Examining the Geometrical Properties, Chemical Composition, and Mechanical Properties of Local Reinforcing Bars in Ghana

Abstract

Steel is used extensively as a concrete reinforcing material in the construction industry in Ghana. Aside from its use as a reinforcing member, many steel-framed structures are also springing up, particularly in the industrial areas of the country. To address the high-demand for reinforcement, several steel manufacturing companies manufacture mild steel bars locally from recycled scrap metals to supplement the tonnage that is imported. However, the quality standards of these reinforcing bars produced in Ghana have been extensively criticized in recent times by the general public, professional bodies, and practitioners in the construction industry. In this research, mild reinforcing bars from three local milling companies randomly classified as STSL, B5PL, and FBML were examined to determine their physical properties (size and surface geometry), chemical composition, and mechanical properties. Similar tests were also conducted on imported bars from a foreign company classified herein as AM. Itwas observed that the locally manufactured reinforcing bars had actual bar diameters smaller than their nominal sizes with a significant reduction in diameters. These significant reductions in bar diameters have a great impact on the strength and capability of a structure to withstand all anticipated loading. The imported bars however had actual sizes almost equal to their nominal sizes. Also, the rib height and rib spacing of the locally manufactured bars were found to be inconsistent. This observation could significantly affect the bond strength of structural elements constructed with these bars. Additionally, the locally manufactured mild steel bars had higher percentages of carbon above the recommended 0.25% in the British and Ghana standards. This increased carbon content beyond their recommended quantities increases the yield and maximum strength of the steel or its ability to support more weight but renders the steel bar brittle and unweldable. Furthermore, the locally manufactured mild steel bars had yield and maximum tensile strength higher than the recommended limits of 250 N/mm^2 and 485 N/mm^2, respectively, as in the British and Ghana standards. The imported high-tensile bars recorded a minimum tensile strength of 609.88N/mm^2 satisfying the minimum requirement. As the Government of Ghana takes steps to ban the importation of reinforcement bars into the country, the Ghana Standards Authority must ensure that locally manufactured bars satisfy the approved criteria to avoid structural failures caused by the use of sub-standard steel bars.

Keywords: mild steel, scrap metals, actual diameter, nominal diameter, rib height, rib spacing, geometrical properties, chemical composition, and mechanical properties.

1.0 Introduction

Steel remains one of the most competent reinforcing materials for structural concrete due to its high-tensile strength capacity and ductility as compared to concrete. Based on design principles, structural engineers determine the areas of steel required as they consider safety and economy. Reinforcing steel bars are embedded in concrete primarily to augment the ability of concrete to resisttension resulting from loading and to improve the ductility of concrete that is generally brittle. Nominal sizes of steel reinforcements usually range from 6mm to 50mm in diameter. The structural engineer's choice of size depends on the ability of the reinforced concrete member to withstand anticipated loads and maintain durability throughout the design life of the structure. For the reinforcement to withstand all tensile and compressive stresses, it must also be bonded to the concrete [1]. The composite action of concrete and reinforcing bars depends on bond stress that develops at the interface of the concrete and the bars. The significant characteristics of the development of bond stress–slip and particularly the maximum bond stress have been reported to be reliant on factors relating to concrete material, surface geometry, size and type of bar, and type of loading, etc.

The Ghanaian construction industry relies greatly on steel as a reinforcing material for most of its construction projects. Apart from steel serving as a reinforcing material, steel-framed structures are also emerging rapidly in industrial areas of Ghana. To meet the high demand for reinforcement, some steel manufacturing companies produce mild steel bars locally from recycled scrap metals to augment the tonnage that is imported [1]. Most often, these bars have surface ribs to improve bondresistance, much like conventional high-yield deformed bars. The Ghana Standard Authority (GSA) has detailed specifications that manufacturers are expected to follow during the manufacturing process [2]. Other internationally accepted codes include BS4449:2005+A2:2009 [3] and ISO 6935-2 [4].

However, the quality standards of these re-bars produced in Ghana have been extensively criticizedin recent times by the general public, professional bodies, and practitioners in the construction industry. Although the GSA [2] has set out some standards for steel manufacturing companies, thecapacity of this regulatory body to enforce these standards has been in doubt. Kankam [1] researched the bond strength of 12mm and 16mm reinforcing steel bars milled in Ghana from scrap metals. The author observed that the ratio of rib spacing to rib height for the bars produced in Ghana ranged between 11.5 and 19.6 which is greater than the maximum limit as specified in BS 4449:2005+A2:2009 [3]. These anomalies have a great impact on the structural integrityof buildings and other civil engineering structures constructed with these bars. As the governmentof Ghana initiates moves to stop the importation of reinforcement bars into the country, there is an absolute need to ensure that re-bars produced locally meet accepted standards to avert issues of structural failures resulting from the use of sub-standard bars.

2.0 Related Literature

2.1 Geometric Properties

The geometric properties of reinforcing bars contribute immensely to the bond between the reinforcement and the surrounding concrete. The bond strength of a reinforcing bar is significantly impacted by its size or diameter. According to Prince and Singh [5], the bonding ability of a bar to the concrete surface decreases as the bar diameter increases. Kim and Yun [6] conducted research entitled 'Evaluation of the Bond Behavior of Steel Reinforcing Bars in Recycled Fine Aggregate Concrete' and came out with similar findings. They observed that the bond strength of reinforced concrete with smaller-sized bars was greater than that of reinforced concrete with relatively larger-sized bars. The increased bond strength in small-sized bars was attributed to the availability of a larger surface area for bonding and low spacing between the ribs of bars. They posited that the reduction in bond strength (to a maximum of 50%) was due to the increased size of the bar used, as larger-sized bars needed a lengthier splice area toobtain their maximum efficiency.

The surface geometry of bars also plays a crucial role in establishing the desired bond between a reinforcement bar and concrete. According to Wang et al. [7], deformed bars achieve 2 to 10 timeshigher strength due to the interlocking mechanism offered by the ribs, which improves bond interaction. The mechanical anchoring and friction between the deformed steel bars and concrete contribute to the increase in bond strength. Zou and Sneed [8] compared the bond strength between plain and deformed steel bars and they observed that deformed bars had far greater bond strength as compared to the plain bars. They attributed this to the interlocking mechanism provided by the deformed bar.

Sabau et al. [9] used flat stainless-steel bars instead of ribbed steel bars as reinforcement in an experiment to determine the bond strength of the material. Their findings showed a low bond strength between the steel and the concrete because of the absence of material interlocking interaction between the twomaterials. Fawaz and Murcia-Delso [10] also assessed the bond strength of bars using iron-based shape memory alloy (FeSMA) in concrete. The findings showed that the bond strength was reduced by 20% as compared to ordinary steel. It was noted that the reduction in bond strength was a result of the smaller rib area on the FeSMA rods as compared to the steel bars.

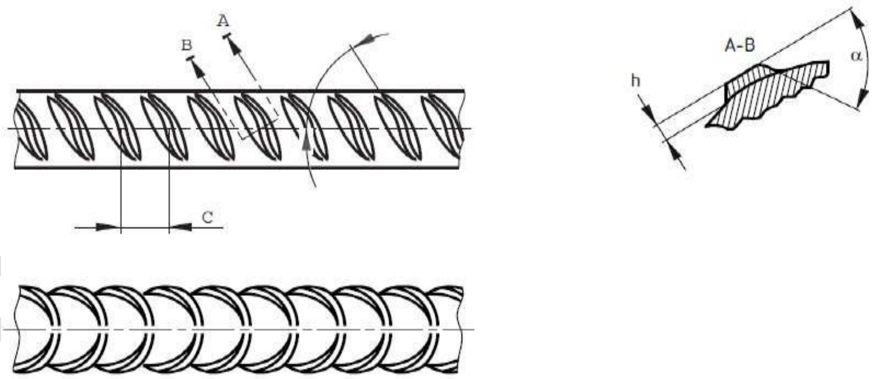


Fig. 1: Illustration of Rib Geometry for Ribbed Bars

As specified by BS 4449:2005+A2:2009 [3], transverse ribs for deformed bars must be shaped like a crescent and should seamlessly encircle the center of the bars. Following the nominal diameter of the bar, the projection of the transverse ribs must cover at least 75% of its circle. The transition from the rib to the core must be radiused, and the transverse rib flank inclination (α) shall be ≥ 45°. Figure 1 illustrates the rib geometry for ribbed bars as described by the BS 4449:2005+A2:2009 [3]. The code further states that when longitudinal ribs are present, their height must not be more than 0.15 d, where 'd' is the nominal diameter of the bar. Table 1 gives the recommended ranges for rib height, rib spacing, and rib inclination according to BS 4449:2005+A2:2009 [3].

Table 1: Ranges for the Rib Parameters

Rib height, h	Rib spacing, c	Rib inclination, β
$0.03d$ to $0.15d$	$0.4d$ to $1.2d$	35^{o} to 75^{o}

d is the nominal diameter of the bar.

2.2 Chemical Properties

The chemical composition of a steel re-bar is a very critical factor that determines its strength. The primary strengthening component that contributes to solid solution and second-phaseproduction (cementite) strengthening processes is Carbon. While carbon does make materials stronger (particularly tensile strength), it also reduces ductility, hardness, and weldability. The percentage of carbon content in a mild steel reinforcement determines the level of brittleness of the bar when subjected to bending. Table 2 shows some major chemical constituents of steel andtheir influence on reinforcement bars [11].

Table 2: Major Chemical Constituents of Steel and their Influence on the Reinforcement Bars

Chemical Component	Property	Effects on the Reinforcement Bars
Nickel (Ni)	Often added to steelto increase hardenability.	It frequently enhances the toughness and ductility of steel, in addition to increasing its strength and hardness.It is commonly used to increase toughness at low temperatures.
Carbon (C)	Hardness, strength, weldability, and brittleness	Increased carbon content raises the tensile strength of the steel, or its ability to support more weight, and viceversa. Less than 0.1% of carbon will weaken the substance. A carbon concentration of 0.3% or more renders the steel bar brittle and unweldable.
Manganese (Mn)	Strength and yield strength	The tensile strength and carbon equivalent properties of steel are both increased by higher manganese content.
Sulphur (S)	It is an impurity insteel which increases its brittleness.	When sulphur concentration is increased, it causes the bar to become brittle during twisting and increases the risk of hot shot during rolling.
Phosphorus (P)	It is an impurity that increases strength and brittleness.	Increased strength and corrosion resistance are attributed to higher phosphorus content, while brittleness is brought on by the production of low eutectoid phosphite in the grain boundary. Additionally, at sub-zero temperatures (transition temperature), it lessens the impact and value.
Copper (Cu)	Strength and corrosion resistance.	As a stabilizer for pearlite, copper it improves the strength and corrosion resistance of the material.
Chromium(Cr)	Weldability and corrosion resistance.	Exists as a scrap impurity that affects the carbon equivalent, improves the weldability, and strengthens the corrosion-resistant qualities.
Carbon Equivalent (CE or Ceq)	Hardness, tensile strength, and weldability.	A little change in carbon equivalent might change the physical characteristics, and this property is necessary to establish the cooling settings in the thermos-mechanically treated (TMT) process. Carbon equivalent for CTD (cold twisted deformed) bars has a maximum restriction of 0.42%; a lower limit is not specified. To that end, the variance in carbon equivalent, as in the case of TMT bars, is permissible as long as the physical and chemical qualities of the rawmaterials remain within predetermined bounds.

Reinforced concrete design principles typically assume elastic deformation of steel followed by plastic yield at constant tension. Thermally rolled plain low-carbon steel with a carbon content of less than 0.3 weight percent yields steel that is almost elastic and completely flexible, with a large strain distortion on the stress-strain curve following yielding.

To produce good reinforcements for structural members, the BS4449:2005+A2:2009 [3], ASTM A615 [12], and the GS 788-2:2018 [2] are designed for producers, fabricators, and buyers of ribbed reinforcing steel (bars, coils, and de-coiled products). These codes offer designations based on the steel grade, the product form, and the dimensions. They also define all typical technical specifications for reinforcing steels, such as chemical analysis, mechanical qualities, rib shape, and dimension tolerances. In terms of chemical composition, and specifically the carbon equivalent value, the weldability standards for all classes of steel are given. The values of individual elements and the carbon equivalent shall not exceed the limits given in Table 3 as specified by BS4449:2005+A2:2009 [3] and GS 788-2:2018 [2]. Any bar that is outside the maximum stated limits in Table 3 during product analysis is regarded as not complying with the British and Ghana standards.

Table 3: Amount of Chemical Composition of Mild Steel Bars (W_t%) According to the BS 4449 and GS 788

Element	C	M_n	Si	P	S	N
	≤	≤	≤	≤	≤	≤
GS788	0.25	1.65	0.60	0.05	0.05	0.012
BS4449	0.25	1.00	0.40	0.05	0.05	

The carbon equivalent value C_{eq} is calculated using the following formula:

$$C_{eq} = C + M_n/6 + (C_r+M_o+V)/5 + (N_i+C_u)/15 \quad (1)$$

Where:

M_n is the percentage of Manganese content.
C_r is the percentage of Chromium content.
V is the percentage of Vanadium content.
M_o is the percentage of Molybdenum content.
C_u is the percentage of copper content.
N_i is the percentage of Nickel content.

Kankam and Adom-Asamoah [13] researched the strength and ductility characteristics of reinforcing steel bars milled from scrap metals. In their chemical analysis, reinforcing steel bars from Wahome, Tema Steel Works, and Ferro Fabrik had average carbon contents of 0.20%, 0.26%, and0.30%, respectively. This implies that only Wahome fell within the BS4449:2005+A2:2009 [3] andGS 788-2:2018 [2] maximum limit of 0.25%. However, phosphorus and sulfur were found in excess quantity in bars from all three companies. According to the authors, the increased amount of these compounds enhanced the strength and hardness of the steel while decreasing their ductility and making the steel brittle.

Banini and Kankam [14] researched the strength, ductility, and chemical properties of reinforcing steel bars in Ghana's Building Construction Industry. A total of 700 pieces of reinforcing bars were obtained from 4 local milling companies, namely, Ferro Fabrik Limited,Sentuo Steel Ltd, Fabrimetal Ltd, United Steel, and a foreign manufacturing company in Ukraine(Arcelor Mittal). These specimens were tested for their chemical and mechanical properties According to the authors, all the locally milled reinforcing bars recorded carbon contents higher than the maximum requirement of 0.25% in the British and Ghana specifications, with an average carbon content of 2.11% for the mild steel bars. Concerning the high-yield bars, all of the local companies evaluated had more than 4.0% carboncontent, whereas imported high-yield reinforcing bars had 1.845% carbon content. The carbon content of high-yield steel bars averaged 5%.

However, Annan et al. [15] had a different view when they studied the microstructure and mechanical properties of steel rebars locally produced in Ghana. In their research, they assembled reinforcing bars obtained from five construction sites in Accra and tested them to ascertain their chemical and mechanical properties. However, they did not check the manufacturers of these locally manufactured bars. On the chemical composition test, they observed that the percentage quantity of most of the major constituents like carbon, manganese, and sulphur all fell within the ranges specified by BS4449:2005+A2:2009 [3] and GS 788-2:2018 [2] even though other minerals recorded marginal increases beyond specifications in these Standards. The authors therefore allayed all fears and concluded that the bars were good for construction works.

Also, Dzogbewu and Arthur [16] conducted comparative studies of locally produced and imported low-carbon steels on the Ghanaian market. Low-carbon steel bars of diameter 19 mm (both locally manufactured and imported) were obtained from the open market for the test. The chemical composition of the local low-carbon steels obtained from the Ghanaian market was compared with the approved standards in GS 788-2:2018 [2]. It was observed that the chemical composition of the imported samples was fine-tuned closer to the approved composition by GS 788-2:2018[2], hence, more ductile and tougher products were produced.

2.3 Mechanical Properties

Kankam and Adom-Asamoah [13] observed that imported bars were more ductile, with higher toughness values and percentage elongation than the locally produced samples. However, the locally produced bars had higher ultimate tensile strength, and higher hardness, and were more brittle than the imported ones. They therefore concluded that the imported low-carbonsteels would be preferable due to their capability to absorb greater energy in case of earthquakes or earth tremors before fracture owing to their high percentage elongation and ductility.

In a comparative analysis of the mechanical properties of locally manufactured reinforcement bars conducted by Banini and Kankam [14], reinforcing bars from Ferro Fabrik Ltd recorded the highest yield strength of 487.41N/mm^2 with an average yield strength of 395.09 N/mm^2. The reinforcement bars from United Steel Ltd and Fabrimetal Ltd obtained minimum and maximum tensile strengths of 487.41 N/mm^2 and 598.42 N/mm^2, respectively, with a mean tensile strength of 520.01 N/mm^2. On the other hand, the yield strength of high-yield reinforcing bars ranged from 341.93 N/mm^2 to 702.83 N/mm^2, with a mean value of 572.87 N/mm^2. The bars from Sentuo steel

Ltd. and imported steel from ArcelorMittal achieved minimum and maximum tensile strengths for high-yield reinforcement bars of 497.36 N/mm^2 and 815.67 N/mm^2, respectively, with an average tensile strength of 707.89 N/mm^2. In their concluding remarks, they stated that some of the bars were fragile due to their high carbon content.Furthermore, upon failure, the majority of the bars achieved minimal or no necking. Additionally,most of the bars exhibited minimal or no cup-and-cone form fractures. In contrast to local steel bars made from scrap metals, the imported reinforcing steel bars, however, demonstrated comparatively superior necking during fracture.

On the contrary, Annan et al. [15] observed that the ultimate tensile strength, yield strength, and percentage elongation of the rebars produced in Ghana were all within the specifications of GS 788-2:2018 [2] when they studied the microstructure and mechanical properties of the steel rebars. The average tensile strength of the specimens was 545.11 MPa, satisfying the GSA minimum value of 400 MPa as stated in GS 788-2:2018 [2]. The findings also showed that, in comparison to specifications in GS 788-2:2018 [2], the rebars at the building site had sufficient yield strength. These research outcomes by the authors [15] contradict the position of many other authors regarding the locally produced reinforcements in Ghana. This disparity calls for further and in-depth investigations as to the actual chemical composition and mechanical properties of the locally manufactured mild steel bars on the market to ascertain how they behave in structural members.

3.0 MATERIALS AND METHODS

3.1 Geometrical Properties

The size and surface geometry of bars are very crucial in determining the bond between concrete and reinforcing bars. The specimens for the test were randomly selected mild steel bars from three of the local milling companies in Ghana. These companies were randomly classified as STL, B5PL, and FBML. Aside from these locally manufactured specimens, imported bars classified as AM were also selected for testing as a control against which the locally manufactured bars could be evaluated. For each company, 30 pieces of 12mm, 16mm, and 20mm diameter mild steel bars of average length of 300 mm were selected from the open market as well as construction sites to study their physical properties. These summed up to a total of 360 pieces of specimens. Using a digital Vernier Caliper, the diameters of the various bars were measured and recorded. The average diameters from these recorded figures were taken as the actual diameter of that specific bar. Figure 2 shows the measuring of the diameter of a reinforcing bar with a digital Vernier Caliper.

Fig. 2: Measuring the Diameter of a Reinforcing Steel Bar with a Vernier Caliper

3.2 Measurement of Rib Height and Rib Spacing

The rib height of the various bars was calculated by dividing the difference between the Total diameter of the bar and the nominal diameter by two as expressed in the equation 2 as follows:

$$Rib\ Height = \{Total\ Diameter\ (including\ ribs) - Nominal\ Diameter\} \div 2 \quad (2)$$

The bars that were sampled had their rib spacing measured from center to center of some selected ribs. It was observed that most of the locally manufactured bars had parallel ribs on both sides. Only a few bars had non-parallel ribs on one side and parallel ribs on the other side, similar to the conventional high-yield deformed bars. For the selected bars, their rib spacing was measured from the sides. This was done by taking the simple mean of the samples that were gathered for each bar size.

3.3 Chemical Composition

The chemical composition analysis was conducted on samples of reinforcing bars using the Scanning Electron Microscope Energy Dispersive X-ray (SEM Edx) method. The SEM Edx is an analytical technique used for the elemental analysis or chemical characterization of a sample. It produces comprehensive, high-resolution pictures of the sample by rastering a focused electron beam across the surface and collecting secondary or back-scattered electron signals. An Energy Dispersive X-Ray Analyser (EDX or EDA) is also used to identify elements and calculate their quantitative compositions. Three (3) samples of reinforcing bars were taken from each of the three local manufacturing companies in addition to imported reinforcements (making a total of 12 specimens) were examined for their chemical composition.

3.4 Mechanical Properties

Three (3) pieces of 12mm, 16mm, and 20mm reinforcing steel bars of length 400mm from each company, as shown in Figure 3, were prepared and tested for their Mechanical Properties. Table 4 shows the details of the specimens tested for their mechanical properties. The test was conducted using an Avery Denison Universal Testing Machine (UTM) with an extensometer clipped to the reinforcing steel bar, as shown in Figure 4. The testing machine setup measures the yield point elongation, compression, bend displacement, yield strength, strain hardening exponent, strain ratio, and shear deformation of the material being examined.

Fig. 3: Samples of the Reinforcements Prepared for the Mechanical Properties Test

Table 4: Details of the Reinforcing steel bars used for the Mechanical Test

Ser.	Bar Type and Size	Quantity	Manufacturing Company
1	12mm Mild Steel	3 Pcs.	STSL
2	16mm Mild Steel	3 Pcs.	
3	20mm Mild Steel	3 Pcs.	
4	12mm Mild Steel	3 Pcs.	B5PL
5	16mm Mild Steel	3 Pcs.	
6	20mm Mild Steel	3 Pcs.	
7	12mm Mild Steel	3 Pcs.	FBML
8	16mm Mild Steel	3 Pcs.	
9	20mm Mild Steel	3 Pcs.	
10	12mm High Tensile Steel	3 Pcs.	AM (imported bars)
11	16mm High Tensile Steel	3 Pcs.	
12	20mm High Tensile Steel	3 Pcs.	

Fig. 4 Testing Steel Bars to find the Mechanical Properties of Reinforcement with an Avery Denison Universal Testing Machine

4.0 RESULTS

4.1 Geometrical Properties

The results of the examination of the geometrical properties (size and surface geometry) of the various reinforcing bars are discussed in the sections that follow.

4.1.1 Analysis of 12mm Bars

The results of the measurements from the digital Vernier Caliper on the 12 mm reinforcing bar revealed that none of the three local milling companies had their actual diameters equal to their nominal diameter of 12mm, as shown in Table 5. The bars from STSL had an average diameter of 10.76 mm, deviating 10.33% from the nominal diameter. In addition, the bars from B5PL had an average diameter of 11.03mm, deviating 8.08% from their nominaldiameter. Similarly, the bars from FBML had an average diameter of 10.80mm witha deviation of 10% from their nominal diameter. Interestingly, the imported rods from AM had an average diameter of 11.97mm with a deviation of 0.25%. It was observed that the imported bars had diameters much closer to their nominal diameters as compared to the locally manufactured bars. Among the locally manufactured ones, bars from B5PL recorded the highest average diameter of 11.03mm. Bars from FBML recorded the next highest average diameter of 10.80 mm while rods from STSL had the lowest average diameter of 10.76mm. Figure 5 is the graphical representation of the nominal and average diameters of the 12mm reinforcing steel bars.

Concerning the rib height and rib spacing, it was observed that all the reinforcing bars from the three local milling companies met the requirement as set out in BS 4449+A2:2009 [3]. This code states thatthe rib height of reinforcements should range from 0.3d to 0.15d, where ‘d’ is the nominal diameter of the bar. The code further states that the rib spacing should range from 0.4d to 1.2d.

However, none of the bars met the ASTM A615 [12] rib height-to-rib spacing ratio of 0.0507 < h/c < 0.072 required for all reinforcements. Another observation was that, except for 12mm bars from STSL, all the bars met the GS 788-2:2018 [2] minimum rib height requirement of 0.05d, where 'd' is the nominal diameter. Additionally, all the locally manufacturedbars had their rib spacing wider than the GSA required range of 0.5d ≤ c ≤ 0.7d, where 'c' is the spacing between ribs. The imported reinforcing bars however satisfied this requirement. Figure 6 shows a graphical representation of the rib-height, and rib-spacing of the reinforcing bars.

Table 5: Physical Properties of 12mm Reinforcing Bars

Ser.	Source of Bar	Bar ID	Bar Type	Nominal Bar size (mm)	Average Bar Diameter (mm)	Deviation from Nominal Diameter (%)	Rib Height (mm)	Rib Spacing (mm)
1.	STSL	STSL R12	Mild Steel	12	10.76	10.33	0.419	9.531
2.	B5PL	B5PL R12	Mild Steel	12	11.03	8.08	1.138	8.857
3.	FBML	FBML R12	Mild Steel	12	10.80	10	0.743	8.967
4.	AM (imported bars)	AM T12	High-Tensile	12	11.97	0.25	1.039	7.320
	Mean				11.14		0.835	8.669
	Standard Deviation				0.490		0.281	0.820

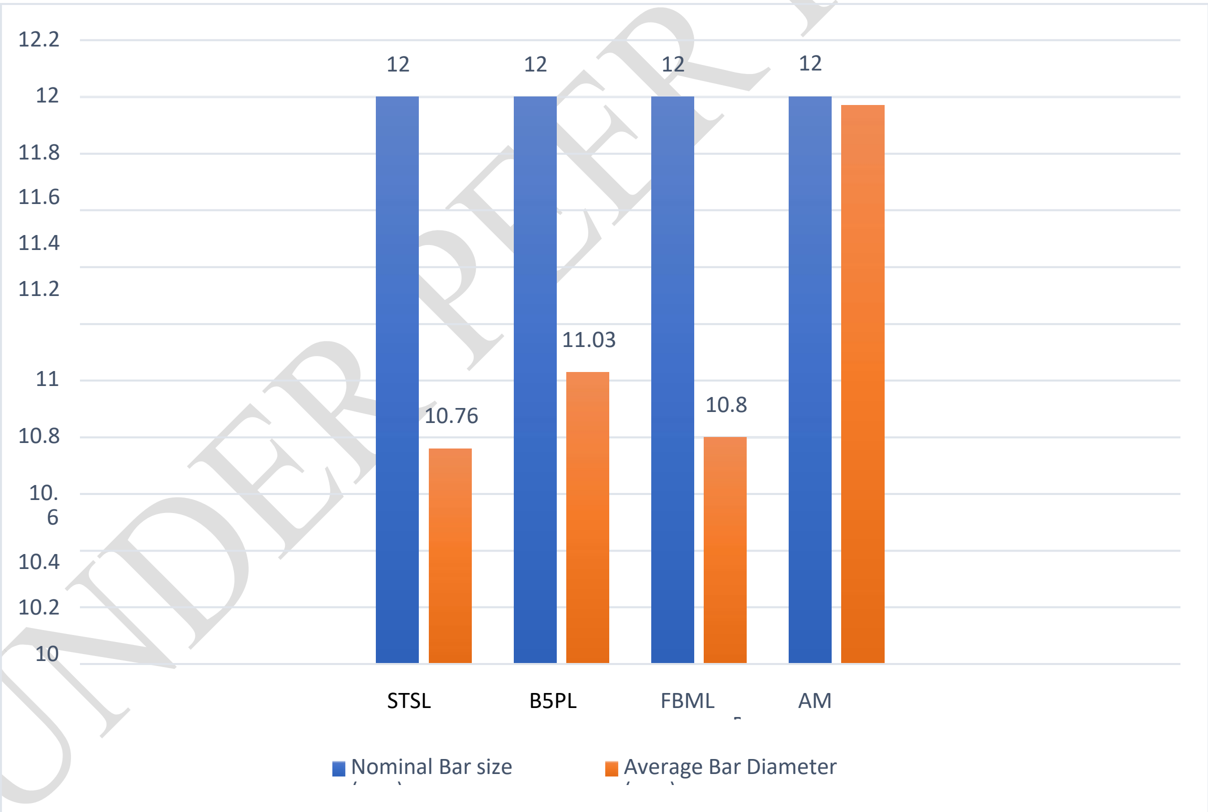


Fig. 5: Nominal and Average Diameters of 12 mm Reinforcing Bars

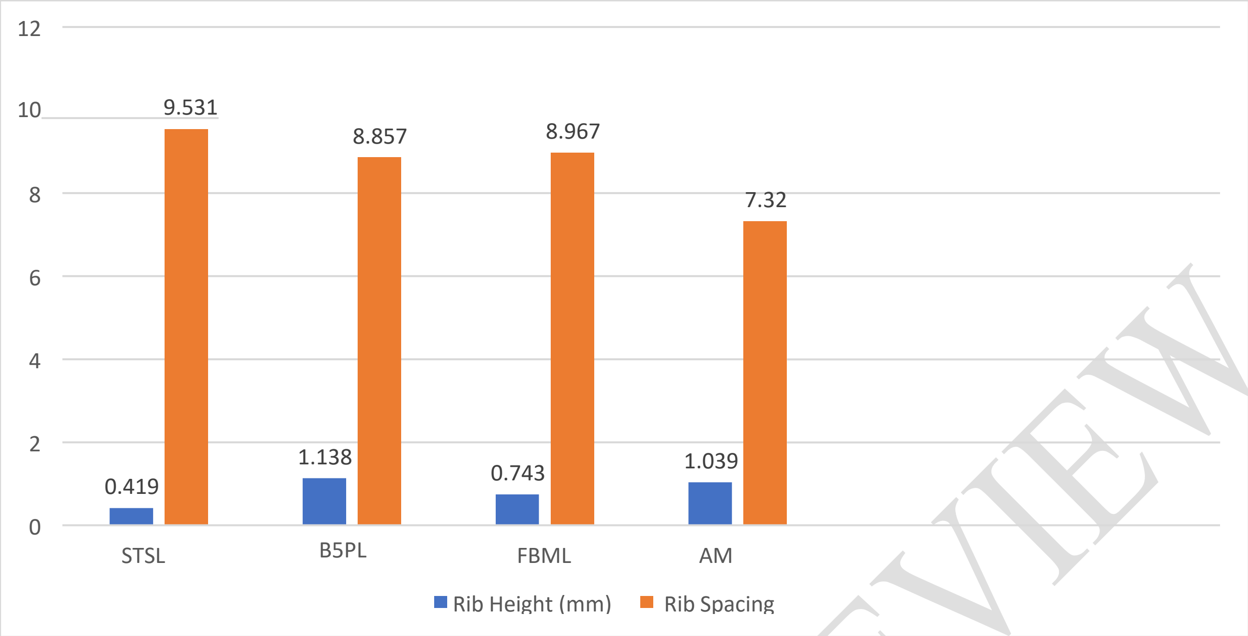


Fig. 6: Rib Height and Rib Spacing of 12 mm Reinforcing Bars

4.1.2 Analysis of 16mm Reinforcing Bars

Similar to the 12mm reinforcements, the results from the measurements taken on the 16mm reinforcements, as shown in Table 6, indicated that none of the three local manufacturers had actual bar diameters that were equal to their nominal diameters. The bar from STSL had an average nominal diameter of 14.71mm with a deviation of 8.06% from their nominal diameter of 16mm. Furthermore, those from B5PL had an average diameter of 14.83mm, deviating 7.31% from their nominal diameter. Furthermore, the rebars from FBML had an average diameter of 14.68mm, having deviated by 8.25%. On the other hand, the imported rods had an average diameter of 15.98mm, deviating by only 0.13% from their nominal diameter. The imported steel bars had diameters that were substantially closer to their nominal bars than the locally made reinforcements. Among the locally manufactured steel bars, B5PL bars recorded the largest average diameter of 14.83mm. This was followed by rods from STSL recording an average diameter of 14.71mm. Steel bars from FBML had the lowest average diameter of 14.68mm. Figure 7 is a graphical representation of the nominal and average diameters of the 16mm reinforcements.

Additionally, reinforcing steel bars from all three local milling companies satisfied the BS 4449+A2:2009[3] requirements for rib height-to-rib spacing ratio. However, none of the bars fulfilled the ASTM A615 [12] rib height-to-spacing ratio of $0.0507 < h/c < 0.072$, which is necessary for all deformed steel bars. Additionally, all the bars (including the imported rods) fulfilled the GS 788-2: 2018 [2] minimum rib height and rib spacing criteria. Figure 8 shows a graphical representation of the rib height and rib spacing of the rebars.

Table 6: Physical Properties of 16mm Reinforcing Bars

Ser.	Source of Bar	Bar ID	Bar Type	Nominal Bar size (mm)	Average Bar Diameter (mm)	Deviation from Nominal Diameter (%)	Rib Height (mm)	Rib Spacing (mm)
1	STSL	STS R16	Mild Steel	16	14.71	8.06	1.077	11.287
2	B5PL	B5PL R16	Mild Steel	16	14.83	7.31	1.016	8.174
3	FBML	FBML R16	Mild Steel	16	14.68	8.25	0.907	10.114
4	AM (imported)	AM T16	High-Tensile	16	15.98	0.13	1.165	11.115
	Mean				15.05		1.041	10.172
	Standard Deviation				0.539		0.093	1.237

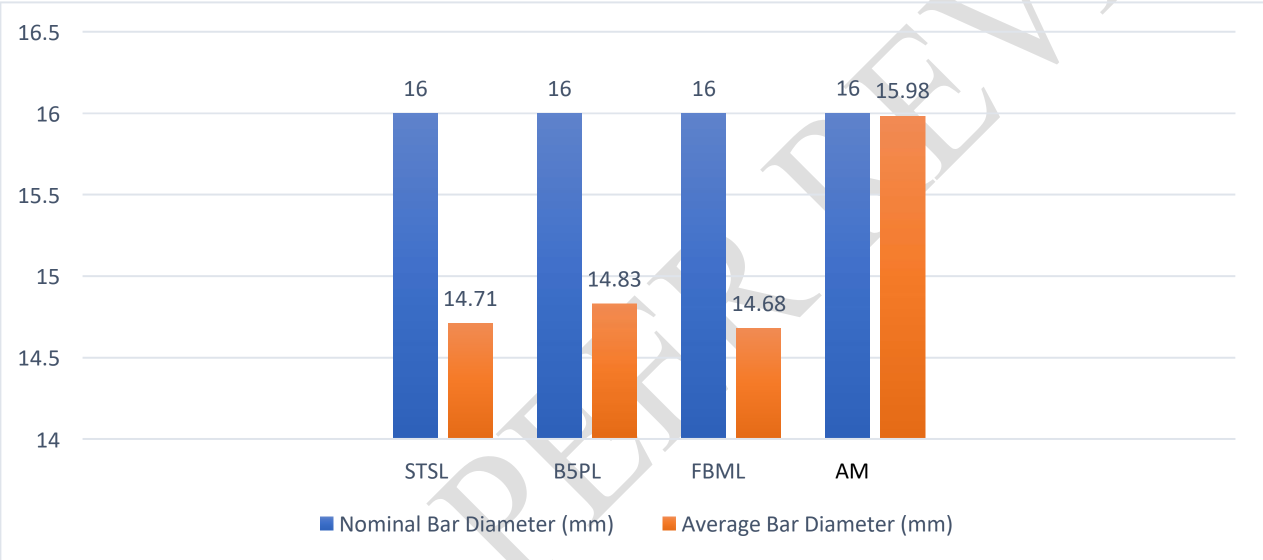


Fig. 7: Nominal and Average Diameters of 16mm Reinforcements

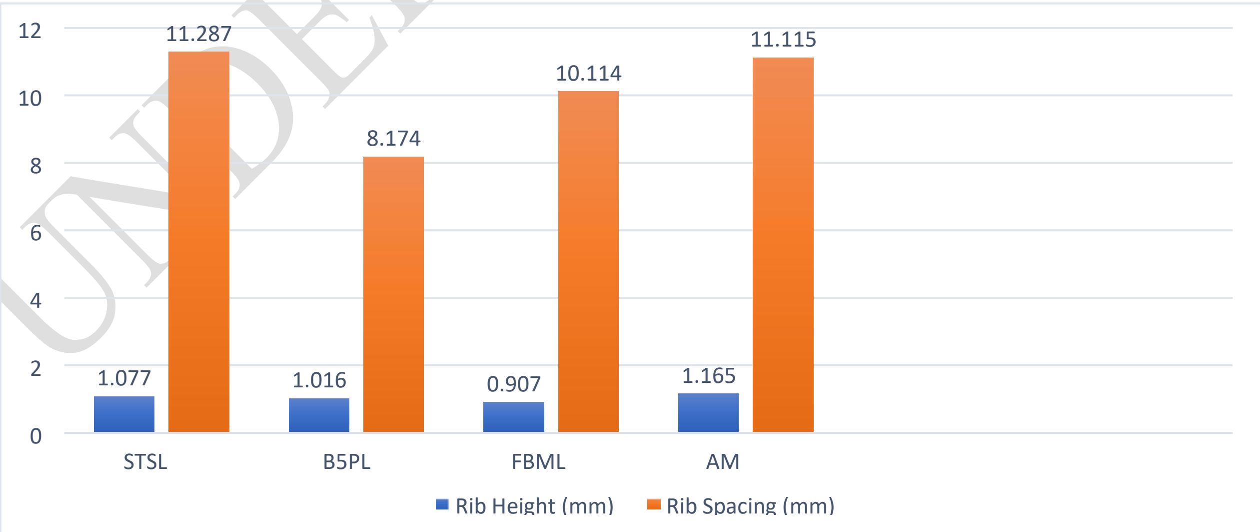


Fig. 8: Rib Height and Rib Spacing of 16mm Reinforcing Bars

4.1.3 Analysis of 20mm Reinforcing Steel Bar

The geometrical measurements taken on the 20mm reinforcing bars, as shown in Table 7, also showed that the nominaldiameter of 20mm was not satisfied by any of the three selected local producers in Ghana. The diameters of the bars from STSL measured 17.71 mm on average, with a deviation of 11.40%. The average diameter of the B5PL bars was 18.67 mm, deviating by 6.65% from the nominal diameter while that of FBML was 18.78 mm on average with6.1% deviation from the nominal diameter. The average diameter of the imported bars was 19.98mm, with a deviation of 0.15%. The imported bars recorded actual diameters almost the same as their nominal bar diameter of 20mm. For the locally manufactured reinforcing bars, it was observed that rods from FBML recorded the highest average diameter of 18.78mm. The next highest average diameter was obtained by B5PL with a value of 18.67mm. Then followed by bars from STSL with an average diameter of 17.71mm. Figure 9 is the graphical illustration of the nominal and average diameters of the 16mm steel bars.

The rib height and rib spacing criteria of BS 4449+A2:2009 [3] were met by the reinforcing steel bars dubbed by the three local manufacturers. The bars also met the GS 788-2: 2018 requirement of rib height. However, except for the imported ones, bars from all three local manufacturers did not meet the requirement of GS 788-2: 2018 [2] in terms of rib spacing. Moreover, none of the test bars from all manufacturers met the rib height-to-spacing ratio requirement of ASTM A615 [12], which is $0.0507 < h/c < 0.072$ and must be met by all deformed reinforcing steel bars. The minimum rib height and rib spacing requirements of GS 788-2: 2018 [2] were also met by all of the bars, including the imported ones. However, all the bars (including the imported ones) did not meet the ASTM A615 [12] rib height-to-rib spacing ratio of $0.0507 < h/c < 0.072$. Figure 10 shows a graphical representation of the rib height and rib spacing of the reinforcing steel bars.

Table 7: Physical Properties of 20mm Reinforcing Bars

Ser.	Source of Bar	Bar ID	Bar Type	Nominal Bar size (mm)	Average Bar Diameter (mm)	Deviation from Nominal Diameter (%)	Rib Height (mm)	Rib Spacing (mm)
1.	STSL	STS R20	Mild Steel	20	17.72	11.40	1.396	14.306
2.	B5PL.	B5 R20	Mild Steel	20	18.67	6.65	1.453	14.071
3.	FBML	FAB R20	Mild Steel	20	18.78	6.1	1.476	14.663
4.	AM (imported bars)	AM T20	High-Tensile	20	19.97	0.15	1.839	13.715
Mean					18.875		1.541	14.188
Standard Deviation					0.798		0.174	0.345

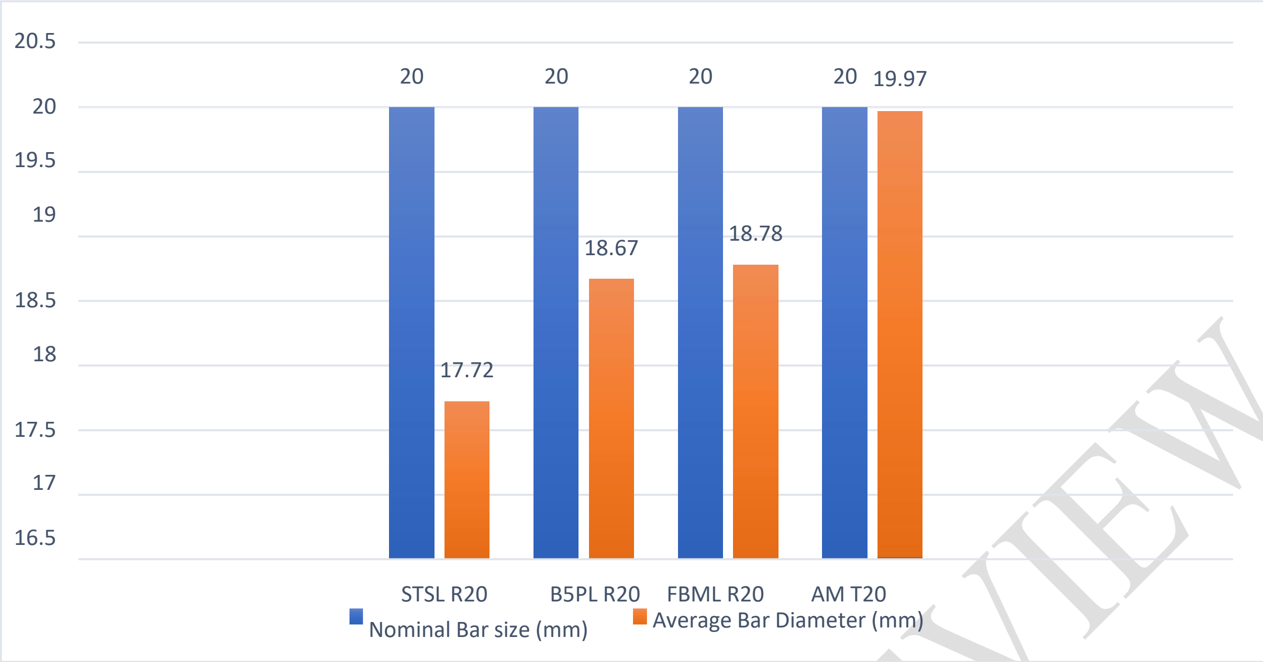


Fig. 9: Nominal and Average Diameters of 20mm Reinforcement

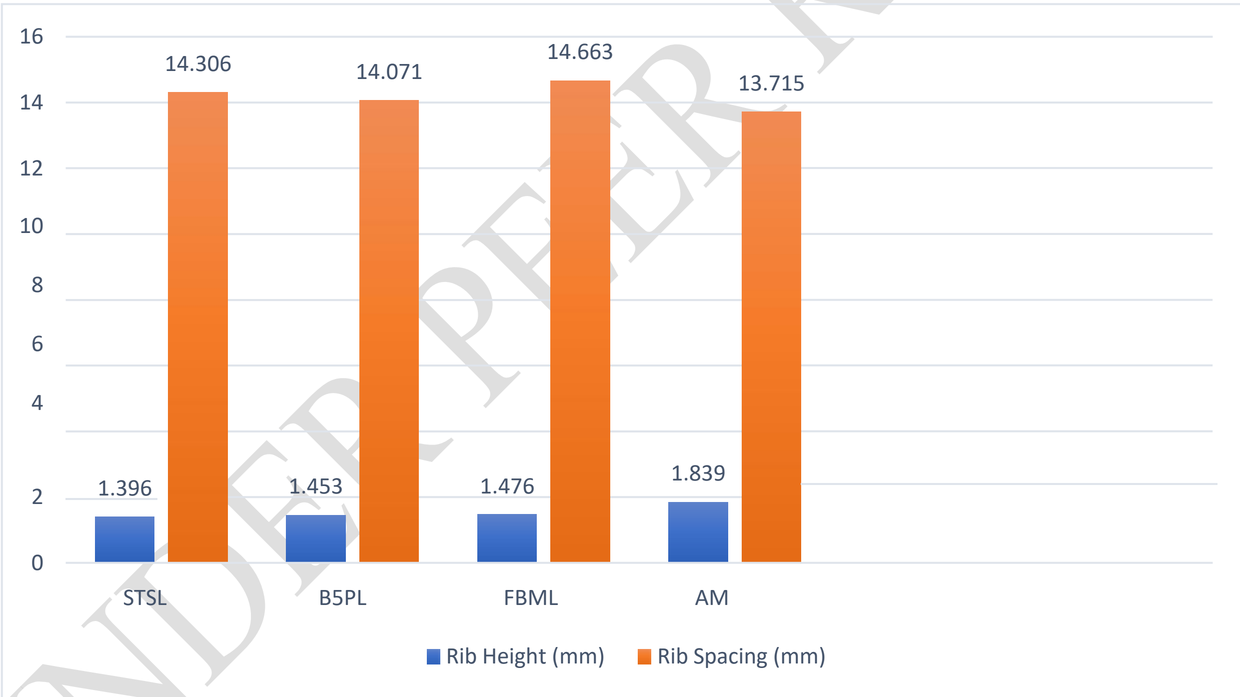


Fig. 10: Rib Height and Rib Spacing of 20mm Reinforcements

4.2 Impact of Geometrical Properties on Structural Elements

The geometrical properties (size and surface geometry) of reinforcing bars are important parameters to the structural engineer as they have a great impact on the bond strength of reinforced concrete elements. The structural engineer's design of the various component members of a structure determines the required sizes and spacing of bars that must be used considering the loading of the structureto ensure that the structure is safe for use. Therefore, using reinforcing bars that have smaller diameters than they actually ought to have been will have a great consequences on the strength and capability of a structure to withstand its anticipated loading. It is also noteworthy that the bond strength of ribbed bars is influenced by the rib height to spacing ratio, which in turn affects the anchoring of bars (known as anchorage bond) in concrete as well as the deformations of flexural reinforced concrete components that include cracking and deflection (known as local bond). As a result, bars that diverge from the recommended ratio are likely to exhibit worse bond strength, which will have an undesirable effect on anchoring and deformationalproperties as stated by Assiamah et al. [17].

4.3 Chemical Composition

The results of the chemical analysis conducted on the mild steel specimens from the local manufacturers had an average carbon content of 2.39%, with actual values ranging between 1.55% and 3.15%. Reinforcing steel bars from B5PL recorded the lowest carbon content of 1.55%, followed by bars from FBML recording 2.49%. STSL recorded the highest carbon content of 3.15%. However, none of these three reinforcement bars met the criteria set out in BS4449:2005+A2:2009 [3] and GS 788-2:2018 [2], which stipulate that the carbon content should not exceed 0.25%. Fluorine was also found in substantial quantities in bars from FBML and STSL. Steel bars from FBML also recorded a high content of Nitrogen. Other alloying compounds were similarly high when compared to standards in BS4449:2005+A2:2009 [3].

On the other hand, the imported high-tensile steel bars recorded a carbon content of 1.87%. This is much lower than the BS4449:2005+A2:2009 [3] and GS 788-2:2018 [2] requirement of 4% carbon content for high-tensile reinforcement bars. Table 8 presents the details of the chemical composition of the various reinforcements studied.

Table 8: Chemical Composition of the Reinforcing Bars in Ghana

		Percentage Average Weight of Chemical Concentration of the Reinforcement Bars													
Bar ID	**Bar Type**	**O**	**C**	**Fe**	**N**	**Cl**	**Si**	**Al**	**Ca**	**Na**	**Mg**	**S**	**K**	**F**	**Cr**
B5PL	Mild Steel	8.65	1.55	89.50	-	-	-	-	-	-	-	-	-	-	0.09
FBML	Mild Steel	8.54	2.49	84.02	1.09	0.16	0.15	0.13	0.07	0.06	0.05	0.03	-	1.89	0.06
STSL	MildSteel	4.64	3.15	91.09	-	-	-	-	-	-	-	-	-	1.27	-
AM	High-Yield	6.74	1.87	91.11	-	-	-	-	-	-	-	-	-	-	-

The need for manufacturing companies to adhere to the recommended percentages of chemicals cannot be over-emphasized as quantities of the various minerals have great impact on the properties of reinforcing steel elements. For instance, increasing the carbon content beyond their recommended quantities increases the tensile strength of the steel or its ability to support more imposed load but renders the steel member brittle and unweldable. Furthermore, increased Sulphur concentration beyond its recommended percentage causes the bar to become brittle during twisting and increases the risk of hot shot during rolling (Prabir et al., 11).

4.4 Mechanical Properties of the Steel Reinforcements

Reinforcing bars from STSL recorded a minimum yield strength of 342.45 N/mm^2,whereas rods from B5PL recorded a maximum yield strength of 498.93 N/mm^2. The average yield strength obtained was 436.91 N/mm^2. Similarly, STSL recorded a minimum tensile strength of 497.08 N/mm^2 whereas bars from FBML recorded a maximum tensile strength of 595.72 N/mm^2. The average tensile strength obtained was 543.99 N/mm^2.

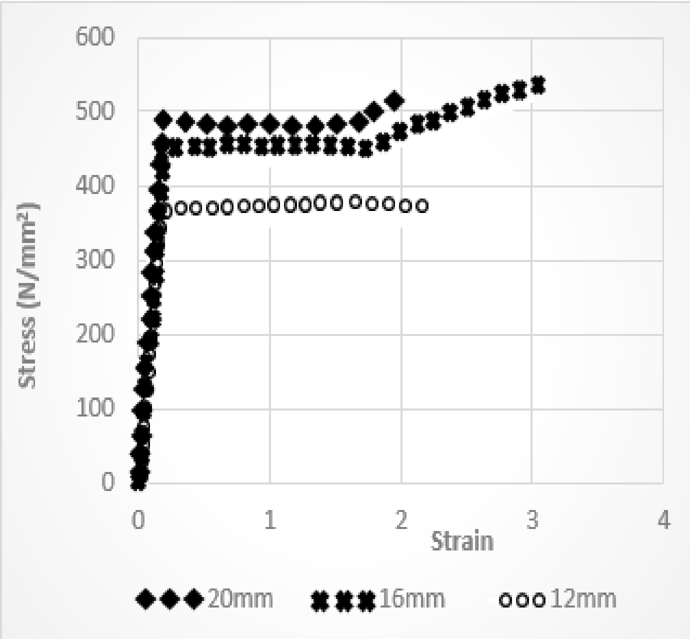
According to BS4449:2005+A2:2009 [3], the minimum tensile strength of mild steel reinforcements is 485 N/mm^2, and the yield strength of 250N/mm^2. This implies that the reinforcements produced by the local milling companies could be classified as medium to high-strength (high-yield) reinforcements. This observation also confirms the findings of Kankam and Adom-Asamoah [13].

The imported high-tensile steel bars recorded a minimum yield strength of 609.88 N/mm^2 and a maximum yield strength of 762.73 N/mm^2. The average yield strength recorded was 703.79 N/mm^2. Additionally, the minimum tensile strength recorded by the imported high-tensile rods was 609.88 N/mm^2 whereas the maximum tensile strength was 762.73 N/mm^2. The high-tensile steel bars satisfied the minimum requirement of 485 N/mm^2 as stated in BS4449:2005+A2:2009

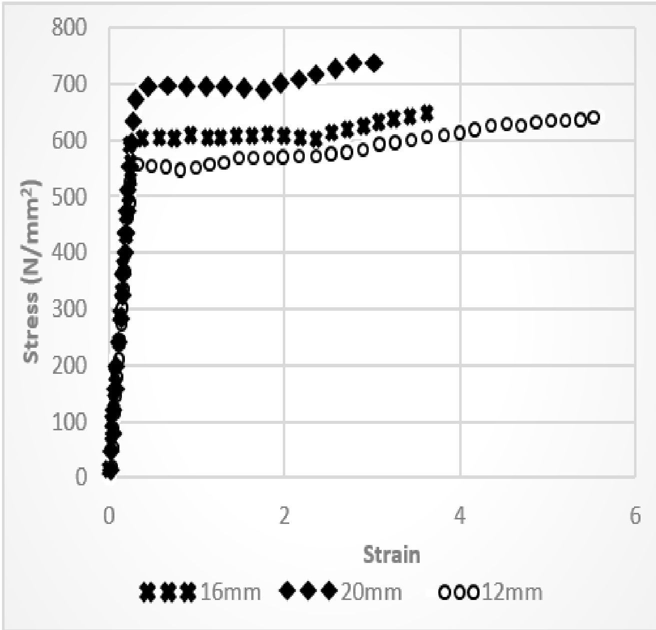
[3]. However, the maximum tensile strength exceeded the recommended limit of 650 N/mm^2. Table 9 shows the test results of the mechanical properties of the various steel specimens. Also, Figure 11 illustrates the stress-strain relationships obtained from the tensile test on the steel bars.

Table 9: Test Result of Steel Bars

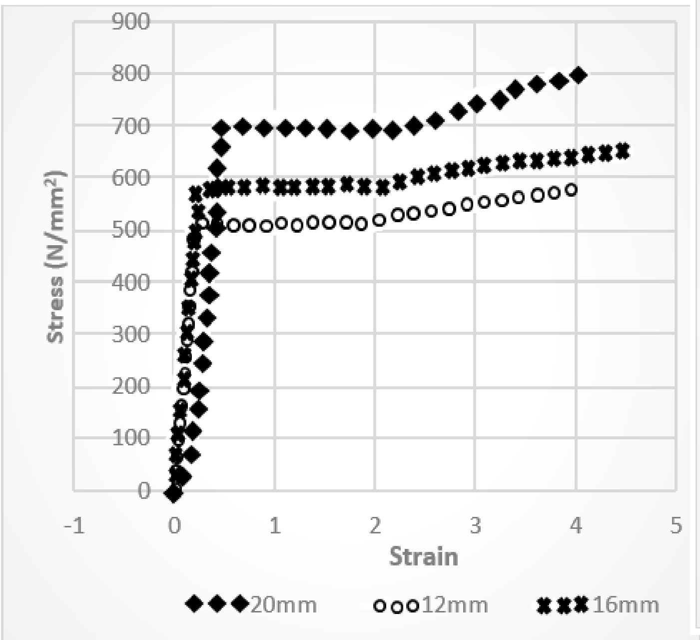
Bar ID	**Bar Type**	**Nominal Bar size (mm)**	**Yield Strength (f_y) N/mm^2**	**Yield Strain (ε_y)**	**Max Strength (f_{max}) N/mm^2**	**Ultimate Strength (f_{ult}) N/mm^2**	**Total Elongation (%)**
STSL R12	Mild Steel	12	378.59	0.0024	501.57	468.87	26.02
B5PL R12	Mild Steel	12	484.24	0.0026	555.19	458.23	18.45
FBML R12	Mild Steel	12	457.41	0.0033	537.39	414.66	18.76
AM T12	High-Tensile	12	679.25	0.0035	762.73	496.99	10.04
STSL R16	Mild Steel	16	359.21	0.0022	582.20	477.42	26.89
B5PL R16	Mild Steel	16	497.12	0.0027	529.27	371.16	18.31
FBML R16	Mild Steel	16	432.84	0.0026	521.48	448.08	21.16
AM T16	High-Tensile	16	489.44	0.0028	609.88	361.09	11.79
STSL R20	Mild Steel	20	342.45	0.0021	497.08	451.69	23.96
B5PL R20	Mild Steel	20	498.93	0.0026	575.98	559.95	23.19
FBML R20	Mild Steel	20	481.38	0.0024	595.72	507.89	21.69
AM T20	High-Tensile	20	579.19	0.0029	738.76	519.70	12.68



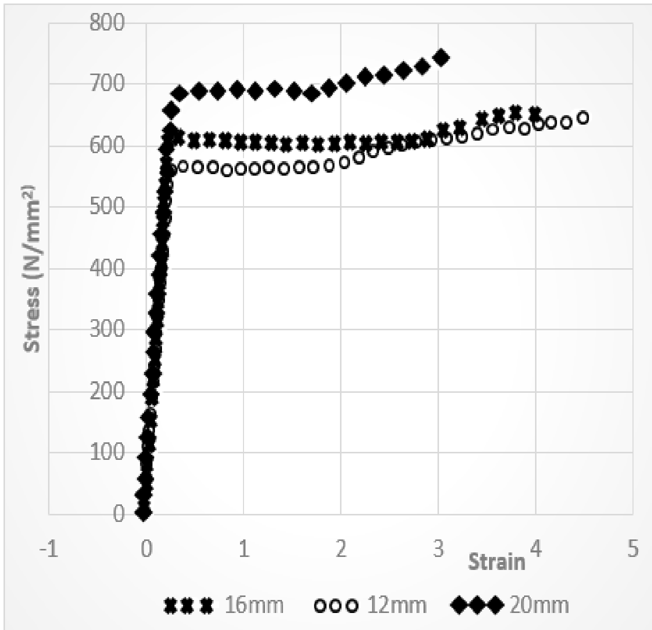
(a) Mild Steel Bars from STSL



(b) Mild Steel Bars from B5PL



(c) Mild Steel Bars from FABML



(d) High Tensile Bars from AM

Fig 11: Stress-Strain Relationships Obtained from the Tensile Test

5.0 CONCLUSION

The size and surface geometry of reinforcements are crucial factors for structural engineers, as they significantly affect the bond strength of reinforced concrete components. Once the structural engineer's design spells out the required sizes of bars, adopting bar sizes that are smaller than theyought to be would undoubtedly have dire consequences on the overall strength and capability of thestructure to withstand its anticipated loads. The study pointed out that:

1. Mild Steel reinforcing steel bars produced in Ghana have actual diameters smaller than their nominal sizes. Additionally, the locally manufactured bars had their rib spacing wider than the GS 788-2:2018 [2] required rangeof $0.5d \leq c \leq 0.7d$, where 'c' is the spacing between ribs, even though they meet the requirement setout in BS4449:2005+A2:2009 [3]. The imported reinforcements however had actual diameters that were almost equal to their nominal diameters and satisfied the requirement of GS 788-2:2018 [2] and BS4449:2005+A2:2009 [3] in terms of rib height and rib spacing. To ensure adequacy of design and safety throughout the design life of a structure, the Ghana Standards Authority must ensure that local milling companies adhere to the required standards.

2. The locally manufactured reinforcing steel bars showed inconsistency in their chemical composition as none of them met the criteria set out in BS4449:2005+A2:2009 [3] and GS 788- 2:2018 [2]. Particularly, the locally manufactured bars had higher percentages of carbon above therecommended 0.25%. Even though this increases the tensile strength of the rods, it also makes them more brittle. Reinforcing steel bars from B5PL recorded the lowest carbon content of 1.55%, followed by bars from FBML recording 2.49%. STSL recorded the highest carbon content of 3.15%. The imported high-tensile steel bars however had a carbon content of 1.87%, lower than the maximum limit of 5%. The increased carbon content beyond their recommended quantities increases the tensile strength of the steel or its ability to support more weight but renders the steel bar brittle and unweldable. It is imperative that the Ghana Standards Authority put measures in place to compel all local milling companies to comply with the stipulatedstandards.

3. Reinforcement bars from STSL recorded a minimum tensile strength of 497.08 N/mm^2, whereas bars from FBML recorded a maximum of 595.72 N/mm^2. Therefore, the mild steel reinforcing steel bars produced in Ghana should be classified as medium to high-strength (or high-yield) steel, confirming the findings of Kankam and Adom-Asamoah [12]. The imported high-tensile bars recorded a minimum tensile strength of 609.88 N/mm^2 and a maximum of 762.73 N/mm^2. These satisfied the minimum requirement of 485 N/mm^2 as stated in BS 4449:2005+A2:2009 [3]. However, their maximum tensile strength exceeded the recommended limit of 650 N/mm^2 by BS 4449:2005+A2:2009 [3]. As the Government of Ghana takes steps to banthe importation of reinforcing steel bars into the Country, the Ghana Standards Authority must ensure that locally manufactured bars satisfy approved criteria to avoid structural failures caused by the use of sub-standard bars.

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