

Investigation of conformity of Reinforcing Steel Bars Used in Kinshasa Construction Industry.

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ABSTRACT

An investigation study was carried out to ascertain the level of conformity with the standards for reinforcing steel bars used in the construction industry of Kinshasa. Thus, the British Standard [BS 4449: 1997](#) was used. Reinforcing steel bars found in Kinshasa market, then tested, came from eleven companies. Tensile test was conducted on sixty-five samples selected from the available and most used reinforcing steel bars. Ten specimens were used for every company diameter size.

After testing, only sixteen over sixty-five specimens (25%) satisfied fully the standard requirements. None of the companies did fully comply with all code requirements. In addition, in respect to the measured diameter most of specimens failed to satisfy the nominal diameter required values. For characteristic strength criteria, only nineteen over sixty-five specimens complete the code requirements. However, all of the reinforcing steel bar samples complied with the minimum ultimate to yield strength ratio as specified by the code provisions. Fifty-tree over sixty-five specimens met the minimum code requirements on elongation criteria. Nevertheless, specimens from 6mm diameter mostly failed. Therefore, steel bars from Kinshasa market should not be used for the reinforcement of structural concrete without first subjecting them appropriately to tensile test, and a constant check by a Government agency is recommended.

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INTRODUCTION

Reinforcing steel bars are ones of the main materials used in the building industry. Most of the time they are used for concrete reinforcement and transferring tensile stresses [\[KOPAS, 2015\]](#). Reinforcement concrete is one of the most durable construction materials, and also among the most widely used in the Democratic Republic Congo (DRC), particularly in Kinshasa.

The tensile strength of concrete is known to be considered as negligible (about 10 percent of the compressive strength) in design. In contrast, while the concrete provides the compressive resistance, the steel is able to provide the tensile resistance. Thus, reinforcements are designed to resist the tensile stresses, which are transferred by bond between the interfaces of the two materials [\[NILSON et al., 2004\]](#).

In 2012, 38% of Sub-Saharan Africa's population lived in cities, and 62% of these city dwellers (nearly 213 million people) lived in slums, and every week 230,000 people are added to the previous number [\[UN Habitat, 2013\]](#). And, in Sub-Saharan Africa's region Kinshasa is the second

megacity in term of population after Lagos with an estimated 10.6 million in habitants in 2015 and an average 6.6% annual growth rate, and may well become the most populated [\[BÉDÉCARRATS et al., 2016\]](#). Unless, its high and uncontrolled urban growth [\[D'ASCENZO, 2013\]](#) can leads to a catastrophe if standard requirements are not respected.

Indeed, it has been reported many cases of structural failure in Kinshasa recently. This has become frequent mostly for buildings with more than three stories. Various reasons have been pointed out from some investigations as the causes of building collapse. Among them, it is estimated that the un conformity of structural properties of materials used in the actual construction may be the cause.

In the market, there are a variety of commercially available bars for concrete reinforcement. The main parameters of difference are cross-sectional dimensions, composition, and surface deformation patterns. One of the principal mechanical properties that need to be specified is the tensile strength [\[CASTRO and CARINO, 1998\]](#).

In design and construction processes, data from reinforcing steel bars are of key information. The properties

of reinforcing steel bars must be known to the users before being applied for design or construction purposes. In Kinshasa construction industry, there are two sources of steel reinforcing bars available, from the local industry, and from other countries.

The internal sources come mainly from the mini mills located in Kinshasa. While, imported steel bars that come into the country are mainly from Angola, Brazil, China, Dubai, Republic of Congo, South Africa, and Turkey. It is important to mention that most of the steel reinforcing bars used inside the country comes from Kinshasa, especially in the western part of the DRC. For some big projects, usually companies involved import their materials directly, which may not correspond to the current study and the above description.

It has been observed however, that only a few of the reinforcing steel bars found in the Kinshasa market have identification marks. Hence, it can be inferred that the level of quality control in the manufacture of these reinforcing steel bars cannot be ascertained.

For steel reinforcing bars, some parameters such as the modulus of elasticity can be assumed to be equivalent for bars from different producers [CASTRO and CARINO, 1998], theoretically. But in practice this is seldom the case, especially in developing countries. From the auteurs' observation, it appears that most local construction companies in Kinshasa make all their reinforcing steel bars procurements from the open local markets without any technical information that guide users on the appropriate use.

In order to investigate those properties with code requirements, the simplest and by far most widely used test for this purpose is the tensile test [FROLI and ROYER-CARFAGNI, 1999].

A comprehensive and random selection of the available steel reinforcing bars in Kinshasa market was made in order to perform the tensile test on. Alike of 650 specimens were tested in the Strength Materials Laboratory of Civil Engineering department, Polytechnic Faculty, of the University of Kinshasa.

The study reported in this paper was undertaken to verify conformity of the properties of available steel reinforcing bars in the Kinshasa market, which is used mostly for construction in the western part of the DRC. While many studies have been conducted on this topic elsewhere [e.g. ARUM, 2008; EJEH and JIBRIN, 2012; EZEKIEL and SILAS, 2017], no such studies have been reported in Kinshasa yet to our knowledge .

MATERIALS AND METHOD

Specimens used

A general survey of all Steel rolling mills in Kinshasa was undertaken. By the time this study was conducted, four (4) local companies were operating and three (3) closed for technical problems. It seems that the economic and political environment of the country at that moment have been harsh

for some companies to keep on their production. Hence, only the products bought in the mills operating by the time of the study were tested.

In the same period, seven (7) different external sources of steel reinforcing bars in the Kinshasa market were found. Those products come from the following countries: Angola, Brazil, China, Dubai, Republic of Congo, South Africa, and Turkey. Steel reinforcing bars form all of them were taken for the present study.

The samples were collected from a total of eleven (11) different companies as earlier stated. Seven (7) of these companies are foreign and their actual names are not known but only the countries of origin are specified. Thus, there are sixty-five (65) samples from eleven (11) different companies including the local ones which were considered for the tensile tests.

The choice of the sample diameters was based on the frequency use of the steel bars in the construction industry and their availability in Kinshasa market at the time of the study. Therefore, the most used and available steel bars collected from the local sources and from foreign sources were found to be the following reinforcing steel bars: 6, 8, 10, 12, 14, 16, 18, 20 and 22-mm diameter bars. All of them were ribbed surface steel bars.

Samples Preparation

Initial overall geometric dimensions were measured on all specimens prior to testing. The details of the measurements are reported in Tables 1-7.

An alphabetical order such as A, B, C and so on, was used in order to label all the specimens selected for the study. This order of identification is neither increasingly nor decreasingly in respect to the corresponding specimen properties. In addition, this order has been used randomly only for the current experimental identification purpose. Every letter implies a single company, and the follow number point out the nominal diameter size in millimeter of the reinforcement steel bars. For instance: B₁₄ and C₁₀ imply company B, fourteen (14) millimeters diameter for tensile test and company C, ten (10) millimeters (mm) diameter for tensile test, respectively and so on. In each diameter for a company, ten (10) specimens were tested for complete test. The value presented in this paper is an average of ten (10) for each test.

The lengths of 500 and 400-mm were used for the diameter bars from 16 to 22 mm and from 6 to 14 mm, respectively. The difference between the two lengths is due to the characteristics of the two different types of universal testing machine used in the laboratory. Each specimen diameter is measured in at least three places and the average is calculated and recorded as the diameter value.

Method of testing

Tensile test is a destructive one, performed at ambient temperature, consists of imposing an increasing deformation at a constant speed and measuring the force required to impose this deformation. An extensometer

measures the elongation of the specimen, and a dynamometer measures the effort. The result is displayed on a screen or plotter via a data acquisition system [BS EN 10002-1, 2001].

In the current study, tensile tests were carried out using two different types of universal testing machine as stated above. The first one was a 60-tons-capacity, manually operated, LOSENHAUSENWERK universal testing machine used for steel bars from 16 to 22 mm of diameters; while the second one was a 200-kN-capacity, automatic operated, MATEST S.P.A. universal testing machine used for steel bars from 6 to 14 mm of diameters.

A test was kept on until the specimen fractured and there was a sudden drop in the load. Only results in which failures occurred in the free-length of the specimen were considered valid for the determination of the tensile strength.

RESULTS

As there is no local standard currently for tensile test, the British Standard (BS4449: 1997) is used in this study. The characteristics such as yield strength, ultimate strength, characteristic strength, and elongation are calculated from information recorded in the tensile test, and they are compared to the code requirements.

The tensile strength was computed according to the formula 1.

$$\sigma_t = \frac{P}{A_0} \quad (1)$$

Where:

- σ_t : Tensile stress,
- P : Applied load,
- A_0 : Initial cross-sectional area of the sample.

Figure 1 depicts an example of data recorded in tensile tests. The graphs recorded from the sixty-five (65) specimens tests were estimated to be too much to be contained in this paper. As such, only this one is shown here for an illustration purpose. It should be warned that this does not mean all graphs have the same shape.

Table II Physical and Mechanical Properties of Steel Bars Specimens of 6 mm diameter

N	Mark	Measured Diameter	Yield Strength	Ultimate Strength	Ratio of Ultimate/Yield strength	Standard Deviation	Characteristic Strength	Elongation
	Unit	mm	N/mm ²	N/mm ²		N/mm ²	N/mm ²	%
1	A ₆	5,5	466,82	668,06	1,43	33,81	379,92	24
2	B ₆	5,3	457,22	663,02	1,45	56,18	312,84	12
3	D ₆	5,5	346,80	554,97	1,60	57,94	197,89	19
4	E ₆	5,5	420,37	635,35	1,51	60,92	263,81	12
5	F ₆	5,3	511,54	712,90	1,39	33,88	424,48	12
6	G ₆	6,0	426,70	614,26	1,44	78,74	224,33	13
7	H ₆	5,4	552,89	698,18	1,26	40,22	449,53	15
8	J ₆	5,7	261,45	490,96	1,88	26,01	194,60	13
9	K ₆	5,5	605,80	678,05	1,12	25,97	539,06	14

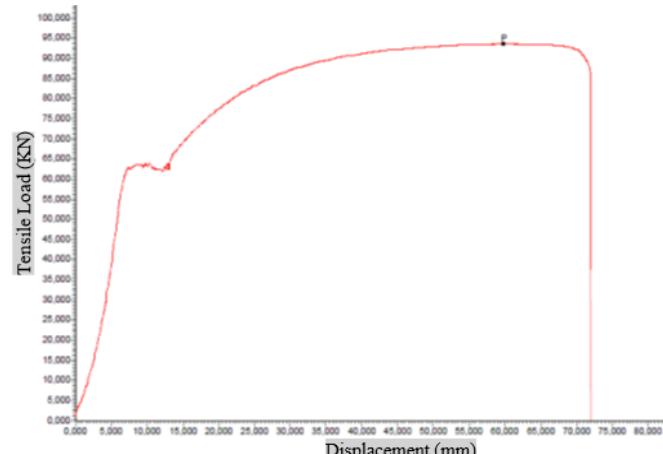


Figure 1| Example of Data Recorded in Tensile Tests: Tensile load (KN) versus Displacement (mm)

The raw load-displacement data were stored on disk and later converted to engineering units. Figure 1 shows examples of the data recorded during a typical tensile test. Those data were used to compute yield strength, ultimate strength, characteristic strength, elongation, and so on.

The strain was calculated using formula 2.

$$\varepsilon = \frac{\Delta L}{L_0} \quad (2)$$

Where:

- ε : Strain,
- ΔL : Elongation,
- L_0 : Original gauge length.

While the yield strength was calculated from data taken from the graph (Load versus elongation). And elongation at fracture (or ductility) in percent (%) was computed by using formula 3.

$$D = \varepsilon * 100 \quad (3)$$

Hence, the mentioned elongation in the following pages (Tables included) refer to ductility in %.

According to the Construction Standard **CS2:1995** in accordance with **BS4449:1997** and **ISO 6935-2** the characteristic strength can be calculated by using formula 4.

$$f_y = f_{av} - k * SD \quad (4)$$

Where:

- f_y : Characteristic strength,
- f_{av} : Average yield stress,
- k : The value for the acceptability index, which equal to 2.57 for $n = 10$,

- n : Number of the results,
- SD : Standard deviation.

Formulae 1 to 4 were used for calculations in the **Tables 1-7** and **9**. The results are presented in the group of same diameter size with the corresponding companies for a better understanding.

Tables 1-7 contain results of the tensile tests and also information about physical and mechanical properties of the steel bars specimens.

Table 2| Physical and Mechanical Properties of Steel Bars Specimens of 8 mm diameter

N	Mark	Measured Diameter	Yield Strength	Ultimate Strength	Ratio of Ultimate/Yield strength	Standard Deviation	Characteristic Strength	Elongation
	Unit	mm	N/mm ²	N/mm ²		N/mm ²	N/mm ²	%
1	A ₈	7,4	485,33	619,00	1,28	13,54	450,53	11
2	B ₈	7,1	567,57	883,60	1,56	75,25	374,17	18
3	C ₈	6,5	629,04	1051,79	1,67	52,48	494,17	14
4	D ₈	7,0	449,61	695,17	1,55	41,17	343,80	20
5	E ₈	7,5	490,56	738,33	1,51	42,65	380,94	16
6	G ₈	6,8	536,81	849,10	1,58	54,04	397,92	16
7	H ₈	6,7	388,09	592,95	1,53	19,21	338,71	22
8	J ₈	6,5	353,34	518,94	1,47	32,17	270,67	23
9	K ₈	7,0	368,51	539,37	1,46	10,38	341,83	21

Table 3| Physical and Mechanical Properties of Steel Bars Specimens of 10 mm diameter

N	Mark	Measured Diameter	Yield Strength	Ultimate Strength	Ratio of Ultimate/Yield strength	Standard Deviation	Characteristic Strength	Elongation
	Unit	mm	N/mm ²	N/mm ²		N/mm ²	N/mm ²	%
1	A ₁₀	9,6	499,49	634,37	1,27	28,14	427,16	13
2	B ₁₀	8,3	491,46	715,55	1,46	41,98	383,58	24
3	C ₁₀	8,6	495,17	758,91	1,53	37,12	399,78	21
4	D ₁₀	8,6	441,87	667,79	1,51	29,58	365,85	24
5	E ₁₀	9,3	668,96	789,49	1,18	15,42	629,33	11
6	F ₁₀	9,3	672,64	831,83	1,24	12,19	641,31	12
7	G ₁₀	9,3	663,08	809,34	1,22	9,75	638,02	12
8	H ₁₀	9,0	480,39	706,33	1,47	7,69	460,62	24
9	I ₁₀	8,7	443,53	627,19	1,41	24,58	380,37	26
10	J ₁₀	8,8	418,73	667,70	1,59	36,72	324,36	22
11	K ₁₀	8,2	463,33	615,31	1,33	5,98	447,97	28

Table 4 | Physical and Mechanical Properties of Steel Bars Specimens of 12 mm diameter

N	Mark	Measured Diameter	Yield Strength	Ultimate Strength	Ratio of Ultimate/Yield strength	Standard Deviation	Characteristic Strength	Elongation
	Unit	mm	N/mm ²	N/mm ²		N/mm ²	N/mm ²	%
1	A ₁₂	11,5	615,38	713,16	1,16	19,23	565,95	14
2	B ₁₂	11,0	497,09	740,63	1,49	11,32	468,00	22
3	C ₁₂	11,0	432,98	634,42	1,47	15,45	393,29	28
4	D ₁₂	10,4	516,12	794,41	1,54	11,99	485,31	23
5	E ₁₂	11,3	585,57	717,64	1,23	3,98	575,33	15
6	G ₁₂	11,0	620,04	759,19	1,22	0,00	620,04	16
7	H ₁₂	11,0	422,47	608,51	1,44	17,14	378,42	24
8	I ₁₂	10,9	430,26	622,91	1,45	12,93	397,02	25
9	J ₁₂	11,0	421,42	609,01	1,45	5,15	408,19	26
10	K ₁₂	10,6	425,53	614,60	1,44	9,74	400,51	24

Table 5 | Physical and Mechanical Properties of Steel Bars Specimens of 14 mm diameter

N	Mark	Measured Diameter	Yield Strength	Ultimate Strength	Ratio of Ultimate/Yield strength	Standard Deviation	Characteristic Strength	Elongation
	Unit	mm	N/mm ²	N/mm ²		N/mm ²	N/mm ²	%
1	A ₁₄	13,2	541,72	678,59	1,25	6,94	523,89	17
2	B ₁₄	12,4	570,16	878,75	1,54	50,04	441,56	21
3	C ₁₄	12,9	484,47	721,80	1,49	3,74	474,85	23
4	D ₁₄	12,8	329,86	463,55	1,41	15,13	290,97	32
5	E ₁₄	13,0	586,90	707,14	1,20	14,47	549,70	17
6	F ₁₄	13,0	587,65	692,03	1,18	50,27	458,45	16
7	G ₁₄	13,0	573,58	676,90	1,18	21,31	518,80	18
8	H ₁₄	12,7	365,82	537,80	1,47	18,39	318,56	29
9	I ₁₄	13,0	595,93	714,03	1,20	5,63	581,46	18
10	J ₁₄	12,8	523,89	743,10	1,42	3,47	514,97	22
11	K ₁₄	12,9	456,96	719,38	1,57	10,14	430,91	22

Table 6 | Physical and Mechanical Properties of Steel Bars Specimens of 16 mm diameter

N	Mark	Measured Diameter	Yield Strength	Ultimate Strength	Ratio of Ultimate/Yield strength	Standard Deviation	Characteristic Strength	Elongation
	Unit	mm	N/mm ²	N/mm ²		N/mm ²	N/mm ²	%
1	A ₁₆	15,1	485,71	628,45	1,29	13,19	451,81	17
2	B ₁₆	13,6	378,21	643,15	1,70	16,12	336,77	17
3	C ₁₆	14,9	381,87	702,56	1,84	31,52	300,85	21
4	D ₁₆	14,9	251,07	360,36	1,44	12,96	217,76	30
5	F ₁₆	14,6	320,01	551,65	1,72	22,49	262,20	26
6	G ₁₆	15,1	325,72	514,51	1,58	8,07	304,97	24
7	H ₁₆	14,4	362,76	569,71	1,57	20,54	309,96	27
8	J ₁₆	14,8	270,11	444,95	1,65	10,13	244,06	28
9	K ₁₆	14,6	299,64	474,87	1,58	7,15	281,27	28

Table 7 | Physical and Mechanical Properties of Steel Bars Specimens of 18, 20- and 22-mm diameters

N	Mark	Measured Diameter	Yield Strength	Ultimate Strength	Ratio of Ultimate/Yield strength	Standard Deviation	Characteristic Strength	Elongation
		Unit	mm	N/mm ²	N/mm ²	N/mm ²	N/mm ²	%
1	A ₂₀	18,8		615,46	761,70	1,24	33,70	528,86
2	C ₂₀	17,0		267,62	421,84	1,58	10,81	239,83
3	C ₂₂	20,7		306,60	469,41	1,53	12,28	275,06
4	H ₁₈	16,1		574,72	691,37	1,20	28,85	500,58
5	H ₂₀	18,1		613,45	732,15	1,19	17,53	568,40
6	H ₂₂	20,3		590,21	737,32	1,25	18,59	542,44

DISCUSSIONS

Based on the results obtained, analysis and discussions are made.

First of all, the reference parameters from code are presented in Table 8 and then, comparisons are done with tested data. *In addition, no specific comments are made in order to compare local and external reinforcing steel bars.*

The parameter utilized for comparison is the characteristic strength. In fact, according to the [BS 4449-1997](#) "For determination of the long-term quality level, the values given shall be for the characteristic strength". Thus, characteristic strength values are compared with the norm standard, for strengths examination.

Table 8 gives more details on the requirements which are considered as reference data for the current study. The parameters of tensile test are yield strength, ultimate strength, characteristic strength, elongation, and standard deviation. They are illustrated in Tables 1-7.

Table 8 | Standard Requirements from [BS 4449-1997](#) used as Reference Data

Min. Stress Ratio of Ultimate/ Yield	Min. Characteristic Strength (fy)	Min. Design Characteristic Strength (0,87*fy)	Min. Elongation at Fracture
	N/mm ²	N/mm ²	%
1,08	460	400,2	14,0

In addition, a verification of minimum design strength for reinforcement was made. The minimum design strength for reinforcement, 0.87*fy, is compared with the corresponding characteristic strength for design which is 400.20N/mm². The last strength is computed from the minimum characteristic strength, 460N/mm², as specified by the code. These key values are contained also in Table 8.

In the Table 9 Ok, X, P, and F mean:

- Ok : Satisfactory,
- X : Unsatisfactory,
- P : Partially complied,
- F : Fully complied.

In the Table 9, the letters a and b mean difference between tensile tested specimen values and the code values, and observation of the conformity of the tested specimen with the code specified, respectively.

Table 9 | Conformity of specimens tested with the Code

N	Marks	Measured Diameter	Ratio of Ultimate/Yield	Characteristic Strength			Design Characteristic Strength		Elongation	General Observation
				a	b	b	a	b		
		Unit	mm			N/mm ²	N/mm ²		%	
1	A ₆	5,50	0,35	Ok	-80,08	X	-69,67	X	10,1	Ok P
2	A ₈	7,40	0,20	Ok	-9,47	X	-8,24	X	-2,5	X P
3	A ₁₀	9,60	0,19	Ok	-32,84	X	-28,57	X	-0,5	X P
4	A ₁₂	11,50	0,08	Ok	105,95	Ok	92,18	Ok	0,1	Ok F
5	A ₁₄	13,16	0,17	Ok	63,89	Ok	55,58	Ok	3,2	Ok F
6	A ₁₆	15,08	0,21	Ok	-8,19	X	-7,12	X	2,9	Ok P
7	A ₂₀	18,84	0,16	Ok	68,86	Ok	59,91	Ok	5,9	Ok F
8	B ₆	5,30	0,37	Ok	-147,16	X	-128,03	X	-1,6	X P
9	B ₈	7,10	0,48	Ok	-85,83	X	-74,67	X	3,5	Ok P
10	B ₁₀	8,30	0,38	Ok	-76,42	X	-66,49	X	9,6	Ok P
11	B ₁₂	11,00	0,41	Ok	8,00	Ok	6,96	Ok	8,0	Ok F
12	B ₁₄	12,40	0,46	Ok	-18,44	X	-16,04	X	7,3	Ok P
13	B ₁₆	13,58	0,62	Ok	-123,23	X	-107,21	X	3,4	Ok P
14	C ₈	6,50	0,59	Ok	34,17	Ok	29,73	Ok	-0,1	X P
15	C ₁₀	8,60	0,45	Ok	-60,22	X	-52,39	X	7,0	Ok P
16	C ₁₂	11,00	0,39	Ok	-66,71	X	-58,04	X	13,5	Ok P
17	C ₁₄	12,90	0,41	Ok	14,85	Ok	12,92	Ok	8,7	Ok F
18	C ₁₆	14,90	0,76	Ok	-159,15	X	-138,46	X	7,2	Ok P
19	C ₂₀	17,02	0,50	Ok	-220,17	X	-191,55	X	17,3	Ok P
20	C ₂₂	20,66	0,45	Ok	-184,94	X	-160,90	X	17,9	Ok P
21	D ₆	5,50	0,52	Ok	-262,11	X	-228,04	X	5,4	Ok P
22	D ₈	7,00	0,47	Ok	-116,20	X	-101,10	X	6,3	Ok P
23	D ₁₀	8,60	0,43	Ok	-94,15	X	-81,91	X	9,6	Ok P
24	D ₁₂	10,40	0,46	Ok	25,31	Ok	22,02	Ok	8,8	Ok F
25	D ₁₄	12,80	0,33	Ok	-169,03	X	-147,05	X	17,9	Ok P
26	D ₁₆	14,90	0,36	Ok	-242,24	X	-210,75	X	15,8	Ok P
27	E ₆	5,50	0,43	Ok	-196,19	X	-170,68	X	-2,2	X P
28	E ₈	7,50	0,43	Ok	-79,06	X	-68,78	X	2,2	Ok P
29	E ₁₀	9,30	0,10	Ok	169,33	Ok	147,32	Ok	-3,4	X P
30	E ₁₂	11,30	0,15	Ok	115,33	Ok	100,34	Ok	1,0	Ok F
31	E ₁₄	13,00	0,12	Ok	89,70	Ok	78,04	Ok	3,3	Ok F
32	F ₆	5,30	0,31	Ok	-35,52	X	-30,90	X	-2,3	X P
33	F ₁₀	9,30	0,16	Ok	181,31	Ok	157,74	Ok	-2,0	X P
34	F ₁₄	13,00	0,10	Ok	-1,55	X	-1,35	X	1,6	Ok P
35	F ₁₆	14,64	0,64	Ok	-197,80	X	-172,09	X	11,6	Ok P
36	G ₆	6,00	0,36	Ok	-235,67	X	-205,04	X	-0,6	X P
37	G ₈	6,80	0,50	Ok	-62,08	X	-54,01	X	1,6	Ok P
38	G ₁₀	9,30	0,14	Ok	178,02	Ok	154,88	Ok	-2,1	X P
39	G ₁₂	11,00	0,14	Ok	160,04	Ok	139,24	Ok	1,6	Ok F
40	G ₁₄	13,02	0,10	Ok	58,80	Ok	51,16	Ok	3,7	Ok F
41	G ₁₆	15,10	0,50	Ok	-155,03	X	-134,88	X	9,7	Ok P
42	H ₆	5,38	0,18	Ok	-10,47	X	-9,11	X	1,5	Ok P
43	H ₈	6,70	0,45	Ok	-121,29	X	-105,52	X	8,0	Ok P
44	H ₁₀	9,00	0,39	Ok	0,62	Ok	0,54	Ok	9,6	Ok F
45	H ₁₂	11,00	0,36	Ok	-81,58	X	-70,97	X	10,1	Ok P
46	H ₁₄	12,70	0,39	Ok	-141,44	X	-123,05	X	14,8	Ok P
47	H ₁₆	14,40	0,49	Ok	-150,04	X	-130,53	X	12,6	Ok P
48	H ₁₈	16,10	0,12	Ok	40,58	Ok	35,31	Ok	1,8	Ok F
49	H ₂₀	18,10	0,11	Ok	108,40	Ok	94,31	Ok	5,5	Ok F
50	H ₂₂	20,26	0,17	Ok	82,44	Ok	71,72	Ok	5,1	Ok F
51	I ₁₀	8,70	0,33	Ok	-79,63	X	-69,28	X	12,2	Ok P
52	I ₁₂	10,90	0,37	Ok	-62,98	X	-54,79	X	10,9	Ok P
53	I ₁₄	13,00	0,12	Ok	121,46	Ok	105,67	Ok	3,6	Ok F
54	J ₆	5,70	0,80	Ok	-265,40	X	-230,89	X	-0,9	X P
55	J ₈	6,50	0,39	Ok	-189,33	X	-164,72	X	8,6	Ok P
56	J ₁₀	8,80	0,51	Ok	-135,64	X	-118,00	X	7,7	Ok P
57	J ₁₂	11,00	0,37	Ok	-51,81	X	-45,08	X	11,6	Ok P
58	J ₁₄	12,80	0,34	Ok	54,97	Ok	47,82	Ok	7,5	Ok F
59	J ₁₆	14,75	0,57	Ok	-215,94	X	-187,86	X	14,3	Ok P
60	K ₆	5,46	0,04	Ok	79,06	Ok	68,78	Ok	-0,2	X P
61	K ₈	7,00	0,38	Ok	-118,17	X	-102,81	X	7,1	Ok P
62	K ₁₀	8,20	0,25	Ok	-12,03	X	-10,47	X	14,1	Ok P
63	K ₁₂	10,60	0,36	Ok	-59,49	X	-51,75	X	10,1	Ok P
64	K ₁₄	12,90	0,49	Ok	-29,09	X	-25,31	X	8,1	Ok P
65	K ₁₆	14,60	0,50	Ok	-178,73	X	-155,49	X	14,4	Ok P

For illustration, A_6 corresponding characteristic strength from the Table 1 is equal to 379.92 N/mm^2 . The A_6 characteristic strength value minus the code reference value gives ($= 379.92 \text{ N/mm}^2 - 460 \text{ N/mm}^2 =$) $- 80.08 \text{ N/mm}^2$. It means that the concern specimen failed to satisfy the code requirement for the corresponding property. In the same way, all verifications and observations in the Table 9 were made.

From the results in the Tables 1–7, 9 and 10, the following observations are made:

Characteristic Strength

Characteristic and design characteristic strengths are ones of the key parameters in design and construction process. From Table 9 and Figure 2, it is noticed that only 19 over 65 specimens, less than 30%, complete the code characteristic strength requirement which is 460 N/mm^2 . This means that many reinforcement steel bars sold in Kinshasa market do not fulfill the characteristic and design strengths code requirements. This may be one cause of failure in the building collapse.

In addition, most of the reinforcement steel bars used in construction industry of western part of DRC including Kinshasa, especially for middle and small constructions are not tested before their use. In the same way, in most parts of DRC the availability of those reinforcing steel bars can be a serious problem; which imply that the one that is available must be used.

Another important observation is that the quasi-totality of the reinforcing steel bars of 6, 8, and 16-mm diameters failed to satisfy the code requirements. It is known that the first two steel bars are ones of the most used in the construction industry of Kinshasa, this may be of great concern.

From Figure 3, all specimens satisfied the code requirements for the Ultimate to Yield Strengths ratio.

Percentage Elongation

The elongation criterion is a significant parameter for reinforced-concrete structures. Sometimes steel bars are needed for special usage. As such parameters like ductility may be of grave importance. This is the case for steel bars in reinforced-concrete structures in seismic areas [REHM et al. 1977].

Table 9 and Figure 4 show the percentage elongation for the nine (9) companies samples collected. It can be perceived that most of the bar samples met the minimum code requirements on elongation criteria, 53 over 65 specimens (almost 82%). The twelve (12) specimens that failed all belong to 6, 8, and 10-mm diameters, with the following details: 6 over 9 samples failed for 6mm diameter, 2 over 9 samples failed for 8mm diameter, and 4 over 11 samples failed for 10mm diameter.

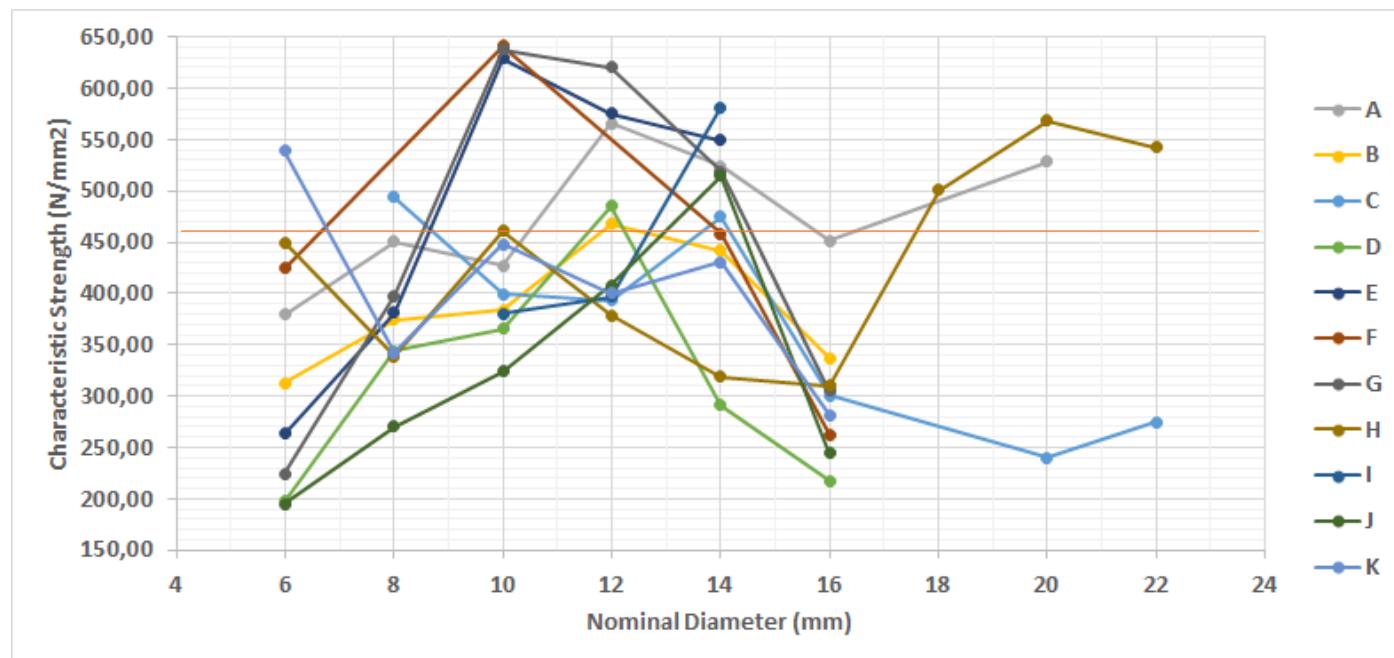


Figure 2| Graphs for Characteristic Strengths against Bar Diameters for the 65 specimens tested

Between those three bars, namely 6, 8 and 10-mm, the ductility of 6mm is of more concern. Indeed, this steel bar is used most of the time as stirrups bar. Thus, the ductility requirement is one of the most important parameters to be fulfilled. However, from the results in Table 9 and Figure 4, it is observed that most of the specimens of 6mm diameter tested, did not comply with the standard requirement which is 14%.

Ductility condition is much more important for the service ability limit state condition of design. For this reason, specimens that failed to fulfill elongation requirements, should not be used in reinforcement as they will not give warning prior to failure due to low ductility. In short, the lack of ductility may lead to sudden collapse without warning [EJEH and JIBRIN, 2012].

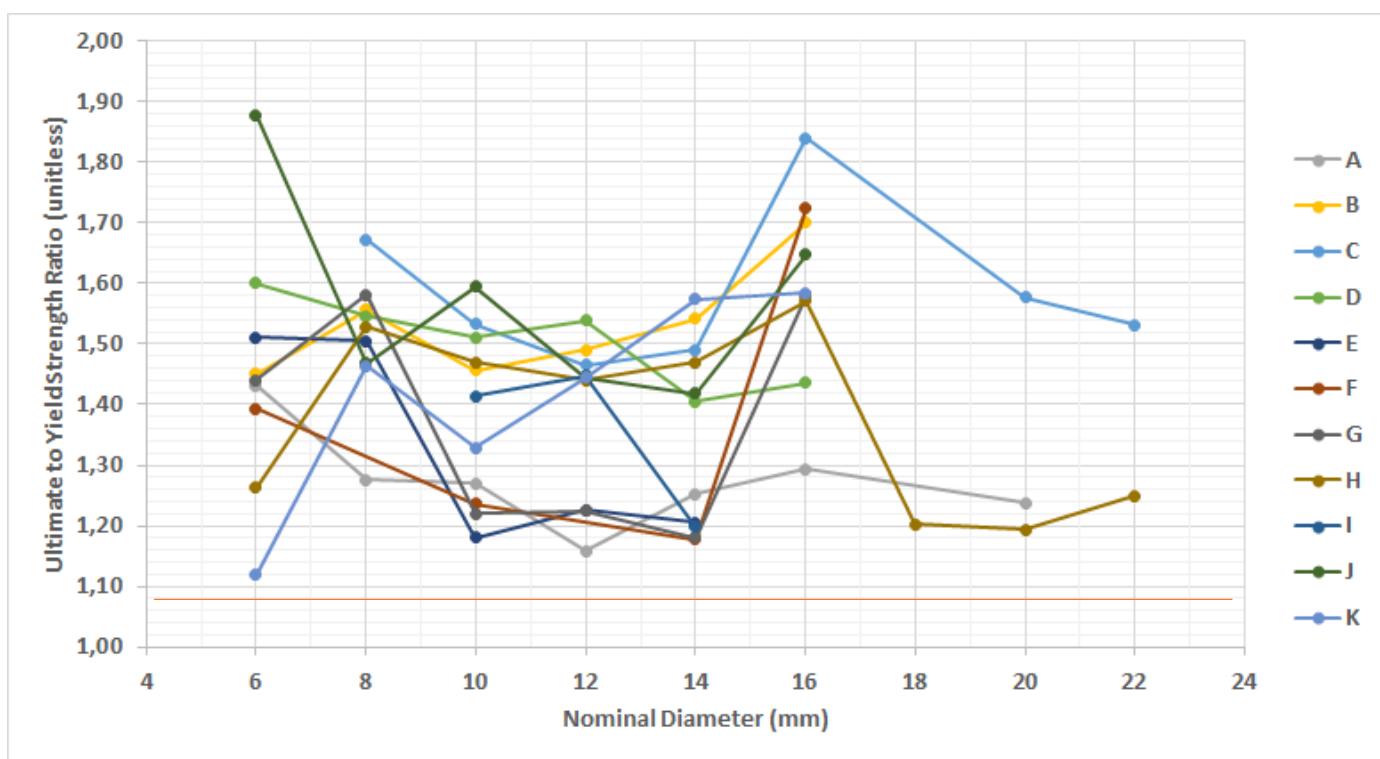


Figure 3| Graphs for Ultimate to Yield Strengths ratio versus Bar Diameters for the 65 specimens tested

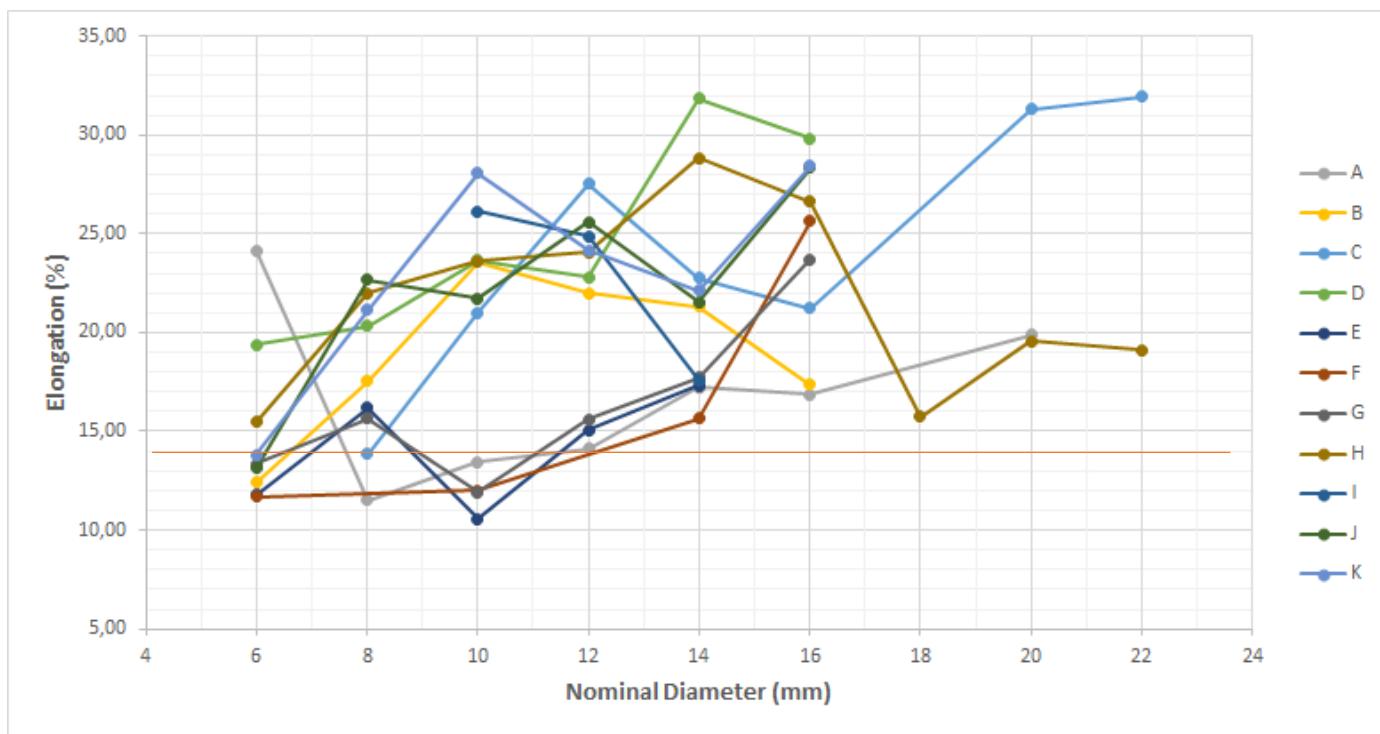


Figure 4| Graphs for Elongation in % against Bar Diameters for the 65 specimens tested

According to [TANNOUS](#) and [SAADATMANESH](#) [1998], the developments in the materials used, manufacturing technique, and quality control may have a serious impact on the properties of reinforcing steel bars products.

Other Parameters

It is necessary to acknowledge or recall that the value of standard deviation determine the skills of the

employees working in the fabrication process reinforcing steel bars in a mill company.

The interval of tolerance value is from 0 to 5. Hence, the high skill personnel employed is illustrated by a small value. Whereas, the value higher than the Code one plus 5 indicates that the people used are of low skills, therefore a lack of quality control in manufacturing can be estimated.

Then, the products can be evaluated either as good or as bad [PECCE et al., 2001; EJEH and JIBRIN, 2012].

Almost seven (7) over sixty-five (65) samples (less than 11%) were examined as good products according to their standard deviation values. None of the companies whose samples were taken fully fulfill the standard deviation criteria.

Table 10| Summarize of Tensile Test Results by Companies and diameters

Reinforcing Steel Bars Diameters (mm)	Companies Designation Marks										
	A	B	C	D	E	F	G	H	I	J	K
6	P	P		P	P	P	P	P		P	P
8	P	P	P	P	P		P	P		P	P
10	P	P	P	P	P	P	P	F	P	P	P
12	F	F	P	F	F		F	P	P	P	P
14	F	P	F	P	F	P	F	P	F	F	P
16	P	P	P	P		P	P	P		P	P
18								F			
20	F		P				F				
22			P				F				

In the **Table 10** above P and F mean partially complied, and fully complied, respectively.

As an overall observation it is noticed that:

- just a few of all specimens tested fulfill totally the code requirements;
- In addition, in respect to the measured diameter most of them failed to satisfied the code requirement values;
- For the reinforcing steel bars of 6, 8, and 16-mm diameters, none of the tested specimens satisfied fully the code requirements;
- The most fully fulfill code requirement are the 12 and 14-mm diameters size;
- Only 16 over 65 specimens (25%) satisfied totally the standard requirements;
- None of the companies did fully comply with all code requirements.

CONCLUSION

Based on the results obtained from the analytical investigation of the present study, the following specific conclusions can be drawn.:

- Only 19 over 65 specimens, less than 30%, complete the code characteristic strength requirement;
- The quasi-totality of the reinforcing steel bars of 6, 8, and 16-mm diameters failed to satisfy the code requirements. It should be known that the first two steel bars are the ones most used in the construction industry of Kinshasa; this may be of great concern.
- All of the reinforcing steel bar samples complied with the minimum ultimate to yield strength ratio as specified by **BS 4449: 1997** code provisions.
- It can be perceived that most of the bar samples

met the minimum code requirements on elongation criteria, 53 over 65 specimens, which is 82%. But specimens from 6mm diameter were the ones that failed the most. This a big concern because this bar is used mostly as stirrups bar. Thus, the ductility requirement is an extremely important parameter to be fulfilled.

- All companies (11) whose samples were collected used unskilled labor in their factory production.

Based on the above analyses the following recommendations are made:

- Steel bars sourced from the open market should not be used for the reinforcement of structural concrete without first subjecting them appropriately to tensile test.
- A constant check and reevaluation by Government agency within the industry is recommended and cannot be over emphasized.
- In exceptional circumstances where measuring the size of bars before use is not practicable, the 8, 10, 12, 14, 16, 18, 20 and 22-mm should be taken as 6, 8, 10, 12, 14, 16, 18 and 20-mm respectively unless actual measurements of the dimensions are carried out.

RÉSUMÉ

Investigation sur la conformité de barres d'armature utilisées dans l'industrie de construction de Kinshasa.

Une étude a été menée pour vérifier le niveau de conformité avec la Norme de barres d'armatures utilisées dans l'industrie de construction de Kinshasa. Pour ce faire, la Norme Britannique **BS 4449 : 1997** a été utilisée. Les barres identifiées sur le marché de Kinshasa, puis testées, proviennent de onze entreprises. Le test de traction était réalisé sur soixante-cinq échantillons sélectionnés parmi les barres les plus utilisées et disponibles sur le marché. Pour chaque échantillon d'une entreprise donnée, dix spécimens ont été testés, soit au total six cent cinquante spécimens.

Après les avoir testés, seuls seize échantillons sur soixante-cinq (25%) ont été jugés conforme à la Norme. Aucune des sociétés ne s'est pleinement conformée à la Norme. En ce qui concerne le diamètre mesuré, la plupart des spécimens n'ont pas satisfait aux valeurs de diamètre nominal requises. En ce qui concerne le critère de la résistance caractéristique, seuls dix-neuf échantillons sur soixante-cinq (29%) répondent aux exigences de la Norme. Tous les échantillons de barres d'armature ont respecté le rapport minimal entre la résistance maximale et la limite d'élasticité, tel que spécifié par les dispositions de la Norme. Cinquante-trois sur soixante-cinq spécimens ont répondu aux exigences minimales de la Norme concernant le critère d'allongement. Cependant, la majorité absolue des échantillons de 6 mm de diamètre n'ont pas respecté ce dernier critère. Par

conséquent, les barres d'armature vendues à Kinshasa ne devraient pas être utilisées sans être testées au préalable, et un contrôle permanent par les structures établies est recommandé.

Mots Clés

Limite Elastique, Ultim, Traction, Caractéristique, Contrainte, Allongement, and Congo.

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WARNING

The authors decline all responsibilities for using any information from this study for other purposes than the current one.

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