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Comparative Evaluation of the Chemical Composition and Physical Properties of Reinforced Concrete Steel Bars Used in Construction in Senegal

El Hadji Amadou Fall Sy[1,2], Dame Keinde[1,2], Malang Bodian[2]

[1]Laboratory for Water, Energy, Environment and Industrial Processes (LE3PI), Higher Polytechnic School, Cheikh Anta Diop University, Dakar, Senegal
[2]Laboratory of Civil Engineering Materials (LMGC), Higher Polytechnic School, Cheikh Anta Diop University, Dakar, Senegal
Email: sy.elhadjiamadoufall@esp.sn, dame.keinde@ucad.edu.sn, bodianthomas@gmail.com

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Abstract

This article presents, the study of a comparative evaluation of the chemical composition and physical properties, linear mass deviations, of four (04) types of steel used in the construction sector in Senegal. Type 1 (E1), Type 2 (E2) and Type 3 (E3) steels are produced by locally established companies and Type 4 (E4) witness bars are imported from the France. The chemical analyses of the different types of steel were carried out by combustion, infrared (IR) detection for carbon and sulfur, by reducing fusion for nitrogen and by optical emission spectrometer (SEO) for the rest of the elements. The composition was determined on bars with a diameter of 10 mm. Linear mass deviations were evaluated for steels with a diameter of 8 mm, 10 mm and 12 mm. The results of the chemical analyses showed that the limit value for the percentage of carbon was exceeded by 29.16% for the steel, type 3. For the other types (1, 2 and 4), the limit values set out in the French standard NF EN 10,080 are not exceeded. As regards the relative differences in mass, the results showed that for steels of local manufacture, all the samples of bars with diameters 10 and 12 mm and 33% of steels with diameters 8 mm do not comply with the standard. The results also indicate that the chemical composition and relative linear mass deviations of the steels, type 4 comply with the standard. Thus, locally manufactured steels are not always suitable for use in reinforced concrete constructions.

Keywords

Local Manufacturing, Reinforced Concrete, Durability, Eurocode 2

1. Introduction

Reinforced concrete is the combination of concrete and steel reinforcement. As concrete has a good resistance to compression and a low resistance to traction [1], steel reinforcements are placed in an adequate way to take up the traction and possibly compression forces. In Senegal, the steel used in the constructions is imported or manufactured by local companies. For the safety and durability of the constructions, the properties of the steels must be in conformity with the assumptions of calculation. The standards applicable in France are used for the realization of structural elements in reinforced concrete in Senegal. The BAEL (*Béton armé aux Etats limites*) 91 mod. 99—French standards, which were used, are currently replaced by Eurocode 2. In these new standards, in reference to the NF EN 1992 - 1-1 standard, the steels to be used for reinforced concrete structures must respect a chemical composition and a linear mass [2]. In most construction sites, only tensile tests are performed at the time of construction. The actors sometimes have no information on the chemical composition and the real linear mass of the steel bars. According to the French standard NF EN 10,080, the weldability of steels is verified from carbon equivalent and limits relating to carbon, nitrogen, manganese, vanadium, phosphorus, chromium, nickel, molybdenum and copper contents.

The durability of the products is also provided by the specified chemical composition [3]. To date, no scientific study has evaluated the conformity of the chemical composition and linear mass of reinforced concrete reinforcement used in the construction sector in Senegal with respect to Eurocode 2. **Table 1** shows the influence of chemical elements on the properties of steel.

Research in some countries shows that the chemical composition of local steels often does not meet the requirements of standards.

In Nigeria, studies were carried out on the compliance of the chemical composition of steel reinforcement in the construction industry with the requirements of British Standards (BS4449). Bars of diameters 8, 10, 12, 16, 20 and 25 mm from 14 companies were used for the studies [5]. The results showed the absence of elements such as vanadium and molybdenum in most samples, as well as the uncontrolled presence of sulphur, phosphorus and nitrogen.

In Saudi Arabia, research was carried out on the chemical composition of locally manufactured reinforcing steels. The study was conducted on ASTM A615 Grade 60 steel bars from eight (08) companies [6]. The results showed that less than 3% of the samples did not comply with the requirements of the ASTM standard on the chemical composition of steels for reinforced concrete structural members.

The work of Odusote *et al.* on the chemical and mechanical properties of locally manufactured steel bars in Nigeria showed that some bars have a higher carbon content than the reference standards. Steel bars of 10, 12 and 16 mm diameter from eight (08) steel mills were used in the studies [7].

Table 1. Influence of different chemical elements on the properties of steels [4].

Chemicals	Property	Effects on the Rebar's
Carbone (C)	Hardness, strength, Weldability and brittleness	Higher carbon contributes to the tensile strength of steel, that is, higher load bearing capacity and vice versa. Lower carbon content less than 0.1% will reduce the strength. Higher carbon content of 0.3% and above makes the steel bar unweldable and brittle.
Manganese (Mn)	Strength and yield strength	Higher manganese content in steel increases the tensile strength and also the carbon equivalent property.
Sulphur (S)	It is an impurity in steel which increases its brittleness.	Presence of sulphur should be limited. Presence of higher sulphur makes the bar brittle during twisting, as higher sulphur content brings the hot shot problem during rolling.
Phosphorus (P)	It is an impurity which Increases strength brittleness	Higher phosphorus content contributes to the increase in strength and corrosion resistance properties but brings brittleness due to the formation of low euctoid phosphicles in the grain boundary. Also lowers the impact and value at subzero temperature level (transition temperature).
Copper (Cu)	Strength and corrosion resistance	Being a pearlite stabiliser, it increases the strength and resistance corrosion property.
Chromium (Cr)	Weldability and corrosion resistance	Present as an impurity from the scrap and influences carbon equivalent; weldability and increases corrosion resistance property.
Carbon Equivalent (CE or Ceq)	Hardness, tensile strength and weldability	This property is required to set the cooling parameters in TMT (thermomechanically treated) process and a slight variation in carbon equivalent may alter the physical properties.

Following the collapse of buildings in Nigeria, researchers have concluded that one of the main causes is that the properties of some steel bars used in construction were not up to standard [8]-[15]. The percentages of chemical elements in steel have an effect on its properties [4].

The non-conformity of the steel bars intended for construction, observed during the research work, shows the importance of checking the properties of the steels. Indeed, for the safety and durability of reinforced concrete structures, it is essential to use quality materials.

The aim of our study is to evaluate the quality of reinforced concrete steels used for construction in Senegal and to verify their compliance with the requirements of Eurocode 2. In this paper, the results of chemical analysis tests and the relative deviations of the linear mass of the steels are presented.

2. Materials and Methods

In the execution phase of the works, a large part of the companies buy the steels directly from the retail suppliers. In order to have information on the characteristics of the steels actually used in the constructions, our samples come from the same suppliers. The so-called local reinforcing steels are sometimes identifiable through the initials of the local producing company. For our research, three (03) types of locally produced steel and one (01) type of steel imported from France, which serves as a control material, are studied. To ensure anonymity, the steels are designated as presented in **Table 2**.

The study of the chemical composition of the steels was carried out on bars of 10 mm diameter per type.

The determination of the chemical composition of the 4 types of steel bars used in our work is carried out by:

- ✓ combustion and IR detection for carbon and sulphur;
- ✓ reducing fusion for nitrogen;
- ✓ Optical Emission Spectrometer (OES) for the rest of the elements.

After determining the mass content of the chemical elements at the level of each type of steel, Equation (1) was used to calculate the carbon equivalent (Ceq) value [3].

$$C_{eq} = C + \frac{M_n}{6} + \frac{C_r + M_o + V}{5} + \frac{N_i + C_u}{15} \tag{1}$$

All the symbols of the chemical elements in the above relation indicate the mass % contents.

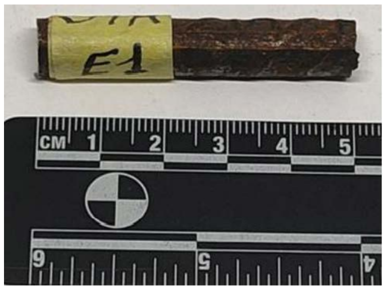
With:

C: carbon, M_n: Manganese, C_r: Chromium, M_o: Molybdenum, V: Vanadium, N_i: Nickel and C_u: Copper.

In order to measure the performance of the steel bars studied, the zone corresponding to each type of steel in **Figure 1** [16] was determined according to their carbon content (C) and equivalent carbon value (Ceq). **Figure 1** shows, according to the values of C and Ceq, an optimum zone of weldability, a regular zone and the zone with a high risk of cold cracking of the steels.

The chemical analysis tests were carried out in the EMTT (*Études Métallurgiques et de Traitement Thermique*) laboratory in France.

Table 2. Description of the steel bars studied.

E1—Type 1—local manufacture	E2—Type 2—local manufacture
	
E3—Type 3—local manufacture	E4—Type 4—Imp. From France
	

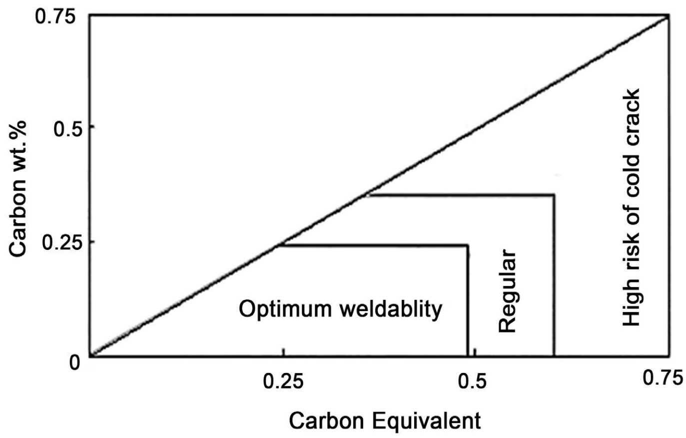


Figure 1. Carbon content/equivalent carbon diagram showing optimum, consistent weldability zone and high risk of cold cracking [16].

For each type of steel, mass was also measured. Furthermore, it should be noted that the actual diameter of the reinforcement is different from the nominal diameter and corresponds to the diameter of a cylinder of revolution with the same linear mass. Thus, for a bar of mass per linear metre "k (in kg/m)" with a density (ρ) equal to 7850 kg/m^3 [2], the actual diameter (d_r in metres) is obtained from Equation (2):

$$d_r = \sqrt{\frac{4k}{\rho\pi}} \tag{2}$$

The linear mass of the bars was calculated for the nominal diameters 8 mm, 10 mm and 12 mm, for all types of reinforcement studied. For each diameter of each type, three (03) samples of length 10 cm were cut from the same reinforcing bar. Figure 2 shows 10 cm steel bars for mass measurement.

An electronic scale was used for mass estimation. Three (03) mass measurements were made for each diameter. The average mass, standard deviation and linear mass were calculated with Excel. Equation (3), allowed to have the values of the relative deviations of linear mass for each type of bar studied.

$$Ecartrelatif\left(\%\right)=\frac{M_m-\rho S_n}{\rho S_n}\times 100 \tag{3}$$

With:

M_m: Measured mean linear mass of samples (kg/m) and S_n: nominal bar area (m^2).

3. Results and Discussion

In this section, the results obtained from the chemical analysis tests are presented, followed by the relative differences in linear mass for each type of bar. The results obtained are compared with the technical specifications of the current French standard.

3.1. Chemical Analysis of Bars

Table 3 shows all the results obtained from the chemical analyses for each type of reinforcement. The content of the chemical elements, in percentage by mass, as specified in EN 10080, is also shown.

The results show that the carbon content, obtained during the chemical analysis of the E3 sample, does not comply with the requirement of the standard. The carbon content obtained exceeds the limit value by 29.16%. Thus, the chemical composition obtained with the E3 sample, from a local company located in Senegal, does not quite meet the requirements defined in standard NF EN 10,080 with a carbon content higher than the maximum allowed. With reference to Table 1, exceeding the 0.3% carbon rate for E3 makes the bar brittle and non-weldable [4]. These properties (brittle and non-weldable) are not adequate for reinforcements compatible with the use of the Eurocode [2]. For bars of types E1, E2 and E4, the percentages by mass of the chemical elements and the carbon equivalent shall be below the limit values.

In our work, the behaviour of the bars with respect to the risk of cold crack formation was studied in order to determine which of the samples had optimum weldability. According to the values of the carbon (C) and equivalent carbon (Ceq) mass percentage obtained during the tests, the zone corresponding to each sample was identified in Figure 3.

According to their position in Figure 3, the E1, E2 and E4 samples have a better behaviour than the E3 sample with regard to the risk of cold crack formation.

Figure 2. Bars 10 cm long for mass determination.

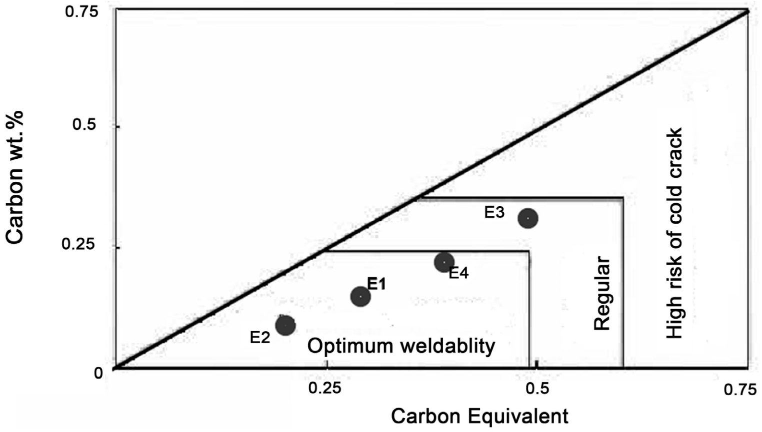


Figure 3. Placement of the samples studied (E1, E2, E3 and E4) in the diagram according to the values of C and Ceq.

Table 3. Chemical composition of samples—NF EN 10180 requirements.

Samples	Chemical elements—Contents (% mass)										
	C	S	P	N	Cu	Mn	V	Cr	Ni	Mo	Ceq
E1	0.15	0.046	0.036	0.0088	0.22	0.544	0.0028	0.109	0.076	0.013	0.29
E2	0.09	0.012	0.014	0.01	0.26	0.364	0.0012	0.101	0.125	0.017	0.2
E3	**0.31**	0.041	0.028	0.0089	0.24	0.706	0.0037	0.181	0.094	0.018	0.49
E4	0.22	0.03	0.022	0.001	0.45	0.626	0.0021	0.121	0.127	0.02	0.39
NF EN 10080 [2]	**0.24**	**0.055**	**0.055**	**0.014**	**0.85**	-	-	-	-	-	**0.52**

This difference, on steels intended for construction, can be linked to production, in particular the lack of control of the composition of raw materials (scrap) used in the manufacture of steels in Senegal, but also the absence of control by a national laboratory.

3.2. Linear Masses and Relative Mass Deviations

The measurements made, including mass, for each type of sample of diameters 8, 10 and 12 mm are shown in Tables 4-6. In Tables 4-6, the actual diameters

Table 4. Masses, diameters and relative mass deviations of 8 mm diameter bars.

	Reinforcement diameter 8 mm			
	Type 1	Type 2	Type 3	Type 4
Mass - Mesure 1 (gram)	37.66	37.68	37.09	38.03
Mass - Mesure 2 (gram)	37.62	37.72	37.11	38.04
Mass - Mesure 3 (gram)	37.68	37.7	37.08	38.03
Average mass (gram)	37.65	37.70	37.09	38.03
Deviation Type	0.03	0.02	0.02	0.01
Linear mass k (kg/m)	0.37653	0.37700	0.37093	0.38033
Nominal Linear Mass (kg/m) [2]	0.395			
Density - standard (kg/m³) [2]	7850			
Actual diameter (mm)	7.81	7.82	7.76	7.85
Relative mass deviation (%)	−4.68	−4.56	**−6.09**	−3.71
Eligible deviation (%) [2]	**±6**			

Table 5. Masses, diameters and relative mass deviations of 10 mm diameter bars.

	Reinforcement diameter 10 mm			
	Type 1	Type 2	Type 3	Type 4
Mass - Mesure 1 (gram)	56.08	57.78	55.61	60.71
Mass - Mesure 2 (gram)	56.12	57.75	55.7	60.7
Mass - Mesure 3 (gram)	56.11	57.86	55.5	60.69
Average mass (gram)	56.10	57.80	55.60	60.70
Deviation Type	0.02	0.06	0.10	0.01
Linear mass k (kg/m)	0.561	0.578	0.556	0.607
Nominal Linear Mass (kg/m) [2]	0.617			
Density - standard (kg/m³) [2]	7850			
Actual diameter (mm)	9.539	9.68	9.497	9.92
Relative mass deviation (%)	**−9.07**	**−6.33**	**−9.88**	−1.62
Eligible deviation (%) [2]	**±4.5**			

Table 6. Masses, diameters and relative mass deviations of 12 mm diameter bars.

	Reinforcement diameter 12 mm			
	Type 1	Type 2	Type 3	Type 4
Mass - Mesure 1 (gram)	82.2	83.49	83.48	87.24
Mass - Mesure 2 (gram)	82.19	83.45	83.47	87.25
Mass - Mesure 3 (gram)	82.15	83.47	83.5	87.25
Average mass (gram)	82.18	83.47	83.48	87.25

Continued

Deviation Type	0.03	0.02	0.02	0.01
Linear mass k (kg/m)	0.82	0.83	0.83	0.87
Nominal Linear Mass (kg/m) [2]		0.888		
Density - standard (kg/m^3) [2]		7850		
Actual diameter (mm)	11.55	11.64	11.64	11.90
Relative mass deviation (%)	**−7.45**	**−6.00**	**−5.99**	−1.75
Eligible deviation (%) [2]		**±4.5**		

of the bars and the relative deviations of the linear mass of the samples from the nominal linear mass are also given.

The results show that, for locally produced steels, all the 10 and 12 mm diameter bars and 33% for 8 mm diameter steels do not comply with the NF EN 10,080 standard. These differences; are mainly related to the production of the steels and constitute a real risk for the durability of the structures and the safety of people. In the final report of May 2021 of a technical commission [17], following building collapses in Senegal, under the direction of the Ministry of Urban Planning, Housing and Public Hygiene, it is stated that the poor quality of materials, particularly reinforcement and concrete, are among the causes of building collapses in Senegal. Our results indicate that locally manufactured steels do not always meet the conditions for their use in projects and show deficiencies in relation to the properties of the reinforcement compatible with the use of Eurocode 2. Indeed, according to Equation (2), the section of reinforcement actually used will not be in conformity with the theoretical section, which leads to a poor assessment of the actual section of reinforcement and, consequently, affects the strength of the reinforced concrete structural elements.

4. Conclusion and Perspective

Chemical analyses and determination of relative linear mass deviations of locally manufactured steel bars showed shortcomings. The results indicate, for the locally produced steels studied, that the relative mass deviations of all types of bars with diameters 10 and 12 mm and 33% of steels with diameter 8 mm, do not comply with the standard. The limit value for carbon content is also exceeded by 29.16% for one of the locally manufactured steel types. Faced with the upsurge in collapses, these results are of paramount importance in the search for a solution but also in the application of Eurocode 2 in Senegal. The results obtained show the need to carry out tests before starting work, to verify the conformity of the characteristics of the materials with the calculation assumptions. A laboratory or agency for the certification of the quality of building materials in Senegal can also be set up. In addition, corrosion of steels is also a determining factor for the durability of structures. Thus, in perspective, it would be useful to study the behaviour of locally manufactured steels in the face of corrosion. Indeed, the materials used for the realization of structural elements must have the necessary qualities for the safety and durability of constructions.

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Conflicts of Interest

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

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