Journal of Materials Science and Engineering A 14 (1-3) (2024) 1-10
doi: 10.17265/2161-6213/2024.1-3.001

Analysis of the Characteristics of Materials Obtained by Recycling Scrap Metal in Guinea

Alpha Issa Diallo[1], Jean Ahmed Kourouma[2], Adama Moussa Sakho[3] and Alexandre Lucien Richard[2]

1. Mechanical Laboratory, Higher Institute of Technology of Mamou, Mamou 063, Republic of Guinea

2. Materials Laboratory of Gamal Abdel Nasser University, Conakry, Mamou, 1147, Republic of Guinea

3. Department of Laboratory Technology, Higher Institute of Technology of Mamou, Mamou 063, Republic of Guinea

Abstract: The aim of this study was to determine the quality of rebar produced from recycled scrap metal collected throughout the country, and imported rebar sold in the Republic of Guinea. To do this, the samples were subjected to various mechanical tests involving traction, bending and microscopic analysis. In the Lambanyi and Casse Sonfonia samples, all the tensile strength values for diameters 12, 14 and 16 were above 550 MPa. Conversely, the iron samples from Baillobaye and the 10 mm diameters of the samples from Casse Sonfonio and Lambanyi have less appreciable values. The limits of elasticity were determined. The various values found vary more or less from the conventional yield strength of the NF A35-016 reference supplied by CBITEC, which is 500 MPa. Microscopic analysis gives us an insight into the internal structure of the iron samples used. This study may provide the company and the vendors with an alternative for their improvements.

Key words: Steel in construction, recycled scrap, strength test, traction, bending.

1. Introduction

The use of steel in the construction of structures has many advantages. It is an essential element in the architectural skeleton of buildings, foundations and reinforced concrete because of its versatility, strength, ability to meet the requirements of metal applications, aesthetic potential and ability to be combined with other materials [1-3]. In the Republic of Guinea, as in most developing countries, the construction of housing and public utility structures very rarely complies with administrative and technical regulations concerning the quality of the materials used in their construction [4, 5]. This poor use of materials is illustrated by the widespread damage caused by bad weather (flooding, strong winds, uneven terrain, etc.). The Republic of Guinea is a humid country, especially in the Lower Guinea, Middle Guinea and Forest Guinea zones, with average rainfall of 4,000, 2,000, 2,500 mm/year respectively. On 10 July 2023, at around 5pm, two buildings collapsed in the urban commune of Matoto (Conakry), killing several people [6]. However, reinforcement in the construction of large structures is made up of steel bars, which contribute to the strength of all the elements of the building. It is used in the construction of reinforced concrete buildings and in foundations; for its strength, plasticity, resistance to frost and heat, and corrosion resistance, it reinforces the properties of concrete and prevents it from cracking [7-9]. However, for some time now in the Republic of Guinea, there has been a proliferation of recycling units for steel of all kinds, used as reinforcing steel in the construction of structures in the country. This is why the manufacturing and conservation processes for steel and other construction materials must be designed in such a way as to guarantee their quality at all times in order to meet customer expectations [9], since the quality of industrial production has now become a requirement for the competitiveness and long-term survival of companies involved in recycling

Corresponding author: Alpha Issa Diallo, Doctoral student, research field: materials and metal construction.

Fig. 1 An example of a point of sale for concrete reinforcing bars in the open air.

scrap metal into construction materials. To this end, managers are called upon to define and implement a genuine approach to improving the quality of their products and services [8] in view of the numerous studies reported on the quality of iron bars sold in certain African countries using different diameters [5], certain companies manufacturing this material continue not to comply with certain criteria. As an extension of these studies, we report in the present work, the study on the quality of reinforcing bars produced from recycled scrap by the company: ODHAV-multi industry (republic of Guinea) which are stored and exposed to the open air in the points of sales as indicated by Fig. 1 by using the techniques of traction, flexion and microscopic in order to determine the quality of this material sold and used in the construction of our works.

2. Materials and Methods

2.1 Presentation of the Study Area

This study was carried out in the ODHAV-multi industries factories located in the Kènendé district in the urban commune of Dubréka (Republic of Guinea), on the left bank of the Soumba River. It is dominated to the east by Mount Kakoulima (1,011 m), also known as the Smoking Dog, once considered a sacred mountain. The population of Dubréka centre was estimated at 1,821,173 in 2016 (Fig. 2).

2.2 Study Setting

The CBITEC laboratories in Kagbélén (Dubréka Urban Community) served as the study setting.

2.3 Sampling

The iron bars used in this study were purchased at the markets of: Lambanyi, casse de Sonfonia, Bailobaya in the commune of Ratoma (Conakry, Capital of the Republic of Guinea) on 27/10/2023. Thirty-two iron sample bars manufactured by the ODHAV multi-industries company (Kindiasi neighbourhood in Kénèndé, urban commune of Dubréka), with diameters of 10, 12, 14 and 16 mm (i.e. eight bars per type of diameter chosen) were purchased and cut to a length of 500 mm each (Fig. 3). For each type of diameter, three pieces were selected and taken to the CBITEC laboratory for testing. The results are shown in Table 1.

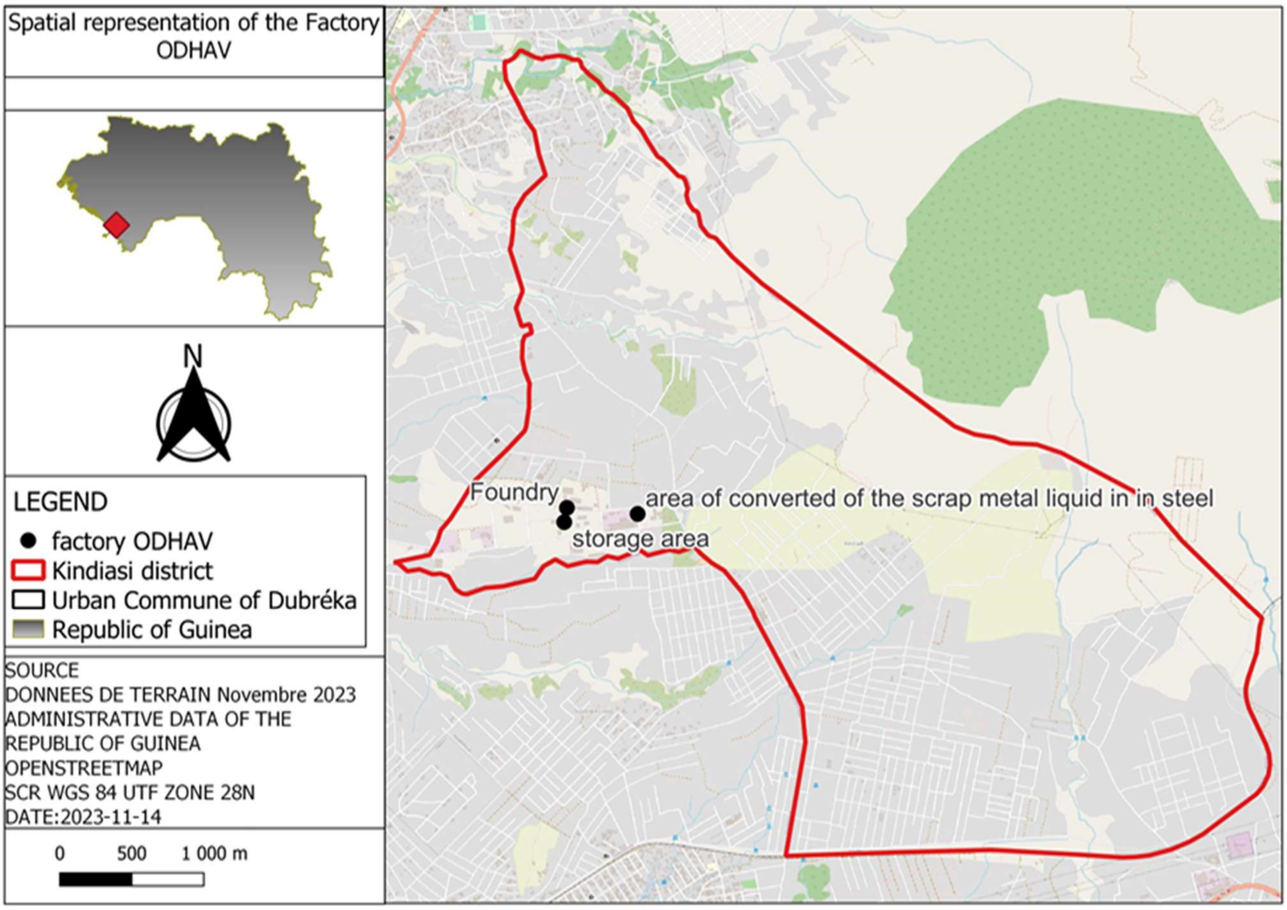


Fig. 2 Map of the ODHAV factory (in the Kindiasi district of Kénèndé, in the urban district of Dubréka) showing the storage, foundry and stick-iron production areas.

Fig. 3 Sample of irons cut into different diameters.

2.4 Equipment and Solvents

- Hacksaw
- Double decimeter
- Clamping vice
- Testing machine (WES-1000B)
- Testing machine (WES-300B)
- 69% nitric acid, with a density of 1.49 g/ml
- Electric optical microscope (Model: Max II 1202.3530M TENSION 220 V 50/60 Hz FUSIBLE 250 mA; LAMPE HALOGÈNE 6 V 20 W No. 1500189)

2.5 Methods

2.5.1 Operating Mode for Traction

The main motor consists of an adjustable support (base, threaded rod, lower clamping set, control box and, support crosspiece (upper clamping set)). Place the 50 cm test specimen between the upper and lower clamping fixtures. Then, use a digital control box, clamp the specimen, and run the device until the specimen breaks, followed by the reading of the parameters on a display (Fig. 4). The values for yield

Fig. 4 The iron bars after bending and the apparatus used for tensile and bending tests.

strength, ultimate tensile strength and elongation ratio were calculated using the following formulas: $R_e = F/S \times 1{,}000$; $R_m = F/S \times 1{,}000$; $A\% = (L_u\text{-}L_o)/L_o \times 100$, where: R_e = conventional yield strength (MPa); R_m = ultimate tensile strength (MPa); $A\%$ = elongation ratio; F = conventional yield load (kN); S = cross-sectional area (mm^2); L_u = initial dimension; L_o = dimension after tension.

2.5.2 Operating Mode of the Bending Device

The main motor consists of an adjustable support (base, threaded rod, lower clamping set, control box and, support cross-member (upper clamping set). In contrast to the tensile test, three sample specimens of the same size (25 cm) from the three sales points (Sonfonia casse, Lambanyi and Bailobaya) were horizontally placed together between the bending devices (Fig. 4). Then, using a digital control box, the device was switched on until the specimens were bent, followed by observation of the specimens after the bending operation (Fig. 5). The results are shown in Tables 1-3.

2.5.3 Experimental Part

(1) Description of Microscopic Analysis

The ordinary experimental set-up used consisted of a brand-name optical microscope (Max II 1202.3530M; RATING 220 V 50/60 Hz; FUSE 250 mA; HALOGEN LAMP 6 V 20 W; No. 1500189), an ordinary camera (NIKON D 3500), with illumination provided by the lamp of an iPhone.

(2) Procedure

Metallographic analysis to determine the microstructure of our sample was carried out with the aid of an optical microscope after polishing, using abrasive papers of varying fineness, of pieces of 40 mm iron bar beforehand, followed by etching with a 5 mL chemical solution of concentrated nitric acid and 50 mL of 96° ethyl alcohol, in order to reveal the aciferous zones when viewing the sample microscopically (Fig. 5).

3. Results and Discussion

The steels used to manufacture reinforced concrete are in most cases produced in electric furnaces from scrap metal [10]. The aim of the present work is to diagnose and determine some of the physico-chemical characteristics of the type of concrete reinforcing bar sample manufactured from recycled scrap metal collected throughout the country and sold in Conakry (Republic of Guinea), with a view to proposing to the manufacturer the possibility of improving these reinforcing bars. To this end, as mentioned above, 32 bars with diameters of 10, 12, 14 and 16 mm, i.e. 8 bars per diameter, were purchased from the following sales outlets: Sonfonia, Lambanyi and Bailobaya (in Ratoma commune). The iron bars were cut into three 50 cm samples, i.e. 9 pieces of the same size. The selected samples were cleaned of impurities and labelled, then packed in a cardboard box and sent to the factory for analysis. Tensile, bending and microscopic tests were carried out using a brand-name machine (Chenxin, made in China). The results of these analyses are shown in Tables 1-3 and Fig. 5. Next, we applied the microscopic viewing technique using the ordinary optical microscope to observe the microstructure of the samples in order to determine the nature of the structure, the shape and size of the grains, the existence of a heat treatment possibility, and the distribution of their constituents (Figs. 6a and 6b).

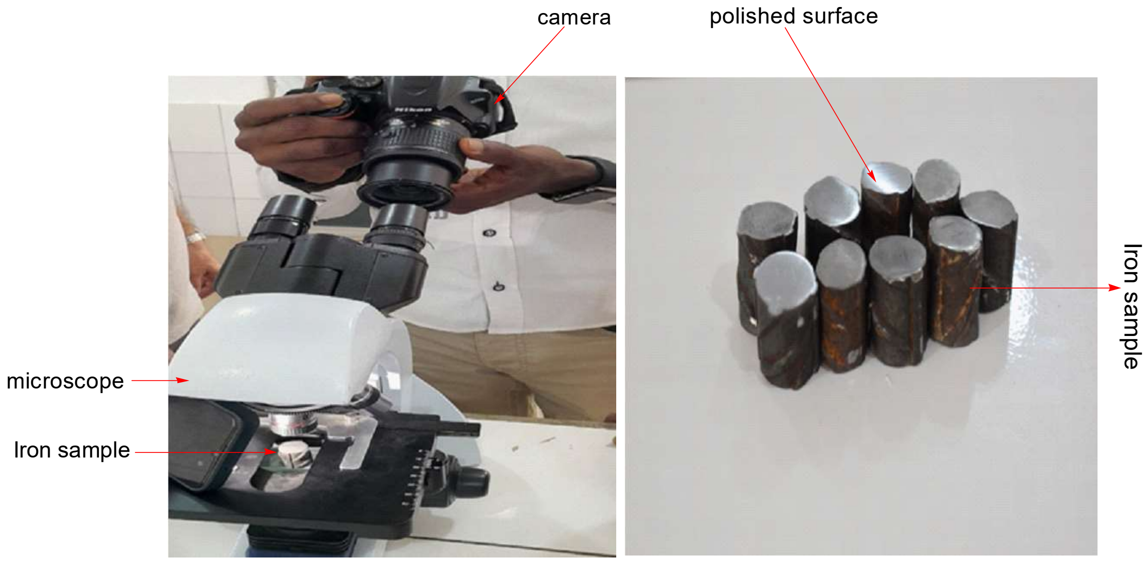
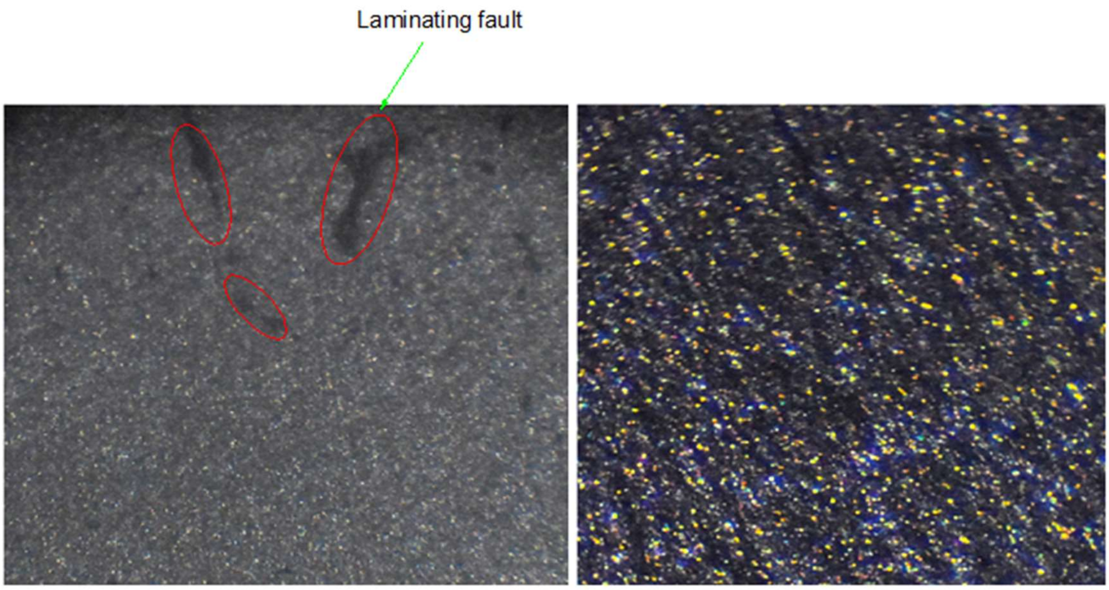


Fig. 5 The pieces of polished iron samples and the microscopic device.



(a) (b)

Fig. 6 Micrographic appearance of two samples showing a ferrito-perilitic structure with a lamination defect (a) and a phase mixture with spheroidal micrograins of various colors (b).

Table 1 Results of the tensile test on hot-rolled ribbed steel bars at the Casse de Sonfonia sales outlet NF A35-016 ODAV.

Diameter (mm)	Cross-sectional area (mm^2)	Conventional yield load	Calculated yield limit	Conventional yield limit	Ultimate load (kN)	Ultimate tensile strength (MPa)	Conventional ultimate tensile strength (MPa)	Calibration distance (mm)	Calibration distance broken (mm)	Elongation ratio (%)
	78.5	35.40	450.96		41.80	532.48		500	558	11.6
Φ10	78.5	35.80	456 .05		43.28	551.34		500	560	12
	78.5	35.26	449.17		42.44	540.64		500	558	11.6
	113	52.59	465.40		63.20	559.29		500	550	10
Φ12	113	60.18	532.57		71.65	634.07		500	554	10.8
	113	55.81	493.89	500	66.69	590.18	550	500	557	11.4
	154	79.96	519.22		95.24	618.44		500	553	10.6
Φ 14	154	79.80	518.18		95.15	617.86		500	553	10.6
	154	76.80	498.70		93.29	605.78		500	556	11.20
	201	103.19	513.38		123.80	615.92		500	566	13.2
Φ 16	201	102.72	511.04		121.24	603.18		500	552	10.4
	201	103.47	514.78		120.94	601.69		500	566	13.2

Table 2 Results of the mechanical performance test on hot-rolled Lambanyi rib steel (Turkish sample) NF A35-016 ODAV.

Diameter (mm)	Cross-sectional area (mm^2)	Conventional yield load	Calculated yield limit	Conventional yield limit	Ultimate load (kN)	Ultimate tensile strength (MPa)	Conventional ultimate tensile strength (MPa)	Calibration distance (mm)	Calibration distance broken (mm)	Elongation ratio (%)
	78.5	36.12	460.13		39.40	501.91		500	558	11.6
Φ10	78.5	36.17	460.76		39.42	502.17		500	547	9.4
	78.5	35.20	448.41		38.42	489.43		500	558	11.6
	113	54.05	478.32		63.84	564.96		500	552	10.4
Φ12	113	56.20	497.35		65.73	581.68		500	551	10.2
	113	56.20	496.46	500	64.82	573.63	550	500	554	10.6
	154	84.48	548.5		97.61	633.83		500	547	9.4
Φ14	154	84.10	546.10		97.98	636.23		500	548	9.6
	154	85.82	557.27		97.75	634.74		500	551	10.2
	201	104.54	520.10		122.34	608.66		500	553	10.6
Φ16	201	101.14	503.18		124.64	620.10		500	545	9
	201	103.48	514.83		122.15	607.71		500	544	8.8

Table 3 Results of tensile testing of hot-rolled ribbed steel bars Bailobaya point of sale NF A35-016 ODAV.

Diameter (mm)	Cross-sectional area (mm^2)	Conventional yield load	Calculated yield limit	Conventional yield limit	Ultimate load (kN)	Ultimate tensile strength (MPa)	Conventional ultimate tensile strength (MPa)	Calibration distance (mm)	Calibration distance broken (mm)	Elongation ratio (%)
	78.5	29.80	379.62		41.00	522.29		500	575	15
Φ10	78.5	29.80	379.62		40.98	522.04		500	573	14.16
	78.5	28.77	366.50		40.19	511.97		500	576	15.2
	113	40.93	362.21		58.12	514.34		500	574	14.8
Φ12	113	41.53	367.52		58.27	515.66		500	594	18.8
	113	42.58	376.81	500	58.66	519.12	550	500	587	17.4
	154	67.50	438.31		70.11	455.26		500	607	21.4
Φ14	154	67.95	441.23		69.10	448.70		500	693	18.6
	154	68.74	446.36		69.75	483.33		500	603	20.6
	201	96.82	481.69		97.15	524.78		500	600	20
Φ16	201	101.15	503.23		105.48	493.28		500	690	38
	201	97.56	485.37		99.15	493.28		500	698	39.6

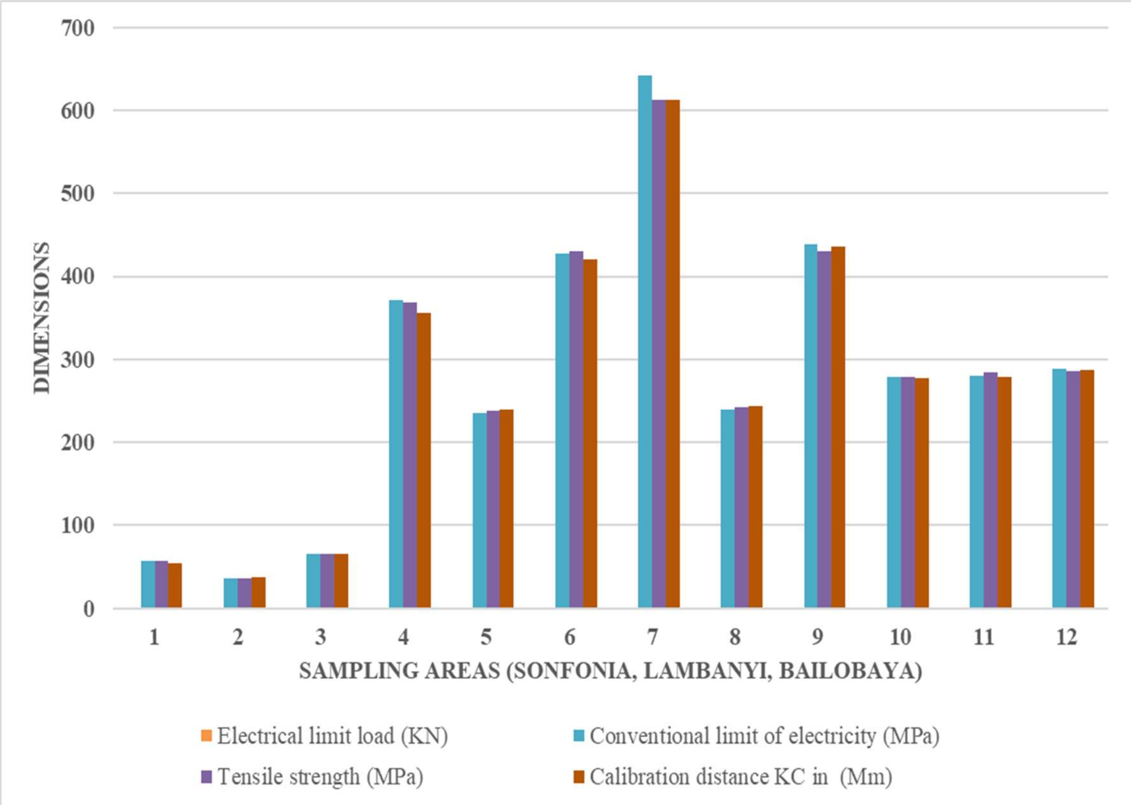


Fig. 7 Bending test of steel bars for 14 mm diameter.

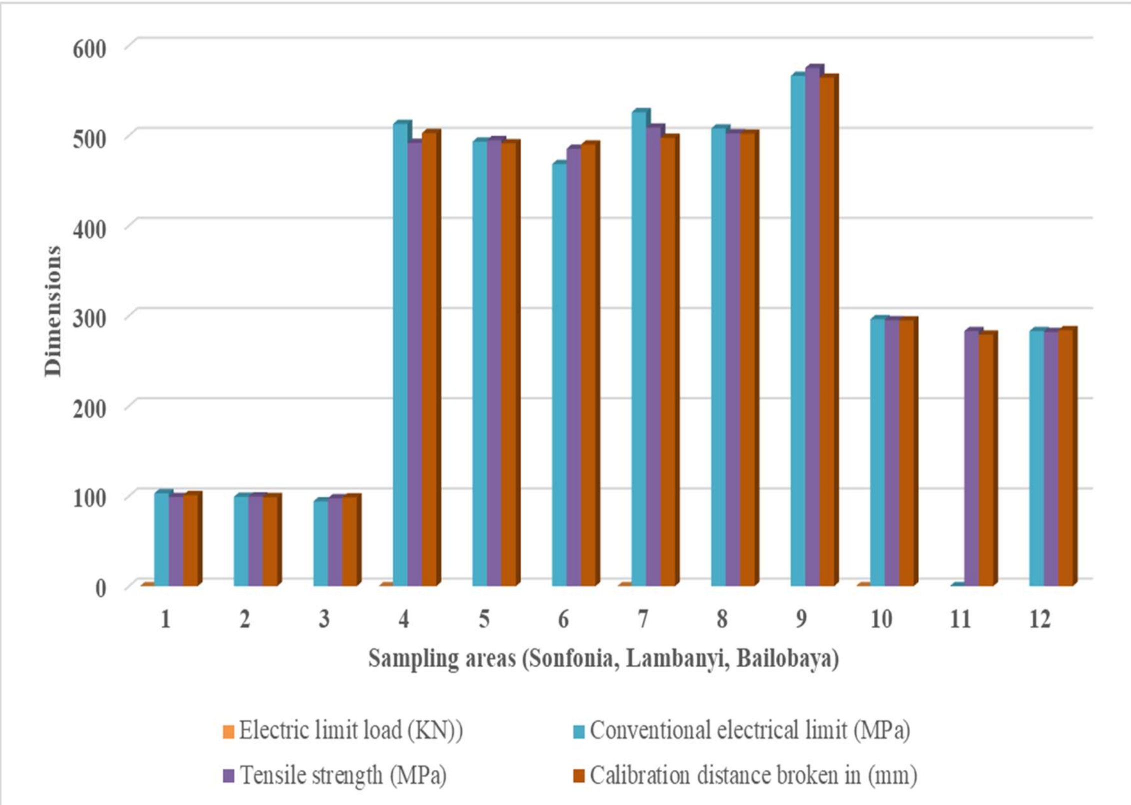


Fig. 8 Bending test on steel bars for 16 mm diameter.

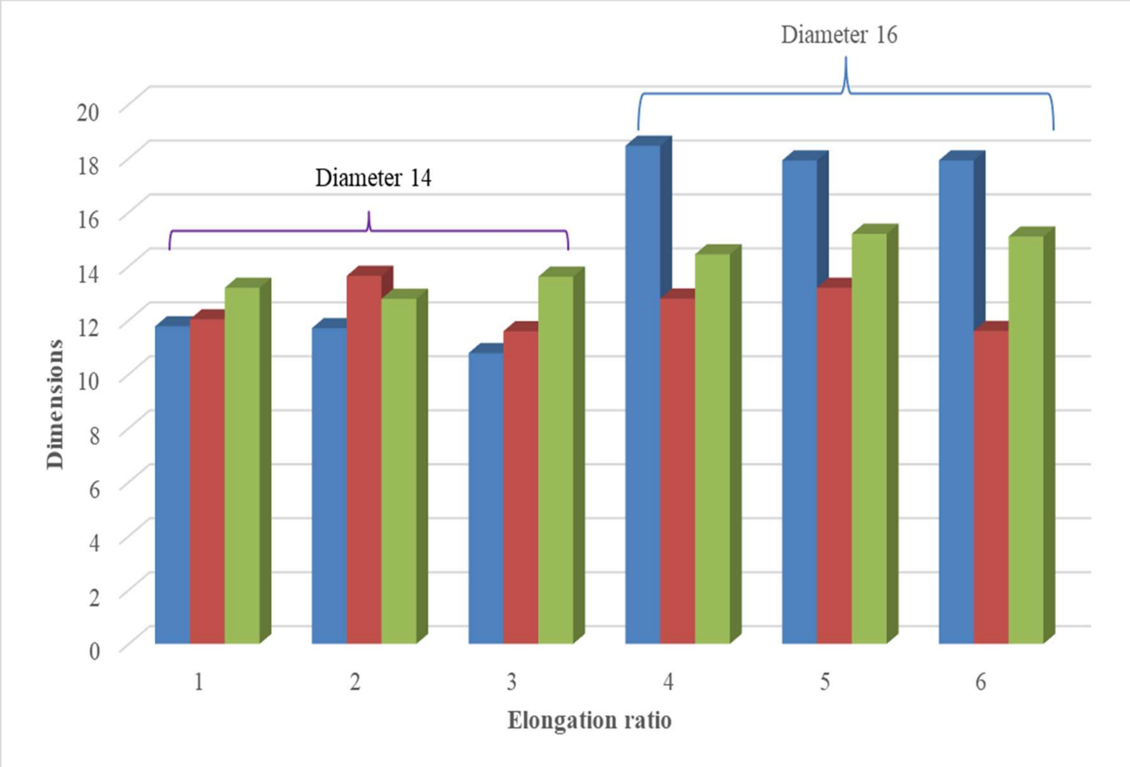


Fig. 9 Elongation ratio (%).

Tensile strength and flexural strength were measured on samples of iron bar purchased from three outlets in the city of Conakry. Yield strength is a physical quantity used to determine the maximum strength a metal can withstand before any deformation [11]. The results are shown in Tables 1-3; Casse de Sonfonia (ODHAV sample), Lambanyi (ODHAV sample) and Bailobaya (ODHAV sample) gave a variation in yield strength of 449.17-532.57; 460.13-557.26; 362.21-503.23 MPa for the four diameter types (10, 12, 14 and 16 mm) respectively. The highest value for each sample was observed at diameter 12 mm, i.e. 532.57 MPa (diameter 12, Sonfonia breakage sample), followed by 519.22 MPa (diameter 14, Sonfonia breakage sample); 557.27 MPa followed by 548.5 MPa (diameter 14, Turkish sample); 503.23 MPa followed by 485.37 MPa (diameter 16, Bailobaya sample). These different values vary more or less from the conventional yield strength load of reference NF A35-016 [11, 12] supplied by CBITEC, which is 500 MPa (Tables 1-3). According to Refs. [5, 13-15], the variation in yield strength from one sample to another depends on the structure and composition of the steels. On the other hand, the ultimate tensile strength values found for diameters: 10, 12, 14 and 16 mm retained for testing (Sonfonia ODHAV, Lambanyi and Bailobaya ODHAV cassia samples) vary from 540.64-634.07 MPa; 489.43-634.74 MPa and 448.70-522.29 MPa respectively. The highest values are: 634.07 MPa followed by 618.44, 617.86, 615.92, 603.13, 601.69, 590.18, 559.29 and 551.34 MPa (diameters 10, 12, 14 and 16 mm, casse sonfonia sample); 636.23, 634.74, 633.83, 620.10, 608.66, 607.71, 581.68, 573.63, 564.94 MPa (diameters 12, 14 and 16 mm, lambanyi sample). For the baillobaya samples, all values found are below the reference value of 550 MPa [11]. On the other hand, in the lambanyi and casse sonfonia samples, all the values for diameters 12, 14 and 16 are above the 550 MPa value [11]. The tensile strength of a metal is its ability to withstand stretching without being irreversibly damaged. In this case, the values found (diameters 12, 14 and 16 mm of the iron samples purchased from the sales outlets: casse sonfonia and lambanyi) can be an indicator of the performance of these iron samples. However, the Baillobaye iron samples and the 10 mm diameters of the casse sonfonio and lambanyi samples show less appreciable values. This is probably due to a number of factors, such as the poor protection of iron bars exposed to the open air at points of sale under heavy rainfall (around 4,000 mm in August/year) and the humidity of the city of Conakry [16, 17], causes iron to oxidize and iron dioxide to form rust, which can spread throughout the iron and even lead to its disappearance (a key factor in metal corrosion), or the absence of industrial heat treatment [18]. The tensile testing process on metals always involves an elongation with an initial length L_o that gradually increases until L_u (which corresponds to breakage). These different elongation values for each iron sample purchased and the conventional yield and tensile strength values and calibration and broken distance are shown in Tables 1-3. Bending tests on the 14 and 16 mm diameter samples selected for these tests gave best results of 612.95, 613.18 and 612.95 MPa for the ODHAV sample from Sonfonia (14 mm diameter); 564.10, 566.18 and 574.94 MPa for the Baillobaya sample (16 mm diameter). The values for the Lanbamyi sample, on the other hand, are below the mean value. According to the microscopic analysis results, the samples show a ferrito-perilitic structure with rolling defects in the form of lacunae (Fig. 6a) and phase mixing with spheroidal micro-grains of varying color (Fig. 6b), which probably indicates the presence of certain metals identifiable by their color, such as copper (red-orange); metal (gray); and cobalt (blue). The parameters influencing the final microstructure of a steel depend on the initial composition of the alloy and the cooling pattern adopted [19]. Fig. 7 shows steel bar bending tests carried out on 14 mm diameter samples from different sampling areas, namely Sonfonia, Lambanyi and Bailobaya. This study takes into account several significant parameters: yield strength (shown in yellow, although not visible), with average values, tensile strength (shown in purple), conventional yield strength (in blue) and calibration distance (in pink). However, Fig. 8 shows the results of bending tests carried out specifically on 16 mm diameter samples from various sampling areas: Sonfonia, Lambanyi and Bailobaya. This rigorous study incorporates several parameters essential for material analysis, including yield strength (identified in yellow, although not visually visible), revealing average values, tensile strength (reported in purple), conventional yield strength (marked in blue) and calibration distance (shown in pink). Fig. 9 shows the elongation ratios (%) for samples of two different diameters, 14 mm and 16 mm, from separate sampling areas: Sonfonia, Lambanyi and Bailobaya. In the case of the 14 mm diameter samples, index 1 represents the diagrams for samples taken in Sonfonia. Index 2 corresponds to the diagrams of samples from Lambanyi. Finally, index 3 details the diagrams of samples from Bailobaya for the same diameter size. For samples with a diameter of 16 mm, index 4 refers to the diagrams of samples taken at Sonfonia. Index 5 shows the diagrams for samples from Lambanyi with a diameter of 16 mm. Finally, index 6 details the diagrams of samples from Bailobaya for this diameter size.

4. Conclusion

The use of steel in the construction of structures requires the verification of certain mechanical and physico-chemical parameters. For this reason, we have studied the physico-chemical and mechanical characteristics of iron samples recycled by the ODHAV Company and sold in various outlets such as Sonfonia, Lanbamyi and Bailobaya in the Ratoma commune (Republic of Guinea). The following technical methods were used: tensile strength test, bending test and microscopic observation of the steel structure. It was found that the lambanyi and casse sonfonia samples, at diameters 12, 14 and 16, exceeded the conventional average value of 550 MPa, while the Bailobaya samples were below the conventional mean value. The bending values of the 14 and 16 mm diameter samples gave the best results: 612.95, 613.18 and 612.95 MPa for the ODHAV sample from Sonfonia (14 mm diameter); 564.10, 566.18 and 574.94 MPa for the Baillobaya sample (16 mm diameter). Compared with the other values, the Lanbamyi samples are below the conventional mean value. The results of the microscopic analysis showed that the samples analyzed present a spheroidal ferrito-perlitic structure with lamination defects in the form of lacunae, and phase mixing with micro-grains with varied colors probably showing copper (red-orange); metal (gray); and cobalt (blue). However, further studies are recommended in order to better understand the performance of steels manufactured in the Republic of Guinea using the scrap recycling process.

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