur content of 0.042 wt% as seen in Table 2. Phosphorus and sulphur are undesirable elements and are therefore required in minimal content in the steel to avoid embrittlement [20]. If the presence of small amounts of manganese is found in the steel (Table 2), the sulphur reacts with iron to cause eutectics, which can result in cracking [21]. The silicon content in the samples was observed to be between 0.115 - 0.428 wt%. With the exception of TM2 which had Si content of 0.4275 wt%, all the other samples recorded a much lower wt% of Si, which may affect the ductility, strength, and hardness of the steels. The relatively high amount of phosphorus and silicon may lead to increase in strength and hardness but a reduction in ductility. The presence of aluminium and silicon also helps to prevent defects by acting as deoxidizers in the steel [22].

The manganese (Mn) percentage level in the steel affects the strength, toughness and hardness [23]. In the steel samples, Mn content ranged between 0.9125 wt% - 0.3730 wt% which was below the 1.0 wt% and 1.65 wt% specified by both BS 4449 and GS 788 standards. Due to the difference in Mn content in all the samples, this may likely affect the strength and toughness of steels with low Mn wt%. Comparing the amount of the elemental composition to the standard minimum composition shown in Table 3, most composition specifications were within limits but producers have to endeavour to adhere to the standard specifications.

3.3 Mechanical Properties

Mechanical properties of materials are important in the determination of the right application or use of that material to avoid catastrophe or failure. Mechanical properties such as ultimate tensile strength, yield strength and area of reduction were measured and recorded as in the stress-strain curves which is shown in Fig. 2. From Fig. 2, the samples first underwent elastic deformation

Table 1. Diameter measurements of the selected steel rebars

Diameter (mm)	Label	Average values (mm)	Standard values (mm)
6	TM1	6.02	6
10	TM2	9.9	10
12	TM3	12.13	12
16	TM4	15.94	16
20	TM5	20.09	20
25	TM6	24.92	25

Table 2. The chemical composition of the steel rebars

Element	Composition (wt%)					
	TM1	**TM2**	**TM3**	**TM4**	**TM5**	**TM6**
C	0.182	0.176	0.173	0.204	0.168	0.191
Mn	0.749	0.913	0.590	0.441	0.373	0.420
P	0.054	0.061	0.056	0.061	0.019	0.049
S	0.041	0.022	0.021	0.039	0.014	0.024
Cr	0.065	0.333	0.112	0.090	0.030	0.142
Mo	0.082	0.086	0.119	0.099	0.084	0.082
Ti	0.013	0.002	0.002	0.002	0.002	0.002
B	0.016	0.001	0.001	0.001	0.001	0.001
Si	0.239	0.428	0.071	0.119	0.156	0.115
Cu	0.010	0.001	0.247	0.192	0.025	0.001
Ni	0.033	0.044	0.128	0.138	0.045	0.087
Sn	0.028	0.040	0.029	0.037	0.008	0.003
Co	0.013	0.001	0.006	0.009	0.002	0.014
Al	0.014	0.009	0.009	0.009	0.009	0.009
Fe	98.463	97.887	98.438	98.562	99.067	98.863

Table 3. Approved elemental composition of mild steel from Ghana Standard Authority (GS 788 2:2008, Building and construction materials – steel for reinforcement of concrete – part 2: Ribbed bars (Ref 17) and BS 4449 (2005 (Ref [24]))

ELEMENT		C	Mn	Si	P	S	N
AMOUNT (Wt%)	GS 788	≤ 0.25	≤ 1.65	≤ 0.60	≤ 0.05	≤ 0.05	≤ 0.012
	BS 4449	0.25	1.00	0.40	0.05	0.05	

as represented by the line from 0 MPa to their respective yield points. Thus, TM1 (6 mm) recorded 574 MPa, TM3 (12 mm) recorded 412.33 MPa and TM4 (16 mm) recorded 374.33 MPa, all of which was above GS 788-2 standards. The deformation continued until the ultimate tensile strengths of each of the samples were reached. Thus, TM1 recorded 578.33 MPa, TM3 recorded 533.33 MPa, and TM4 recorded 523.67 MPa, all also were above GS 788-2 standards of 400 MPa minimum. The samples then began to neck till they finally fractured.

From the plot in Fig. 2, TM1 had the highest ultimate tensile strength of the three samples but did not undergo much necking before fracture. This can be as a result of the relatively low ductility. TM3 and TM4 however, recorded lesser ultimate tensile strengths but underwent considerable necking before fracture, pointing to higher ductility. This can be linked to the Si content as discussed earlier. The high silicon content of TM1 (0.2385) compared to TM3 (0.071) and TM4 (0.0119), resulted in a higher strength but reduced the ductility as discussed earlier. In general, the tensile curves can be said to be dependent on the diameter of the samples as the smallest diameter produced the fastest fracture time while the largest gave the longest fracture time. This was further elaborated in Table 4.

The rebars tested all met the required yield strength and ultimate tensile strength (Fig. 3) and elongation for GS 788 standards but failed to meet the BS 4449 requirement, except for TM1 which met the yield strength standard as indicated in Table 4. One problem was with the ductility of TM1, which was below the required value (while the TM3 and TM4 met the standard value of 1.25 Rm/Reh minimum). This showed that the rebar had low ductility as predicted earlier. From Fig. 2 and Table 4, it was apparent that as the diameters (TM1, TM3 & TM4) increased, the ultimate tensile strengths and yield stresses decreased. Whilst with increasing diameter, area reduction and elongation also increased. The values of the hardness ranged between 123.7 - 323.7 (Table 5). It can also be seen that as the diameter decreases, so does the hardness values (Table 5).

3.4 Microstructural Analysis

The microstructure of some steel rebars are shown in Fig. 4. The microstructures revealed ferrite and pearlite phases. The dark areas were the pearlite phases, and the bright areas were the ferrite phases. This may be due to the chemical composition of less than 0.25 wt% C in the steel rebars [4**]**. The lower carbon content revealed higher area volumes of bright areas visually which agrees with literature [4**]**.

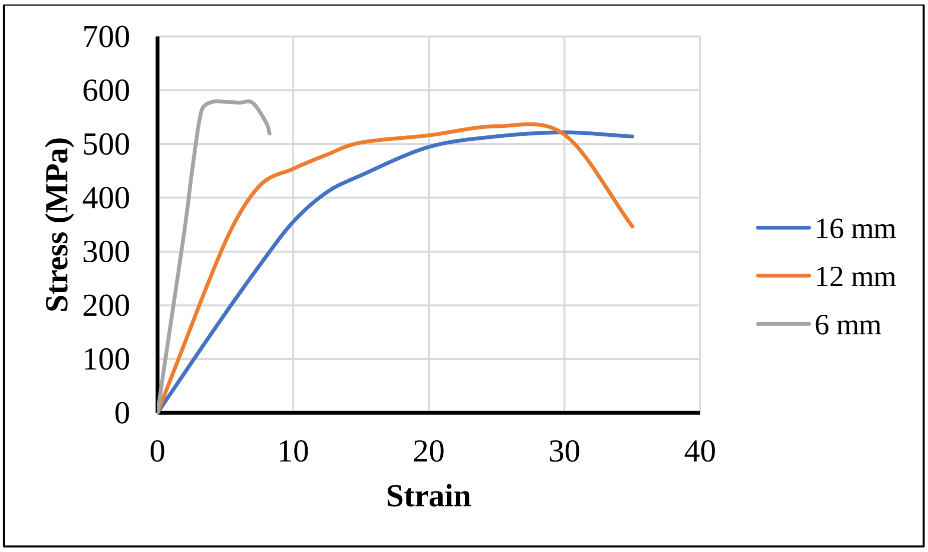


Fig. 2. Stress strain curves of the three samples measured

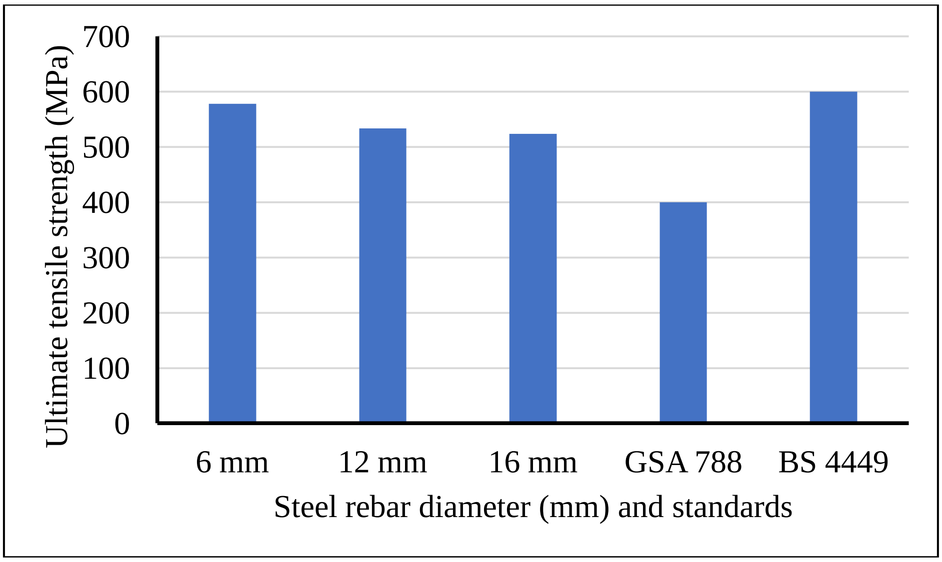


Fig. 3. Comparing ultimate tensile strength of sample rebars with the standard values

Table 4. The tensile test results (average values)

Property	**Sample sizes**			**(GS 788-2 :2008)**			**BS 4449**
	TM1	**TM3**	**TM4**				
Original diameter (mm)	6.1	10.33	17.23	6	12	16	
Fracture diameter (mm)	5.11	8.71	14.39				
Original length (mm)	500	500	500				
Fracture length (mm)	645	646.67	651.67				
Ultimate tensile strength (Rm) (N/mm^2)	578.33	533.33	523.67	400 min.			600
Yield strength (reh) (N/mm^2)	574	412.33	374.33	300 min.			460
Elongation (%)	29	29.33	30.33	14 min.			14
Cross sectional area (mm^2)	28.8	84.27	233.83	28.3	78.5	227	
Fractured surface cross-sectional area (mm^2)	20.48	59.54	162.78				
Area reduction (%)	28.89	29.33	30.37	17 min.			

Table 5. Leeb hardness values of samples

Sample	TM1	TM2	TM3	TM4	TM5	TM6
Leeb Hardness	323.7	207.7	195.3	188.7	154.7	123.7
Brinell (HB)	91.6	45.5	40.7	38.1	24.7	12.5
BS4449	120					

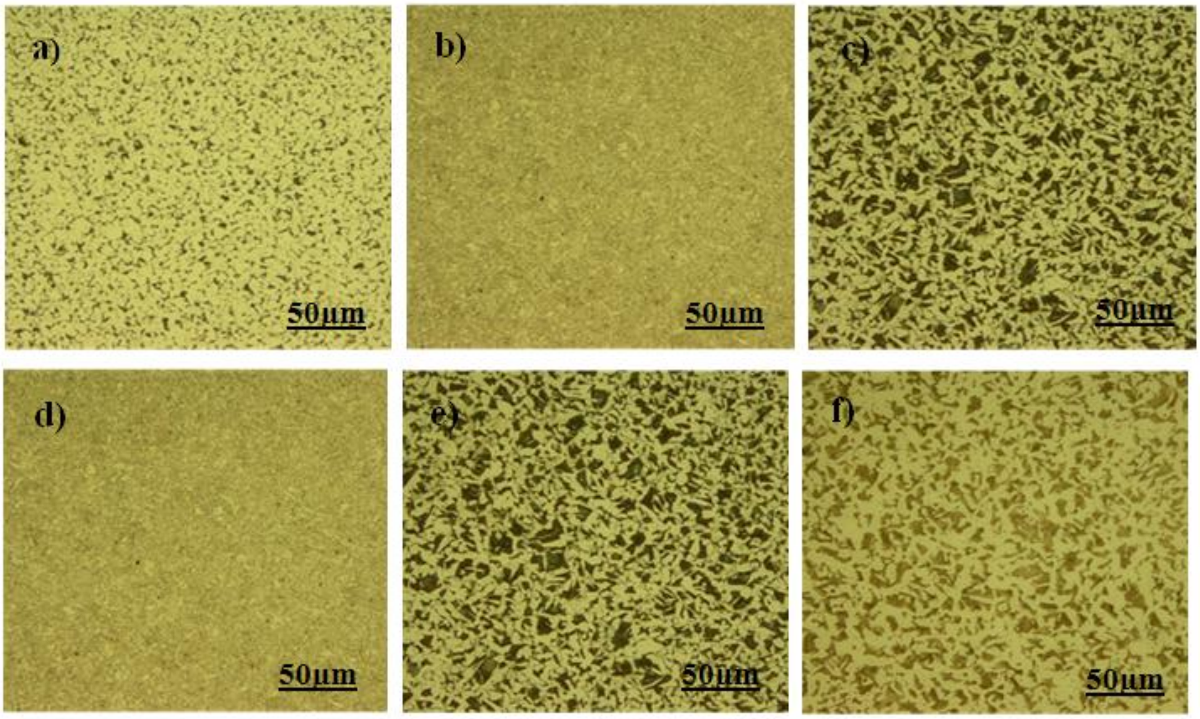


Fig. 4. Microstructure of samples a) microstructure of TM1 rebar b) microstructure of TM2 rebar c) microstructure of TM3 rebar d) microstructure of TM4 rebar e) microstructure of TM5 rebar f) microstructure of TM6 rebar

The ferrites are soft and ductile while the pearlites are hard and relatively strong. This combination might have contributed to the high strength and ductile rebars. It has also been reported that titanium in the steel rebars help in recrystallization, and this might have contributed to the observed small grains and the high tensile strengths, above the standards shown. Cooling from liquid until solidification, delta ferrite and austenite phases are formed and further cooling to about 600-650°C lead to the nucleation of alpha ferrite at the grain boundaries of the austenite grains, and then the remainder of the austenite formed pearlite [4].

From Fig. 4, there were no apparent defects such as blow holes found during the microstructural analysis. This might be attributed to the use of de-oxidizers such as aluminium being used efficiently [4]. Blow holes/pin holes are defects that adversely affect the metal and may increase the probability of failure occurring [25]. The presence of these defects can lead to bigger problems during reheating of the billet. The major cause being the presence of moisture in the cast or inefficient deoxidation. Proper degassing of the molten metal can help efficiently avoid such defects [26].

4. CONCLUSION

The following conclusions can be drawn from the results and analysis of the study of the samples;

- The steel rebars used by builders in Ghana had sizes that were within allowed nominal sizes as specified by the GSA and the British Standards. Thus, the diameters measured gave average values which were close to that of standard values.
- The chemical compositions of the rebars were good as they were within the mild steel range. The study however uncovered discrepancies in the chemical compositions of the steel samples

which may lead to undesirable mechanical properties. There is therefore a need to chemically examine products to check the presence of elements such as silicon, sulphur and phosphorus which are needed, but must be controlled.

- The rebars had an ultimate tensile strength, yield strength and elongation % within GSA limits. The average tensile strength for the samples was 545.11 MPa since a minimum value of 400 MPa was expected as stated by GSA. The test results revealed that the rebars at the construction site have adequate yield strength as compared to the GS 788-2:2008 standard. The rebars were quite ductile as standards for both elongation and area reduction were exceeded. The microstructure of the rebars showed ferrite and pearlite with ferrite being the dominant phase. There were no defects (pores or blow holes) found in the microstructure.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Sund RB, Bishop J. Accent on science, C.E. Merrill Publishing Co.; 1980.
2. Frey PA, Reed GH. The Ubiquity of Iron, ACS Chem Biol. 2012;7(9):1477-1481.
3. Callister Jr.WD, Rethwisch DG. Materials Science and Engineering_ An Introduction, - John Wiley, 9th ed; 2014
4. Askeland DR, Fulay PP, Wright WJ. The Science and Engineering of Materials - Instructor's Solutions Manual, Sci. Eng. Mater. 2005:1–126.
5. Groover MP. Fundamentals of Modern Manufacturing Materials, Processes, and Systems, John Wiley & Sons, INC, 4th ed; 2010.
6. Wang GC. Ferrous Metal Production and FerrousSlags in The Utilization of Slag in Civil Infrastructure Construction. Woodhead Publishing. 2016:9-33.
7. Yang Y, Raipala K, Holappa L. Ironmaking, in Treatise on Process Metallurgy, Volume. 2013;3:2–88.
8. Kalpakjain S, Schmid SR, Musa H. Manufacturing Engineering and Technology, Prentice Hall, Singapore. 2009;325-326. 6th Ed.
9. Ede A, Olofinnade M, Olofinade O, Joshua O. Experimental Investigation of Yield Strengths of Steel Reinforcing Bars Used in Nigerian Concrete Structures, Int. J. Sci. Eng. Res. 2014;5(4):76-83.
10. Bhardwaj BP. Handbook on Steel Bars, Wires, Tubes, Pipes, SS. Sheets Production with Ferrous Metal Casting & Processing. Delhi : Niir Project Consultancy Services; 2014.
11. Osei V. The Construction Industry and Its Linkages to the Ghanaian Economy-Polices To Improve the Sector's Performance, Int. J. Dev. Econ. Sustain. 2013;1(1):56–72.
12. Kankam CK, Adom-Asamoah M. Strength and ductility characteristics of reinforcing steel bars milled from scrap metals, Materials and Design. 2002;23:537–545.
13. Tandoh JB, Amesimeku EK, Forson A, Nuviadenu C, Ahiamadjie H, Quashigah G, Gazoya E, Sackey-Lee H. Corrosion Behavior of Iron Steel Bars on the Ghanaian Market; Elemental Composition and Mechanical Properties Perspective Res. J. Appl. Sci. Eng. Technol. 2019;16(4):166–174.
14. Danso H, Boateng I. Is the Quality of Cement a Contributing Factor for Building Collapse in Ghana?, West African Built Environ. Res. Conf; 2013.
15. Hawkson EE. School Block collapses, kills 2 at Dzorwulu. *Graphic Online*, Accra; 2019. Available:https://www.graphic.com.gh/news/general-news/school-block-collapses-kills-2-at-dzorwulu.html
16. Adewuyi RA, Ajao KS, Ambli IO, Aremu NI, Ibrahim HK, Abdul JM. Quality Evaluation of Commercially Available Steels in Some Selected Nigerian Markets, ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering. 2019;103–115.
17. Ghana Standards Authority. GS 788-2.Specification for Steel bars for Concrete Reinforcement; 2008.
18. Domfeh KA. Buyer Beware: iron rod standard could endanger your building Modern Ghana; 2012. Available:https://www.modernghana.com/news/405781/buyer-beware-iron-rod-standard-could-endanger-your-building.html
19. Zhou P, Jin-ming L, Zhang F, Hui-bin W, Di T. Influence of Chromium on Corrosion Behavior of Low-alloy Steel in Cargo Oil Tank O_2-CO_2-SO_2-H_2S Wet Gas Environment, J. Iron Steel Res. Int. 2015;22(7):630–637.
20. Guo-hua X, Han D, Mao-qiu W, Wei-jun H. Effect of Sulfur Content and Sulfide Shape on Fracture Ductility in Case Hardening Steel, J. Iron Steel Res. Int. 2011;18(8):58–64.
21. Mukherjee M, Pal TK. Role of Microstructural Constituents on Surface crack formation during

hot rolling of standard and low nickel austenitic stainless steels, Acta Metall. Sin. (English Lett). 2013;26(2):206–216.

22. Davies RG. Influence of silicon and phosphorous on the mechanical properties of both ferrite and dual-phase steels. Metall. Trans. A. 1979;10(1):113–118.
23. kou He X, qiang Yang Z, Wang Z, bin Qiao S, dong Liu Z. Effect of Mn content on microstructure, tensile and impact properties of SA508Gr.4N steel for reactor pressure vessel. J. Iron Steel Res. Int. 2020;27(4):461–470.
24. British Standard (BS4449), Steel for the Reinforcement of Concrete – Weldable Reinforcing Steel - Bar, Coil and Decoiled Product – Specification; 2005.
25. Rao BN, Ashokkumar R. Effect of blow-holes on reliability of cast component," Sadhana. 2008;33:733–751.
26. Solanki V, Mukhopadhyay G. Metallurgical analysis of transverse crack of rebars Eng. Fail. Anal. 2019;104:1143–1156.
