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ARTICLE

Structural strengths of concrete beams reinforced with various types of steel reinforcements

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ABSTRACT

The recurrent premature failures of public infrastructure which render most constructed facilities structurally deficient and functionally obsolete require urgent attention. This paper presents the results of the investigated properties and durability of both local and imported steel reinforcing bars in Nigeria. Flexural strengths of concrete structures reinforced with steel rebar specimens and subjected to third-point loading of 150 mm × 150 mm × 750 mm beam specimens of grade 20 N/mm^2 concrete in accordance with BS 1881. The flexural stiffness of imported bars for 12 mm and 16 mm were 22.3 kN/mm^2 and 49.9 kN/mm^2 respectively, while the local and TMT imported bars were 11.5% and 7.5% lower. The modulus of rupture of the RC beams reinforced with imported, TMT and local bars were 13.3 N/mm^2, 13.3 N/mm^2 and 11.1 N/mm^2 for the 12 mm bar size and 20 N/mm^2, 22.2 N/mm^2 and 15.6 N/mm^2 for the 16 mm bar size. In conclusion, though the imported bars marginally satisfied the ASTM and BS standards in strength except durability, while local bars did not meet the two requirements. Hence, the development of National Building Codes that reflect the actual material characteristics is imperative to avert premature failure.

1. Introduction

The structural integrity of reinforced concrete structures is hinged on the reliability of the characteristic strength the concrete and the ductility of the reinforcing materials[1,2]. Hence, the degree of compliance or discordance with the design specifications in terms of geometric sizing and tensile strength parameters is a good measure to determine whether or not they contribute to the incidence of building failures in the country[3].

To eradicate frequent collapse of building that result into unexpected loss of lives and investment as a result of catastrophic structural failure, thorough evaluation of material properties cannot be underemphasized4. Investigations have shown that building components tend to fail at different rates depending on quality of materials, designs and construction method, environmental conditions and the use of the building[4,5]. However, substandard materials and design errors were identified as to major causes of component or element failures.

The assessment of geometric/size variation of local and imported steel rebar coupled with the experimental study of mechanical properties of steel rebar and the flexural

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strength test of concrete beams and slabs reinforced with rebar will contribute immensely to the body of knowledge by assessing the limitation of the materials thereby safeguarding the huge public and private investments as well as ensuring safely of lives and properties. Then, the study of the price and strength of the two reinforcing steel types would enable the engineers, project managers or clients construction professionals to assess whether the price different matches the strength difference.

Kareem[6] reported in his studies of tensile and chemical nature of selected locally made steel bars. The samples were machined to a standard tensile test pieces and tensile strength tests were done on it with the use of tensile strength testing machine. The result obtained from chemical analysis was compared with that of the global concrete reinforcement steel bars standards. The findings revealed that the selected steel bars are in good agreement with what is obtainable in both local and international standards. However in chemical analysis results, percentage carbon content in steel is somewhat low as compared to the foreign similar steel product.

Daodu[7] presented the stress-strain characteristics of reinforcing steel samples obtained from the Delta Steel Company, Aladja. Contrary to the recommendations of British Standards BS 4419 and BS 4482, these samples were machined before being tested because of non-availability of the suitable tensile testing machine. His test results indicated that the high tensile steel bars with higher amount of carbon and manganese possess higher strength and are less ductile than the mild steel bars. The work concluded that the strength of all grades of tested reinforcing bar samples compared well with the specifications in various international standards. This assertion, however, requires further investigation as samples were obtained from only one company which does not represent the entire steel rebars properties in Nigerian markets. Hence, the ongoing study extends the investigation into the appraisal of the quality of reinforcing steel bars produced in major steel plants in Nigeria and few imported types.

Adejimi[8] attributed the various structural failure of building in Nigeria to the general deterioration in project management supervision and material quality, unprogressive design concepts and unethical construction practice. It was found that of all the 718 tested steel bar specimens of different diameters, only 31% fell within the properties expected of hot rolled high tensile steel bar requirements, while 23% met the requirements for mild steel bars. Others were outside these two categories. The test results did not meet the requirements of BS 4449 which specifies a minimum yield stress of 460 N/rnm2 with minimum elongation of 14% for hot rolled high yield steel bars or minimum yield stress of 250 N/mrn² with minimum elongation of 22% for hot rolled mild steel bars[10]. It was recommended for the locally produced steel reinforcing bars that the required characteristic yield stress of high yield steel type fall within 300 — 350 N/mm^2 range with minimum elongation of 14% elongation of rupture and ultimate tensile strength of 110 to 130% of yield stress respectively.

The effect of temperature on the strength properties of reinforcing steel bars has attracted the attention of several researchers in recent times. Edwards and Gamble[9] examined a number of reinforcing bars which were heated to temperatures of 500-800°C and then slowly cooled in a furnace, simulating one possible exposure condition in a severe fire. The bars were tested in tension after they had cooled. The yield stresses reduced to a minimum of 73 % of the original strength, while the ultimate strengths were dropped to a minimum of 83 % of the as-rolled strength. Data such as this is needed by the Engineers, faced with the evaluation of a structure which has been damaged by a severe fire. The effect of fire on reinforcing steel bars is to cause deterioration in strength of the structure[10].

Notable researchers[11,12] examined the bond characteristics of reinforcing bars in concrete. Stachurski and Syczeskin[13] specifically investigated the bonding strength of reinforcing bars embedded in concrete by subjecting it to a tensile force with respect to the surrounding concrete. The findings revealed that values of tensile loads for smooth bars at which the bond was broken were found to be well below the tensile failure loads of the bars. Stachurski and Syczewski[13] further asserted in agreement with experimental investigations previously conducted by other investigators[11,12] that shrinkage of concrete does not increase, but decrease the bond between steel and concrete. It was also discovered that plain reinforcing bars (mild steel) and prestressing strands are insensitive to variations in the loading rate, whereas deformed bars show a significant higher bond resistance with increasing loading rate[13,14,15].

Raji[16] investigated the strength and strain of reinforcement bars under rapid loading type. Experiences in the development and production of reinforcing steel was discussed by Jungwirth[17], who asserted the importance of reinforcement in the building process which form about 6% to 15% of the cost of the basic structure. It has been established that high tensile steel reinforcement is subject to atmospheric corrosion from the moment it is manufactured to the time of receiving protection from the concrete. Melchers and Li[18] examined the influence of corrosion damage on the fatigue limit of high tensile wire reinforcement in marine environment. The findings showed a substantial decrease in strength under cyclic loads when

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the reinforcement had been exposed to corrosion for only a short time. It was also established that the most rapid decrease in strength under cyclic load takes place in reinforcement exposed to corrosion under stress. Similar test conducted by Basu[19] on the resistance of high tensile cold-worked ribbed reinforcement to fluctuating loads revealed that the corrosion fatigue effect of the fatigue resistance of the reinforcement is not very significant.

Bullis and Bhattacharjee[20] studied the rheological qualities of a new high strength reinforcing steel and gave data on improved high strength hot rolled steel for concrete reinforcement, designated as class A-VI which was developed in the Soviet Union. It was claimed that steel of analogous high quality was not available elsewhere in the world. The rheological properties of this steel have been determined under conditions of exposure temperatures (60°C -100°C) and with varying temperatures associated with concrete placing. Specimen 12 mm diameter bars were used for the steels and stress-strain characteristics investigated in accordance with BS 1881: part 117[21] .

2. Methodology

Flexural strength tests were conducted in compliance with BS 1881: part 118[22] and the experimental setup are presented in Figure 1. The lateral displacement (vertical deflection) was measured using well calibrated dial gauges mounted underside at the third-points and mid-span. The specimen was placed on a support span and the load applied to the center by the loading nose producing three points bending at a specified rate. The maximum capacity of the machine is 500 kN with three dial gauges arranged to measure the central deflection of the beams. Line loads was applied equally at the two third-points of the span. The load from a hydraulic jack was supported on the beam at the third points.

Figure 1. Flexural strength setup for beam under third-point loading

Twelve beams were casted. Three beams were reinforced with 12 mm local steel reinforcements in both longitudinal and transverse directions with concrete cover of 12 mm and compared with another three beams reinforced with 12 mm imported steel rebars. Also three beams were equally reinforced with 16 mm local steel reinforcements and compared with another three beams reinforced with 16 mm imported steel reinforcements. The beam specimens had approximate dimensions of 150 mm × 150 mm × 750 mm. The specimens were kept in an exposed environment until the time of the test (28 and 120 days).

The concrete beams were produced from ordinary Portland cement (OPC), fine aggregate from natural river sand and coarse aggregate from crushed granite of nominal maximum size of about 17 mm. The mix proportion by weight was 1:3:6 (20 N/mm^2).

The flexural strength of the beam specimens was calculated thus:

$$f_{cr} = M Z_u = 6bh M_u \quad \text{(Eq 1)}$$

$$z = b\frac{h^2}{6} \quad \text{(Eq 2)}$$

$$Mu = \frac{PL}{6} \quad \text{(Eq 3)}$$

Where:

F_{cr}: the modulus of rupture (flexural strength)

P: the failure load at collapse

M_u: the ultimate moment resulting from the ultimate load b, h — width and overall depth of the beam section

L: the distance between knife edges on which the sample is supported Z — the section modulus

3. Results and Discussions

The relationship between the stress and strain of any material and other parameters are determined from the Stress-strain curve. It is unique for each material and is found by recording the amount of deformation (strain) at distinct intervals of tensile or compressive loading. These curves reveal many of the properties of a material (including data to establish the Modulus of Elasticity, E). It can be seen in Figure 1 that the concrete curve is almost a straight line. There is an abrupt end to the curve. This, and the fact that it is a very steep line, indicates that it is a brittle material. The curve for the cast iron is slightly higher, indicating that it is also a brittle material. Both of these materials will fail with little warning once their limits are surpassed. The curve for mild steel has a long gently curving "tail". This indicates a behavior that is distinctly different than either concrete or cast Iron[23]. The graph shows that after certain point mild steel will continue to strain (in the case of tension, to stretch) as the stress (the loading) remains

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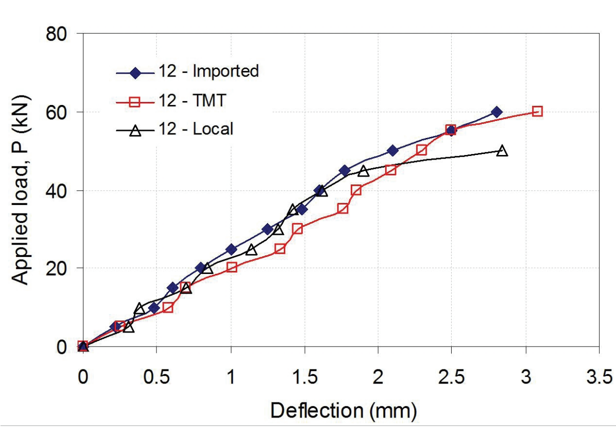
more or less constant. The steel will actually stretch like taffy. This is a material property which indicates a high ductility. There are a number of significant points on a stress-strain curve that help one understand and predict the way every building material behaves. Four primary failure modes are common during the flexural strength test[23]. These include; tension failure, when the tension reinforcement has yielded before the concrete fails. Compression failure, when the tension reinforcement remains unyielded even when the concrete has failed completely by crushing, shear failure, when the concrete fails literally as if no shear reinforcement is provided, and balanced failure - when concrete fails almost simultaneously as the tension reinforcement begins to yield. The stiffness of the beams reinforced with 16 mm bar size, regardless the steel types, was higher than the 12 mm bar size as shown in Figure 2. The stiffness measured as the slope of the load-deflection curve revealed that beams reinforced with 16 mm bar size were 77%, 140% and 86% higher than those reinforced with 12 mm for the imported, TMT, local respectively. For the 12 mm bar RC beams, the stiffness of the imported was the highest, while TMT and local bars were 14% and 6% lesser. However, the imported and local were comparable for the 16 mm bars, while the TMT was 17% higher.

Due to the relatively small span of the beam, the failure modes experienced during testing were essentially compression and shear. Shear, in the sense that, it attained the maximum value at the support. Also, since the span was small and the loading pattern was such that the first and last one-third of the span had the same shear force of one-half the applied load. The compression failure was also evident because the beams completely failed by crushing without yielding of the reinforcing bars. The modulus of rupture or flexural stress measured at the extreme bottom fibre of the RC beams reinforced with imported, TMT and local bars were 13.3 N/mm^2, 13.3 N/mm^2 and 11.1 N/mm^2 for the 12 mm bar size and 20 N/mm^2, 22.2 N/mm^2 and 15.6 N/mm^2 for the 16 mm bar size.



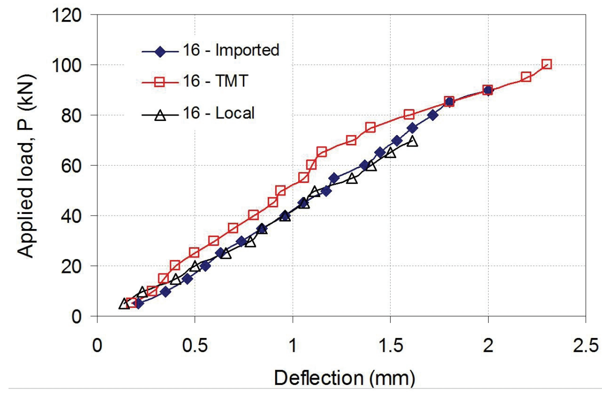


Figure 2. Flexural strength assessment of square concrete beams reinforced with different bar types of sizes (a) 12 mm and (a) 16 mm

4. Conclussions

1) The stiffness of the beams reinforced with 16 mm bar size were 77%, 140% and 86% higher than those reinforced with 12 mm for the imported, TMT, local respectively.

2) For the 12 mm bar RC beams, the stiffness of the imported was the highest, the TMT and local bars were 14% and 6% lesser).

3) The imported and local steel bars were comparable for the 16 mm, but the TMT was 17% higher.

4) The modulus of rupture or flexural stress measured at the extreme bottom fibre of the RC beams reinforced with imported, TMT and local bars were 13.3 N/mm^2, 13.3 N/mm^2 and 11.1 N/mm^2 for the 12 mm bar size and 20 N/mm^2, 22.2 N/mm^2 and 15.6 N/mm^2 for the 16 mm bar size.

5. Recommendations

1) Extensive experiments should be carried out and the composition and the effects on reinforced concrete composites.

2) Research should be carried out on the bond strengths for each type of the reinforcing bars.

3) The effect of corrosive environment such as water, alkaline and acidic environments should also be investigated.

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