Industrial Growth and Standards Compliance of Steel bars in the Nigeria Construction Industry

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Abstract: Concrete have high resistance to compressive stresses; however any appreciable tension due to bending will break the microscopic rigid lattice resulting in cracking and separation of the concrete. The use of steel rods as reinforcement in concrete will produce a composite material referred to as Reinforced Concrete, capable of resisting compression, bending and other direct tensile actions. British Standard code, BS 4449 - Specification for Carbon Steel bars for the Reinforcement of Concrete, stipulates some basic engineering parameters of steel appropriate for use in concrete.

This study focuses on these sectional and strength characteristics of manufactured reinforcing steel bars, produced by steel industries located in Lagos and Ogun State, western Nigeria. The test was carried out in accordance with BS 4449, using an Automated Universal Testing Machine. The Effective Mass, Effective Cross Sectional Area, Effective Diameter, Tensile Strength, Yield Strength, Stress Ratio and Elongation at Fracture for bars of varying sizes from each company of production were obtained. The test results were compared with the standards respectively. The results show that all the sample parameters did not satisfy the British Standard values except for the consideration of ± 8% tolerance on the effective cross sectional area.

Key Words: Fracture, Stress Ratio, Tensile Strength, Tolerance, Yield Strength

1. Introduction

Metals including steel have a linear stress-strain relationship up to the yield point, and the stress decreases after the yield point. This is due to the interaction of carbon atoms and dislocations in the stressed steel. Cold worked and alloy steels do not show this effect. For most metals yield point is not sharply defined, below the yield strength all deformation is recoverable, and the material will return to its initial shape when the load is removed and this is known as elastic deformation. For stresses above the yield point the deformation is not recoverable, with the material not returning to its initial shape and it’s known as plastic deformation. For many applications plastic deformation is unacceptable, and the yield strength is used as the design limitation.

After a metal has been loaded to its yield strength it begins to “neck” as the cross-sectional area of the specimen decreases due to plastic flow. Necking is not observed for materials loaded in compression. The peak stress on the engineering stress-strain curve is known as the ultimate strength. After a period of necking, the material will rupture and the stored elastic energy is released as noise and heat. The stress on the material at the time of rupture is known as the breaking strength.

High yield bars are manufactured either with a ribbed surface or the form of a twisted square. Ribbed bars are usually described by the British Standard Institution Code [1] as type 2 bars, provided that the specified requirement is satisfied. All deformed bars have an additional mechanical bond with the concrete so that higher ultimate bond stresses may be specified.

The difference between the grade 460A and grade 460B according to BS 4449 is shown in the Fig. 1 and Fig. 2 below.

Fig1: Grade 460A Steel

Fig2: Grade 460B Steel

Corrosion of steel reinforcement immersed in sodium and seawater media, was studied, the
reinforced concrete immersed was observed by electrode potential and pH measurement; it was observed that corrosion was greater in mild steel concrete reinforcement than carbon steel. They also found that seawater is more aggressive to both mild steel and medium carbon steel. [2]

Engineering characteristics of locally manufactured steel reinforcing bars in Nigeria was determined, from a single source of the locally produced steel in comparison to imported steel. The report showed that imported high yield steel bars contained high value of ferrous and carbon content than the corresponding locally produced ones, thus resulting in higher yield and ultimate strength. The yield stress of locally manufactured steel was very low ranging between 63.76 - 204 N/mm². [3]

The behaviour of Tobacco extract on corrosion of mild steel in acidic & salty media was observed. The result obtained in the research work indicate that the Tobacco extract of maximum concentration of 50% reduced the rate of corrosion of mild steel in 0.1m/HCL while inhibitor concentration of 35% average gave complete protection against corrosion of mild steel in 3.5% NaCl. They concluded that tobacco extract in the range 20% - 50% is capable of reducing or eliminating corrosion of mild steel in acidic and salty environment. [4]

The effects of vibration on the mechanical properties of low carbon steel welded joints was examined. The result shows that the yield strength increased with the frequency of vibration up to a maximum value of 378 N/mm² at about 47Hz; the percentage elongation had a generally increasing trend and the impact strength steadily declined while the hardness property initially increased with the frequencies of vibration up to a maximum value of 1.6kN/mm² at about 30Hz but dropped thereafter. [5]

The corrosion resistance of Type 304 Austenitic stainless steel in strong acids was examined, and it was observed that at an ambient temperature the material can resist corrosion in tetra-oxosulphate (VI) acid contaminated with sodium chloride (2%) at a very high concentration. [6]

Report of an overview of the history of steel production in Nigeria, relating the effort made by the Federal Government to develop the steel industry in Nigeria dates back to the pre-independent era in 1958, but achieved insignificant result. Action was directed towards the establishment of mini mills that would substitute the limited quantity of imported steel which the country was using then.

The supply was boosted with the availability of iron ore in the country and coal was also available. The feasibility of an integrated Steel plant was initiated, with various international bodies making proposals, but in 1967, a team of soviet expert was invited to conduct a feasibility study for setting up an iron and steel plant. The soviet experts presented a feasibility report which recommended the use of the blast process for iron making. The report also pointed out further that iron ore deposits in the country were of poor quality, and recommended that further geological surveys for exploration of better iron ores and coal for the proposed iron and steel industry should be carried out, which led to the establishment of Ajaokuta Steel Company in September, 1979 and was planned to be built in three stages. [7]

The last stage was the expansion of the complex to produce 5.2million tones of various types of finished and semi-finished steel products including heavy plates and sections; but this plan has never been successful. The Itake iron-ore project was to eventually satisfy about 10 percent of its requirements. The steel plant also utilizes limestone which is locally sourced from Mbamosing in Calabar, natural gas supplied from the Ugbelli gas fields, but all the plans were elusive. The National Metallurgical Development Centre, Jos was one of the entities carved out of the now defunct Nigeria Steel Development Authority (NSDA), and was established in 1972, The centre has manufactured suitable high temperature furnace lining bricks from local materials and has documented data on the major fire clay deposits in addition to carrying out detailed characterization and documentation of the foundry moulding sands available in the country.

The National Steel Raw Materials Exploration Agency, Kaduna was also established in 1971, and was designed to produce and feed the three inland rolling mills at Jos, Katsina and Oshogbo with billets. The project raw material, i.e. iron-ore was scheduled to be imported from Brazil; while the Delta Steel Company Limited was commissioned in 1981, and it was conceived as one of the key industrial project and the National Iron Ore Mining Company Limited, Itakpe came on board in February 1987. [7]

African steel Mills located at Odogunyan, Lagos came on board in the year 2000 as a result of the response to the clarion call for direct foreign investment programme of the Federal Government for investment in the country.

The factory’s production line consists of two essential sections, namely melting and the rolling
As the name suggests, the melting section takes care of the iron scraps, where they are melted into liquid in the oven and are then poured into moulds to form ingots and later to finished products such as square rods, flat bars, angles, channels bar, square bars and universal sections of various sizes. Other privately owned steel industries uses this means as well. Presently the local sourcing of recycled steel material is the order of the day, with more new steel industries producing billets and products from this waste, while importation has been reduced near to about 10%. These recycled steel has a lot of impurities, thereby having tones of slag as steel by-products. [8]

2. Methodology

2.1 Reinforcement Sampling

High yield bars with a ribbed surface were sampled at random, with identified trade mark from the open steel market (Owode-Onirin market, Ikorodu road, Lagos).

The samples tested were identified with five (5) major local steel producing companies in Lagos and Ogun State area, the industries are listed as shown below in Table 1.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Steel Industries</th>
<th>Specified Diameter of bars</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M.F.L Steel Mills, Odogunyan, Lagos State</td>
<td>12mm only</td>
</tr>
<tr>
<td>2</td>
<td>Sun flag Steel Mills, Odogunyan, Lagos State</td>
<td>12mm &amp; 16mm</td>
</tr>
<tr>
<td>3</td>
<td>African Steel Mills, Odogunyan, Lagos State</td>
<td>12mm &amp; 16mm</td>
</tr>
<tr>
<td>4</td>
<td>Monarch Steel Mills, Odogunyan, Lagos State</td>
<td>12mm &amp; 16mm</td>
</tr>
<tr>
<td>5</td>
<td>Phoenix Steel Mills, Ogijo, Ogun State</td>
<td>12mm only</td>
</tr>
</tbody>
</table>

2.2 Products Identification

According to BS 4449, 1997; the entire product tested in this project belongs to the steel grade 460A – type 2 bars, the surface should be marked at intervals not greater than 1.5m, as shown in Plate 1-5 below.

Plate 1: MFL Steel

Plate 2: Sun flag Steel

Plate 3: African Steel

Plate 4: Monarch Steel

Plate 5: Phoenix Steel

Three (3) bars per sample were labeled and taken for test, the samples were cut to sizes (0.7m), in conformity with a minimum cut length of 0.5m as specified in BS 4449 to allow grip. The actual diameters were measured using a calibrated caliper and then weighed with a sensitive weighing machine to two decimal places in grams, to a maximum of 25kg, as shown in Plate 5 below. Samples were weighed as shown in Plate 6 and tested with a computerized universal testing machine; with a maximum load of 1000KN, at the Lagos State Material Testing Laboratory, Ojodu, Berger, Lagos.

The computerised system enables a high degree of accuracy of load reading and graphical presentation. The machine automatically record parameters like tensile strenght, yield strenght, percentage elongation test duration, stress-strain e.t.c. average value of the parameters taken for the bars tested are thereafter compared to the standard

Plate 6: Sample Weighing

Plate 6: Weighing of Samples

The universal testing machine is used for tensile, compression, bending and steaming test of timber, plastics, cement, concretes etc; and it’s as shown in Plate 7, with the hydraulic and computer unit attachments. The view of the display of the stress-strain graph is shown in Plate 8 which can be printed out on the printer.

Plate 7: Universal Testing Machine

Plate 8: Stress-Strain graph on the Computer Screen

The machine was controlled to discharge the sample from the jaws, each sample was assembled together in length and the new elongated length was measured and recorded. The tensile strength, yield strength, elongation, upper and lower yield point were recorded automatically on the computer which were later printed for each sample tested.

3. Results And Discussion

3.1 Standard Provision According to BS 4449

According to BS 4449 the cross sectional area and mass of the bars shall be calculated on the basis that steel have a mass of 0.00785kg per square mm per meter run.

\[ A = \frac{M}{0.00785L} \]

With a tolerance of ±4.5 on mass and ±8% on effective cross sectional area for 12mm and 16mm respectively. Table 2 shows the standard cross-sectional area (mm²) and mass (kg/m) for steel of nominal size 12mm and 16mm respectively.

<table>
<thead>
<tr>
<th>Nominal size (mm)</th>
<th>Cross – Sectional Area (mm²)</th>
<th>Mass (kg/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>113.1</td>
<td>0.888</td>
</tr>
<tr>
<td>16</td>
<td>201.1</td>
<td>1.572</td>
</tr>
</tbody>
</table>

3.2 Tensile Properties

BS 4449 gives the provision that the yield strength \( R_y \) stress ratio \( R_m/R_y \), and elongation at fracture \( A_{gt} \) of steel obtained from test specimen prepared and tested shall be as specified in the table below. The result obtained for the entire samples tested using the same procedures are as presented in Tables 4 and 5 for tensile properties of high yield steel bars of nominal size 12mm and 16mm respectively, while Table 3 shows the standard tensile properties of steel, i.e the yield strength, stress ratio and the elongation at fracture.

The yield strength (N/mm²) is a reflection of the tensile strength; the yield strength is usually used as a major parameter in the provision of reinforcement bars in reinforced concrete elements [9] i.e. columns, beams, slabs, foundation e.t.c
Table 3: Standard Tensile Properties of Steel

<table>
<thead>
<tr>
<th>Grade</th>
<th>Yield Strength $R_e$ (N/mm²)</th>
<th>Stress Ratio $R_m/R_e$ (mm)</th>
<th>Elongation at Fracture $A_{gt}$ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>250</td>
<td>1.15</td>
<td>22</td>
</tr>
<tr>
<td>460A</td>
<td>460</td>
<td>1.05</td>
<td>12</td>
</tr>
<tr>
<td>460B</td>
<td>460</td>
<td>1.08</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 4, shows the tensile properties of steel bars of 12mm nominal size, all except steel bars from Monarch Steels Mills did not meet the specified effective mass in kg per meter run of $\pm 4.5$ % of 0.888kg/m from the BS 4449 code; Monarch Steels Mills has a value of 0.848kg/m. The effective diameter of 11.69mm from Monarch is also the highest value compared to the expected 12mm, followed by Phoenix with 11.54mm. The tolerance of $\pm 8$% was stated f or the effective cross-sectional area from the code, with a value of 107.29 mm² and 104.59 mm² Monarch and Phoenix Steel Mills falls in the range which has a minimum value of 104.05 mm², considering the negative tolerance allowed for values in the code.

The grade of steel bars tested is 460A (yield strength 460N/mm²), it can be observed that from Table 4, that none of the steel bars meet the required value, with the highest also recorded for Monarch Steel Mills at 389N/mm² for nominal size 12mm, followed by African Steel (386N/mm²) and Phoenix with 380N/ mm². The stress ratio would definitely not be in order since the tensile and yield strength values are not conforming to standard values.

The elongation at fracture results indicates that 12mm bars from Monarch Steel Mill are truly elastic, with a value of 12.2mm, closely followed by Sun flag Steel products with 11.6mm as compared with the standard of 12mm.

The general performance of the tensile properties of 12mm steel bars indicates that steel products from Sun-flag Steel Mills deviate most from the standards required by the BS 4449, 1997.

Table 4: Average Tensile Properties of Steel

<table>
<thead>
<tr>
<th>Nominal Size</th>
<th>12mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Properties</td>
<td>Effective Mass (kg/m)</td>
</tr>
<tr>
<td>African S.</td>
<td>0.813</td>
</tr>
<tr>
<td>Monarch</td>
<td>0.848</td>
</tr>
<tr>
<td>Phoenix</td>
<td>0.821</td>
</tr>
<tr>
<td>Sun flag</td>
<td>0.802</td>
</tr>
<tr>
<td>M.F.L</td>
<td>-------</td>
</tr>
</tbody>
</table>

Table 5: Average Tensile Properties of Steel

<table>
<thead>
<tr>
<th>Nominal Size</th>
<th>16mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Properties</td>
<td>Effective Mass (kg/m)</td>
</tr>
<tr>
<td>African S.</td>
<td>1.477</td>
</tr>
<tr>
<td>Monarch</td>
<td>1.532</td>
</tr>
<tr>
<td>Phoenix</td>
<td>-------</td>
</tr>
<tr>
<td>Sun flag</td>
<td>1.549</td>
</tr>
<tr>
<td>M.F.L</td>
<td>1.347</td>
</tr>
</tbody>
</table>

The results of tensile properties for 16mm nominal size are as shown in Table 5, African Steel and M.F.L Steel Mills products effective mass did not meet the minimum standard of 1.501kg/m considering the tolerance of $\pm 4.5$ % specified in the code, Phoenix Steel Mills do not have 16mm nominal size from bars in the market as at the period of the market sampling survey. The highest value of the effective diameter was observed for bars from Sun flag Steel Mills with a value of 15.85mm while M.F.L. shows the lowest value of 14.78mm.
Only the products from M.F.L did not meet the minimum standard of effective cross-sectional area of 185mm\(^2\) considering the tolerance of \(\pm 8\%\), surprisingly steel products from M.F.L. has the best value of 427N/mm\(^2\) though not satisfactory when compared to the value of 460N/mm\(^2\), even though the effective mass, diameter and cross-sectional area does not meet the required standard values; his therefore means that in the provision of steel bars using M.F.L. steel products more numbers would be required to resist a particular load from the structure to compensate for these reduction in cross-sectional area. The value of the yield strength of 229N/mm\(^2\) from African Steel Mill is highly unacceptable and could be a dangerous indication.

Monarch and Sun flag Steel products shows good elasticity, with values of 12.6mm and 13.1mm respectively as elongation at fracture point during the tensile test session.

4. Conclusion

Monarch Steel Mills steel product proved to be the best of the steel manufacturing industries in terms of the values of yield strength, mass, cross-sectional and elasticity of material, followed by Sun flag except for its poor yield strength values. The yield strength of 460 N/mm\(^2\) is not safe to be used as characteristics strength of steel bars (f\(_y\)) in the design of reinforced concrete element in buildings. It would be safe to use a range of 370 - 380 N/mm\(^2\) for 12mm nominal bar size and as low as 300 N/mm\(^2\) for 16mm bar size, when locally manufactured steel bars are envisaged for use; tensile failure of structures would definitely be recorded when higher stress values are used in the design procedure, against the actual steel stress.

The use of recycled steel waste may be responsible for the non-compliance of steel bars standard in the production cycle, particularly as the nominal size increases, due to decreased carbon content in the steel waste. The practice of usually providing steel cross-sectional area values above the calculated value is the best practice to ensure a safe structure.

Further it would be better if engineers get steel bars tested before their usage in structures, and also conceive the idea of localizing a national steel code based on the parameters achievable by an average steel industry in Nigeria, using the British code (BS 4449) as a basis.

5. Acknowledgement

The support of the Lagos State Material Testing Laboratory, Ojodu, Berger, Lagos, in testing the steel samples is acknowledged.

6. References


