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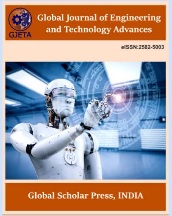

(RESEARCH ARTICLE)

Microstructural analysis of some reinforcement steel rods used for concrete reinforcement and their effect on the mechanical properties, and carbon equivalent values of the reinforcement steel rods

Emmanuel. O. Onche [2], A.P. Ihom [1, *], Emmanuel Udama Odeh [1], and Aondona T. Philip [1]

[1] *Department of Mechanical and Aerospace Engineering. Faculty of Engineering, University of Uyo, Uyo. PMB 1017 Uyo-Nigeria.*
[2] *Department of Mechanical Engineering, Faculty of Engineering, University of Abuja-Nigeria.*

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Abstract

The microstructural analysis of some reinforcement steel rods used for concrete reinforcement and their effect on the mechanical properties, and carbon equivalent values of the reinforcement steel rods have been studied. The work subjected the samples to test specimen preparation as required by standard specification for each test. Samples from five different mini mills were investigated for hardness, impact strength, composition, and microstructure. The result obtain from the work, has clearly shown that the microstructure of all the samples investigated reflected the hardness, impact strength, and the CEV of the samples. The microstructure of sample D with spheroidal pearlite dark areas, and a ferrite matrix had the highest hardness value of 34.61BHN, impact strength of 274.7J and CEV of 0.545. These values correlate with the microstructure. The work showed that as the CEV is increased the hardness and the impact strength of the material also increased. The work also show that as the total carbon (TC) % in the samples increased the microstructure becomes darker and the hardness and the impact strength also increased. In conclusion the microstructure of the reinforcement steel rods had effect on the hardness, impact strength properties, and carbon equivalent value of the reinforcement steel rods.

Keywords: CEV; Reinforcement; Steel rod; Mechanical properties; Analysis; Concrete

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1. Introduction

It is an established fact that the microstructure of steel reinforcement rods determines its mechanical properties [1];[7];[14];[16];[19];[21]. In this era in the country Nigeria, where hardly a year passes without incidences of building collapse and structural failures, it is incumbent on researchers to continue to investigate the properties of materials used for buildings and other steel reinforced concrete structures in the country [9];[18]. Most of the reinforcement steel rods used in the country today are of the high yield strength (HYS) type with the chemical composition aligning to that grade of steel [15]. This work examines this grade of steels produced from different mini mills across Nigeria. The work collected samples from five (5) different mini mills for the purpose of testing two mechanical properties and relating it with the microstructure and the carbon equivalent value (CEV) of the HYS bars. Literature has clearly shown that the microstructure and CEV of steels affects the mechanical properties of the steels [1];[7];[19].

According to Ihom [1], there is a relationship between composition, strength and structure [1]. 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, refining processes, rolling, and cooling rate of the bars. The

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[*] Corresponding author: AP Ihom

three constituents of steel which most affect strength and hardness, they are; total carbon, silicon and phosphorus. An index known as the carbon equivalent value combines the effects of these elements.

$$\text{Carbon Equivalent (CE)} = TC\% + (Si\% + P\%)/3 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (i)$$

Steel with carbon equivalent values of less than 0.83% are called hypoeutectoid steels, those having carbon equivalent values higher than 0.83% are hypereutectoid steels. Since the microstructure (and hence the strength) of carbon is a function of composition, a knowledge of the CEV of steel can give an approximate indication of the strength to be expected in any sound section of HYS steel reinforcement rod [1].

The objective of this research is to analyse the microstructure of some HYS reinforcement steel rods from some Nigerian mini mills and to relate the microstructure's effect on the hardness, impact strength and CEV of the HYS steel reinforcement rods.

2. Material and methods

This research work utilized HYS rolled steel products from various mini mills across Nigeria. The equipment used in preparing the various samples into test specimens include; power saw, lathe machine, hack saw, impact testing machine, Brinell hardness testing machine, spectro Lab analyser and universal strength testing machine.

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, for Brinell hardness test, and impact strength test. The test specimen for the Brinell hardness test was machined using a lathe machine into 12mm thick and 12 mm long. The test specimens for the impact test were machined into Izod notch test specimen. Specimens for composition were equally prepared according to equipment used for the tests. Figure I show some of the test specimens prepared for the Brinell hardness test and impact strength test.

Figure 1 Some Impact Test Specimens and Hardness Test Specimens Prepared from Samples A, B, C, D, and E Obtained from Different Mini Mills

2.2. Microstructural Study of HYS Ribbed Reinforcement Steel Bars from Five Mini-Mills in Nigeria

The samples of the five HYS ribbed reinforcement steel bar from five 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.

2.3. Hardness Test

The specimens tested for Brinell hardness test had a diameter of 12 mm and a length of 12 mm each. The test specimens were from five different mini mills; coded A, B, C, D, and E. 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.

2.4. Impact Strength Test

The impact strength test was carried out using impact testing machine installed in the Mechanical and Aerospace Engineering Department Materials Laboratory. The test was conducted in accordance with ASTM specification, the Izod notched specimens as shown in Figure I were clamped to the clamping device on the impact tester and the swinging device was lifted to its highest potential and released from that point to strike the specimen causing it to fail. The energy absorbed by the specimen before failure was recorded on a scale attached to the machine in joules.

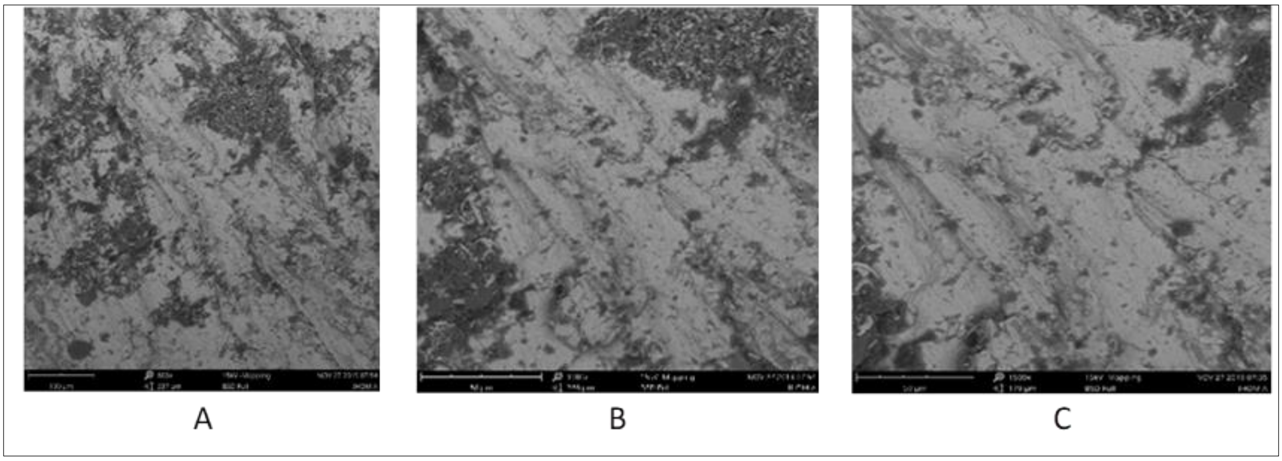
2.5. Chemical Composition of HYS Reinforcement Steel Bar from Five Mini-Mills in Nigeria.

Samples of HYS rolled steel bars from the five mini-mills 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-mills and to also establish their carbon equivalent values. The chemical analysis was carried out using spectro-lab metal analyzer (Fe-01-F).

3. Results

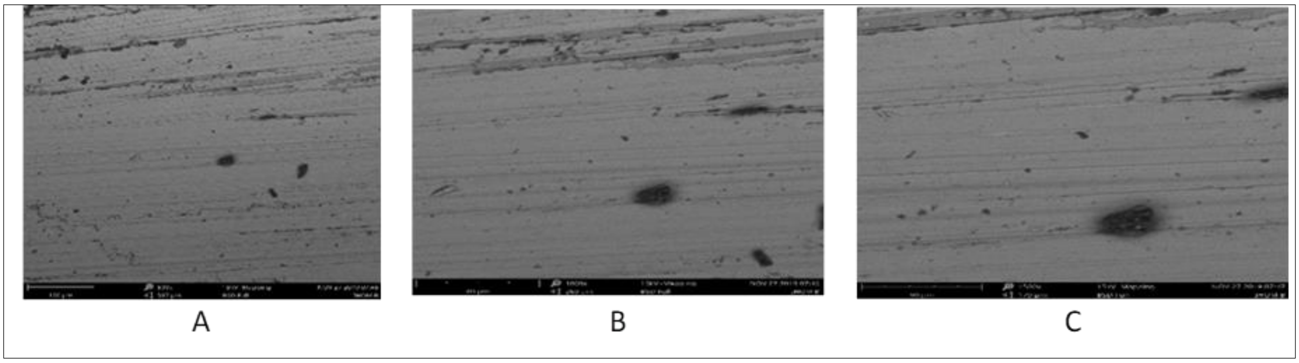
The results of the research work are as presented below:

3.1. Microstructures of the Five HYS Reinforcement Steel Rod Samples from the Mini Mills



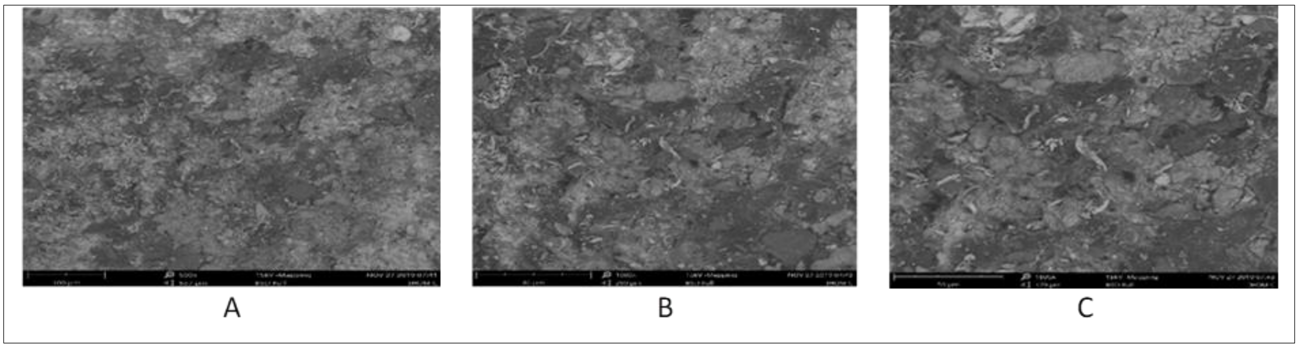
Micrograph (a) is x 500, micrograph (b) is x 1000 and micrograph (c) is x 1500, all the magnifications show a ferrite matrix background and dark areas of pearlite as indicated above

Figure 2 SEM Microstructures of HYS Steel Bar Sample A at Different Magnifications



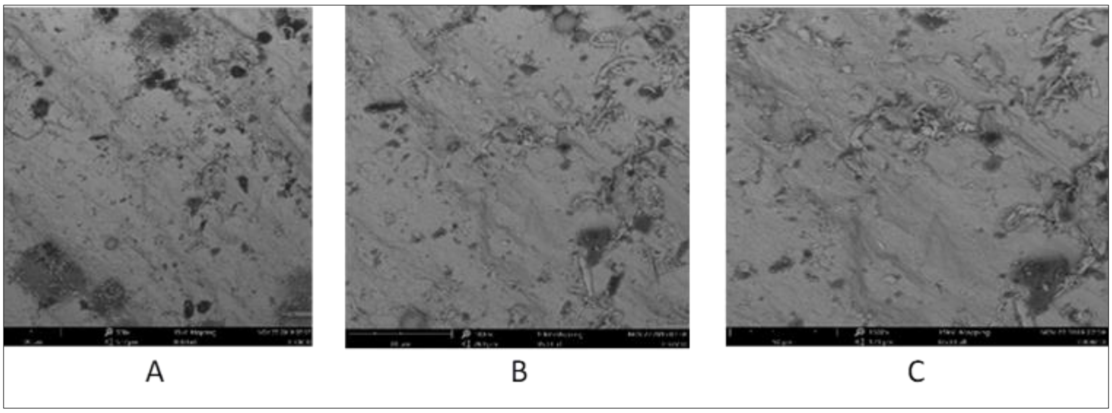
Micrograph (a) is X500, micrograph (b) is X1000 and micrograph (c) is X1500, all the magnifications of the micrograph show a ferrite matrix background and dark areas of pearlite and others as indicated above

Figure 3 SEM Microstructures of HYS Steel Bar Sample B at Different Magnifications



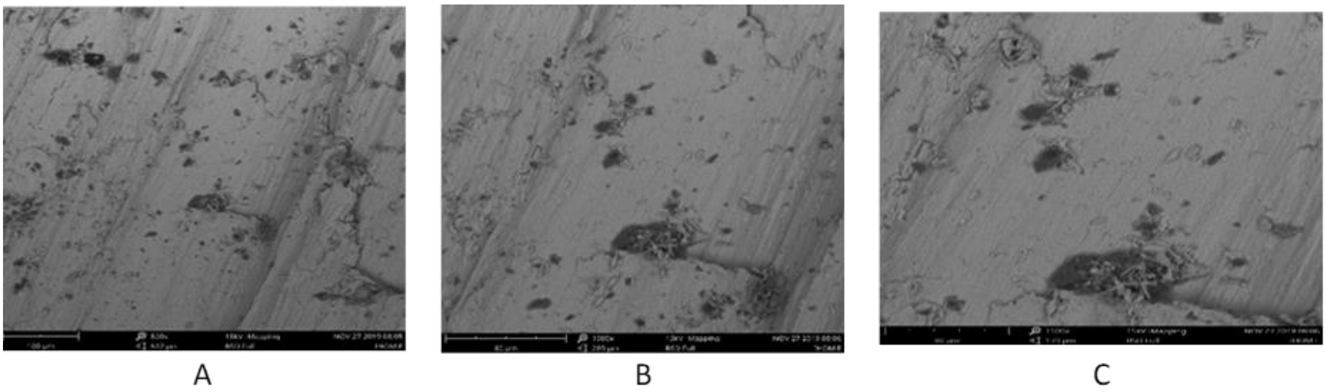
Micrograph (a) is x 500, micrograph (b) is x 1000 and micrograph (c) is x 1500, all the magnifications show light matrix background of ferrite and dark areas of pearlite as indicated above. The pearlite cannot be resolved at this magnification

Figure 4 SEM Microstructures of HYS Steel bar Sample C 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

Figure 5 Scanning Electron Microscope Microstructure of HYS Steel bar of Sample D at Different Magnifications



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

Figure 6 SEM Microstructures of HYS Steel Bar Sample E at Different Magnifications

3.2. Mechanical Properties Test and Chemical Property Test of the HYS Steel Bars from the Five Mini Mills

Table 1 Hardness and Impact test values of some concrete steel reinforcement rods from local mini mills in Nigeria and their carbon equivalent values (CEV)

S/No.	Company Identity	Average Hardness	Average Impact Strength	TC%	Si%	P%	CEV
1	A	32.39	272.3	0.256	0.248	0.036	0.351
2	B	26.59	251.7	0.391	0.275	0.054	0.501
3	C	31.76	274.0	0.361	0.257	0.027	0.456
4	D	34.61	274.7	0.475	0.186	0.025	0.545
5	E	29.07	268.3	0.206	0.280	0.033	0.310

TC = Total carbon; CEV = Carbon equivalent value

4. Discussion

4.1. Microstructural Analysis of the morphology of the Five HYS Steel Bars from the Mini Mills as it Relates to their Mechanical and Chemical Properties

Figure 2 shows the three different magnifications of the SEM microstructures of the steel bar sample A 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 [16], 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 agrees with the Spectro-Lab Metal Analyzer result which says the steel is a plain carbon steel with a 0.256C%. 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 [1][7][14][19][21]. Table 1 shows that sample A has hardness value of 32.39BHN, impact strength of 272.3 and CEV of 0.351. These values relate with the microstructure of Figure 2. According to Ihom, [1], 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 casting. 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 CEV of the steel increases so also the hardness, impact strength, and other strength values [1][2]-[11].

The morphology as revealed by the SEM of Figure 3 indicates pearlite (black areas), ferrite matrix (light areas) and defect-like spots. According to Higgins [16], 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 B disagrees with the spectro-lab metal analyzer result which says the steel is a plain carbon steel with 0.391%C. The SEM results also confirms why the steel bar has moderate impact strength and low hardness value. The SEM morphology reveals a ferrite matrix, deformed cementite and aligned grains, dark spots and lines, which are obviously from the rolling operation. The amount of pearlite seen in the morphology did not agree with the carbon content of the steel. The most likely explanation to this anomaly is that the rolling process was poorly adjusted. The microstructure of the steel bar also indicate that it is in a work-hardened state [12]-[20]. Defects like segregations, pinholes and inclusions, arising from liquid steel treatment methods are known to reduce the ductility of steel in deformation or loading [1]-[5][14][16][20]. Sample B has hardness value of 26.59BHN, impact strength of 251.7 J and CEV of 0.501. These values relate with the microstructure of Plate III. According to Ihom, [1], 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 casting. 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 CEV of the steel increases so also the hardness, impact strength, and other strength values [1].

Figure 4 shows the morphology of the steel bar as revealed by the SEM. The morphology of sample C as revealed by the SEM indicates pearlite (black areas), ferrite matrix (light areas), and defect-like spots. According to Higgins [16], 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 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 reasonable hardness and impact strength. 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 [14]-[23]. Sample C has hardness value of 31.76 BHN , impact strength of 274J and CEV of 0.456. These values relate with the microstructure of Figure 4. According to Ihom, [1], 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 casting. 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 CEV of the steel increases so also the hardness, impact strength, and other strength values [1][20]-[23].

Figure 5 shows the morphology of the steel bar as revealed by the SEM. The morphology as revealed by the SEM of sample D indicates pearlite (black areas), ferrite matrix (light areas), and defect-like spots. According to Higgins [1], 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 agrees with the Spectro-Lab Metal Analyzer result which says the steel is a plain carbon steel with 0.475%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. 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 hardness and impact strength confirms the sample as a HYS steel rolled under controlled rolling conditions [14]-[23]. Sample D has the highest hardness value of 34.61BHN, impact strength of 274.7J and CEV of 0.545. These values relate with the microstructure of Figure 5. According to Ihom, [1], 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 casting. 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 CEV of the steel increases so also the hardness, impact strength, and other strength values [1].

The morphology as revealed by the SEM of Figure 6 indicates pearlite (black areas), ferrite matrix (light areas), and defect-like spots. According to Higgins [16], 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 E agrees with the Spectro-Lab Metal Analyzer result which says the steel is a plain carbon steel with 0.206%C. The SEM results also agrees with the reasonable values of hardness, impact strength, and CEV. 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, so as to recover from deformation [14]-[23]. Sample D has hardness value of 29.07BHN, impact strength of 268.3J and CEV of 0.310. These values relate with the microstructure of Figure 6. According to Ihom, [1], 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 casting. 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 CEV of the steel increases so also the hardness, impact strength, and other strength values [1][14]-[23].

5. Conclusion

'Microstructural Analysis of Some Reinforcement Steel Rods used for Concrete Reinforcement and their Effects on the Mechanical Properties, and Carbon Equivalent Values of the Reinforcement Steel Rods' have been investigated and the following conclusions drawn from the investigation:

- the work has clearly shown that the microstructure of all the samples investigated reflected the hardness, impact strength and the CEV of the samples.
- The microstructure of sample D with spheroidal pearlite dark areas and a ferrite matrix had the highest hardness value of 34.61BHN, impact strength of 274.7J and CEV of 0.545. These values correlate with the microstructure.
- The work show that as the CEV is increased the hardness and the impact strength of the material also increased

- The work also show that as the total carbon (TC) % in the samples increase the microstructure becomes darker and the hardness and the impact strength also increases.
- In conclusion the microstructure of the reinforcement steel rods had effect on the hardness and impact strength properties of the reinforcement steel rods.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest in this work. This work was self-sponsored by the authors and it was their collective decision to send the work for publication in this journal.

References

[1] Ihom, A.P. (2022) Modern Foundry Principles and Practice, 1st Edition, Uyo: published by PAI Memorial Centre for Innovation and Research, pp316-318.

[2] 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

[3] 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

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

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

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

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

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

[9] 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.

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

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

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

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

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

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

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

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

[18] 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

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

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

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

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

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

Author’s short biography

	**Prof. Aondona Paul Ihom** is a professor with the department of Mechanical and Aerospace Engineering, Faculty of Engineering, University of Uyo, Uyo-Nigeria. His research interests are in Materials and Production engineering, where he has worked assiduously in materials development and improvement, and equipment design and production. The researcher has been particularly interested in adaptable technologies that can withstand the impact of climate change and mitigate the effects of the extremities of global warming. He has encouraged sustainable engineering in his designs and developments. Alleviating human suffering is the object of all his research works. He can be contacted through the following links: Email: ihomaondona@uniuyo.edu.ng, Phone: +2348035813571; ORCID ID: https//orcid.org/0000-0002-6293-869x; WOS ID: GQZ-1999-2022; YouTube ID: https//YouTube.com/@paulihom.