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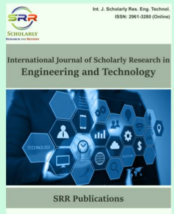

(RESEARCH ARTICLE)

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A study of the mechanical properties and chemical composition of some HYS 12 concrete reinforcement steel rods produced in Nigeria

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Abstract

'A Study of the Mechanical Properties and Composition of Some HYS 12 Concrete Reinforcement Steel Rods Produced in Nigeria' has been carried out. The work started with the collection of samples from four different mini mills in Nigeria. These samples were prepared into standard test specimens for the various tests according to the standard specifications for those tests, which included hardness test, impact strength test, tensile test and chemical composition test using Spectro-lab metal analyzer (Fe-01-F). From the results obtained; the study has shown that the value of the mechanical properties that were investigated, which included; hardness, impact strength, yield strength, ultimate tensile strength, and % elongation at failure were all determined by their chemical compositions; particularly, carbon, silicon, and phosphorus. Specimen G_4 has the highest mechanical properties of all the mechanical properties tested. It has a hardness value of 34.4BHN, impact strength of 275.0J, yield strength of 526.13 N/mm^2, and ultimate tensile strength of 610.01N/mm^2. Specimen F_3 has the highest % elongation at failure of 15.67%. Specimen A_1 has the least % elongation at failure of 8.57%. The higher the value of the strain hardening rate the better for HYS 12 concrete reinforcement steel rods, since this will allow sufficient time for occupants of the building to escape before final failure. In conclusion the work has clearly shown that the mechanical properties of the HYS 12 rolled steel rods studied were dictated by the size, amount, and distribution of the Carbon / cementite phase and on the structure of the metal matrix. This in turn depended on the chemical composition of the specimens, in particular their carbon and Silicon content, and also on processing variables such as method of melting, inoculation practice and the cooling rate of the rolled steel bars. The three constituents of steel, which most affect strength and hardness, they are; total carbon, silicon, and phosphorus.

Keywords: Mechanical properties; Chemical composition; HYS 12; Strength; Reinforcement; Steel rods

1 Introduction

HYS 12 concrete reinforcement steel rods or bars are produced in Nigeria by various mini mills. Owing to their vast demand by the Nigerian building and construction industry; HYS 12 concrete reinforcement steel rods are also imported into the country from different countries like China, India, and others. The type of HYS reinforcement steel rod used in a construction is specified by the structural engineer, who does this after his load analysis of the structure. If the load to be carried by the structure is low, he recommends a low HYS size reinforcement bar, and if it is high he recommends a higher size HYS reinforcement steel bar. HYS 12 is used to reinforce concrete cement cast in buildings and structures of different types. Concrete cement cast alone is very strong in handling compressive loads, but very poor in handling tensile loads. This explains why reinforcement bars are used to avoid the concrete cast failing in tension (Higgins, 1985; Khanna, 2009; Ihom, *et al.,* 2020a; Ihom, *et al.,* 2020b; Ihom *et al.,* 2021; Ekohotblog, 2021).

From above it also becomes obvious why the study of mechanical properties and chemical composition of HYS 12 concrete reinforcement steel bars is important. Many researchers have rightly said that poor quality mechanical

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properties in HYS12 concrete reinforcing steel rod will result in low strength of concrete cast and would result in reduced ability to bear load (Cottrel, 1980; Bolton, 1999; Bolton, 2000; Khanna, 2009). HYS 12 rods are produced to standard specifications, and if production specifications are not met the bars are of poor quality (JIS, 2008: Ihom, *et al.,* 2020a; Ihom, *et al.,* 2020b; Ihom *et al.,* 2021). Several researchers have equally observed that the mechanical properties of HYS 12 concrete reinforcement steel rods are determined by the chemical composition of the steel and the rolling conditions and procedure, which also influence the grain size, shape, and orientation (Ihom, 2022; Shrager, 1969; Higgins, 1985; Khanna, 2009; Ihom, *et al.,* 2020a; Ihom, *et al.,* 2020b; Ihom *et al.,* 2021). The chemical composition also affects the microstructure of the HYS 12 and the structure also determines the mechanical properties (Khanna, 2009; Ihom, 2013).

It is therefore imperative that to avoid structural failure arising from low-strength reinforced concrete cement cast a study of the mechanical properties and chemical composition of some HYS 12, concrete reinforcement steel rods produced in Nigeria should be investigated, since building and structural collapse has become a menace in Nigeria with extreme climatic conditions aggravating the situation (Ekohotblog, 2021).

2 Material and methods

2.1 Materials

The materials used for the research work were HYS 12 rolled steel reinforcement bars obtained from four different mini mills in Nigeria. Fig. 1 show some of the reinforcement steel bars collected from different mini mills in Nigeria.

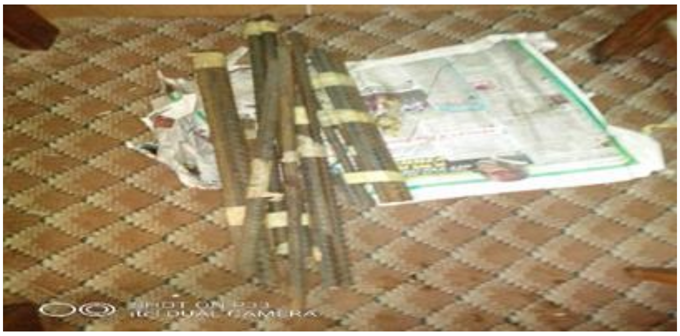

Figure 1 Remnant of reinforcing steel bar samples collected from different mini mills across Nigeria

2.2 Method

2.2.1 Test Specimen Preparation

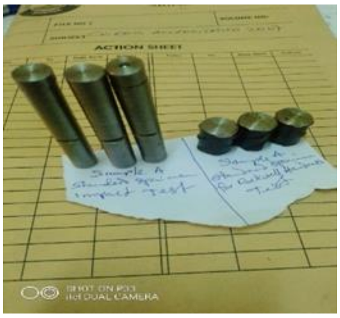	
Impact strength and hardness test specimens for A1	Impact strength and hardness test specimens for C2

Figure 2 Impact Test Specimens and Brinell Hardness Test Specimens Prepared from Samples A_1, C_2, F_3, and G_4 Obtained from Four Different Mini Mills

The test specimen for this research were prepared according to ISO and JIS standards JIS Z2243:1998; ISO/0156506-1:96 (MOD); British and European Standard BSEN10045, and BS 4449:2015+A3:2016, for Brinell hardness test, impact strength test, and tensile test. The test specimen for the Brinell hardness test was machined using a lathe machine into 12mm diameter and 10 mm long. The test specimens for the impact test were machined into Izod notch test specimen. For tensile test; since full –size tensile test was adopted; the test specimen were cut according to the standard size required for the universal strength testing machine. Specimens for composition were equally prepared according to equipment used for the tests. Fig. 2 show some of the test specimens prepared for the Brinell hardness test and impact strength test.

2.2.2 Brinell Hardness Test

The specimens tested for Brinell hardness test had a diameter of 12 mm and a length of 10 mm each. The test specimens were from four different mini mills; coded A_1, C_2, F_3, G_4. The Brinell hardness test was determined by forcing a hard steel ball into the test specimen clamped to the Brinell hardness tester. According to ASTM specifications, a 10 mm diameter ball was used and a constant load of 500kg was applied for all the specimens. The same indenter was also used for all the specimens. In each case the diameter of the indentation left on the surface of the test specimen was measured. The Brinell hardness number was obtained by dividing the load used, in kilograms, by the actual surface area of the indentation, in Square millimeters. In this test the Brinell number was converted to force per millimeter square by multiplying the load by 9.81 before dividing it by actual surface area.

2.2.3 Tensile Test of HYS 12 Samples from Four Mini Mills

Tensile test was also carried out on the samples of HYS 12 from the four mini mills using full-size tensile test. This was informed by the fact that in service reinforcement steel rods embedded in concrete structure handle the tensile component of the stress on the structure. The compressive component of the stress on reinforced structures are mainly handled by the concrete cast. The samples were sent to the Department of Mechanical and Aerospace Engineering, University of Uyo-Nigeria for the tensile test. All the samples were tested according to reference code/standard:BS 4449:2015+A3:2016. The results were tabulated.

2.2.4 Chemical Composition of HYS 12 Reinforcement Steel Bar from Four Mini-Mills in Nigeria.

Samples of HYS 12 from the four mini-mill were sent to Defence Industries Corporation of Nigeria (DICON) for analysis. The essence of the test was to determine the chemical composition of the samples from the mini-mill. The chemical analysis was carried out using spectro-lab metal analyzer (Fe-01-F). .

3 Results

The results of this research work are as presented in Tables 1-5 below:

3.1 Results of Mechanical Properties Test

Table 1 Results of Mechanical Properties of Some HYS 12 Rolled Steel Rods in Nigeria

Mini Mill	**Bar type/Diameter (mm)**	**Average Hardness**	**Average Impact (J)**	**Yield Strength (N/mm^2)**	**Ultimate Tensile Strength (N/mm^2)**	**Strain hardening range**	**UTS/ YS**	**% Elongation at Failure**
A_1	HYS12	32.39	272.3	505.09	530.45	25.36	1.05	8.57
C_2	HYS12	31.76	274.0	431.43	530.45	99.02	1.23	14.29
F_3	HYS 12	33.50	273.4	441.95	495.08	53.13	1.12	15.67
G_4	HYS 12	34.40	275.0	526.13	610.01	83.88	1.16	14.29

3.2 Result of Chemical Composition of HYS 12 Reinforcement Steel Bar from Four Mini-Mills in Nigeria

Table 2 Chemical Composition of Specimen A_1 /Quality Analysis (Fe-01-F)

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co
%	0.256	0.248	0.66	0.036	0.057	0.322	0.100	0.020	0.259	0.0006	0.014
Element	**Ti**	**Nb**	**V**	**W**	**Pb**	**Mg**	**B**	**Sn**	**Zn**		
%	0.0042	<0.0040	0.0093	0.010	<0.0030	<0.0010	0.0043	0.016	<0.0020		
Element	**As**	**Bi**	**Ca**	**Ce**	**Zr**	**La**	**Fe**				
%	0.012	0.0072	0.0020	0.0078	0.0048	0.0012	97.9				

Table 3 Chemical Composition of Specimen C_2 /Quality Analysis (Fe-01-F)

Element	C	Si Mn	P	S	Cr	Ni	Mo	Al	Cu	Co
%	0.361	0.257 0.57	0.027	0.040	0.150	0.044	0.0065	0.0025	0.152	0.0075
Element	**Ti**	**Nb**	**V**	**W**	**Pb**	**Mg**	**B**	**Sn**	**Zn**	
%	0.0032	<0.0040	0.0057	<0.010	<0.0030	<0.0010	0.0039	0.0043	- 0.031	
Element	**As**	**Bi**	**Ca**	**Ce**	**Zr**	**La**	**Fe**			
%	0.014	<0.0020	0.0027	<0.0030	0.0023	0.0033	98.3			

Table 4 Chemical Composition of Specimen F_3 /Quality Analysis (Fe-01-F)

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co
%	0.299	0.205	0.55	0.029	0.033	0.210	0.061	0.0092	0.0031	0.186	0.0065
Element	**Ti**	**Nb**	**V**	**W**	**Pb**	**Mg**	**B**	**Sn**	**Zn**		
%	0.0024	<0.0040	0.0065	<0.010	<0.0030	<0.0010	0.0036	0.0059	0.018		
Element	**As**	**Bi**	**Ca**	**Ce**	**Zr**	**La**	**Fe**				
%	0.012	<0.0020	0.0015	<0.0030	0.0025	0.0015	<98.4				

Table 5 Chemical Composition of Specimen G4 /Quality Analysis (Fe-01-F)

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co
%	0.479	0.411	1.08	0.021	0.035	0.102	0.035	0.0099	0.047	0.115	0.0078
Element	**Ti**	**Nb**	**V**	**W**	**Pb**	**Mg**	**B**	**Sn**	**Zn**		
%	0.0044	<0.0040	0.0090	<0.010	<0.0030	<0.0010	0.0035	0.0012	<0.0020		
Element	**As**	**Bi**	**Ca**	**Ce**	**Zr**	**La**	**Fe**				
%	0.012	0.0032	0.0044	0.0082	0.0033	0.0059	97.6				

4 Discussion

4.1 A Study of the Mechanical Properties and Chemical Composition of some HYS 12 Concrete Reinforcement Steel Rods Produced in Nigeria.

Table 1 is the result of mechanical properties of some HYS 12 rolled steel rods in Nigeria. The Table shows that Specimen A_1 has the following mechanical properties: hardness value of 32.39BHN, impart strength of 272.3J, yield strength of 505.09 N/mm^2, ultimate tensile strength of 530.45N/mm^2, strain hardening range of 25.36, and % elongation at failure of 8.57%. Looking at Table 2 specimen A_1 has total carbon of 0.256%, 0.248% Si, and 0.036%P. According to Ihom, (2022), the properties of plain carbon steel depend on the size, amount, and distribution of the Carbon / cementite phase, and on the structure of the metal matrix. This in turn depend on the chemical composition of the iron, in particular its carbon and Silicon content and also on processing variables such as method of melting, inoculation practice and the cooling rate of the rolled product. The three constituents of steel, which most affect strength and hardness, they are; total carbon, silicon, and phosphorus. This combines into an index called carbon equivalent value. As the carbon equivalent value (CEV) of the steel increases so also the hardness, impact strength, and other strength values (Ihom, 2022). According to Higgins (1985), pearlite areas in plain carbon steel increase as the carbon content increases. When this happens the steel morphology becomes gradually darker; with increased hardness and strength.

Table 1 shows specimen C_2 with the following test results: hardness 31.76BHN, impact strength of 274.0 J, yield strength of 431.43 N/mm^2, ultimate tensile strength of 530.45N/mm^2, strain hardening range of 99.02, and % elongation at failure of 14.29%. Table 3 show that specimen C_2 has total carbon content of 0.361%, 0.257%Si, and 0.027%P; these three elements are known to increase the hardness and strength of steel.

Table 1 show specimen F_3 with the following mechanical properties: hardness of 33.50BHN, impart strength of 273.40J, yield strength of 441.95N/mm^2, ultimate tensile strength of 495.08N/mm^2, strain hardening range of 53.13 and % elongation at failure of 15.67%. Table 4 shows that specimen F_3 has total carbon content of 0.299%, 0.205%Si, and 0.029%P; these three elements in steel are known to increase the mechanical properties of steel as their quantities in the steel increases (Shrager, 1969; Higgins, 1985; Khanna, 2009).

Table 1 show specimen G_4 with the following mechanical properties: hardness of 34.4BHN, impact strength of 275.0J, yield strength of 526.13 N/mm^2, ultimate tensile strength of 610.01N/mm^2, strain hardening range of 83.88, and % elongation at failure of 14.29%. Table 5 shows that specimen G_4 has total carbon content of 0.479%, 0.411%Si, and 0.021%P, these three mentioned elements in steel increase the mechanical properties particularly strength, and hardness as their value increases in the steel (Ihom, 2022).

Specimen G_4 has the highest mechanical properties of all the mechanical properties tested as seen above, this is because from the chemical composition Tables above, it also has the highest values of carbon and silicon. According to Ihom, (2022), the properties of plain carbon steel depend on the size, amount, and distribution of the Carbon / cementite phase and on the structure of the metal matrix. This in turn depend on the chemical composition of the iron, in particular its carbon and Silicon content and also on processing variables such as method of melting, inoculation practice and the cooling rate of the rolled product. The three constituents of steel, which most affect strength and hardness, they are; total carbon, silicon, and phosphorus (Ihom, 2022).

Specimen A_1 has yield strength and ultimate tensile strength which are second only to those of specimen G_4. Its hardness and impact strength and % elongation at failure are however, lower than those of specimen F_3, higher strength values of Specimen A_1 can still be explained in its carbon content of 0.256%, 0.248%Si, and 0.035%P. This agrees with Ihom, (2022), the properties of plain carbon steel depend on the size, amount, and distribution of the Carbon / cementite phase and on the structure of the metal matrix. This in turn depend on the chemical composition of the iron, in particular its carbon and Silicon content and also on processing variables such as method of melting, inoculation practice and the cooling rate of the rolled product. The three constituents of steel, which most affect strength and hardness, they are; total carbon, silicon, and phosphorus ((Ihom, 2022; Shrager, 1969; Higgins, 1985; Khanna, 2009; Ihom, *et al.,* 2020a; Ihom, *et al.,* 2020b; Ihom *et al.,* 2021).

The mechanical properties of the other specimens too can be linked to their chemical compositions, and also on processing variables such as method of melting, inoculation practice and the cooling rate of the rolled HYS 12 steel product (Ihom, 2022).

Ductility apart from the strength properties of hardness, impact strength, yield strength, and ultimate tensile strength; ductility of HYS rolled steel is very important this is because it avoids catastrophic failure in reinforced concrete structures (Ogbodo *et al.,* 2022). In this work specimen F_3 has the highest % elongation at failure of 15.67%, followed by specimens C_2 and G_4, which both have 14.29%, specimen A_1 has the least value of % elongation at failure of 8.57%. Strain hardening range is the extent of plastic deformation before final failure of the specimen. Specimen C_2 has the highest value of 99.02 and a careful look at these values shows that the higher they are; the better will be the ductility of the HYS rolled steels. % elongation at failure as a mechanical property is also affected by the chemical composition of the iron, in particular its carbon and Silicon content and also on processing variables such as method of melting, inoculation practice and the cooling rate of the rolled product. The three constituents of steel, which most affect strength and hardness, they are; total carbon, silicon, and phosphorus (Ihom, 2022). Ductility is a very important parameter and requirement for structural steel bars used for reinforcement purposes in buildings, and other concrete structures. It has been stressed in several literatures (Ihom, 2022; Shrager, 1969; Higgins, 1985; JIS, 2008; Khanna, 2009; Ihom, 2013; Ihom, *et al.,* 2020a; Ihom, *et al.,* 2020b; Ihom *et al.,* 2021; Ekohotblog, 2021; Ogbodo *et al.,* 2022) that reasonable ductility in structural reinforcement bars or rods prevents catastrophic or sudden failure in buildings and structures, thereby allowing the occupants to take advantage of the warning failure, which would normally start with a crack and gradual sagging of the building or structure *(Ogbodo et al., 2022)*

5 Conclusion

A Study of the Mechanical Properties and Chemical Composition of some HYS 12 Concrete Reinforcement Steel Rods Produced in Nigeria' has been conducted and the following conclusions have been drawn from the study:

- the study has shown that the values of the mechanical properties that were investigated, which include; hardness, impact strength, yield strength, ultimate tensile strength, and % elongation at failure were all determined by their chemical compositions particularly, carbon, silicon, and phosphorus.
- Specimen G_4 has the highest mechanical properties of all the mechanical properties tested. It has hardness value of 34.4BHN, impact strength of 275.0J, yield strength of 526.13 N/mm^2, and ultimate tensile strength of 610.01N/mm^2
- Specimen F_3 has the highest % elongation at failure of 15.67%
- Specimen A_1 has the least % elongation at failure of 8.57%
- The higher the value of the strain hardening rate the better for HYS 12 concrete reinforcement steel rods, since this will allow sufficient time for occupants of the building to escape before final failure.

In conclusion the work has clearly shown that the mechanical properties of the HYS 12 rolled steel rods studied were dictated by the size, amount, and distribution of the Carbon / cementite phase and on the structure of the metal matrix. This in turn depend on the chemical composition of the iron, in particular its carbon and Silicon content and also on processing variables such as method of melting, inoculation practice and the cooling rate of the rolled steel bars. The three constituents of steel, which most affect strength and hardness, they are; total carbon, silicon, and phosphorus.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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