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# THE PERFORMANCE ANALYSIS OF ORGANIC ENERGIZERS WITH RESPECT TO INDUSTRIAL ENERGIZERS IN PACK-CARBURIZATION OF MILD STEEL FOR IMPROVED MECHANICAL PROPERTIES

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**ABSTRACT:** *The Performance Analysis of Organic Energizers with respect to Industrial Energizers in Pack Carburization of Mild Steel for Improved Mechanical Properties'' have been carried out. The work undertook the preparation of various carburizing compounds. One group contained industrial chemical energizers while the second group contained organic energizers. The carburizing boxes containing the carburizing compounds and test specimens were put in the electric furnace and carburized at 920$^oC$ for 8hrs after which it was removed quenched in water and then dried. The specimens were then prepared for microstructural analysis, surface hardness and hardness profile for case depths deduction. The result of the work revealed that the carburizing compounds containing organic energizers outperformed the compounds with industrial chemical energizers. The best compound was compound F which had case depth of 0.24 mm and surface hardness of 81.53 HRC. The three best compounds; compounds F, D and C were all from the group containing only organic energizers. This work has proven that organic energizers are efficacious and can be used in the pack carburization of mild steel for improved mechanical properties.*

**KEYWORDS:** Performance, Efficacious, Mild Steel, Organic Energizers; Mechanical Properties, Hardness

## INTRODUCTION

In the early days of case hardening the commonest methods of casehardening were pack-carburization and flame hardening. With the introduction of liquid and gas carburization a lot of heat treatment shops moved away from pack-carburization on the grounds that the process was a dirty process; even though very cheap to operate as compared to liquid and gas carburization. The wastes from the packs contain industrial chemicals like barium carbonate, sodium carbonate and calcium carbonate which are usually used as energizers. Disposing of these wastes in line with Environmental Protection Agency's specifications around the world is always a big problem; as a result of this most countries are no longer using pack carburization. However, here in Nigeria where our technology is still at the elemental level, we are still using pack carburization and hence the need for replacing the industrial energizers with organic energizers. It has been said by several authors that organic carbonates are more environmentally friendly that the industrial mineral carbonates. That is the position of the proponents of green chemistry (Shrager, 1961; Ihom, *et al.*, 2013; Asuquo, and Ihom, 2013; Ihom, 2014; Poinern, 2015).

Green chemistry is one of the new branches of chemistry, and it involves the design of products and processes that reduce or eliminates the use or generation of hazardous substances. Green synthetic routes for manufacturing Nps and nanostructures are an emerging branch of nanotechnology as the biomolecules around us are safer generally and offer a cost-effective alternative in many cases. For example, today one would be rather reluctant to undertake Michael Faraday's 1857 method of reducing gold chloride with red phosphorus in a volatile, toxic carbon disulphide solution as a technique to create gold NPs. In many conventional methods, there is a tendency to use expensive chemicals and processes that use toxic materials that present hazards such as environmental toxicity and carcinogenic activity. There has been a push toward an alternative pathway of minimizing the use and production of hazardous materials in chemical research (Poinern, 2015; Selvam, *et al.*, 2017).

"Sustainable or green technique pathways that creates materials utilizing relatively nontoxic chemicals to create nanomaterial are well favoured and are welcomed avenues of R & D efforts around the world. Following initial reports showing the feasibility of reducing silver ions to Ag NPs, there has been a general move to explore plant extract as a means of reducing, silver to produce NPs and nanostructures of this metal. In some plants, the acidic components can easily aid the reduction of the metallic ions. Furthermore, these studies showed that Ag NPs created this way possesses good antimicrobial activity. The fact that no capping agent or templating agent is needed makes this chemical route an attractive one. For instance the biogenesis of Ag NPs by extracts such as those from the neem (azadirachta indica), geranium leaves (pelargonium graveolens), and alfalfa (medicago sativa) has already been proven, and the list of plants capable of this reducing effect on silver ions is increasing'' (Shreya, *et al.*, 2015; Jannathul, and Lalitha, 2015; Biswas, and Dey, 2015; Poinern, 2015; Benakashani, *et al.*, 2016; Bansal, *et al.*, 2017; Selvam, *et al.*, 2017).

Just as can be seen from the quotation above the new trend in every manufacturing field is to produce products that are harmless and less hazardous to the environment. Barium carbonate is mooted as having environmental toxicity and carcinogenic activity. Most engineering materials have unique properties that render them useful in many applications. Before any engineering material is subjected to use, it must satisfy certain range of properties suitable for that purpose, the usage is determined by its availability, cost effectiveness, wear resistance, durability and other functional requirement. Mild steel is one class of steel that contains low amount of carbon (0.1% - 0.25%) and it has a density of 7850 kg/m$^3$. Mild steel has wide range of application in the production of engineering element like gears, cam, shaft, pinions, keys etc., in developing countries like Nigeria, mild steel is commonly used for machinery construction because of its availability, dominance, workability, ductility, and cost effectiveness, among others (Ihom and Offiong, 2014).

There are numerous limitations encountered in the usage of the mild steel particularly as regard to wear resistance, hardness and strength. Most machines constructed in the developing world like Nigeria using this engineering material, do not last long especially when moving components of the machine-like gear, shaft, valves, disc, cam etc which requires a tough core and a hard surface are constructed of mild steel without case hardening heat treatment (Ihom, *et al.*, 2012).

According to Ihom and Offiong (2014), case hardening of a material can be accomplished by subjecting the component to high temperature in the presence of a carbonaceous material which may be solid, liquid or gaseous. Energizers are often used to speed up the process. It is a process used to produce high surface hardness for wear-resistance supported by a tough, shock-resistant core. A survey of the Nigerian market has revealed a dearth of commercial pack carburizing compound that fabricators, machinists and blacksmiths who produce or recondition vital engineering component could conveniently use to carburize or case harden them. The resultant effect of this is the non-treatment of such produced parts with the consequent results of fast wear, tear and failure of the parts made up of mild steel (Dempsey, 2002).

Mild steel, due to its dominance and workability among the classes of steel, has found broad relevance in the production of engineering components on the account of its low cost and easy fabrication. These components require the mechanical properties of impact strength, tensile strength and hardness for safe usage and tough purposes. Rapid penetration of the surface of steel can only be effective if the solute element dissolves interstitially. Once dissolved, the element increases the hardness of the surface by forming interstitial carbides, nitrides or borides; depending on the diffusion atoms (Azoro, 2017).

By varying carbon content and the heat treatment of the resultant alloy, we can obtain an enormous range of mechanical properties. The addition of alloying elements such as nickel, chromium and molybdenum extend the properties further. Metallic materials are ideally suitable for application in heavily stressed components that require high durability. The degree of functionality and component performance is strongly tied to the effectiveness of the processing technology deployed for a given application (Shrager, 1961).

Pack carburization uses solid carburizing materials as the carbonaceous source. Commercial pack carburization utilizes energizers in the case hardening of mild steel. Different types of energizers are used together with carbonaceous materials to increase the carbon potential of carburizing materials. The commonly used commercial energizers are $BaCO_3$, $Na_2CO_3$ and $CaCO_3$. In a work carried out by Okongwu (1989), he assessed the efficacy of some naturally occurring minerals carbonates as energizers in pack carburizing. The objective of the research work was to reduced cost and pollution problem associated with the use of industrial carbonates of calcium, sodium and barium. The researcher observed that reasonable case depths were obtained with the naturally occurring mineral carbonates, when compared with the industrial carbonates (Okongwu, 1989).

The ability of the organic energizers to replace the industrial energizers will be determined by performance indices such as higher surface hardness value on casehardened steel, higher case depth and effective case depth, and higher wear resistance. In addition to improved impact resistance; of critical importance is environmental friendliness. This work seeks to analyze the performance of the two energizers; organic carbonates and industrial chemical carbonates and this leads to the objective of this research work which is to carry out the performance analysis of organic energizers with respect to industrial chemical energizers in pack carburization for improved mechanical properties of mild steel materials.

## MATERIALS AND METHOD

### Materials

Materials used for the research included; acetone, clay, nital solution, emery cloth, mild steel rod of 20 mm diameter, coal, charcoal, $BaCO_3$, $Na_2CO_3$, $CaCO_3$, NaOH, cowbone, snail shell, periwinkle shell, egg shell, banana peels, plantain peels, waste plastics, water, and polishing powder. All were sourced locally within Nigeria. The mild steel was obtained at Delta Steel

Company, Aladja. The chemical composition is shown in Table 1 and Plates I-III show charcoal, coal and other materials that were used in the work.

**Plate I: Charcoal a Carbon Source**

**Plate II: Coal another Carbon Source**

**Plate III: Pulverized Carbonaceous Materials and Energizers**

**Table1: 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. Plate IV shows the hammer mill grinder that was used in grinding the materials.

**Plate IV: Hammer Mill**

## Method

### Specimen and Material Preparation

Pack carburizing process was carried out in a muffle electric furnace at Civil Engineering Laboratory, University of Uyo. Carbonaceous elements like coal were obtained from Nigerian

Coal Corporation, mining site, Iva, in Enugu state, while charcoal and all the energizers 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 sieved size. The mild steel specimens were packed into boxes half-filled with the compounds as indicated in Table 2. After which the compounds were added to cover the specimens. 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 V shows how the mild steel specimens were prepared for carburizing.

**Table 2: Different Carbon Sources with Industrial Chemical Energizers in some Compounds**

| Compound | Composition |
|---|---|
| A | 55% Coal, 15% $CaCO_3$, 10% $Na_2CO_3$, 20% $BaCO_3$ |
| B | 25% Coal, 30% Charcoal, 15% $CaCO_3$, 10% $Na_2CO_3$, 20%$BaCO_3$ |
| C | 65% Coal, 10% Pericles shell, 5% Cow Bones 20% Plantain peel. |
| D | 30% Coal, 30% Charcoal, 10% Egg shell, 10% Snail 10% plantains shell |
| E | 45% Coal, 20% plastic waste, 10% Egg shell, 5% Snail shell 10% Plantain peel, 10% banana peel |
| F | 20% Charcoal, 20% Coal, 20% Plastic Waste, 5% Egg shell, 5% cow bone, 5% Snail shell, 5% periwinkle shell, 10% plantain peel, 10% Banana peel |

**Plate V: Mild Steel Sample**

**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 82.6 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.

## DISCUSSION AND RESULTS

### Results

The results of the research work are presented here under for discussion and analysis from figs. 1-9 and Plates VI-VII.

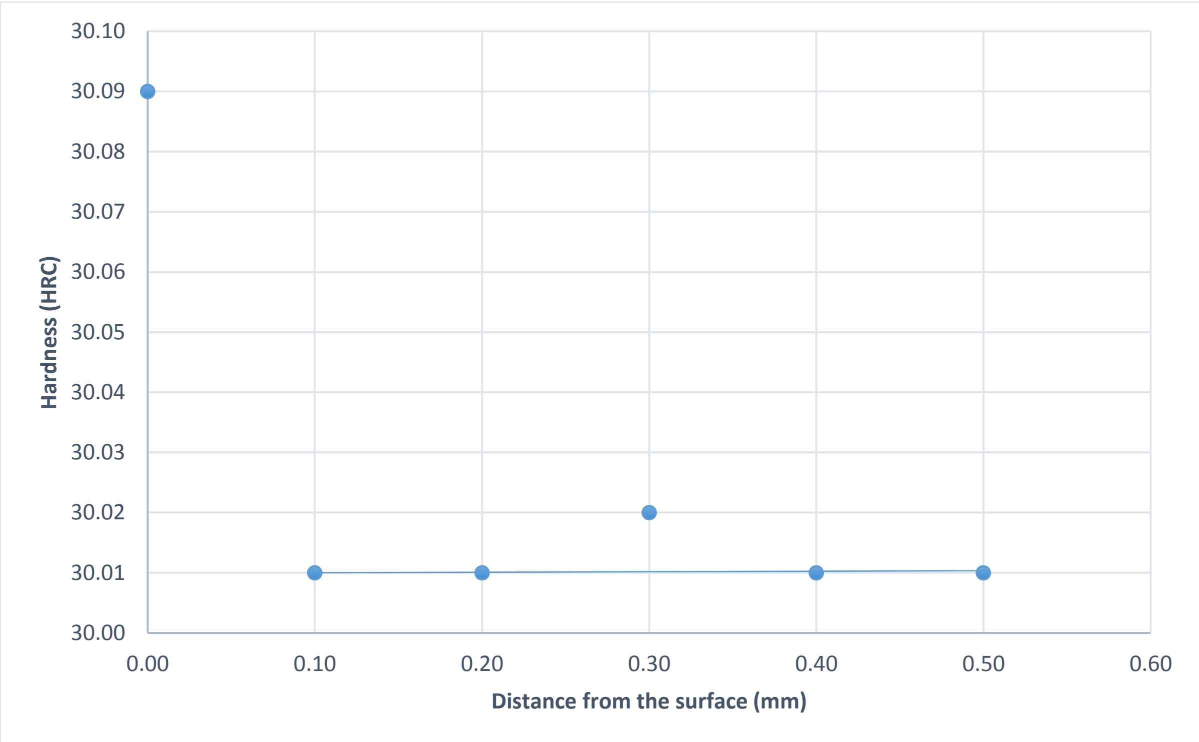


**Fig.1: Hardness Profile of the Un-Carburized Mild Steel Specimen against Distance from the Surface**

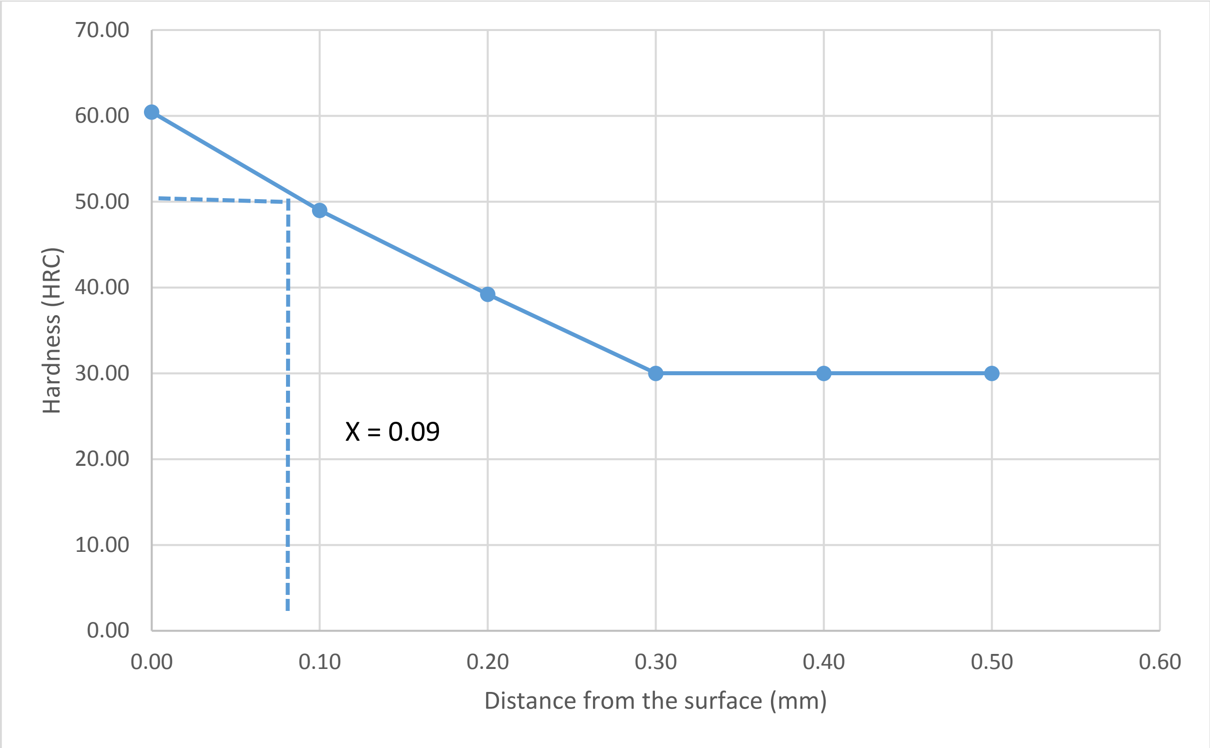


**Fig.2: Hardness Profile of Mild Steel Treated in Compound A for Case Depth Extraction**

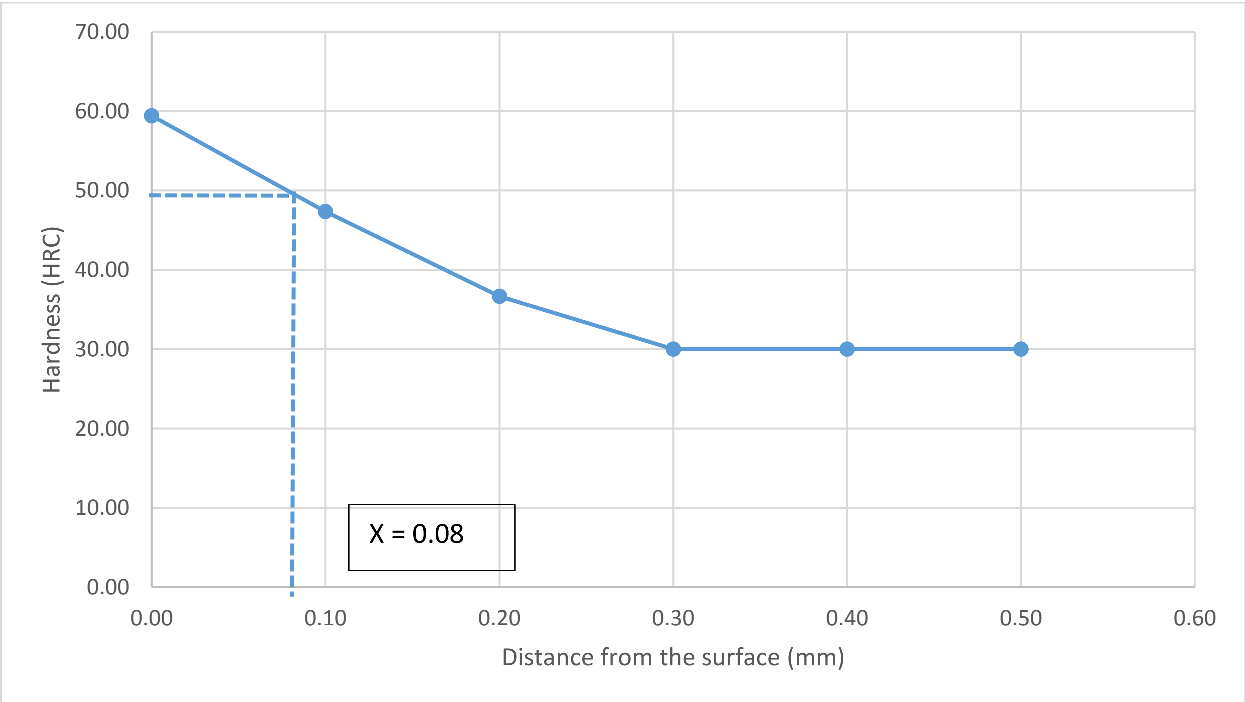


**Fig.3: Hardness Profile of Carburized Steel Specimen in Compound B for Case Depth Extraction**

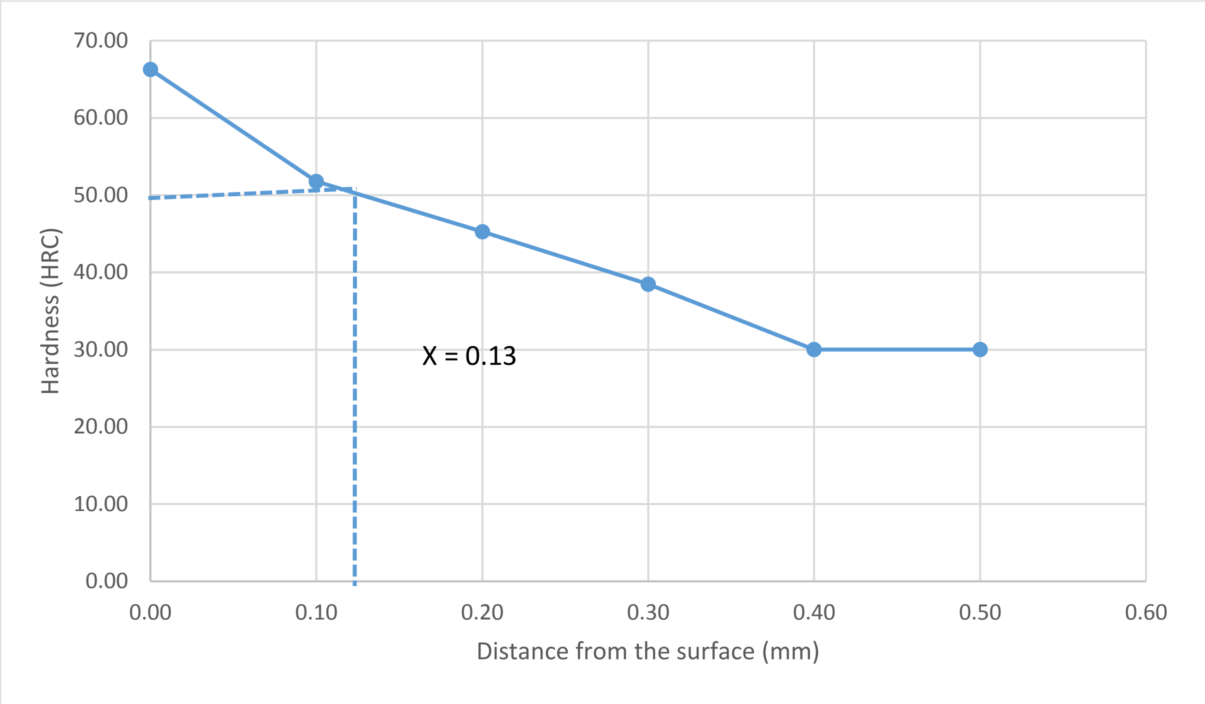


**Fig.4: Hardness Profile of Carburized Steel Specimen in Compound C for Case Depth Extraction**

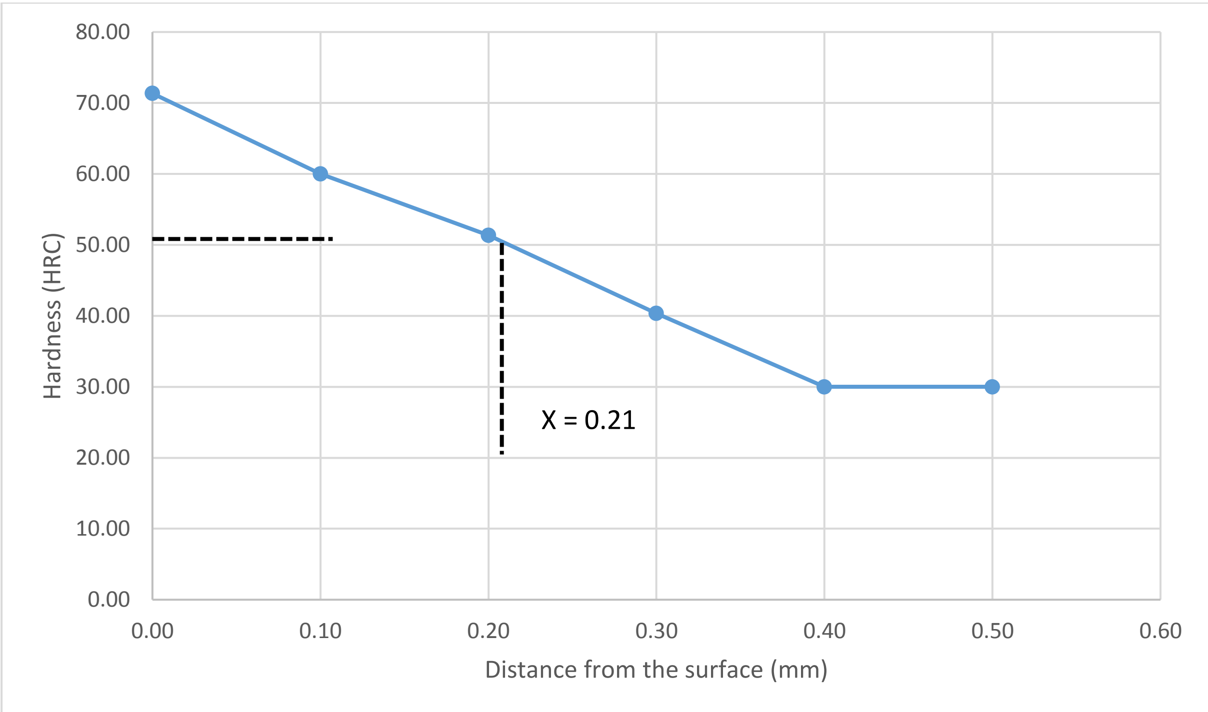


**Fig.5: Hardness Profile of Carburized Steel Specimen in Compound D for Case Depth Extraction**

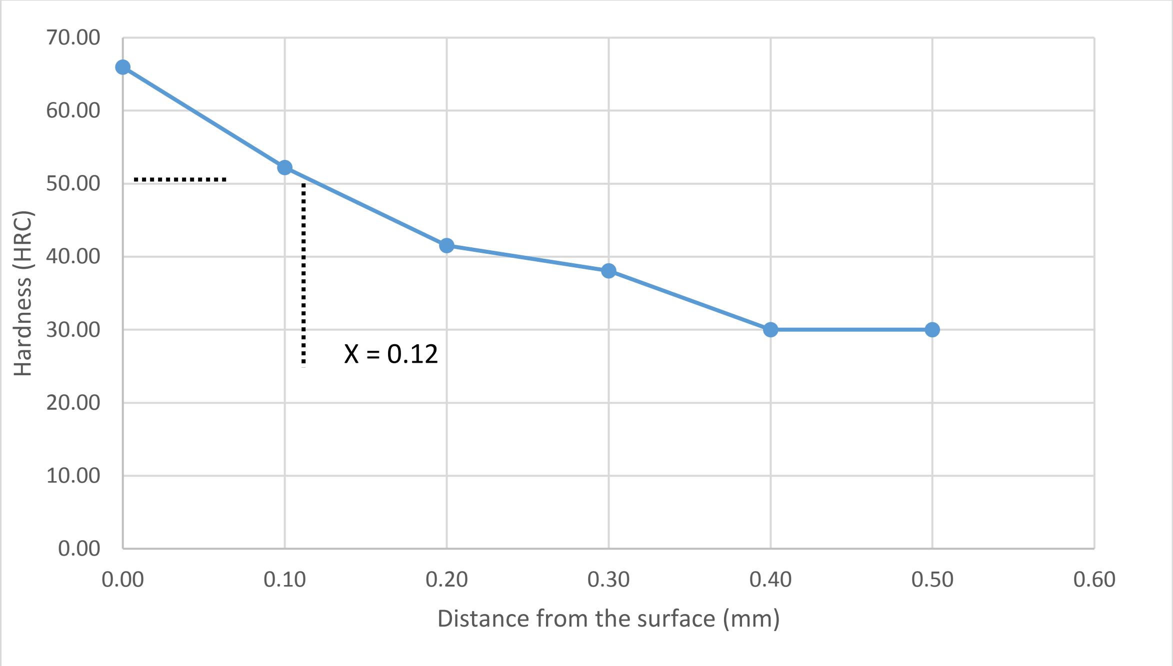


**Fig 6: Hardness Profile of Carburized Steel Specimen in Compound E for Case Depth Extraction**

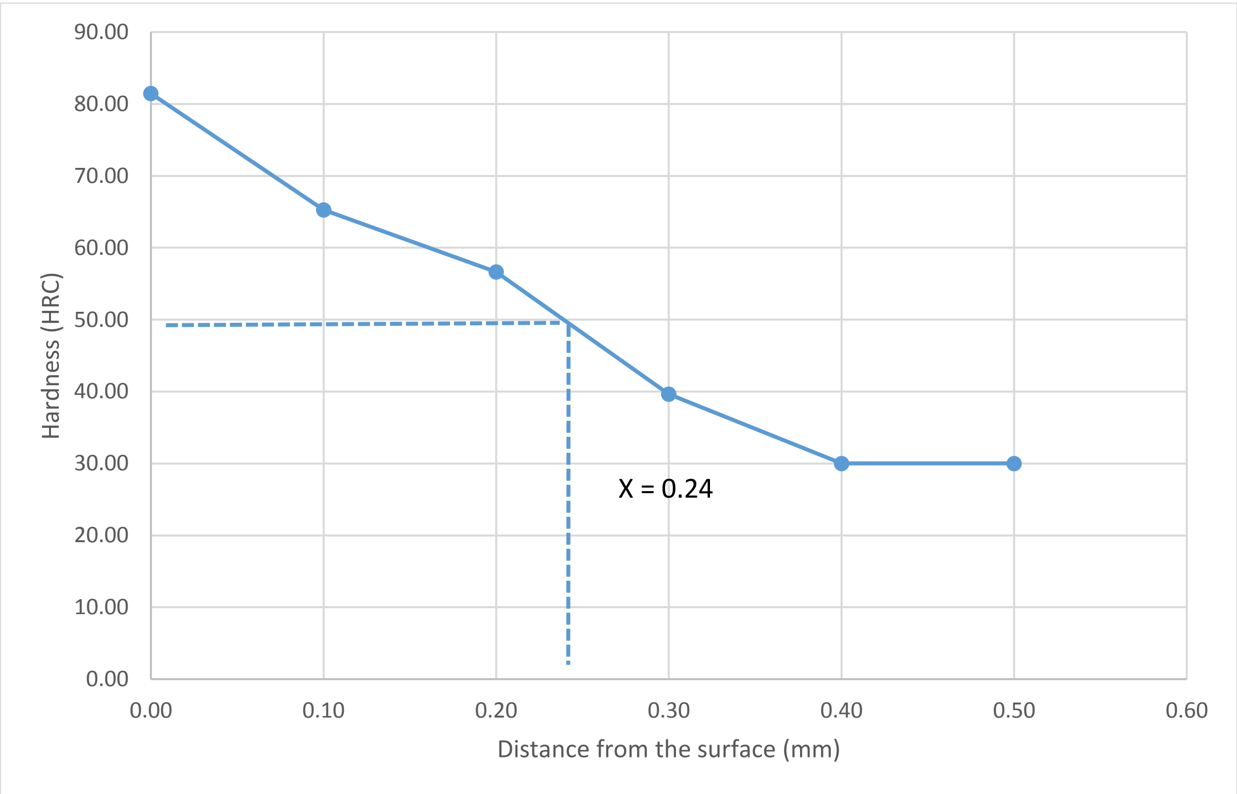


**Fig 7: Hardness Profile of Carburized Steel Specimen in Compound F for Case Depth Extraction**

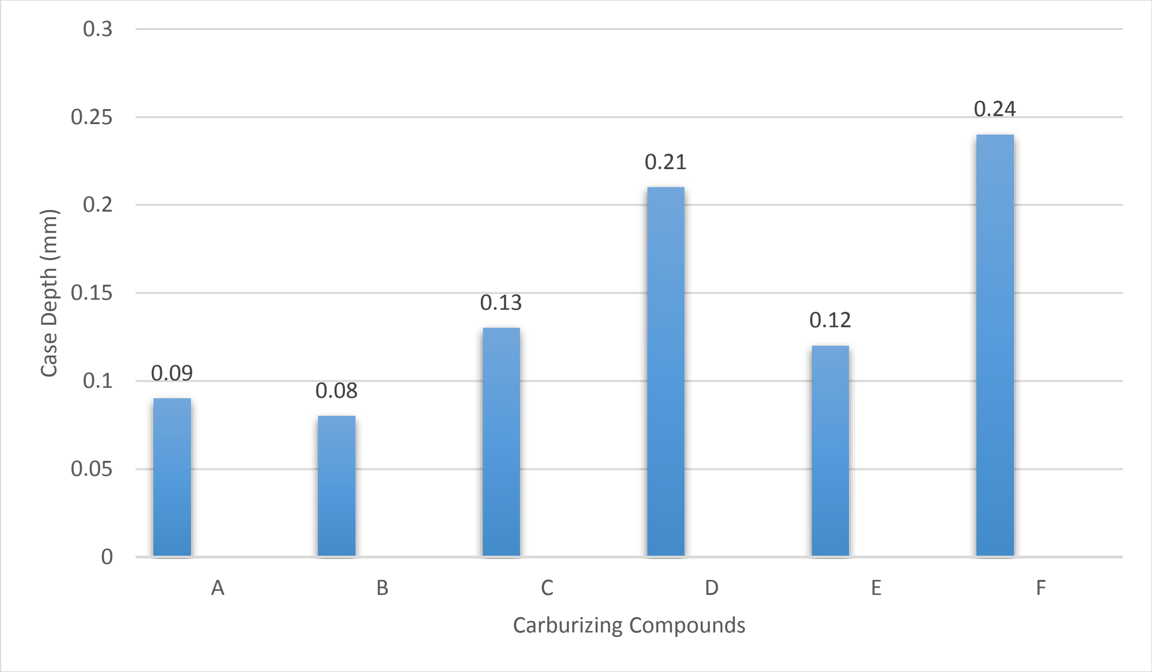


**Fig. 8: Bar Chart Showing Case Depth Produced by Various Compounds on Test Specimens**

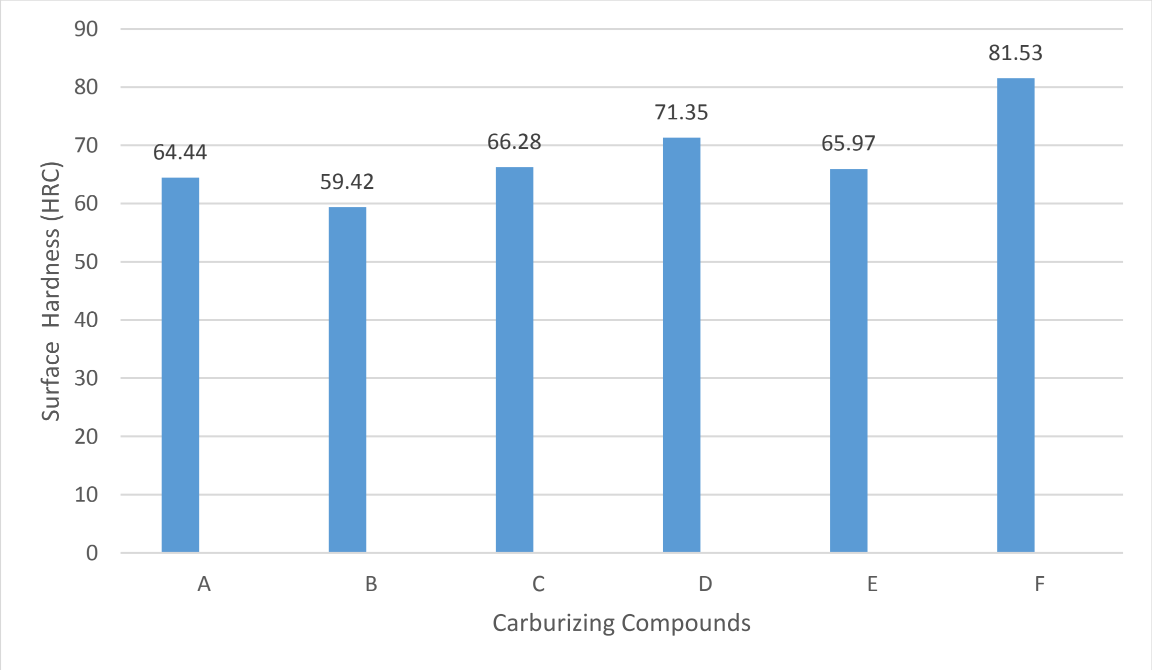


**Fig. 9: Bar Chart Showing Surface Hardness Produced by Various Compounds on Test Specimens**

**Microstructural Analysis**

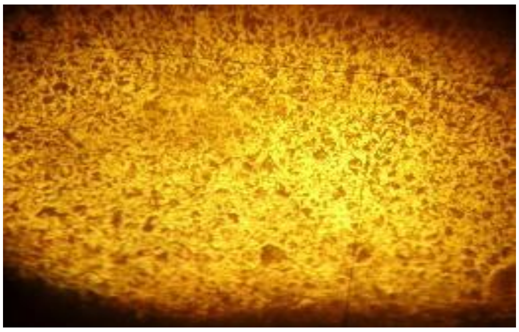

**Plate VI: Micro Structure of Untreated Mild Steel with a Pearlite Structure in a Ferritic Matrix (Magnification X 200)**

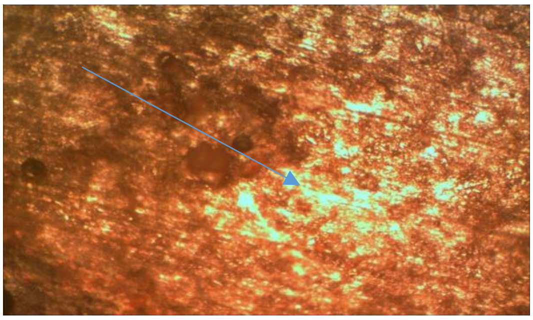

**Plate VII: Micro Structure of Carburized Specimen using Compound D, showing Darker Case and Lighter Core (Magnification X 200).**

## 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).

Figs. 2-3 represent the plots of the hardness profile of two compounds; compounds A and B which all have industrial chemical energizers. Compound A produced a case depth of 0.09 mm on the test specimen and fig. 9 showed that it produced a surface hardness of 64.44 HRC on the test specimen. Compound B produced a case depth of 0.08 mm and fig. 9 showed that it produced a surface hardness of 59.42 HRC on the test specimen.

Figs.4-7 is the hardness profile plots of carburizing compounds without industrial chemical energizers. The compounds are made up of carbonaceous materials, organic, plants and animal wastes. Some of the plants and animal wastes contain carbonates which serve as energizers during carburization. For instance, snail shell, periwinkle shell, Egg shell, cow bone, and the peels (Ihom, 1991; Ihom, *et al.,* 2013; Azoro, 2017) Compound C produced a case depth of 0.13 mm on the test specimen and fig. 9 showed that it produced a surface hardness of 66.28 HRC on the test specimen. Compound D produced a case depth of 0.21 mm and fig. 9 showed that it produced a surface hardness of 71.35 HRC on the test specimen. Compound E produced a case depth of 0.12 mm and fig. 9 showed that it produced a surface hardness of 65.97 HRC on the test specimen. Compound F produced a case depth of 0.24 mm and fig. 9 showed that it produced a surface hardness of 81.53 HRC on the test specimen.

Comparing the results of compounds with industrial chemical energizers with those of compounds with waste organic energizers, plants and animals' wastes. It can be seen that the best performing compounds occur under compounds without industrial chemical energizers. The best compound is compound F with case depth of 0.24 mm and surface hardness of 81.53HRC. The composition of this compound is 20% charcoal, 20% coal, 20% plastic waste, 5% egg shell, 5% cow bone, 5% snail shell, 5% periwinkle shell, 10% plantain peel, 10% banana peel. This compound is closely followed by compound D with case depth of 0.21mm and a surface hardness of 71.35HRC and then compound C with case depth of 0.13 mm and surface hardness of 66.28 HRC. All these are compositions without industrial chemical energizers. The implication in terms of application is that mild steel with this treatment can withstand wear and exhibit high wear resistance when used as moving part of a machine (Ihom, 1991; Azoro, 2017). The results have shown that carburizing compounds containing industrial chemicals are not necessary in producing good cases on mild steels. This is clear from the above since the compounds without the chemical energizers have outperformed the ones with chemical energizers. This was achieved after 8hrs. of carburizing at the temperature of 920$^{o}$C for all the compounds; carburizing conditions were the same for all the compounds. 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 performance of the three compounds being better than the other compounds boils down to the efficacy of their energizers which is more effective than the others (Ihom, 1991; Azoro, 2017). 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). Figs. 8-9 showed the performance of all the carburizing compounds on tests specimens. The superiority of the natural organic energizers over the industrial chemical energizers is clearly shown in the two bar charts.

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. 2-7. 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

''The Performance Analysis of Organic Energizers with respect to Industrial Energizers in Pack Carburization of Mild Steel for Improved Mechanical Properties'' have been carried out and the following conclusions drawn:

i.) The organic energizers used in the pack carburization of mild steel specimens outperformed the industrial chemical energizers

ii) The best compound was compound F with case depth of 0.24 mm and surface hardness of 81.53 HRC

iii) The second-best compound was compound D with case depth Hardness of 0.21 mm and surface hardness of 71.35 HRC

iv) The third best compound was compound C with case depth of 0.13 mm and surface hardness of 66.28 HRC

v) All the three best compounds were compounds with organic energizers; a clear indication that the organic energizers outperformed the industrial chemical energizers.

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