Mechanical Characteristics Test of Concrete Steel Bars Available in Côte d'Ivoire

Conand Honoré Kouakou* , **Ibrahima Bakayoko, Mamery Adama Serifou, Edjikémé Emeruwa**

Université Félix Houphouët-Boigny, UFR des Sciences de la Terre et des Ressources Minières, Laboratoire des Sciences du sol, de l'eau et de Géomatériaux, Abidjan, Côte d'Ivoire
Email: *honore_kouakou2@yahoo.fr, bakib8@gmail.com, smadamsdedjen@yahoo.fr, edijksmat@yahoo.com

Abstract

Buildings collapse has now become a recurrent phenomenon in Côte d'Ivoire. Therefore, this study was conducted to find out the reasons for these disasters, and check in particular to the extent, and concrete steel bars produced in Côte d'Ivoire and used in buildings' structures are involved. Samples having 6, 8, 10 and 12 mm in diameter steel taken from the five (5) major manufacturers or suppliers of the Ivorian market were subjected to physical, chemical and mechanical tests to determine their performance. A comparison of these results with the NF EN 10080 and NF A35 080-1 standards made it possible to calculate the probability to have out-of-standard products in a structure. Pieces having 60 cm were cut from three bars of the same thickness and then subjected to tests. These are the chemical test by optical emission spectrometer, physical tests by caliper measurements of diameter, height of bolts and ribs and calculation of linear mass, and tensile tests with the help of hydraulic press. These tests made it possible to determine the characteristics of the steel bars. Then, these characteristics were compared with standards NF EN 10080 and NF A35 080-1, in order to judge their conformity for construction. Finally, the likelihood of having non-standard steel bars in a structure is calculated. These tests indicate that the relative surfaces of the bolts of the various bars HA6, HA8, HA10 and HA12 vary from 0.146 to 0.323 respectively; 0.120 to 0.312; 0.101 to 0, 297 and 0.142 to 0.482. Likewise, their calculated linear masses of these bars are respectively between 28.3 mm^2 and 222 g/m; 50.3 mm^2 and 395 g/m; 78.5 mm^2 and 617 g/m; and 113 mm^2 and 888 g/m. In addition, their yield strengths and elongations at break vary from 344 MPa to 582 MPa and from 0.2% to 15% respectively. According to analysis of these results, 100% of steel bars would lead to a steel-concrete adhesion that complies with standard requirements and 100% have a linear mass or density lower than the standard. Similarly, on the mechanical aspect, 70% of steel bars have a yield strength lower than 400 MPa and 95% have an inappropriate ductility. Non-compliance with cross-sections, inadequate performance and

non-compliance with the chemical composition of steel bars expose buildings to low durability and even sudden collapse of their structural elements. Concrete steel bars contribute a great deal to failures found in buildings.

Keywords

Building Collapse, Steel Bars, Standards, Adhesion, Mechanical Performance

1. Introduction

Over the last ten years, the construction industry in Côte d'Ivoire has experienced a real dynamism. Unfortunately, this growth in activity has been associated with a series of disasters and building collapses in Abidjan. This phenomenon of building collapses has become recurrent and disturbing, especially with the high number of casualties.

It is unbelievable that buildings keep collapsing, more precisely ordinary buildings (at most four-storey buildings) despite all the normative requirements that govern the construction industry and the large number of engineers. However, numerous failures brought about either in the supporting ground, in achieving the structure or in the quality of building materials can lead to this situation. Indeed, designing a stable and long-lasting structure requires a robust structure (framework) generally made of steel bars containing concrete of which quality is a function to the performance of its constituent materials. Consequently, this research aims to understand the reasons for buildings' collapse on the ground of the performance analysis of steel bars produced by companies in Côte d'Ivoire.

Steel bars are incorporated into concrete to make up for the concrete's tensile strength deficiency [1]. The construction industry in Abidjan has so far increased the number of steel bar manufacturers or importers to more than a dozen [2], five of which are actually in operation. The most commonly used concrete steel bars are of diameters 6, 8, 10 and 12 mm, and they must comply with the requirements of NF EN 10080 and NF A35 080-1 standards [3] [4]. Thus, this article helped finding out from various tests, the geometrical, physical, chemical and mechanical characteristics of concrete steel bars from these five manufacturers. The results obtained were compared to prescribed standards in order to assess the probability that a failing bar may be found in a building's structure.

2. Equipment and Methods

2.1. Equipment

The equipment consists of steel bars of diameter 6, 8, 10 and 12 mm, acquired from the five concrete steel manufacturers known in Côte d'Ivoire. The bars are 12 m long bolts steel bars.

2.2. Methods

2.2.1. Sampling

To test the mechanical performance of concrete steel bars produced by a company, we randomly select three 12 m long bars with diameters of 6; 8; 10 and 12 mm. Then each bar is cut into several 60 cm pieces (samples). The same is repeatedly done for products from the five identified companies. Finally, three samples of diameter 6, 8, 10 and 12 mm per company from different steel bars of same diameter are used for each test. Table 1 shows the total number of samples as per diameter and per company for a given test.

2.2.2. Experimental Techniques

1) Chemical analysis of bars

The chemical analysis of bars was carried out with a Spectromax spark source optical emission spectrometer. Since the measuring port could only accommodate samples having 14 mm in diameter at least, the analysis was carried out on special steel bars supplied by the 5 manufacturers (HA14 or HA16).

This spectrometer makes it possible to determine the concentration of thirty-two (32) chemical elements as well as the carbon equivalent value. However, control indicators according to the NF EN 10080 [3] standard are only related to the elements: C, Mn, Cr, Mo, Ni, Cu, S, P and N as well as C_{eq} (the equivalent carbon). The C_{eq} value is given by the formula:

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}. \tag{1}$$

2) Geometric measurements

To identify the geometrical parameters of steel bars, a 30 cm caliper with a 0.02 mm precision was used. It was used to measure the height of bolts and ribs, the diameter of a bar and the spacing between bolts in accordance with NF EN 10080 [3] standard (Figure 1). The number of ribs and bolts slant were also determined (Figure 1). In addition to these parameters, the bolt area proportion (PSrv), the relative bolt area (Srv) and the linear mass of bars (Ml) are calculated from the following formulas.

h: bolts height; c: bolts spacing; β: bolts slant; α: bolts flanks slant; d: nominal bar diameter

Table 1. Number of samples as per company and per diameter for a test.

Steel bars diameter (mm)	Companies					Total
	FA1	FA2	FA3	FA4	FA5	
6	3	3	3	3	3	15
8	3	3	3	3	3	15
10	3	3	3	3	3	15
12	3	3	3	3	3	15
Total	12	12	12	12	12	60

FAx: Manufacturern°x.
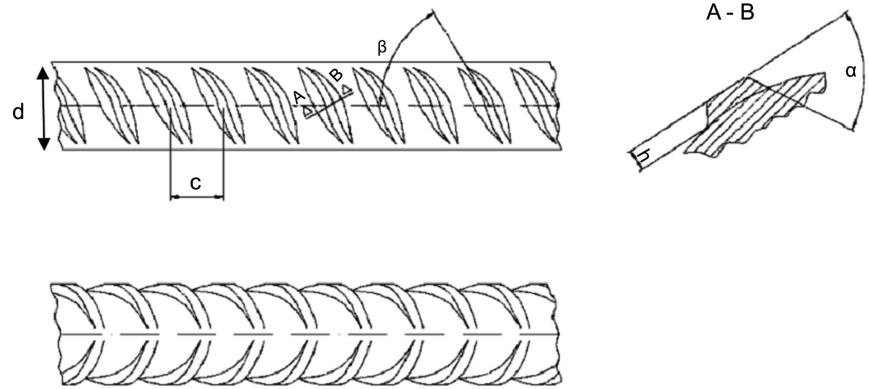
Figure 1. Descriptive elements of a concrete steel bar.

$$\text{Srv} = kF_R \sin\frac{\beta}{\pi dc} \tag{2}$$

$$\text{Ml} = \frac{m}{l} \tag{3}$$

with k: number of oblique or transversal bolts rows; F_R: area of the longitudinal cross-section of a rib along its axis

3) Mechanical tensile test

The tensile strength of steel bar samples is determined using a TESTWELL tensile press associated with a HOYTOM type computer device. This machine, which operates at constant load, allows to continuously record the force and the displacement undergone by the sample and then calculate the tensile strength (σ_T), the strain (ε_T) and the stress coefficient (Z) from the formulas:

$$\sigma_T = \frac{F}{S_0} \tag{4}$$

$$\varepsilon_T = \frac{l_f - l_0}{l_0} \tag{5}$$

$$Z = \frac{S_0 - S_f}{S_0} \tag{6}$$

with l_0 and l_f: initial and final length; S_0 and S_f: initial and final section; F: applied force. These values made it possible to draw the stress-strain curves in tension from which the following parameters are determined:

- the yield strength or modulus of elasticity (Re);
- the maximum tensile strength (Rm);
- the ratio Rm/Re;
- the elongation at break (A%).

2.2.3. Data Processing

Data were processed according to the diagram in **Figure 2**. The test values obtained from samples taken from the different manufacturers are compared with the threshold values set by the standards. If the average value is below or above the threshold value of 5%, the sample is defective, otherwise it is of good quality.
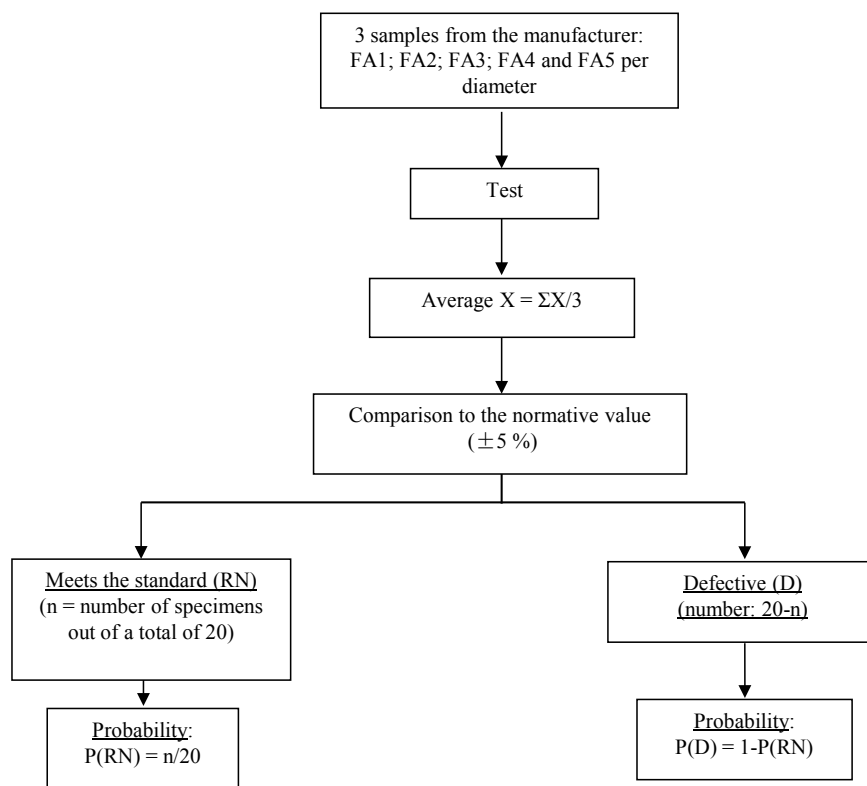
Figure 2. Data processing diagram.

3. Results and Discussion

3.1. Physical and Geometrical Characteristics

The average values of physical and geometrical characteristics are summarized in Table 2.

3.1.1. Nominal Diameter and Linear Mass

The theoretical cross-sections and linear masses for steel bar types (HA6, HA8, HA10 and HA12) are 28.3 mm^2 and 222 g/m; 50.3 mm^2 and 395 g/m; 78.5 mm^2 and 617 g/m; and 113 mm^2 and 888 g/m, respectively. A comparison of the sectional area and linear mass values obtained for the different steel bar types from the various companies generally shows deficits of up to 29% and 28% respectively of the theoretical sectional area and mass (Table 2). These discrepancies can be explained by the desire for manufacturers to make more profit or by problems in bars shaping process.

Steel bars HA12 and HA10 for FA1 and HA10 and HA8 for FA3 have diameters equal to or greater than the nominal diameters because their sectional deviations have zero or positive values. Thus, 10% of the bars studied have diameters equal to the nominal diameters and 80% of the steel bars produced have cross-sections lower than the nominal values. This is likely to affect the strength of the structural elements (foundations, columns, beams and floors), as the dimensioning calculations carried out by the Ivorian engineering offices are based on these nominal diameters. This results in a low reinforcement and leads to the

Table 2. Physical and geometrical characteristics of steel bars.

Steel type	Manufacturer	Section obtained	Es	Ml	Emt	hv (mm)	Ev (mm)	Iv (°)	hn (mm)	PSrv (%)	Srv
	FA1	21.2	−25.0%	168	−24.5%	0.1	4.81	60	0.3	42	0.146
	FA2	23.8	−16.0%	159	−28.3%	0.9	2.72	60	0.5	51	0.323
HA6	FA3	23.8	−16.0%	172	−22.7%	0.6	4.44	50	0.2	39	0.213
	FA4	23.8	−16.0%	172	−22.7%	0.6	4.44	60	0.2	47	0.256
	FA5	25.5	−9.8%	170	−23.4%	0.7	4.26	50	0.4	39	0.307
	FA1	49.0	−2.6%	304	−23.0%	0.1	5.68	55	0.6	43	0.120
	FA2	40.7	−19.1%	274	−30.6%	1	4.92	60	0.5	55	0.237
HA8	FA3	55.4	10.2%	358	−9.3%	0.7	6.11	65	0.9	26	0.153
	FA4	44.2	−12.2%	299	−24.3%	0.1	6.19	60	0.4	73	0.312
	FA5	36.3	−27.8%	296	−25.1%	0.1	4.68	50	0.5	54	0.216
	FA1	78.5	0.1%	470	−23.8%	0.2	6.48	55	0.5	36	0.101
	FA2	67.9	−13.5%	466	−24.5%	0.2	5.55	60	0.6	39	0.297
HA10	FA3	80.1	2.1%	489	−20.7%	0.3	7.82	65	0.4	45	0.190
	FA4	65.0	−17.1%	479	−22.3%	0.1	7.47	60	0.5	34	0.177
	FA5	58.1	−26.0%	463	−24.9%	0.1	6.09	50	0.5	43	0.226
	FA1	113.1	0.1%	678	−23.6%	0.5	7.76	75	1.2	42	0.144
	FA2	95.9	−15.1%	647	−27.2%	1.7	6.55	60	0.3	42	0.298
HA12	FA3	109.4	−3.2%	666	−25.0%	0.1	6.85	65	0.8	34	0.142
	FA4	96.8	−14.4	678	−23.6%	0.1	6.49	60	0.6	68	0.482
	FA5	79.2	−29.9	658	−26.0%	0.1	8.30	50	0.9	71	0.239

Es: Deviation from section; Ml: Linear mass obtained; Emt: Deviation from theoretical mass; hv: Height of bolts; Ev: Spacing of bolts; Iv: Slant of bolts; hn: Height of ribs; Srv: Relative area of bolts; PSrv: Proportion of bolt area.

appearance of damaging cracks on poorly dimensioned structural elements. These cracks reflecting a lack of solidity can affect other elements such as masonry supported by poorly calculated beams [5]. On the other hand, the importance of steel bars' diameters lead to non-compliance with structural provisions, especially bars embedding and spacing between them into concrete. This reinforcement densification hinders large aggregates placement during concreting, which causes segregation. The corollary is an increase in porosity, and therefore a decrease in the mechanical strength and durability of reinforced concrete and causing the corrosion of reinforcements [6].

According to NF EN 10080 and NF A35 080-1 standards [3] [4], permissible linear mass deviations are ±4.5% for bars with a diameter greater than 8 mm and ±6% for bars with a diameter less than or equal to 8 mm. All characterized samples have linear mass deviations beyond this tolerance. Thus, 100% of steel bars produced do not meet the linear mass requirements prescribed by these standards.

3.1.2. Characterization of Adhesion between Steel Bars and Concrete

According to Eurocode 2 [7], which deals with the calculation rules for rein-

forced concrete structures, and Leonhardt and Momming in Makni and Daoud [8], the relevant parameter for assessing the quality of steel bars adhesion is the relative surface area of bolts. This consideration is confirmed by Zuo and Darwin [9] who, in a study, observed that when the relative surface area of a bar decreases from 0.085 to 0.11, the measured slippage for adhesion stress decreases by 50% to 70%. Moreover, the NF A35 080-1 standard [4] assesses the adhesion of a steel bar from bolts relative surface. For this standard, adhesion is acceptable when the relative surface is greater than the limit value of 0.035 for HA6 and 0.04 for the three other types of bar. In addition, bolts heights and spacings, and the heights of ribs shall be included respectively:

- for HA6, between 0.18 and 0.9 mm; 0.4 and 7.2 mm; 0 and 0.9 mm;
- for HA8, between 0.24 and 1.2 mm; 3.2 and 9.6 mm; 0 and 1.2 mm;
- for HA10, 0.3 to 1.5 mm; 4 to 12 mm; 0 to 1.5 mm;
- for HA 12, between 0.36 and 1.8 mm; 4.8 and 14.4 mm; 0 and 1.8 mm.

The measurements made on steel bars from different manufacturers contained in Table 2 indicate that whatever the manufacturer and steel type, the values of bolts relative surfaces are above the limit values. All these steel bars would thus have good adhesion to concrete. In addition, all the manufacturers meet the requirements of this standard for bolts relative surface area and slant. On the other hand, about other parameters (height and spacing of bolts, and ribs height), the manufacturers who respected the guidelines prescribed by this standard are the ones for bars type HA6, FA3, FA4 and FA5, for the HA8, FA2 and FA3, for the HA10, FA3 and HA12, FA1 and FA2.

In addition, the NF EN 10080 standard [3] assesses the adhesion of a steel bar from bolts surfaces proportions. The adhesion is acceptable when bolts relative surfaces proportion reaches the minimum value of 75%. The results obtained on the different tested samples (Table 2) indicate that, whatever the bar type, bolts relative surfaces proportions are below this limit and would therefore be poor.

Thus, considering bars adhesion, 100% of the characterized steel bars are in compliance with NF A35 080-1 standard [4]. On the other hand, compared to NF EN 10080 standard [3], none (0%) of the bars are good.

3.2. Chemical Composition of Steel Bars

The main chemical characteristics of the studied steel bars are listed in Table 3.

The table shows that the main element of steel, Fe, has contents between 97.7 and 99.3%. The other elements, notably C, S, P, N and Cu, have contents ranging from 0.0679% to 0.243%; 0.0143% to 0.0392%; 0.0291% to 0.0412%; 0% to 0.0405% and 0.0092% to 0.188%, respectively. The carbon contents below 2% confirm that the studied bars are made of steel, since according to literature, steel is a metal alloy consisting mainly of iron and carbon in proportions between 0.02% and 2%. Furthermore, Roy and Blin-Lacroix [10] classify steel into the following categories: extra-mild, mild, mid-mild, mid-hard, hard and extra-hard for carbon contents of 0.05% to 0.15%; 0.15% to 0.2%; 0.2% to 0.3%; 0.3% to 0.6%; 0.6% to 0.75% and 0.75% to 1.2%, respectively. According to this

Table 3. Chemical composition of concrete steel bars.

Chemical elements	FA1	FA2	FA3	FA4	FA5	Maximum values according to NF EN 10080 Standard
Iron (Fe)	97.7	99.3	98.3	98.3	99	-
Carbon (C)	0.194	0.0679	0.218	0.243	0.0931	**0.24**
Sulphur (S)	0.0154	0.0239	0.039	0.0392	0.0143	**0.055**
Phosphorus (P)	0.0299	0.0258	0.0412	0.0386	0.0291	**0.055**
Nitrogen (N)	0.0193	0.0022	0.0405	<0.001	0.0026	**0.014**
Copper (Cu)	0.014	0.0092	0.144	0.188	0.0115	**0.85**
Manganese (Mn)	1.36	0.412	0.491	0.546	0.332	-
Chromium (Cr)	0.0667	0.0187	0.266	0.18	0.31	-
Silicon (Si)	0.405	0.049	0.216	0.202	0.134	-
Vanadium (V)	0.124	<0.00050	0.0038	0.0019	0.0016	-
Nickel (Ni)	0.0148	0.0081	0.0733	0.0821	0.0082	-
Aluminium (Al)	0.0026	0.0009	0.0021	0.0024	0.002	-
Molybdenum (Mo)	0.0057	0.0034	0.0322	0.017	0.0031	-
Carbon equivalent (C_{eq})	0.462	0.142	0.374	0.392	0.213	**0.52**
Chromium equivalent (Cr_{eq})	1.2874	0.1691	0.9462	0.803	0.7151	-

classification, manufacturers FA3 and FA4 produce semi-soft steels, manufacturers FA2 and FA5 produce extra-soft, and manufacturer FA1 produces soft. According to these authors, only mild, mid-mild and mid-hard steels are suitable for the reinforcement of reinforced concrete. Thus, two manufacturers (40%) have steel that do not comply with this recommendation.

In addition, depending on a specific application, chromium is added to steel at levels ranging from 0.25% to 30% to improve its mechanical properties and corrosion resistance [11]. Precisely between 0.5% and 9%, chromium increases the harden ability and retention of mechanical properties at temperatures above room temperature, and at higher contents, at least 12%, it improves corrosion and oxidation resistance. Thus, steel is considered stainless when its chromium content is greater than 13% by mass [12]. All characterized bars have a chromium content ranging from 0.01% to 0.31%. These are oxidizable steel and therefore likely undergo corrosion under favorable conditions.

Moreover, according to NF EN 10080 standard [3], a quality concrete steel bar must have a chemical composition close to that given in Table 3. According to the results obtained (Table 3), manufacturers FA2, FA4 and FA5 produce steel that comply with the chemical requirements of this standard. Thus, 40% of steel bars are of poor quality, as both manufacturers have products with nitrogen contents above the limit of 0.14% imposed. Indeed, an increase in nitrogen content leads to a decrease in the steel ductility [13] [14] and therefore a possible tendency to break sharply. However, the standard specifies that this nitrogen

limit may be exceeded in the presence of fixing elements. According to Montagnon and Moraux [15], the nitrogen-fixing elements are titanium and aluminum, but the nitrogen content is much higher than that of these two nitrurigenic elements. Thus, their effect could be neglected.

3.3. Mechanical Properties under Tensile Test

The tensile tests carried out on the various samples resulted in stress-strain curves that are grouped into two sets according to curves shape. **Figure 3** shows a copy of these two shape types. They correspond to hot-rolled steel bars (**Figure 3(a)**) and cold-rolled steel bars (**Figure 3(b)**). Hot-rolled bars have higher elongation than cold-rolled bars. FA1 and FA3 produce hot-rolled bars, while FA2, FA4 and FA5 produce cold-rolled bars.

Table 4 displays the actual values of the apparent yield strength (R_{eact}), the yield strength (Re), the tensile strength (Rm), the elongation at break (A) and the stress coefficient (Z).

Eurocode 2 and BAEL 91 [7] [16] recommend a minimum yield strength of 400 MPa for concrete steel bars. Bars of type HA6 of FA1, FA2 and FA3, type HA8 of FA3 and FA4, and type HA12 of FA1 and FA2 have yield strengths above this minimum value. The yield strength is an intrinsic parameter of the product, its variation from one bar to another depends on the chemical composition and/or the structure of steel bars, and therefore on their shaping.

Table 4 displays the values of bars apparent yield strength. Comparison of these values with the minimum yield strength defined by the standards indicates that bars from FA1 and FA3 of HA10 type and from FA1 of HA12 type have
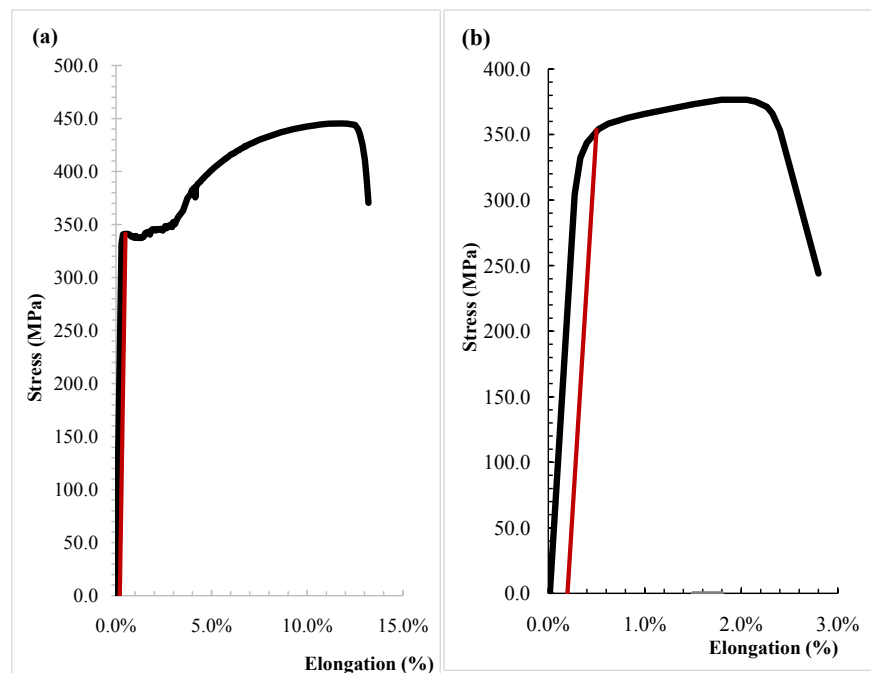

Figure 3. Stress-strain curve of steel bars under tensile test (a) Cold-rolled bar; (b) Hot-rolled bar.

Table 4. Tensile strength.

Steel Type	Manufacturer	Re_{act} (MPa)	Re_{act}/Re_{nom}	Re (MPa)	Rm (MPa)	Rm/Re	A (%)	Z (%)
	FA1	542	1.36	406	406	1.00	2.5	43.8
	FA2	505	1.26	424	424	1.00	2.5	53.5
HA6	FA3	474	1.19	398	398	1.00	0.9	44.4
	FA4	474	1.19	398	398	1.00	0.9	44.4
	FA5	470	1.18	424	433	1.02	0.2	54.4
	FA1	408	1.02	398	492	1.24	9.3	47.0
	FA2	467	1.17	378	378	1.00	1.5	61.8
HA8	FA3	447	1.12	492	582	1.18	10.8	63.1
	FA4	464	1.16	408	422	1.04	3.5	65.6
	FA5	523	1.31	378	378	1.00	1.2	44.8
	FA1	344	0.85	344	449	1.31	11.9	60.3
	FA2	427	1.07	369	384	1.04	2.5	56.3
HA10	FA3	378	0.95	385	489	1.27	8.0	52.0
	FA4	431	1.08	357	376	1.05	1.5	60.8
	FA5	521	1.30	385	392	1.02	3.0	45.5
	FA1	363	0.91	363	485	1.34	15.0	59.9
	FA2	467	1.17	396	405	1.02	1.8	57.5
HA12	FA3	505	1.26	489	573	1.17	5.5	61.7
	FA4	429	1.07	367	387	1.05	7.3	56.7
	FA5	534	1.34	374	389	1.04	3.6	48.6

$Re_{act} < Re_{nom}$. These three bars are of poor quality. This is due to their structure, which is also a function of the rolling pressure. According to Ashby and Jones [17], this pressure increases linearly from the edge to the core of bars. Indeed, for a bar with a large diameter, it would require a significant forming pressure to reach the right structures, thus the optimal value of the apparent yield strength.

The value of the Rm/Re ratio is used to determine the steel grade. According to Eurocode 2 and NF A35 080-1 standards [4] [7], grades A, B and C must have minimum Rm/Re values of 1.05, 1.08 and 1.15 respectively. For only grade C, there is a maximum value of 1.35. According to this classification, 10% of the studied bars could be grade A; 30% grade C and 60% are non-compliant because they do not meet the requirements of the least stringent grade (1.05). None of the HA6 bars meet this requirement. It should be noted that the grade commonly used is grade A. Class B and C products are recommended for bridges [7] and seismic constructions [18].

For elongation at break, Husson and OCAB [19] [20] recommend minimum values of 14% for 400 MPa steels. Thus, only 5% of bars meet this recommendation, the others have very low or almost zero elongations.

With respect to the stress-strain coefficient, 70% of the bars have formally

mixed fractures and 30% have mixed or ductile type breaks, according to the classification made by Dénéréaz [21].

This mechanical analysis showed that none of the characterized steel bars meets all the normative requirements and technical recommendations. Thus, 100% of the products are rigorously evaluated as mechanically non-compliant. It should also be noted that some of the values obtained are to be worried about regarding their structures solidity, being agreed that the structural calculations are made on the basis of BAEL 91 or Eurocode 2 [7] [16] specific normative values.

4. Conclusions

This study made it possible to take stock or make inventory of fixture of the quality of concrete steels produced and sold in Côte d'Ivoire. Samples of the most commonly used concrete steel bars in the building industry were subjected to physical, mechanical and chemical characterizations. We can make the following conclusions:

- 100% and 80% of steel commercially available in Abidjan have, respectively, a linear mass that does not comply with the standards requirements and a diameter that is smaller than the nominal ones.
- 100% and 55% of steel have low adhesion to concrete, because their bolts height and surface area do not reach the minimum value prescribed by the standards.
- the mechanical characteristics of most steel do not meet the normative requirements of high adhesion class Fe 400 bars. Non-compliant products are 70% for yield strength, 75% for tensile strength and 95% for elongation. In addition, two (2) manufacturers produce hot-rolled steel bars and the other three (3) produce cold-rolled steel bars.
- 40% of steel is extra-mild steels and 60% is mild steel. These steel bars have poor corrosion resistance.

All the characterized steel bars are not in compliance with the normative requirements. Some of the values obtained are to be worried about regarding their structures solidity, being agreed that the structural calculations are made on the basis of specific normative values, either BAEL 91 or Eurocode 2. All these failures are likely to contribute a great deal in the appearance of cracks on walls, and especially in the sudden collapse of some buildings.

Also to limit the damage caused by the use of these poor quality products, regular quality checks and sanctions that may go up to withdrawal business authorization should be highly considered. On the other hand, to guarantee the quality of the works, a study of the performance (bending resistance, porosity, adhesion) of a concrete beam containing a combination of steel bars conforming to standards and non-standard should be carried out.

Conflicts of Interest

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

References

[1] Fall, M., Diagne, I., Niang, F., Mandiang, Y., Gaye, S. and Sissoko, G. (2010) Caractérisation qualitative des aciers doux produits par l'industrie sidérurgique sénégalaise. *Journal des Sciences*, **10**, 13-22.

[2] Goafricaonline (2019) Industries métallurgiques de Côte d'Ivoire.
http://www.goafricaonline.com/ci/annuaire/societes-metallurgie?p=1

[3] NF EN 10080 (2005) Aciers pour l'armature du béton—Aciers soudables pour béton armé.

[4] NF A35 080-1 (2013) Aciers pour béton armé. Aciers soudables—Partie 1: Barres et couronnes.

[5] Philipparie, P. (2011) La pathologie des façades: Diagnostic, réparations et prévention. Éditions CSTB, Nancy.

[6] Chaib, S. and Lassoued, R. (2016) Apport des fibres sur les caractéristiques du béton autoplaçant durci. *Troisième conférence internationale sur l'énergie, les matériaux, l'énergétique appliquée et la pollution*, Constantine, 278-283.

[7] Eurocode 2 (2005) calcul des structures en béton—Partie 1-1: Règles générales et règles pour les bâtiments.

[8] Makni, M. and Daoud, A. (2012) Caractérisation géométrique des barres d'acier pour béton armé par méthodes expérimentales. *Annales du bâtiment et des travaux publics*, 47-52.

[9] Zuo, J. and Darwin, D. (2000) Adhesion Slip of High Relative Rib Area Bars under Cyclic Loading. *ACI Structural Journal*, **97**, 331-334. https://doi.org/10.14359/864

[10] Roy, J.-P. and Blin-Lacroix, J.-C. (1998) Le dictionnaire professionnel du BTP. Éditions Eyrolles, Paris.

[11] Berger, P. (2019) Influence des éléments d'addition.
http://philippe.berger2.free.fr/productique/ressources/metallurgie/trait_thermic/influence_des_elements_d.htm

[12] Salazar, D. (2008) Étude de partage de la plasticité cyclique d'un acier duplex par microscopie à force atomique. Thèse de doctorat, université des Sciences et Technologie de Lille.

[13] Vogt, J.-B. (1982) Influence de la teneur en azote sur le comportement en fatigue oligocyclique d'aciers inoxydables austeriitiques type 18-1 2 hypertrempes. Thèses de doctorat, université de Lille.

[14] Hélie, M. (2019) Matériaux métalliques: Phénomènes de corrosion, support de cours—Université d'Évry—Val d'Essonne (France), 10-13.
https://www.cefracor.org/fr/file/44/download?token=KSUuMJeZ

[15] Montagnon, J. and Moraux, J.-V. (2000) Acier inoxydable sans nickel pour applications biomédicales, Fascicule de brevet européen.

[16] BAEL 91 (2000) Règles techniques de conception et de calcul des ouvrages et constructions en béton armé, suivant la méthode des états limite.

[17] Ashby, M.F. and Jones, D.R.H. (2014) Matériaux: Propriétés, applications et conception. Édition DUNOD, Belgique.

[18] Eurocode 8 (2005) Calcul des structures pour leur résistance aux séismes—Partie 1: Règles générales, actions sismiques et règles pour les bâtiments.

[19] Husson, J.-M. (2006) Études de structure en béton BAEL 91 révisé 99—BTS, DUT, écoles d'ingénieurs, génie civil: Formation autonome—Edition Casteilla.

[20] OCAB (2018) Aciers pour béton armé: Barres à nervures ou à empreintes—Fils à

nervures ou à empreintes à haute ductilité. Prescriptions Techniques OCAB PTV no. 302-Rev (9).

[21] Dénéréaz, C. (2015) Matériaux II: Travaux pratiques Essai de traction sur barres d'armature Partie théorique. Support pédagogique, École polytechnique fédérale de Lausanne.