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Improvement of ASTM A53 Steel Durability Using Agrowastes as Carburizing Agent

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Abstract: The importance of steel in manufacturing and construction over the past century cannot be over-emphasized and easy accessibility couple with excellent mechanical properties make it preferable over others. However, the problem of durability has posed a serious concern as majority of steel application are meant for long term use. Several attempts have been made to improve the durability of steel in the past and increase of carbon content in low carbon steel was found to be a suitable agent. Although getting carbon is not the challenge rather obtaining it from a sustainable source that has zero environment impact. This research identified two separate agrowaste that has high carbon content the issue of sustainability brought about the development of carburizing agent from agrowaste that are easily accessible namely palm kernel and eggshell which is employed in this research. The use of agrowaste was found to be effective as there was notable increase in grain structure of the carburized steel when compared to the control sample without carburized agent in it.

Keywords: Steel, durability, carbon, carburized agent, environmental impact, agrowastes, palm kernel shell, eggshell production output

1. Introduction

Various steel types have different carbon content, for low carbon steel, it has carbon constituents of 0.15 % to 0.45 %. The most essential type of steel is low carbon steel as it contains physical and mechanical properties which are generally accepted for different use. This carbon steel is not remotely delicate or bendable considering its reduced carbon constituents. It has very much reduced unbending nature and it is flexible. As the carbon substance develops, the metal breezes up without a doubt harder and more grounded although less bendable yet rather progressively hard to weld. This endeavor is to investigate on the properties of carburization temperature and time on the mechanical chattels of carburized mellow steel, with the use of (PKS) as carburizer and egg shaft as pulverizer. Carburizing is the spot the steel is warmed in a heater. The outer most coat of a carbon poor part is braced with carbon through systems for carbon spread. The advancement of carbon substance impacts the material to solidify. The outcome is a hard and wear safe surface with an extraordinary core interest. The carburizing framework does not set the steel it just structures the carbon

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substance to some pre picked essentialness underneath the surface to an agreeable dimension to permit following extinguishing hardening [1 -2].

The further the expansion of the steel in a carbon-rich state, the more the carbon passageway would be undisputed and the higher the quality of carbon. The carbon-filled portion should have relatively high carbon content, so it can be reinforced very well by fire or retention. Surface strengthening shapes are subject to temperature, warming and cooling intensity, heat treatment time, media coverage and temperature. The key parameters which convince the possibility to achieve surface quality are post heat treatment and pre-heat treatment cases. The hardness of the martensite is basically the simplicity and the farthest point of a steel which can be reinforced to a specified essence [1]. Whether gas powered or electrically operated are the furnaces used in the fuel process. Temperature for carburizing is between 850 ° C and 1050 ° C. Carburizing temperature, stifling time, carbon factor, as well as carburization time in oil are the most critical constraints in carburizing processes. The latest research revolves around the influence of mechanical characteristics of carburized delicate steel of the carriage temperature and hold time [2].

Mild Steel could likewise be alluded to as low carbon steel with lower carbon content than various steels in this manner typically it is more straightforward for it for cold-forming techniques to be associated with it because of their fragile and malleable structure. Mild steel turns into a sensible decision on account of its ease and simplicity of dealing with particularly when quality is not the most significant factor in thought [3]. Due to its relatively low price, mild steel is the most used type of steel with the appropriate mechanical characteristics for a variety of applications in industry [4]. Low carbon steel, because of its low carbon content, mostly does not satisfy certain product requirements. The surface hardening is applied to components that have to be hard on the surface to stand up to wear and wear damage as they are softer on the interior to stand up against shock and impact charges [5] to allow low carbon steel to achieve the required mechanical properties.

The term 'carburization' uses the thermal process to decrease the dense surface of the steel while maintaining its useful properties. Throughout the process of machining, this design is made of low carbon steels and further improved distinctive parts, gears and covers for composite steel [6]. Carburizing creates dominance and guarantees wear, by spreading carbon to the metal surface that provides protection while retaining an explicitly lower hardness within. This treatment is linked to low-carbon machine steels. Strong, solid surface parts and complex forms of the mind may be made out of costly materials tolerably reduced and that are quickly processed or surrounded before heat treatment [6]. The process carburizing is a period/temperature process; the carburizing state is brought into the radiator for the normal time to ensure the correct significance of event. The amount of carbon in the gas can be lowered to permit scattering, keeping up a key separation from excess carbon in the surface layer [6].

Coming about to carburizing, the work is either immediate cooled for later cover solidifying or splashed especially into oil. Drench affirmation is made to accomplish the ideal properties with excellent dimensions of dimensional change. Hot oil smothering might be utilized for insignificant curving yet might be obliged in application by the quality necessities for the thing. Obviously, bearing races might be press extinguished to keep up their dimensional qualities, limiting the essential for over-the-top post warm treatment beating. Every so often, thing is tempered, by then cryogenically took care of to change over held austenite to martensite, and after that re-tempered [7] Carburizing is usually utilized for an extended time. Nevertheless, with developments in heat processing systems the carburization technique has developed mechanisms that increase the rigidity and solidity of items like carbon steel wire springs and carbon steel mechanisms. The formation of carbon on a low carbon steel surface at suitable temperatures is central to carburizing.

Nomenclature	
ASTM	American Society for Testing and Materials
SEM	Scanning Electron Microscope
PKS	Palm Kernel Shell

The specific objectives of this study among others are to process the pulveriser and energizer through local source, to show that local materials can be used to achieve the effects of industrially produced chemical carburizers, to study the influence of carburization process on the ASTM A53 mild steel and at the same time to study the performance of the material after carburization process has taken place.

The novelties in this study among others are that the study involves the processing of palm kernel shell into carburizing agent and eggshell as energizer for strengthening of mild steel, the carburization was carried out using a muffle furnace set at 2000 °C. The surface and core hardness, microstructure and compositional test was carried out on the carburized material. In this study, automobile companies and other metal related factories would be needing research like this to further buttress their understanding of metals and how they can be easily fine-tuned without polluting the environment or costing so much. The findings in this study also state that components of local source with the critical concoction structure can be used for a similar purpose to swap the synthetic materials mechanically provided. This means reduced cost of the carburization process due to the high price of these industrial chemicals and means that waste domestic materials can be recycled to produce value to the economy.

2. Methodology

Carburizing is the way to plunge the outer surface of carbon in steel. Carbonation can thus be classified in three groups, namely, gas carburization, carburizing packages with heavy carbonate combinations (carburizers), as well as fluid carbonization. The main reason behind the carburizing process consists in having a hard surface and wearing protection for machine components by advancing the carbon surface layer to an obsession of 0.75 to 1.2 percent and subsequent dousing.

Carbonized and quenched steel (case-set) has a greater constraint on fatigue. Carbonation can be applied to low carbon steels containing 0.1 percent to 0.18 percent carbon. For large parts steel can be used with higher carbon content, 0.2 to 0.3%. In recent time, there has also been a trend to use carburize steel for medium and small machine parts, which has higher carbon content. A more grounded focal point has been put on steel with an expanding carbon content (0,25 to 0,35 percent) which allows the importance of a carburized case to be greatly reduced following warmth treatment [8]. The materials used in this study are pure waste materials which can be easily sourced for in the community. These are materials regarded as unwanted shafts or waste product to be discarded. This waste materials serve as examples as to why recycling should be held of utmost importance to avoid waste and to maximize utility and use.

2.1 Preparation of Material

The carburizing agents used in this research are carbon rich materials which are encased with the steel in a carburizing box. During carburization, the carbon from the agents then impacts into the steel inner and outer surface. The agents used are listed below.

2.1.1 Palm Kernel Shell (PKS)

PKS is one of the bottomless agrarian squanders, not used preferably and produced from the fruits of palm kernels. After the palm oil has been discharged from a single-carp oil palm natural object, palm kernel shell is recovered as staying waste in the extraction of the bit from a nut [9]. In this study the PKS after pulverization was used as our main carburizing agent, this is because of its high carbon content and ease of availability [10 -11].

2.1.2 Egg Shell

Egg shell and the pulverized powder contains a good measure of calcium carbonate simply like periwinkles, snails (shells), and others in that mollusk family [12]. In this study, eggshell is used as a carburizing agent also serving the purpose of an energizer. This is because of its calcium carbonate content, availability and cost effective.

2.1.3 Mild Steel

Mild steel has been widely applied for components such as shafts, riggings, pinions, cams, hand appliances, rural gear, and so on, because of its workability, strength, design, and quality among the steel types [6]. Such components require mechanical hardness affect their safe and tough capacities on consistency and elasticity. Smooth steel, which lets manufacturers and engineers easily produce components with these important mechanical features, typically does not have. These parts produced from mellow steel then require carburizing and case solidification heat applications in order to operate in these mandatory mechanical properties [13]. Two small circular shape and two long cylindrically shaped metals were used for the carburization process, this is due to the fact I would be using them for different tests.

2.1.4 Steel Box

During the carburizing procedure, metallic boxes were made to case the metals in such a manner they can be closed and opened and also able to encase the carburizing agents and mild steel. These steel boxes are made of high melting point steels to ensure they do not melt or affect the carburizing process in any way.

2.2 Equipment

2.2.1 Vickers Hardness Tester

The Vickers hardness test was carried out at engineering materials development institute (EMDI), Akure. The method gives a precise measurement of the correct hardness result required. The light from the indicator set on the all-around cleaned test laying on the plastic development stand and consequently center around the examples and catch. The caught surfaces exist in ranges which are precisely controlled to four balanced axes. Vickers hardness analyzers naturally computes and report the fitting hardness result [14].

2.2.2 Muffle furnace

The uniqueness of a muffle furnace is that it isolates the material to be heated from all side-effects of ignition from the heat source [15]. With present day electrical heaters, this implies heat is connected to a chamber through enlistment or convection by a high-temperature heating curl inside a protected material. The protecting material successfully goes about as a muffle, keeping heat from getting away.

2.2.3 Optical Microscope (OM)

The optical microscope (OM) was carried out at engineering materials development institute (EMDI), Akure using Olympus BH2 Microscope. The OM is utilized for perception of specimen surfaces. Is a light optical microscope that uses visible light as well as a system of lenses to magnify images of small samples. OM is designated to produce magnified photographic images as well as visual images of small objects. It has three purposes, namely the production of a magnifying picture of the object, the separation of different image information and the representation of the final image by the human eye or the camera [16]. A diffraction determines the resolution limit of optical microscopes, regulated in effect by numerical opening of the optical device and the wavelength (λ) of the used light.

2.3 Carburization Preparation

The agents being used, i.e., PKS and egg shaft were first dried to remove any moisture content and then they were milled into even units to upsurge the area of the surface of the agents and to rise the effectiveness of the carbon to let go into the atmosphere in the steel boxes. Both agents were then mixed in a ratio of 70:30. This is due to the higher carbon content of palm kernel shell and the fact that the calcium carbonate in the eggshell serves only as an energizer to catalyze the infusion of the carbon into the surface of the steel.

2.3.1 Steel pieces and Box Preparation

The sets of steel pieces used in this study were cut into four sets. The two steel boxes were made with two faces detachable and were designed for the inside of the carburizer and the steel components. They were made in dimensions 200X50 X 200 mm. A small extension was created on one side of the steel boxes to convey the steel boxes during high temperature usage.

2.3.2 Carburization Process

The carburization was done in a muffle furnace at various temperature and holding time combination to examine the impacts these distinctive time and temperature mixes have on the improvements, made by the carburization procedure. The steel boxes were first loaded with the steel pieces which are then covered in the carburization agents in accordance with the work reported in [19]. The 2 steel boxes are then put to the muffle furnace and it is turned on and the heating procedure begins at a consistent rate. At the point when the temperature reaches the desired point, the temperature is locked by then and the holding time starts to check. Once the time achieves the primary assigned temperature point which is a hour, one box is removed and after that the counter proceeds till it gets to the following purpose of expulsion which is following a 30 minute interim and the following box is removed. In this case where there are two boxes in use, the procedure is carried out again with the same agents but different sample steel to achieve the remaining readings. This process is repeatedly carried out with different degrees in temperatures and time in minutes. The primer test starts from 900 °C at that point increments to 1100 °C. The temperature of the combustion technique was ensured to be under the melting level to determine the steel obtained in all cases by the steel austenizing temperature [17-18]. The temperature mixtures are represented in Table 1.

Table 1 - Holding time per carburizing temperatures in degrees

Holding Time @ Number of minutes			
950 °C @ 60mins	1000 °C @ 60mins	1050 °C @ 60mins	1100 °C @ 60mins
950 °C @ 90mins	1000 °C @ 90mins	1050 °C @ 90mins	1100 °C @ 90mins
950 °C @ 120mins	1000 °C @ 120mins	1050 °C @ 120mins	1100 °C @ 120mins
950 °C @ 180mins	1000 v @ 180mins	1050 v @ 180mins	1100 °C @ 180mins

2.4 Mechanical Tests and Analysis

2.4.1 Micro hardness Testing

The hardness test is performed by utilizing a tool called durometer, which applies unmistakable weights, picked, according to models implying a precedent properly organized; the heap is associated through an indenter of different sorts depending on the scale which is being used. The micro hardness testing was carried out by assessing the degree of the imprint left by the indenter on the precedent, in the wake of partaking awed the heap for a measured time for the Brinell and Vickers.

2.4.2 Core Hardness Test

A load is connected to a solidified steel ball that sits on a level surface of the metal holding up to be assessed. After this, the distance across of the scratch that structures are evaluated. The hardness is estimated with this equation: The Brinell number showing the metal's hardness is then the load on the ball in kilograms partitioned by the circular surface zone of the dent in square millimeters.

2.4.3 Compositional Analysis Test

This test gives a definite depiction of the small-scale structure of the carburized steel. By contrasting the carburized steel and the uncarburized steel, the distinction in the microstructure made by the expanded carbon substance of the surface of the steel would then be able to be inspected. This test is completed utilizing a metallurgical Microscope. The table below shows a breakdown of the individual sample according to particular temperature and holding time and the test carried out on each sample.

Table 2 - Sample Labels for Testing Process

Carburizing temperature (℃)	Holding time (mins)	Microstructure Test	Hardness Test	Compositional Analysis
950 ℃	60.0mins	1_A	1.0_B	1.0_C
950 ℃	90.0mins	2_A	2.0_B	2.0_C
950 ℃	120.0mins	3_A	3.0_B	3.0_C
950 ℃	180.0mins	4_A	4.0_B	4.0_C
1000 ℃	60.0mins	5_A	5.0_B	5.0_C
1000 ℃	90.0mins	6_A	6.0_B	6.0_C
1050 ℃	60.0mins	7_A	7.0_B	7.0_C
1050 ℃	90.0mins	8_A	8.0_B	8.0_C
1100 ℃	60.0mins	9_A	9.0_B	9.0_C
1100 ℃	90.0mins	10_A	10.0_B	10.0_C
CONTROL	CONTNROL	CONTROL_A	CONTROL_B	CONTROL_C

2.4.4 Compositional Analysis

The compositional analysis of the grade steel (ASTM A53) metal used is listed in Table 3.

Table 3 - Compositional analysis

Rudiments	Configuration
Carbon	0.251%
Silicon	0.852%
Magnesium	0.951%
Potassium	0.051%
Sulfur	0.144%
Chromium	0.382%
Nickel	0.210%
Molybdenum	0.206%
Aluminium	0.022%

3. Results and Discussion

In this section, after all the carburization process and mechanical tests have been carried out, we will be reviewing the results gotten from the carburization process and the tests performed on them, showing results and what they mean in relation to their improvement from the original. Tables and graphs are used to express these data. Results gotten from the micro analysis and hardness tests performed are expressed in Figures 1 to 4, and tables 1 to 7. The hardness plot for the surface, intermediate and core was presented in Figure 1, while the surface hardness readings at different holding time and temperature is depicted in Figure 2. Intermediate and the core chart showing the changes in hardness at different holding time and carburizing temperature is as shown in Figures 3 and 4 respectively.

3.1 Hardness Test

The hardness test produced values of the surface, intermediate and core samples of the steels at varying temperatures is presented in Table 4.

Table 4 - Samples and their carburization temperature representation

Sample	Carburizing temperature (℃)
1_B	950
2_B	950
3_B	950
4_B	950
5_B	1000
6_B	1000
7_B	1050
8_B	1050
9_B	1100
10_{ABC}	1100

Table 5 - Hardness for surface, intermediate and core

Sample(s)	Surface (Hv)	Intermediate (Hv)	Core (Hv)
CONTROL	79.7	132.5	124.5
1B	117.1	125.4	128.1
2B	124.5	127.2	123.76
3B	131.9	129	119.43
4B	139.3	130.8	115.1
5B	139.15	127.35	120.3
6B	139	123.9	125.5
7B	127.7	120.95	122.2
8B	116.4	118	118.9
9B	108.1	127.4	147.7
10B	118.5	146	133.5

Table 6 - Hardness values (Hv) for Intermediate at varying temperatures and time

Temperature	60 minutes	90 mins	120 mins	180 mins	control
950 ℃	117.10	124.50	131.90	139.30	79.70
1000 ℃	139.150	1390	119.240	99.470	79.70
1050 ℃	127.70	116.40	104.160	91.930	79.70
1100 ℃	108.10	118.50	105.560	92.630	79.70

Table 7 - Hardness values (Hv) for Core at varying temperatures and time

Temperature	60 mins	90 mins	120 mins	180 mins	control
950 ℃	127.9	124.160	118.730	114.90	125.10
1000 ℃	119.90	126.10	124.820	125.10	125.10
1050 ℃	121.90	119.10	121.170	123.140	125.10
1100 ℃	146.80	134.10	131.150	128.10	125.10

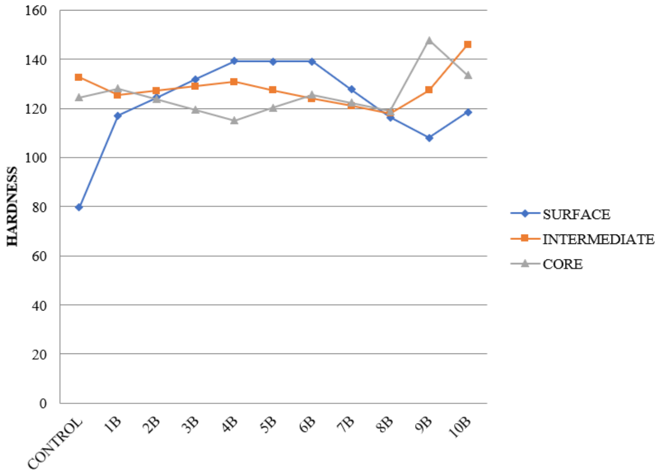

Fig. 1 - Hardness plot for surface, intermediate and core

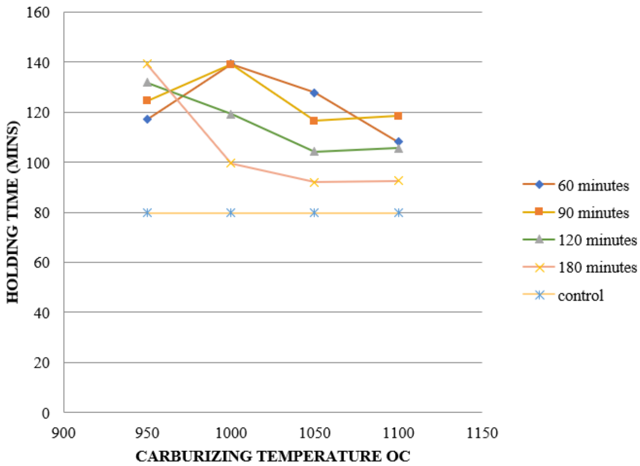

Fig. 2 - Plots of surface hardness readings at different holding time and temperature

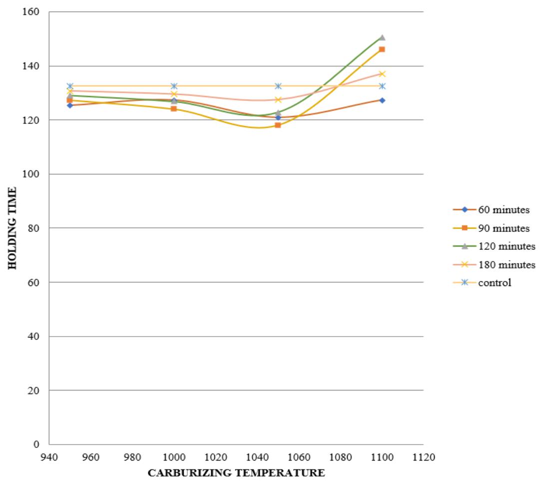

Fig. 3 - Intermediate chart showing the changes in hardness at different holding time and carburizing Temperature

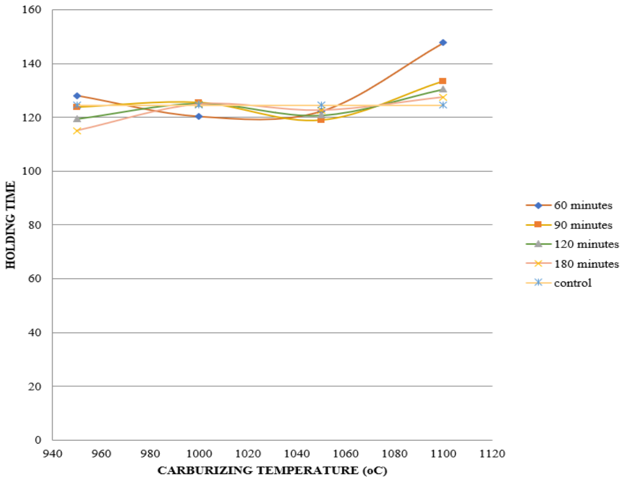

Fig. 4 - Core chart showing the changes in hardness at different holding time and carburizing temperature

3.2 Microstructure Analysis

The micro structural analysis produced micrographs of the surface, intermediate and core of the samples at 100x magnification to showcase the difference in the structure created by the infusion of carbon into the steel during the carburization process. The micrographs are as shown in Figures 5 - 10.

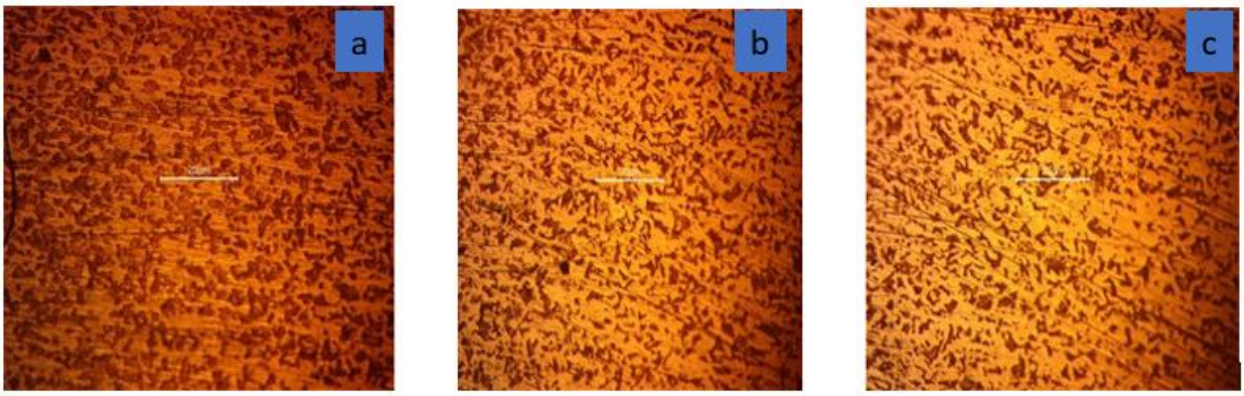

Fig. 5 - The micrograph at 100x MAG for 1A showing (a) Edge X (b) Middle X (c) Core X

The micrographs shown in Figure 5 are performed at a holding time of 60 minutes and carburizing temperature of 950 °C. From the diagrams we can see that the grain structures are different from each other at different stages, i.e. the edge, middle and core. This is due to the carbon infusion into the carburized metal thereby causing a change in the grain structure. Comparing the grain structure formation between sample 1A and the control, we can see that the change in the structure in 1A is more compact and arranged from the CONTROL sample which is very scattered. Though this is not the best result achieved from the carburized samples.

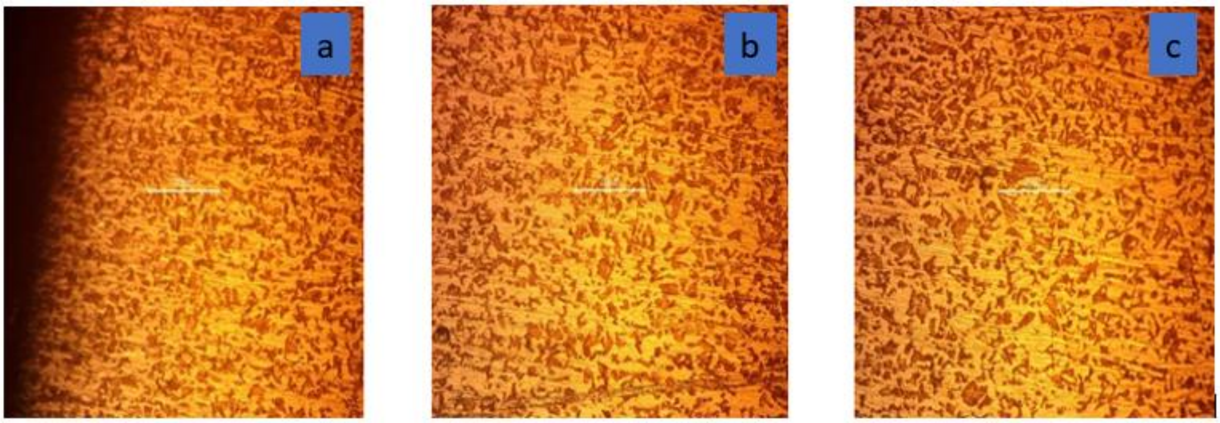

Fig. 6 - The micrograph at 100x MAG for 4A showing (a) Edge X (b) Middle X (c) Core X

The micrographs shown in Figure 6 are performed at a holding time of 180 minutes and carburizing temperature of 950 °C. From the micrographs we can see that the grain structures are different from each other at different stages, i.e. the edge, middle and core. This is due to the carbon infusion into the carburized metal thereby causing a change in the grain structure. Comparing the grain structure formation between sample 1A and the control, we can see that the change in the structure in 1A is more compact and arranged from the CONTROL sample which is very scattered. Though this is not the best result achieved from the carburized samples.

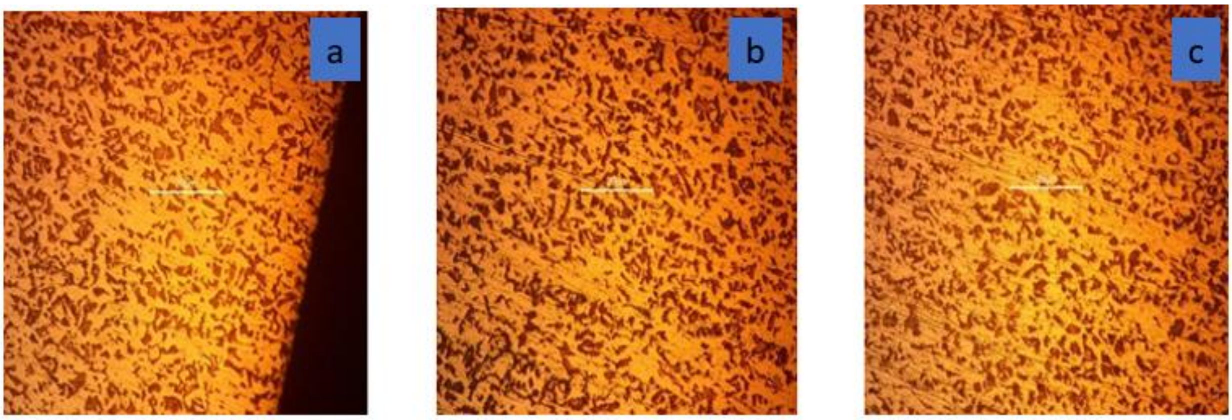

Fig. 7 - The micrograph at 100x MAG for 6A showing (a) Edge X (b) Middle X (c) Core X

The micrographs shown in Figure 7 are performed at a holding time of 90 minutes and carburizing temperature of 1000 °C. From the diagrams we can see that the grain structures are different from each other at different stages, i.e. the edge, middle and core. This is due to the carbon infusion into the carburized metal thereby causing a change in the grain structure. Comparing the grain structure formation between sample 1A and the control, we can see that the change in the structure in 1A is more compact and arranged from the CONTROL sample which is very scattered. Though this is not the best result achieved from the carburized samples.

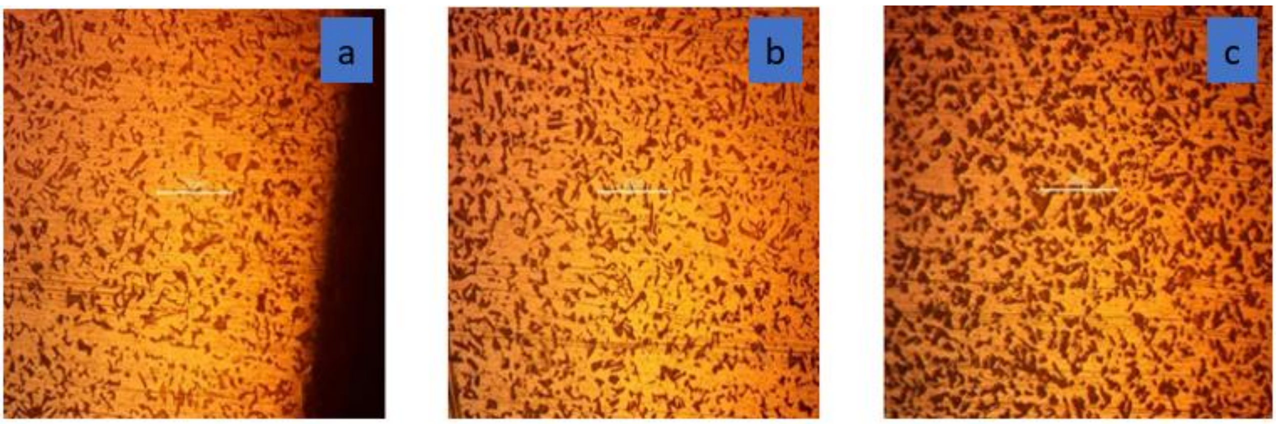

Fig. 8 - The micrograph at 100x MAG for 9A showing (a) Edge X (b) Middle X (c) Core X

The micrographs shown in Figure 8 are performed at a holding time of 60 minutes and carburizing temperature of 1100 °C. From the diagrams we can see that the grain structures are different from each other at different stages, i.e. the edge, middle and core. This is due to the carbon infusion into the carburized metal thereby causing a change in the grain structure. Comparing the grain structure formation between sample 1A and the control, we can see that the change in the structure in 1A is more compact and arranged from the CONTROL sample which is very scattered. Though this is not the best result achieved from the carburized samples.

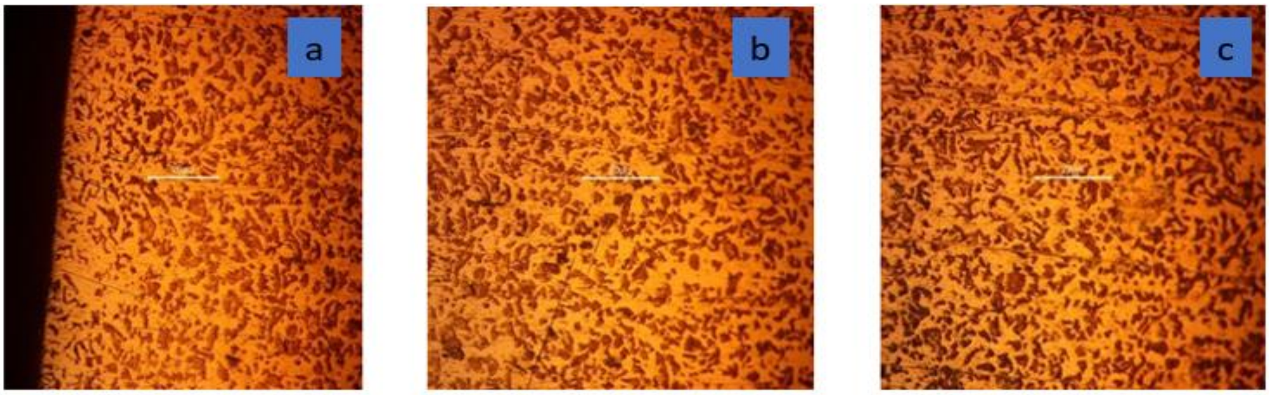

Fig. 9 - The micrograph at 100x MAG for 10A showing (a) Edge X (b) Middle X (c) Core X

The micrographs shown in Figure 9 are performed at a holding time of 90 minutes and carburizing temperature of 1100 °C. From the diagrams we can see that the grain structures are different from each other at different stages, i.e. the edge, middle and core. This is due to the carbon infusion into the carburized metal thereby causing a change in the grain structure. Comparing the grain structure formation between sample 1A and the control, we can see that the change in the structure in 10A is more compact and arranged from the CONTROL sample which is very scattered. This is the best grain structure for each part, i.e. the edge, middle and core. Comparing it to all the carburized samples including the control, it has a better grain structure, and this agreed with the work of Oreko et al [21]. This can be attested to the fact that the carburization took place at a very high temperature and a longer holding time which gave the carbon additives more time to be infused into the metal.

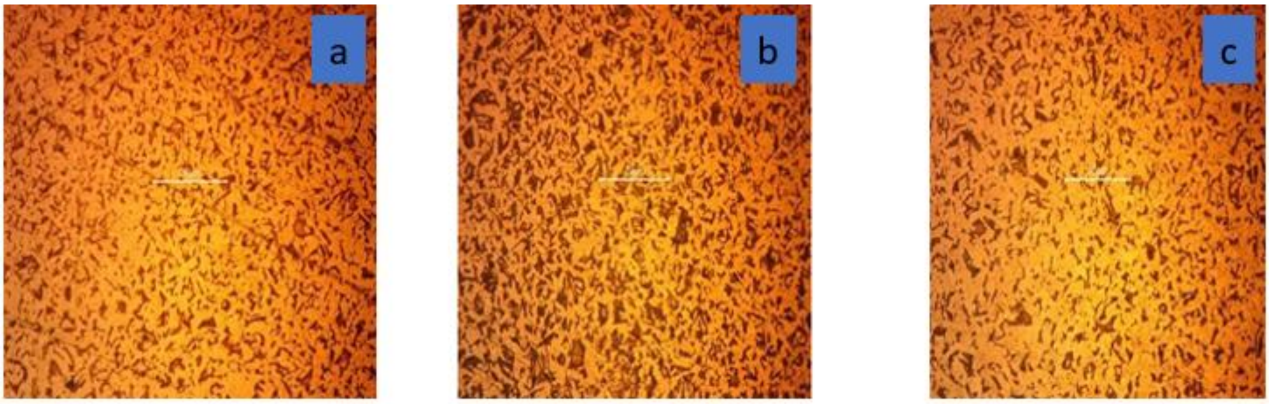

Fig. 10 - The micrograph at 100x MAG for Ctrl showing (a) Edge X (b) Middle X (c) Core X

The micrographs shown in Figure 10 are performed on the steel before carburization process was done and comparing it to all other analysis, we can see there is better grain structure in the carburized metals. Though they all varied, there was no symmetrical improvement with increase or decrease time and temperature. The best result was then gotten at 1100 °C at 90 minutes of holding time.

The micrographs shown from Figures 5 to 10 shown the microstructure analysis offers us by means of the information that the higher holding time used during the carburization process at diverse temperature, the additional carbon will infuse into the superficial of the steel in accordance with the work of Aramide et al [20]. Looking at the figures above, comparing the control figure with the carburized figures at different holding time and carburizing temperature, we'll notice the darker shades are more in the carburized figures than that of the control. These figures are very well explanatory. Although looking at the carburized figures, notice the carbon content differ between the surface, intermediate and core, i.e. there is no symmetrical other to which the carbon present into any of the stages are.

The hardness test outcome appeared above demonstrates the adjustment in the mechanical assets of the carburized steel. The first is the hardness of the surface in which increases by and large at each example test, this is a consequence of the carbon from the carburizing specialist having more opportunity to imbue into the outside of the material and structure a more profound case which is more earnestly than the center of the material. This is in line with the work of Afolalu *et al*., [1, 7] who stated that the micro hardness of steel during carburization increases with increased holding time. Likewise, from the charts it tends to be considered that to be the holding time increments, there is an expansion in hardness, yet we see that this expansion happens at a reducing rate.

Looking at the holding time between 120 to 180 minutes compared to the holding time of 60 minutes or that of 60 to 120 minutes and 120 to 180 minutes, the difference is quite obvious. The reason was postulated by [17-18] as being that the carbon in the carburizer diminishes after a long length of time. Studying the graph, we notice that the best carburization procedure occurred at 1100 °C at the highest holding time, this is because of the rise in temperature which makes it easier for the carbon from the carburizing agent infuse into the steel at a faster rate.

4.0 Conclusion

From the experimental works carried out, the results gotten and their discussion, it can be concluded that:

i. the point of the task can be accomplished with the approach utilized and that there is a specific peak level where an ideal blend of surface hardness and center hardness can be figured out. This peak level of 1100 °C and 90 minutes holding time affirms that a higher holding time makes a superior carburization impact, yet the temperature has a state of affectation where expanded temperature causes a downturn in the pattern of changes.
ii. The chemical composition of the mild steel (ASTM A53) use was determined and presented using spectrometric analysis.
iii. The hardness properties of the carburized mild steel (ASTM A53) were determined using Vickers hardness testing.
iv. The carburizing temperatures were of step 50 °C, varying from 950 °C to 1100 °C.
v. The holding time for carburization were of step 60 minutes, varying from 60 to 180 minutes.
vi. The surface hardness values show that at 60 and 90 minutes and at temperature 1000 °C, the highest value of hardness was recorded at the surface.
vii. The intermediate hardness values got its highest value at 90 and 120 minutes while the carburizing temperature was 1100 °C.
viii. The highest harness value for the core surface was obtained at 60 and 90 minutes and the carburizing temperature then was 1100 °C.
ix. The microstructural analysis at different harness surface under investigation were studied, captured and presented.
x. The grain structures are different from each other at different stages, i.e. the edge, middle and core. This is due to the carbon infusion into the carburized metal thereby causing a change in the grain structure.

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