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Analysis of the ductility of reinforcement structural steel rods from some local mini mills in Nigeria using theoretical and statistical approach

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Abstract

Analysis of the ductility of reinforcement structural steel rods from some local mini mills in Nigeria using theoretical and statistical approach has been carried out. Ductility is one parameter required of reinforcement structural steels; it prevents sudden failure of reinforced concrete structures. In this work samples were collected from four different mini mills and subjected to tensile test. The initial gauge value of the test specimens was noted. The failed test specimens were then joined together individually to measure the final length at failure and to calculate the % elongation at failure. Stress –strain plots were made to determine the pattern of deformation and failure. The results show that all the specimens have stress-strain curves typical of ductile materials. The % elongation at failure of specimen 3 was the highest at 15.37, the other specimens too all had reasonable % elongation; meaning they are ductile materials. The statistical approach used in the analysis of the work produced results that completely agreed with the theoretical analysis of the work. The statistical analysis used included the use of expected values calculation to select the best ductile specimen, the use of bar chart to show the specimen with the highest % elongation and the one with the lowest value of % elongation, the use of $\chi 2$ to test if all the specimens have the same % elongation or ductility, and the use of spearman rank correlation coefficient to test if the % elongation is associated with the maximum loading of the specimens. In conclusion the work has highlighted the need for structural reinforcement steel bars to have reasonable ductility in order to avoid sudden failures associated with brittle materials, when used in buildings and other concrete structures.

Keywords: Ductility; Reinforcement; Structural steel rods; Mini mills; Theoretical; Statistical

1. Introduction

Ductility is a very important parameter and requirement for structural steel bars used for reinforcement purposes in buildings, and other concrete structures. It has been stressed in several literatures ([1];[2];[3];[4];[5]) that reasonable ductility in structural reinforcement bars or rods prevents catastrophic or sudden failure in buildings and structures, thereby allowing the occupants to take advantage of the warning failure, which would normally start with a crack and gradual sagging of the building or structure ([6];[7];[8]).

Shragger [9], defines ductility as the property that permits permanent deformation by stress in tension without rupture. Ductility determines the level to which a metal can be cold worked without rupture. Examples are wiredrawing and making of curved fenders of automobiles. According to Bolton [8] materials which develop significant permanent deformation before they break are called ductile. A measure of the ductility of a material is obtained by determining the length of a test piece of the material, then stretching it until it breaks and then, by putting the pieces together, measuring

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the final length of the test piece ([10]; [11]). A brittle material will show little change in length from that of the original test piece, but a ductile material will indicate a significant increase in length. The measure of the ductility is then the percentage elongation, i.e

$$\%\ \text{elongation} = \frac{Final - Initial\ length}{Initial\ length}\ x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

A reasonably ductile material, such as mild steel will have an elongation of about 20%, or more. A brittle material such as cast iron, will have an elongation of less than 1%. In this days of building collapse in Nigeria the use of reasonably ductile structural reinforcement rods is important to reduce catastrophic failures ([8];[12]).

According to Lucey [13], statistical analysis or, more simply, statistics deals with quantitative data. Statistical analysis is a scientific method of analyzing masses of numerical data so as to summarise the essential features and relationships of the data in order to generalize from the analysis to determine patterns of behavior, particular outcome or future tendencies ([13]; [14]). Statistical analysis can be applied to problems in Engineering and science and many other diverse fields of study. In this work the objective is to analyze the ductility of structural reinforcement steel bars or rods from some local mini mills in Nigeria using theoretical and statistical approach.

2. Material and methods

2.1. Materials and Equipment

The materials used for the research work were ribbed reinforcement steel bars collected from different mini mills across Nigeria. For this work only 12 mm bars were used. Table 1 shows the samples that were used in the research work. The equipment utilized in the quality analysis of the samples included; files, hack saw, lathe machine, Vernier calipers, protractor, universal strength testing machine.

2.2. Sample Collection

To actualize this project; samples were collected from different mini mills across Nigeria. Only mills with the capability of producing their own billets or rolling stocks from liquid steel produced using scraps were considered in this research work. The mini-mills operating on imported billets were not considered. Table 1 gives details of the location from where samples were collected.

Table 1 Samples of 12 mm Reinforcement steel Bars Collected from Different Mini Mills

Across Nigeria			
S/No.	**Sample Label**	**Location**	**Ribbed Reinforcement steel rod size (mm)**
1	1	Lagos	12
2	2	Abia	12
3	3	Cross-River	12
4	4	Kano	12

2.3. Tensile Test

The only mechanical test carried out on the samples was tensile test. This was informed by the fact that in service reinforcement rods embedded in the concrete structure handle the tensile component of the stress on the structure. The compressive component of the stress on reinforced structures are mainly handled by the concrete cast. The four (4) samples were sent to Mudiame International Limited, Port-Harcourt-Nigeria for the tensile tests. % elongation which is a measure of ductility of the specimen was determined by obtaining the length of a test piece, putting the pieces together after the failure and measuring the final length of the test piece. The % elongation is then calculated as in equation (1). All the samples were tested according to reference code / standard: BS 4449:2015+A3:2016. The results were plotted on graph and tests results were tabulated.

3. Results

The results of the tensile tests are presented in Figs. 1-4, and Table 2 result is the basis for the statistical analysis.

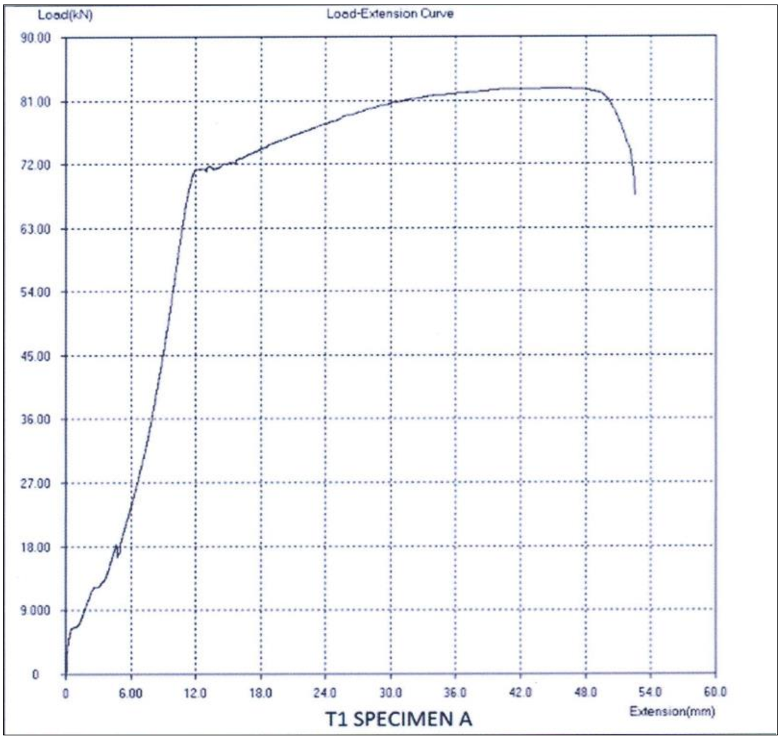

Figure 1 Load-Extension Curve for Specimen 1

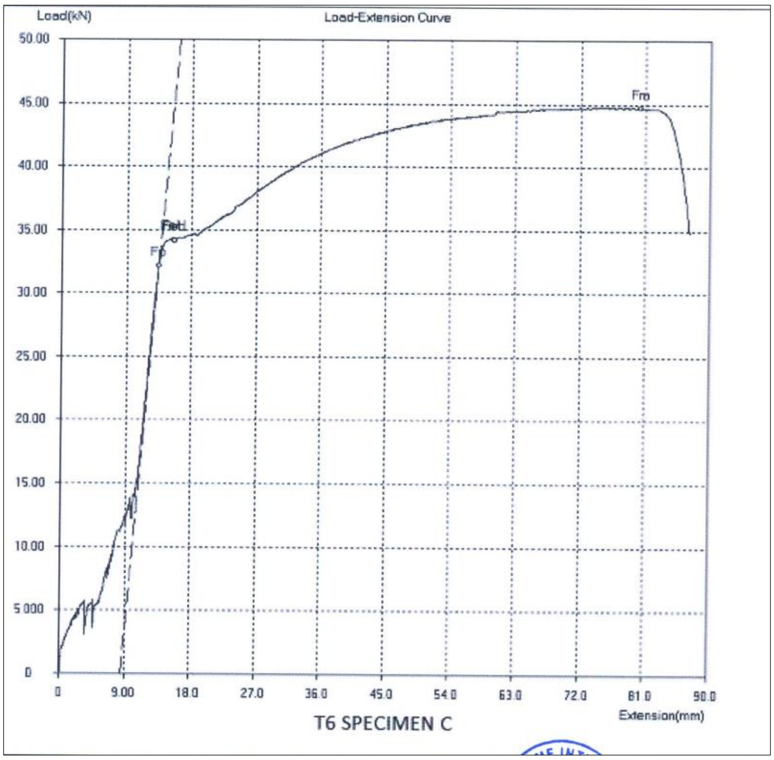

Figure 2 Load-Extension Curve for Specimen 2

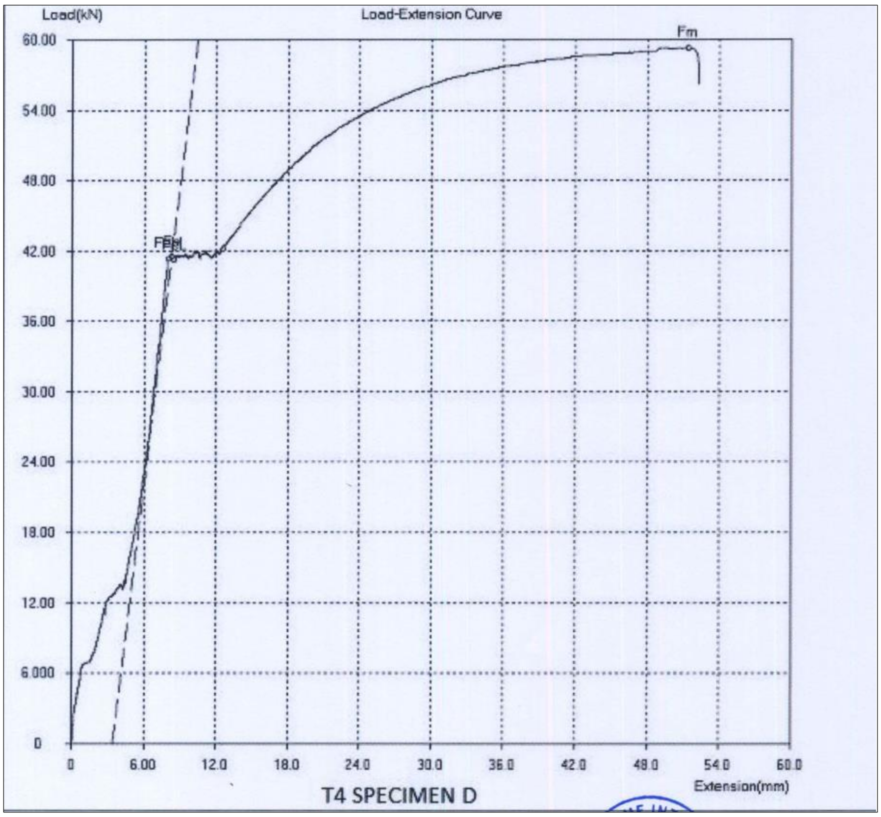

Figure 3 Load-Extension Curve for Specimen 3

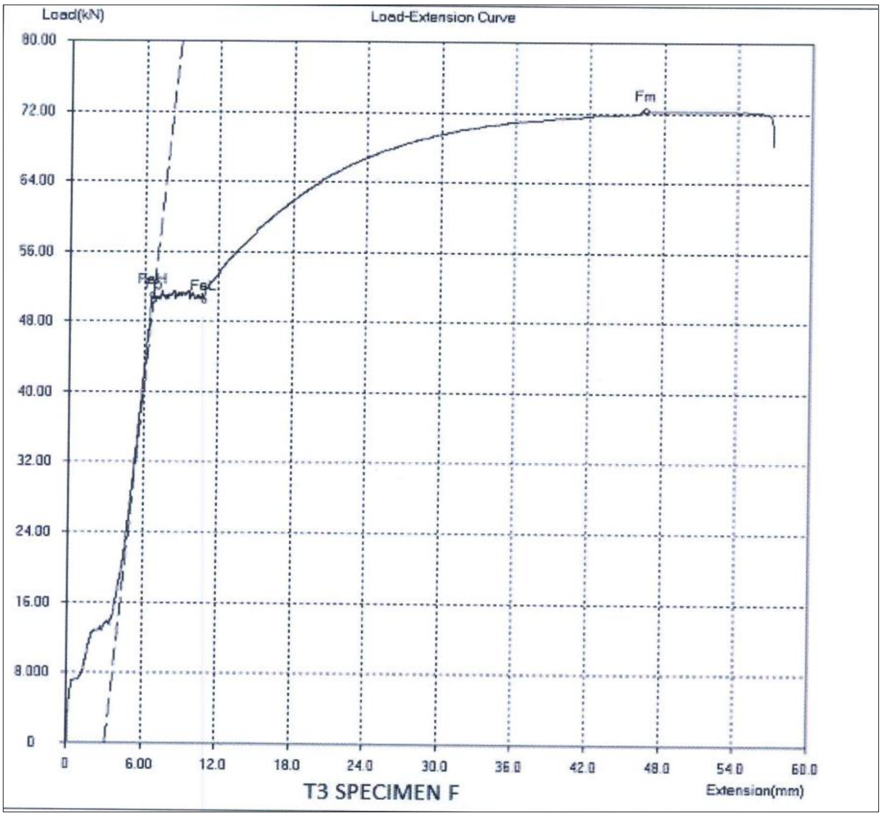

Figure 4 Load-Extension Curve for Specimen 4

Table 2 Tensile Test Results for the Four Specimens

Specimen	Nominal Diameter (mm)	Cross-sectional Area (mm²)	Maximum Load (kPa)	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)	% Elongation at failure
1	12	113.10	82.75	732	630	11.50
2	12	113.10	44.75	396	303	11.71
3	12	113.10	59.30	524	366	15.37
4	12	113.10	72.30	639	451	10.31

4. Discussion

4.1. Theoretical approach

Figures 1-4 represent the stress-strain curve for specimens 1-4. According to Bolton [8] a reasonably ductile material, such as mild steel, will have an elongation of about 20%, or more. A brittle material such as a cast iron, will have an elongation of less than 1%. The specimens used in this work were not dead mild steel, some of them had carbon content well above 0.3%, because of high yield strength and high ultimate tensile strength requirement of the reinforcement steel bars as structural reinforcement steel bars ([6];[1];[15]). As the carbon content increases it affects the ductility but the strength of the steel is increased ([9];[3]). Both ductility and strength are important factors in reinforcement steel bars, however this work focuses on the ductility. Figs 1-4 of the stress-strain curve all exhibit the deformation pattern of ductile materials, which is elastic region, yield point, work-hardening region, ultimate tensile strength corresponding to maximum load, further deformation, necking and final ([8];[3];[4]). Table 2 clearly shows that none of the specimen had % elongation less than one which means that all the specimens are ductile steel materials. Specimen 3 has the highest % elongation of 15.37, followed by specimen 2 which has % elongation of 11.71. Specimen 4 has the least % of 10.31; all the specimens can be said to have reasonable ductility [7];[8].

4.2. Statistical Approach

From Table 2 expected value calculation can be used to select the best ductility. As explained earlier under introduction reasonable ductility is expected in reinforcement steel rods to avoid catastrophic failures in concrete reinforced structures. Table 3 below show expected value calculations of % elongation for four specimens.

Table 3 Expected Values of % Elongation (Ductility)

S/N	Specimen	% Elongation	% Elongation x P	Expected Value (EV)
1	1	11.50	11.50 x 0.2352	2.705
2	2	11.71	11.71 x 0.2395	2.805
3	3	15.37	15.37 x 0.3144	4.832
4	4	10.31	10.31 x 0.2109	2.174

P stands for probability.

From Table 3 the highest expected value is from specimen 3 with expected value of 4.832. Specimen 3 is therefore selected as the best ductile specimen among the four specimens [13].

4.3. Ductility Values using Bar Chart

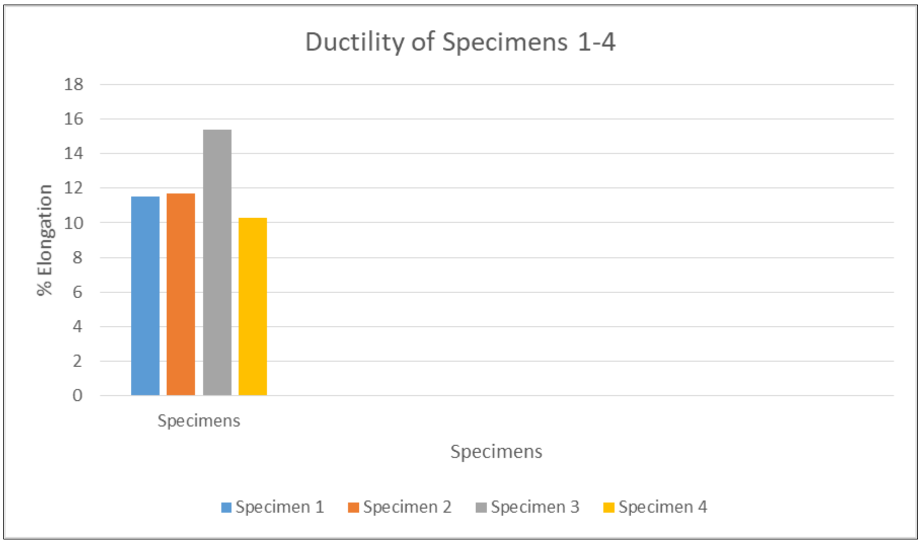

Figure 5 % Elongation of the four Specimens also indicating their level of ductility

The bar chart in Fig. ~~1~~ 5 clearly shows the % elongation of the specimens at failure, this is also the level of their ductility. The chart shows that specimen 3 has the highest level of 15.37 % elongation and the highest ductility ([8];[15];[16])

4.4. Determination of χ^2

Table 4 Gives the actual values of the tensile tests conducted on the specimens

Actual Values					
Specimen	**Max. load (kPa)**	**Ultimate tensile strength (MPa)**	**Yield Strength (MPa)**	**% Elongation**	**Total**
1	82.75	732	630	11.50	1456.25
2	44.75	396	303	11.71	755.46
3	59.30	524	366	15.37	964.67
4	72.30	639	451	10.31	1172.61
Total	259.1	2291	1750	48.89	4348.99

Table 5 is the Table of expected values calculated from Table 4

Table 5 Expected Values

Expected values					
Specimen	**Max. load (kPa)**	**Ultimate tensile strength (MPa)**	**Yield Strength (MPa)**	**% Elongation**	**Total**
1	171	1509	1152	32	1456.25
2	89	783	598	17	755.46
3	103	913	697	20	964.67
4	130	1146	875	25	1172.61
Total	259.1	2291	1750	48.89	4348.99

$$\chi 2 = \sum \frac{(O-E)^2}{E} \ldots\ldots\ldots\ldots\ldots (2)$$

Where,

O = the observed values,
E = the expected values

Table 6 Final Calculated $\chi 2$

Observed values (O)	Expected values (E)	(O – E)	$(O – E)^2$	$\frac{(O-E)^2}{E}$
82.75	171	-88.25	7788.10	45.54
44.75	89	- 44.25	1958.10	22.00
59.30	103	- 43.70	1909.69	18.54
72.30	130	- 57.70	3329.29	25.61
732	1509	- 777	603729	400.10
396	783	- 387	149769	191.28
524	913	- 389	151321	165.74
634	1146	- 507	257049	224.30
630	1152	- 522	272484	236.53
303	598	- 295	87029	145.53
366	697	- 331	109561	157.19
451	875	- 424	179778	205.46
11.50	32	- 20.5	420.25	13.13
11.71	17	- 5.29	27.98	1.65
15.37	20	- 4.63	21.44	1.07
10.31	25	- 14.69	215.80	8.63
Total			$\chi 2$	1862.30

It is required to test at the 5% level, the following hypothesis:

H_0: All the specimens tested have the same level of ductility (% Elongation)
H_1: The specimens tested do not have the same level of ductility (% Elongation)

4.5. $\chi 2$ Table Value

Degree of freedom v = (rows- 1) (columns-1) = (4-1) (4-1) = 9

The value of the cut-off point of $\chi 2$ for 9 degrees of freedom and 5% significance level from the table is 16.919. As the calculated value (1862.30) is greater than the table value of 16.919 we reject the null hypothesis accept the alternative hypothesis which says the ductility of the specimens are not the same. This position agrees with results of Table2, expected values of Table 3 and bar chart ductility values of fig. 5.

4.6. Spearman Rank Correlation Coefficient

The essence of the determination of spearman correlation coefficient is to find out if there is any association between the maximum load and % elongation of the various specimens.

Table 7 Maximum Load and the % Elongation of the various Reinforcement Steel Rods

Specimen	Maximum Load (kPa)	% Elongation
1	82.75	11.50
2	44.75	11.71
3	59.30	15.37
4	72.30	10.31

Table 8 Spearman Rank Correlation coefficient

Specimen	Maximum Load (kPa) Rankings	% Elongation Rankings	d	d^2
1	1	3	-2	4
2	4	2	2	4
3	2	1	1	1
4	3	4	-1	1
			$\sum d^2$	10

$$\therefore\ R = 1 - -\frac{6\sum d^2}{n(n^2-1)} = 1 - \frac{6\ x\ 10}{6(16-1)} = 0 \dots\dots\dots\dots\dots..(3)$$

As the spearman rank correlation is 0, this value lies between +1 and – 1. Positive 1 means a perfect association between maximum loading and % elongation at the point of the specimen failure. Negative one means perfect negative association between the two variables. The calculated value of R from equation 3 is 0, which means there is no association between the maximum load and the % elongation of the specimens. The value of R is correct because whatever, association if there was may have happened at the individual level of the testing of each specimen. In addition the % elongation is normally measured after the maximum load must have occurred, and therefore has no direct effect on the final % elongation, which then is a product of several variations in [9];[1];[8].

5. Conclusion

Analysis of the ductility of reinforcement structural steel rods from some local mini mills in Nigeria using theoretical and statistical approach has been carried out and the following conclusions drawn from the study:

- Ductility is a very important parameter required of structural steels used as reinforcement rod in buildings and concrete structures.
- All the specimens tested have a reasonable % elongation which is the measure of the ductility of the specimens
- Specimen 3 out - performed all the other 3 specimens with % elongation of 15.37.
- The stress-strain curve of all the four specimens have a pattern similar to that of ductile materials
- All the statistical analysis carried out corroborated with the theoretical approach. The statistical analysis used include the use of expected values calculation to select the best ductile specimen, the use of bar chart to show the specimen with the highest % elongation and the one with the lowest value of % elongation, the use of $\chi 2$ to test if all the specimens have the same % elongation or ductility, and the use of spearman rank correlation coefficient to test if the % elongation is associated with the maximum loading of the specimens.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest in this publication, since it is done with the consent of all members concerned.

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