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Conformity of steel rebar used for reinforced concrete in Nigeria to the British Standards' Benchmarks

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Selection of construction materials are normally based on their ability to support design loads all through the service life of the structure to be built. For a reinforced concrete structure, the prime choices fall on the quality of concrete and steel reinforcing bars. Concrete is a composite of cement matrix which fills the space between aggregates and binds them together. Concrete quality fluctuates considerably for various reasons such as immense variability of constituent materials' properties, the skill of the producer, placement procedure and environmental issues. Concrete is universally accepted for its excellent compressive strength. Concrete's poor tensile strength is normally combined with the high tensile strength of steel reinforcing bar, providing a reinforced concrete composite that is universally accepted for construction. Steel is manufactured in specialized plants and the properties are controlled and certified by the manufacturer. The designer is, therefore, more confident in specifying steel quality complying with a relevant standard, while the choice of concrete mixes is not easy. Nevertheless, concrete and steel complement each other, compensating the weaknesses in the properties of the two materials, thereby making it a universal accepted construction material that has built the world's most buildings and infrastructure. But due to the frequent cases of the collapse of reinforced concrete buildings and infrastructure in Nigeria, a study of the properties of steel samples available in Nigeria is essential. The scope of this research is on factors that influence the ductility of reinforced concrete, i.e., the properties of steel rebar. This study considers the yield strength and the chemical properties of the three most common diameters of steel rebar used in Nigeria. The results show some deviations in mechanical characteristics and chemical properties of some of the samples. This confirms that some of the samples fell short of the BS codes' benchmarks for steel rebar.

Keywords*: Concrete, Steel Rebar, Reinforced Concrete, Building Collapse, Ductility, Yield Strength*

1. Introduction.

The Knowledge of the properties of the constituent materials such as steel rebar is vital to avoid fragile collapse. Building collapse is common in Nigeria, but ductile members guarantee ample warning before collapse occurs. Nigeria is one of the nations that suffer the sudden collapse of building structures and low height reinforced concrete structures are the most affected (Ede and Pascale 2016, Joshua et al. 2018). Concrete, the primary material for the reinforced concrete structure is a composite and largely influenced by the constituent materials (Neville and Brooks 1993, Li 2011, Bamigboye et al. 2016, Ede et al. 2016). Efforts in the recent times to make concrete more sustainable have led to a myriad of constituent materials substitution (Olofinnade et al. 2016, Ede et al. 2017, Olofinnade et al. 2017, Ede et al. 2018). Nonetheless, the particular material inclusion that has given concrete its place in history is the inclusion of steel rebar to take care of its greatest weakness of low tensile strength (BS 8110-1 1997). The inclusion of steel rebar embedded in concrete gave rise to reinforced concrete, the second-generation concrete that have found extensive applications in building and infrastructural construction around the world. On the other hand, the use of this proven composite material is faced with frequent brittle failure in Nigeria and many developing nations due to complex property flaws (Bamigboye et al. 2017). One of these intrinsic properties flaw revolves around ductility, the ability to support prolonged deformation, thereby giving adequate warning before failure occurs. Concrete is a very brittle material, which can boast of good compressive strength, but very weak in tension (about 10% of its compressive strength). When reinforced concrete is over reinforced, the steel will not will not yield, and therefore, will remain dormant without developing interlocking bond with concrete. This will not be beneficial when concrete is stressed beyond its' limit, for which ensuring failure mode will be fragile collapse. On the other hand, when the composite is under-reinforced, such that steel rebar attain its yield strength, then there is a better interlocking bond between steel and concrete, such that in case of failure, concrete will still be the component to fail first, but the ductile behaviour guarantees that there will be an ample warning before the collapse occurs. This is more desirable mod of failure, because the occupants can escape before final failure. This research is focused on parameters that influence ductility which in turn reduces the risk of fragile collapse of reinforced concrete structures. The data considered for this research are of two types. The first consisted of mechanical strength and chemical properties of reinforcing steel of high yield steel grade 460 from a steel company in Ikeja, Lagos, Nigeria. The diameter of reinforcing bars considered for the first set of data was of 12mm, 16mm and 20mm. The second set of data considered were rebar from building sites in various parts of Lagos, Nigeria. 16mm steel rebar, the most commonly used for columns of low rise reinforced concrete structures, which are the most prone to a building collapse in Nigeria were considered for the second set of data.

2. Materials and Methods

This research aims to provide benchmarks and give an analysis of the steel rebar. The mechanical strength and chemical properties of reinforcing steel will be carried out. Mechanical strength and chemical analysis of rebar steel were conducted on reinforcement steel samples of high yield steel grade 460 from a steel company in Lagos, Nigeria. The diameter of reinforcing bars considered were of 12mm, 16mm and 20mm, representing the sizes commonly adopted for slabs, beams and columns, respectively. Three samples of each of the three diameters were adopted for mechanical and chemical tests.

The specific parameters of the reinforcement steel measured during the mechanical strength tests were Ultimate tensile strength, Yield strength and Elongation. The equipment used was the universal testing machine of the University of Lagos. The chemical test was made possible with the aid of X-ray fluorescent spectrometer of the Ahmadu Bello University Zaria.

In order to effectively ascertain what is obtainable in building sites of Lagos State, samples of 16 mm diameter rebar obtained from building sites of four Local Government areas of Lagos, Nigeria were also considered. These secondary data consisted of one hundred and eleven (111) samples collected from one hundred and six (106) building sites distributed in four (4) Local Government Areas (LGAs) of Lagos State of Nigeria. The rebars were tested in a standard laboratory according to British Standards (BS 4449 1997) to obtain factors that impact ductilities such as ultimate strengths, yield strengths and elongations. To prevent the collapse of reinforced concrete buildings, the steel yield strength is expected be greater than the design strength prescription of 460MPa (Ede et al. 2014, Bamigboye et al. 2017). For the two set of data, statistical tools were adopted for analysis. Examination of the data will give clues to its conformity to the British Standards specifications for reinforced concrete structures and how much the distribution of data can be correlated to the phenomenon of fragile building collapse especially as it relates to columns which are the most delicate part of a building structure.

3. Results

Results of the data from a steel company in Ikeja Lagos is presented first and then follows the data from building sites of Lagos.

3.1. Results and Discussions of the Samples from IKEJA Steel Company

Table 1 shows the mechanical tests results, while table 2 shows the results of the chemical composition of the samples Ikeja steel company.

Table 1. Result of mechanical tests

Bar diameter (mm)	Sample	Ultimate stress (N/mm^2)	Yield stress (N/mm^2)	Elongation (%)
12	LT121	627	425	14.2
12	LT122	673	464	15.8
12	LT123	518	472	16.7
16	LT161	677	560	11.7
16	LT162	673	575	16.7
16	LT163	722	542	20
20	LT201	704	625	21.7
20	LT202	808	606	14.2
20	LT203	705	462	12.5

Table 2. Chemical composition of samples

Bar diameter (mm)	Carbon content (%)		Manganese content (%)		Sulfur content (%)		Phosphorous content (%)	
	Obser.	BS 4449	Obser.	BS 4449	Obser.	BS 4449	Obser.	BS 4449
12	0.24	0.25 ± 0.02	0.4	0.5 ± 0.05	0.06	0.05 ± 0.005	0.05	0.05 ± 0.005
16	0.27	0.25 ± 0.02	0.6	0.5 ± 0.05	0.08	0.05 ± 0.005	0.06	0.05 ± 0.005
20	0.23	0.25 ± 0.02	0.4	0.5 ± 0.05	0.06	0.05 ± 0.005	0.05	0.05 ± 0.005

Chemical properties of steel include major elements such as Carbon, Manganese, Phosphorus, Sulfur, and Nitrogen. They showed average values of: 0.247% carbon content, 0.467% manganese content, 0.067% sulfur content and 0.0533% phosphorus. The chemical composition values for these elements are very close to the BS 4449 prescription and helped to throw light on the good quality of the steel of the first set of data as proved by good yield strength obtained.

A critical look at the yield strength on table 1 showed that 92% of steel samples tested surpassed BS 4449 code of practice of 460 N/mm2. The steel samples also showed a higher value of chemical content which complimented its yield strength values.

The statistical mean yield strength showed a value of 525Mpa which is well above the design standards. This shows that the high chemical composition of individual element helped to produce high strength. This showed that the adoption of the BS code prescription of 460MPa should be encouraged. The standard deviation of the 67.55 shows that there are conditions however where steel yield may just be a bit below standard. The probability of perfection is never certain though the mean value indicated that the adoption of code prescription is valid.

The mean elongation of (15.94%) is above the code specification of (14%). The deviation from the prescribed ductility limit will be linked to the higher chemical composition verified. Studies have shown that an increase in carbon content mainly increases the hardness of steel and leads to a decrease in ductility. Ductility is very vital for reinforced concrete structures as it enables the structure to deform in such a manner to show adequate sign of impending failure. This in contrast to fragile behavior which is often very catastrophic. The mean ultimate tensile strength of 678MPa tends to show that the steel samples will have high tensile strength.

As observed in Tables 1 and 2, it can be seen that the chemical makeup of steel dictates the mechanical strength. The yield strength is highly influenced by carbon content and other elemental makeup.

3.2. Results and discussions of samples from building sites in Lagos

Figures 1 to 4 present the analysis of one hundred and eleven (111) samples collected from one hundred and six (106) building sites distributed in four (4) Local Government Areas (LGAs) of Lagos State of Nigeria.

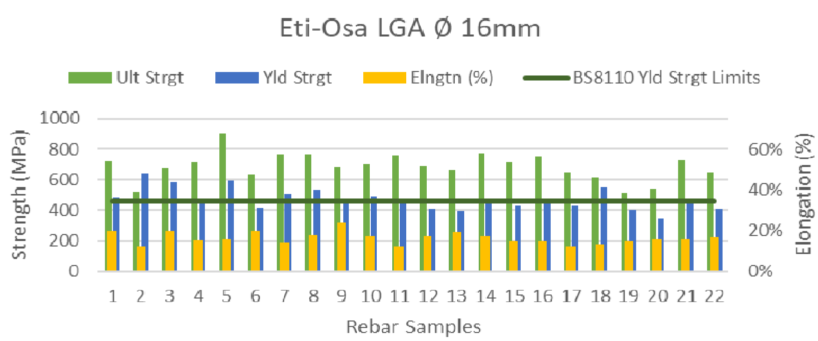

Figure 1. Rebar Ultimate strength, Yielding Strengths and Elongations for Eti-Osa LGA's samples

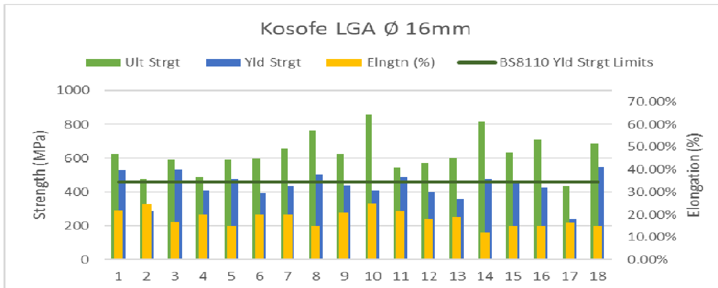

Figure 2. Rebar Ultimate strength, Yielding Strengths and Elongations for Kosofe LGA's samples

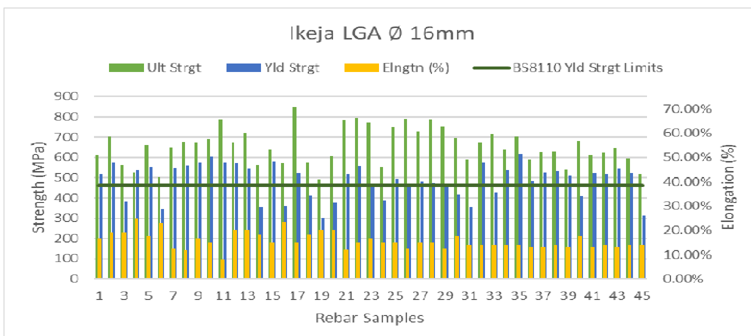

Figure 3. Rebar Ultimate strength, Yielding Strengths and Elongations for Ikeja LGA's samples

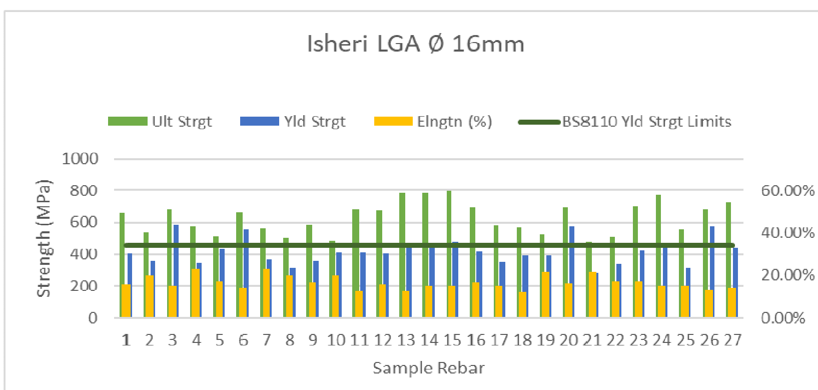

Figure 4. Rebar Ultimate strength, Yielding Strengths and Elongations for Isheri LGA's samples

From the analysis of these data from building site, it can be verified that samples *showed 36% non-conformity of yield strength for figure 1, 44% for figure 2, 28%* for figure 3 and 70% for figure 4. Elongation exceeded the code specification of 14% in almost all the samples.

Comparing the 8% non-conformity of yield strength for the first data set to the high values obtained for all the second data set, it very obvious that what is obtainable in practice is very far from the code specification. That shows that the risk of building collapse is very high, based on the high level of non-conformity of the yield strength rebar samples obtained from the construction sites. It is possible that the company that provided samples of data set 1 might be among the few companies that adhere to the code specification, while many other undergrounds are out there supplying defective reinforcing bars to the market.

4. Conclusion

The results of two sets of data of reinforcing steel bars used in reinforced concrete structures were presented in this research. Chemical and mechanical tests of the first set of data showed good traits to achieve conformity to the British Standards. Analysis of the second set of data shows a very high rate of deviation from the code specifications. This result will help to forecast the risk of non-ductility of reinforced concrete structures constructed within the considered Local Government areas and help to control the risk of brittle Building Collapse that is rampant in some part of Lagos State of Nigeria. This result will help researchers and design engineers in formulating new design criteria for safer, more resilient and sustainable reinforced concrete structures in Nigeria. It will also aid the work of regulatory bodies in controlling the quality of steel manufactured for reinforced concrete structures and the monitoring agencies in enforcing design codes in building sites.

It is recommended that the government and monitoring agencies take a closer look into the steel industry of the country and on the quality of imported steel products into the country. Closer monitoring of the quality of rebar adopted for various structural elements is essential.

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