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Research Paper

The efficacy of carburizing compounds with different carbon source and added industrial energizers for surface treatment of mild steel for mechanical property improvement

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ABSTRACT

''The Efficacy of Carburizing Compounds with Different Carbon Source and added Industrial Energizers for Surface Treatment of Mild Steel for Mechanical Property Improvement'' has been studied. The research work involved material sourcing and carburizing compounds preparation. Five compounds were prepared in carburizing steel boxes in which mild steel specimens were embedded, covered and sealed with clay. Electric muffle furnace was used for the carburization process. The pack carburization boxes were inserted in the furnace at operational temperature of 920^{o}C and holding time of 8 hours. They were then removed and the specimens quenched in water. The specimens which were earlier on prepared by machining using lathe were cut into two and the cut-side was ground, polished and etched for metallographic analysis. For hardness test; the carburized specimens were not etched. The result of the work showed that carbon source determines the efficacy of the carbon material as a carburizing compound in pack carburizing. It was also noticed that charcoal alone produced case depth of 0.08 mm and surface hardness of 58.42HRC, while coal had case depth of 0.06 mm and surface hardness of 54.42 HRC under the same conditions of holding time and carburizing temperature. The addition of industrial chemical energizers drastically improved the efficacy of the carburizing compounds, but the combination of coal and charcoal to energizers did not lead to any synergistic effect in terms of high case depth and surface hardness. The best carburizing compounds were compounds C and D because of the presence of the energizers; they had surface hardness of 64.44 HRC and 64.39 HRC respectively. In the absence of energizers; the charcoal performed better than the coal.

Keywords: Carbon source; energizers; efficacy; surface treatment; mild steel; carburizing compound

INTRODUCTION

The fixed carbon in different carbon sources in most cases is not the same. The carbon concentration in wood charcoal is not the same with coal and neither is it the same with bone charcoal or sugar cane charcoal. Carbon availability at the surface of mild steel which at high temperature normally provide nascent carbon during pack carburization determines the success of carbon diffusion into the steel surface at austenite temperature. Carbon source with higher fixed carbon will definitely make more carbon available at the steel surface than sources with low amount of carbon. Energizers raise the carbon potential of the carburizing pack making a difference in the efficacy of the process; leading to higher case depth than when only carbon source is used (Shrager, 1961; Avner, 1974; Higgins, 1983; Aramide *et al*., 2009; Azoro, 2017). It might be interesting to find out how different carbon sources might influence case hardening with or without the presence of industrial energizers in the carburizing compounds.

According to Ihom *et al.* (2011), the use of surface treatment to improve corrosion resistance, wear resistance, heat resistance, ornamental properties, functional properties, friction reduction, hardness improvement etc is now a known practice. Surface treatment, may be applied at the completion (or finishing) of mechanical fabrication of components and are in every sense finishing processes. Advances in surface finishing technology have given rise to high performance machines and automobiles.

Ihom *et al.* (2012) cited that ‘’dead mild steels containing up to 0.15% C are used for general presswork and other applications where high ductility is necessary in forming. Mild steel containing 0.15-0.3% C are referred to as wrought. Wrought forms are used as rolled stocks (RSJ) and other structural members, shafting, levers, and various forgings. Steels used for sand castings usually contain 0.3-0.35% C they are also considered as mild steels (Higgins, 1983; Shrager, 1961). These set of steels described above do not respond to hardening heat treatment, but only annealing treatment for grain refinement (Saita, 2008). However, given their wide area of application they do encounter service limitations, one of such limitations have to do with low hardness and wear resistance particularly when used as shafts and other rotating parts of machines. To improve on the hardness and wear resistance, several casehardening methods are normally used which include nitriding, carbonitriding, cyaniding, carburizing e.t.c just to mention a few surface hardening techniques. These techniques are used to improve the surface hardness of mild steel. The technique involves the use of various raw materials for the impregnation of different elements in the surface of the mild steel to improve the hardness and wear resistant properties. This normally improves the service life of the part made of mild steel (Aigbodion and Hassan, 2009; Ihom *et al.*, 2012).

In this particular research work the efficacy of carburizing compounds with different carbon sources and industrial chemical energizers for surface treatment of mild steel is being investigated. This forms the core objective of the research work to establish the efficacy of carburizing compounds with different carbon source and industrial chemical energizers for surface treatment of mild steel. It will be interesting to know to what extent the fixed carbon of the carbon source influence the efficacy of the carburizing compound.

MATERIALS AND METHODS

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, NaOH, 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. Plates I-II show charcoal and coal that were used in the work.

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

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 1.18 mm sieve size.

The mild steel specimens were packed into boxes half-filled with charcoal in one box, coal in another, and other boxes contained charcoal, $BaCO_3$, Na_2CO_3, and $CaCO_3$; coal, $BaCO_3$, Na_2CO_3 and $CaCO_3$; and charcoal, coal, $BaCO_3$, Na_2CO_3 and $CaCO_3$. 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°C/hr was set and the specimens were heated to 920°C and held for 8 hrs. 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.

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

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

Plate I: Charcoal a Carbon; **Plate II:** Coal another Carbon

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

Compound	Composition
A	100% Coal
B	100% Charcoal
C	55% Coal, 15% $CaCO_3$, 10% Na_2CO_3, 20% $BaCO_3$
D	55% Charcoal, 15% $CaCO_3$, 10% Na_2CO_3, 20% $BaCO_3$
E	25% Coal, 30% Charcoal, 15% $CaCO_3$, 10% Na_2CO_3, 20%$BaCO_3$

Plate III: Mild steel sample

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

Figure 1 is the hardness profile of the un-carburized

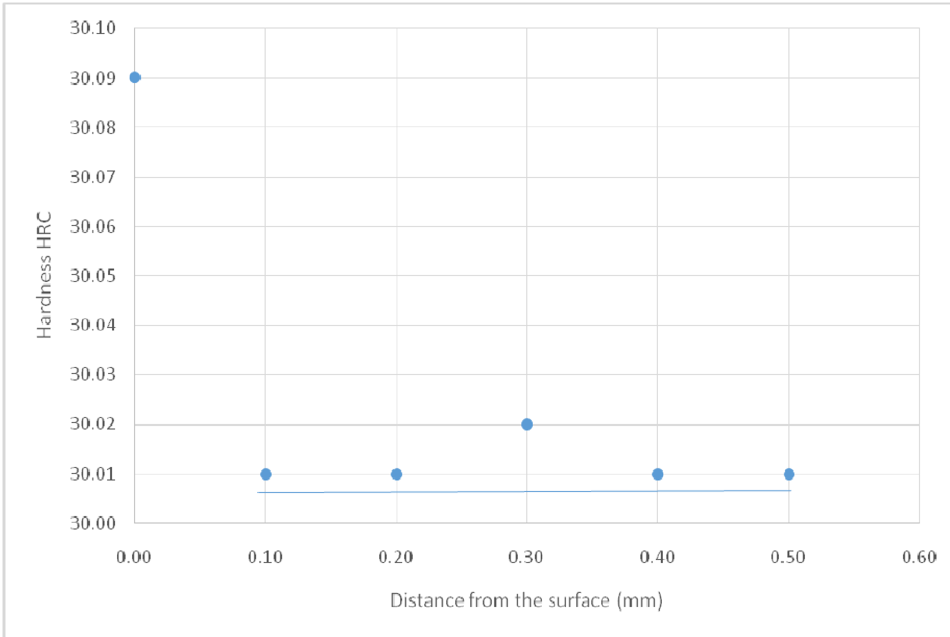

Figure1. Hardness profile of un-carburized specimen against distance from the surface.

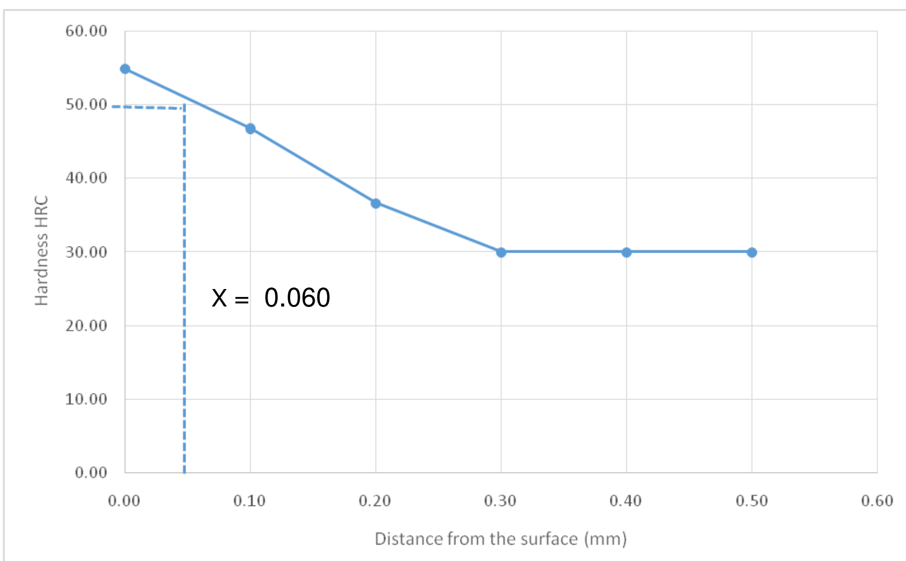

Figure 2. Hardness profile of carburized specimen using compound A against distance from the surface.

specimen against distance from the surface of the specimen. The plot is almost a straight line showing the uniformity and homogeneity of the un-carburized mild steel microstructure. The little variations may be from scales or inclusions. This agrees with previous works by several authors who made similar observations (Ihom, 1991; Ihom, *et al.,* 2012; Asuquo and Ihom, 2013; Ihom *et al.,* 2013). Figure 2 is the hardness profile of carburized mild steel using compound A against d istance from the surface of the specimen. Compound A, is only coal. It produced a case depth of 0.06 mm. Figure 3 is the hardness profile of carburized mild steel using compound B against distance from the surface of the specimen. The plot produced a case depth of 0.08 mm. Compound B is just charcoal. Figure 4 is the hardness profile of carburized mild steel using compound C against distance from the surface of the specimen. The plot produced a case depth of 0.09 mm. Compound C was

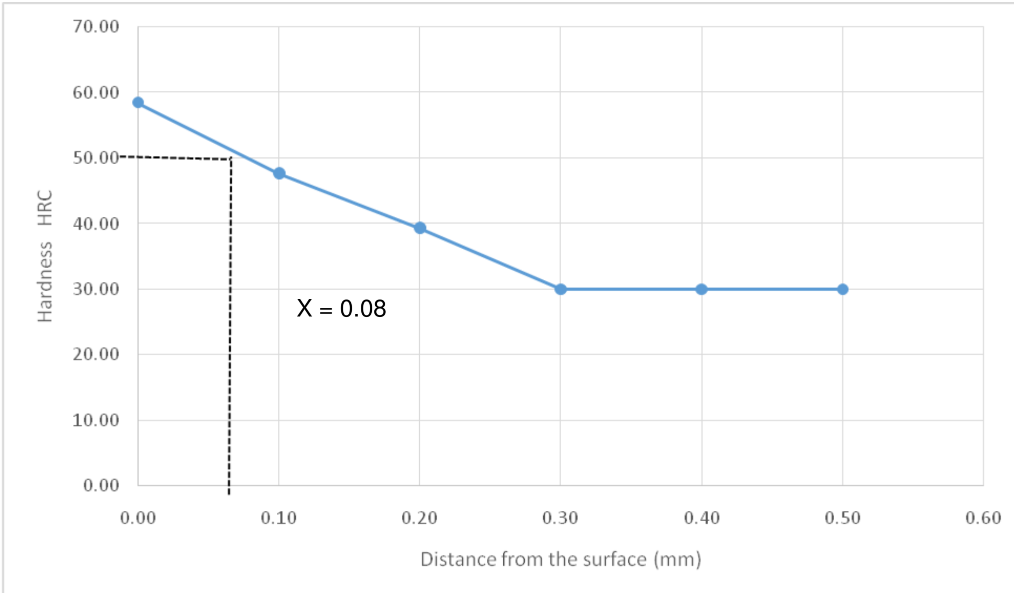

Figure3. Hardness profile of carburized specimen using compound B against distance from the surface.

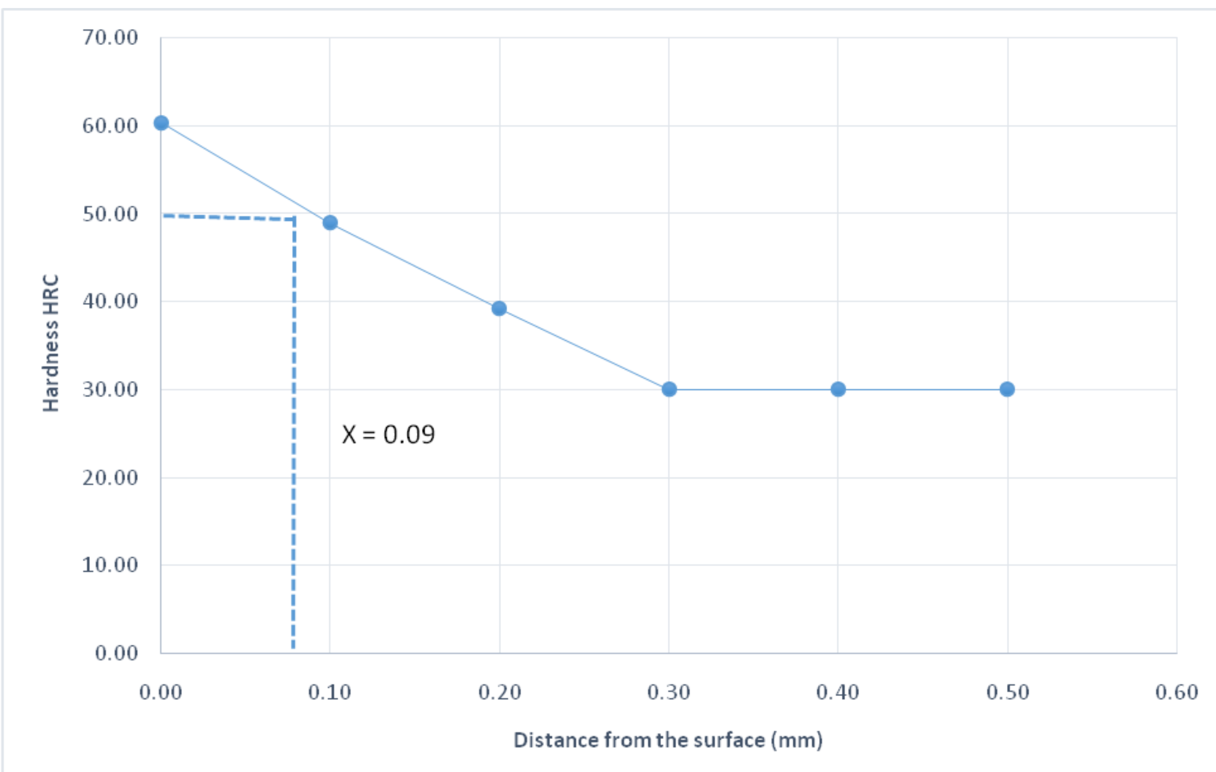

Figure 4. Hardness profile of carburized specimen using compound C against distance from the surface.

made up of 55% Coal, 15% $CaCO_3$, 10% Na_2CO_3 and 20% $BaCO_3$. Figure 5 is the hardness profile of carburized mild steel using compound D against distance from the surface of the specimen. The plot produced a case depth of 0.11 mm. The compound D was made up of 55% Charcoal, 15% $CaCO_3$, 10% Na_2CO_3 and 20% $BaCO_3$. Figure 6 is the hardness profile of carburized mild steel using compound E against distance from the surface of the carburized specimen. The plot produced a case depth of 0.08 mm. The carburizing compound E is

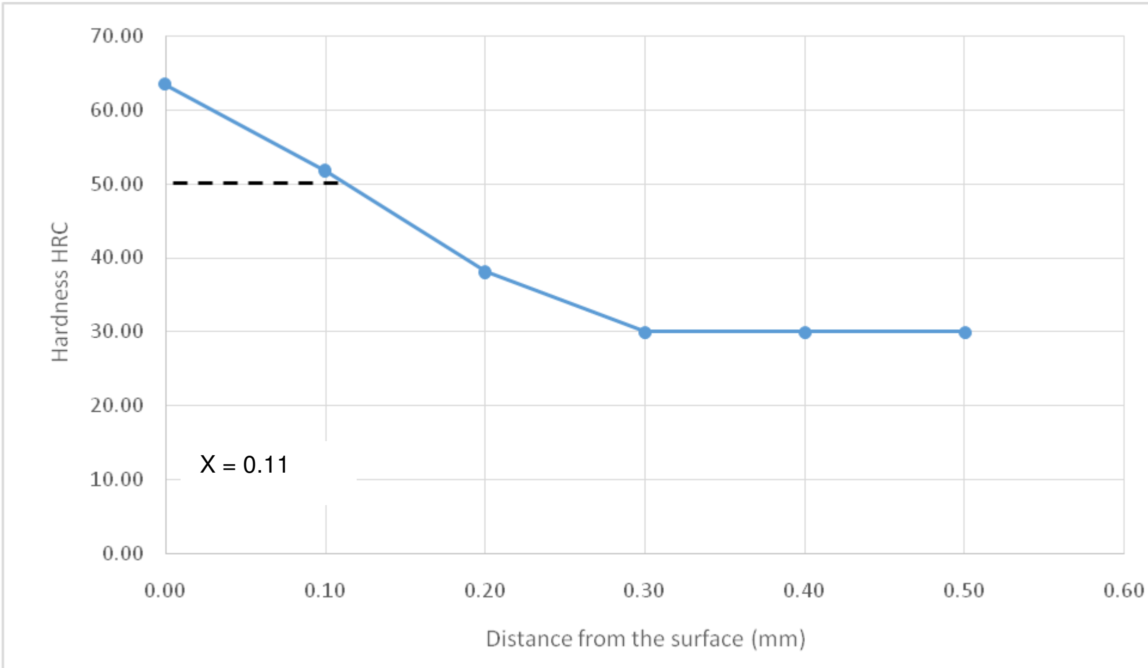

Figure 5. Hardness profile of carburized specimen using compound D against distance from the surface.

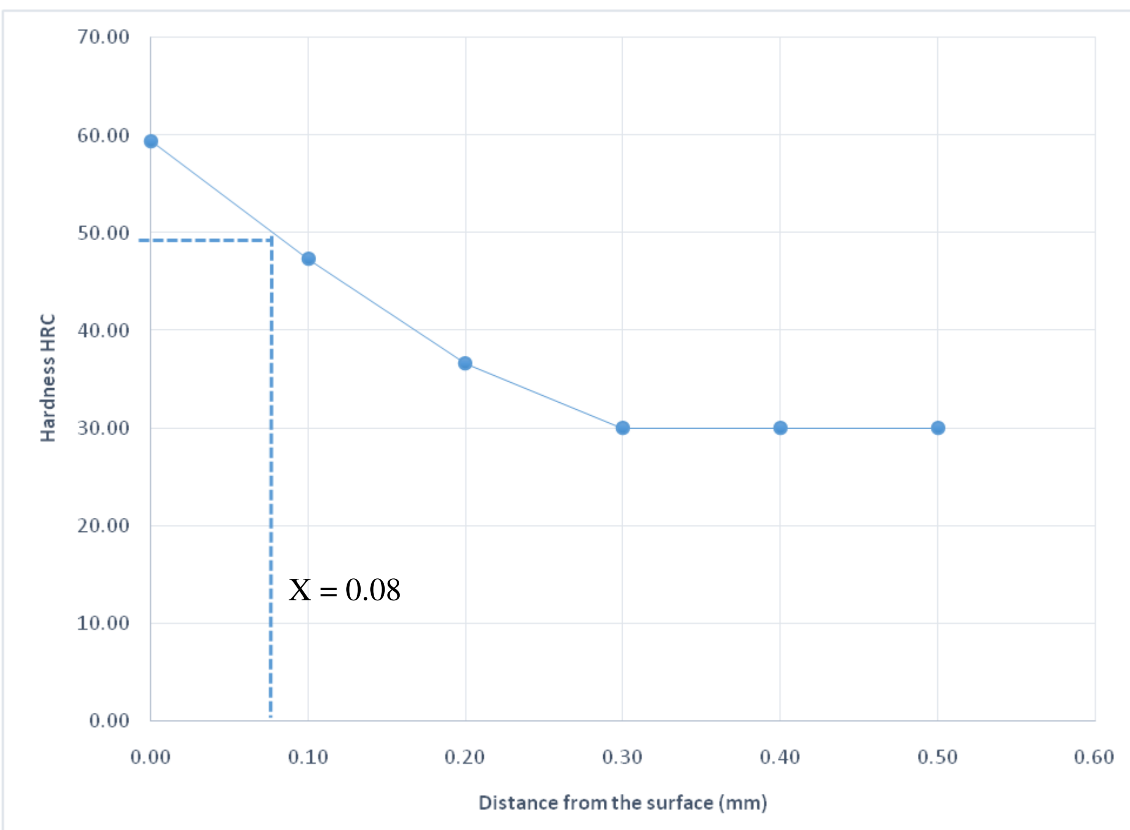

Figure 6. Hardness profile of carburized specimen using compound E against distance from the surface.

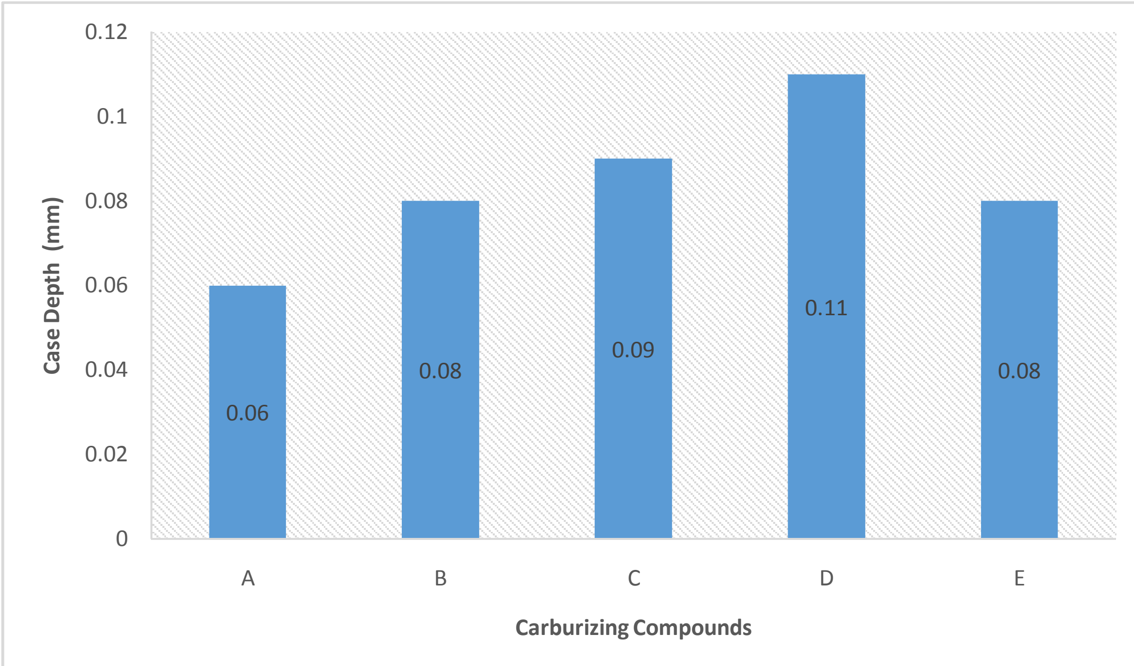

Figure 7. Bar chart of case depths of the various carburizing compounds.

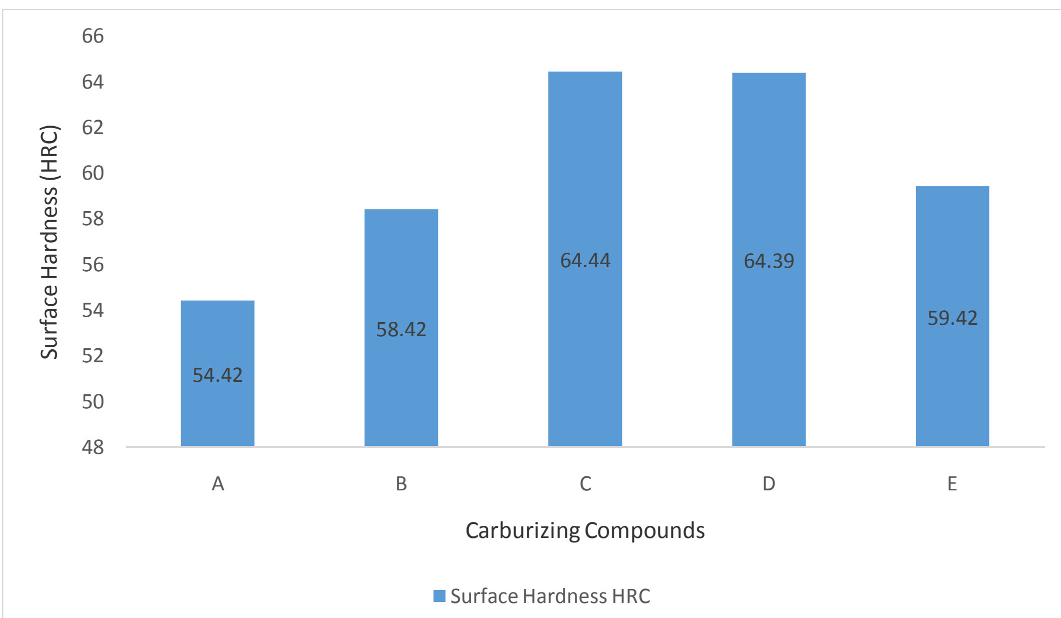

Figure 8. Bar chart of surface hardness variation with carburizing compounds.

made up of 25% Coal, 30% Charcoal, 15% $CaCO_3$, 10% Na_2CO_3 and 20% $BaCO_3$. Figure7 is the bar chart of case depth variation with the various carburizing compounds used in the research work. The chart shows that the highest case depth of 0.11 mm was produced by compound D followed by the case depth value of 0.09 mm produced by compound C. Compounds B and E had the same case depth value of 0.08 mm. Figure 8 is the bar chart of surface hardness variation of the various carburizing compounds used in the research work.

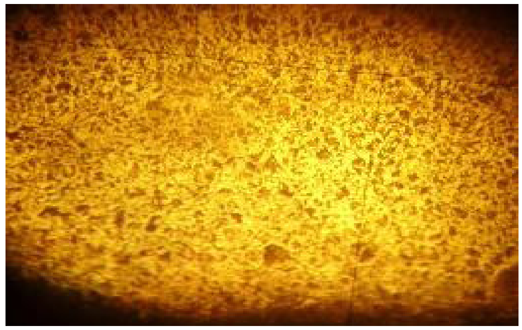

Plate IV. Micro structure of untreated mild steel with a pearlite structure in a ferritic matrix (Magnification X 200).

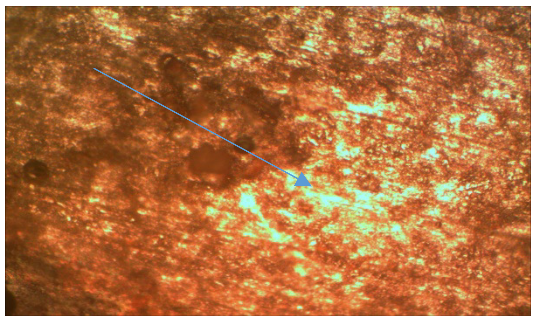

Plate V: Micro Structure of carburized specimen using compound D, showing Darker Case and Lighter Core (Magnification X 200).

Carburizing compound C had the highest surface hardness of 64.44HRC, followed closely by carburizing compound D with surface hardness value of 64.39 HRC. Compound E followed with surface hardness of 59.42HRC which was also closely followed by compound B with 58.42 HRC. Carburizing compound A came last with surface hardness value of 54.42HRC. Figures 2-8 clearly present the performance of the carburizing compounds as case hardening materials. Their efficacy has been shown from the case depth and surface hardness they produced on the mild steel specimens. Under the same conditions of holding temperature of 920°C and 8 h holding time; coal alone produced a case depth of 0.06 mm and surface hardness of 54.42HRC. Charcoal alone produced case depth of 0.08 mm and surface hardness value of 58.42 HRC. In compounds C and D industrial chemical energizers were added individually to coal and charcoal. Compound C which had coal gave a case depth of 0.09 mm and surface hardness of 64.44 HRC and Compound D which had charcoal produced a case depth of 0.11 mm and a surface hardness of 64.39HRC. Here again the compound with charcoal had a better case depth and a competitive surface hardness with the compound containing coal. In compound E the two sources of carbon were combined With industrial chemical energizers to verify their synergistic effect. Unfortunately, the compound E produced the same case depth of 0.08mm just like charcoal alone produced. The surface hardness was 59.42 HRC which was still not so different from compound B surface hardness value of 58.42HRC. There was therefore no synergy in combining the two sources of carbon. However, it was observed that in all the cases where the energizers were added the efficacy of the carburizing material was enhanced.

The experiment was conducted under the same conditions of time and temperature, so for one carbon source to be better than the other, it has to do with the carbon content of the source and its carbon potential. This position has been upheld by several researchers who have done similar works (Ihom *et al.,* 2005; Ihom *et al.,* 2013; Azoro, 2017).

Plates IV-V show 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 (Figure 1) is different from (Figures 2-6). 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 work ''The Efficacy of Carburizing Compounds with Different Carbon Source and Industrial Chemical Energizers for Surface Treatment of Mild Steel'' has been undertaken. The following findings and conclusions have been drawn from the work:

i) The carbon source determines the efficacy of the carbon material as a carburizing compound in pack carburizing.
ii) Charcoal alone produced case depth of 0.08 mm and surface hardness of 58.42HRC, while coal had case depth of 0.06 mm and surface hardness of 54.42 HRC under the same conditions of holding time and carburizing temperature.
iii) The addition of industrial chemical energizers drastically improved the efficacy of the carburizing compounds.
iv) The combination of coal and charcoal to energizers did not lead to any synergistic effect in terms of high case depth and surface hardness.
v) The best carburizing compounds were compounds C and D because of the presence of the energizers.
vi) In the absence of energizers the charcoal performed better than the coal.

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