International Journal of Mechanical and Civil Engineering
Volume 2, Issue 2, 2019 (pp. 11-22)
www.abjournals.org

THE DEVELOPMENT OF ECOFRIENDLY ENERGIZERS AS REPLACEMENT FOR INDUSTRIAL CHEMICAL ENERGIZERS IN THE CASEHARDENING OF MILD STEEL MATERIALS

Ihom Paul Aondona and Kingsley Uwaekwuna Azoro

Department of Mechanical and Aerospace Engineering, University of Uyo, Uyo, PMB 1017
Uyo, Akwa Ibom State-Nigeria.

ABSTRACT: *Efforts have been made in this work titled ''the Development of Ecofriendly Energizers as Replacement for Industrial chemical Energizers in the Casehardening of Mild Steel Materials'' to develop an ecofriendly carburizing compound, which will agree with the green chemistry concept of avoiding the release of waste products to the environment. The work started with the carburization of test specimens in three carburizing compounds A, B and C. This was carried out in the electric furnace for 8hrs at the carburizing temperature of 920°C after which the specimens were removed and quenched in water. They were then dried and prepared for surface hardness test, hardness profile and microstructural analysis. The result of the above tests showed that the ecofriendly compound C which had a mixture of charcoal, periwinkle, cow bone and banana peel had the highest surface hardness of 69 HRC and case depth of 0.18 mm as against compound B which followed with 0.11 mm case depth and 64.39 HRC surface hardness. Compound B contained industrial chemical compounds which have environmental challenges in terms of health and safety. The work has proven that the developed carburizing compound C can be used to replace the carburizing compound with industrial chemical energizers given the good result it has produced.*

KEYWORDS: Compounds, Casehardening, Mild Steel, Industrial Chemical, Ecofriendly Energizers, Ecofriendly Compound

INTRODUCTION

We are living in a world today where issues of the environment are at the forefront of the burner. We want to have safe and clean atmosphere, rivers, underground waters, soil and even the vegetation around us. This has really been threatened by anthropogenic activities of man; engendered by his quest for industrialization and high standard of living (Ihom, 2014). Recent developments have informed scientists and engineers that it cannot be business as usual. This informs the development of concepts such as sustainable development and green chemistry. The crux of the matter is that, if humanity must continue to exist on planet earth then we must green our manufacturing methods; the use of hazardous chemicals must be discarded or discouraged. Industrial chemicals used as energizers in casehardening have the tendency of passing some hazards to the environment which are also harmful to man. Biological materials and organic materials from plants and animals tend to be mild and this informed the current surge in their exploitation in research to replace industrial chemicals (Ihom, 2014; Poinern, 2015). For instance, previous works have shown that eggshells and cow bones contain calcium carbonate and their efficacy as energizers in pack carburization of mild steel have equally been proven. In separate works carried out by Ihom (1991) and Ihom *et al.*, (2013) the authors were able to show that carburization of mild steel is enhanced with the addition of cow bones to the carburization materials. The use of municipal and agricultural solid waste in metallurgy and materials engineering is steadily increasing; sugar cane bagasse has been used for aluminium alloy particulate composite as well as for casehardening of mild steel (Aigbodion *et al*., 2009)

Different materials are used in order to enhance the surface finish of metals; the type of material used depends on the technique and type of surface finish desired. Surface finishing processes include: impregnation of surfaces of metals with different elements, heat treatment and others. Impregnation of metal surfaces with different elements include processes like carburization, carbonitriding and nitriding which in recent years have undergone a lot of transformation in terms of practice and methods (Saita, 2008; Ihom, *et al.*, 2012; Ihom, et al., 2013; Azoro, 2017).

There are different carbon materials with different carburizing potentials; some however, have low carburizing potentials. The carburizing potential of such materials with low carburizing potential can be raised by the use of energizers; these energizers enhance the carburizing potential of the carburizing material. Different carbonates are used as energizers or enhancers in carburizing; notable among these carburization enhancers are sodium carbonate, barium carbonate and calcium carbonate (Azoro, 2017). These are used as industrial chemicals; in view of environmental concerns the objective of this present research work is to develop ecofriendly organic energizers as replacement for industrial chemical energizers used for casehardening of mild steel.

MATERIALS AND METHOD

Materials

Materials used for the research included; acetone, clay, nital solution, emery cloth, mild steel rod of 20 mm diameter, charcoal, $BaCO_3$, Na_2CO_3, NaOH, water, and polishing powder. All were sourced locally within Nigeria. The mild steel was obtained at Delta Steel Company, Aladja. Others included periwinkles shells, cow bones, and banana peels. The chemical composition of the mild steel is shown in Table 1, and Plates I-V show charcoal, pulverized banana peel, mild steel specimen, periwinkle shells, and cow bones that were used in the work.

Plate I: Charcoal a Carbon Source

Plate II: Pulverized Banana Peel

Table 1: Chemical Composition of Mild Steel from Delta steel Company

C	Si	Mn	P	S	Cr	Mo	Ni	Sn	Cu	V
0.13	0.15	0.47	0.043	0.006	0.01	0.01	0.01	0.001	0.03	0.002

Equipment

The equipment used were hacksaw, lathe machine, Vernier calipers, grinding and polishing equipment, electric furnace, heat resistant steel boxes, hardness testing machine (Rockwell), and metallurgical microscope.

Method

Pack carburizing process was carried out in a muffle electric furnace at Civil Engineering Laboratory, University of Uyo. Carbonaceous elements like charcoal, banana peels and all the energizers; industrial chemical and organic were obtained within Uyo.

All the carbonaceous elements and energizers were pulverized in a hammer mill in Agricultural Engineering laboratory into powder form to increase the surface area. It was sieved using 1.18mm sieve size. The mild steel specimens were packed into boxes half-filled with charcoal in one box, and other boxes contained charcoal, $BaCO_3$, Na_2CO_3, $CaCO_3$; and charcoal, periwinkle shell, cow bone and banana peel as indicated in Table 2. The mild steel was then completely covered with the compound. The box covers were fixed and sealed using clay to avoid air ingress. The boxes were then transferred into the heat treatment furnace. An appropriate temperature gradient of 400^oC/hr was set and the specimens were heated to 920^oC and held for 8hrs. The specimens were then quenched in water and allowed to cool before removing them. Table 2 shows the carburizing compounds that were used in the research work. Plate III shows how the mild steel specimens were prepared for carburizing.

Table 2: Carburizing Compounds and their Composition

Compound	Composition
A	100% Charcoal
B	55% Charcoal, 15% $CaCO_3$, 10% Na_2CO_3, 20% $BaCO_3$
C	65% Charcoal, 10% Periwinkle shell, 5% Cow Bone 20% Banana Peel

Plate III: Mild Steel Sample

Plate IV: Periwinkle Shells

Plate V: Cow bones

Hardness Test

The quenched specimens were tested for hardness according to ISO6508-1:1999 metallic materials standard using Rockwell Hardness Testing machine, calibration standard blocks of 59.6HRC and 69.6 HRC were used to check all the measurements taken. The testing process required the selection of scale C with a preliminary test force of 98.07N, additional test force of 1373 N and the total test force of 1471N. The preliminary force was expected to set the specimen before the application of the final testing load. The result of the test was then displayed on the dial, and readings were taken from the C scale. The hardness profile for determination of case depth was obtained by cutting the specimen into two. The cut-face was then ground and polished. Hardness values were obtained from the surface edge towards the center of the specimen at an interval of 0.1 mm and five readings were taken. The surface hardness of all the specimens was also taken.

Metallography

The specimens for metallography were taken by cutting the test specimen into two. The cut-face was ground using grit 240-600 silicon carbide grinding paper on the grinding belt. It was then transferred to the polishing disc. 1-micron alumina powder was used for the pre-polishing and the final polishing was undertaken using 0.5-micron silicon carbide powder. The specimens were thoroughly washed using distilled water. Warm air from the air blower was used to dry the specimens. Each specimen was then etched in nital solution and washed in distilled water and dried using an air blower before it was examined using a metallurgical microscope equipped with a camera and linked to computer.

RESULTS AND DISCUSSION

Results

The results of the work are presented in Figs. 1- 6 and Plates VI-VII below

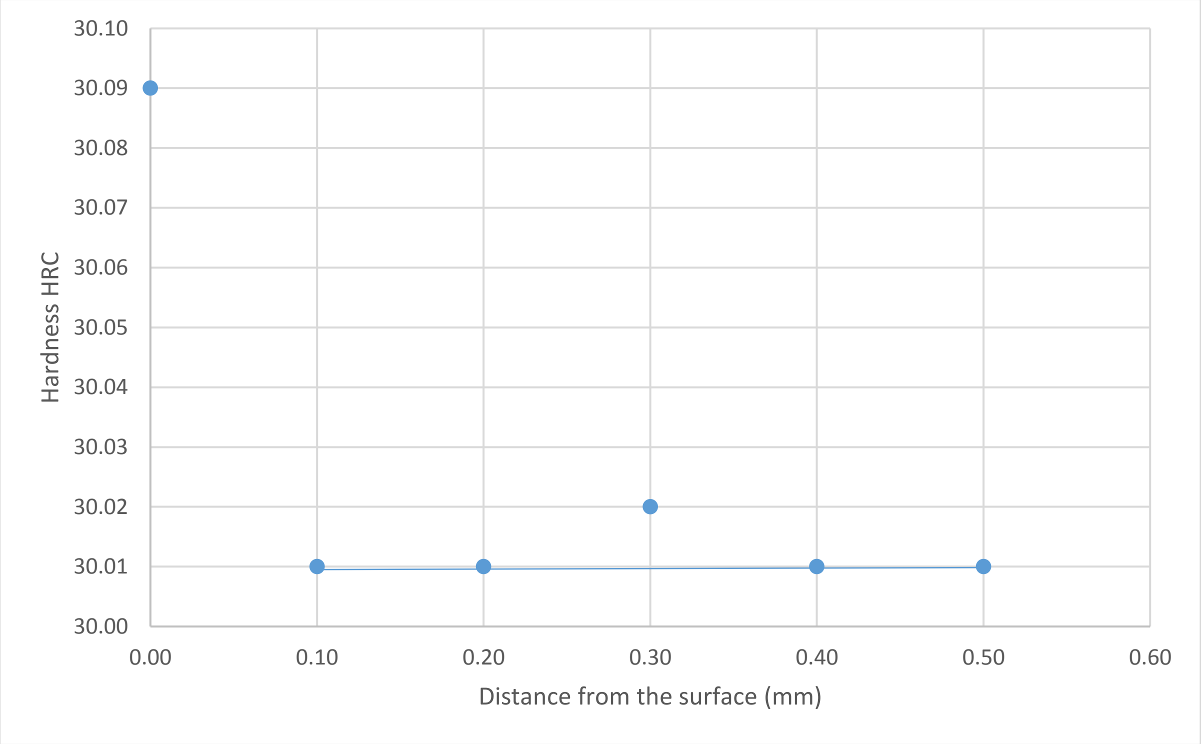

Fig. 1: Hardness Profile of the Un-carburized Mild Steel Specimen against Distance variation from the Surface of Specimen towards the Core.

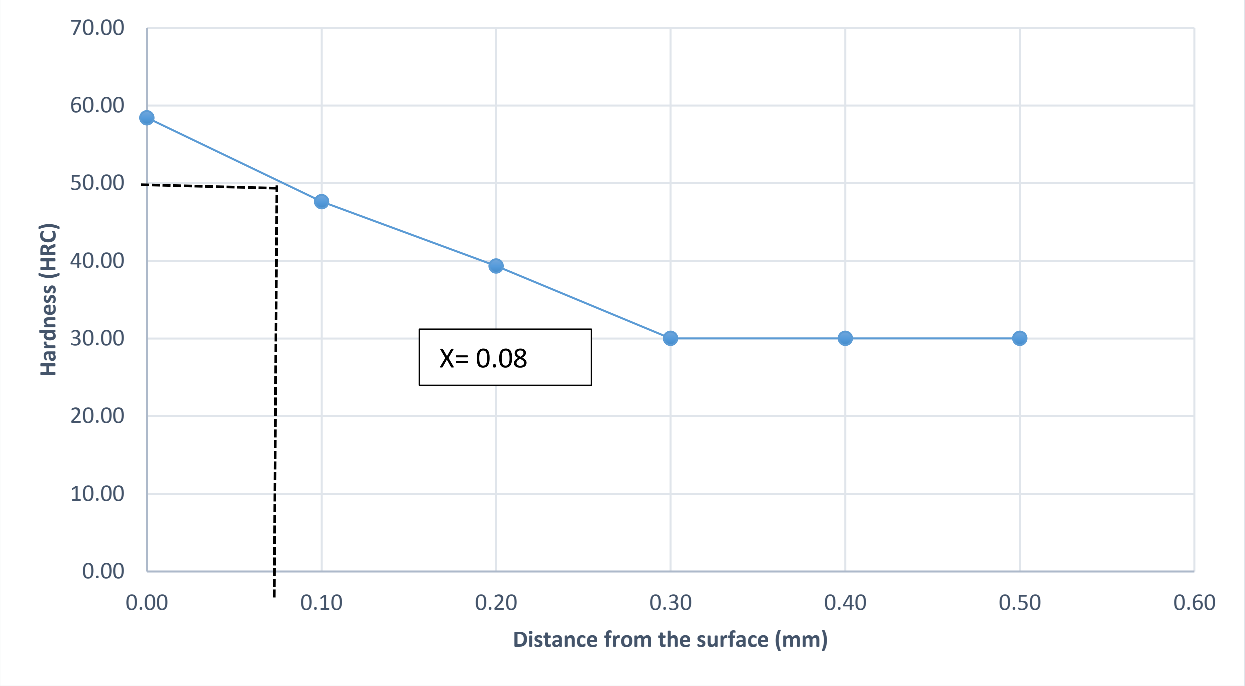

Fig.2: Hardness Profile of Carburized Specimen using Compound A against Distance from the Surface

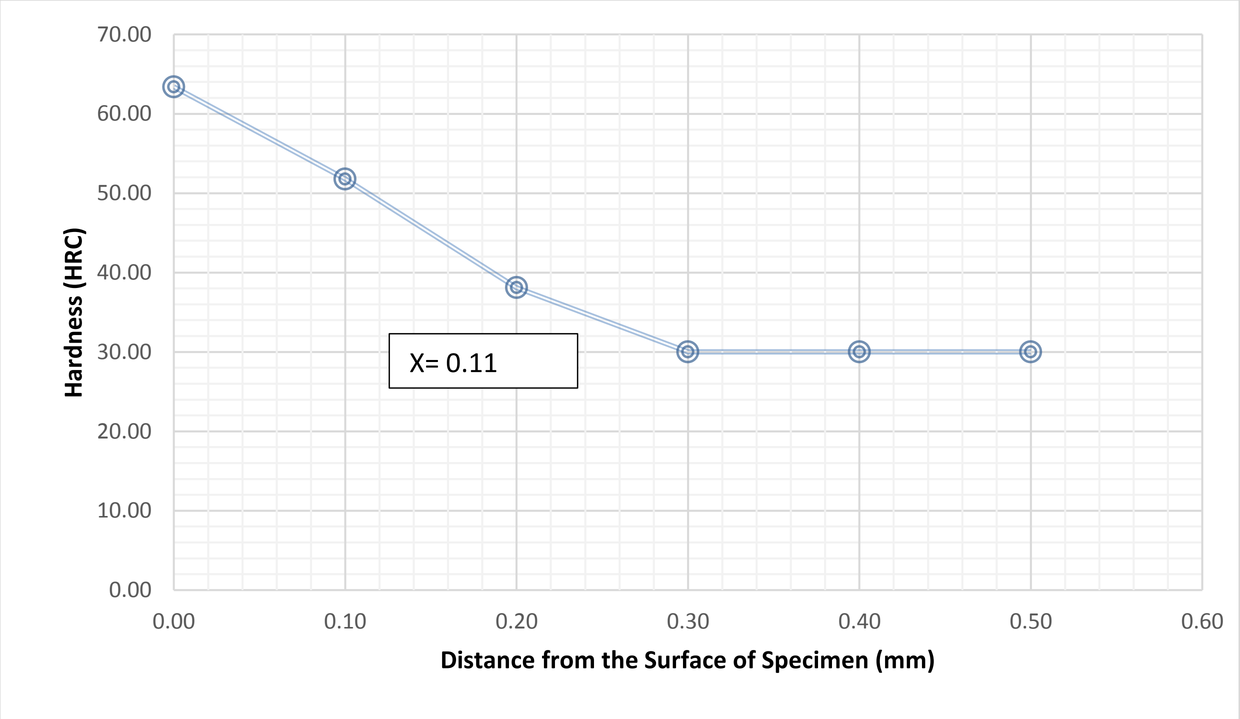

Fig. 3: Hardness Profile of Carburized Specimen using Compound B against Distance from the Surface.

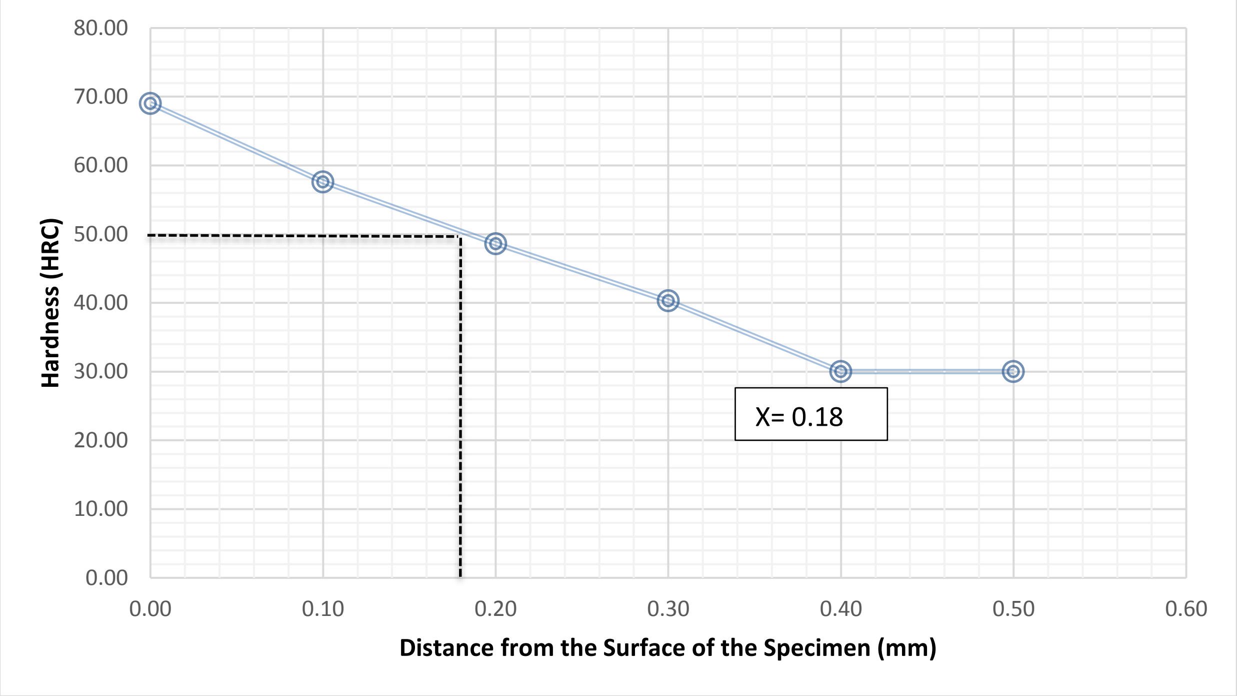

Fig.4: Hardness Profile of Carburized Specimen using Compound C against Distance from the Surface

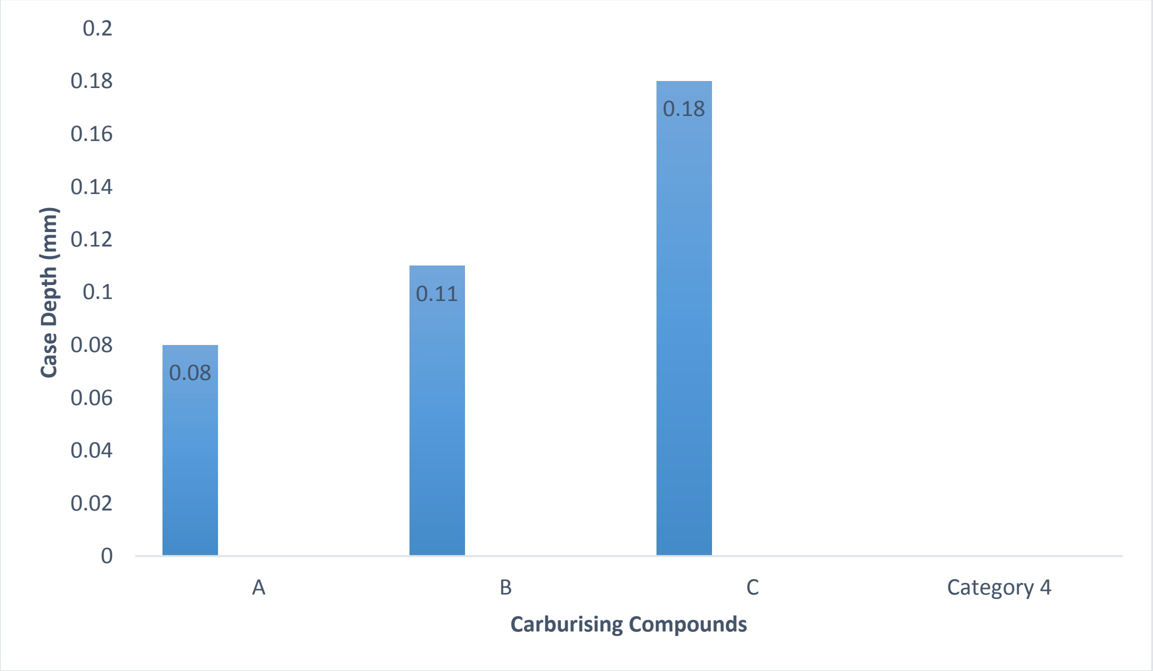

Fig.5: Bar Chart of Case Depth Variation of Developed Carburizing Compounds

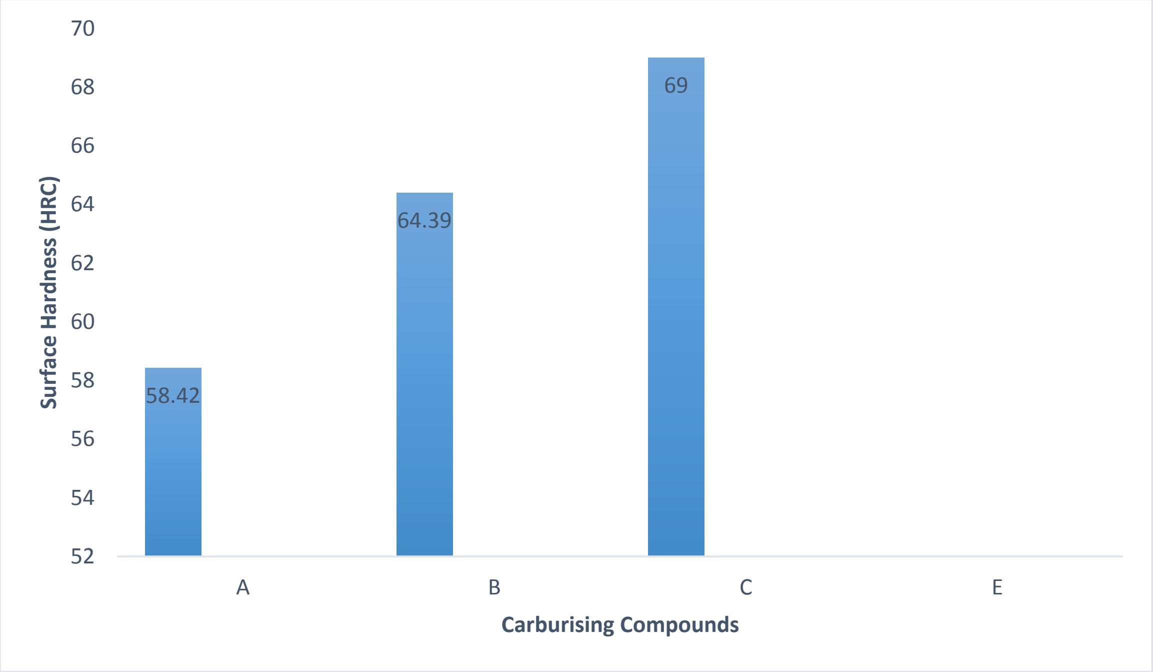

Fig.6: Bar Chart of Surface Hardness Variation with Developed Carburizing Compounds

Microstructural Analysis

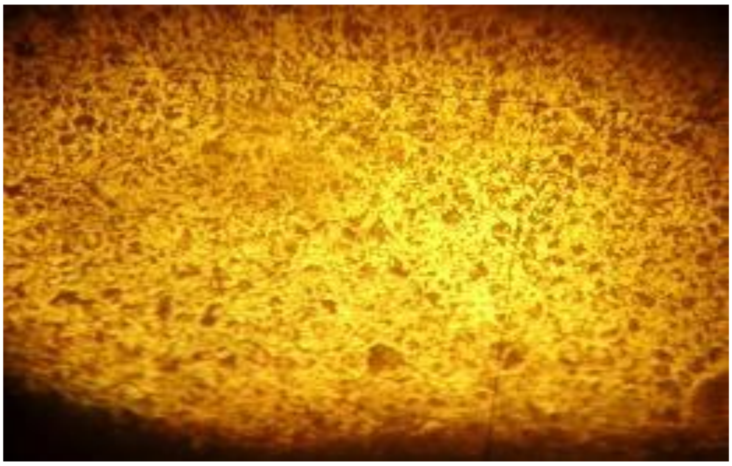

Plate VI: Micro Structure of Untreated Mild Steel with a Pearlite Structure in a Ferritic Matrix (Magnification X 200)

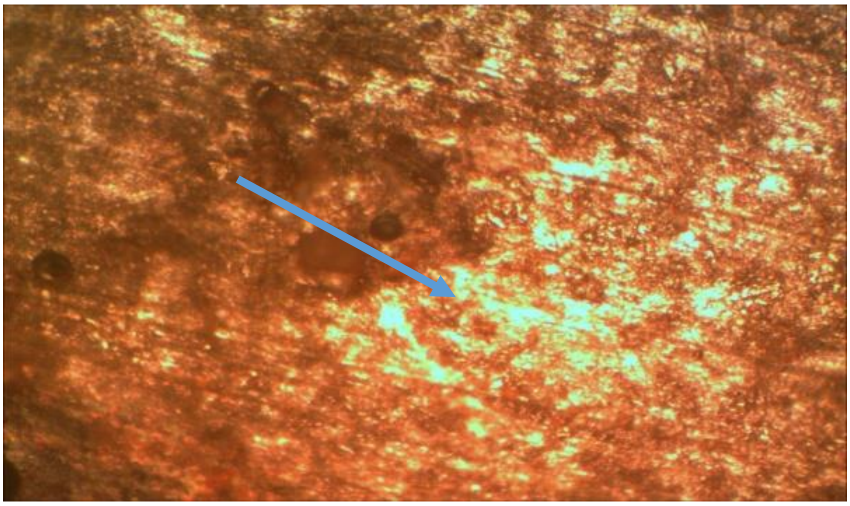

Plate VII: Micro Structure of Carburized Specimen using Compound D, showing Darker Case and Lighter Core (Magnification X 200).

DISCUSSION

Fig. 1 is the hardness of the un-carburized mild steel against distance variation from the surface of the specimen towards the core of the specimen. The plot shows a straight line with two marks off the line; this is normal and occurs as a result of scales from the surface of the rods and inclusions inside the rod. The straight line illustrates the homogeneity of the mild steel microstructure, which is responsible for the hardness profile. This explanation agrees with the position of several authors (Ihom, 1991; Ihom, *et al.,* 2012; Asuquo and Ihom, 2013; Ihom, *et al.*, 2013).

Fig. 2 is the hardness profile of the carburized mild steel specimen in compound A against distance variation from the surface of the specimen towards the core of the specimen. Compound A is 100% charcoal and its carburizing effect produced a case depth of 0.08 mm and surface hardness of 58.42HRC on the surface of the mild steel specimen. This was achieved after 8hrs. of carburizing at the temperature of 920°C. This temperature and holding time are sufficient for diffusion of nascent carbon from the charcoal into the specimen. At that temperature the steel was transformed into austenite with FCC structure which has space to accommodate interstitial carbon. Diffusion in solids is a very slow process which needs time; the 8hrs from the result seem to be sufficient. The carbon potential of the charcoal that provided nascent carbon for the achievement of the case depth also seem to be good or else no carburization would have occurred. This fact is attested to by several researchers (Avner, 1974; Aramide, *et al.*, 2009; Asuquo, and Ihom, 2013). The same thing can be said of figs. 3-4. Fig. 3 is the hardness profile of the carburized mild steel specimen in compound B against distance variation from the surface of the specimen towards the core of the specimen. Compound B is made up of industrial energizers and charcoal (55% Charcoal, 15% $CaCO_3$, 10% Na_2CO_3, 20% $BaCO_3$) it produced a case depth of 0.11mm and surface hardness of 64.39 HRC. Great improvement over the values attained by charcoal alone; this feat is made possible by the presence of the industrial chemical energizers in the compound. Energizers are able to do this by increasing the carbon potential of the carburizing compound. The carbonates breakdown into oxides and carbondioxide. The carbondioxide then combines with carbon in the charcoal to form carbonmonoxide which releases nascent carbon on the surface of the mild steel. The process goes on in cycles, thereby raising the carbon potential of the carburizing process. This mechanism of energizers in carburizing processes has been put forward by several researchers and authors (Shrager, 1961; Ihom, 1991; Ihom, *et al.*, 2012; Asuquo and Ihom, 2013; Ihom, *et al.,* 2013). Fig.4 is the hardness profile of the carburized mild steel specimen in compound C against distance variation from the surface of the specimen towards the core of the specimen. Compound C is a mixture of organic and natural energizers and charcoal (65% Charcoal, 10% Periwinkle shell, 5% Cow Bone 20% Banana Peel) and its carburizing effect produced a case depth of 0.18 mm and surface hardness of 69.0 HRC on the surface of the mild steel specimen. The compound is formulated to utilize the natural and organic carbonates in periwinkle shell, cow bones and banana peels including their carbon source. The concept of green chemistry has made us to understand that chemicals from plants and animals have less impact on the environment than industrial chemicals such as are used in compound B which constitutes some health hazards and therefore the problem of safe disposal (Ihom, *et al*., 2013; Ihom, 2014; Poinern, 2015). If compound C's performance as shown in fig. 4 is better than compound B which is shown in fig.3, then it is better to use compound C for casehardening of mild steel for the sake of the environment and the strict government control on disposal of hazardous chemicals. As highlighted above the natural energizers have been able to produce a better carbon potential as reflected in the result of the carburized mild steel specimen.

This argument above is confirmed by figs.5 and 6 which are bar charts and they confirm that compound C which uses natural and organic energizers have higher case depth (0.18 mm) and surface hardness (69HRC) than the other two energizers. It can therefore be said that the developed ecofriendly carburizing compound can be used to replace industrial chemical energizers to reduce pollution burden on the environment from this source of pollution.

Plates VI-VII shows the microstructure of un-carburized mild steel and carburized mild steel that has been carburized using the carburizing compounds in the work. The two plates are just explaining why fig. 1 is different from figs. 2-4. The un-carburized mild steel has a homogeneous microstructure, whereas the carburized mild steel has a hard carbon-rich dark surface and a soft-light carbon impoverished core (Azoro, 2017).

CONCLUSION

Efforts have been made to develop an ecofriendly carburizing compound from plants and animal wastes which are considered under green chemistry concept to be less severe on the environment than industrial chemical energizers. In this work ''The Development of Ecofriendly Energizers as Replacement for Industrial Chemical Energizers in the Casehardening of Mild Steel Materials'' the authors have been able to establish the followings as findings and conclusions

i.) The development of ecofriendly carburizing compound based on charcoal, periwinkle, cow bone, and banana peel has been actualized

ii.) The work showed that compound C which is the ecofriendly compound had better case depth and surface hardness on the test specimen than compound A and B.

iii.) Compound C was able to produce a case depth of 0.18mm and a surface hardness of 69 HRC these values were better than those of compound B with industrial chemical energizers. The values for compound B were 0.11mm for case depth and 64.39 HRC for surface hardness.

iv.) The carburized specimens all showed improvement in hardness property over and above the un-carburized mild steel.

v.) The work has demonstrated that industrial chemical energizers can be replaced by natural and organic energizers from wastes plants and animal sources.

Acknowledgements

The authors of this research work wish to acknowledge the Technologists in the Faculty of Engineering workshop, the Technologists in the Civil Engineering Laboratory, and Agricultural Engineering Laboratory; all of the University of Uyo. We also want to thank the Technologists in Federal University of Technology, Owerri and Michael Okpara University of Agriculture, Umudike where the hardness tests and microstructural analysis were done. We appreciate all of you for your time and assistance.

REFERENCES

Aigbodion, V.S., Hassan, S.B (2009) Experimental Correlation between Wear Rate and Wear Parameters of Al-Cu-Mg/ Bagasse Ash Particulate Composite, J. Mater Design 2009, 10055

Aramid, F. O., Ibitoye S. A. and Oladele I. O. (2009), Effects of Carburizing Time and Temperature on the Mechanical Properties of Carburized Mild Steel using Activated Charcoal as Carburizer, *Materials Research Journal* 12(4): pp 483 – 487. Accessed on 25th August, 2016 http://www.scieio.br.com

Asuquo, L. O and Ihom, A. P (2013), Variation of Effective Case Depth with Holding Time of Mild Steel using Various Carburizing Compound, *International Journal of Metal and Steel Research Technology* 1: pp 12-18.

Avner, S.H. (1974) Introduction to Physical Metallurgy, Internation Student Edtion, McGrawHill, Tokyo-Japan, 305-335

Azoro, K.U. (2017) Production of Casehardening Compound for Surface Treatment of Mild Steel for Mechanical Property Improvement, M.Eng. Dissertation in the Department of Mechanical and Aerospace Engineering, University of Uyo-Nigeria.

Higgins, R.A. (1983) Properties of Engineering Materials, Seventh Reprint Hodder Stoughton: London, UK 199-201

Ihom, A.P. (1991) Case Hardening of Mild steel using Cowbones, B.Eng Degree thesis submitted to Department of Materials and metallurgical engineering, University of Jos 1991, 1-35

Ihom, A.P. (2014) Environmental Pollution Prevention and Control: The Current Perspective (A Review), Journal of Multidisciplinary Engineering Science and Technology (JMEST), Germany, ISSN: 3159-0040, 1 (5)

Ihom, A.P., Nyior, G.B., Ambayin, M (2012) Surface Hardness Improvement of Mild Carbon Steels using Arecaceae Waste Flower Droppings, the Pacific Journal of Science and Technology, vol.13. No 1, 133-136.

Ihom, A.P., Nyior, G.B., Nor, I.J., Ogbodo, N.J. (2013) Investigation of Egg Shell Waste as an Enhancer in the Carburization of Mild Steel, America journal of Material Science and Engineering Vol. 1, No2, 29-33

Ihom, A.P., Nyior, G.B., Suleiman, M.U. and Ibrahim, G.Z. (2011) Improving Surface Hardness of Steel using Rice Husk Waste, Nigerian Journal of Tropical Engineering, vol. 7. No2 107-115

Ihom, A.P., Yaro, S.A. and Aigbodion, V.S. (2005) The Effects of Carburisation on the Corrosion Resistance of Mild Steel in Four Different Media, J. of Corr.Sc. and Tech., vol.3, 18-133.

Poinern, G.E.J. (2015) A Laboratory course in Nanoscience and Nanotechnology, 1st Edition, London: CRC Press, Taylor & Francis Group, pp95-101

Saita, Y. (2008) Fundamental Heat Treatment Processes for Steels, Lecture paper at training on Heat Treatment and Metal Finishing Technology for Improving Metal Property, JICA, Nagoya, Japan, 1-15

Shrager, A.M. (1961) Elementary Metallurgy and Metallography, 6th Edition Dover Publications: Mineota, NY, 69-290