Experimental Investigation of Yield Strengths of Steel Reinforcing Bars Used in Nigerian Concrete Structures

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Abstract - Concrete is the most widely used construction material in the world and is best used in conjunction with reinforcing steel for optimal results. But a lot of behavioral and durability issues affect the performance of this composite material. The level of understanding of these durability issues depends on the sophistication of the environment of application of the material. In the developing nations such as Nigeria, where the incidence of building collapse is very frequent and over 95% of the cases of collapse affect reinforced concrete structures, a lot need to be done to understand effectively the true causes of the building collapses. Among these include the behavior of the reinforcing steel adopted in Nigerian construction industry. This research evaluates the behavior of reinforcing steel used in Nigerian concrete structures. The research considers the test results of 12mm and 16mm reinforcing bars adopted for structural purposes within Lagos State environment which have experienced the most cases of building collapse in Nigeria. A total of 433 samples from sites located in 10 Local Government Areas of Lagos State were analyzed with statistical tools. About 42% of the 12mm bars and 46% of 16mm bars failed to meet the BS code prescription of 460N/mm^2 yield strength and about 28 % and 33% of 12mm and 16mm bars, respectively, failed to meet the Nigerian's professional's prescription of 410N/mm^2.

Index Terms— Collapsed Buildings, Ductility, Reinforced Concrete, Steel Reinforcement, Yield Strength

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1 INTRODUCTION

Concrete is the most widely used construction material in the world and is mostly used with steel reinforcements giving rise to reinforced concrete material. This composite material in which cement acts as the matrix to absorb compressive stresses, protect the reinforcing steel bars and redistributes loads has the steel bars embedded to absorb the tensile stresses. Concrete is fragile in nature while steel is very ductile which makes the two material very complementing as building materials. Reinforced concrete design concept which was originally developed with steel as the main tensile stress bearing component is beginning to see a lot of innovations with the recent introduction fiber reinforced polymer (FRP) as a substitute for steel [1]. The vast adoption of steel reinforcement is attributed to good ductility, compatibility of the thermal coefficients of concrete and steel, good bonding that enhance stress transfer between the materials and versatility of applications.

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The optimal use of reinforced concrete has many durability issues to be resolved depending on the quality of constituent material, the production process, the environment of applications and conditions of exposure. The level of understanding of these durability issues depends upon the sophistication of the environment of application of the material. In the developing nations such as Nigeria, where the incidence of building collapse and infrastructural decay is very frequent [2], a lot need to be done to understand effectively the true causes of these structural failures.

To proceed further in this research, a look is taken on the two principle materials used in reinforced concrete structures, i.e., the normal concrete and steel reinforcing bars and on the reinforced concrete as a building material.

2. MATERIALS AND METHOD

2.1 Properties of Reinforcing Steel Bars

Steel has the same high strength in tension and compression and it is ductile. Ductility is the ability to undergolarge plastic deformation before failure. Steel that has yielded sustains cracked concrete and helps reduce the risk of sudden collapse as there is an ample warning before failure. The main issues that affect the performance of reinforcing steel bars are the characteristic strengths, concrete cement bond and the condition of exposure which is the sole determinant of the durability of reinforced concrete structures. Based on the conditions of exposure and environment, the amount of cover concrete over steel reinforcement influences the durability of reinforced concrete [3]. This is greatly influenced by the rates at which oxygen, carbon dioxide, chloride ions and other potentially deleterious substances penetrate the concrete, and the concrete's ability to bind these substances [4]. The degree of exposure anticipated for the concrete during its service life together with other relevant factors relating to mix composition, workmanship and design are normally considered for reinforced concrete structures. One of the measures known to improve the durability of concrete is the cover to embedded reinforcing steel. Choice of the cover to steel considered at the design stage is more often than not based on environmental conditions determined in function of degree of exposure anticipated for the concrete during its service life. The protection of the steel in concrete against environmental degradation depends upon the alkaline environment provided by an adequate thickness of good quality concrete. Table 3.4 of the BS 8110 code contains the nominal cover to steel reinforcement to meet specified periods of fire resistance. For beams, the cover thickness increases in proportion to the increasing size of the beam and the fixity at the supports, but must not exceed certain value to avoid adding unnecessary self-weight that could lead to other problems.

The design strength of steel reinforcement used in concrete structures in Nigeria is 460N/mm^2 based on the BS code and the specification is to be determined according to [5].

2.2 Properties of Concrete

Concrete is the most used civil construction material and has significantly influenced the nature of most civil engineering projects. Concrete is in itself a composite material made of cement, fine aggregates (sand), coarse aggregates, water, mineral admixtures and chemical admixtures.

It could be expressed broadly using four of its properties workability, cohesiveness, strength and durability and is characterized by three different states: plastic, setting and hardened state. Durability of concrete is duly a function of design, grade of concrete, cement content of the mix, methods of construction, maintenance, conditions of exposure and environment [4].

Most concrete is specified to meet special requirements such as strength, workability and durability under normal conditions of exposure and at times may be required to have special properties or to resist more severe conditions of exposure such as resistance to thermal cracking, wear resistance, improved fire resistance, very high strength, surface finishes and light weight. The most common defect that occurs in concrete is cracking due to the weak tensile strength. It therefore represents an intrinsic property of concrete. This weakness is normally absorbed by the reinforcing bars. Cracking of concrete affects the appearance, in some cases affects the structural adequacy and durability. Cracking can occur as plastic shrinkage cracks or it could be also caused by movement of formworks. It could occur in the form of crazing which resembles a map pattern. It extends through the surface, caused by minor shrinkage as a result of drying conditions. It is avoided by good finishing and curing. Honeycombing occurs when too much coarse aggregates appear on the surface with cavities underneath. This occurs as a result of poor compaction or if a bony mix is used without enough sand. Corrosion of reinforcement's barsoccurs when cover concrete is not adequate or is badly placed. The grade of concrete suitable for a particular structure should be selected to provide an appropriate degree of durability as well as strength. The relevant quality that meets these criteria will depend on both the constituent materials and mix proportions. The design strength conventionally prescribed for concrete structures is the 28 days compressive strength.

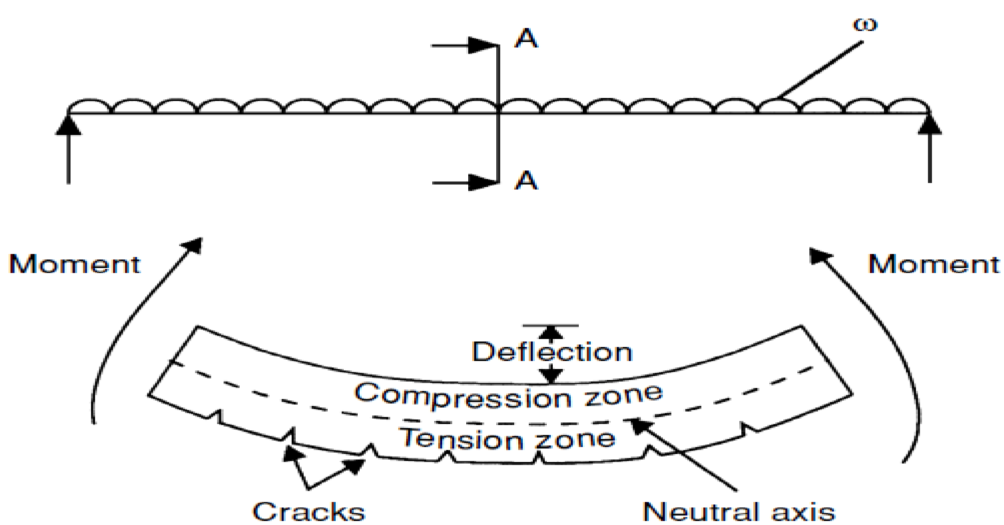

Fig. 1: a uniformly loaded simply supported beam under flexure [6].

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2.3 Reinforced Concrete Design

According to the reinforced concrete code used in Nigeria [4], the aim of design is the achievement of an acceptable probability that structures being designed will perform satisfactorily during their intended life. With an appropriate degree of safety, they should sustain all the loads and deformations of normal construction and use and have adequate durability and resistance to the effects of misuse and fire. It is assumed that the quality of the concrete, steel and other materials and of the workmanship adopted is adequate for safety, serviceability and durability. The design should satisfy the requirement that no ULS is reached under the worst combination of ultimate loads.

In the simplest case of a simply supported, singly reinforced, rectangular beam subject to a uniformly distributed load ω as shown below in Fig. 1, all the tensile stresses in the member are assumed to be resisted by the steel reinforcement. Under uniform load, the tensile stress in the reinforcement will assume an elasto – plastic forma as in Fig. 2.2 of [4] while the concrete in compression will assume a parabolic form of the stress–strain relationship as in Fig. 2.1 of [4].

The actual stress distribution at a given section and the mode of failure of the beam will depend upon whether the section is under-reinforced or over-reinforced [6]. If the section is over-reinforced the steel does not yield and the failure mechanism will be crushing of the concrete as the compressive strength is exceeded. If the section is under-reinforced, the steel yields and failure will again occur due to crushing of the concrete after ductile behavior that provides ample warning signs of failure.

Over-reinforcing is uneconomical and could lead to a more catastrophic collapse as there may not be warning of impending failure while under-reinforcing is more economical since a greater proportion of the steel strength is utilized and the behavior is ductile. As steel is expensive and ductile structures provide warning before failure, it is therefore normal practice to design sections which are under-reinforced as it meets the two basic requirements of safety and economy needed for designed structures.

Fig. 2 shows a combined strain diagram for concrete and steel valid for ultimate limit state design. The mechanism of collapse at the ultimate limit state and the corresponding equations of equilibrium vary in correspondence of the eccentricity of the normal force applied and on the ratio of the area of steel reinforcement to the concrete area. Zone "1" corresponds to a section under pure tension stress and collapse will occur for the attainment of limits in the reinforcements. Zone "2" corresponds to section under bending which fails for the attainment of the limit of tensile reinforcement (collapse of tensile reinforcement), while the deformation in concrete varies between the minimum and maximum values. The collapse within this region occurs in a very fragile mode and is caused by a very low level of tensile reinforcement. Zone "3" corresponds to section under bending for which the tensile reinforcement is in the phase of plastic behavior. The collapse occurs for the attainment of maximum deformation in concrete.

The failure is of a ductile type and corresponds to normal percentage of reinforcement. This is the most favorable mechanism of collapse and all designs should be geared towards the behavior of this zone. Line "b" corresponds to balanced design for which the collapse should be attained for the contemporaneous attainment of limit of deformation in the two materials. Zone "4" corresponds to a situation where the tensile reinforcement is working in the elastic phase and the collapse will occur for the attainment of collapse in the concrete. This leads to a fragile collapse and corresponds to an excessive percentage of tensile reinforcement. Zone "5" corresponds to a completely compressed section with little or no ductility. The limit of neutral axis adopted in the design of beams (x= 0.45d) is indicated in the diagram.

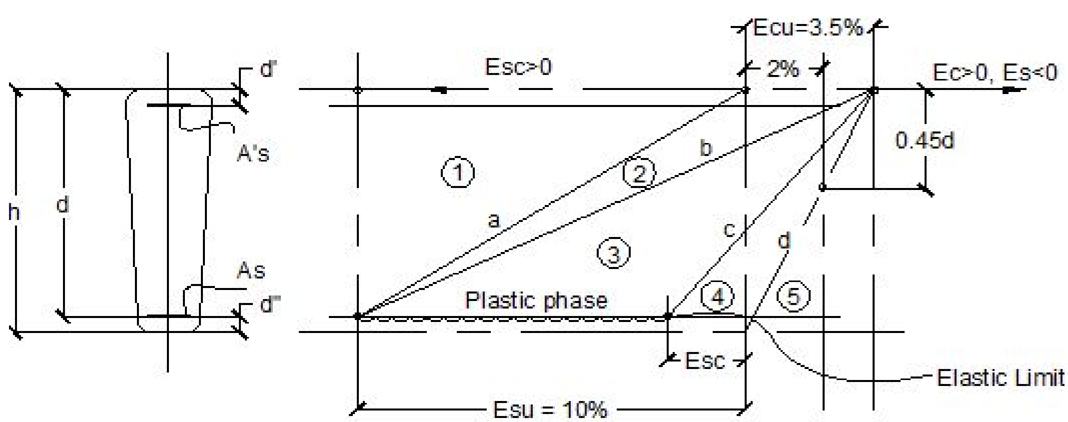

Fig. 2: combined strain diagram for reinforced concrete design.

Having introduced the concrete and steel materials and the design process for good reinforced concrete structural product, it is now necessary to look at the situation on ground in Nigeria. Most structures in Nigeria are concrete structures, principally in the form of reinforced concrete frames for buildings, pre-stressed concrete for bridges and sand-crate bricks for walls and for mono-storey buildings. In the past 30 years, the incidence of building collapse have been very rampant in Nigeria and over 95% of building collapse verified in Nigeria affects concrete structures [7]. This situation calls for a more elaborate study on the properties of the constituent materials used for reinforced concrete structures in Nigeria. This research focuses on the behavior of reinforcing bars used in Lagos State which is the area that has experienced the greatest phenomenon of building collapse in Nigeria. Reinforcing steel bars are chosen for this research since scanty information on the true performance are available to the structural designers.

One big problem affecting steel products used in Nigeria is lack of correct information on available resources.There is no structured market and so it is very difficult to guarantee the quality of products and it is very challenging for the designer to identify the right properties for use in designs. The Nigerian market is infested with steel products from different countries, manufactured and tested according to different codes. From cost point of view, Chinese products are cheap, but the qualities cannot be guaranteed. Another problem is the use of foreign codes, the BS codes (which are no longer being updated as Euro code is the only valid code in the whole Europe). The conflict of design codes is then compounded with the conflicts of testing codes for both local and imported steel materials which sums up to create big problem for the designer and ultimately affect the quality of Nigerian built structures. In the recent years, many researches have taken place on the behavior of reinforcing steel adopted in Nigerian building industry and neighboring West African countries. The use of substandard steel reinforcement in reinforced concrete structures has been hypothesised as one of the most significant cause of building collapse in Nigeria [8]. The research investigated the mechanical of 12mm diameter steel bars commonly used for reinforcing floor slabs and of the nine samples considered, only about 30% had acceptable tensile strength. [9] researched on 19 samples of the most common diameters often adopted for structural purposes (8, 10, 12, 16, 20, 25 mm diameters), focusing much on the sources (foreign and made in Nigeria) and tested them for yield and ultimate strengths according to the provisions of [5]. This research showed that all the samples considered possessed diameters lesser than the true value and that majority of the samples failed to attain the min characteristic strength prescribed by the BS code. [10] used optical emission spectrometer to carry out chemical analysis and optical microscopy to examine microstructures of three samples of reinforcing steel bars obtained from three collapsed cites in Lagos. Most of the properties checked failed the prescriptions of [5] and [11] indicating the brittle nature of reinforcing bars adopted in Nigeria and reinforcing the hypothesis of steel bars contributing significantly to the collapse of buildings for the evident lack of ductility. [12] studied the physical and chemical properties of reinforcing steel bars milled from scrap metal in Ghana. The result of this research showed limited ductility which is not good enough for reinforced concrete structures as it make the members to be brittle and very unsafe under cyclic loadings.

Due to the fore mentioned problems affecting steel products available in Nigerian market and the limited nature of the samples considered in the previous researches cited above, this research considers a vast number of samples of 12mm and 16mm diameters steel bars used for buildings in almost every Local Government Area of Lagos State within a year. 12mm and 16mm diameters steel bars were chosen because they form the bulk of diameters most used for structural applications in buildings and therefore the diameters supposed to have been used in the most collapsed building is Nigeria. The sources of the steels considered here are those available in Nigerian market which various clients adopted for various structures in Lagos State and were tested in material testing laboratory within the State.

2.4 Method

The steel data considered here are those available in Nigerian market which various clients utilized for various concrete structures in Lagos State and were tested in a material testing laboratory within the State. The data were collected from various construction sites in different Local Government Areas of Lagos State where the steel materials were used. The data consisted of diameter of bars tested, average ultimate stress, average yield stress and the elongations. Of these data, only the 12mm and 16mm diameters steel bars were chosen for this research because they form the bulk of diameters most used for structural applications in buildings and therefore the diameters supposed to have been used in the most collapsed building is Nigeria. Statistical methods of analysis were adopted for this research and the results are presented below.

3. EXPERIMENTAL RESULTS

The result presented here is that of the 10 Lcal Government Areas are of Lagos State with the greatest adoption of 12mm and 16mm diameter steel reinforcing bars. Fig. 3 shows the distributions of the yield strengths of 148 samples of 12mm steel reinforcements obtained from different construction sites within Lekki Local Government Area, which is the local area with the greatest concentration of work in progress for the period considered while Fig. 4 shows the distribution for 143 samples of 16mm bars for sites from the same area. The large number of data for sites in this area permits a very clear vision of the yield strength distribution of the reinforcement adopted from different sites. The data are arranged such as to show the samples that met the code prescription of 460N/mm^2 and those that failed to meet up. On the left side till the single value indicated shows the samples that failed, while from the values after the highlighted yield strength to the extreme right shows the samples that passed. Fig. 5 shows the failure rate of 12mm samples used in the 10 Local Government Areas of Lagos State chosen for this research while Fig.6 shows the failure rate of 16mm samples. Figs. 7 and 8 show the pass and the failed samples for the selected areas respectively. Fig.9 shows the distribution of all the 433 samples data of 12mm and 16mm bars considered in this research.

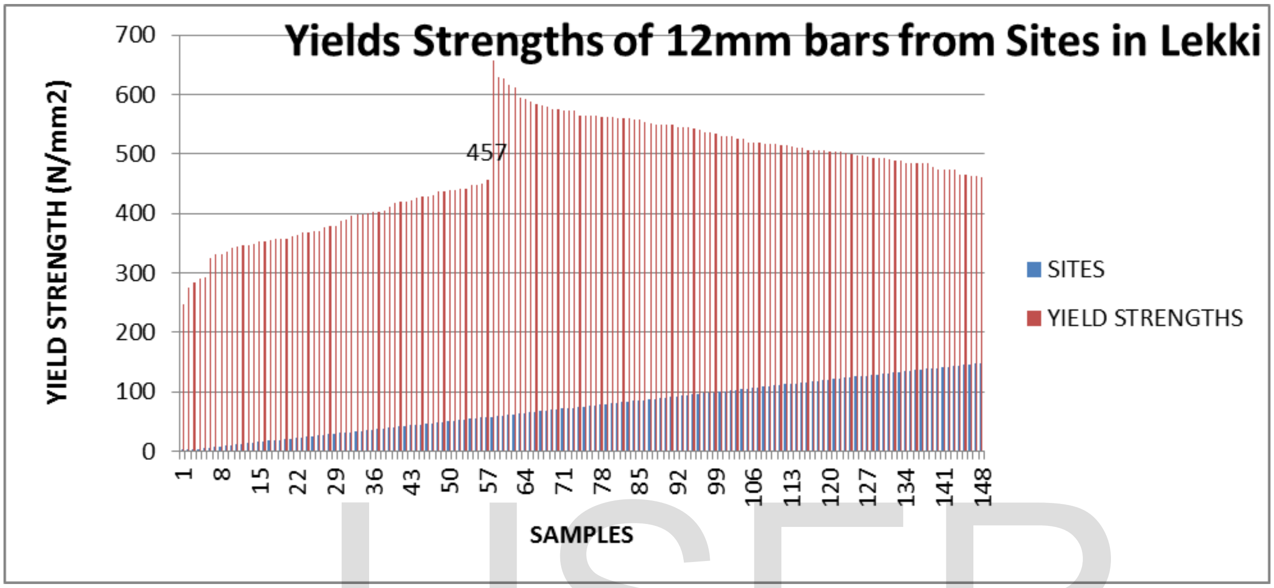

Fig. 3: Yield Strengths of 12mm samples from sites in Lekki Local Government Area

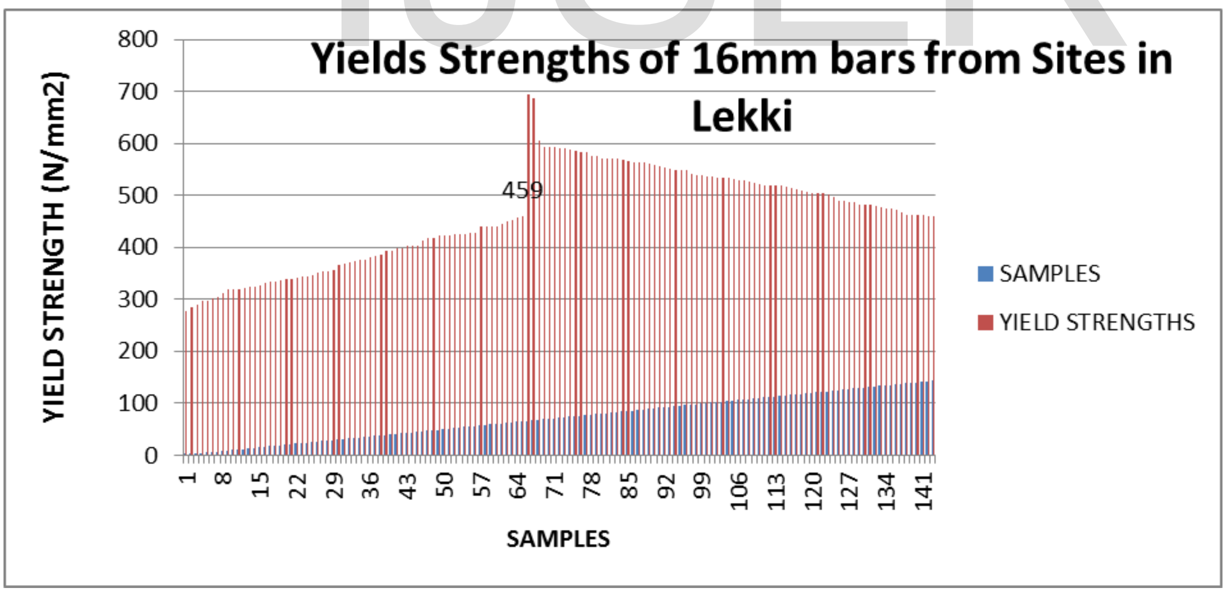

Fig. 4: Yield Strengths of 16mm samples from sites in Lekki Local Government Area

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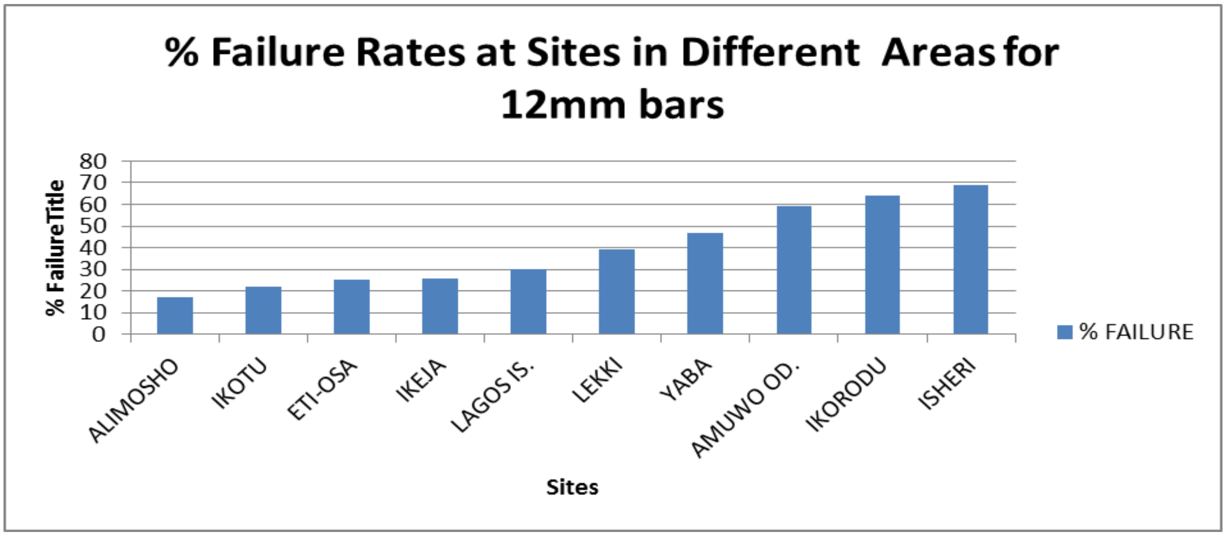

Fig.5: Percentage failure rate for 12mm bars at sites within the selcted areas

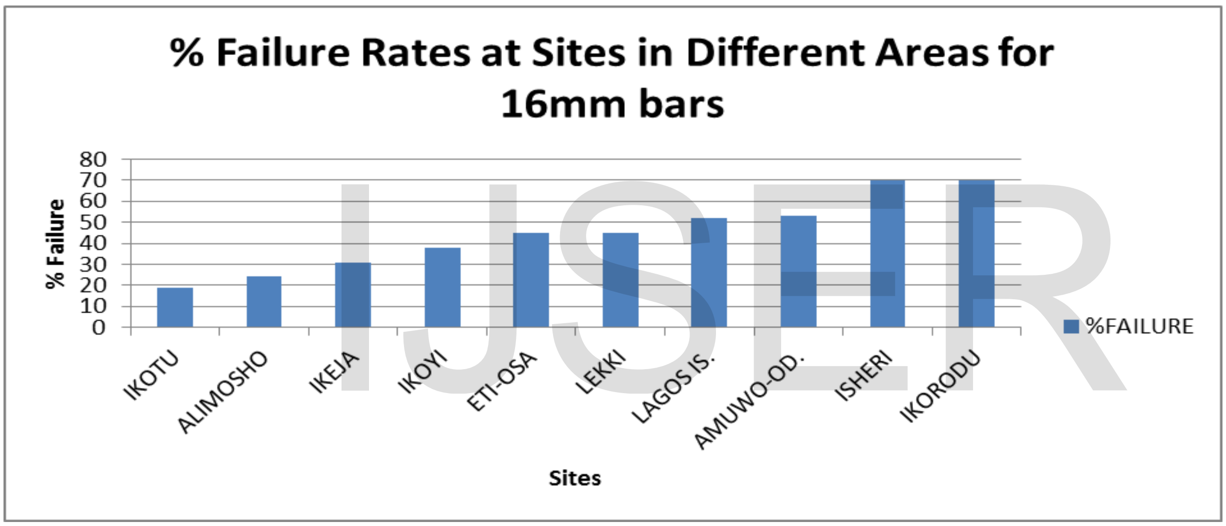

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Fig.6: Percentage failure rate for 16mm bars at sites within the 10 selected areas

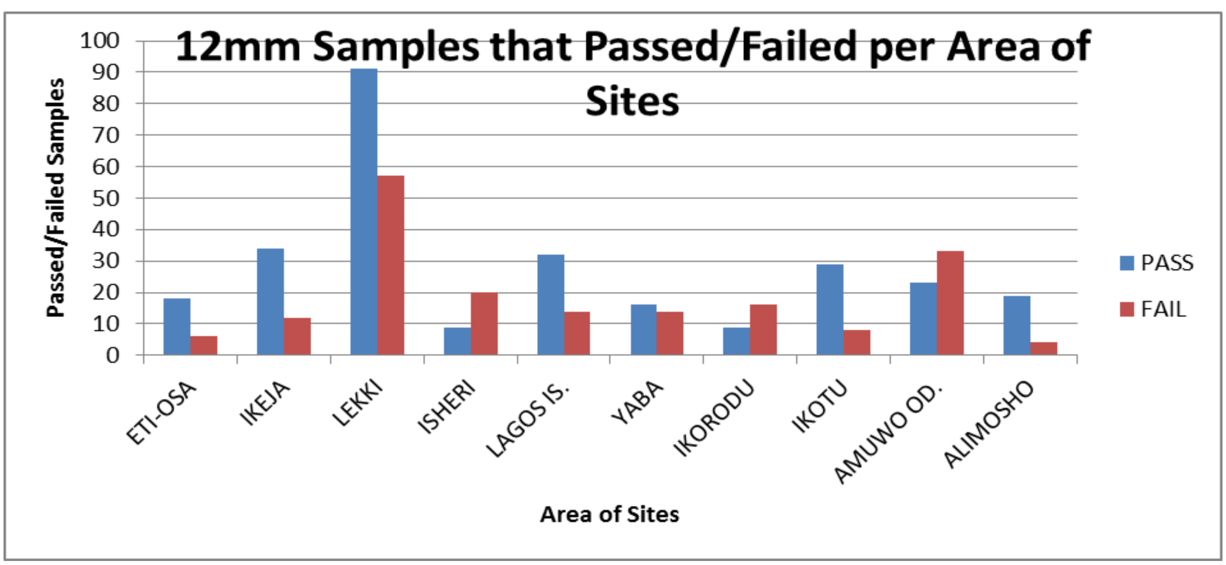

Fig.7: Passed and failed samples obtained within the selected areas for 12mm bars

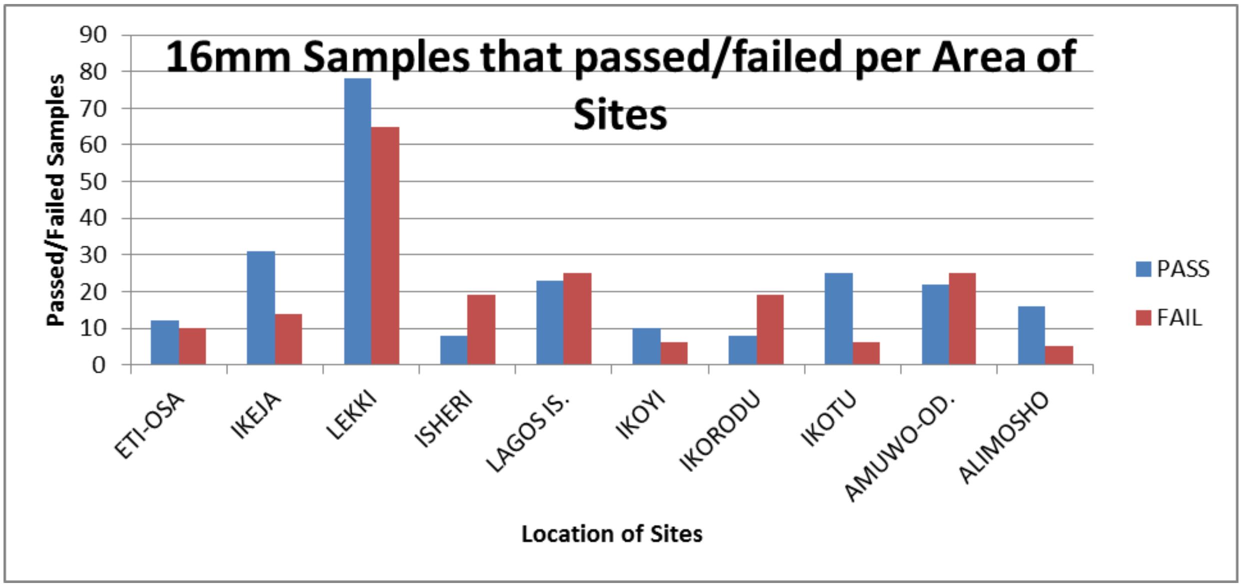

Fig.8: Passed and failed samples obtained within the selected areas for 16mm bars

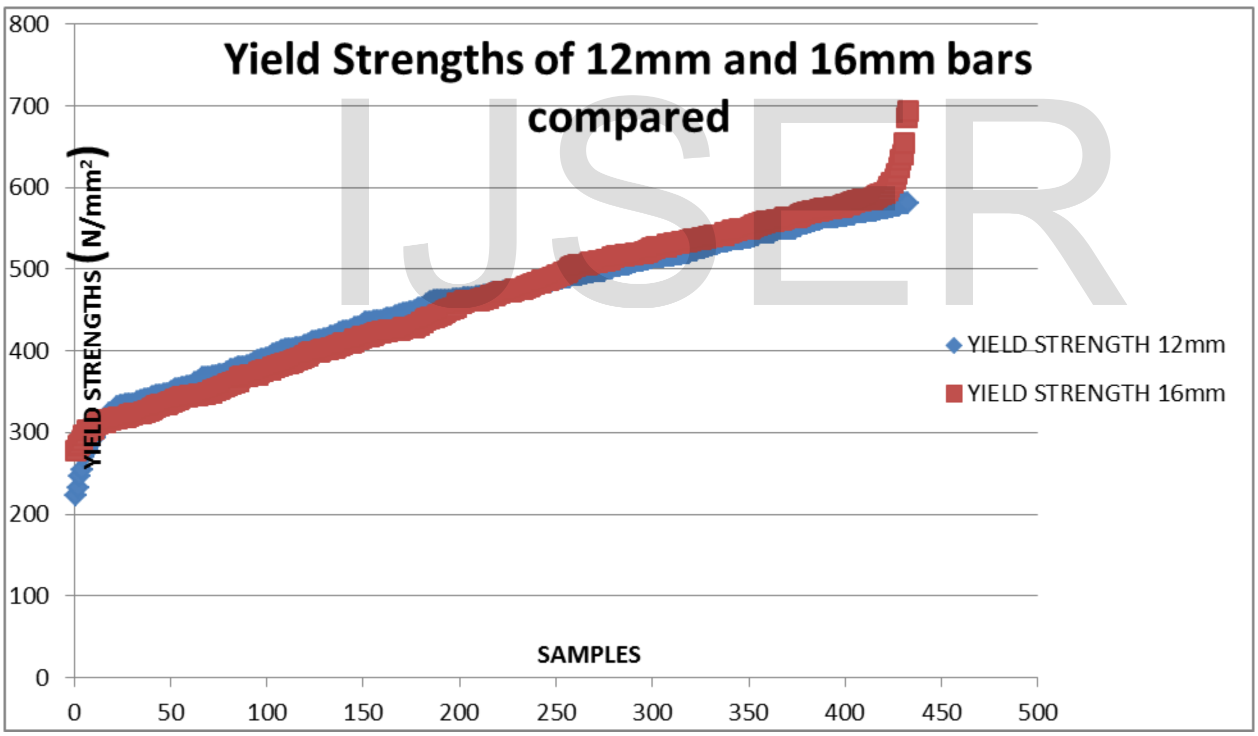

Fig.9: Distribution of all the test data of 12mm and 16mm bars considered in this research

4. OBSERVATIONS AND DISCUSSION

From the results shown above, the failure rate among the tested samples is very high. With about 42% of the 12mm bars and 46% of 16mm bars falling below the BS code prescription of 460N/mm^2 is not a good news. The two diameters chosen for this research are the most used for normal concrete works, this poor results will reflect on the quality of works done with them. Going by the common suggestion by the professionals to reduce the yield strength of steel bars to 410N/mm^2, about 28% and 33% of 12mm and 16mm bars, respectively, failed to meet the 410N/mm^2 criterion. So, this unorthodox approach of reducing the yield strength does not help the matter. At a time in which UK, the originator of the BS code that is adopted as the design code in Nigeria has moved from 460N/mm^2 yield strength to 500N/mm^2 yield strength, reducing yielding strength to 410N/mm^2 will only encourage the manufactures to produce steel of weaker strengths. In the samples considered, yield strength as low as 233N/mm^2 was encountered. Efforts should be intensified to improve the quality of steel used in Nigerian construction industry as data from this research does not offer conmfortable news for the health of structures realized with the analyzed samples. It is remarkable to note that the failure rate of 16mm bars are greater than that of 12mm bars both under the the strength consideration of 460N/mm^2 and of 410N/mm^2. Furthermore, it will be advisable to execute similar studies on other commercially available diameters of bars commonly adopted for civil structures such as 10mm, 20mm, and 25mm to understand the trend of their yield strengths.

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