Grading of Steel Rebar's used in Cement Concrete Based on Compression Test

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ABSTRACT

Compressive strength test is the most common test carried out on concrete and is considered good enough for design and decision making for concrete and reinforced concrete works. Meanwhile the quality of steel used for reinforcement works is determined by its tensile strength, yield strength, weight and elongation. In addition, the chemical composition content which affects the quality is also determined. However, it is difficult to know all these things for a common man and so a simple test called bend test conducted on site is usually carried out to assess the quality of steel. When bent to make an angle of 90 to 135 degrees and then bent back straight, there should be no cracks on the rebar and its original shape retained once it is straightened, one can be assured that it is of best quality. Even at this the strength of the rebar which informs its Grade cannot be known. Since the compression strength test is universally acceptable for concrete grading, it should be equally universally acceptable for rebars. This informed the authors decision to work and recommend appropriate ratio of height to diameter as 2 for yield stress for circular rebars. Fourteen and twenty four Samples of supposed mild steel rebars and high yield steel rebars where tested in compression. Half of this was tested for height to diameter ratio of 1 and the other half tested for a ratio of 2. The result revealed for a ratio of 2 that the high yield steel where of grade 60 or grade 420 since the average of the stresses for this ratio was 460.01N/mm^2 meanwhile the supposed mild steel was actually medium tensile steel and not mild steel as was reported in the purchase certificate. The result of this study support the grading in ASTM A 615, BS4449, Euro Standard(DIN 488) and Indian Standard (IS: 1786) and compares favorably with recent works.

Key Words: *Rebar, Steel, Grade, Yield Strength, Cement Concrete.*

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1. INTRODUCTION

1.1 Background of study

Steel plays a significant role in the construction industry and nation-building. It is common in Nigeria that that concrete is designed with a reinforcement steel characteristics strength (Fy) of 410N/mm^2 in place of the recommended one of BS 8110 (1-1997) [1] specification of 460N/mm^2, therefore attention should be given to the manufacturing of steel bars used to meet service requirements and examine their mechanical properties of our steel industry which will go a long way in determining the suitability and conformity with standards.

Thus there is a growing concern that rebars being used in sites may have been falling short of the design expectation as stipulated in the standards, because of lack of testing equipment for control and compliance on site.

The outcome of investigations carried out by researchers shows that non-conformance of structural properties of materials and the use of substandard steel rebars are among the other causes of premature failures of structures around the world particularly in many part of Nigeria. Thus, there is a need to investigate the grade of steel bars produced by various steel mills used in Nigeria for conformity with the codes such as BS 4449 (1997)[2], this will help to improve the product quality and as well as limit structural failure of building experience in the country.

Reinforcing Steel possesses several properties however, those whose specifications obtained in the codes like Nigerian Steel Standard (NST.65-Mn. (1994) [3], British Standard (BS4449(1997)[2], American Society for Testing and Materials ASTM, A706. (1990)[4] and many others are the tensile properties, compression test, bend test and chemical composition. Generally, there are

two major forms of steel utilized in finishing up construction works, mild steel and high yield steel bars. Yield strength is the most common property that the designer will be required as the basis used in design codes regulations

The use of a grade by itself only indicates the minimum permissible yield strength, and it must be used in the context of a material specification in order to fully describe product requirements for rebar. In US, the grade designation is equal to the minimum yield strength of the rebar in Ksi (1000 psi) while in the Uk and Europe is equal to the minimum yield strength of the rebar in Mpa for example grade 60 rebar has a minimum yield strength of 60 ksi in the US and is 420 MPa in the UK. Rebar is most commonly manufactured in grades 40, 60, and 75 with higher strength readily available in grades 80, 100, 120 and 150. Grade 60 (420 MPa) is the most widely used rebar grade in modern US construction. Historic grades include 30, 33, 35, 36, 50 and 55 which are not in common use today.

Rebar grades are customarily noted on engineering documents, even when there are no other grade options within the material specification, in order to eliminate confusion and avoid potential quality issues such as might occur if a material substitution is made. Note that "Gr." Or GR. is the common engineering abbreviation for "grade"

Table 1.0: Different grade of steel bars (Source: adapted from gharpedia.com)

Steel Grade	Yield Strength Psi [Mpa]
Grade 40 [280]	40000[280]
Grade 60 [420]	60000[280]
Grade 75 [520]	75000[280]
Grade 80 [550]	80000[280]
Grade 100[690]	100000[280]

To achieve this simple compression test at the point of sale is proposed in this work. This research work covers the investigation of compressive strength of high yield steel bars of diameter 10mm, 12mm,16mm, and 20mm and mild steel bars of diameter 10mm,12mm, and 16mm.

Table 1.1: Grades of Rebar in Different Codes

American Standard (ASTM A 615)[5]	Euro Standard(DIN 488)[6]	British Standard BS4449: 1997[2]	Indian Standard (IS: 1786)[7]
Grade 75 (520)	BST 500 S	GR 460 A	Grade Fe – 415, Fe – 500, Fe – 500D
Grade 80 (550)	BST 500 M	GR 460 B	Grade Fe – 550

Grades in mild steel bars

Table 1.2: Physical Requirement of Mild Steel Bars

Types of Nominal size of bar	Ultimate Tensile Stress in N/mm^2	Yield Stress N/mm^2
Mild Steel Grade I or Grade 60 or Fe 410-S		
For Bars upto 20mm	410	250
For Bars above 20mm upto 50mm	410	240
Mild Steel Grade II or Grade 40 or Fe 410-o		
For Bars upto 20mm	370	225
For Bars above 20mm upto 50mm	370	215
Medium Tensile Steel Grade -75 or Fe- 540-w-ht		
For Bars upto 16mm	540	350
For Bars above 16mm upto 32mm	540	340
For Bars above 32mm upto 50mm	510	330

2.0 MATERIALS AND METHOD

The primary research materials used for this investigation are Mild Steel and high yield Steel Bars. The steel bars were commercially obtained from distributors of two steel company in Nigeria. The Mild Steel bars were purchased from Yongxing steel company situated in Benin City, Edo state while High yield steel from Saba Steel industrial Nigerian limited Kirikikiri Apapa Lagos State Nigeria. The test materials purchased from distributors in Yenagoa Bayelsa State were subjected to compression test.

2.1 Equipment's

- Dial Gauges,
- Measuring Tape,
- Vernier Calliper,
- Spirit Level,
- Weighing Scale
- Proving Ring
- Universal Compression Test Machine.

2.2 Compression Method of Testing Steel

During a compression test, the material experiences opposing forces that push inward upon the specimen from opposite sides or is otherwise compressed. The test sample is usually placed in between two metal bearing blocks that distribute the applied load across the whole surface area of two opposite faces of the test sample, then the plates are pushed along by a Compression machine inflicting the sample to flatten in the case of height to diameter ratio of 1 and 2 respectively. For higher ratio the sample may/will buckle.. (IS 13780, 1993)[8]. The compression strength is evaluated as force applied divided by area of material with an S.I unit of N/mm^2

2.3 Mild steel bar

A total of 18 samples were collected from Yongxing steel company situated in Benin City, Edo state. Each diameters was cut into various length and sample three for compression test.

Table 2.0: Sample collection data for Mild steel

Diameter	Lengths(mm)	
M16	32	16
M12	24	12
M10	20	10

2.4 High Yield steel

A total of 24 samples were collected from Saba Steel industrial Nigerian limited situated in Kirikikiri Apapa Lagos State Nigeria.Each diameter was cut into various length and sample three for compression test.

Table 2.1: sample collection data for high yield steel

Diameter	Lengths(mm)	
H20	40	20
H16	32	16
H12	24	12
H10	20	10

2.5 Samples Labeling

For the purposes of identification samples were labelled with two capital letters high yield steel (**H**) and mild steel (**M**) as assigned with and identifying code bars as illustrated: **H**16**C**1 and **H**16**C**2 and **H**16**C**3 and **M**16**C**1 and **M**16**C**2 and **M**16**C**3. Here H and M means High yield steel and Mild steel Respectively. 16 stands for the rebar diameter and C1,C2 and C3 mean sample 1, sample 2 and sample 3 respectively

2.6 Samples Preparation

A total of 52 samples were tested for compression. The samples preparation was done in accordance to British standard code of practice BS4449 (1997) clause 1.9 and BS4449: 1969 clause 15 respectively.

2.7 Experiment Methods

Laboratory work was carried out at the civil engineering laboratory in Niger Delta University, Amassoma Bayelsa state, Wilberforce Island Nigeria. The compression machine used for this experiment is a 20 tons' machine calibrated through a 30 tons proving ring with a dial gauge attach to the instrument. The compression test was performed on specimens from mild steel and high yield steel bars.

2.8 Compression Test Setup

Figure 1 shows a compression Test on steel bar ongoing

3.0 EXPERIMENTAL DESIGN AND FACTORIALS

3. 1 Compressive Strength or Yield Strength;

 In accordance to BS EN 12390-3 (2009)[9] will constitute the major mechanical test and findings of this investigation. The compressive strength shall be calculated as the ratio of the crushing load at failure (N) to the area of the material being loaded.

$$\text{Compressive Strength (N/mm}^2) = \frac{\text{Failure load(N)}}{\text{Area of material(mm2)}}$$

3.2   Experiment Procedure

Each specimen was measured with a measuring tape and Vernier calliper to determine the Length and diameter of the cross section. The samples were duly label according to their length before testing. The specimen was inserted vertically between the jaws (upper and lower) part of the machine, varied lengths adjustment was made to accurately set to length and then introduce a load which will grip the specimen in the jaws of the machine.

The right-hand side position the compression has the hydraulic jack pump attach to the machine. Apply load by prescribed rate through harden handle steel rod until the load reaches at maximum, which failure occurs and the failure load the machine will stop reading and return to zero. Each samples length was tested for three times and the average failure load was recorded.

3.3 Precaution

The following precaution were taken while carrying out the test to ensure accurate result.

- We ensured the dial gauge was set to zero before loading

- We ensured the steel bar is balanced vertically before loading

- We ensured reasonable distance was taken during reading to avoid the shot out of the steel bars.

- We ensured that the specimen is measured accurately.

- We ensured the specimen is properly placed to meet between the upper and down compression plates.

- We ensured the loading is to be increased gradually.

- We ensured the specimen is placed at the centre of cross head in other to obtain a uniform compressive loading.

The failure load was recorded through the proving ring and the load cell attached to the compression machine immediately the steel bar fails.

4.0 RESULTS AND DISCUSSIONS

4.1 Results

The results of the laboratory work are presented in Table 4.1 to 4.11.

Table 4.1: 10mm diameter Mild steel bar on compression test Showing failure loads and stresses (actual average measured diameter (d) = 9.89mm, area (A) = 97.81mm^2

Length (mm)	FAILURE LOAD (KN)				Stress(N/mm^2)	L/D
	M10C1	M10C2	M10C3	P(Average)		
20	39.00	40.00	38.00	39.00	398.73	2.02
10	75.00	74.00	71.50	73.50	751.46	1.01

Table 4.2: 12mm diameter Mild steel bar on compression test Showing failure loads and stresses (actual average measured diameter (d) = 12mm, area (A) = 144mm^2

Length (mm)	FAILURE LOAD (KN)				Stress(N/mm^2)	L/D
	M10C1	M10C2	M10C3	P(Average)		
24	51.50	52.00	53.00	52.17	362.27	2.00
12	123.00	120.00	118.00	120.33	835.65	1.00

Table 4.3: 16mm diameter Mild steel bar on compression test Showing failure loads and stresses (actual average measured diameter (d) = 15.95mm, area (A) = 254.4mm^2

Length (mm)	FAILURE LOAD (N)				Stress(N/mm^2)	L/D
	M16C1	M16C2	M16C3	P(Average)		
32	90000.00	89000.00	90000.00	89666.67	352.46	2.01
16	140000.0	138000.0	139500.0	139166.6	547.04	1.00

Table 4.4: 10mm diameter High Yield steel bar on compression test Showing failure loads and stresses (actual average measured diameter (d) = 9.75mm, area (A) = 74.66mm^2

Length (mm)	FAILURE LOAD (N)				Stress(N/mm^2)	L/D
	H10C1	H10C2	H10C3	P(Average)		
20	35000.00	35000.00	34000.00	34666.67	464.33	2.05
10	66200.00	64000.00	65800.00	65333.33	875.08	1.03

Table 4.5: 12mm diameter High Yield steel bar on compression test Showing failure loads and stresses (actual average measured diameter (d) = 11.89mm, area (A) = 165.02mm^2

Length	FAILURE LOAD (N)				Stress(N/mm^2)	L/D
(mm)	H12C1	H12C2	H12C3	P(Average)		
24	51000.00	50000.00	52000.00	51000.00	459.34	2.02
12	110000.00	100000.00	99000.00	103000.00	927.68	1.01

Table 4.6: 16mm diameter High Yield steel bar on compression test Showing failure loads and stresses (actual average measured diameter (d) = 15.84mm, area (A) = 197.06mm^2

Length	FAILURE LOAD (N)				Stress(N/mm^2)	L/D
(mm)	H16C1	H16C2	H16C3	P(Average)		
32	91000.00	92000.00	89000.00	90666.67	460.10	2.02
16	135000.00	134500.00	132000.00	133833.33	679.15	1.01

Table 4.7: 20mm diameter High Yield steel bar on compression test Showing failure loads and stresses (actual average measured diameter (d) = 19.60mm, area (A) = 301.72mm^2

Length	FAILURE LOAD (N)				Stress(N/mm^2)	L/D
(mm)	H20C1	H20C2	H20C3	P(Average)		
40	140000.00	136000.00	137000.00	137666.67	456.27	2.04
20	222000.00	221000.00	223000.00	222000.00	735.78	1.02

Table 4.8: High Yield steel bar on compression test Showing failure loads and yield stresses

At L/D of 2

Diameter	FAILURE LOAD (N)				Stress(N/mm^2)	% diff
(mm)	HC1	HC2	HC3	P(Average)		
10	35000.00	35000.00	34000.00	34666.67	464.33	-0.93911
12	51000.00	50000.00	52000.00	51000.00	459.34	0.145649
16	91000.00	92000.00	89000.00	90666.67	460.10	-0.01956
20	140000.00	136000.00	137000.00	137666.67	456.27	0.813026
any					460.01	

Table 4.9: High Yield steel bar on compression test Showing failure loads and ultimate stresses

At L/D of 1

Diameter	FAILURE LOAD (N)				Stress(N/mm^2)	% diff
(mm)	HC1	HC2	HC3	P(Average)		
10	66200.00	64000.00	65800.00	65333.33	875.08	-8.78363
12	110000.00	100000.00	99000.00	103000.00	927.68	-15.3225
16	135000.00	134500.00	132000.00	133833.33	679.15	15.57297
20	222000.00	221000.00	223000.00	222000.00	735.78	8.53314
any					804.42	

Table 4.10: Mild steel bar on compression test Showing failure loads and yield stresses

At L/D of 2

Diameter	FAILURE LOAD (N)				Stress(N/mm^2)	% diff
(mm)	MC1	MC2	MC3	P(Average)		
10	39.00	40.00	38.00	39.00	398.73	-7.42999
12	51.50	52.00	53.00	52.17	362.27	2.39344
16	90000.00	89000.00	90000.00	89666.67	352.46	5.036553
any					371.15	

Table 4.11: Mild steel bar on compression test Showing failure loads and ultimate stresses

At L/D of 1

Diameter	FAILURE LOAD (N)				Stress(N/mm^2)	% diff
(mm)	MC1	MC2	MC3	P(Average)		
10	75.00	74.00	71.50	73.50	751.46	-5.63362
12	123.00	120.00	118.00	120.33	835.65	-17.4683
16	140000.0	138000.0	139500.0	139166.6	547.04	23.10194
any					711.38	

4.2 Discussions

From tables 4.1 to 4.11, it is observed that for ratio L/D of 2 presents less stresses than for L/D of 1. From experience from concrete cubes and cylinders this is expected. The deviation from the average is also very low than for stresses of L/D of 1. The yield stress for concrete cylinders adopted in the euro code and other international codes is L/D of 2 (150mm diameter and 300mm depth), we therefore draw from this to note table 4.8 and table 4.9 have the average stresses 460.01Mpa and 371.15 Mpa respectively are the respective yield stresses of the high yield steel and the supposed mild steel. From table 1.0 the high yield steel is of Grade 60[420] since it is greater than 420Mpa and less than 520Mpa. The result obtained for the mild steel, indicates fom table 1.2 it is a medium tensile steel of grade 75. However it should be noted that these mild steel samples are square in cross section and from cube conformity knowledge the strength is expected to be much higher than those of cylinders. Future work should be directed to address the concluded subject.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion.

From the results of the tests conducted, the following conclusions are made.

i.   The yield stress of a rebar is the value of the maximum stress when a rebar is tested in compression for a sample with ratio of depth to diameter is 2

ii. The yield stress of all the high yield rebar's is $460N/mm^2$ are same compared to the BS4449:1969, 1995 & 1997 standards for high yield steel which is 460N/mm2 minimum

iii. The yield stress of all the mild rebar's is $371N/mm^2$ are greater than $250N/mm^2$ minimum value compared to the BS4449:1969, 1995 & 1997 standards.

iv. The grade of the high yield rebar's is grade 60[420]

v.   The grade of the mild steel rebar's is grade 75[420]

vi. The grade of a rebar can be easily determined at the point of purchase by the simple compression test presented in this paper.

5.1 Recommendation

On the basis of the findings of this study, the following recommendations are hereby made.

1. Future research work should be directed to establishing a conformity between a square and circular rebar using the method presented in this paper

2. Material testing Engineers are advised to use this method because it is very cheap and easy when compared to the tensile testing method.

3. Efforts should be geared towards methods of obtaining many other desired mechanical properties of rebars using the compression method.

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