International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 8 Issue 02 Series. I || Feb 2019 || PP 56-62

Assessment of the Quality of Steel Rods from two Cement Production Sites

Abdul Ganiyu F. Alabi[1], Adeshina B. Kayode[2]
[1]*Professor, Department of Material Science and Engineering, Kwara State University, Malete, Ilorin, Nigeria*
[2]*Senior Engineer, Department of Mechanical Engineering, Dangote Cement Plc, Obajana, Kogi State, Nigeria*
Corresponding Author: Adeshina B. Kayode

Abstract: *The chemical and mechanical properties of selected steel rods from two industrial sites namely; Dangote Cement Plc, Obajana, Kogi State (DCO) and Dangote Cement Plc, Ibese, Ogun State (DCI), Nigeria were investigated. The investigations were done at Midwal Engineering Limited, Lekki, Lagos, Mudiame International Limited, Awoyaya, Lagos and Umaru Musa Yaradua University, Katsina. A Universal Testing Machine was used to carry out the tensile test while the chemical composition was obtained from an Optical Emission Spectrometer. Scanning Electron Microscope was used to examine the surface fractograph. The hardness values were obtained from Rockwell hardness tester. The Ultimate Tensile Strengths (UTS) of all the samples surpassed the BS4449: 2005+A2:2005, A707M-15 and Nst.65-Mn standards. Sample* DCI_{16} *possessed highest strength while sample* DCI_{12}*had the least strength. The hardness values are 22.4HRC for* DCO_{12}*, 21.5HRC for* DCO_{16}*, 20.0HRC for* DCI_{12}*, and 22.2HRC for* DCI_{16}*. The hardness values and ductility properties of the reinforcing steel rods are higher than the BSS4449: 2005+A2:2005 and A707M-15 standards.The results of the study showed that the reinforcing steel rods were adequate. Thus, it can be recommendedfor structural use and load-bearing applications where strength is a major goal.*

Keywords*: –Cement, Concrete, Reinforcing steel rods, Surface fractograph, Yield strength*

Date of Submission: 26-01-2019 Date of acceptance: 09-02-2019

I. INTRODUCTION

Cement manufacturing facility usually involve intricate engineering designs. A number of vital questions require answers before a decision can be made on a material and hence its selection. Adequate knowledge of service load as well as good match between service conditions and selection criteria are paramount toprevent structural failures and their attendant consequences. Therefore, a good knowledge of materials and their properties will be helpful to both engineers and designers to avoid mistakes that may lead toengineering failures [1].

Generally, sand aggregates materials composed of hard core particles of varying sizes are mixed with cement and water to form concrete. Concrete hardens to become strong in compression but weak in tension. There isneed to compensate for this deficiency. According to [2], concrete performs optimally when used in conjunction with reinforcing steel rods. Steel is a preferred choice for reinforcement of concrete on account of its good tensile strength and easy procurement in simple form asbars [3].Although several other materials such as reinforced polymer, bamboo, plastic filament, ceramic composites and steel rods have been tried as reinforcing materials in the past [1],[4]. Steel is by far the most commonly used material as reinforcement for concrete.

Steel is an alloy predominantly of iron and carbon, usually containing measurable amount of manganese and often readily formable. Carbon steel owns its distinctive properties chiefly to its carbon content. The brittle and low tenacitynature of concrete is compensated by the ductility and strength of steel rods. The steel rods do not function only to strengthen the concrete but also to control concrete volume changes due to temperature and moisturevariation. It also helps to keep the cracks tightly closed [5]. Other advantages of steel as reinforcing material for concrete include resistance to corrosion in the cement environment and its ability to form a relatively strong adhesive bond with cured concrete [1]. The adhesion is enhanced with the incorporation of contours or indentation unto the surface of the steel members during the rolling process which permit a greater degree of mechanical interlocking [6],[7].

In the cement industry, however, concrete beams and columns are usually integral parts of the structural designs. These elements function not only as support members but also as anchorage for suspended loads. Cement plant has several heavy equipment and overland installations. Hydrostatic precipitator for instance, is a dust emission control facility seated on concrete beams with several support pillars. Other installations include; pendulum coolers, pre-heater cyclones, rotatory feeders, bucket elevators, rotatorykilns and belt conveyors. Supports are needed for these load bearing facilities. Therefore, it is vital to ensure that steel rods used for the support pillars of these installations are of good quality so that structural failure and its attendant consequences can be averted.

Unarguably, reports of structural failures are becoming a matter of major concern in the construction industry. It is therefore, necessary to examine the chemical and mechanical properties of reinforcing steel rods used for structural works particularly, in the cement manufacturing industry where coal, limestone and clay are to be conveyed through some distance, the structural integrity of support pillars need to be adequate. Therefore, the aim of this research is to assess the quality of steel rods from two cement manufacturing sites in Obajana, Kogi State and Ibese, Ogun State, Nigeria and determine their conformitywith recommended British [8], American [9] and Nigerian [10] standards.

II. METHODOLOGY

2.1 Samples collection

The materials for this work are ribbed steel bars of circular cross section of nominal diameters 12mm and 16mm. The steel rods are obtained from two different sites where coal conveyor structures are constructed, namely: Dangote Cement Obajana (DCO) and Dangote Cement Ibese (DCI). Eight (8) specimens of each sample of steel rods of diameters 12mm and 16mm are collected from each location. Altogether, thirty-two (32) specimens are prepared in accordance with ASTM standard. The specimens' chemical compositions and mechanical properties are to be investigated. Also, the surface fractographs before and after fracture will be examined to understand the mode of failure.

2.2 Chemical composition

The analyses of the chemical composition of the samples was done using Belec Vario Optical Emission Spectrometer with (Serial Number 120105). Firstly, each specimen of the samples were grounded for five seconds using metallographic abrasive grinder in order to expose the core surface of the samples after which it is polish to a mirror finish with soft emery paper. In order to eliminate contaminant it is rinsed with ethanol and air-dried with a hand dryer. The samples were mounted one after another on the Optical Emission Spectrometer. The average percentage chemical composition of each rod samples was captured on a display monitor attached to the equipment.

2.3 Tensile test

The tensile properties of the reinforcing steel rod samples were determined using an Instron Universal Tensile Machine (Model Number WAW-500E). The steel rods of length 400mm each were placed one after another vertically on the load frame of the test machine and gripped 50mm on both end of the test specimen with the jaws. The specimen was subjected to tensile load at a strain rate of 2mm/minute until the specimens fractured. The tensile machine is connected to a digital extensometer that capture quantitatively the load-extension readings. Eight (8) specimens of each samples were subjected to tensile load and the average values taken.

Figure 1: Steel rods specimens for tensile

2.4 Hardness test

Thesteel samples were placed on the anvil of Rockwell hardness testing machine (Model Number ZHV30S) one after another and the table adjusted upward until the mirror-finish surface of the specimens touch the spheroconical indenter. An ambient temperature of 25^{o}C is ensured with an initial load of 10kg applied perpendicular to the surface for a dwell time of three seconds. This was followed by an additional load of 140kg for another ten seconds. The attached digital monitor captured the corresponding Rockwell hardness value for the steel rods. The test was repeated three times on the surface of each specimens and average values were taken.

2.5 Fractography

The surfaces of the specimens before tensile load and after fracture were examined on PHENOM PROX Scanning Electron Microscope (Model Number 800-07334).Specimens from each of the steel rods before load application and after fracture were collected and the new surfaces protected from contaminants and atmospheric oxidation. The surface were carefully rinsed with ethanol and air-dried with hand dryer to get rid of moisture. The specimens were carefully placed onto the specimen holder. It was then inserted in the vacuum chamber and examined under the Scanning Electron Microscope to reveal the microstructures.

III. RESULTS AND DISCUSSION

3.1 Chemical composition

The chemical composition of the reinforcing steel rod samples as obtained from the Optical Emission Spectrometer is shown in Table 1.0. The results revealed that all samples fall within the medium carbon steel as the carbon content range between 0.30-0.45percent as suggested by [1]. The samples have carbon content range of 0.30-0.32 percent which are slightly higher than the British and Americanstandards. The sulfur content of the steel rods samples are significantly lower compared to recommended standard with DCI_{12} having the least value. This is good for the steel rods on account of the negative impact which sulfur is known to have on properties[11]. The manganese and chromium content of the investigated samples are higher than the recommended standards. This is desirable because chromium is a good carbide former which help to lock up dislocation thus, improve the hardness and strength of the steel rods. The present of vanadium in trace account for the finer structure of the steel rods because of its high tendency to retard grain growth. Other elements present in the composition include nickel, titanium and niobium which confer good strength and high hardness to the steel. It further account for the high tensile strength of the investigated steel rods which surpassed the recommended standards. See Table 2 and Fig. 2.

Table 1: Chemical composition of samples

S/N	SPEC.	%C	%Si	%Mn	%P	%S	%Cr	%Mo	%Ni	%V	%Ti	%Nb	%Fe
1	**DCO_{12}**	0.320	0.340	1.464	0.002	0.003	0.032	0.006	0.028	0.077	0.003	0.012	97.713
2	**DCO_{16}**	0.300	0.360	1.440	<0.001	0.003	0.088	0.006	0.023	0.089	0.003	0.013	97.674
3	**DCI_{12}**	0.300	0.340	1.433	0.002	0.002	0.036	0.005	0.027	0.075	0.003	0.011	97.766
4	**DCI_{16}**	0.310	0.370	1.448	<0.001	0.004	0.082	0.008	0.026	0.089	0.004	0.010	97.648
5	**BS4449**	0.240	0.400	1.000	0.050	0.055	0.050	-	0.012	-	-	-	-
6	**A707M**	0.250	0.400	1.000	0.050	0.050	0.045	-	-	-	-	-	-
7	**Nst65-**	0.350	0.300	1.200	0.040	0.040	0.040	-	-	-	-	-	-

Table 2: Mechanical properties of the steel samples compared with standards

Specimens	DCO_{12}	DCI_{12}	DCO_{16}	DCI_{16}	BS4449	ASTM A706	Nst.65-Mn
Ultimate Tensile Strength **(N/mm^2)**	677.00	680.00	689.00	702.00	540.00	590.00	600.00
Yield Strength **(N/mm^2)**	544.00	542.00	562.00	569.00	500.00	500.00	500.00
Elongation (%)	15.25	14.50	12.00	12.60	12.00	10.00	14.00
Strain/Harding Ratio (mm/mm)	1.24	1.26	1.23	1.23	1.15	-	-

Table 3: Specimens' properties compared with past related work

Specimens	%Carbon	Yield strength (N/mm^2)	Ultimate Tensile(N/mm^2)	Elongation (%)	Hardness	Sources
DCO_{12}	0.320	544.00	677.00	15.25	22.40	(AA2018)*
DCO_{12}	0.300	542.00	680.00	14.50	21.50	(AA2018))*
DCO_{16}	0.300	562.00	689.00	12.00	20.00	(AA2018))*
DCI_{16}	0.310	569.00	702.00	12.60	22.20	(AA2018))*
A12	0.259	405.64	582.44	31.42	18.04	(AE2016)
A16	0.329	389.12	591.01	27.95	18.21	(AE2016)
B10	0.330	410.73	667.73	27.11	20.71	(AE2016)
B12	0.169	404.64	544.80	31.54	16.83	(AE2016)
B16	0.291	373.14	556.14	30.42	17.05	(AE2016)
EC	0.339	460.14	597.21	9.02	21.19	(OA2012)

IC	0.311	486.31	585.71	11.72	20.22	(OA2012)
SC	0.345	551.50	625.75	9.80	19.63	(OA2012)
SF	0.530	400.00	692.73	18.00	48.00	(AO2010)
US	0.398	400.00	651.58	28.00	44.00	(AO2010)
NS	0.383	400.00	610.79	28.00	47.83	(AO2010)
AS	0.483	325.00	660.17	25.00	45.10	(AO2010)

Remarks: (AA2018) - Alabi and Adeshina; (AE2016) - Alabi et al.; (OA2012) - Odusote and Adeleke; (AO2010)-Alabi and Onyeji. **Present work*

3.2 Yield strength and Ultimate tensile strength

Carbon is an important constituent of steel because of its stability to increase the hardness and strength [1]. The strength of steel increases proportionately with increase carbon while ductility and toughness decreases [12]. The trend of properties for the yield strength as revealed in Figure 2, show that all samples investigated had yield strength of at least 108% of the recommended standards. The yield strength of the samples when compared with past related works of [11] and [13] is significantly higher. See Table 3. The high yield strength obtained from the steel samples is due to the present significantly large amount of manganese and chromium. This is in agreement with [3] who concluded that manganese major function in steel is to improve the mechanical properties such as strength. The property trends for the tensile strength shows that all samples surpassed the recommended standards. In figure 2, the value of the UTS for DCI_{16} at 702N/mm^2 is the highest while DCO_{12} at 677N/mm^2 has the least value. The present of silicon and manganese are responsible for the high value for the UTS.

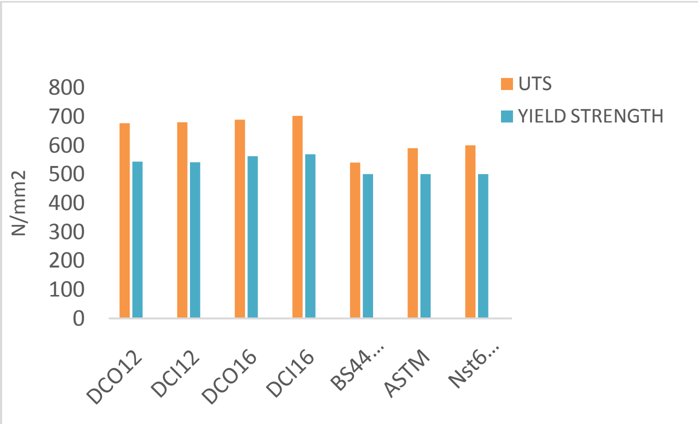


Figure 2: ultimate tensile and yield strength of steel rods compare with standards

3.3 Elongation

Percentage elongation determines the ductility of steel and can vary with the carbon content. It decreases as the carbon content increases. In the steel rods investigated all samples exceeded the values in the standard. Apparently, because of the higher manganese and nickel content of the samples compare to standard. In Figures 3, $\mathbf{DCO_{12}}$ with carbon content 0.32% showed appreciable elongation which is over 150% of ASTM A706 standard. It can also be deduce from Table 2, that high ultimate tensile strength does not translate to high ductility. Sample $\mathbf{DCO_{16}}$ with ultimate tensile strength 130% of BS4449 standard have approximately the same ductility as the standard, unlike sample $\mathbf{DCO_{12}}$ which is 125% of the standard but about 27% more ductile. This shows that while sample $\mathbf{DCO_{16}}$ can bear more load it does not have commensurable retention ability as $\mathbf{DCO_{12}}$ before fracture. The carbon content show slight variations of about 0.1-0.2 percent which is the reason for the close range of elongation shown by the samples steel rods. The samples elongation compare with past work of [11], [1] is significantly lower though higher than [13].

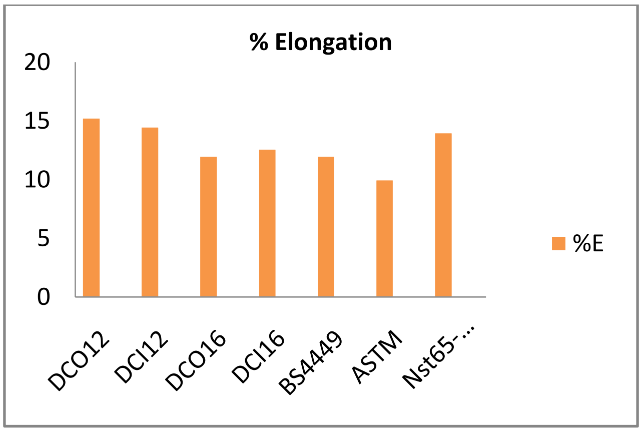


Figure 3: Comparison of % Elongation of the various steel samples with standards

3.4 Hardness

The hardness values obtained from the investigated steel samples show variation with respect to the amount of carbon percentage in the steel. $DCO_{12}$with carbon composition of 0.32% and hardness value of 22.4HRC show the highest hardness. This is closely followed by $DCI_{16}$with hardness value of 22.3HRC. DCI_{12} is the least with hardness value of 20.0HRC. The investigated steel rods are found to be adequate as their hardness values surpassed the BS4449. Also, when compared with past work it is found to show similarity of values. See Table 3.

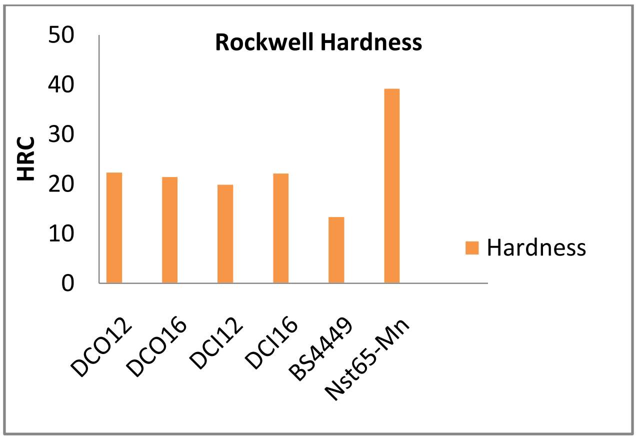


Figure 4: Comparison of samples Hardness with estimated standards

3.5 Fractography

The surface fractographs of the steel rod samples before load and after fracture is shown in Fig. 5. All samples before load application show a homogenous microstructures. This contrast with the surface after fracture which exhibit a rough and dull fracture facets with relatively high surface area. The fracture face consisted of copious ductile dimples with large cup and cone shapes. This is indicative of a ductile fracture. It further show that the materials used in construction are good materials that give warning before failure. Samples DCO_{16} and DCO_{12} pores are shallow compared to DCI_{16} and DCI_{12}. According to [14], pores sizes and distribution are a measure of ductility, therefore it can be concluded that DCO_{16} and DCO_{12} are more ductile of the investigated samples. Thus sample DCI_{16} with high strength and limited ductility can be used for pillars while samples DCO_{12} with high strength and high ductility can be used for slabs or beds.

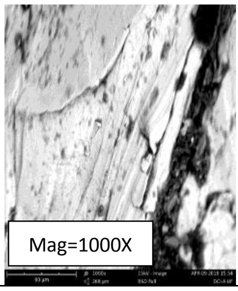
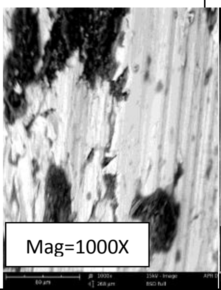
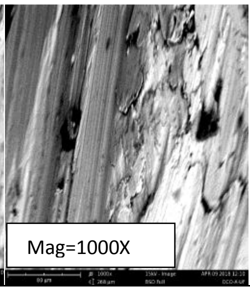
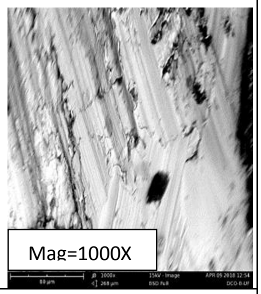
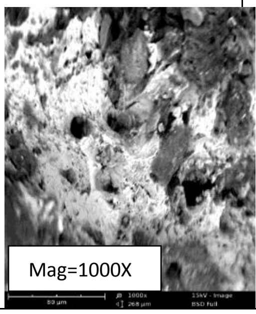
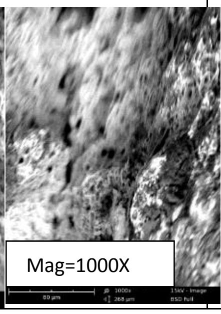
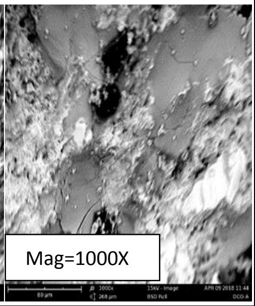
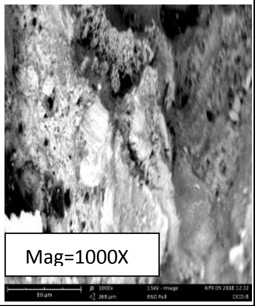
SPECIMENS	DCI_{16}	DCI_{12}	DCO_{16}	DCO_{12}
BEFORE LOAD				
AFTER FRACTURE				

Figure 5: Specimens surfaces as revealed under SEM

IV. CONCLUSION

The results obtained from this work show that the steel rods for construction at these two industrial sites are of good quality since the mechanical properties so obtained surpassed those of the standards. In particular, excellent values of strength and ductility obtained which were $677N/mm^2$ and 15.25% for DCO_{12} and $702N/mm^2$ and 12.6% for DCI_{16} respectively, as compared to those of the standards. The chemical composition of materials used in this work are also in conformity with recommended standards. The fracture surfaces showed a ductile failure which is good for materials of construction in a cement factory in order to avoid catastrophicsituation.

V. RECOMMENDATION

1. The engineering monitoring committee of Council for the Regulation of Engineering in Nigeria (COREN) must ensure that corporate sites are monitored for quality assurance.
2. Corporate bodies must encourage constant review of materials of construction at their sites and present results of such in case of visit by monitoring committee or agency of government.
3. Since it is established that Nigeria made steel competes favorably with their foreign counterpart importation should be discourage to stem capital flight.
4. Meaningful action must be taken to ensure major steel producing plants such as Ajaokuta Steel Company Limited (ASCL) and Delta Steel Company Limited (DSC) are revitalized to promote indigenous technology.
5. Meaningful engagement with engineering institutionsnecessary in order to conduct a review of Nigeria engineering codes and standard for classification of steels.

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