

Comparative Assessment of Locally Produced Reinforcing Steel Bars for Structural Purposes: 12 mm Steel Bars from Delta Steel Company (DSC), Warri-Nigeria as a Case Study

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Abstract

Some relevant Chemical and Mechanical Properties of 12 mm ribbed steel bars from three different Heat Numbers of Delta Steel Company (DSC), Warri were investigated. The results of the chemical analysis show that the three samples have percent carbon content higher than the 0.25%C recommended by BS 4449 of 1997 and 0.30% recommended by ASTM A706. The results show that sample 1 has 0.32%C, sample 2 has 0.38%C and sample 3 has 0.31%C. This high percent carbon must have contributed to the high tensile strength values obtained. The values of the percentage elongation at fracture for all the tested steel samples surpassed the 12% recommended by BS and 10% recommended by ASTM A706. The results of the hardness test show 26.31 HRC for sample 1, 26.50 HRC for sample 2, and 26.40 HRC for sample 3. These values are higher than 13.48 HRC and 23.85 HRC estimated for BS4449, 1997 and ASTM A706 respectively. This means that most steel bars used for construction projects in Nigeria have higher mechanical property values than the standards, hence satisfy the required quality for construction.

Keywords: 12 mm steel rods; Local product; Reinforcing steel bars; Structural purposes

Introduction

12 mm steel rod is an important reinforcing bar for concrete. Steels are iron-carbon alloys that may contain appreciable concentrations of other alloying elements. There are thousands of alloys of steel that have different compositions. The mechanical properties of steel are sensitive to the percentage carbon content which is usually less than 2.14% [1]. Steels are classified as low carbon (<0.25%C), medium carbon (0.25-0.60%C) and high carbon (0.60-1.4%C). Sub classes also exist within each group according to the content of impurities/alloying elements other than carbon. For alloy steels, more alloying elements are intentionally added in specific concentration to achieve certain properties. Carbon is the cheapest and one of the most effective alloying elements for hardening iron. The higher the carbon content the greater the hardenability of the steel and the greater is the strength, hardness and wear resistance. However, ductility, weldability and toughness are reduced with increasing carbon content [2]. Materials are reinforced to make them stronger (increase strength). When improved strength is the major goal, the reinforcing components must have a large aspect ratio. This means that its' length-diameter ratio must be high so that the load is transferred across potential points of fracture. This is why steel rods are placed in concrete structures as reinforcing components. Unreinforced concrete, although have great compressive strength, is very weak in tension. It is this lack of tensile strength that leads to the necessity of reinforcement, which carries any tensile forces present in the structure [3]. Although a variety of materials such as glass, fibres and plastic filaments have been used as reinforcement, most concrete members are reinforced with steel in the form of bars, wire mesh and strand. It has high strength, ductility and stiffness. Steel reinforcement imparts great strength and toughness to concrete. Reinforcement also reduces creep and minimizes the width of cracks. Steel serves as a suitable reinforcement material because its coefficient of thermal expansion (5.8×10^{-6} to 6.4×10^{-6}) is nearly the same as that of concrete (5×10^{-6} to 7×10^{-6}). This means that there will be no relative movement between embedded bars and concrete in the reinforced concrete work

due to temperature changes (Rao, 1967). Other advantages of steel as a reinforcing material for concrete includes the fact that it is not easily corroded in the cement environment and it forms a relatively strong adhesive bond with cured concrete. This adhesion may be enhanced with the incorporation of contours onto the surface of the steel members which permits a greater degree of mechanical interlocking. Further bond or adhesion is provided by the natural roughness of the mill scale of hot rolled reinforcing bars [4].

Additional features that make for the satisfactory joint performance of steel and concrete are as follows:

(a) While the corrosion resistance of bare steel is poor, the concrete that surrounds the steel reinforcement provides excellent corrosion protection, minimizing corrosion problems and the corresponding materials cost.

(b) The fire resistance of unprotected steel is impaired by its high thermal conductivity and by the fact that its strength decreases sizably at high temperatures. Conversely, the thermal conductivity of concrete is relatively low. Thus damage caused by even prolonged fire exposure, is greatly limited to the outer layer of concrete and a moderate amount of cover provides sufficient thermal insulation for the embedded reinforcement [5]. There are several processes of steel production which include; Electric Arc Steelmaking, Basic Oxygen

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Steelmaking, Open Heart Process, etc. In Delta Steel Company Ltd, (DSC), Warri, the methods employed are the Basic Oxygen and the Electric Arc Steelmaking. As at the time of this work, only the electric arc steelmaking method was used to smelt scraps.

For the purpose of this work, the materials of concern are the structural/construction materials with special interest on iron and steel. Steel is a crystalline alloy of iron, carbon and other elements, which hardens when quenched over its critical temperature. It contained no slag and may be cast, rolled or forged. Carbon is the most important constituents because of its stability to increase the hardness and strength of the steel. More mass of steel is used than all other metals combined in structural applications. 12 mm steel rod is an important reinforcing bar for concrete. Information on this product from our local industries and imported ones are never available and such may be responsible for the high failure rate of construction projects in the nation. This work therefore is to assess some relevant chemical and mechanical properties of steel rods (12 mm) produced by Delta Steel Company Ltd (DSC), Warri and to compare same with two (2) standards namely; British Standard (BS4449, 1997), and American Society for Testing and Materials (ASTM, A706).

Experimental Methods

Three samples of 12 mm diameter steel bars were taken from three different heat numbers (922812, 922821 and 922662) at Delta Steel company Ltd. These samples were physically observed chemically analysed and mechanically tested at the same company.

Various measuring implements such as vernier calliper, tape, ruler etc were used to measure and observe some of the physical properties. The chemical analysis was performed using a photometric machine to display the compositions of the steel samples on a screen. The mechanical properties tested were Yield and tensile Strengths; Percentage Elongation (%E), hardness and bend tests (Tables 1-3).

Discussion

Table 1 shows the results of some of the physical observations and measurements conducted on the three samples. The average rib gap is

Sample	Heat No.	Rib Gap (mm)	Rib Dept (mm)	Diameter	Colour
1	922812	12.72	2.01	12.01	Luster/Grey
2	922821	12.69	2	12.03	Luster/Grey
3	922821	12.7	2	12	Luster/Grey
Average		12.7	2	12	Luster/Grey

Table 1: Physical observations.

Sample	Heat No.	%C	%Mn	%Si	%S	%p	%Cu	%Cr
1	922812	0.32	0.47	0.19	0.04	0.04	0.1	0.1
2	922812	0.38	0.54	0.35	0.044	0.04	0.22	0.05
3	922812	0.31	0.61	0.28	0.041	0.02	0.23	0.08
BS 4449,1997		0.25			0.05	0.05		
ASTM A706		0.3	1.5	0.5	0.045	0.035		

Table 2: Chemical analysis.

Sample	Heat No.	Weight (G)	B TS(N/mm ²)	B _{ys} (N/mm ²)	B _{ts} (N/mm ²)	%E	Hardness (HRC)	Bend
1	922812	440	649.35	424.58	649.35	25	26.1	OK
2	922812	438	645.25	422.5	645.25	22.5	26.5	OK
3	922812	442	648.9	425.15	648.9	23	26.4	OK
BS 4449,1997			600	460	600	12	13.48	
ASTM A706			550	415	550	14	23.85	

Table 3: Mechanical analysis.

12.70 mm while the rib dept is about 2.00 mm. Ribs/lugs are protutions on the surface of the steel bar used to improve the bond between the reinforcing steel and the concrete. Ribs also help to inhibits longitudinal movement of the bar relative to the concrete which surrounds the bar in construction works. The closer and deeper the ribs, the stronger the bonds and the less the movement of the bar within the concrete/structures. The three samples have luster/grey colour which is typically of steel rod. This grey colour may be attributed to the formation of thin film of oxide on the surface of the samples. This oxide does not flake away but adheres tightly to the steel surface thus inhibiting further corrosion/rust [6]. The average length of the rod is about 18.10 m. Steel bars are supplied in standard length of up to 18 m (BS4449, 1997). Bars with greater length will bend excessively when picked up because of their flexibility (Leet and Bernal). On the other hand, shorter length would cause wrong structural computations which are based on standard length.

Table 2 shows the comparison of the results of the chemical analysis of the three samples with BS4449, 1997 and ASTM A706 standards. It shows that the percent carbon content (%C) for sample 1 is 0.32%, for sample 2 is 0.38% and for sample 3 is 0.31% against 0.25% for BS and 0.3% for ASTM. It follows that all the three samples have higher %C than the standards. There are other alloying elements such as Mn, Si, Cu, S, P, Cr, etc. The percentage content of all these elements are within the standard specifications as shown in Table 2.

Carbon is the cheapest and one of the most effective alloying elements for hardening iron. The higher the carbon content the greater the hardenability of the steel and the greater is the strength, hardness and wear resistance. However, ductility, welderbility and toughness are reduced with increasing carbon content [7]. Although sample 3 has the lowest %C, it has high yield and tensile strenght. This may be attributed to high copper and manganse contents. These elements form carbides which impede dislilocation motion and thus hardening the steel. Sample 1 has higher %C, low %Mn and low %Cu but lower strength, lower hardness and higher %E. Thus proving the positive effects of Cu and Mn on the hardening of steel.

The presence of sulphur and phosphorous have negative effect on reinforcing steel if present above 0.05%. High sulphur content weakens the steel and could lead to the development of directional properties, reduction in weldability and increase in brittleness. The maximum recommended percent of sulphur in reinforcing steel is 0.05 %.(Allen, 1979). The sulphur content in the investigated steel samples were 0.040% for sample 1; 0.044% for sample 2 and 0.041 for sample 3. These values are lower than the recommended and thus are within

acceptable range. On the other hand, high phosphorous content in steel increases the tendency towards coarse grained steel with the attended reduction in strength. The recommended phosphorous content in reinforcing steel is 0.05% [7]. From Table 2 it can be observed that the three samples have lower %P than the two standards being compared. There are many other alloying elements found in traces. Generally these residual elements are not present in an amount that may individually contribute significantly to the properties of the steel. However, combination of various elements affects the hardenability, impact and tensile properties [8].

Table 3 shows the results of the mechanical tests conducted on the 3 samples. The results show that sample 1 has yield strength of 424.58 N/mm²; sample 2 has yield strength of 422.5 N/mm² and 425.15 N/mm² for sample 3. These values are lower than 460 N/mm² recommended by BS4449, 1997 but higher than 415 N/mm² recommended by ASTM A706. Since the 3 samples have higher %C and high %C causes increase mechanical strength, it follows that there are discrepancies in the yield strengths obtained and the value recommended by BS4449, 1997. These discrepancies which were not noticed with the ultimate tensile strengths of the 3 samples may be due to high residual elements. The same negative effect is observed in the results of the %E in Table 3 which shows a higher %E instead of lower since they contain higher %C. These may also be due to high percentage of residual elements in the samples which understandably affects the mechanical properties negatively. This is in agreement with Moore, 1997 that the major problem in using scraps for steelmaking is residual elements. According to Moore, the levels of residual elements such as copper, manganese, etc must be kept very low to avoid serious reduction in the mechanical properties of the steel. It however means that these samples, with regards to BS4449, 1997 standard are not suitable for structural purposes. On the other hand, with regards to ASTM A706 the samples satisfied both the yield and the ultimate tensile strengths recommendation.

The hardness test results show that the 3 samples have higher hardness values than the standards. This is true in all ramifications since the samples have higher carbon content and higher residual elements all of which affect hardenability positively. One of the main requirements of standardization and mass production is the reproductively of products with consistent properties within set standards. Hardness tests have been used to check for uniformity of products in line with the submission of McGannon (1970) that the extensive use of hardness testing in the steel industry is primarily because of its usefulness in the control of uniformity of products. The differences between the hardness results of the 3 samples are negligible. It can then be concluded that there is consistency in the products produced from DSC, Warri. It also follows that DSC, Warri conducts proper pre-treatments of scraps (raw materials) before usage. This is in line with the conclusion of Nyior, [9] who carried out similar investigation on some steel industries in Nigeria and adduced that the discrepancies in consistency were due to lack of pre-treatments of scraps by these industries.

Conclusion

Some relevant chemical and mechanical properties of 3 samples of 12 mm steel bars taken from three different heat numbers of DSC, Warri have been investigated. The results of the chemical analysis show that the 3 samples contain higher %C than the values recommended by BS4449, 1997 and ASTM, A706. This high %C must have attributed to the observed high Tensile strength and hardness. The chemical results also reveal the presence of residual elements in significant percentage. Some of these elements form carbides in steel which in turn impede

dislocation motion and thus the observed high strength and hardness. Ironically, %E which is the measure of ductility were found to be higher than the standards. This ought not to be so since the samples contain high %C. However, the presence of some residual elements such as Sulphur, phosphorous, etc which according to Moore, 1997 have negative effects on mechanical properties of steel must have contributed to this [10-13].

Generally, it can be said that there is inadequate information on the actual behaviour of most reinforcing steel bars produced by Nigerian Steel Industries which are already in use in structural concrete for the construction of all types of buildings, bridges, hydraulic structures, etc., yet they are classified as mild (instead of medium carbon) steel in design specifications. This must be why there are high records of structural failures in Nigeria. Thus reinforced concrete design in Nigeria may not be fully reliable. This investigative work on the chemical and mechanical properties of reinforcing steel bars produced from recycled scraps shows that the characteristic tensile strength is high compared with the standards. The bars did not exhibit significant necking down and cup and cone failure, similar to those observed in the case of standard mild steel plain bars. It would be of interest to know if reinforcing steel bars in other localities behave similarly [14]. Meanwhile the information here provides an idea of the mechanical properties (Ultimate tensile Strength, and Hardness) of steel bars manufactured from DSC, Warri which are higher than standards. Hence the samples fit the Nigerian specifications.

Recommendation

- The results of the mechanical tests revealed that the tensile strength and yield strength are very close to the lower limits of the standards and thus increase of these properties is recommended.
- The major raw material of this industry is scraps. Most often, neither the sources of these scraps nor their pre-treatments are considered important by most steel industries in Nigeria. This leads to the production of steel whose specifications cannot be attested to. It is therefore recommended that strategies of checking the types, sources and pre-treatment of these scraps be put in place in all such industries.
- More investigations on this work would be necessary from various localities to ascertain the suitability of the materials available in our local markets for use by the construction industries.

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