Examining The Mechanical Properties Of Some Hys 16 Rolled Steel Reinforcing Bars In Nigeria And Establishing Any Correlation Between Their Mechanical Properties, Composition, And The Structure Of The Steels

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***Abstract*—Examining the mechanical properties of some HYS 16 Rolled Steel Reinforcing Bars in Nigeria and establishing any correlation between their Mechanical Properties, Composition, and the Structure of the BCC Steels as research topic has been undertaken. The work was carried out by collecting samples of HYS 16 rolled steel reinforcing bars from three different mini mills in Nigeria. These specimens were prepared into test specimens according to the standard specifications of the tests. The tests carried out on the HYS 16 Rolled steel reinforcing bars test specimens include; hardness test; tensile test, chemical composition test, and microstructure analysis. The result of the work show that the composition of the samples determined the structure of the HYS 16 steels, and the structure determined the measured mechanical properties of the HYS steels. The mechanical properties of the three samples relate to the composition with some slight deviations in the case of sample C_2, which may be due to several reasons relating to processing, elements present, and heat treatment. The mechanical properties of the three HYS 16 steels correlate with the structure and morphology of the three HYS 16 rolled steel rod samples. The D_3 sample with the highest mechanical properties of 34.61BHN, 274.70J impact value, 826.19 N/mm^2 yield strength, and 830.48N/mm^2 ultimate tensile strength had a uniformly distributed fine grains of cementite phase within the ferrite matrix of the sample. Sample C_2 has the best % elongation at failure of 13.64% and this correlates to the high strain range of the sample of 126.90. The highest impact resistance of 274.70J and hardness resistance of 34.61BHN was exhibited by sample D_3 these values also reflect in the high yield strength and high ultimate strength of the sample because there is a correlation between them. In conclusion there is a correlation between the mechanical properties of the samples studied with their composition and their microstructure. At the temperature this study was conducted all the samples had BCC structure and can as well be referred to as BCC steels.**

Keywords—Correlation; Composition; Structure; Properties; HYS 16; Rolled steel reinforcing bar.

I. Introduction

The properties of engineering materials are controlled by their chemical composition and their microstructure [1]-[4]. The properties of the materials in turn determine their areas of engineering application. In recent times global warming has resulted in extreme weather conditions. This has impacted aggressively on engineering materials sometimes resulting in negative consequences. Issues of buildings and other structural collapse has become a regular occurrence in Nigeria. This has raise the issue of integrity of HYS steel reinforced concrete structures in most cities in Nigeria [1];[16]. Whereas, some people tend to lay the blame on the quality of HYS rolled steels used for concrete reinforcement; the truth is that the quality of other materials like cement, gravel, sand, wood, water and other factors like design, and workmanship also matter. This paper however, focuses on the mechanical properties of some HYS 16 rolled steel bars commonly used in highly loaded and high-rising structures in Nigeria. The paper intends to establish any correlation between their mechanical properties, chemical composition, and the structure of the BCC Steels.

Khanna [5], observed that the property of a material is a factor that influences quality and also quantitative response of a given material to imposed stimuli and constraints, like forces, temperature, environment, etc. properties render a material suitable or unsuitable for particular use in industry. The material property is independent of the dimension or shape of the material. The tensile strength of annealed, fine grained pure aluminium will be around 4.8 x10^7N/m^2 (1.45 x 10^{-4} PSI) irrespective of the dimensions of the specimen tested. Mechanical properties include those characteristics of material that describe its behavior under the action of external forces. Mechanical properties determine the behavior of engineering materials under applied forces and loads. The responses of the materials to applied forces will depend on the type of bonding, the structural arrangement of atoms or molecules and the type and number of imperfections, which are always present in solids except in rare circumstances for this reason, mechanical properties are very sensitive to manufacturing processes and operations, which may result in highly variable characteristics even in materials of the same chemical composition. Some mechanical properties include elasticity, plasticity, toughness, resilience, tensile strength, yield strength, impact strength, ductility, malleability, hardness, etc [1]-[9]. According to Smallman and Bishop [6] common mechanical tests may be used, not to study the 'defects state', but to check the quality of the products produced against a standard specification. It is inevitable that a large number of different machines for performing the tests are in general use [6]. Mahtsentu [4] observed that the mechanical properties of metals determine the range of usefulness of a material and establish the service life that can be expected. Mechanical properties are also used to help classify and identify materials. Structural materials are anisotropic, which means that their material properties vary with orientation. The variation in properties can be due to directionality in the microstructure from forming or cold working operation, the controlled alignment of fibre reinforcement and a variety of other causes. When studying materials and especially when selecting materials for a project/ design, it is important to understand key properties [3];[9];[11]-[13].

According to National Bureau of Standards [3] steel may be defined as an alloy of iron and carbon (with or without other alloying elements) containing less than about 2.0 percent of carbon, usefully, malleable or forgeable as initially cast in addition to carbon, elements like manganese, silicon, phosphorus and sulphur are normally present in steels. Steels may be broadly classified into two types: (i) carbon and (ii) alloy. Carbon steels owe their properties chiefly to the carbon. They are frequently called straight or plain carbon steels. Alloy steels are those to which one or more alloying elements are added in sufficient amounts to modify certain properties [3];[15]-[21] .

The atoms in all solid metals are arranged in some definite geometric (or crystallographic) pattern. The atoms in iron or steel, immediately after freezing, are arranged in what is termed the body-centred cubic (BCC) system. In this crystal structure the unit cell consists of a cube with an iron atom at each of the eight corners and another in the center. Each of the many individual grains (crystals) of which the solid metal is composed is built up of a very large number of these unit cells, all oriented alike in the same grain. Steel is allotropic; it has different forms at different temperatures, but steel exists in the BCC structure at room temperature. Different allotropic forms of iron have different crystal structure and also properties. This confirms the correlation between crystal structure and properties. The properties of iron are affected very markedly by additions of carbon [3]-[14]. This confirms the existing relationship between composition and property. It is possible for solid iron to absorb or dissolve carbon the amount being dependent upon the crystal structure of the iron and the temperature. The body-centred (alpha or delta) iron can dissolve, but little carbon, whereas the face-centred (gamma) iron can dissolve a considerable amount, the maximum being about 2.0 percent at 2065Of. This solid solution of carbon in gamma iron is termed austenite. The solid solution of carbon in delta iron is termed delta ferrite, and the solid solution of carbon in alpha iron is termed alpha ferrite, or more simply, ferrite. Theoretically, iron must be alloyed with a minimum of 0.03 percent of carbon before the first minute traces of pearlite can be formed on cooling [3]-[6];[11]-[13].

HYS 16 rolled steel reinforcing bars or rods after cooling to room temperature transforms to BCC structure from the rolling structure of FCC which is γ - iron. The transformations are also associated with phase changes the steel changed from austenite to a mixture of ferrite plus pearlite, since HYS 16 steels are hypoeutectoid steels with carbon content less than 0.35% in most instances. These changes listed above affect the mechanical properties of the steels. The addition of carbon, the rolling process all increase the strength and hardness of the steel, with corresponding decrease in ductility, by cold working. BCC (α-Iron) is stronger than FCC (γ- Iron) because the capacity of α-iron to accommodate carbon atom is less than that of FCC (γ- Iron) making the interstitial position of carbon in BCC structure to increase the mechanical properties of the steel. From above it is clearly established that there is a correlation between composition, structure, property, and application of steels [3]-[22].

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2.0 MATERIALS AND METHOD

2.1 Materials

The materials used for the research work were HYS 16 rolled steel reinforcement bars obtained from three different mini mills in Nigeria. Plate. I show some of the reinforcement steel bars collected from different mini mills in Nigeria.

Plate I: Remnant of reinforcing steel bar samples collected from different mini mills across Nigeria

2.2 Method

2.2.1 Test Specimen Preparation

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 [10];[14];[19], for Brinell hardness test, and impact strength test. The test specimen for the Brinell hardness test was machined using a lathe machine into 16mm diameter and 16 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 and microstructure tests were equally prepared according to equipment used for the tests. Plate II show some of the test specimens prepared for the Brinell hardness test and impact strength test.

Impact strength and hardness test specimens for A_1 | Impact strength and hardness test specimens for C_2 | Impact strength and hardness test specimens for D_3

Plate II: Impact Test Specimens and Brinell Hardness Test Specimens Prepared from Samples A_1, C_2 and D_3 Obtained from Three Different Mini Mills.

2.2.2 Hardness Test

The specimens tested for Brinell hardness test had a thickness of 16 mm and a length of 16 mm each. The test specimens were from three different mini mills; coded A_1, C_2 D_3. 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 16 Samples from three Mini Mills

Tensile test was also carried out on the samples of HYS 16 from the three 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 16 Reinforcement Steel Bar from three Mini-Mills in Nigeria.

Samples of HYS 16 from the three 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).

2.2.5 Microstructural Study of HYS 16 Ribbed Reinforcement Steel Bars from Three Mini-Mills in Nigeria

The samples of the three HYS 16 ribbed reinforcement steel bar from three mini-mills in the country were sent to Kaduna for HRSEM using Phenom SEM Model Pro X. These tests were carried out to give the morphology of the steel bars.

3. RESULTS AND DISCUSSION

3.1 Results

This research work investigated the mechanical properties, chemical composition and structure of HYS 16 ribbed reinforcement steel bars from three mini mills and the results of the tests conducted are captured in Tables 1-4 and Plates III-V.

3.1.1 Results of Mechanical Properties Test

Table 1 Mechanical Properties of HYS 16 Rib-Rolled Steel Bars in Three Mini Mills in Nigeria

Mini Mill	Bar Type	Hardness (BHN)	Impact value (J)	Yield Strength (N/mm^2)	Ultimate Tensile Strength (N/mm^2)	UTS-YS Range (strain-hardening)	UTS/YS	Elongation %
A_1	HYS 16	32.39	272.30	599.84	606.70	6.86	1.01	9.38
C_2	HYS 16	31.76	274.00	430.07	556.97	126.90	1.30	13.64
D_3	HYS 16	34.61	274.70	826.19	830.48	4.29	1.005	9.14

3.1.2 Results of Chemical Composition for the Three HYS 16 Samples

Table 2 Chemical Composition of Sample A_I

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	0.0006	0.259	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				

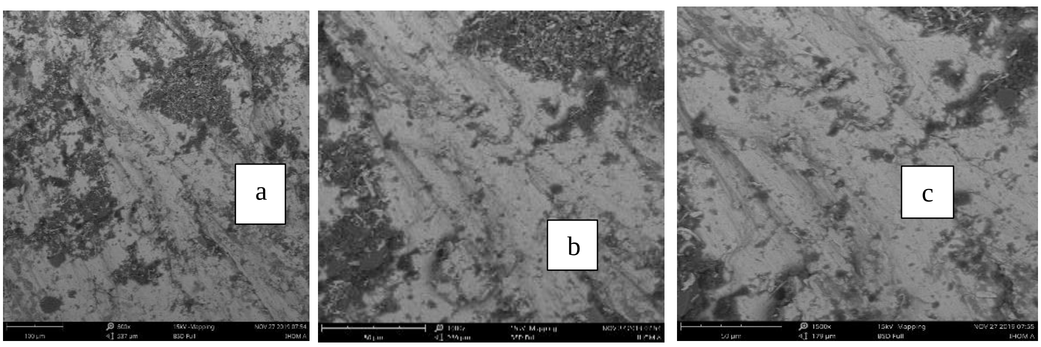
Table 3 Chemical Composition of Sample C_2

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 Sample D_3

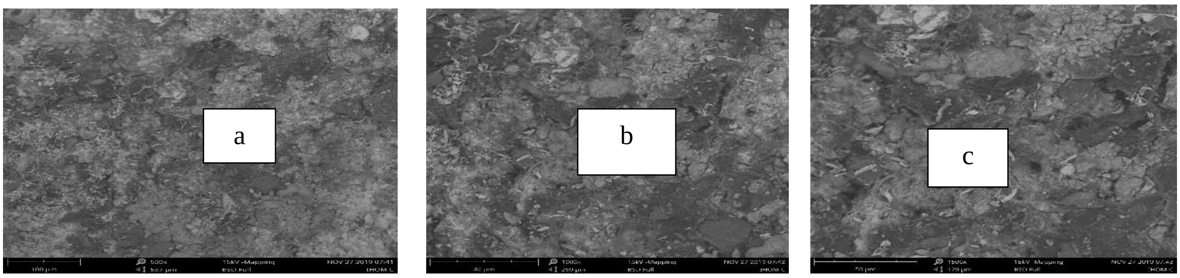
Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co
%	0.475	0.186	0.59	0.025	0.052	0.171	0.072	0.012	0.057	0.238	0.0083
Element	Ti	Nb	V	W	Pb	Mg	B	Sn	Zn		
%	0.0094	<0.0040	0.0065	<0.010	<0.0030	0.0041	0.0031	0.0048	0.0024		
Element	As	Bi	Ca	Ce	Zr	La	Fe				
%	0.012	<0.0020	>0.016	0.0052	0.0017	0.014	<98.0				

3.1.3 Microstructure of the three HYS 16 Reinforcement Steel Bar Samples



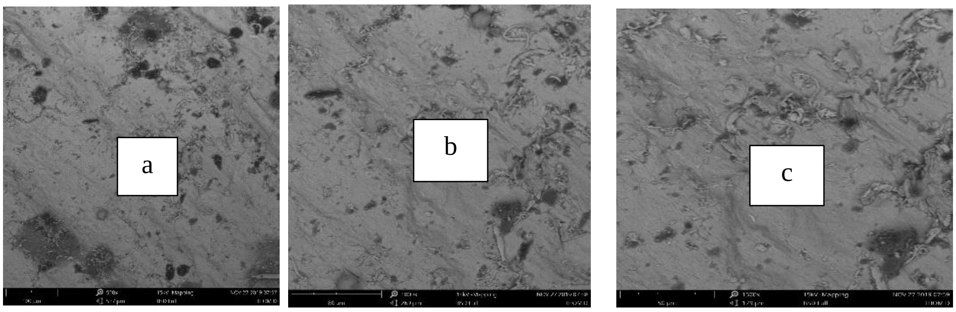
Micrograph (a) is x 500, micrograph (b) is x 1000 and micrograph (c) is x 1500, all the magnifications show a ferrite matrix background and dark areas of pearlite as indicated above

Plate III: SEM Microstructures of HYS 16 Steel Bar Sample A_1 at Different Magnification.



Micrograph (a) is x 500, micrograph (b) is x 1000 and micrograph (c) is x 1500, all the magnifications show light matrix background of ferrite and dark areas of pearlite as indicated above. The pearlite cannot be resolved at this magnification.

Plate IV: SEM Microstructure of HYS 16 Steel bar Sample C_2 at Different Magnifications



Micrograph (a) is x500, micrograph (b) is x1000 and micrograph (c) is x1500. All the magnifications show a ferrite matrix background and dark areas of pearlite as indicated above

Plate V: Scanning Electron Microscope Microstructure of HYS 16 Steel bar of Sample D_3 at Different Magnifications

3.2 Discussion

3.2.1 Mechanical properties test

Table 1 gives the mechanical properties results for Brinell hardness, impact strength measured in terms of energy absorbed before fracture, yield strength, ultimate tensile strength, and elongation % at failure of the three HYS 16 samples from different mini mills. Sample D_3 has the highest mechanical properties; it has Brinell hardness number of 34.61, impact strength value of 274.70 J, yield strength of 826.19 N/mm^2, ultimate tensile strength of 830.48N/mm^2, and elongation % at failure of 9.14% (the least among the three samples). The mechanical properties of HYS 16 from A_1 mini mill follows that of D_3 mini mill. It had a better value, but close value of elongation% at failure of 9.38%, and also the impact value of 272.30J is not too far from D_3 mini mill's 274.7J impact value.
HYS 16 from C_2 mini mill has the highest elongation % at fracture of 13.64%; this may explain why it has impact value of 274 J, despite having lower mechanical properties as compared to the other HYS 16 from the two other mini mills. The hardness of the three HYS 16 steel rods from the three mini mills is within the common range of steel reinforcement rods in Nigeria [14];[17]. The HYS 16 rods will have reasonable resistance to scratch when used in concrete reinforcement. Impact tests values normally show the amount of energy absorbed by the material before failure or fracture. The ability of the three HYS 16 steel rods to withstand shock and impact before failure lies between 272.30 – 274.70J which is a close range indicating that their shock resistance performance is very close [4]-[6]. Table 1 equally shows that HYS 16 from C_2 mini mill has the strain hardening range of 126.90; this explains why it has the highest elongation % and high impact value of 274J. Engineering designs are mostly done using yield strength rather than ultimate tensile strength. This is done so that the material will have good factor of safety or safety factor. Using the strain hardening range and the UTS/YS values it can be seen that using the yield strength of C_2 HYS steel rod or selecting HYS 16 of C_2 mini mill will provide a high degree of safety; this is because the properties shows that it is ductile and will not fail catastrophically [4];[8].

3.2.2 Chemical Composition for the Three HYS 16 Samples

From Table 2; the chemical composition of HYS 16 steel from mini mill A_1 has the carbon content of 0.256%C qualifies the steel as a low carbon steel used for structural purposes. The silicon content is within limit. The phosphorus content is slightly above limit, as is the sulphur. The Cr and Ni contents are above specification and the other elements are within specifications. The chemical composition of this steel bar is no doubt responsible for the

high ultimate tensile strength of 606.70N/mm^2, and high yield strength of 599N/mm^2 exhibited by this steel. Its elongation at fracture is 9.38%, however, this is short of the expected value of a minimum of 28% for steels belonging to this class. The possible cause may be due to impurities or Cr and Ni exceeding specified value of Ni +Cr <0.35 [19].
From Table 3: the chemical composition of HYS 16 steel from mini mill C_2 has the carbon content of 0.361%C, which shows that the steel is slightly above the range for low carbon steel and it is a medium carbon steel that can be considered for constructional purpose. The yield strength is 430.07 N/mm^2 and the ultimate tensile strength is 556.97 N/mm^2; this steel values are somehow close to that of S30C steel, but its elongation at fracture is a far cry from the minimum elongation of 25%. The possible reason may be due to the presence of defects-limiting elongation at fracture. This defects must have limited the steel bar attaining the maximum elongation by early initiation and propagation of cracks as the load was applied. The defects might even have arisen from the nature of treatment given the liquid steel using deoxidizers before casting. In any case the elongation agrees with German standard specification DIN 17100 which is used for high tensile steel rebar [13]-[15];[19]. As the quantity of carbon in iron increases the strength increases, ductility reduces and brittleness increases, however, in this case the HYS 16 steel rod has a reasonable elongation at failure of 13.64%. The process may have been responsible [3]-[6].
From Table 4; the chemical composition of HYS 16 steel from mini mill D_3 has the carbon content of 0.475%C. This indicates that it is a constructional steel because it is a medium carbon steel and not mild or low carbon steel which is used for structural purpose. The sulphur content is above <0.035%, but tolerable. All the other elements are within specified limits. The chemical composition of sample D_3 steel bar explains why the elongation at fracture is not up to the specified minimum of 25% [19]. This sample however, had the elongation % of 9.34%. This may be due to the effects of elements like Cu, Mn and Cr which are there. It is however, difficult to conclude, since liquid steel final treatment also affect this property. The composition of this steel bar however, agrees with German Iron and Steel Quality Standard specification DIN488 and DIN17100 for reinforcement steel rebar, except that the carbon content is more than 0.42% and the manganese is less than 0.9. The elongation at fracture is however, within the DIN specified range of 6-16% [8];[11]-[16];[19] it is a known fact that as the carbon content of steel increases the strength increases, the brittleness also increases and the ductility decreases. The HYS 16 from D_3 mini mill has the highest hardness of 34.61 BHN, the highest impact value of 274.70J, the highest yield strength of 826.19N/mm^2, and ultimate tensile strength of 830.48N/mm^2 among all the three tested samples. In conclusion it should be noted that the samples from the mini mills are high yield strength (HYS) reinforcement steel rods; this must have informed the high carbon content of the steel rebar [22] .

3.2.3 Microstructure Analysis of the three HYS 16 Reinforcement Steel Bar Samples

Plate III shows the three different magnifications of the SEM microstructures of the steel bar sample A_1 in the order: X500, X1000, and X1500. The morphology as revealed by the SEM indicates pearlite (black areas), ferrite matrix (light areas) and defect-like spots. According to Higgins (1983), pearlite areas in plain carbon steel increase as the carbon content increases. When this happens the steel morphology becomes gradually darker. The morphology of sample A_1 agrees with the Spectro-Lab Metal Analyzer result which says the steel is a plain carbon steel with 0.256%C. Defects like segregations, pinholes and inclusions, arising from liquid steel treatment methods are known to reduce the ductility of steel in deformation or loading. The microstructure relates to some extent with some of the mechanical properties [13];[15];[19].
Plate IV shows the morphology of the steel bar as revealed by the SEM. The morphology of sample C_2 as revealed by the SEM indicates pearlite (black areas), ferrite matrix (light areas), and defect-like spots. According to Higgins [15], pearlite areas in plain carbon steel increase as the carbon content increases, when this happens the steel morphology becomes gradually darker. The morphology of sample C_2 agrees with the Spectro-Lab Metal Analyzer result which says the steel is a plain carbon steel with 0.361%C. The SEM result also confirm why the steel bar has reduced ultimate tensile strength and yield strength, and reasonable elongation at fracture. For DIN 17100 quality standard specification for high tensile reinforcement steel bars the elongation is still within the range of 6-16%. The SEM micrograph shows that the grains have recovered fully from the rolling operation. Defects like segregations, pinholes and inclusions, arising from liquid steel treatment methods are known to reduce the ductility of steel in deformation or loading [13]-[15];[19].

Plate V shows the morphology of the steel bar as revealed by the SEM. The morphology as revealed by the SEM of sample D_3 indicates pearlite (black areas), ferrite matrix (light areas), and defect-like spots. According to Higgins [15], pearlite areas in plain carbon steel increases as the carbon content increases, when this happens the steel morphology becomes gradually darker. The morphology of sample D_3 agrees with the Spectro-Lab Metal Analyzer result which says the steel is a plain carbon steel with 0.475%C. The SEM result also confirm why the steel bar has the highest ultimate tensile strength and yield strength, with reduced elongation at fracture. For DIN 17100 quality standard specification for high tensile reinforcement steel bars the elongation is still within the range of 6-16%. Defects like segregations, pinholes and inclusions, arising from liquid steel treatment methods are known to reduce the ductility of steel in deformation or loading. High carbon content in steel also increases strength but reduces ductility. Poor adjustment of the rolling process does also give rise to reduced mechanical properties of steel bars when grains are not given sufficient temperature and time for recrystallization. The high yield strength confirms the sample as a HYS steel rolled under controlled rolling conditions [13]-[15];[19];[22].

4. CONCLUSION

This paper has examined the mechanical properties of some HYS 16 rolled steel reinforcing bars in Nigeria and has established the correlation between their mechanical properties, composition, and the structure of the BCC steels. From this work the following inferences can be drawn:

1. The composition of the samples determine the structure of the HYS 16 steels, and the structure determine the measured mechanical properties of the HYS steels.
2. The mechanical properties of the three samples relate to the composition with some slight deviations in the case of sample C_2, which may be due to several reasons relating to processing, elements present, and heat treatment
3. The mechanical properties of the three HYS 16 steels correlate with the structure, and morphology of the three HYS 16 rolled steel rod samples. The D_3 sample with the highest mechanical properties of 34.61BHN, 274.70J impact value, 826.19 N/mm^2 yield strength, and 830.48N/mm^2 ultimate tensile strength had a uniformly distributed fine grains of cementite phase within the ferrite matrix of the sample.
4. Sample C_2 has the best % elongation at failure of 13.64%, and this correlates to the high strain range of the sample of 126.90.
5. The highest impact resistance of 274.70J and hardness resistance of 34.61BHN was exhibited by sample D_3 these values also reflect in the high yield strength and high ultimate strength of the sample because there is a correlation between them.
6. In conclusion there is a correlation between the mechanical properties of the samples studied with their composition and their microstructure. At the temperature this study was conducted all the samples had BCC structure and can as well be referred to as BCC steels.

ACKNOWLEDGEMENT

The authors wish to sincerely acknowledge the Technologist (Engr. Isaac Okon) and his assistants in Laboratory 1 of the Department of Mechanical and Aerospace Engineering, who carried out the mechanical tests on the HYS 16 samples from the various mini mills. We are equally grateful to DICON that conducted the SEM and Spectrolab analysis on the HYS 16 samples.

REFERENCES

[1] Ogbodo,J.N, Aondona, P.T, Offiong, A. and Ihom, A.P. (2022) Analysis of the Ductility of Reinforcement Structural Steel Rods from some Local Mini Mill in Nigeria using Theoretical and Statistical Approach, Int. Journal of Frontiers in Engineering and Technology Research, 2022, 03(01), 020-028

[2] Ogbodo,J.N, Ihom, A.P., and Aondona, P.T, (2022) Further Study of Stress-Strain Deformation of Some Structural Reinforcement Steel Rods with Different Diameters from a Mini Mill in Nigeria using Theoretical and Regression Analysis, Int. Journal of Frontiers in Engineering and Technology Research, 2022, 03(01), 020-028

[3] NBS (1966) National Bureau of Standards Monograph 88 Issued Nov. 1, 1966. Supersedes Circular 493 and Monograph 18

[4] Mahtsentu, A. (2022) Engineering Materials, first Edition, Academia.org, download

[5] Khanna, O.P. (2008) A Textbook of Material Science and Metallurgy, 7th Edition, New Delhi: Dhanpat Rai Publications; pp43.1-43-52

[6] Smallman, R.E. and Bishop, R.J. (1999) Modern Physical Metallurgy and Materials Engineering, Sixth Edition, Oxford: Btterworth Heinemann, pp197-201

[7] Adebayo, A. (2016). *Nigeria*: *Tackling Challenges in Steel Sector*. Daily Trust, Abuja. www.allafrica.com

[8] Balogun, S., Esezobor D., Adeosun S., and Sekunowo O. (2009). *Challenges of Producing Quality Construction Steel Bars in West Africa: Case study of Nigeria Steel Industry*. Journal of Mineral & Materials Characterization & Engineering, Vol. 8, No. 4, pp 283 – 292, USA.

[9] Bolton, N.C. (1999) Materials for Engineering; 4th Reprint, London: Butterworth-Heinemann, A division of Reed Educational and professional Publishing Ltd, pp27-30

[10] B.S Standard: BSEN1002 Methods of tensile testing of metals (formerlyBS18) Standards specified as BSEN are European standards which are adopted as British standards.

[11] Champion, R.C and Arnold, E.C. (1969) Motor Vehicle Calculations and Science, Part 2, Edward Arnold (Publishers) Ltd, London, pp298-299

[12] Chapman, W.A.J. (1972) Workshop Technology Part 1 LPE, Edward Arnold (publishers) Ltd. London, pp20-21

[13] Cottrell, A (1980) An Introduction to Metallurgy, 2nd Edition LPE. UK:The English Language Book Society and Edward Arnold (publishers) Ltd, pp509

[14] DIN (1980) *German Steel and Iron Quality Standards DIN 488 and DIN 17100.*

[15] Higgins R.A. (1985) Properties of Engineering Materials 5th Edition, UK: Hodder and Stoughton Educational, pp178-184

[16] Ihom, A.P. (2013) Case Hardening of Mild Steel using Cowbone as Energizer, African Journal of Engineering Research, Vol.1 (4) pp99-101

[17] Ihom,A.P., Uko, D.K, and Eleghasim, C.O. (2020) Quality Analysis of Locally Produced Reinforcing Steel Bars Vis-à-vis the Incidences of Collapse of Building in Nigeria, Int. Journal of SEI, 9 (102), 26-43

[18] Jain, R.K (2009) production Technology, 14th Reprint, New Delhi: Khana Publishers, pp19-27

[19] JIS Standard (2008) Japanese Industrial Standard Designation and Specification for Metals and Metal Products

[20] Shrager, A.M. (1969) Elementary Metallurgy and Metallography, third Edition, New York: Dover Publications, pp80-203

[21] Uko, D.K. *(2020) Iron-Carbon Phase diagram (a review).* MSE 300 Materials Laboratory Procedures. Department of Materials Science and Engineering, University of Tennessee.

[22] Vlad, C. M. (1986). *A comparison between the Temprimal and Tempcore processes for high strength rebars*. 27th Mechanical Working and Steel Processing Conference Proceedings, Iron and Steel Society, Vol. 23, p. 908 – 912.