International Journal of Engineering Materials and Manufacture (2024) 9(2) 41-51
https://doi.org/10.26776/ijemm.09.02.2024.02

Experimental Investigation into Strength Properties of Ribbed Mild Steel Reinforcing Bars (RMSRBs) Produced by Local Companies in Ghana

Sumaila Mohammed and Humphrey Danso

Received: 15 February 2024
Accepted: 19 March 2024
Published: 15 April 2024
Publisher: Deer Hill Publications

ABSTRACT
The construction of high-rise buildings has increased the production and demand of ribbed mild steel reinforcing bars (RMSRBs) in Ghana. This study aimed at investigating the strength properties of RMSRBs manufactured in Ghana from scrap metals. Three steel-producing companies were considered for this study. A total of 90 samples of 12, 16, and 20mm diameters with lengths of 500, 50, and 20mm were used for the study. The prepared specimens were subjected to tensile strength test, chemical composition analysis, micro-hardness test, and microstructure analysis. The results indicate that the average tensile strength of between 576.00 and 768.40N/mm^2 were above the minimum tensile strength of 250N/mm^2 recommended by ASTM E8/E8M-16a. The carbon equivalent values (CEVs) of between 0.287 and 0.333% obtained were almost within the range of 0.3 to 0.55% recommended by ASTM A706/A706M-09b. It was also identified that the average Vickers hardness values of between 255.76 and 295.38HV were acceptable. The microstructural images showed good distribution of the pearlite and ferrite of the core. One Way ANOVA results indicated that the differences in the tensile strength values for 12mm (p-value <0.000) and 16mm (p-value =0.001) were statistically significant, however, the 20mm (p-value =0.138) was not statistically significant. The study, therefore, concludes that the strength properties of the 12, 16, and 20mm diameters of the RMSRBs produced by the three different companies in Ghana meet the standard requirements, and are recommended for use by contractors for the production of reinforced concrete.
Keywords: Chemical composition, ribbed mild steel, reinforcing bars, strength properties, Vickers hardness.

1 INTRODUCTION

The increase in the population of human settlements globally has contributed to increased infrastructural development. This has resulted in high demand for ribbed mild steel reinforcing bars (RMSRBs) to counteract tensile stresses in concrete structures. As reported by previous studies (Danso & Akwaboah, 2021; Danso 2018 and 2013), the use of local materials needs to be supported and reinforced to provide sufficient strength with adequate quality to withstand the effects of climate conditions. According to Abioye and Billihaminu (2016), reinforcement is a method of increasing the strength properties of concrete structural members. Steel bars of different diameters have been prescribed for use in reinforcing concrete. The choice of steel bars is based on strength, cost, accessibility, ease of erection, aesthetics, sustainability, and other environmental concerns (Ede et al., 2015). The performance of reinforced concrete as structural material depends strongly on the properties of the steel bars and concrete (Boateng et al. 2023). The ribbed steel bars have the advantage of increasing the bond strength at the concrete steel interface to improve the tensile and compressive properties of the reinforced concrete.

Structures are designed to ensure that they do not fail prematurely, whether collapse or service failure. Unfortunately, cases of premature structural failure are on the increase. In Ghana, reported cases of structural failure have recently become frequent, especially for buildings (Danso & Boateng, 2015). Ayodele (2009) examined the role of reinforcement in the collapse of buildings in Nigeria. The study revealed that the physical, chemical, and mechanical properties of different ribbed mild steel bars produced by different companies were different and some did not meet the acceptable standard. This is confirmed by Ayininuola and Olalusi, (2004) that the use of poor quality and

Sumaila Mohammed[a], Humphrey Danso[b] ✉
[a]Department of Construction Technology and Management Education
[b]Department of Architecture and Civil Engineering
Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development
P.O. Box 1277, Kumasi-Ghana
[a]E-mail: sumailamoham@gmail.com
[b]E-mail: hdanso@aamusted.edu.gh
dansohumphrey@yahoo.co.uk

Reference: Sumaila Mohammed & Humphrey Danso (2024). Experimental Investigation into Strength Properties of Ribbed Mild Steel Reinforcing Bars (RMSRBs) Produced by Local Companies in Ghana. *International Journal of Engineering Materials and Manufacture*, 9(2), 41-51.

substandard steel bars are among the causes of building failure in the construction environment. The variation in scrap feeds and impurities present in the scraps may contribute to a decline in the strength of ribbed mild steel bars which affects the quality (Atsbeha, 2017).

A study by Assiamah et al. (2023) evaluated the physical characteristics of reinforcement bars available in Ghana and concluded that local milling companies producing mild steel reinforcing bars should improve on the standardization of the diameter of reinforcing bars they produce. Dzogbewu and Arthur (2013) carried out comparative studies of locally produced and imported low-carbon steels on the Ghanaian market with two different batches of samples (rebars) from local and foreign producers with 12mm bars only. Kankam and Adom- Asamoah (2002) studied the strength and ductility characteristics of reinforcing steel bars milled from scrap metals and found that the tensile strength was high with very little elongation value of 9.6, 10.6 and 11.8 for the company A, B and C respectively leading to limited ductility compared with standard mild steel bars. They used an Avery Denison universal testing machine to perform the mechanical test, and the mode of failure indicated little or no necking and brittle behaviour of the steel.

Adebisi and Ndaliman (2015) studied the influence of process parameters (reinforcement fraction, stirring speed, The above studies focused on the physical and ductility properties of reinforced bars and 12mm diameter bars. There is a need to study the strength properties of various sizes of RMSRBs produced by different manufacturers. Therefore, this study focused on the strength properties of 12, 16, and 20mm diameters of RMSRBs produced by three different producers. The study further examined the chemical compositions and the hardness of ribbed mild steel reinforcing bars, and the microstructure analysis of ribbed mild steel reinforcing bars RMSRBs produced by local companies in Ghana. These were done to ascertain the conformity of RMSRBs' properties to standards.

2 MATERIALS AND METHODS

An experimental research design was used in sourcing data for analysis in this study. This section of the paper presents the materials, procedures, and methods that were used in the experimental work.

2.1 Materials

The main materials that were used in this experimental study are ribbed mild steel reinforcement bars (RMSRBs). These RMSRBs were obtained from three major local manufacturing companies in Ghana. The local manufacturing companies that manufacture the RMSRBs are Sentuo Steel Company (STS), Ferro Fabrik Limited (FFL), and Tema Steel Limited (TSL). For the purpose of identification, STS, FFL, and TSL are denoted by letters A, B, and C, respectively. Samples of the RMSRBs used for the study are shown in Figure 1.

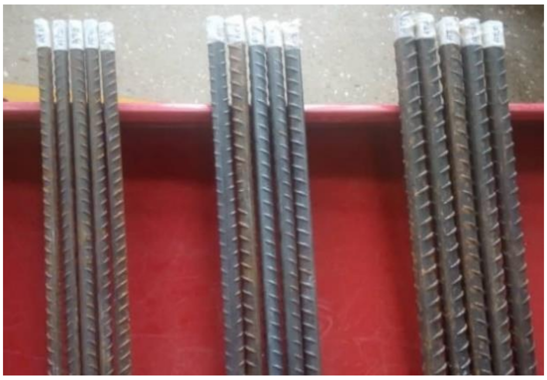

Figure 1: Untreated ribbed mild steel reinforcing bars

2.2 Preparation of Specimens

Three different sizes (12, 16, and 20mm diameters) of grade 250N/mm^2 of the RMSRBs were randomly selected and used for the experimental work. Five specimens of lengths 20, 50, and 500mm were prepared as samples for testing as shown in Figure 1. A total of ninety (90) specimens were used for the testing of the properties of the RMSRBs. Forty-five (45) of the specimens were used for tensile strength test, fifteen (15) each for chemical composition test, micro-hardness test, and microstructure analysis as shown in Table 1. For the chemical composition test, micro-hardness test, and microstructure analysis only the 16mm diameter RMSRBs were prepared for the study.

Table 1: Number of Ribbed mild steel reinforcing bars sampled.

Test	Bar Size (mm)	Grades (N/mm^2)	Length (mm)	No. of Samples	Total Sample
Tensile Test	12	250	500	5	15
	16	250	500	5	15
	20	250	500	5	15
Chemical Composition	16	250	50	5	15
Hardness Test	16	250	20	5	15
Microstructure	16	250	20	5	15
Total					90

2.3 Testing of Specimens

The specimens were tested after the preparation. The tests that were conducted are tensile strength, chemical composition, hardness, and microstructure.

2.3.1 Tensile Strength Test

The tensile strength test was conducted following the ASTM A706/A706M-09b (2022) test standard. The universal testing machine (model WAW-1000H) was used to carry out the tensile strength test of the RMSRBs as shown in Figure 2a. The test machine was linked to a computer-controlled system in which the load and extension data were graphically displayed together with the calculations of stress and strain. A total of 45 test specimens comprising 15 each specimen of 12, 16, and 20mm were tested. Each specimen was placed in the upper and the lower jaws (well gripped) of the test machine, and the uniaxial load was applied at both ends at the rate of 5mm/min till the specimen failed (Figure 2b). The ultimate tensile strength, Young's Modulus, percentage elongation, and fracture stress data were obtained from the test machine. Equation 1 was used for the ultimate tensile strength test calculation.

$$s = P/A \tag{1}$$

Where, s=ultimate tensile strength, P=force required to break RMSRBs, and A= cross-sectional area.

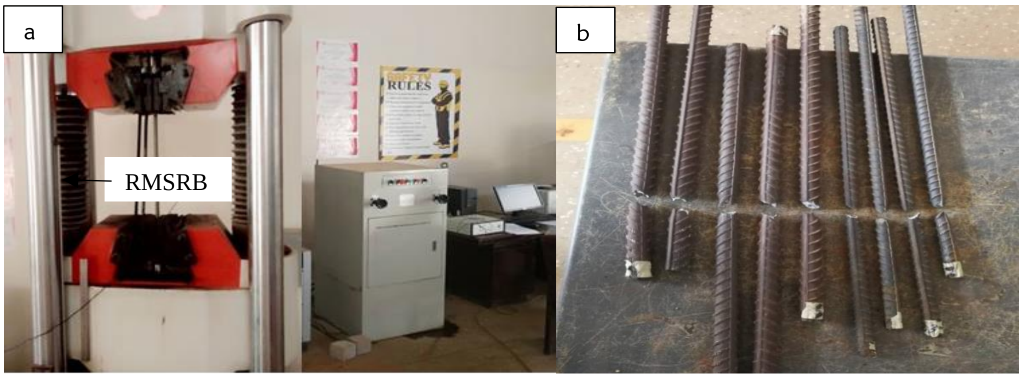

Figure 2: Determining tensile strength of the RMSRBs: (a) Universal Testing machine (model waw-1000H), (b) failed nature of RMSRBs.

2.3.2 Chemical Composition Test

The chemical composition of the RMSRBs was determined using the Angstrom V-950 Spectrometer apparatus shown in Figure 3a. Specimens of length 50mm (see Figure 3b) were cut to the cross section of the RMSRBs perpendicular to the axis and grounded flat for spectrometry. Each specimen was placed in position and the spark pointer positioned on the grounded surface of the specimen. The percentage chemical composition data were tabled automatically by the computer connected to the Spectrometer.

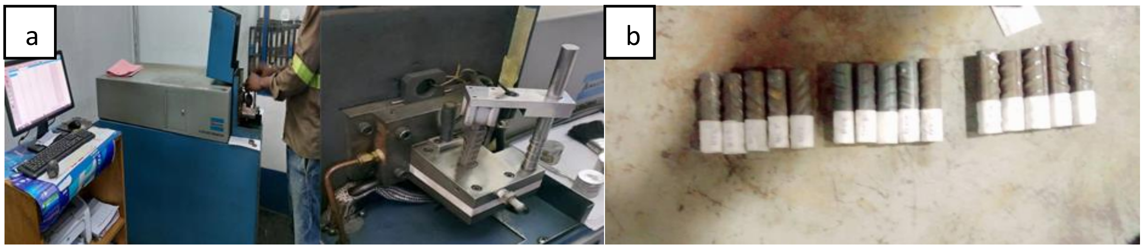

Figure 3: Determining the chemical composition of the RMSRBs: (a) setting up angstrom V-950 Spectrometer (b), prepared specimen for chemical composition test.

2.3.3 Hardness Test

The Vickers hardness test was conducted following the ASTM E92-17 (2017) test standard. This study employed a Vickers hardness tester to measure the scratch hardness of the RMSRBs. Figure 4a shows the experimental setup for the micro-hardness test. The Vickers hardness tests method was made to utilize test forces ranging from 9.807 x 10-13 to 1176.80 N (1gf to 120 kgf). A diamond indenter in the form of a right pyramid of a square base of an angle of 136° between opposite faces under a load (F) parallel to the axis of the specimen was applied to the surface. Each hardness test was carried out on a fresh surface of RMSRBs specimen as shown in Figure 4b. Vickers hardness values were found to be higher for indentation made closer to the axis of RMSRBs than for other surface regions. This suggests that smaller indentations produce higher value. The equation used in VH is shown in equation 2.

$$VH = 1.854\left(\frac{F}{D^2}\right) \qquad (2)$$

Where, VH=Vicker hardness value, F= load applied and D =the area of indentation.

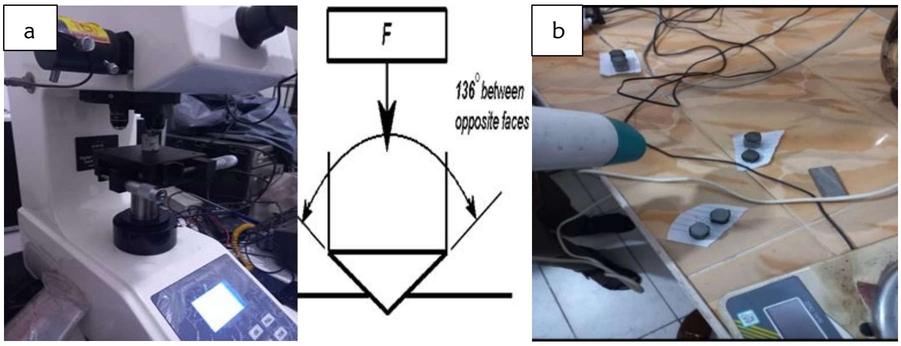

Figure 4: Determining the hardness of the RMSRBs: (a) set up for Vickers hardness test, (2) prepared specimen for Vickers hardness test.

2.3.4 Microstructural Test

Specimens of lengths of 20mm were cut from the cross section of the ribbed steel bars perpendicular to the axis of RMSRBs and were used for microstructural analysis. The surfaces of the specimens were micro-polished with aluminium oxide powder and etched by a mixture of 2% nitric acid with 98% ethanol. Micrographs of the etched surfaces were obtained using Olympus-412 photomicroscope as shown in Figure 5 using a magnification of 100×, and the micrographs were used to analyse the microstructure of the specimens.

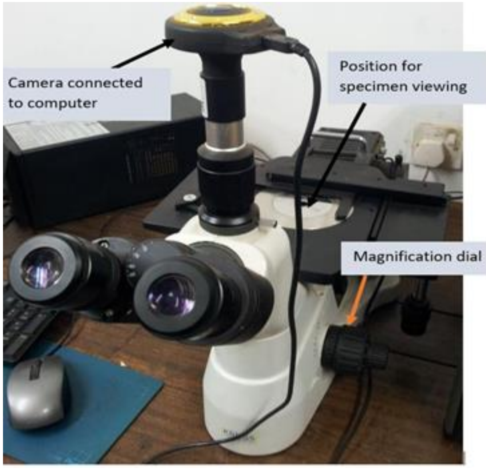

Figure 5: Determining the microstructure of the RMSRBs.

2.4 Statistical Analysis

One-factor Analysis of Variance (ANOVA) test at a significance level of 0.05 was performed to determine differences in ultimate tensile strength, chemical composition value (CEV), and hardness properties of ribbed mild steel reinforcing bar in the study. For the ultimate tensile strength test result, one factor ANOVA tests were run for 12mm, 16mm, and 20mm RMSRBs for the three companies. The carbon equivalent value (CEV) of one factor ANOVA for 16mm was completed, and a single factor ANOVA of Vickers micro hardness for 16mm was conducted. Equation three was used for ANOVA analysis as shown in equation 3.

$$F = MSB/MSE \tag{3}$$

where F = ANOVA coefficient, MSB = mean sum of square between groups, and MSE= mean sum of errors.

3 RESULTS AND DISCUSSION

3.1 Tensile Strength of RMSRBs

The average tensile strength results of the RMSRBs are presented in Table 2. The results also show the average modulus of elasticity and the average elongation percentage of company A, B, and C.

Table 2: Average strength results of RM.

Company	Diameter (mm)	Maximum Load (kN)	Maximum Tensile Strength (N/mm²)	Upper yield Load (kN)	Upper yield strength (N/mm²)	Modulus of Elasticity (GPa)	Displacement	Elongation (%)
A	12	60.36	768.40	52.51	668.75	255.97	56.19	11.24
B	12	50.72	585.60	36.35	419.80	222.77	88.25	17.65
C	12	50.61	644.40	46.48	591.50	246.78	52.80	10.56
A	16	109.90	713.80	87.08	566.00	232.96	50.17	10.03
B	16	89.61	582.20	61.88	401.75	237.46	90.65	18.13
C	16	96.16	624.60	76.98	500.00	206.59	65.12	13.02
A	20	146.58	576.00	122.03	479.67	244.25	59.14	11.83
B	20	151.74	596.20	100.70	395.67	202.24	90.71	18.14
C	20	182.30	610.40	141.66	474.20	238.16	85.45	17.08

Figure 6 illustrates the tensile strength of 12, 16, and 20mm RMSRBs. For the 12mm diameter RMSRBs, the tensile strength of 768.4, 644.4, and 585.6 N/mm² were obtained, respectively for company A, C, and B specimens. For 16mm diameter RMSRBs, the average tensile strength of 713.8, 624.6, and 582.2 N/mm² were obtained, respectively for company A, C, and B specimens. The 20mm diameter RMSRBs recorded average tensile strengths of 610.4, 596.2, and 576 N/mm² were obtained, respectively for Company C, B, and A specimens.

The results indicate that the tensile strength of company A obtained the highest average tensile strength among the 12 and 16mm RMSRBs and company C obtained the highest for the 20mm. There were corresponding elongation values of 11.24, 10.03, and 17.08 (see Table 2) for 12, 16, and 20mm, respectively. A study by Kankam and Adom-Asamoah (2002) obtained 560, 500, and 550 N/mm² average tensile strength. These gave corresponding elongation values of 9.6, 11.8, and 10.6 for the three samples. The findings of this study are consistent with the findings of Shunichi and Morifumi (2006). The results obtained from this study (between 582.20 and 768.40N/mm²) imply that the RMSRBs produced in Ghana were above the minimum tensile strength of 250N/mm² recommended by ASTM E8/E8M-16a (2019) and ASTM E8/E8M –22 (2022). Tensile strength of 20mm diameter RMSRBs specimen tends to be lower than the 12mm and 16mm diameter specimens because of shear-lag effect. Due to uneven stress distribution next to the jaw of the test machine, moreover, not all the area of cross section were directly gripped in the jaw. This contributed to fracture not occurring at the mid-span of the RMSRBs as shown in Figure 2b. The failure mechanism occurred when the stress (load) increases beyond the elastic limit of the RMSRBs undergo deformation which is known as the yield point. Further increase of stress beyond the ultimate strength point reduces the cross-sectional area called necking, which means a breaking stage. At this stage, the RMSRBs breaks, thus the curve drops as shown in Figure 7.

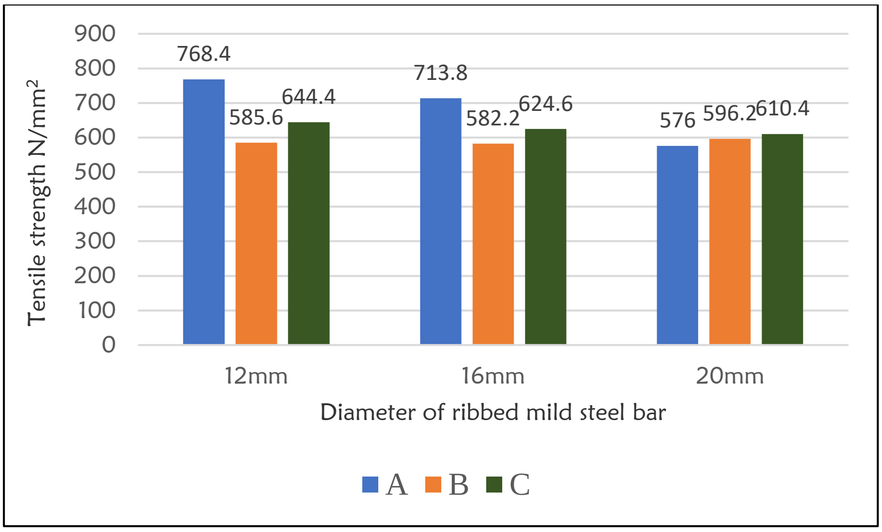

Figure 6: Tensile strength of the RMSRBs

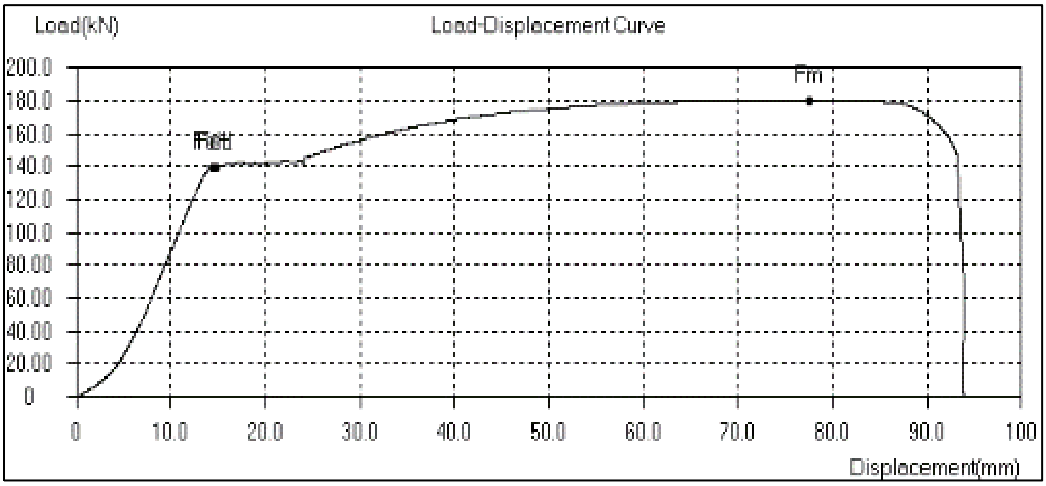

Figure 7: Stress-strain graph of the RMSRBs

3.2 Chemical Composition of RMSRBs

The results of the chemical composition test of 16mm diameter RMSRBs are presented in Table 3. From the table, the chemical compositions of the steel bars are slightly different from each other. The combined effect of the alloying elements of the steel bars and their carbon equivalent values (CEV) were calculated using the standard formula in equation 4 (Guo et al., 2013):

$$\text{CE} = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Ni+Cu}{15} \quad (4)$$

Where, C = carbon (%), Mn = manganese (%), Cr = chromium (%), Mo = moleydedum (%), V = vanadium (%), Ni = nickel (%) and Cu = copper (%)

Table 3: Results of chemical compositions of RMSRBs

Company	Chemical composition (%)										CEV
	Fe	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	
A	98.802	0.101	0.469	0.056	0.025	0.086	0.169	0.100	0.202	0.099	0.257
	98.629	0.185	0.525	0.048	0.034	0.117	0.216	0.082	0.215	0.065	0.348
	98.449	0.107	0.607	0.047	0.039	0.259	0.208	0.113	0.226	0.066	0.288
	98.854	0.059	0.471	0.063	0.024	0.085	0.174	0.096	0.204	0.085	0.213
	98.860	0.071	0.464	0.061	0.026	0.083	0.175	0.094	0.204	0.077	0.222
Average	98.719	0.126	0.507	0.055	0.030	0.126	0.188	0.097	0.210	0.078	0.287
B	98.814	0.191	0.268	0.027	0.023	0.107	0.197	0.106	0.253	0.093	0.325
	98.772	0.181	0.279	0.037	0.027	0.124	0.228	0.105	0.256	0.084	0.319
	98.854	0.220	0.263	0.044	0.028	0.110	0.176	0.101	0.209	0.078	0.340
	98.776	0.194	0.282	0.044	0.028	0.128	0.203	0.107	0.252	0.083	0.329
	98.825	0.176	0.295	0.028	0.019	0.113	0.229	0.093	0.229	0.072	0.307
Average	98.808	0.192	0.277	0.036	0.025	0.116	0.207	0.102	0.240	0.082	0.323
C	98.559	0.188	0.477	0.043	0.027	0.162	0.270	0.105	0.178	0.092	0.347
	98.696	0.128	0.449	0.029	0.025	0.141	0.264	0.102	0.171	0.088	0.279
	98.525	0.163	0.516	0.037	0.028	0.212	0.259	0.099	0.173	0.090	0.325
	98.672	0.211	0.437	0.033	0.019	0.134	0.251	0.099	0.166	0.089	0.358
	98.524	0.191	0.511	0.041	0.021	0.190	0.248	0.105	0.178	0.104	0.356
Average	98.595	0.176	0.478	0.037	0.024	0.168	0.258	0.102	0.173	0.093	0.333

The chemical composition was analysed using carbon equivalent value (CEV). Carbon equivalent value combines seven chemical elements (Carbon, Manganese, Chromium, Molybdenum, Vanadium, Nickel, and copper) in a relationship that can be used to conclude based on their percentage. The comparison of the chemical composition in terms of CEV is shown in Figure 8. CEV of 0.287, 0.323, and 0.333% were obtained, respectively for company A, B, and C specimens. The CEV of company A, which was 0.287% can be run off to 0.3%. Companies B and C had all ten samples within the excellent range. Only two samples from company A were below the excellent range. Company B and C exhibited acceptable percentages because the carbon and phosphorus content in the material met the minimum percentage (0.25 and 0.040 respectively) as specified by ASTM A706/A706M-09 (2010). The CEVs obtained were within the range of 0.3 to 0.55% recommended by ASTM A706/A706M-09b (2010). According to ASTM A706/A706M-09 (2022), the CEV in the range of 0.3 to 0.55% shows much better mechanical performance than a steel bar. A study by Ssempijja (2019) also obtained CEV within the range of 0.3 to 0.55%. Therefore, the tensile strength values obtained from the current study which are higher than the minimum recommended values can be attributed to the acceptable CEV of the RMSRBs that are manufactured in Ghana.

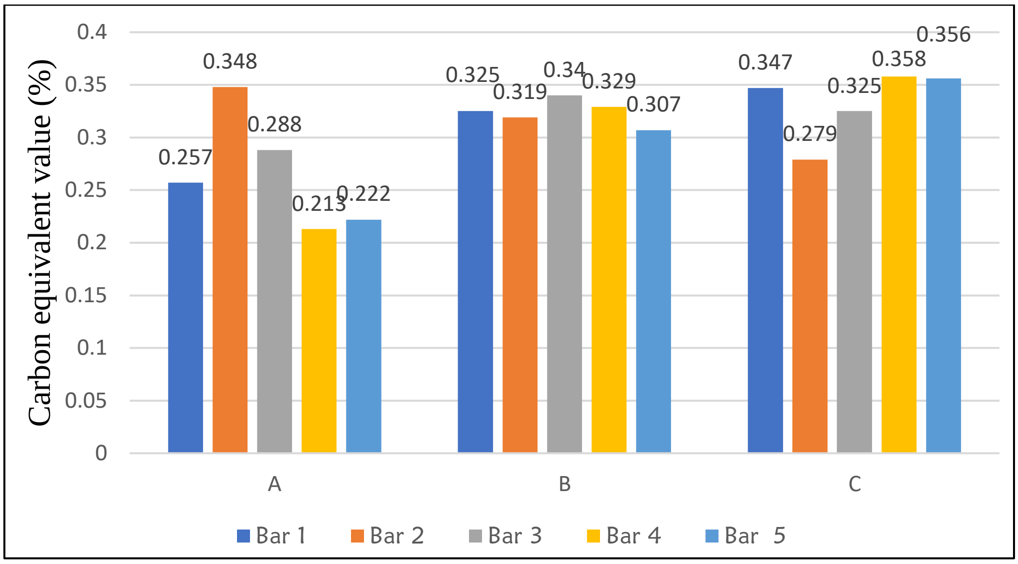

Figure 8: Carbon equivalent value (CEV) of the RMSRBs

3.3 Micro-Hardness of RMSRBs

The micro-hardness test results are shown in Table 4. The hardness test was performed to identify the hardness strength of the RMSRBs. Hardness test results comparison for companies A, B, and C are illustrated in Figure 9. It can be observed that the average hardness values are 295.38, 291.16, and 255.76HV, respectively for companies A, B, and C RMSRBs. Comparing the hardness value with the CEV, it can be observed that, the higher the hardness value the lower the carbon equivalent value. Company A had the lowest CEV of 0.287% with the highest average hardness value of 295.38. Company C had a higher CEV of 0.333 with the lowest hardness value of 255.76HV. The results show that the Vickers hardness values for all the companies were higher than the recommended hardness value of 150HV (Totten, 2007; Ponle et al., 2014). According to Totten (2007), the hardening capacity of steel depends mainly on its carbon content and to a lesser extent on its content of alloying elements and the grain size of austenite grains. Average Vicker hardness value of 295.38, 291.16 and 255.76 as obtained in this study depicted the hardness level of RMSRBs.

Table 4: Results of Vickers hardness of RMSRBs

Company	Sample Number	Hardness value (HV)			
		Value	Maximum	Minimum	Difference
A	1	194.0	403.3	194.0	209.3
	2	246.4			
	3	254.8			
	4	378.4			
	5	403.3			
	Average	295.38			
B	1	227.4	363.0	194.0	135.6
	2	268.5			
	3	336.0			
	4	363.0			
	5	260.9			
	Average	291.16			
C	1	228.6	295.0	228.6	66.42
	2	250.4			
	3	234.5			
	4	295.0			
	5	270.3			
	Average	255.76			

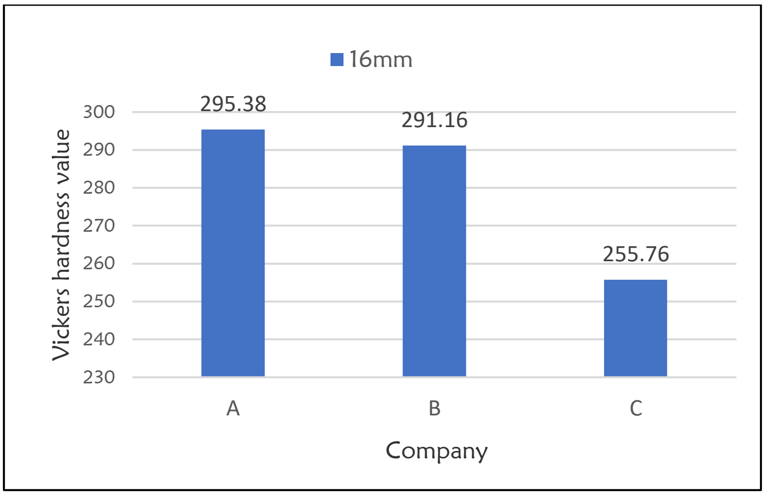

Figure 9: Vickers hardness value of the RMSRBs

3.4 Microstructural Analysis of RMSRBs

The core zone micro-structure of RMSRBs was analysed with Photo Microscope at a 100× magnification lens as shown in Figure 10. All the RMSRBs, regardless of chemical composition and strength levels, exhibited a composite microstructure consisting of ferrite and pearlite phases in the core. The micro-graphs showed ferrites are the white patches that are not clearly visible, and the pearlites are the dark patches that are more visible. The relatively uneven distribution of phases is visible around some areas in the core of the images of specimen A. The images of specimens B and C had a good distribution of the pearlite and ferrite of the core. This could be the reason why RMSRBs from company A obtained higher tensile strength than companies B and C. Martensite was not detected in any of the specimen therefore, the results are similar to the results of previous studies (Chen et al., 2017; Balogun et al., 2009). Dzogbewu and Arthur (2013) also found similar pattern of ferrite and pearlite in the micro-graph images.

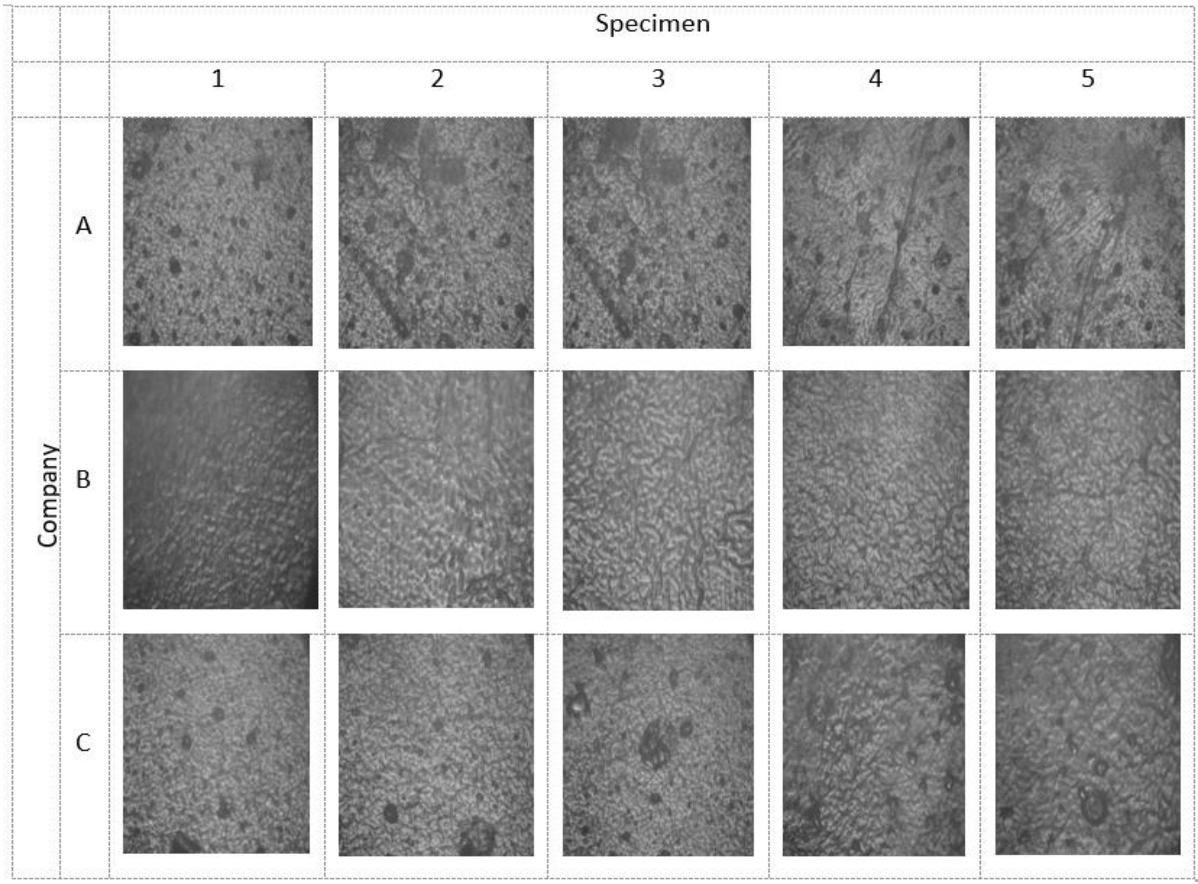

Figure 10: Metallography/Microstructure images of the RMSRBs

3.5 Results of One Way ANOVA

Table 5 presents the One-Way ANOVA results. The p-value of tensile strength of 12mm (<0.000) 16mm (0.001) and 20mm (0.138) indicate that the differences in the tensile strength for 12 and 16mm specimens were less than the specified significant level of 0.05. Therefore, the differences in the tensile strength values obtained for 12 and 16mm are statistically significant. However, the p-value of tensile strength of 20mm (0.138) indicates the differences in the tensile strength were not statistically different. It can also be seen from the ANOVA analysis results in Table 5 that the p-value of hardness value of 16mm (0.572) was greater than the specified significant level of 0.05 and therefore, the difference is statistically not significant, while the CEV p-value of 0.030 was less than 0.05 and therefore, the difference is statistically significant.

Table 5: Summary of ANOVA Tests Result

Type of Test	Bar Size (mm)	p-Value	Number of Company	Total Sample
Tensile strength	12	< 0.000	3	15
	16	0.001	3	15
	20	0.138	3	15
Hardness	16	0.572	3	15
CEV	16	0.030	3	15

4. CONCLUSIONS

This experimental study examined the strength properties of 12, 16, and 20mm diameters of ribbed mild steel reinforcing bars (RMSRBs) produced with scrap metals from three different companies in Ghana. The study further determined the chemical compositions, hardness, and microstructure properties of the RMSRBs. The findings of the study are summarized below.

1. The study found that the average tensile strength of between 576.00 and 768.40 N/mm^2 was obtained from the 12, 16, and 20 mm RMSRBs produced by the three companies in Ghana. These strength values are above the minimum tensile strength of 250N/mm^2 recommended by ASTM E8/E8M-16a.
2. Chemical composition for the 16mm diameter RMSRBs of carbon equivalent values (CEVs) of between 0.287 and 0.333% were obtained from the three manufacturing companies in Ghana. The CEVs obtained were within the range of 0.3 to 0.55% recommended by ASTM A706/A706M-09b.
3. The study found that the average hardness values of between 255.76 and 295.38HV for RMSRBs produced by the three companies in Ghana. These Vickers hardness values are above the 150HV recommended by previous studies.
4. The microstructural images of the RMSRBs showed good distribution of the pearlite and ferrite of the core. This is the reason why the RMSRBs produced by the three companies in Ghana obtained high tensile strength.
5. The One-Way ANOVA results indicated that the differences in the tensile strength values for 12mm (p-value <0.000) and 16mm (p-value =0.001) were statistically significant, however, the 20 mm (p-value =0.138) was not statistically different. The difference in the hardness value of 16mm (p-value =0.572) was found to be statistically not significant, while the difference in the CEV value (p-value =0.030) was found to be statistically significant.
6. The study, therefore, concludes that the strength properties of the 12, 16, and 20mm diameters of the RMSRBs produced from three different companies in Ghana meet the standard requirement, and are recommended for use by contractors for the production of reinforced concrete.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. Danso H., Akwaboah M. (2021) Assessment of the quality of burnt bricks produce in Ghana: The case of Ashanti region. Case Studies in Construction Materials, 15, 1-13, https://doi.org/10.1016/j.cscm.2021.e00708.
2. Danso H. (2013). Building houses with local available materials in Ghana: Benefits and Problems. International Journal of Science and Technology, 2(2), 225-231.
3. Danso H. (2018). Identification of key indicators for sustainable construction materials. Advanced Materials Science and Engineering. 1-7, https://doi.org/10.1155/2018/6916258.
4. Abioye T., Billihaminu A.O. (2016). Investigation into the strength characteristics of reinforcement steel rods in Sokoto Market Sokoto State Nigeria. International Journal of Research in Engineering and Technology, 2(2), 66-66.
5. Ede A.N., Egunjobi E.O., Bamigboye G., Ogundeji J. (2015). Assessment of quality of steel reinforcing bars used in Lagos, Nigeria. International Research Journal of Innovation and Engineering, 1(3), 1-8.

6. Boateng E., Kankam C.K., Danso A.K., Ayarkwa J., Acheampong A. (2023) Bond Characteristics of Deformed Steel Rebar in Palm Kernel Shell (PKS)-Rubberised Concrete Composite. Journal of Civil Engineering and Construction, 12(2):69-77, https://doi.org/10.32732/jcec.2023.12.2.69
7. Danso H., Boateng I. (2015). Quality of Type I Portland cement from Ghana and UK. Civil and Environmental Research, 7(1) 38-47, http://www.iiste.org/Journals/index.php/CER/article/view/19065/19310.
8. Ayodele E.O. (2009). Collapse of Buildings in Nigeria-Roles of Reinforcement. Continental Journal Environmental Sciences, 3, 1-6.
9. Ayininuola G.M., Olalusi O.O. (2004). Assessment of building failure in Nigeria: Lagos and Ibadan Case Study. African Journal of Science and Technology, 5(1), 73-78, https://www.ajol.info/index.php/ajst/article/view/15321.
10. Atsbeha A. (2017). Analysis on Mechanical Properties of Locally Produced Reinforcement Bars for Building Construction Application, Doctoral dissertation, Mekelle University.
11. Assiamah S., Kankam C.K., Banini E.K., Adinkra Appiah K. (2023). Physical and Geometrical Characteristics of Reinforcing Steel Bars in Construction Industry of Ghana. Journal of Materials Science Research and Reviews, 6(1), 40-53, https://journaljmsrr.com/index.php/JMSRR/article/view/227/451.
12. Dzogbewu C.T.K, Arthur Y.D. (2013). Comparative studies of locally produced and imported low-carbon steels on the Ghanaian market. Journal of Natural Science, 1(1), 15-22.
13. Kankam C.K., Adom-Asamoah M. (2002). Strength and ductility characteristics of reinforcing steel bars milled from scrap metals. Materials Design, 23(6), 537-545, https://doi.org/10.1016/S0261-3069(02)00028-6.
14. ASTM A706/A706M-16b (2022). Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement, ASTM International, West Conshohocken, PA, United States, https://www.astm.org/a0706_a0706m-16.html.
15. ASTM E92-17 (2017). Standard Test Method for Knoop and Vickers Hardness of Materials, ASTM International, West Conshohocken, PA, United States, https://www.astm.org/e0092-17.html.
16. Shunichi H., Morifumi N. (2006). Effect of Micro Alloying Elements on mechanical Properties of Reinforcing Bars. ISIJ International, 46(10), 1510 –1515, https://www.jstage.jst.go.jp/article/isijinternational/46/10/46_10_1510/_pdf.
17. ASTM E8/E8M–16a (2019). Standard Round Specimens for Tension Testing, ASTM International, West Conshohocken, PA, United States, https://www.astm.org/jte20190549.html.
18. ASTM E8/E8M –22 (2022). Standard Test Method for Tension Testing of Metallic Materials, ASTM International, West Conshohocken, PA, United States, https://www.astm.org/products-services/standards-and-publications/standards/workitem-wk83107.
19. Guo Z., Saunders N., Miodownik A.P., Schillé J.P. (2013). Introduction of materials modelling into processing simulation–towards true virtual design and simulation. International Journal of Metallurgical Engineering, 2(2) 198-202.
20. ASTM A706/A706M-09 (2010). Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement, ASTM International, West Conshohocken, PA, United States, https://www.astm.org/a0706_a0706m-09.html.
21. Ssempijja D. (2019). Investigations into the mechanical performance of Ugandan made carbon steel bars, Master's Degree dissertation, Kyambogo University, https://kyuspace.kyu.ac.ug/handle/20.500.12504/747.
22. Totten G.E. (2007). Steel Heat Treatment Handbook 2nd Ed. CRC Press, Taylor & Fancis Group.
23. Ponle E.A., Olatunde O.B., Awotunde O.W. (2014). Mechanical properties of reinforcing steel rods produced from recycled scraps. International Journal of Engineering Science, 3(2), 14-34. https://theijes.com/papers/v3-i2/Version-3/C032030014034.pdf.
24. Chen X., Li J., Cheng X., He B., Wang H., Huang Z. (2017). Microstructure and mechanical properties of the austenitic stainless steel 316L fabricated by gas metal arc additive manufacturing. Materials Science and Engineering: A, 703, 567-577, https://doi.org/10.1016/j.msea.2017.05.024.
25. Balogun S., Esezobor D., Andeosun S., Sekunowo O. (2009). Challenges of Producing Quality Construction Steel Bars in West Africa: Case Study of Nigeria Steel Industry. Journal of Minerals & Materials Characterization & Engineering, 8(4), 283–291, https://file.scirp.org/pdf/JMMCE20090400004_67861438.pdf.