Characterization of Low Carbon Steel Bar Used For Reinforcing Animal House Building

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Abstract

The quality of the low carbon reinforcing steels bars used in the construction of an animal house in the University of Ilorin premises have been investigated in this research. This was motivated by the fact that it has been noted that the use of the substandard reinforcing bars by construction industry is leading to collapse of many structures in many countries. The selected steel rod (low carbon steel) was subjected to laboratory tensile test and chemical composition analysis using the Universal testing machine and the atomic emission spectrometer respectively. The value of the Ultimate Tensile Stress (UTS) is 673N/mm², the Elastic Limit (EL) is within the range of 383N/mm² - 430N/mm² for all the rods, the yield point ranges between 400N/mm² - 460N/mm², the breaking point is 598N/mm² and the average young modulus is 88.7N/mm. The result were compared with the existing set standards for specified class of reinforcing steel bars and found to be in agreement with the minimum allowable range as specified in the Nigeria Industrial Standard. It was found that the bars had specified value of yield strength and has a minimum carbon content of 0.234%. The percentage of other elements such as Silicon, Manganese, Phosphorous, Sulphur, Copper and Nitrogen were also in agreement with the NIS standard of the elemental concentration.

Keywords: Mechanical Properties, Tensile Test, Yield Strength, Working Stress, Ultimate Stress

INTRODUCTION

The mechanical properties of reinforcing steel bar play a major role in the service life of building structures such as skyscrapers and bridges. Reinforcing steel used for construction works is specified in terms of their yield strength, ultimate tensile strength, percentage elongation. Good assessment of these properties should be ensured, such that their use in construction works meet relevant code specifications (Apeh, 2013).

Huyett, (2004) reported that, steel is the generic term for a large family of iron–carbon alloys, which are malleable, within some temperature range, immediately after solidification from the molten state. The principal raw materials used in steelmaking are iron ore, coal, and limestone. These materials are converted in a blast furnace into a product known as "pig iron," which contains considerable amounts of carbon(above 1.5%), manganese, sulfur, phosphorus, and silicon. Steel is truly a versatile material. About twenty-six different elements are used in various proportions and combinations in the manufacture of both carbon and low alloy structural steels (Ponleet.al., 2014).Steel bars can be grouped as plain bars and deformed bars or rebars according to their surface profiles (Gu et.al, 2016).

Steel exhibits a wide range of mechanical characteristics of which the strength factor is the dominant property (Bernard, 2010). Although the behaviour of steel is greatly affected by its chemical composition, heat treatment and the method of manufacturing, there are some physical properties that determine the behaviour of reinforcement for concrete such as yield strength, ultimate strength, Young's modulus of elasticity, Poisson's ratio and percentage elongation. The structural engineer may seem to be more interested in the physical properties of steel, but these properties, however, cannot be realistically attained without the proper chemical composition of the steel, according to Charles and Mark, (2002).

Generally the methods of producing high quality reinforcing steel bars can be classified into various distinct categories (Buliaminu, 2009), but this research is limited to: Reinforcing steel bars produced by micro-alloying technique. For these bars, the yield strength can be increased by modifying the chemical composition. These are generally ribbed bars.

Reinforcing twisted bars subjected to strain hardening after hot-rolling, for instance by cold deformation. This method enables the production of high strength weld able reinforcing bars from low carbon and manganese steels, but it leads to a decrease of ductility and stress-strain diagram with no yield plateau.

The formal method consist of adding a percentage of alloying element of the molten metal during the production process which produces bars with high yield strength but the process is costly while the later method consist of twisting the bars after been cooled to room temperature which produces bars with high yield strength with low ductility. A thermos-mechanical treatment (TMT) process known as TEMPCORE process can replace the above method due to its advantages of producing bars with yield strength accompanied by a high ductility. The standards for reinforcing bars are set by International Standard Organization and local statutory body. The manufacturing has an effect on mechanical properties of reinforcing steel if the alloying elements are not well controlled. Also the cold working by twisting the bar increase the strength of the bar but reduces its ductility.

Hence, the anticipated variability on the mechanical properties of the steel are affected by the thermo-mechanical processing parameters, chemical composition and heat-treatment, i.e. the steel manufacturing process, according to Ryu (2008). In the Western African region, it is noted that there has been a rapid expansion in building industry and consequently an increase in consumption of reinforcing bars that are either sourced from local mills or overseas sources or a combination of both. While variation in properties of the reinforcing bars is known to exist, attempt to formally compile the information is not there. Not much study has been carried out on the characterization and variability of mechanical properties of reinforcing steels used in the region of this study as it has been done in the western countries. Therefore, the main objective of this research is to test the reinforcing steel bars (from a building construction in a university campus in Nigeria) made from scrap to determine whether their chemical composition and microstructures have influence on their mechanical properties and to investigate how compliant the related properties are with the specified standard values by the authorized regulatory body.

MATERIALS AND METHODS

Materials

Samples for the study are steel rods being use in a building construction. It is referred to as *low carbon steel bar* with a very low carbon composition of ≤ 0.24% and other components.

There were six samples of the steel bar collected from the building construction site of the animal house in the university of Ilorin premises, Ilorin; identified as A, B, C, D, E, and F. The samples were of the same dimensions; length of 20mm and diameter of 12 mm. Samples A, B, C, and D had a tensile strength analysis.

Methods

The specimens were tested using the ***Instron Universal Testing Machine (UTM)*** with a capacity of 600KN. Data for Yield Strength (YS), Ultimate Tensile Strength (UTS) Fracture/Breaking Strength (BS), percentage Elongation (PE) and percentage Reduction area were computed and tabulated. Sample A was experimented and deformed to ***fracture test***, ***within elastic limit test*** was observed on sample B, ***before yield test*** was taken on sample C and ***before failure test*** was carried out on sample D after deformation.

The lathe is a machine used majorly for shaping of metal, wood, or other material. All lathes, apart from the vertical turret type, have one thing in common for all usual machining operations; the workpiece is held and rotated around a horizontal axis while being formed to size and shape by a cutting tool (AIDP, 1988).

The basic lathe that was designed to cut cylindrical metal stock and developed further to produce screw threads, tapered work, drilled holes, knurled surfaces, and crankshafts.
Modern lathes offer a variety of rotating speeds and a means to manually and automatically move the cutting tool into the work piece. The diameter 12mm of the sample steel bar makes a specialized hold down. Due to the fine pitch of the screw threads that move the thimble and the right hand measuring rod, it is easy to use enough force in closing the rods on the object being measured to deform either the rods or the object. A friction Screw is used, which applies just enough torque to rotate the thimble so it doesn't deform the bar or the measuring rod. The turning process was done for the tensile stress to take place.

The chemical composition analysis on sample E was carried out using Atomic Emission Spectrometer (AES) metavision. AES is described by Twyman (2005) as that which involves the measurement of electromagnetic radiation emitted from atoms. Twyman reported that both qualitative and quantitative data can be obtained from this type of analysis. In the former case, the identity of different elements reflects the spectral wavelengths that are produced, while in the latter case, the intensity of the emitted radiation is related to the concentration of each element.

Atomic emission spectrometer determines the element concentration via a quantitative measurement of the optical emission from excited atoms. Thus, by determining which wavelengths are emitted by a sample and by determining their intensities, the analyst can qualitatively and quantitatively find the elements from the given sample relative to a reference standard.

RESULTS AND DISCUSSION

Material Identification

The material identification of the sample low carbon steel 10501 for the color, spacing and quantity of sparks (spark test) produced by grinding are shown in Table 1.

Table 1: Low carbon steel spark grinding test

Volume	Moderately
Length	Long
Color close to wheel	White
Streaks near end of stream	White
Quantity of spurts	Very many
Nature of spurts	Fine repeating

The SAE (Society of automotive Engineers) number of the sample carbon steel is SAE 10234, 1 for type of steel (carbon), 0 for percent of alloy (none) and 234 for carbon content (0.234% carbon).

Chemical Composition Analysis:

The chemical composition analysis of the sample using Atomic Emission Spectrometer (AES) METAVISION is shown in the Table 2.

Table 2: Chemical composition analysis of the sample bar

Element	%	Average
C	0.234	0.2340
Si	0.193	0.1930
Mn	0.633	0.6330
P	0.035	0.0350
S	0.045	0.0450
Cr	0.095	0.0950
Ni	0.119	0.1190
Cu	0.484	0.4840
Nb	0.006	0.0060
Al	<0.0001	0.0001
B	0.002	0.0020
W	0.007	0.0070
Mo	<0.0001	0.0001
V	<0.0001	0.0001
Ti	<0.0001	0.0001
Fe	98.147	98.1470

The main chemical elements that were significantly contributing to the strength of the bars were carbon, silicon and manganese. From the test, the other chemical components were not significant in contributing to the strength of the bar.

Mechanical Test

Tensile test and chemical composition analysis were carried out. Tables 3,4 and 5 show a compilation and data of results of mechanical properties of the sample steel bar A, B, C and D for obtaining Yield strength, Ultimate tensile, Fracture/Breaking strength, percentage elongation and percentage Reduction in Area.

Considering Figure 1, **Sample A** has the ***yield strength (YS)*** of 457N/mm², ***Ultimate tensile strength (UTS)*** of about 673N/mm^2 and the ***percentage elongation at peak***of 87.01%as estimated from the results stated in Tables 3,4 and 5, together with the use of equation 3.5. **Samples B and C** have neither yield strength nor any ultimate tensile strength as a result of the process they undergo, i.e. not being allowed to reach the yield point. The percentage elongations of samples B and C are 22.55% and 24.68% respectively.

Sample D has yield strength of about 393N/mm², which also complies with the standard value specified and has percentage elongation of 74.64%. The average percentage elongation of the samples is 52.22%

The percentage elongation indicates the capacity of the material to be drawn into wire. Having been used in construction, the steel rod that meet the specified standard percentage of elongation will stretch reasonably under load in the construction. Hence, giving room for the extension that may be produced as a result of the applied load, either by other materials around the construction or by the inhabitant of the structure after construction, and without breaking.

It has been pointed out that stress is based on the magnitude and position of application of load, the dimensions of the member, and properties of the material (Ryder, 1969). The working stress (also referred to as maximum permissible stress) is dependent on considerable factors like type of load, dimensions of the member, the character of the material, Hooke's law assumed to apply. Since the samples under study are having the considered mechanical properties within the standard range (as compared in Tables 6 and 7), failure of the steel rods due to working stress is believed not to be experienced. Mechanical failure of steel rods in construction has both social and economic consequences. The *factor of safety* is normally defined as the ratio of the Ultimate tensile stress (UTS) or Yield stress and the working stress, as reported by Ryder, (1969), i.e.

$$\text{Factor of safety} = \frac{Ultimate\ stress}{Working\ stress}$$

The Percentage reduction in area of samples A, B, C and D were estimated to be 53.32%, 56.44%, 53.74% and 53.88% respectively, while the average percentage reduction in area is obtained as 54.35%. Percentage reduction in area is considered to be a better measure of ductility, since it is independent of the gauge length, but elongation and contraction comprises'uniform' and 'local' deformations in proportions depending on the material.

The Young modulus was obtained using equation 3.1 below. For samples A, B, C, and D, we have 81.543N/mm^2, 83.004N/mm^2, 93.234N/mm^2 and 97.004N/mm^2 respectively. The average Young modulus of the steel rod was obtained as 88.69N/mm^2.

Ultimate tensile stress, though less than the true stress occurring in the necked portion, is the stress which a member can stand distributed over its original area and this interests the designer (Ryder,1969).

Table 3: Mechanical properties of the sample steel bar A, B, C and D

Sample type	Applied Force (N)	Stress at breaking point (N/mm^2)	Stress at peak point (N/mm^2)	Stress at upper yield point (N/mm^2)	Young Modulus (N/mm^2)	Strain at upper yield point (%)	Strain after fracture (%)	Time to failure (sec)
FAILURE TEST–for A	35578.000	579.831	673.696	457.469	4988.187	5.312	-99.000	120.817
WITHIN ELASTIC TEST–for B	20001.000	405.986	405.986	404.586	5034.550	4.373	-99.000	27.048
BEFORE YIELD TEST–for C	22288.000	420.317	426.188	426.188	6651.817	4.935	-99.000	37.047
BEFORE FAILURE TEST–for D	28248.000	534.809	541.480	398.596	5097.122	4.016	-99.000	119.353

Table 4: Mechanical properties of the sample steel bar A, B, C and D continues

Sample type	Elongationat Peak point (mm)	Strainat peak (%)	Force at 0.000 %(N)	Strainat Yield point (%)	Forceupper yield point (N)	Stressat yield point (N/mm^2)	Diameter (mm)
FAILURE TEST–for A	17.402	17.401	5.000	5.312	24159.000	457.469	8.200
WITHIN ELASTIC TEST–for B	4.510	4.509	5.000	4.373	19932.000	404.586	7.920
BEYOND YIELD TEST–for D	4.936	4.935	5.000	4.935	22288.000	426.188	8.160
BEFORE FAILURE TEST–for D	14.928	14.925	5.000	4.016	20794.000	398.596	8.150

Table 5: Summary of the analyzed mechanical properties of the sample steel bar A, B, C and D

	Applied Force (N)	Stress at breaking point (N/mm²)	Stress at peak point (N/mm²)	Stress at upper yield point (N/mm²)	Young Modulus (N/mm²)	Strain at upper yield point (%)	Strain after fracture (%)
Minimum value	20001.000	405.986	405.986	398.596	4988.187	4.016	-99.000
Mean value	26528.750	485.236	511.838	421.710	5442.919	4.659	-99.000
Maximum value	35578.000	579.831	673.696	457.469	6651.817	5.312	-99.000
Standard Deviation	6962.764	85.442	123.312	26.622	807.167	0.577	0.000
	Time to failure (sec)	**Elongation at Peak point (mm)**	**Strain at peak (%)**	**Force at 0.000 %(N)**	**Strain at Yield point (%)**	**Stress at yield point (N/mm²)**	**Diameter (mm)**
Minimum value	4.510	4.509	5.000	4.016	19932.000	398.596	7.920
Mean value	10.444	10.443	5.000	4.659	21793.250	421.710	8.108
Maximum value	17.402	17.401	5.000	5.312	24159.000	457.469	8.200
Standard Deviation	6.685	6.684	5.000	0.577	1853.313	26.622	0.127

Tensile test results were analyzed using the following equations:

Young Modulus, YM = $\frac{stress}{strain} = \frac{Fl}{Ae}$, from the ***slope*** of the curve (3.1)

Ultimate Tensile Strength, UTS = $\frac{\text{Maximum Load, ML}}{\text{Nominal Area, A 1}}$ (3.2)

Yield Strength, YS = $\frac{\text{Yield Load, YL}}{\text{A 1}}$ (3.3)

Breaking Strength, BS = Breaking Load, $\frac{\text{Breaking Load,BL}}{A1}$ (3.4)

Percentage Elongation, PE = $[\frac{[(L2 - L1)}{L1}]$ x 100; (3.5)

Percentage Reduction in Area, PRA = $[\frac{[(A1 - A2)}{A1}]$ x 100; (3.6)

Area, (A_1 or A_2) $= \frac{\pi D1^2}{4}$ OR $\frac{\pi D2^2}{4}$; (3.7)

where L_1 is the initial length of the test piece; L_2 is the final length of the test piece; D_1,

initial diameter of piece; D_2, final diameter of piece; A_1, initial area of test piece; A_2, final area of the piece. Length and diameters of the test pieces were measured before and after the test by venier caliper and micrometer screw gauge.

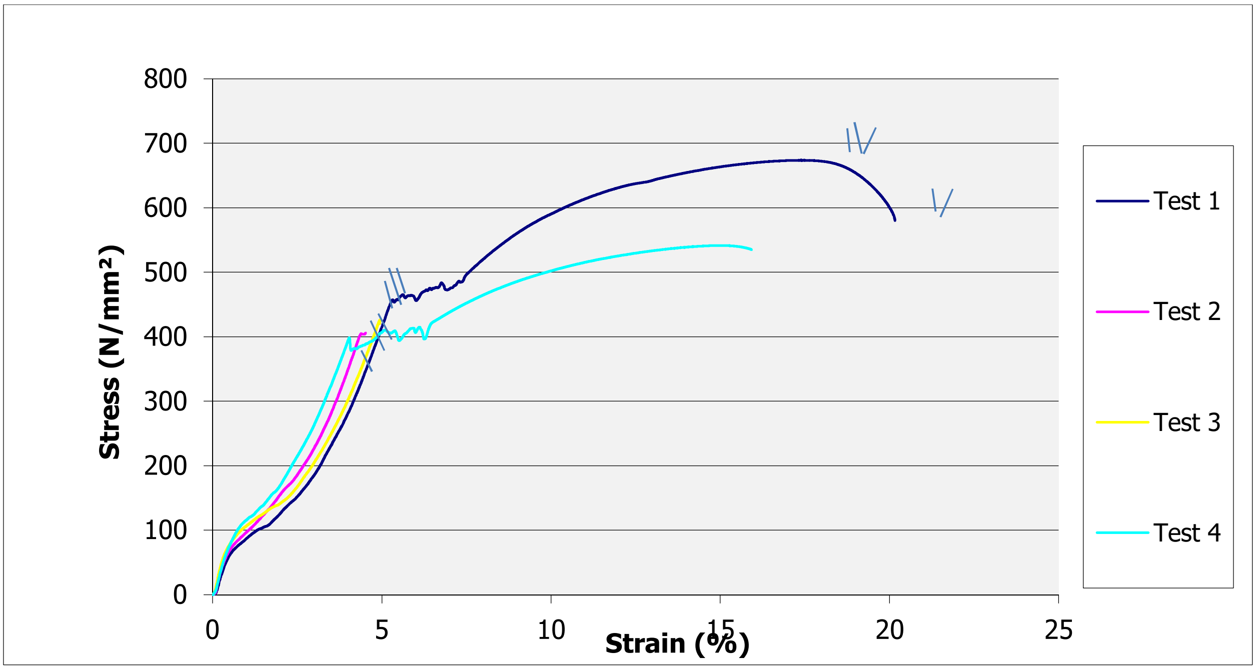

Figure 1: Stress against Strain for the tensile test.

Key: *Test 1, Test 2, Test 3 and Test 4 are for Samples A,B,C and D respectively.*

For mild steel and even low carbon steel, to a varying degree, the behaviour's show the same phenomena. When the tensile load is applied during the tensile test in testing machine used, for the very small strains involved in the early part of the test, the elongation of a measured length (called the gauge length) is recorded. The load is increased gradually, and at first the elongation, and hence the strain, is proportional to the load (and hence to the stress). This relation (i.e. Hooke's law) holds up to a value of the stress known as the *limit of proportionality* (Point I, Figure 1). Hooke's law ceases to be obeyed beyond this point, although the material may still be in the "elastic" state, in the sense that, if the load were removed, the strain would also return to zero. The point II shows the *elastic limit.* If the material is stressed beyond this point, some plastic deformation will occur, i.e. strain which is not recoverable if the load is removed. The next important occurrence is the *yield point* III, at which the rod shows an appreciable strain even without further increase in load. After yielding has taken place, further straining can only be achieved by increasing the load, the stress-strain curve continuing to rise up to the point IV. The strain in the region from III to IV is in the region of 100 times that from 0 to III, and is partly elastic (i.e. recoverable), but mainly plastic (i.e. permanent strain). At this stage (IV) the bar begins to form a local "neck" (see Figure 1), the load falling off from the maximum until fracture/breaking at V. Although in design the material will only be used in the range 0-I, it is useful to examine the other properties obtained from the test.

Comparison with Standard Values

The obtained values for the UTS and YS are higher than the minimum standard values as given by the Nigeria industrial Standards (NIS117-1992), which are 420N/mm^2 and 280N/mm^2 respectively (Table 6), as reported by Buliaminu, 2009. This shows that the steel bars used in the construction are of good quality, as its yield strength and ultimate tensile strength do not fall below the minimum set standards. The percentage elongation also, when compared with the minimum standard value of 18%, is suitable for use. As seen in Table 7, this may be due the relatively moderate low carbon content of the samples which actually reduces the brittleness of the steel rod. The more the carbon content, the more brittle a steel rod is. The carbon content increases, the amount of ferrite present in steel rod decreases while the amount of pearlite increases (Odusote and Adeleke, 2012). When the carbon content of the low-carbon steel reached 0.8 percent, it will entirely be composed of pearlite (with an enhanced ductility).

Table 6: Comparison of the Established values of the mechanical properties with the Standard values

Mechanical properties	Minimum standard values given by NIS117-1992	Established tensile tests values obtained
Ultimate Tensile strength (UTS)	420N/mm^2	673N/mm^2
Yield Strength (YS)	280N/mm^2	457N/mm^2
Percentage Elongation	18%	52.22 %

Table 7: Comparison of the obtained elemental composition of the sample with the Standard values

Elemental content	Minimum standard values given by NIS117-1992	Established chemical analysis values obtained
Carbon, C	0.18-0.24%	0.234%
Manganese, Mn	0.40-0.60%	0.633%

CONCLUSION

The results from the experiments and the analysis are recounted for the sample bars, self-tempered (ribbed bars) taken from a construction of an animal house in University of Ilorin Campus in Nigeria. The results of the tensile strength analysis were then compared with the minimum allowable range as specified by Nigeria Industrial Standards (NIS117-1992). A good number of bars from the building site met the required standard specification. Also, the survey revealed that the major percentage of bars that contractors have been using was of high yield strength.

The results of the chemical analysis were also compared with the minimum required range as specified by Nigeria Industrial Standard NIS117-1992 (carbon equivalent value).

The chemical and tensile analyses showed that the concrete reinforcement steel bars were chemically and mechanically acceptable for use in-house and abroad. The extra strengths obtained from tensile analyses have extended the application of the steel bars to the areas where high strength above the minimum set standard by NIS is required.
It was therefore recommended that the concerned standard regulatory bodies should enforce the laws guiding production and distribution of reinforcing steel rods in the country for optimum safety, as also given by Tunde and Olawumi, 2016; most especially, the quality control department of the agency.

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