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Assessment of Deviation in Quality of Steel Reinforcing Bars Used in Some Building Sites in Cameroon

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Abstract

The present work evaluated the deviations in the quality of steel reinforcing bars in terms of markings, diameter, yield strength and ductility in order to facilitate the drawing up of a yield strength value for the Cameroon National Annex to Eurocode 2. The methodology of the work started with the collection of steel samples from various active building project sites in four different towns viz: Bamenda, Douala, Maroua and Yaoundé and testing their tensile strength and elongation using a Universal Testing Machine and also carrying out the bending test. Results show that bars without marked manufacturer's name fell all the tests. Other results show that 52% of all the steel had yield stresses below 400 Mpa and the highest deviation in the yield strengths was 22.50%. The study recommends that properly marked grade 500 steel bars should be adopted in the Cameroon national annex to Eurocode 2.

Keywords

Eurocode 2, National Annex, Reinforcement Steel, Deviations, Yield Strengths

1. Introduction

There have been many incidences of building collapse in Cameroon leading to loss of lives and property and poor quality materials amongst other causes has been identified as the major cause. Investigations conducted at the collapsed building sites have shown deficiency in quality of steel reinforcing bars [1] [2] [3]. The process of designing a building structure starts with the selection of materials based on their properties and the type of stresses to be supported. For the design of reinforced concrete structure, which is one of the most built structures around the world, the choice will fall on concrete and steel reinforcing bars. The quality of concrete and steel reinforcement bars chosen must have adequate strength to guarantee a ductile behavior expected of reinforced concrete structure, so that the structure will be safe and functional to fulfill the purpose for which it is built [4] [5] [6].

Reported cases of building cases are not only limited to Cameroon, in Nigeria, reported cases of structural failure have become very frequent, especially for buildings. Several researchers have investigated the causes of building collapse [7]. One of the most frequently adduced causes is the non-conformance of structural properties of materials used to the actual design specifications [8] [9]. [4] stressed that, in Nigeria, it has become a common practice to design concrete with the reinforcement steel's characteristic yield strength (Fy) of 410 N/mm^2 in place of BS8110 code [10] specification of 460 N/mm^2. This drop in quality itself has become a reck less habit as most contractors even provide reinforcement with characteristic yield strength lower than 410 N/mm^2. The quality of concrete and steel reinforcement bars chosen must have adequate strength to guarantee a ductile behavior expected of reinforced concrete structure, so that the structure will be safe and functional to fulfill the purpose for which it is built [9]. Steel reinforcing bars available in Nigeria's Construction Industry are obtained from both internal and external sources. The internal sources come mainly from both the indigenous major plants and the mini mills located in different parts of the country. Imported steel bars coming into Nigeria are mainly from Russia and Ukraine or imported directly by the multinational company concerned [11]. The importance of steel in structures cannot be neglected as the proper combination of both steel and concrete form the major components that ensure a structure is in perfect condition [1]. The quality of steel reinforcement used must be adequate to guarantee a ductile behavior expected of reinforced concrete structure.

Previous studies on the chemical, physical and strength characteristics of steel reinforcing materials revealed the dangers of maximizing profit at the expense of quality, a situation that poses a major challenge to the structural reliability and durability of buildings and civil infrastructure [12] [13] [14]. Hence, it is imperative to carefully study the intrinsic and mechanical properties of reinforcing steel bars in order to guarantee safe and durable constructed facilities [15] [16]. Moreover, extensive investigations on the mechanical properties of steel reinforcement produced from different manufacturing sources and processes are crucial to ascertain suitability and reliability for infrastructure development and compliance with the specifications of relevant local and international standards for building and civil engineering construction works [17] [18]. Standardization of size and tensile strengths of steel reinforcement bars should be established for different steel manufacturing industries to enhance reliable design of structures. This should be coordinated by the regulatory agency and the relevant professional bodies [19].

[19] conducted a tensile strengths tests on reinforcing steel bars in the Nige-

rian construction industry and found out that, the characteristic strength for most of the locally produced steel reinforcing bar was low as compared to the 460 N/mm^2 characteristic strength standard values specified in BS 4449, where 60% of the tested samples fell much below the would-be high yield value, rather showing similarities of mild steel bars. These authors also concluded that there is a serious concern that the steel used on sites is falling short of the design expectation because of lack of technical consciousness to test material before being used for control and compliance purposes on sites [4]. Manufacturers of steel bars seem not to follow standard procedures right from inappropriate raw material feeds to production methods and consequently produce steel bars of different qualities, some of which are substandard and still being sold on local market to build complex buildings in untested and unknown status. According to UK CARES Part 1 [20] the use of metal scraps in steel making is almost inevitable and therefore what is important is putting in place control measure to ensure quality scraps that result in quality steel bars.

In Cameroon, it is the Standards and Quality Agency (ANOR) [5] that is responsible for issuing building regulations for housing. ANOR's aspiration is to build, together with its stakeholders, a structured, efficient, competitive economy that respects the environment and the well-being of Cameroonians for an emergence by 2035. In 2018 ANOR recommended the use of Eurocode 2 in the dimensioning of reinforced concrete structures in the country. Since the country is yet to draw up a national annex to Eurocode 2, this organ has prescribed the use of the French National annexe for the meantime. The French National annex uses a yield strength value of 500 Mpa for the reinforcement steer bars, this value effectively falls within the acceptable range recommended in the Eurocode of 400 Mpa to 600 Mpa [6]. The quality of steel reinforcement in developing countries as observed by other researchers is low. Therefore, the objective of this research is to evaluate the deviation in the quality of steel reinforcing bars from the required standards.

2. Ductility, Elongation and Bending Properties

2.1. Ductility

Ductility of a material is its ability to plastically deform without fracturing when placed under a tensile stress that exceeds its yield strength. The most common measure of ductility is the percentage of change in length of a tensile sample after breaking which is generally reported as % elongation. Ductility measurement has also been categorized as uniform elongation that provides a measure of the ability of the reinforcement to deform, both elastically and plastically, before reaching its maximum strength. This further indicates that strength of the steel increases when it is loaded beyond its yield strength. **Figure 1** shows a comparison of ductile and brittle materials. Ductility property requires a slight link to brittleness which is its tendency to fail upon load application without going through plastic deformation, the material breaks or structure fails so suddenly without warning [21].

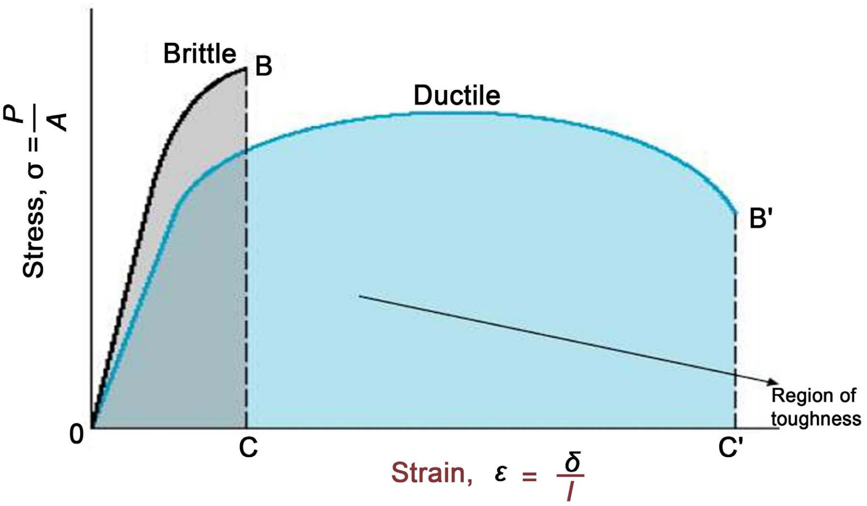

Figure 1. Comparison of ductile and brittle materials (22).

2.2. Elongation

Elongation is the increase in gauge length of a material under tension forces usually expressed as percentage of the original length, or expressed as the total elongation over a prescribed gauge length that extends across the fracture of a bar. Uniform elongation (eu) is the strain that occurs as the bar reaches its peak stress expressed as a percentage; it is the elongation at the maximum load, while total elongation (et) is the elongation of the original gauge length of specimen under tensile tension at fracture. Figure 2 Idealizes stress-strain curve with various tensile properties of a steel bar during a tensile strength test showing the region of uniform elongation.

2.3. Bending Properties

Most reinforcing bars will require to be bent before being placed into concrete, however they may fracture on bending if radius of bend is too tight. The bend and re-bend tests on steel reinforcing bars are two ways of evaluating ductility of reinforcement. The bend diameter varies with the bar diameter and in some codes varies with grade. The test specimen passes if no cracks appear on the outside of the bent portion of the bar [2]. The method of testing is that the bar being tested is supported by two pins with a distance of three times the bar diameter plus the plunger. The force is applied through a plunger placed midway between the supports.

3. Methodology

This part presents materials and methods used in this study to investigate the quality of steel reinforcing bars available in some active building sites in Cameroon and their performance. It illustrates the approach to the research giving a step-by-step procedure of the work involved right from selection of samples, preparation of specimens for testing and finally testing.

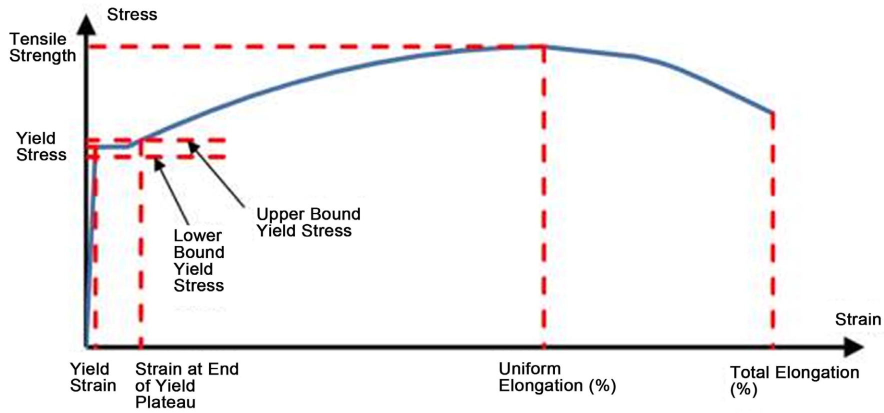

Figure 2. Idealized stress-strain curve with various tensile properties [22].

3.1. Steel Reinforcing Bars Used

The Steel reinforcing bars used in this research were deformed bars of 10 mm, 12 mm and 14 mm high yield of grade 400 N/mm^2 and grade 500 N/mm^2 collected from active building sites in Bamenda, Douala, Maroua and Yaounde.

3.2. Samples Labeling

All the samples collected have been labeled with the letter S. The letter S stands for sample number. The order of identification does not mean S1 is better than S2 , as the designations are only for identification purposes.

3.3. Samples Preparation

For the tension test, ten samples were tested for each diameter 10 m and 12 mm steel meanwhile 04 samples were tested for diameter 14 mm steel. Each sample consists of a length of 500 mm. Each sample diameter is measured in three places and the average is obtained as the diameter. Different reinforcing steel bar samples of deformed type from Bamenda, Douala, Maroua and Yaounde were collected from different active building construction and tested.

Much emphasis was vested on the possible properties that may influence the flexural performance behavior were investigated. The investigated properties include tensile strength, elongation and bending characteristics. Twenty four (24) steel samples each of 500 mm from the four (4) towns were prepared for the test of tensile strength, elongation and bending for diameter 10 mm, 12 mm and 14 mm.

3.4. Formulae Used

Each specimen was subjected to tension in accordance with the NF EN 10080 [23] provisions, and after fracture, the average Yield Strength (YS), and the Percentage Elongation (%E) were obtained according to the formulas:

$$\text{Yield Strength (N/mm}^2\text{)} = \frac{\text{Yield force}}{\text{cross sectional area of the steel}}$$

$$\text{Percentage elongation (\%)} = \frac{\text{final length} - \text{original length}}{\text{original length}}$$

4. Results and Discussions

Table 1 Present the results of investigation of the various steel used in the building sites within the areas of study. Results from the eighty sites reveal that twelve (12) different brands of reinforcement steel were used. Five were without brand names and the other six had brand names. The reinforcement grades either had grade Fe E400 or Fe E500. The diameters studied were 10 mm, 12 mm and 14 mm. The majority of the building sites (90%) used grade Fe E400 for the 10 mm steel bars and 70% used Fe E500 for the 12 mm diameter steel bars meanwhile all the sites that used diameter 14 mm bars used grade Fe E500. 100% of the sites use diameter 10 mm and 12 mm bars meanwhile only 9% use diameter 14 mm bars. The results show that many steel producers hide their identity and all the steel possesses the grade and diameter. All the building sites use diameter 10 and 12 mm steel.

Figure 3 presents the six elements of marking to be found on the steel reinforcement bar. The assessment found that all 24 bars had different markings that were not harmonized at all, while some 04 bars indicated only the bar diameter and grade such as 10 or 12, and did not indicate the manufacturer while 19 of the other samples indicated only manufacturer, diameter and grade with no country of origin, bar type and cast number. Seventy-nine (79%) of the steel bars were marked with the manufacturer's name, meanwhile zero percent (0%) of the bars marked the country of origin of the bars. This shows that any steel bar can infiltrate the country without being integrated into the construction. In all the sites 100% of the bars had marked diameters and grades. Twenty percent marked the bar type meanwhile 30% marked the cast number. To make it worse one of the sample was not labeled at all, a situation that raises a lot of concern whether regulators are in control. This shows that many steel producers hide their identity as a disguise traceability in case of failure because, of the producer's intention to produce substandard products.

Figure 4 shows the deviation of diameter of steel diameter 10 mm. In line with EN 10080:2005 requirements it specifies a tolerance of ± 6.0% for 8 mm and 10 mm bars. The deviation of diameter 10 mm steel reinforcement bars ranged from 1% to 15%. It can be seen on figure that three bars are out of the tolerance range, while 7 fall within the acceptable range. Additionally all the three bars which are out of diameter range are amongst those that did not mark the producers name on them. These results show that the steel with no marking of manufacturer's name has diameters below the tolerance range. The diameters that are much lower than standard requirements have very serious implications to design resulting from under estimation of steel area (Ast) and eventually under design. Also Short of proper diameter is an intended act of steel producers and with purpose of cost saving and loss to buyers.

Figure 5 shows the deviation of diameter of steel diameter 12 mm and 14 mm. In line with EN 10080:2005 requirements, it specifies a tolerance of ±4.5% for 12 mm bars and above. The deviation of diameter 12 mm and 14 mm steel

Table 1. Results of various steel sources and markings used on the various sites.

S/N	Company Name	Grade	Diameter	B'da	D'la	Ndere	Y'DE
				40 SITES	34 SITES	08 SITES	30 SITES
1	PROMETAL	500	10	03	13	/	08
		500	12	26	19	05	19
		500	14	04	08	/	03
		400	10	40	34	08	30
		400	12	11	19	03	11
2	AMS	400	10	09	/	/	/
		500	12	04	01	/	/
3	MUN TUT	500	12	06	03	/	01
		400	10	02	04	/	02
4	PHSM	500	12	01	/	01	/
		500	10	02	/	/	/
5	/	400	10	01	2	/	10
6	/	400	10	01	1	/	1
7	/	400	10	01	1	/	1
8	/	400	12	01	8	/	13
9	/	400	12	01	1	/	2
10	AC	500	10	03	12	/	15
		500	12	11	18	/	12
		500	14	03	5	/	02
		400	10	09	10	/	16
		400	12	04	10	/	16
11	METRO	500	12	01	03	/	04
12	METALARIQUE	500	10, 12, 14	05	04	1	09
		400	10, 12	07	11	1	18

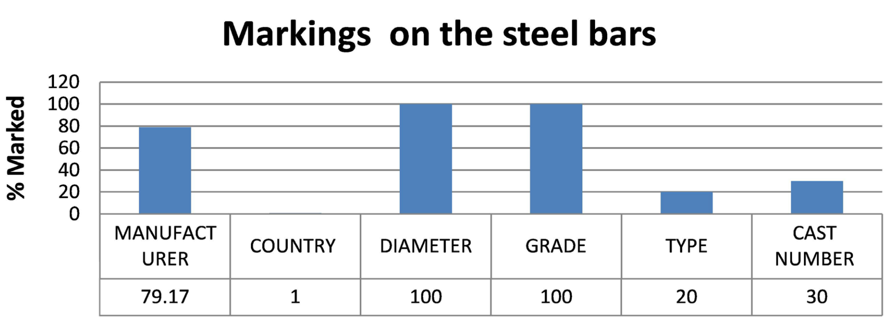

Figure 3. Percentages of each marking on steel reinforcement bars.

reinforcement bars ranged from 0% to 12.5%. It can be seen in the figure that three bars are out of the tolerance range, while 11 fall within the acceptable range. Additionally all three bars which are out of diameter range are amongst those that did not mark the producers name on them. These results show that the steel

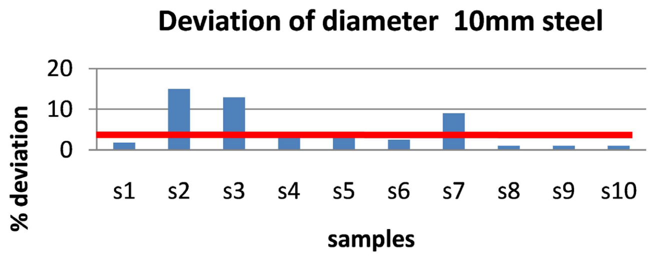

Figure 4. Percentage deviation of 10 mm diameter of steel.

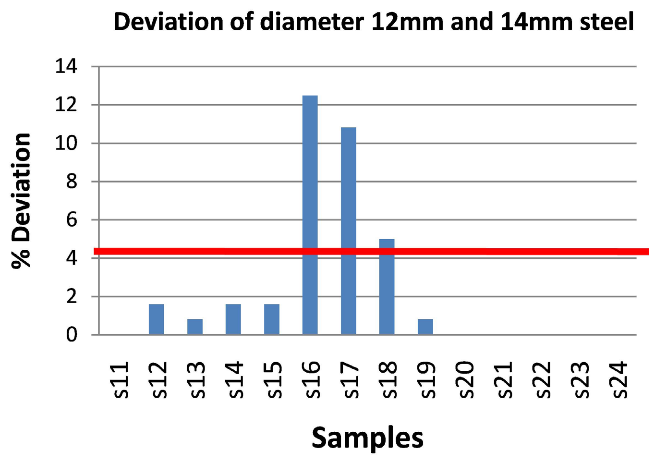

Figure 5. Percentage deviation of 12 mm and 14 mm diameter of steel.

with no marking of manufacturer's name have their diameters below the tolerance range. The diameters that is much lower than standard requirements have very serious implications to design resulting from under estimation of steel area (Ast) and eventually under design. Also Short of proper diameter is an intended act of steel producers and with purpose of cost saving and loss to buyers.

Figure 6 presents the yield strength percentages per steel diameter. It was found that for diameter 10 mm steel 70% of the yield strength was below 400 Mpa, while 20% was between 400 - 450 Mpa and only 10% went above 450 Mpa. It was also found that for diameter 12 mm steel 40% of the yield strength was below 400 Mpa, while 10% was between 400 - 450 Mpa and 50% went above 450 Mpa. It was found that for diameter 14 mm steel 0.00% of the yield strength was below 400 Mpa, while 25% was between 400 - 450 Mpa and 75% went above 450 Mpa. For all the combined results 46% of all the steel had yield stress below 400 Mpa, 16% fell between 400 - 450 Mpa and 38% of then yield stress was above 450 Mpa. These results show that the majority of steel yield strength on construction site is still below 400 Mpa (Figure 7).

Figure 8 shows Laboratory test results used to determine the percentage pass and failure rate of the materials being tested using a standard of 400 Mpa and 500 Mpa from NF EN 10080. Due to the substandard quality of reinforcement found within the country this study adopts adopt yield strength of 450 N/mm^2. The red line indicates a yield stress from 450 N/mm^2 while the green line indicates a yield stress of 400 N/mm^2. The deviation of 10 mm diameter steel varies

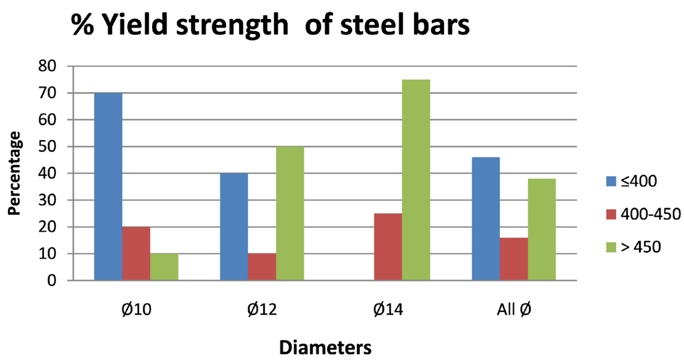

Figure 6. Percentages of yield strength per steel diameter.

Figure 7. Some broken test specimens after tensile tests.

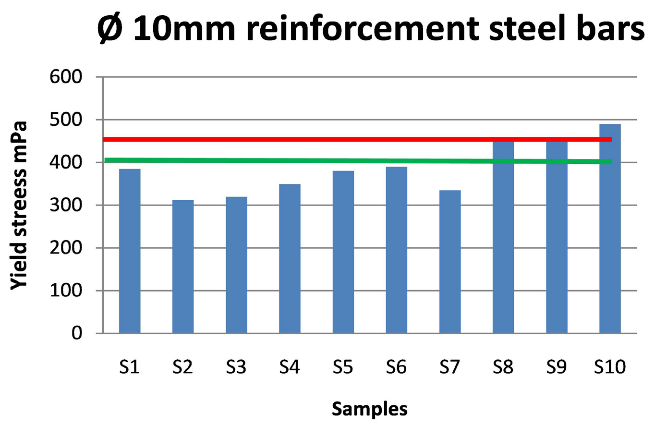

Figure 8. Yield strengths of diameter 10 mm steel.

from m 2% to 22%. Eurocode 2 recommends the use of values from 400 Mpa therefore any steel value below 400 is considered very bad. From the above figure, it is evident that only three out of the ten (10) reinforcement steel bars tested met the minimum marked grade of 400 MPa. This means 70% of total tested samples failed to meet high yield steel requirements of 400 N/mm^2. Three of the failed samples S2, S3 and S7 in minimum yield stress show deviations between 15% and 22% from the minimum required yield strength. This poses a very serious concern about strength and stability of the structures and buildings using these reinforcement bars in question. Its anticipated that observed poor yield strengths will have considerable effect flexural strength of the beam. Eurocode 2 recommends a minimum of HA400 steel to use and any value of less than 400 MPa is not accepted.

Figure 9 shows Laboratory tests used to determine the percentage pass and failure rate of the materials being tested using a standard of 400 Mpa and 500 Mpa from NF EN 10080. The red line indicates a yield stress from 450 N/mm^2 while the green line indicates a yield stress of 400 N/mm^2. The deviation of 12 mm diameter steel varies from 0.00% to 22.50%. Eurocode 2 recommends the use of values from 400 Mpa therefore any steel value below 400 is considered very as bad. From the above figure, it is evident that six out of the ten (10) reinforcement steel bars tested met the minimum marked grade of 400 MPa. This means 70% of total tested samples failed to meet high yield steel requirements of 400 N/mm^2. Two of the failed samples S16 and S17 in minimum yield stress show deviations between 15% and 22.5% from the minimum required yield strength. This poses a very serious concern on strength and stability of the structures and buildings using these reinforcement bars in question. Its anticipated that observed poor yield strengths will have considerable effect flexural strength of the beam.

Figure 10 shows Laboratory test results used to determine the percentage pass and failure rate of the materials being tested using a standard of 500 N/mm^2 from NF EN 10080. The red line indicates a yield stress from 450 N/mm^2. Eurocode 2 recommends the use of values from 400 Mpa therefore any steel value below 400 is considered very bad. The deviation of 14 mm diameter steel varies from 0.00% to 0.8%. From the above figure, it is evident that all four (4) reinforcement steel bars tested met the minimum marked grade of 400 MPa. This shows that diameter 14 mm bars are produced with greater quality than lower diameters.

Figure 11 shows yield stress results of all bars used in this study, Laboratory tests results were used to determine the percentage pass and failure rate of the materials being tested using a standard of 500 N/mm^2 from NF EN 10080. The deviation of 10 mm diameter steel varies from 0.00% to 22.50%. The red line indicates a yield stress from 450 N/mm^2 while the green line indicates a yield stress of 400 N/mm^2. From the above figure, it is evident that 13 out of the twenty-four (24) reinforcement steel bars tested met the minimum marked grade of 400 MPa. This means 52% of total tested samples failed to meet high yield steel requirements of 400 N/mm^2. This poses a very serious concern on strength and stability of the structures and buildings using these reinforcement bars in question. It is anticipated that observed poor yield strengths will have considerable effect flexural strength of the beam. Therefore Cameroon must concert to look at the value of steel yield strength to use for diamensioning.

Figure 12 above, presents results elongation of 24 samples of steel bars. EN 10080:2005 Provisions specifies that the minimum elongation should be 14%, any bar with a percentage less than the stipulated automatically fails the elongation

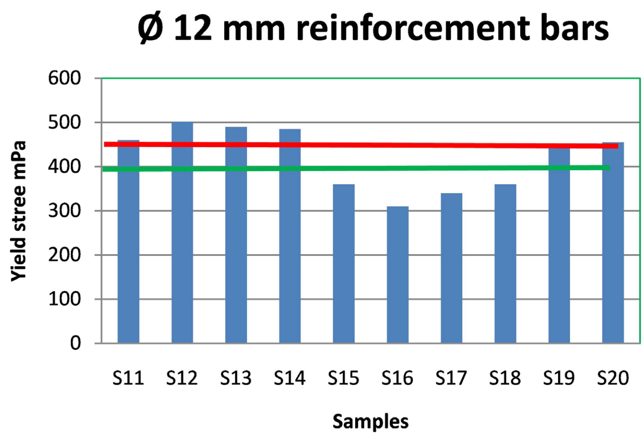

Figure 9. Yield strengths of diameter 12 mm steel.

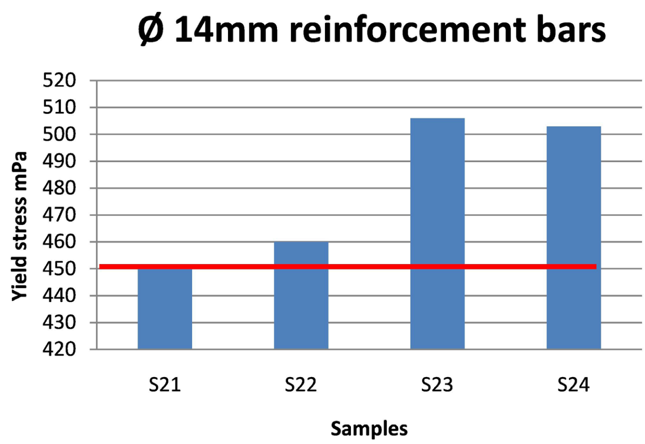

Figure 10. Yield strengths of diameter 14 mm steel.

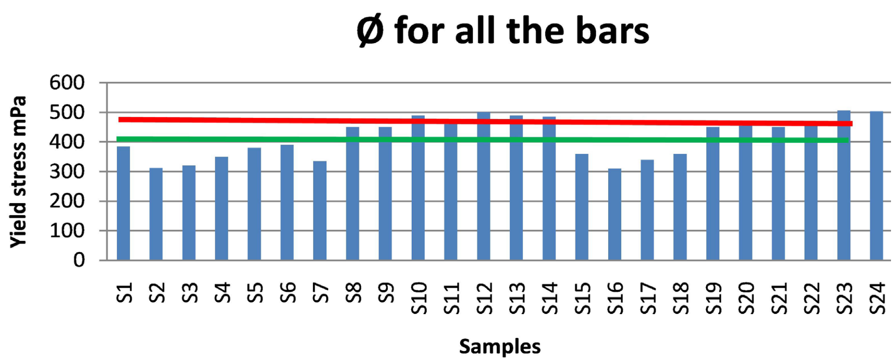

Figure 11. Yield strengths of all the diameters of steel.

test. The green line on the figure above indicates an elongation of 14% and above. It can be seen that 19 reinforcement steel bars passed the elongation test and five of the samples failed the test. From the information of marking of steel bars, all the bars that failed the elongation test did not have manufacturer name on it. These samples that failed in elongation will not give warning prior to failure due to low ductility. Lack of ductility usually leads to sudden collapse without warning.

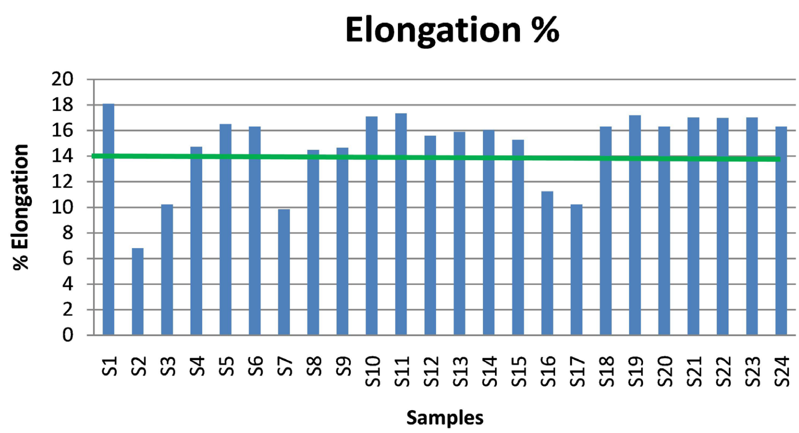

Figure 12. Yield strengths of diameter 10 mm steel.

Bending test

The bend test was carried out in accordance with the BS4449 (1997) provisions.

The bending test to verify the ductility from elongation results in 05 reinforcement samples that failed the ductility test through micro-cracks and one of the samples, sample S3 experienced total breaking (Table 2). This indicates that using such steel in construction leads to serious instability problems and structural failure without warning signs because nonductile elements fail without warning. All the other 19 samples with marked manufacturer's name, grade and diameter passed the bend test for they did not show any sign of micro cracks, nor any form of fracture or unacceptable bending deformation. This shows that refusal to have proper bar marking may be interpreted as a way to disguise traceability in case of failure because, of the producer's intention to produce substandard products.

Table 2. Bending test to verify the ductility.

S/N	specimen	Bar diameter (mm)	Former diameter (3d + 3) mm	Observations	Decision of EN 10080:2005 Provisions
1	S1	10	33	No Cracks Observed	Satisfactory
2	S2	10	33	Cracks Observed	Unsatisfactory
3	S3	10	33	Total breakage	Unsatisfactory
4	S4	10	33	No Cracks Observed	Satisfactory
5	S5	10	33	No Cracks Observed	Satisfactory
6	S6	10	33	No Cracks Observed	Satisfactory
7	S7	10	33	Cracks Observed	Unsatisfactory
8	S8	10	33	No Cracks Observed	Satisfactory
9	S9	10	33	No Cracks Observed	Satisfactory
10	S10	10	33	No Cracks Observed	Satisfactory
11	S11	10	39	No Cracks Observed	Satisfactory

Continued

12	S12	10	39	No Cracks Observed	Satisfactory
13	S13	10	39	No Cracks Observed	Satisfactory
14	S14	10	39	No Cracks Observed	Satisfactory
15	S15	10	39	No Cracks Observed	Satisfactory
16	S16	10	39	Cracks Observed	Unsatisfactory
17	S17	10	39	Cracks Observed	Unsatisfactory
18	S18	10	39	No Cracks Observed	Satisfactory
19	S19	10	39	No Cracks Observed	Satisfactory
20	S20	10	39	No Cracks Observed	Satisfactory
21	S21	14	45	No Cracks Observed	Satisfactory
22	S22	14	45	No Cracks Observed	Satisfactory
23	S23	14	45	No Cracks Observed	Satisfactory
24	S24	14	45	No Cracks Observed	Satisfactory

5. Conclusions and Recommendations

- In most of the cases the actual properties are lower than the marked properties.
- All reinforcement steel bars without manufacturers name and other markings did not meet the minimum norms requirements. From the results, failure to have a bar marking or proper bar marking is interpreted in this study as a disguise to traceability in case of failure and obviously with intention of producing substandard reinforcement bars, while short of proper diameter is an intended act of steel producers and with purpose of cost saving and loss to buyers.
- The yield strengths of the reinforcements used on various sites deviate within the ranges from 0% to 10% in grade 500 and between 2% and 22.5% in grade 400 steel.
- To ensure that the steel used remains within the minimum range of Eurocode 2, a yield strength of 500 should be adopted. The study recommends that properly marked grade 500 steel should be adopted in Cameroon national annex. Any attempt to continue using grade 400 steel is dangerous because any lower value deviation in the yield stress of HA400 immediately falls out of the minimum of HA400 recommended in Eurocode 2.
- To ensure that the steel grade is maintained the deviation maximum value of 22.5 should be given due attention while drawing up the national annex.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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