Journal of Engineering Research and Reports

Volume 24, Issue 12, Page 57-74, 2023; Article no.JERR.98540
ISSN: 2582-2926

Strength and Deformational Characteristics of Concrete Beams Reinforced with Steel Bars Locally Produced from Recycled Metal Scrap in Ghana

John K. Quarm Junior [a*], Charles K. Kankam [b], Prosper Tudagbe-Obuor [c], Vincent K. Akortia [d], Emmanuel K. Banini [e], Evans Biney [f], Peter K. Adzakey [g] and Christopher Kofi Dzivenu [h]

[a] *Directorate of Physical Development and Estate Management, UCC, Cape Coast, Ghana.*
[b] *Civil Engineering Department, KNUST, Kumasi, Ghana.*
[c] *Works Department Yilo Krobo, Somanya, Ghana.*
[d] *Works Department Ho West District Assembly, Dzolokupe, Ghana.*
[e] *Directorate of Engineer Services GHQ, Ghana Armed Forces, Burma Camp, Accra, Ghana.*
[f] *48 Engineer Regiment, Ghana Army, Ghana.*
[g] *Cape Coast Technical University, Ghana.*
[h] *Civil Engineering Department, KNUST, Kumasi, Ghana.*

Authors' contributions

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

Article Information

DOI: 10.9734/JERR/2023/v24i12860

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/98540

Original Research Article

Received: 09/02/2023
Accepted: 12/04/2023
Published: 18/04/2023

**Corresponding author: Email: engjohn37@gmail.com;*

ABSTRACT

This study was conducted to examine the structural behavior of concrete beams reinforced with local steel bars available in Ghana. The concrete was prepared from conventional materials of ordinary Portland-limestone cement, pit sand and granitic stones. Steel bars of sizes 12mm, 10mm, and 8mm from different millers used to reinforce the concrete beams were tested to study the stress-strain relationship of the bars. The main reinforcing steel bars in the concrete beams comprised 12mm high tensile and 12mm mild steel bars produced by four different companies. The four companies from which these steel bars were obtained are Ferro Fabric Limited (FFL), United Steel Company (USC), Sentuo Steel Limited (STS) and Fabrimetal (FAB). The specific objectives of this study were to determine the actual strength and sizes of steel bars used to reinforce concrete (steel bars of nominal sizes 12mm, 10mm and 8mm from different millers), to study the stress- strain relationship of the bars, to study the ultimate limit state characteristics of beams reinforced with different bars and to investigate the deformational behaviour of concrete beams reinforced with different bars (i.e., cracking, deflection).

Data collected were analyzed using theoretical and experimental approaches. The experimental results confirmed theoretical analysis that indicated that governing failure loads of the beams were due to steel yielding first with the exception of one beam in which the governing failure load was by shear. On average the experimental cracking and failure loads in the beams reinforced with high-yield steel bars were slightly higher than the theoretical loads, while they were observed to be slightly lower in the beams reinforced with mild steel bars. With regard to cracking, the beam reinforced with FFL ribbed mild steel developed the highest number of cracks at failure which represent a very good bonding between steel and concrete as compared to the other companies. Beams reinforced with FAB high-yield steel had the highest failure load as compared to the other steels. It is important to ensure standardization of the rebars in the Ghanaian market such as the size of the bar, the rib spacing, and the rib height through the dissemination of information to stakeholders including structural and material engineering manufacturing companies and contractors.

Keywords: High yield bars; Mild steel bars; standardization; rib.

1. INTRODUCTION

Concrete is a composite material made of aggregates bonded together by cement paste which hardens over time [1]. It is a synthetic building material that is made by mixing cement, fine aggregate, coarse aggregate, and water in appropriate proportions. This mixture hardens as a result of a chemical reaction between cement and water, known as hydration, and binds the aggregates to form a rock–like mass. Concrete continues to set throughout the curing process and gains strength as long as it is kept moist and warm. Durable, strong concrete is made by correctly dosing and mixing the various materials and additives, which aids in the hardening of the concrete after casting [2-5].

The quality of the concrete is largely determined by the quality of the cement-water paste that binds the aggregates together. The strength of the concrete is reduced when excessive water is added to the paste [6].

Reinforcing steel bars or mesh of steel wires are used primarily as a tension-resisting material in reinforced concrete and reinforced masonry constructions to strengthen the concrete while it is subjected to tension. Additionally, it can be utilized in compression to increase the concrete's compressive strength; for instance, the majority of reinforced concrete columns are subjected to compressive stresses.

Primary reinforcement is used to provide resistance to support design loads whereas secondary reinforcement is used for the distribution of stresses and aesthetic purposes by providing localized resistance to limit cracking and temperature-induced stresses. The latter reinforcement also provides resistance to concentrated loads by spreading them through a wider area. Moreover, it assists other steel bars in accommodating their loads by holding them in the correct position. Moreover, external steel tie bars are used to constrain and reinforce masonry structures, sometimes as a means of building conservation [7].

Table 1. Properties of reinforcing steel bars [8]

Beam ID	Bar source and nominal size	Type of steel	Bar size (mm)	Yield strength (f_y) N/mm^2	Maximum strength (f_{max}) N/mm^2	Ultimate Strength (f_{ult}) N/mm^2	Total elongation (%)
B1	FAB 12R	Mild	10.15	639.68	752.54	577.88	18.70
B2	USC 12R	Mild	10.59	454.30	641.70	477.01	25.54
B3	STS 12R	Mild	11.08	424.91	585.55	546.17	26.00
B4	FFL 12R	Mild	10.97	555.26	652.14	547.33	18.03
B5	STS 12Y	High yield	11.69	533.52	792.12	754.85	18.19
B6	FAB 12Y	High yield	11.82	656.00	774.44	574.00	11.60
B7	USC12Y	High yield	11.36	752.71	848.96	555.28	10.62
B8	FFL 12Y	High yield	11.68	672.47	789.21	588.41	10.68
	Loc 6R*	Mild	4.86	506.72	668.43	490.54	1.96
	FAB 10R**	Mild	9.32	615.64	732.904	571.665	9.17

**Used for shear stirrup; **Used as compression steel bar*

This paper presents the results of study of comparative structural performance of concrete beams reinforced with different types of steel bars available in Ghana. Banini and Kankam [8] investigated the strength characteristics of different reinforcing steel bars in Ghana and their results are presented in Table 1.

2. DETAILS OF EXPERIMENTAL WORK

2.1 Materials

Fine aggregates, coarse aggregates of 12.5mm maximum size, steel bars, potable water, and Portland limestone cement which satisfies the requirement of ASTM C150 [9] and steel bars were employed to prepare the reinforced concrete beams.

A sieve analysis and silt test conforming to BS 1377: 1990 [10] were carried out for both the fine and coarse aggregate. A silt test was conducted on the fine aggregates in accordance with BS 1377 :1990 [11]. The mechanical properties of the steel bars of sizes 12mm, 10mm, and 6mm from different millers used to reinforce the concrete beams were tested using an Automatic Universal tensile and compression machine (PROETI 2000 kN) in accordance with standard procedures (ASTM E8/E8M) [12] to study the stress-strain relationship of the bars [8].

2.2 Preparation of Concrete Test Specimens

2.2.1 Mix design

Concrete mix proportions of 1:2:4 (cement; fine aggregates; coarse aggregate) by weight with water / cement ratio of 0.55 were used to prepare the concrete. The concrete mix design was in accordance with IS: 10262 (1982) [13]. The cement content of 380 kg / m³ was used to meet a minimum requirement of 300 kg / m³ in order to avoid balling effect. Two sets of three control test specimens (cubes and prisms) were cast respectively for beams B1 to B4 and B5 to B8.

2.2.2 Mixing, casting and curing

Mixing of the concrete was done mechanically in a concrete mixer. The proportions of fine aggregates and cement were first batched into the concrete mixer, followed by the coarse aggregates. Mixing of the constituent materials was done in the dry state for about two minutes, and then batched water was progressively added to the dry mixed materials in the mixer. Mixing was standardized and had a consistent hue in a plastic mix. For thorough mixing, the time for blending was 1.5 to 2 minutes per rotation. The concrete mixer’s output was 15 to 20 mixtures per hour. A slump test (Fig. 1) was conducted to determine the workability of the concrete. A total of 9 control concrete cubes measuring 150mm x 150mm x 150mm (Fig. 2) and 9 prisms measuring 100mm x 100mm x 400mm were cast to study the compressive strength and modulus of rapture of the concrete mixes. Concrete for each test specimen was cast in three layers and each layer was compacted by tampering 25 strokes using a rod.

Curing of the test beams, cubes and prisms was by fully covering the specimens with wet sacks (Fig. 3) to obtain a temperature equivalent to ambient average laboratory temperature of 28ºC and 100 per cent relative humidity to avoid micro–cracking of the test specimens.

Three cubes were cured for 7 days while the remaining cubes, prisms, and beams specimens were cured for 28 days.

2.3 Preparation of Control Specimens

Controlled specimens were prepared to determine the compressive and tensile strength of the concrete in accordance with BS12390-1. The metal cubical moulds of size 150mm x 150mm x 150mm and the prism moulds of size 100mm x 100mm x 400mm were used with the internal surfaces of the molds being cleaned and applied with oil. The moulds were placed on a smooth horizontal non–porous base plate. The concrete was poured in 3 layers in the molds and appropriately tamped to remove all air. After 24 hours, the specimens were de-molded and cured outside under a wet sack.

2.3.1 Compressive strength of concrete

The actual dimensions and weight of each cube were measured after they had been examined immediately after being removed from the wet sack and wiped clean. The test cube was placed in the compression machine in such a manner that the load was gradually applied centrally to opposite sides until it was crushed and the maximum applied load was recorded. The compressive strength was computed as the ratio of the maximum load to cross – sectional area of the cube. The average compressive strength of the three cubes was taken. The test was conducted in accordance with the requirements of British Standards BS EN 12390-3: 2000 [14].

2.3.2 Modulus of rupture of concrete

The test prisms cured under wet sacks were tested immediately upon removal of the sack and their actual dimensions had been measured. The test specimen was simply supported over 400mm span in a rigid steel frame and centrally loaded as shown in Fig. 5. The load was applied using a hydraulic jack until the specimen failed and the maximum load was recorded [15].

2.4 Preparation and Testing of Reinforced Concrete Beam

The formwork for the beam consisted of timber of dimensions 1950mm x 120mm x 200mm. It was constructed on a horizontal level floor oiled and lined with a black polythene sheet. The prepared reinforcement was placed on the horizontal surface into the formwork and was braced at the top as illustrated in Fig. 4. It was filled with concrete and compacted ensuring that a uniform cover of 25mm was kept all around by fixing a 25mm spacer blocks underneath and at the sides of the reinforcement. The top of the cast concrete was ensured to have a concrete cover of 25mm, then smoothened and marked after initial setting. A total of eight (8) beams were cast and their details are presented in Table 2.

The beam specimens were removed from their moulds after 24 hours and cured under wet hessian cloth for 28 days. Prior to testing they were brushed off all debris, and painted with white emulsion paint on all sides (Fig. 6).

Fig. 1. Slump test

Fig. 2. Concrete test cubes

Fig. 3. Curing of specimens

Fig. 4. Wooden formwork for Beams

Fig. 5. Flexural test on concrete prism

Table 2. Description of concrete beams

Beam ID	Concrete strength (N/mm^2)	Modulus of rupture (N/mm^2)	Cross section b × h (mm^2)	Span L (mm)	Effective depth (mm)	Spacing of stirrups (mm)
B1	19.5	4.0	120×200	1950	183	165
B2	19.5	4.0	120×200	1950	182.7	165
B3	19.5	4.0	120×200	1950	182.5	165
B4	19.5	4.0	120×200	1950	182.5	165
B5	15.3	3.8	120×200	1950	182.2	165
B6	15.3	3.8	120×200	1950	182.09	165
B7	15.3	3.8	120×200	1950	182.32	165
B8	15.3	3.8	120×200	1950	182.16	165

Fig. 6. Concrete beams ready for testing

2.4.1 Loading

Prior to testing the beams were painted with emulsion paint in all sides to facilitate monitoring of cracks development (Fig. 6). The testing consisted of a rigid steel frame and a hydraulic jack for loading. A two-point symmetrical loading system was adopted and applied to the beams. The beam specimens were simply supported with a clear span of 1650mm. The supports, dial gauge, and loading positions were indicated and marked on the beams before loading. The beam was lifted carefully and mounted on the frame. Visual checks by means of magnifying glass were conducted to monitor crack development in the beams during loading. A dial gauge was mounted under the beam to measure the central deflection.

The load was applied to the beam at intervals of 2 KN using the 200 KN capacity hydraulic jack which was centrally placed. A spreader steel beam was used to transfer the load to the specimen through two symmetrical loading points located at 650mm from the supports. The first crack load, deflection, number of cracks, crack spacing, maximum crack width, total number of cracks and final failure load were recorded. A 30cm transparent rule was placed against the crack and with the help of a magnifying glass, the width of the crack was measured.

3. THEORETICAL FLEXURAL ANALYSES

3.1 Modulus of Rupture of Unreinforced Concrete

For central point loading on the prism, simply supported at ends, the modulus of rupture and tensile strength of the concrete is expressed as;

$$f_t = \frac{3}{2} \quad \frac{P_{max}\ L}{BD^2} \tag{1}$$

where:

f_t = modulus of rupture (N/mm²); P_{max} = applied maximum load (N); L = span of the prism; B = width of the prism; D = Depth of the prism.

The modulus of rupture was 4N/mm^2 and 3.8N/mm^2 for beams B1 to B4 and B5 to B8 respectively (Table 2).

3.2 Cracking Load

3.2.1 Cracking moment of reinforced concrete beam

In a reinforced concrete beam, the cracking moment (M_{cr}) of the concrete is obtained based on its modulus of rupture (f_t) in a beam simply supported at its ends and loaded equally at the third points as shown in Fig. 7 as follows:

$$M_{cr} = \frac{f_t \times BD^2}{6} \tag{2}$$

where:
M_{cr}= Cracking moment; f_t= modulus of Rupture (N/mm^2); B = width of the beam (mm);
D = Depth of the beam (mm)

All the reinforced concrete beams had cross-sectional dimensions of 120mm X 200mm, simply supported over a span of 1950mm and loaded at the third points as shown in Fig. 7.

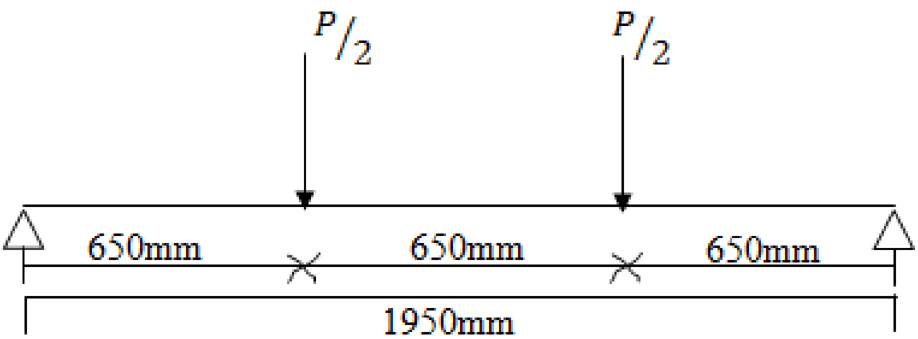

Fig. 7. Beam loaded equally at the third points

3.2.2 Theoretical cracking load for beams

The theoretical cracking load of the beam, that is simply supported at its ends and loaded equally at the third point as shown in Fig. 8, can be obtained from Eq. 3 as follows:

$$P_{cr} = \frac{6M_{cr}}{L} \quad (3)$$

where:
P_{cr} = theoretical cracking load (kN); M_{cr} = cracking moment (Nmm); L = Span of beam (mm).

The theoretical cracking loads for the eight beams are presented in Table 3.

3.3 Analysis of Theoretical Failure Load

3.3.1 Theoretical failure based on steel yielding first

The ultimate load of the beam simply supported and loaded at its third points as shown in fig 7 is expressed by Equation 4 as follows:

$$P_{ult} = \frac{6Mrs}{L} \quad (4)$$

where

M_{rs} = Moment of resistance of steel in tension; P_{ult} = failure load of beam; L = Span of the beam.

The moment of resistance of steel in tension is derived as follows [16]:

$$M_{rs} = 0.87f_yA_s \times 0.775d \quad (5)$$

Where

f_y is the yield strength of reinforcing steel bar in concrete beam. The values of fy for the steel from the different millers were obtained from Banini and Kankam [8] and Tudagbe-Obuor [17] d is the effective depth of the beam = 183mm; A_s is the area of steel reinforcement.

Based on the value of f_y of steel from the different millers (Table 1) failure loads of the beams on the assumption of yielding of steel are presented in Table 3.

3.3.2 Theoretical failure load based on concrete crushing first

The theoretical failure load of a reinforced concrete beam, simply supported and loaded equally at the third points, based on concrete crushing first in compression is derived from Equations 4 and 6 as follows;

$$P_{ult} = \frac{6Mrc}{L} \quad (5)$$

where

M_{rc} = Moment of resistance of concrete beam based on concrete in compression; P_{ult} = Concrete crushing load; L = Span of the beam

$$\mathrm{Mrc} = 0.156\mathrm{Fcu\,bd}^2 + 0.87\mathrm{fy\,As\,(d - d^1)} \quad (6)$$

Where

$_{fcu}$ = concrete compressive strength = 15.3 N/mm^2; d = effective depth = 183mm;
d' = effective depth of compression steel bar steel bars = 12 + $\frac{9.32}{2} = 19.32$
b = beam width = 120mm
Diameter of compresion rebar = 9.32mm,

As is the area of two steel rebars in compression $= \frac{2\pi \text{ x } 9.32^2}{4} = 136.44\mathrm{mm}^2$

On the basis of yield strength of compression bar as shown in Table 1 of specific miller [8], and Obuor [17], the failure loads of the beam assuming that concrete crushes first rises computed and the results are presented in Table 3.

3.3.3 Theoretical failure load on the assumption that shear failure occurs first

Shear in reinforced beams without shear reinforcement causes cracks to develop on inclined planes near the supports when the shear strength of concrete is exceeded [18]. In design, it is generally desirable to ensure that ultimate strengths are governed by flexure rather than by shear. Shear failures, which in reality are failures under combined shear forces and bending moments, are characterized by small deflections and lack of ductility.

The shear failure load (Vr) including tension reinforcement of the beam is obtained from

Eq. 7 as follows;

$$Vr = 0.87\,\frac{\mathrm{Asv}}{\mathrm{Sv}}\,\mathrm{fy} * d + \mathrm{Vc} * \mathrm{bd} \quad (7)$$

Where,
Vr = shear failure load; fy = yield strength of links; Vc = design concrete shear strength; Asv = total cross-section of links at the neutral axis at a section; Sv = spacing of links along the member; b = width of the beam; d = effective depth of the beam

The test results of Banini and Kankam [8] and Obuor [17] as summarized in Table 1 were used to compute the shear resistances of the specific beams in accordance with BS 8110: Part 1 [16]. The results are presented in Table 3.

4. THEORETICAL AND EXPERIMENTAL RESULTS

4.1 Load-deflection Curves

Fig. 8 shows the load-deflection curves for eight concrete-reinforced beams with steel bars from different steel manufacturing companies. Beams 1 to 4 were reinforced with ribbed mild steel bars and 5 to 8 with high-yield ribbed tensile steel bars. Each of the beams was subjected to a monotonic loading with load increments of 2 kN and deflection measurements were taken at each load increment. The cracking load was recorded and the incremental loading of the beam continued until failure. The loading of the beam was increased until the beam failed and the failure load was noted. Before cracking occurred, the slope of the load-deflection curves of the beams was steep and approximately linear, indicating the elastic behavior of the beam. Once flexural cracks developed a change in the slope of the curves was observed and they remained fairly linear until the beams failed by mostly yielding the steel followed by crushing of the concrete after an extensive deflection and cracking extending deeply into the concrete compression zone. Only beam (B7) failed in shear as predicted by theoretical analysis.

4.2 Cracking Loads

Table 3 shows the theoretical and experimental cracking loads for beams reinforced with mild steel bars and high-yield steel bars from the different manufacturers. The experimental cracking loads (P'_{cr}) of the beams reinforced with mild steel bars averaged 0.408 (approximately 40 percent) of the theoretical cracking loads (P_{cr}). On the other hand, the experimental cracking loads (P'_{cr}) of the beams reinforced with high-yield steel bars averaged 1.398 (approximately 140 percent) of the theoretical cracking loads (P_{cr}). It is also observed from Table 3 that the beams reinforced with mild steel bars developed first crack at lower loads than the beams reinforced with high-yield steel bar.

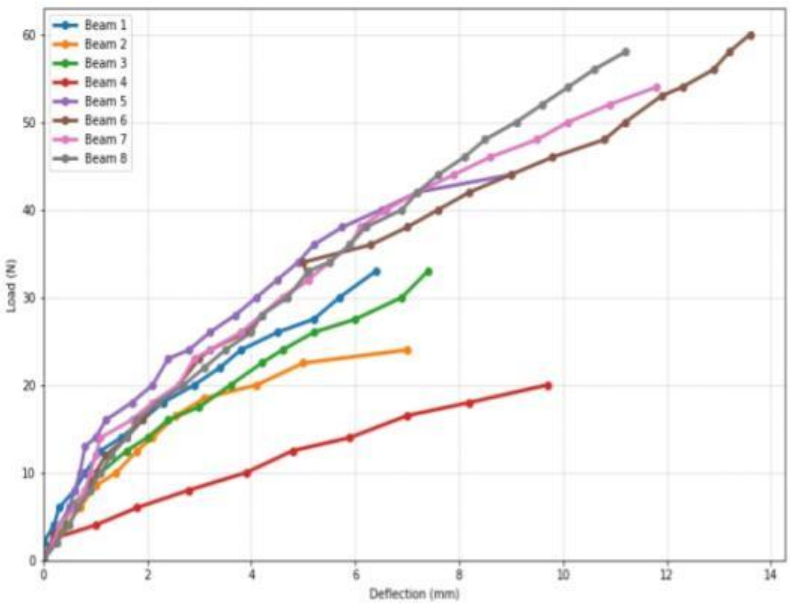

Fig. 8. Load – Deflection response of beams

Also, it can be seen from the experimental cracking loads that beams 1 to 4 reinforced with mild steel bar had their first crack appearing at different loads with B4 having the lowest value of 2kN followed by B1 and B3 with 4kN and 6kN respectively. With these observations it can be concluded that rebar use in B3 can carry high load before the initial crack appeared when subjected to loading, followed by B1 and B2 and then B4. Again, observing from the table it can be seen from the experimental cracking load that beams 5 to 8 reinforced with high-yield steel bar had their first crack appear at the same load of 14kN except beam B6 that had a lower value of 10kN. It can therefore be concluded that, rebars used in B5, B7 and B8 can carry high load before their initial crack loads appeared when subjected to loading, followed by B6. It can also be concluded that beams reinforced with high-yield bars sustain higher load than those reinforced with mild steel bars. Prior to cracking, concrete beam B6 reinforced with high-yield bar even with the lowest cracking load of 10kN exhibited greater resistance to cracking than all the beams reinforced with mild steel bar.

4.3 Failure Loads

Table 3 presents the theoretical and experimental failure loads of the beams subjected to monotonic loading. The beams were reinforced with mild steel ribbed bars and high yield steel bars produced by different reinforcement manufacturers in Ghana. The experimental failure loads (P'_{ult}) of the beams reinforced with mild steel bars averaged 0.813 of the theoretical failure loads. On the other hand, the experimental failure loads (P'_{ult}) of the beams reinforced with high-yield steel bars averaged 1.042 of the theoretical (P'_{ult}). The theoretical failure loads (P'_{ult}) for beams 1,2,4 and 7 exceeded the experimental failure load by 6.21%, 20.90%, 49.69% and 1.82%. on the other hand, experimental failure loads of beams 3,5,6 and 8 exceeded the theoretical failure loads (P'_{ult}) by 2.89%, 1.62%, 10.50% and 6.50% respectively. It is also observed from Table 3 that the failure loads (P_{ult}) of the beams reinforced with mild steel bars were lower loads than those of the beams reinforced with high-yield steel bar. Failure loads of beams reinforced with mild steel bars ranged from 20kN to 32kN. Of the beams reinforced with mild steel bars, beam B4 recorded the lowest failure load of 20kN followed by B2 with 24kN and then B1 and B3 32kN. With these observations it can be concluded that rebar steel bars manufactured by companies FAB and STS and used in B1 and B3 can resist higher applied loads before failure when subjected to loading, followed by B2 and then B4 (reinforced with bars manufactured by USC and FFL). Again, observing from the same table, it can be seen from the experimental failure loads that beam 5 to 8 reinforced with high-yield steel bars recorded different loads. B5 with STS reinforced steel bars had the lowest value of 44kN followed by B7 with 54kN and then B8 with 58kN. B6 with FAB steel developed the highest failure load of 60kN. It can therefore be concluded that FAB high-yield steel bars are capable of providing the highest resistance in concrete beams subjected to monotonic loading followed by FFL steel, USC steel and then STS steel in that order. Furthermore, it can be concluded that beams reinforced with high-yield bars expectedly sustain higher load than those reinforced with mild steel bars. Thus, every beam reinforced with high yield steel bar with the lowest failure load of 44kN was higher than all the beams reinforced with mild steel bar.

4.4 Cracking Mode

The crack pattern, number of cracks and maximum crack width in each beam after failure are presented in Table 4 and depicted in Figures 9 to 16. At failure, beams reinforced with mild steel bars developed fewer cracks with larger crack spacing than those reinforced with high-yield steel bars. The high-yield steel bars developed better and greater bond stress with concrete as a result of their ribs configuration and characteristics as compared with mild steel bars [8]. At failure B1 and B2 developed about the same number of cracks of 4 each while B3 and B4 had 5 and 8 number of cracks respectively. Beams B1 to B4 developed the same crack width of 4mm at failure with different cracks spacing ranging from 209mm to 245mm. The maximum crack spacing occurred in B1 (245mm) followed by B2 (216mm) B3 (210mm) and B4(209). Beams reinforced with high-yield steel bars also developed different crack patterns; different types of cracks but same maximum crack width (3mm). B5 and B8 had the same number of cracks (11), B6 and B7 had varying number of cracks of 13 and 9 respectively while crack spacing varied for all beams from 95mm to 164mm. The maximum crack spacing occurred in B7 (164mm) followed by B8 (136mm) and then B5 (129mm) with the minimum in B6 (95mm). Beams B5 to B8 had the maximum deflection ranging between 9mm to 13.7mm. The lowest maximum deflection

Table 3. Cracking and failure loads of beams

Beam ID	Theoretical cracking load P_{cr} (kN)	Experimental cracking load P'_{cr} (kN)	Theoretical failure load (P_{ult}) based on			Experimental failure load P'_{ult} (kN)	P'_{cr}/P_{cr}	P'_{ult}/P_{ult}
			Steel Yielding (kN)	Concrete crushing (kN)	Shear failure (kN)			
B1	9.8	4	34.12*	74.29	55	32	0.408	0.938
B2	9.8	4	30.34*	74.22	55	24	0.408	0.791
B3	9.8	6	31.10*	74.09	55	32	0.612	1.029
B4	9.8	2	39.75*	74.09	55	20	0.204	0.503
			Average				0.408	0.873
B5	9.3	14	43.30*	65.00	55	44	1.500	1.016
B6	9.3	10	54.30*	61.02	55	60	1.075	1.105
B7	9.3	14	57.72	74.03	55*	54	1.500	0.982
B8	9.3	14	54.46*	65.85	55	58	1.500	1.065
			Average				1.398	1.042

*Note: * Governing failure load of beam*

Table 4. Cracking mode

Beam ID	Maximum deflection at failure (mm)	Maximum cracks width at failure (mm)	Average cracks spacing (mm)	Number of cracks at failure	Types of cracks at failure
B1	6.35	4	245	4	Pure flexural cracks
B2	7	4	216	4	Pure flexural cracks
B3	7.41	4	210	5	4 Pure flexural cracks + 1 flexural-shear
B4	9.7	4	209	8	Pure flexural cracks
B5	9	3	129	11	1 horizontal splitting cracks and 10 pure flexural cracks
B6	13.7	3	95	13	2 diagonal shear cracks + 1 horizontal splitting crack + 2 flexural-shear +6 pure flexural cracks
B7	11.7	3	164	9	1 horizontal splitting crack + 2 diagonal shear cracks + 6 pure flexural cracks
B8	11.2	3	129	11	1 horizontal splitting crack + 3 flexural-shear cracks + 7 pure flexural cracks

Fig. 9. Beam 1 at failure

occurred in B5 (9mm) followed by B8 (11.2mm) and then B7 (11.7mm). The highest maximum deflection occurred in B6 (13.7mm). All beams developed different types of cracks but B6 and B7 developed more than one type of crack. Also, the crack width gradually increased based on the type of steel bar used in the concrete, with the high yield steel bars having the highest number of cracks. The high yield steel bars beams had the lowest crack width of 3mm compared with the mild steel bar beams whose maximum crack width at failure was 4mm. In addition, all the beams exhibited good cracking as a demonstration of good bonding between the reinforcing bar and the surrounding concrete with B6 having the highest number of cracks 13 followed by B5 and B8 with 11 number of cracks and then B7 with 9 number of cracks. In beams reinforced with mild steel bars, beam (B1 to B4), B4 developed the best bonding between the rebar and the concrete as was reflected in the large number of cracks developed and lowest crack spacing. For beams B5 to B8 reinforced with high-yield steel bars B6 developed the greatest bonding between the rebar and the concrete due to the largest number of cracks and crack spacing that developed on the beam [19-21].

4.5 Failure Mode

In a simply supported beam subjected to third point loading, the middle third section of the span is subjected to constant bending moment and zero shear force while the remaining spans experience bending moment and constant shear force at each load level. The first crack for all the beams specimens was found to appear within the middle third span where the maximum strain occurred. Figs. 9 to 16 show the various beams at failure.

All the eight (8) beams had the same dimensional properties namely, 1950mm long, 120mm wide and 200mm deep with an effective span of 1650mm. Beam B1 was reinforced with 10.15mm diameter mild steel bar with a yield strength of 639.68N/mm^2 from FAB with a clear concrete cover of 12mm which was the same in all the beams. The stirrup bar size and spacing were the same in all the beams 165mm centers respectively. The rebar had a rib height of 0.543mm and a rib spacing of 8.969mm. At failure the beam developed four cracks with maximum crack width of 4mm and average crack spacing of 245mm. The types of cracks observed on the beam at failure were vertical flexural cracks in the central moment sections. The first crack occurred when the beam was loaded up to a load of 4kN with a deflection of 0.04mm. The beam finally failed at a load of 52kN with a maximum deflection of 6.35mm.

Beam B2 was reinforced with a 10.59mm diameter mild steel bar with a yield strength of 454.30N/mm^2 from USC. The rebar had a rib height of 0.503mm and a rib spacing of 8.937mm. At failure, the beam developed four cracks with a maximum crack width of 4mm and average crack spacing of 216mm. The type of crack observed on the beam at failure was the flexural cracks. The first crack occurred when the beam was loaded up to 4kN with a deflection of 0.38mm. The beam finally failed at a load of 24kN with a maximum deflection of 7mm.

Beam was reinforced with an 11.08mm diameter mild steel bar with a yield strength of 424.91N/mm^2 from STS. The rebar had a rib height of 0.418mm and a rib spacing of 9.529mm. At failure, the beam developed five cracks with a maximum crack width of 4mm and average crack spacing of 210mm. The cracks consisted of 4 pure flexural cracks and one flexural shear crack. The first crack occurred when the beam was loaded up to 6kN with a deflection of 0.49mm. The beam finally failed at a load of 32kN with a maximum deflection of 7.41mm.

Fig. 10. Beam 2 at failure

Fig. 11. Beam 3 failure mode

Fig. 12. Beam 4 failure mode

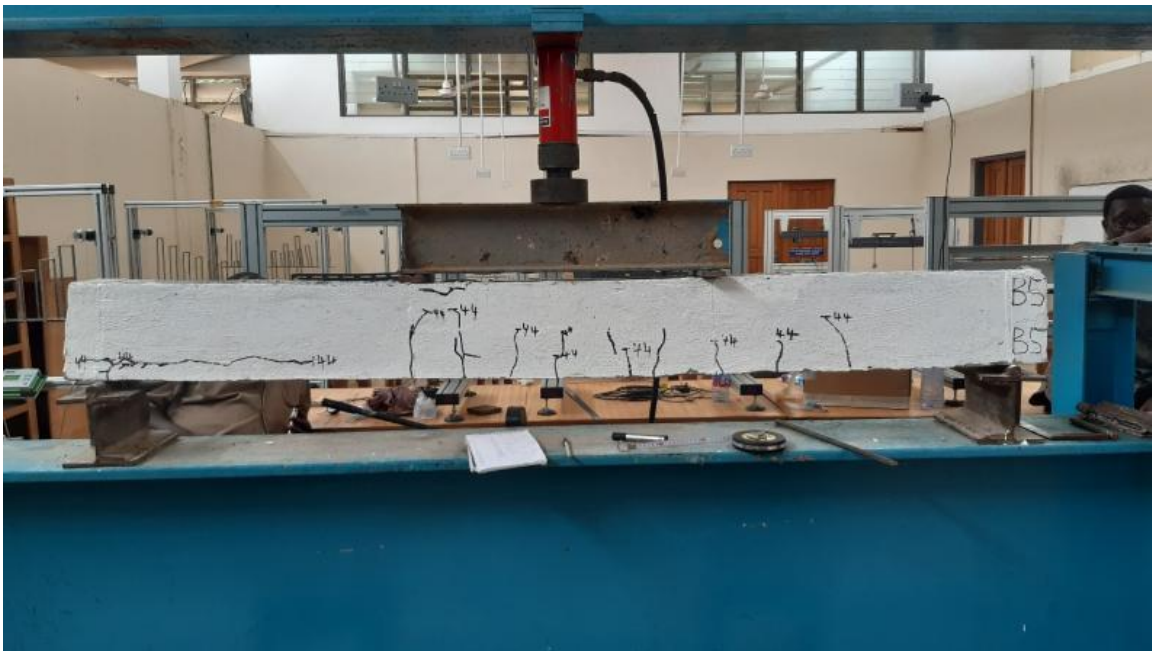

Fig. 13. Beam 5 failure mode

Beam B4 was reinforced with a 10.97mm diameter mild steel bar with a yield strength of 555.26N/mm^2 from FFL. The rebar had a rib height of 1.137mm and a rib spacing of 8.847mm. At failure, the beam developed 8 cracks with a maximum crack width of 4mm and average crack spacing of 209mm. The cracks comprised pure flexural and one flexural shear. The first crack occurred when the beam was loaded to 2kN with a deflection of 0.2mm. The beam finally failed at a load of 20kN with a maximum deflection of 9.7mm.

Beam B5 was reinforced with an 11.69mm diameter high-yield steel bar with a yield strength of 533.52N/mm^2 from STS. The rebar had a rib height of 0.553mm and a rib spacing of 8.286mm. At failure, the beam developed 11 cracks with a maximum crack width of 3mm and average crack spacing of 129mm. The types of cracks observed on the beam at failure consisted of one splitting horizontal crack and 10 flexural cracks. were horizontal and shear cracks. The splitting horizontal crack indicated shear bond failure towards the left end of the beam [22]. The first crack occurred when the beam was loaded to 14kN with a deflection of 1.02mm. The beam finally failed at a load of 44kN with a maximum deflection of 9mm.

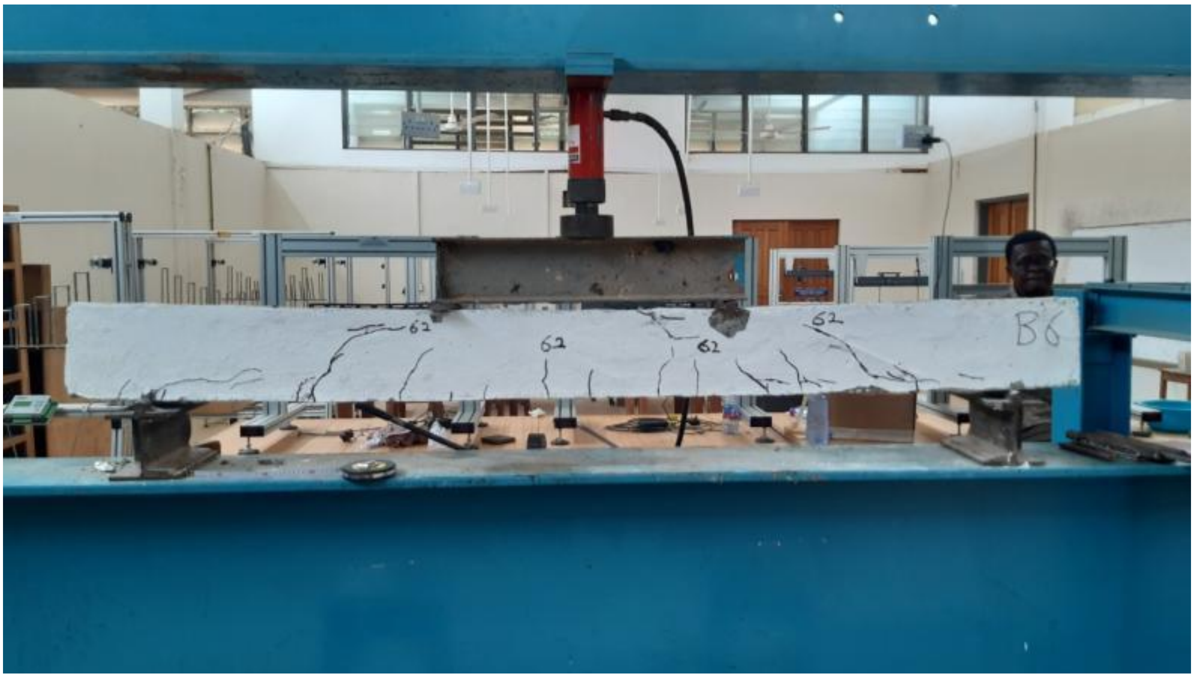

Fig. 14. Beam 6 failure mode

Fig. 15. Beam 7 failure mode

Fig. 16. Beam 8 failure mode

Beam B6 was reinforced with an 11.82mm diameter high-yield steel bar with a yield strength of 656 N/mm^2 from FAB. The rebar had a rib height of 0.834mm and a rib spacing of 8.781mm. At failure, the beam developed 13 cracks with a maximum crack width of 3mm and average crack spacing of 95mm. The types of cracks observed on the beam at failure were shear, flexural-shear, and pure flexural cracks. The first crack occurred when the beam was loaded up to 10kN with a deflection of 1mm. The beam finally failed at a load of 60kN with a maximum deflection of 13.7mm.

Beam B7 was reinforced with an 11.36mm diameter high-yield steel bar with a yield strength of 752.71N/mm^2 from USC. The rebar had a rib height of 1.038mm and a rib spacing of 7.225mm. At failure, the beam developed 9 cracks with a maximum crack width of 3mm and average crack spacing of 164mm. The types of cracks observed on the beam at failure were one splitting horizontally near the right end (indication of shear bond failure), diagonal shear cracks, and pure flexural cracks. The first crack occurred when the beam was loaded up to 14kN with a deflection of 1.2mm. The beam finally failed at a load of 54kN with a maximum deflection of 11.7mm.

Beam B8 was reinforced with a 11.68mm diameter high-yield steel bar with a yield strength of 672.47N/mm^2 from FFL. The rebar had a rib height of 0.891mm and a rib spacing of 8.953mm. At failure, the beam developed 11 cracks with a maximum crack width of 3mm and average crack spacing of 136mm. The types of cracks observed were horizontal splitting shear, flexural shear, and flexural cracks. The first crack occurred at a load of 14kN and a deflection of 1.54mm. The beam finally failed at a load of 58kN with a maximum deflection of 11.2mm [23-25].

5. CONCLUSION

Laboratory experimental tests were conducted to check the strength and deformation behavior of structural concrete beams reinforced with different steel bars available on the Ghanaian market. The investigation involved the determination of cracking loads, ultimate failure loads, load-deflection behavior, and cracking characteristics of concrete beams reinforced with steel Bars produced by different companies. It was observed that beams reinforced with high-yield steel bars performed better with regard to ultimate strength, and deformation characteristics than mild steel bars even though both types of steel are deformed (ribbed).

The observation made at the end of the analysis shows that the strength of the mild steel bar and high tensile steel bar from the manufacturers were FAB 155.87%, USC 81.72%, STS 69.96%, FFL 122.10%, STS 15.98%, FAB 42.61%, USC 63.63% and FFL 46.19% higher than the standard of 250N/mm2 for mild steel and 460N/mm2 for high tensile steel respectively.

This demonstrates that high-yield steel bars have stronger bonding properties, as seen by the beams' improved cracking behavior, as shown by a higher number of cracks and smaller fracture spacing and breadth.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Rocco CE. Effect of aggregate shape on the mechanical properties of simple concrete. Engineering Fracture Mechanics; 2009.
2. Bamigboye G, Ede AN, Egwuatu C, Jolayemi J, Olowu OA, Odewumi T. Assessment of compressive strength of concrete produced from different brands of Portland cement. Civil and Environmental Research. 2015;7.8.
3. Gündüz L. Use of quartet blends containing fly ash, scoria, perlitic pumice and cement to produce cellular hollow lightweight masonry blocks for non-load bearing walls." Construction and Building Materials. 2008;22.5:747-754.
4. Shoukry SN, William GW, Downie B, Riad MY. Effect of moisture and temperature on the mechanical properties of concrete. Construction and Building Materials. 2011;25.2:688-696.
5. Ferraris CF, Karthik HO, Russell H. The influence of mineral admixtures on the rheology of cement paste and concrete. Cement and Concrete Research. 2001;31.2:245-255.
6. Arum C, Olotuah AO. Making of strong and durable concrete. Emirates Journal for Engineering Research. 2006;11.1:25-31.
7. Merritt FS, Loftin MK, Ricketts JT. Standard handbook for civil engineers. Fourth Edition, McGraw-Hill Book Company. 1995;8.17.
8. Banini EK, Kankam CK. Strength, ductility and chemical properties of reinforcing steerl bars in Ghana’s construction industry. Journal of Materials Science Research and Review. 2022;9(4).
9. ASTM. ASTM C150: Standard specification for Portland cement. Annual Book of ASTM Standards; 2001.
10. British Standards Institution. BSI. 1377 Part 1 (1990): General Requirement and Sample Preparation. British Standard Institute, London; 1990.
11. British Standards Institution. BSI. BS 1377: Part 2: 1990: Methods of Test for Soils for Civil Engineering Purposes. British Standards Institution; 1990.
12. ASTM E8/E8M. standard Test Method for testing of metallic materials. ASTM International, West Conshohocken, PA, United States; 2016.
13. Indian standard, recommended guidelines for concrete mix design, IS 10262:1982, Bureau of India Standard, New Delhi.
14. BS EN 12390-3: Testing of hardened concrete Part 3: Compressive Strength of Test Specimens, British Standard Institution, London, UK; 2000.
15. BS EN 12390-5: Testing of hardened concrete Part 5: Flexural Strength of Test Specimens, British Standard Institution, London, UK; 2000.
16. BSI, British Standard. "8110-1: 1997. Structural use of concrete–Part 1: Code of practice for design and construction.
17. Tudagbe-Obuor P. Structural behaviour of concrete beam reinforced with local steel bars in Ghana. MSc thesis. Kwame Nkrumah University of Science and Technology, Kumasi, Ghana; 2020.
18. Al-Nasra M, Naiem MA. Shear reinforcements in the reinforced concrete beams. American Journal of Engineering Research (AJER). 2013;2.10:191-199.
19. Buabin TK, Kankam CK, Meisuh BK. Bond Strength of reinforcing Steel bars locally milled from scrap metals in Concrete prepared with palm kernel shell as coarse aggregate. International Journal of Engineering and Technical Research. 2017;7(11):26 - 31.
20. Kankam CK. Bond strength of reinforcing steel bars milled from scrap metals. Materials and Design ELSEVIER Science Ltd. 2004;25(3).
21. Kankam CK. Relationship of bond stress, steel stress and slip in reinforced concrete”. Journal of Structural Engineering ASCE. 1997;123(1).
22. Kong FK, Evans RH. Shear, bond and torsion. Reinforced and Prestressed Concrete. Springer, Boston, MA. 1987;198-247.

23. British Standard Institution. Methods for Determination of Compacting Factor, BS 1881, Part 103, British Standard Institution, London; 1983.
24. British Standard Institution. Methods for determination of compressive strength of concrete cubes BS 1881, Part 116, British Standard Institution, London; 1983.
25. Dey S, Kumar VP, Goud KR, Basha SKJ. State of the art review on self-compacting concrete using mineral admixtures. Journal of Building Pathology and Rehabilitation. 2021;6.1:1-23.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/98540