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Physical and Geometrical Characteristics of Reinforcing Steel Bars in the Construction Industry of Ghana

Sampson Assiamah [a*], Charles K. Kankam [b], Emmanuel K. Banini [b] and Kwadwo Adinkrah Appiah [c]

[a] *Department of Building Technology, Sunyani Technical University, Sunyani, Ghana.*
[b] *Department of Civil Engineering, School of Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.*
[c] *Department of Civil Engineering, Sunyani Technical University, Sunyani, Ghana.*

Authors' contributions

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

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ABSTRACT

Steel milling companies are taking advantage of readily available scrap metals as raw materials to produce reinforcing bars. Major steel importers also continue to import reinforcing bars into the country to fill the gap between production and demand for steel reinforcing bars in Ghana. The question of whether these bars meet internationally accepted standards remains unanswered. This research generally sought to evaluate the geometrical and physical characteristics of reinforcing bars available in the Ghanaian market. These three specific objectives were achieved: identification of specific types of reinforcing bars in the market, examination of the physical properties and surface geometry and comparing these properties of the rebars with recognized standards. The samples collected were manufactured by four steel reinforcing bars milling companies in the

**Corresponding author: Email: sampson.assiamah@stu.edu.gh;*

country and one imported source. Physical and geometrical evaluation of the reinforcing bars showed that actual diameters of mild steel reinforcing bars traded in Ghana deviated significantly from the designated diameters. However, high yield reinforcing bars traded in the country were not significantly smaller in diameter compared to their designated nominal diameters. Mild steel bars should be labeled with bar size and the name of the milling company to prevent the sale of under-sized steel bars to consumers. This will also promote traceability. Strict enforcement of standards should be encouraged to ensure adherence to local and international standards for producing and importing reinforcing bars.

Keywords: Steel bars; physical properties; surface geometry; high yield; mild steel.

1. INTRODUCTION

Steel is widely used as reinforcement material because of its useful properties and availability. This building material is essentially an alloy consisting of mostly iron and carbon with other materials either as alloys or impurities [1,2]. One of the main reasons why steel is useful as a reinforcing bar in concrete is because its elongation due to high temperatures (that is coefficient of thermal expansion) is nearly equal to that of concrete, therefore the two materials are able to bond better under thermal expansion than other materials [3]. Steel is also the most important ferrous metal in construction [4,5].

According to the world steel figures of 2019 published by the World Steel Association, some of the largest steel-producing countries are China, India, Japan and U.S. China accounts for roughly 50% of the total steel production in the world [6].

Modern steel production makes use of recycled materials as well as traditional raw materials like iron ore, coal and limestone [7-17].

According to the World Steel Association data of 2018, steel production in the world was 1808.6 metric tonnes of which the Republic of China produces 928.3 metric tonnes. That is 51.3% of the world's production. China exported 74.8 metric tonnes of steel produced in 2017.

Rahman [2] defined plain reinforcing bars as normally mild steel rebars which are usually round in shape. The yield strength requirement of this type of bar is normally 250N/mm2. These types of reinforcing bars are used in concrete for special purposes, such as dowels at expansion joints, where bars must slide in a metal or paper sleeve, for contraction joints in roads and runways, and for column spirals. They are easy to cut and bend without damage. Smaller diameters are produced in a form of coils. Cold twisted bars are described as steel bars with lugs, ribs, projections or deformations on the surface. They are extensively used for reinforcement purposes in construction. The author further stated that these types of reinforcing bars are normally used for heavy structural engineering projects such as bridges, dams, high-rise structures, etc.

Some important characteristics of cold twisted bars include the following: low carbon value, superior bonding strength, welding capability, high tensile strength, wide application range and satisfactory malleability [2].

The steel manufacturing industry in Ghana has grown rapidly in the last decade. However, mining iron ore could not be developed to match the demands of new steel-producing companies. Importing iron ore as raw material for steel production is very expensive for a growing middle-level economy like Ghana. The local steel industry is dominated by the production of steel reinforcing bars and steel coils with the manufacturing process mainly done by a hot rolling process of converting scrap metals and billets into reinforcing bars, coils and steel balls for the construction, mining and allied industries. The local production of steel started in the 1960s with the establishment of GIHOC Steel Company, the forerunner of Tema Steel Company Limited.

Steel producing companies have taken advantage of the high demand for reinforcement bars and are producing steel bars from scrap metals which are readily available in the country. The local milling companies have started producing high yield (high tensile strength) reinforcing bars which was not the case previously. The main steel distribution companies are also importing a lot of reinforcement bars into the country. Both the imported and locally milled rebars are readily available in the open market for any client to buy and use for civil engineering structures. The question of whether these locally milled and imported rebars meet important internationally accepted standards as far as their physical characteristics are concerned remains unanswered. Previous research studied the chemical compositions and their influence on the mechanical properties of these steel bars [7,12]. This research sought to evaluate the physical characteristics of these reinforcement bars available in the country Ghana.

2. MATERIALS AND METHODS

2.1 Sampling of Test Materials

A simple random process was adopted. A total of one hundred pieces (100) each of the 12mm and 16mm nominal diameter reinforcing bars were selected. Other reinforcing bars selected included 75 pieces of 20mm nominal diameter, 75 pieces of 25mm nominal diameter and 50 pieces of 32mm nominal diameter. These samples were collected from the major steel distributors in the country. Some samples were also collected from construction projects sites. A total of 675 samples of reinforcing bars were selected as representative samples from five steel manufacturing companies. Four of the companies are local milling companies in Ghana while the remaining one represents reinforcing bars imported into the country. The imported steel bars samples were from a steel manufacturing company in Ukraine (Arcelor Mittal).

For instance, out of the total of 100 samples of high yield 12mm nominal diameter rebars, twenty-five (25) pieces were collected from Sentuo Steel Company (STS), 25 pieces from Ferro Fabrik Ltd (FFL), 25 pieces from Fabrimetal Ghana Ltd and 25 pieces were imported. The total number of all reinforcing bar sizes collected was six hundred and seventy-five pieces (675). Details of the reinforcing steel bar samples collected are shown in Table 1.

2.2 Measurement and Test Methods

The samples collected were taken through a series of measurements and laboratory tests that are described in the following sections.

2.2.1 Ribs height and spacing measurement

Bond is necessary not only to ensure an adequate level of safety allowing composite action of steel and concrete but also to control structural behavior along with sufficient ductility. The bond in reinforced concrete (RC) members depends on a number of factors such as the reinforcing unit (bar or multi-wire) and the stress state in both the reinforcing unit and surrounding concrete. Other parameters such as concrete cover, space between rebars, number of layers and bundled bars, casting direction and bar position play an important role. Several research studies have been conducted on the influence of deformation patterns and rib geometry on bonds [18,19].

The rib height and spacing measurement were important to give an indication of bond strength for the reinforcement bars available in the Ghanaian market. The rib height was calculated by dividing the difference between the Total Diameter of the bar and the Nominal diameter by two as expressed in equation 1 as follows [20]:

Rib Height= {Total Diameter (including ribs) –Nominal Diameter} ÷ 2   Eq 1.

Table 1. Number of reinforcing bars sampled

Nominal diameter (mm)	Grade of rebar	Number of companies/ construction site	Number of samples	Total samples
12	Mild Steel	4	25	100
	High Yield	4	25	100
16	Mild Steel	4	25	100
	High Yield	4	25	100
20	Mild Steel	3	25	75
	High Yield	3	25	75
25	Mild Steel	-	-	-
	High Yield	3	25	75
32	Mild Steel	-	-	-
	High Yield	2	25	50
	Total			675

The ribs spacing of the sampled steel bars was measured from the center to the center of ribs. Most manufacturing companies have unparalleled rib design on one side of the rebar and parallel design on the opposite side. Therefore, Rib spacing measurements were taken from ribs parallel to each other. Average rib spacing was also calculated as a simple mean of samples collected for respective diameters.

Fig. 1 shows some of the test reinforcing steel specimens with their ribs.

2.2.2 Bar diameter measurement

Diameter consistency is very essential for the safe and reliable design of any structure. The structural engineer needs accurate information on the diameter of the bars available in the market when selecting bar sizes during the design of a structure. The diameters of reinforcing bars in the open market varied significantly from the internationally accepted standard diameters of reinforcing bars. It was common to see steel distributors selling 10.5mm, 11mm, 11.5mm for a standard 12mm nominal steel bar; and 14mm and 15.5mm for a standard 16mm nominal diameter rebar.

The diameters of reinforcing bars were carefully measured using a pair of digital calipers HDCD01150 manufactured by ING-CO TOOLS COMPANY LIMITED OF CHINA. Diameters were recorded using a Microsoft excel workbook. The bar diameter was measured at three different locations of each sample, the average of which was recorded as the diameter for that particular sample. The average diameter of each bar size was calculated as a simple mean of the 25 pieces each of all sampled diameters. For instance, 25 pieces of samples of a 12mm diameter bar specimen taken from the company Ferro Fabrik Ltd were measured and the average then became the actual diameter recorded for the company. Fig. 1 shows typical reinforcing steel specimens with labels.

3. TEST RESULTS

3.1 Categorization of Reinforcing Steel

The reinforcing steel bars are categorized according to the manufacturer’s strength categorization. That is high yield or high tensile bars are separated from low yield or mild steel bars. Most of the reinforcing steel bars imported into the country belong to the high-yield steel bars category. It is, therefore necessary to group the locally manufactured steel into their respective categories to give an equal basis for analysis.

The imported steel bars are of the high yield category, therefore the physical and tensile properties of the imported steel bars collected from the market for study are compared with those of the same grade produced locally. The reinforcing steel bars collected are classified in Table 2.

3.2 Physical Properties and Surface Geometry of Reinforcing Steel Bars

The results and analysis of the physical properties or surface geometry of the reinforcement bars available in the local market are shown in Tables 3 to 10 and Figs. 2 to 9 as follows:

3.2.1 Analysis of 12mm high yield reinforcing bars

The results of the size measurement of the reinforcing bars as detailed in Table 3 show that the mean diameter obtained for 12mm nominal high yield reinforcing bars was 11.64mm with a standard deviation of 0.196mm. Maximum and minimum actual diameters of 11.82mm and 11.36mm were obtained from local miller Fabrimetal Limited (with a minimum deviation of 1.49%) and imported (with the maximum deviation of 5.36%) steel reinforcing bars respectively. The mean value of 11.64mm of the actual diameters at a mean deviation of 3.04% from the 12mm nominal diameter showed that high-yield steel reinforcing bars designated as 12mm nominal bars in the local market did not deviate significantly from the designated nominal diameter.

Maximum and minimum ribs height of 1.038mm and 0.553mm were obtained for the imported steel and Sentuo steel limited respectively. The mean value of 0.83mm with a standard deviation of 0.203mm for ribs height, while maximum and minimum ribs spacing of 8.95mm and 7.23mm respectively with mean ribs spacing of 8.31mm and a standard deviation of 0.78mm were obtained from the analysis. Only one of the 12mm nominal reinforcing bars (STS 12Y) met ASTM A615 [21] rib height to rib spacing ratio requirement of $0.0507 < h/c < 0.072$ with reference to the measured test data presented in Table 3 and Fig. 2.

Fig. 1. Typical labeled bar specimens

Table 2. Typical classification of reinforcing steel bars in Ghana

Bar source	Bar ID	Nominal bar size (mm)	Average ribs height h (mm)	Average ribs spacing	Bar classification
Ferro Fabrik Ltd	FFL 12R	12	1.137	8.847	Mild Steel
United Steel Co.	USC 12R	12	0.503	8.937	Mild Steel
Fabrimetal	FAB 12R	12	0.543	8.969	Mild Steel
Sentuo Steel Ltd	STS 12R	12	0.418	9.529	Mild Steel
Ferro Fabrik Ltd	FFL 16R	16	1.014	8.175	Mild Steel
United Steel Co.	USC 16R	16	0.880	11.145	Mild Steel
Fabrimetal	FAB 16R	16	0.807	10.014	Mild Steel
Sentuo Steel Ltd	STS 16R	16	1.074	11.287	Mild Steel
United Steel Co.	USC 20R	20	0.953	14.971	Mild Steel
Fabrimetal	FAB 20R	20	1.476	5.832	Mild Steel
Sentuo Steel Ltd	STS 20R	20	1.398	14.256	Mild Steel
Ferro Fabrik Ltd	FFL 12Y	12	0.891	8.953	High Yield
Imported steel	IMP 12Y	12	1.038	7.225	High Yield
Fabrimetal	FAB 12Y	12	0.834	8.781	High Yield
Sentuo Steel Ltd	STS 12Y	12	0.553	8.286	High Yield
Ferro Fabrik Ltd	FFL 16Y	16	1.101	9.986	High Yield
Imported steel	IMP 16Y	16	1.162	11.105	High Yield
Fabrimetal	FAB 16Y	16	0.994	10.121	High Yield
Sentuo Steel Ltd	STS 16Y	16	1.218	11.526	High Yield
Ferro Fabrik Ltd	FFL 20Y	20	1.500	14.129	High Yield
Imported steel	IMP 20Y	20	1.822	13.524	High Yield
Fabrimetal	FAB 20Y	20	1.247	12.485	High Yield
Ferro Fabrik Ltd	FFL 25Y	25	2.208	18.746	High Yield
Imported steel	IMP 25Y	25	2.233	17.797	High Yield
Fabrimetal	FAB 25Y	25	1.253	13.545	High Yield
Imported steel	IMP 32Y	32	2.233	17.793	High Yield
Fabrimetal	FAB 32Y	32	1.979	19.582	High Yield

3.2.2 Analysis of 16mm high yield reinforcing bars

High-yield nominal 16mm reinforcing bars had a mean actual diameter of 15.48mm with a standard deviation of 0.20mm. As illustrated in Table 4 and Fig. 3, the least and maximum actual diameters were 15.22mm and 15.72mm respectively with a mean deviation of 3.26% from the 16mm nominal diameter. Mean ribs height and ribs spacing were 1.11mm and 10.68mm with a standard deviation of 0.12mm and 0.75mm respectively. Both rib height and spacing conformed to BS 4449:2005+A2:2009

[22] requirement of 0.03d to 0.15d for ribs height and 0.4d to 1.2d for ribs spacing, where "d" is the nominal diameter. However, none of the high yield nominal 16mm reinforcing bars conformed to ASTM A615 [21] rib height to rib spacing ratio requirement of 0.0507 < h/c < 0.072.

3.2.3 Analysis of 20mm high yield reinforcing bars

From the results presented in Table 5, high yield reinforcing bars with a nominal diameter of 20mm from two local companies and one imported source had an actual mean diameter of 19.38mm at a standard deviation of 0.29mm. The mean actual diameter deviated averagely at 3.09% from the 20mm nominal diameter of the steel bars.

Additionally, the mean ribs height and spacing recorded were 1.55mm and 13.38mm with a standard deviation of 0.29mm and 0.83mm in that order. Even though ribs parameters of the 20mm nominal diameter high yield reinforcing bars conformed to the BS4449:2005+A2:2009 [22] requirement of 0.03d to 0.15d for ribs height and 0.4d to 1.2d for ribs spacing, where "d" is the nominal diameter, none of them met the ASTM A615 [21] rib height to rib spacing ratio requirement of 0.0507 < h/c < 0.072 as deduced from the measured data presented in Table 5 and Fig. 4.

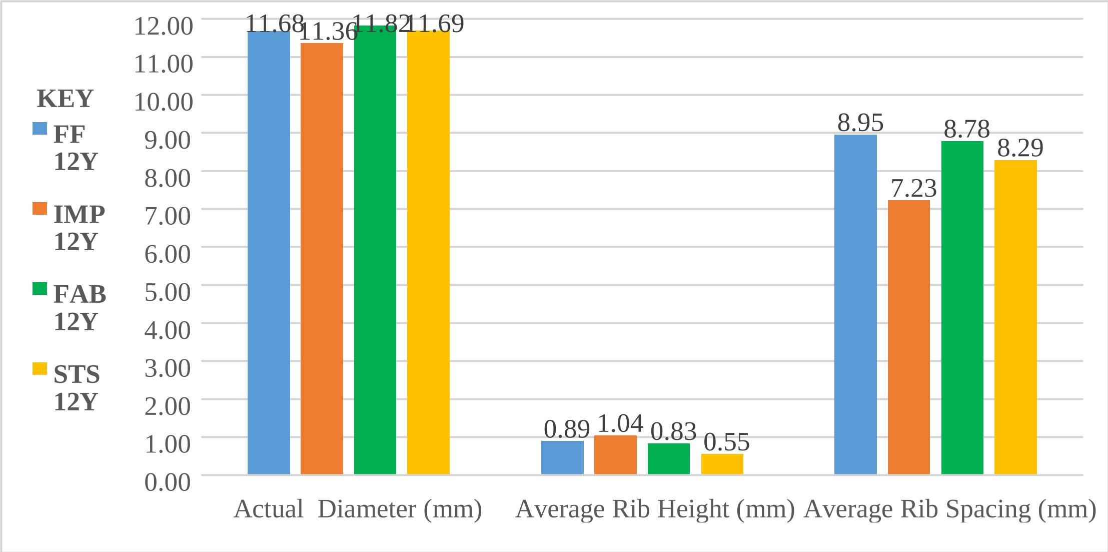

Fig. 2. Surface geometry of 12mm nominal high yield steel reinforcing bars

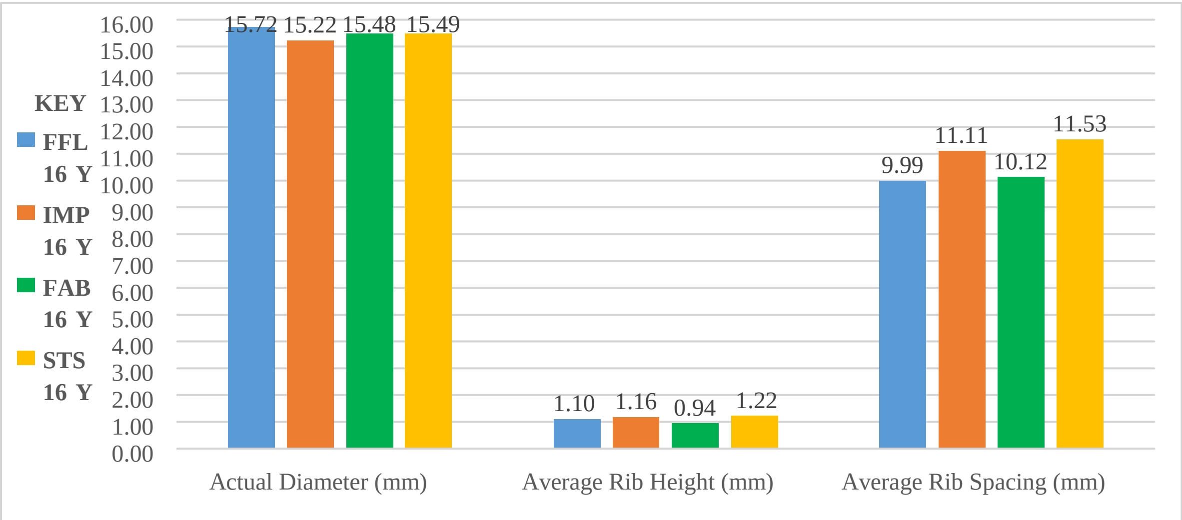

Fig. 3. Surface geometry of 16mm nominal high yield steel reinforcing bars

Table 3. Dimensional properties of 12mm nominal high yield steel bars

Brand of Steel	Grade/ID	Average actual diameter(mm)	Deviation from nominal diameter (%)	Average actual length (m)	Average rib height (mm)	Average rib spacing (mm)
Ferro Fabrik Ltd	FFL 12Y	11.68	2.70	11.94	0.891	8.953
Imported	IMP 12Y	11.36	5.36	12.04	1.038	7.225
Fabrimetal	FAB 12Y	11.82	1.49	12.00	0.834	8.781
Sentuo Steel Ltd	STS 12Y	11.69	2.59	12.00	0.553	8.286
Mean		11.64	3.04	12.0	0.83	8.31
Standard Deviation		0.196			0.203	0.78

Table 4. Dimensional properties of 16mm nominal high yield steel reinforcing bars

Brand of Steel	Grade/ID	Average actual diameter (mm)	Deviation from nominal diameter (%)	Average actual length (m)	Average rib height (mm)	Average rib Spacing (mm)
Ferro Fabrik Ltd	FFL 16Y	15.72	1.76	11.90	1.101	9.986
Imported	IMP 16Y	15.22	4.86	12.00	1.162	11.105
Fabrimetal	FAB 16Y	15.48	3.23	11.92	0.944	10.121
Sentuo Steel Ltd	STS 16Y	15.49	3.19	11.94	1.218	11.526
Mean		15.48	3.26	11.94	1.11	10.68
Standard deviation		0.20			0.12	0.75

Table 5. Dimensional properties of 20mm nominal high yield steel reinforcing bars

Brand of Steel	Grade/ID	Average actual diameter (mm)	Deviation from nominal diameter (%)	Average actual length (m)	Average rib height (mm)	Average rib spacing (mm)
Ferro Fabrik Ltd	FFL 20Y	19.52	2.43	12.00	1.579	14.129
Imported	IMP 20Y	19.05	4.76	12.04	1.822	13.524
Fabrimetal	FAB20Y	19.58	2.08	11.94	1.247	12.485
Mean		19.38	3.09	11.99		13.38
Standard deviation		0.29			0.29	0.83

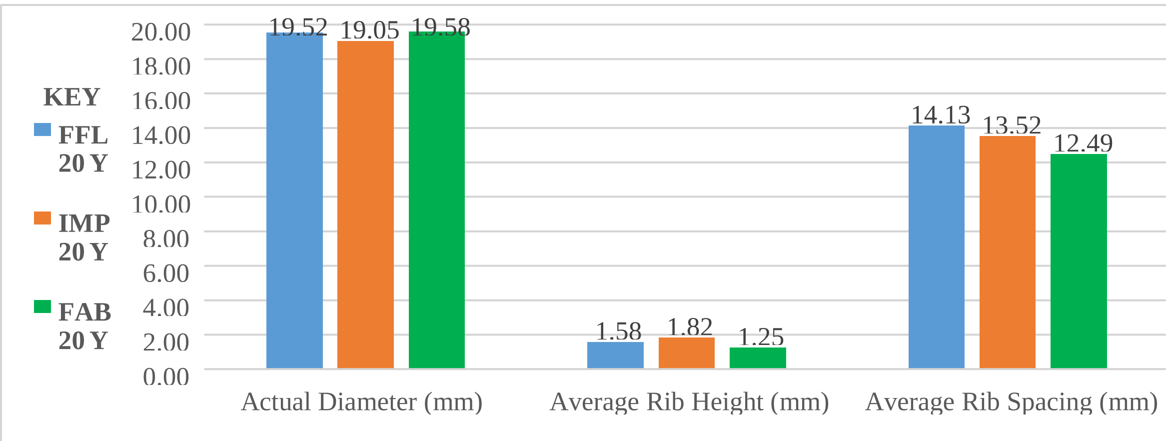

Fig. 4. Surface geometry of 20mm nominal high yield steel reinforcing bars

3.2.4 Analysis of 25mm high yield reinforcing bars

Analysis of results detailed in Table 6 shows that the mean diameter obtained for 25mm nominal high yield reinforcing bars was 24.22mm with a standard deviation of 0.299mm. Furthermore, the mean ribs height and spacing recorded were 1.9mm and 16.69mm with the standard deviations of 0.299mm and 2.77mm respectively. The mean actual diameter deviated averagely at 3.12% from the 25mm nominal diameter of the steel bars.

Both rib height and spacing conformed to the BS4449:2005+A2:2009 [22] of 0.03d to 0.15d for ribs height and 0.4d to 1.2d for ribs spacing, where “d” is the nominal diameter. On the other hand, none of the high yield nominal 25mm diameter reinforcing bars conformed to ASTM A615 [21] rib height to rib spacing ratio requirement of 0.0507 < h/c < 0.072 as illustrated in Table 6 and Fig. 5.

3.2.5 Analysis of 32mm high yield reinforcing bars

Two samples of 32mm nominal diameter reinforcing bars were analyzed of which one was from an imported steel milling company and the other from Fabrimetal Limited. As shown in Table 7, the mean actual diameter was 30.63mm at a standard deviation of 1.01mm. The mean actual diameter deviated averagely at 4.31% from the 32mm nominal diameter of the steel bars.

Ribs height and spacing were average of 2.11mm and 18.69mm which did not conform to ASTM A615 [21] rib height to rib spacing ratio requirement of 0.0507 < h/c < 0.072. The test results are also illustrated in Fig. 6.

3.2.6 Analysis of 12mm mild steel reinforcing bars

From the results presented in Table 8 and Fig. 7, mild steel reinforcing bars from the four local companies had a mean actual diameter of 10.7mm for 12mm nominal reinforcing bars with a standard deviation of 0.42mm. The mean actual diameter deviated at 10.85% from the nominal 12mm diameter of the steel bars. The analysis therefore, showed that all the reinforcement bars obtained from the market deviated significantly from the required nominal diameter of 12mm.

The mean ribs height and ribs spacing of 0.65mm and 9.07mm with a standard deviation of 0.33mm and 0.31mm respectively were obtained for the four steel milling companies in Ghana. Based on the details of Table 8, United Steel, Fabrimetal and Sentuo steel limited met the ASTM A615 [21] required ratio for ribs height to ribs spacing of 0.0507 < h/c < 0.072.

3.2.7 Analysis of 16mm mild steel reinforcing bars

The results detailed in Table 9 indicate that the mean diameter obtained for 16mm nominal mild steel reinforcing bars was 14.24mm with a standard deviation of 0.165mm for the four milling companies. A maximum diameter of 14.441mm was obtained from United Steel Company while the least diameter of 14.04mm was obtained from Fabrimetal Limited. The mean diameter of 14.24mm for the four milling companies deviated at 9.75% from the designated 16mm nominal diameter, therefore the reinforcing bars fall below specification. Additionally, mean ribs height and spacing of 0.94mm and 10.16mm with standard deviation of 0.122mm and 1.44mm respectively were obtained for the four milling companies. From the results in the table, none of the mild steel reinforcing bars of 16mm nominal diameter met the ASTM A615 [21] required ratio for ribs height to ribs spacing of 0.0507<h/c<0.072. However, all the reinforcing bars conformed to BS4449+A2:2009 [22] ranges for rib parameters requirement of 0.03d to 0.15d for ribs height and 0.4d to 1.2d for ribs spacing, where “d” is the nominal diameter as revealed by the test data in Table 9 and Fig. 8.

Table 6. Dimensional properties of 25mm nominal high yield steel reinforcing bars

Brand of steel	Grade/ID	Average actual diameter (mm)	Deviation from nominal diameter (%)	Average actual length (m)	Average rib height (mm)	Average rib spacing (mm)
Ferro Fabrik Ltd	FFL 25Y	24.49	2.06	12.00	2.208	18.746
Imported	IMP 25Y	23.90	4.41	12.04	2.233	17.793
Fabrimetal	FAB 25Y	24.28	2.90	11.94	1.253	13.545
Mean		24.22	3.12	11.99	1.90	16.69
Standard deviation		0.299			0.299	2.77

3.2.8 Analysis of 20mm mild steel reinforcing bars

Table 10 shows that only three of the local milling companies had their 20mm nominal diameter reinforcing bars available in the market. The mean diameter for the three companies was 18.40mm at a standard deviation of 0.66mm. The maximum and minimum actual diameters of 19.158mm and 17.942mm were obtained from Fabrimetal Limited and United Steel Limited respectively. The reinforcing steel bars deviated averagely at 7.99% from the 20mm nominal diameter.

Moreover, the mean ribs height and spacing of 1.28mm and 14.11mm with standard deviation of 0.282mm and 0.932mm respectively were obtained. Even though only United Steel Limited met the ASTM A615 [21] required ratio for ribs height to ribs spacing of $0.0507<h/c<0.072$ as detailed in Table 10, all the three reinforcing bars met the BS 4449:2005+A2:2009 [22] requirement of 0.03d to 0.15d for ribs height and 0.4d to 1.2d for ribs spacing, where "d" is the nominal diameter as noted from analysis of results in Table 10 and Fig. 9.

3.2.9 Length of steel bars

The length of bar within a given bar size group varied slightly as shown in Tables 2 to 10. Also, for the same type of reinforcing steel bar, the variation in bar length is minor. However, the bar length varied significantly between high yield steel and mild steel bars. The average length of high yield steel bars ranged from 11.94m to 12.0m, whereas that of mild steel bars varied very slightly between 8.93m and 8.94m.

4. DISCUSSION

4.1 Effect of Bar Size

From the design point of view, if the bar is under-sized, the use of nominal bar diameter without actually measuring the bar size will lead to an over-estimation of the ultimate moment of resistance as well as deformational resistance (i.e. cracking, deflection, creep etc.) of flexural concrete members. Similar over-estimation of capacity will also result in other concrete members such as columns. The deficiency in the bar size can therefore lead to unexpected structural distresses in reinforced concrete members.

4.2 Effect of Bar Rib Spacing and Height

The rib height to spacing ratio influences the bond strength of ribbed bars that in turn controls the anchorage of bars (ie anchorage bond) in concrete as well as deformations involving cracking and deflection (ie local bond) of flexural reinforced concrete members. Therefore, the steel bar types that deviated from the standard ratio will tend to have reduced bond strength and consequently adverse anchorage and deformational characteristics.

Table 7. Dimensional properties of 32mm nominal high yield steel reinforcing bars

Brand of steel	Grade/ID	Average actual diameter (mm)	Deviatio from nominal diameter (%)	Average actual length (m)	Average rib height (mm)	Average rib spacing (mm)
Imported	IMP 32Y	29.91	6.54	12.00	2.233	17.793
Fabrimetal	FAB 32Y	31.34	2.07	11.90	1.979	19.528
Mean		30.63	4.31	11.95	2.11	18.69
Standard deviation		1.01				

Table 8. Dimensional properties of 12mm nominal mild steel reinforcing bars

Brand of steel	Grade/ID	Average actual diameter (mm)	Deviation from nominal diameter (%)	Average actual length (m)	Average rib height (mm)	Average rib spacing (mm)
Ferro Fabrik Ltd	FFL 12R	10.972	8.57	8.92	1.137	8.847
United Steel Co.	USC 12R	10.588	11.77	8.95	0.503	8.937
Fabrimetal	FAB 12R	10.149	15.42	8.90	0.543	8.969
Sentuo Steel Ltd	STS 12R	11.084	7.63	8.94	0.418	9.529

Mean		10.70	10.85	8.93	0.65	9.07
Standard deviation		0.42			0.33	0.31

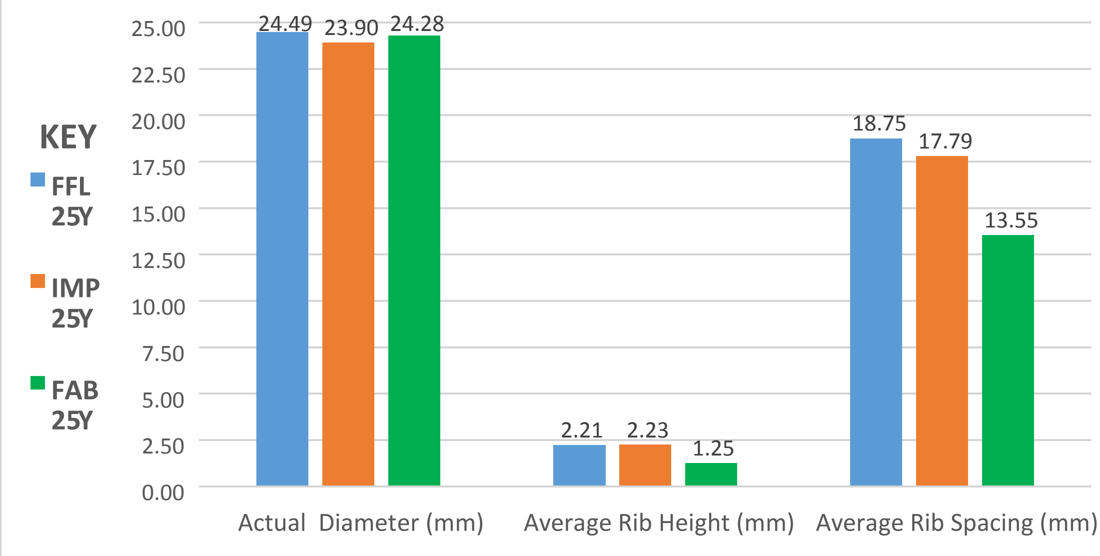

Fig. 5. Surface geometry of 25mm nominal high yield steel reinforcing bars

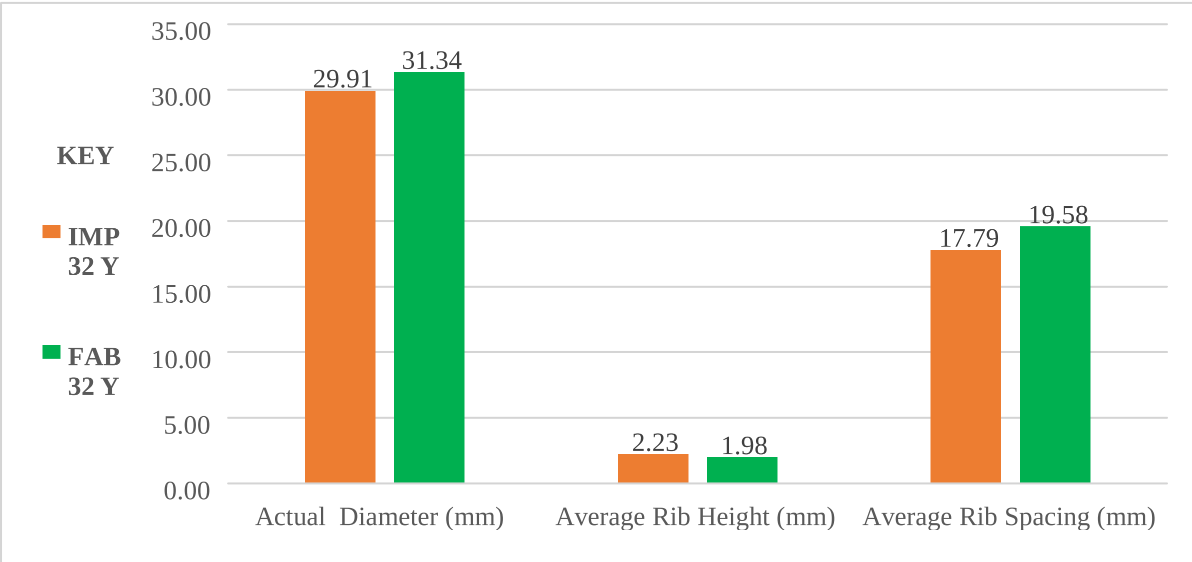

Fig. 6. Surface geometry of 32mm nominal high yield steel reinforcing bars

Table 9. Dimensional properties of 16mm nominal mild steel reinforcing bars

Brand of steel	Grade/ID	Average actual diameter (mm)	Deviation from nominal diameter (%)	Average actual length (m)	Average rib height (mm)	Average rib spacing (mm)
Ferro Fabrik Ltd	FFL 16R	14.235	11.03	8.94	1.014	8.175
United Steel Co.	USC 16R	14.441	9.75	8.94	0.880	11.145
Fabrimetal	FAB 16R	14.037	12.27	8.94	0.807	10.014
Sentuo Steel Ltd	STS 16R	14.235	11.03	8.92	1.074	11.287
Mean		14.24	9.75	8.94	0.94	10.16
Standard deviation		0.165			0.122	1.44

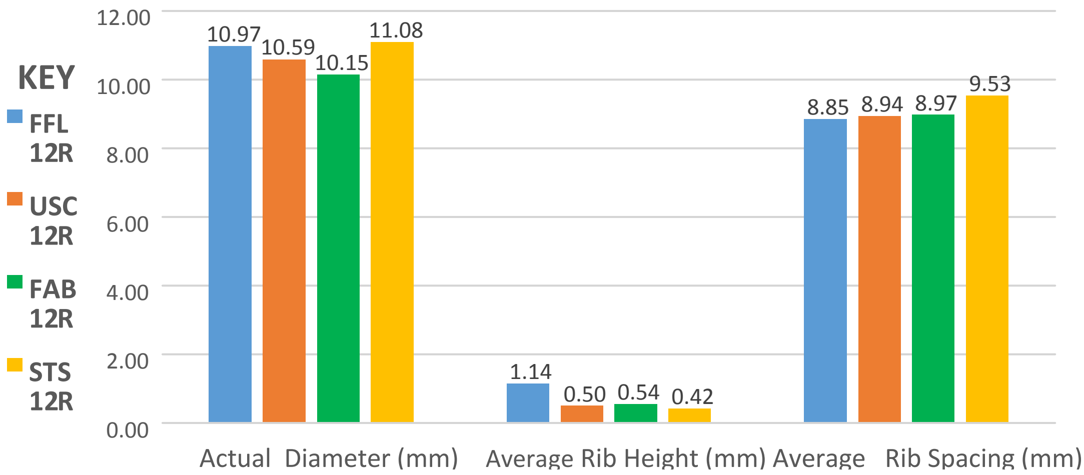

Fig. 7. Surface geometry of 12mm nominal mild steel reinforcing bars

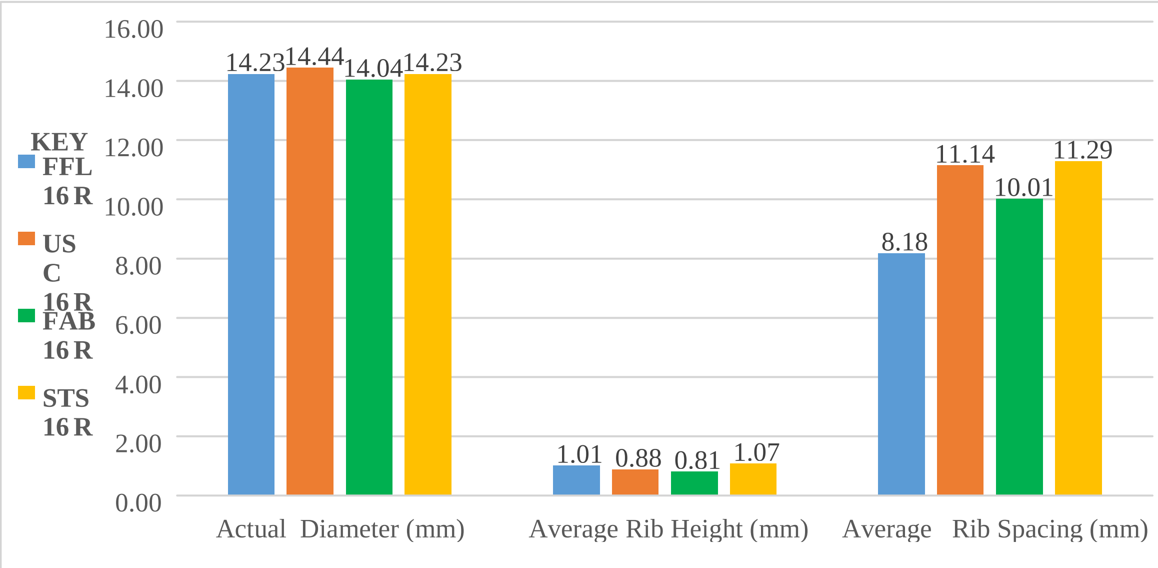

Fig. 8. Surface geometry of 16mm nominal mild steel reinforcing bars

Table 10. Dimensional properties of 20mm nominal mild steel reinforcing bars

Brand of steel	Grade/ID	Average actual diameter (mm)	Deviation from nominal diameter (%)	Average actual length (m)	Average rib height (mm)	Average rib spacing (mm)
United Steel Co.	USC 20R	17.942	10.29	8.93	0.953	14.971
Fabrimetal	FAB20R	19.158	4.21	8.92	1.476	13.123
Sentuo Steel Ltd	STS 20R	18.108	9.46	8.94	1.398	14.256
Mean		18.0	7.99	8.93	1.28	14.11
Standard deviation		0.66			0.282	0.932

4.3 Effect of Bar Length

The structural engineer's decisions on cutting and lapping of length of bars that are usually based on standard bar lengths available in standard practices will likely lead to challenges and shortcomings in their design works. The design aspects with regard to structural member lengths of bars and their lapping should be based on as measured dimensions with respect to each company's product.

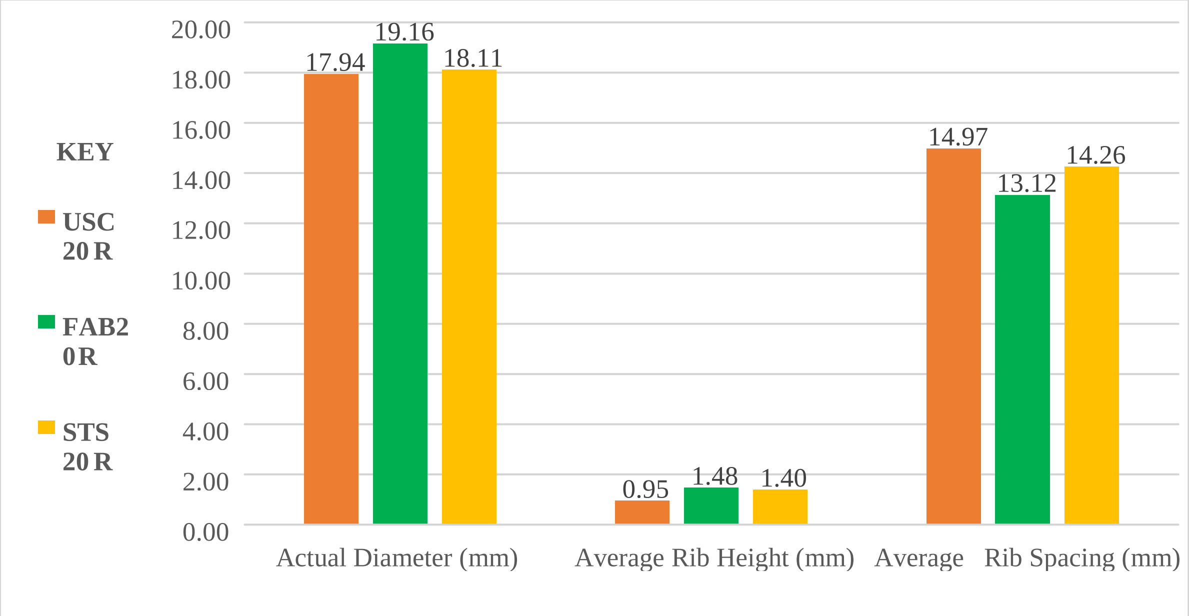

Fig. 9. Surface geometry of 20mm nominal mild steel reinforcing bar

5. CONCLUSIONS

The sizes of mild steel reinforcing mild steel bars milled in Ghana deviated significantly from the nominal diameters with average percentage reduction of 10.85%, 14.69% and 7.99% for 12mm, 16mm and 20mm nominal diameters respectively for all the companies. This showed that the mild steel reinforcing bars traded in the Ghanaian construction market were far less in diameter than the diameters they were designated to be.

Most of the reinforcing mild steel bars did not meet the ASTM standard rib height to rib spacing ratio requirement of $0.0507 < h/c < 0.072$. Three of the companies had 12mm reinforcing bars meeting the standard requirement, however, none of the 16mm nominal diameter steel bars met the requirement. Additionally, only one of the 20mm nominal diameter steel bars (United Steel Limited) met the rib height to rib spacing ratio requirement.

With reference to high yield reinforcing steel bars traded in Ghana., the actual bar sizes deviated slightly from their nominal diameters, showing average percentage shortcomings of 3.04%, 3.26%, 3.09, 4.31 and 3.1% for 12mm, 16mm, 20mm, 25mm and 32mm nominal diameters respectively for all companies. This shows that the high-yield reinforcing bars traded in the Ghanaian market were largely consistent with the diameters they were designated to be. However, the imported reinforcing bar of 32mm had the highest deviation from the nominal diameter with a reduction of 6.54%.

Almost all of the high yield reinforcing bars did not meet the ASTM standard rib height and rib spacing ratio requirement of $0.0507 < h/c < 0.072$. Only the 12mm nominal diameter steel bar milled by Sentuo Steel Limited met the ASTM rib parameters requirement. The bar lengths were inconsistent and the difference between them was most significant between the high yield steel and mild steel bars.

On the basis of the above, it can be concluded that Local milling companies producing mild steel reinforcing bars should improve on the standardization of the diameter of reinforcing bars they produce. Mild steel bars should be labeled with bar size and the name of the milling company to prevent sale of under-sized steel bars to consumers. Strict enforcement of standards should be encouraged to ensure adherence to local and international standards for producing and importing reinforcing bars in Ghana.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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