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Production of Cutting Tools from Recycled Steel with Palm Kernel Shell as Carbon Additives

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ABSTRACT: Machining is an integral and indispensable part of production technology with cutting tool playing key roles in its operations. This work therefore developed cutting tool from scrapped crank shaft, connecting rod, alloy additives and palm kernel shell. These materials were chosen due to their hardness and availability. The scrapped crankshaft and rod (100 kg) containing 0.560 % carbon were charged into electric induction furnace with maximum temperature 3000^{o}C. The composition of the charged materials was analyzed with the UV-VIS spectrometer before and after melting. In order to raise the carbon content of the melt to 0.65% target (HSS) and upgrade relevant elements, alloy additives were added. Annealing was the first treatment carried out in muffle treatment furnace at temperature at 900^{o}C for 9 hrs then cooled to 300^{o}C. The annealed materials were machined into 20 pieces of long (199 x 12 x 12 mm) and short (20x 12 x12 mm) sizes. Further treatments of hardening, normalizing and tempering were also carried out on the cutting tools. The tools were then carburized with pulverized carbon using 20 % Barium trioxocarbonate (V) as an energizer in a muffle treatment furnace. Each of the samples was soaked at temperature of 800^{o}C, 850^{o}C, 900^{o}C and 950^{o}C for 60, 90 and 120 minutes holding time. Micro-hardness and surface hardness of the tool were 47.9 and 76.8HR, while for control sample were 46.1 and 76.3HR respectively.

KEYWORDS: Machining, production, cutting tool, Recycled steel, palm kernel shell, carburization.

1 BACKGROUND

Metal cutting operations puts extreme demands on the cutting tools and tools material through conditions of high forces, high contact pressure, high temperature, and intense chemical attack on work materials which worn out before the life span. Cutting edges of treated tools have improved properties with the ability to increase the cutting speed, the feed rate, time of cut and the depth of cut. In order to meet the parametric requirements, the tools should be of high hardness and should be considerably resistant to abrasive, adhesive, diffusive and chemical wear [6], [1].

In order to increase life spam of a cutting tool, surface engineering treatments will brings extensive rearrangements of atoms in metals and alloys structure with a corresponding marked variation in properties. The major and most valuable one of these methods are heat treatment processes such immersion hardening, induction hardening and case carburizing. These are generally applied to enhance the hardenability of materials by improving the surface hardness [4]

"Reference [5]" defined carburization as a diffusion-controlled process that involves penetration of carbon into surface and core of the materials. The longer the soaking period stay in carbon –rich environment the more the concentration of carbon penetration into the surface and core of the materials. The most commonly performed steel heat treatments in present age is carburization, with some years ago of about four thousand years it was performed by packing the low carbon wrought iron parts in charcoal, then increase the temperature of the pack to red heat(elevated temperature) for several hours. The entire pack of charcoal and materials, were then dumped into water to quench it. The surface became very hard, while the interior or "core" of the part retained the toughness of low carbon steel [14].

"Reference [10]" reported that carburization using powdered palm kernel shell at 1000^0C and 1100^0C and tampered showed higher value in tensile strength than the material not tempered which concluded that palm kernel shell and animal bone carburizers have good potential to be used as carburizer. The used of $BaCO_3$, $CaCO_3$ and Na_2CO_3 as the most familiar energizer that are commonly used in carburizing in order to increase the carbon potential penetration into the core of the materials. Bone has been used by considering the organic component to serve the purpose of carbonaceous materials whiles the carbonate in inorganic serve as an energizer [3].

"Reference [15]" shows that using natural occurring carbonates will reduces the cost of chemical energizer and also minimize the environmental pollution. "Reference Paul [11]" investigated that cowbone should be used as an energizer in pack carburizing process and the composition of charcoal and cowbone give better hardness that using charcoal alone.

"Reference [7]" investigated that the physical and thermal properties of pulverized palm kernel shell shown a strong potential for use both as particulate and environmentally friendly, thus provides simulation for sustainable lifestyle change in waste diversification.

Surface hardening of low carbon steel with palm kernel shell as shown in fig. 1 above has significant value impact on surface hardness and wear resistance of materials. The carburizing media usually responded well to all surface hardening with PKS giving the highest hardness value which make it more efficient than graphite [2].

Metal cutting of machining can be regarded as highly non-linear and thermo-mechanical process of which the coupling is introduce through localized heating and temperature increase in the work piece, this is usually caused as a result of rapid plastic flow and friction along the tool-chip interface [3],[9].

Machining operation has the steam pressure as the dominant parameter for surface roughness followed by the feed while cutting speed has a minimal effect on surface hardness compare to other available parameters. And for better result in finishing during machining high steam pressure, high cutting speed and lower feed are preferable. Metal cutting is considered as one of the most important of manufacturing processes. This is particularly true for production processes where the idle and down times arising from various factors prove to be one of the major impediments in achieving the goal [13]. Cutting tools wear is the main challenges of modern machining industries which reduced the focus on achieving high tool performance and in term of work piece dimensional accuracy, surface finish, high production rate, high wear on the cutting tools and high economy of machining in term of cost saving. The demand for more efficient cutting tool increases continuously with technology. Most of the cutting tools in use are imported and the cost of replacement is high, hence there is need to develop them locally. The recycle steels are available locally in adequate quantity. This study therefore, developed cutting tools from recycled steel (crank shaft and connecting rod), alloy additives and palm kernel shell.

2 MATERIALS AND METHODS

2.1 MATERIAL

The materials used for the project were recycled carbon steel (crankshaft and rod), silica sands; benzoate and coal dust, water, pure form (alloying elements) of Graphite C, Silicon(Si), Manganese (Mn), Chromium (Cr), Molybdenum (Mo), Nickel (Ni), palm kernel shell, iron rod . Barium trioxocarbonate (v) (BaCO3), Engine Oil, units of steel boxes of density 700g/cm3, 13units of fabricated iron boxes, 50litres of Engine Oil, and12 units of steel boxes of density 700g/cm3. Pulverized palm kernel shell used was processed at Federal Institute of Industrial Research Oshodi, Lagos (FIIRO). The equipment used for the casting Engineering foundry Ltd. Lagos were, Electric Induction furnace (Electroterm India) of 30000C and 1000kg capacity, grinding machine, ladle, Steel mould, green sand/Universal tester (150kg capacity), permeability tester and spectrometer.The equipment used for the carburization and test at EMDI, Akure and Federal University of Technology Akure were; Muffle Electric furnace of 15000C capacity, Lathe machines, Grinding machine, 12 heat resisting steel boxes, Digital weigh scale,hacksaw, polishing machine, Rockwell hardness testing machine.

2.2 METHODS

Having selected our scraps 100 kg of recycled carbon steel (crank shaft and rod), these materials were weighed and charged into the furnace. The composition were taken with spectrometer before and after melting, some portion was taken to metallurgical laboratory for analysis test and the results of composition analysis before melting are shown in Table 1 There was reduction in chemistry of the materials selected for melting from the original due to oxidation reaction during melting.

Alloying was carried out by increasing the percentage of carbon and silicon element of the materials to obtained treated mild steel of HSS (High Speed Steel) of comparative standard composition as shown in Table 2 below.

Casting was carried out at Engineering Foundry Ltd-Lagos with an Induction furnace of temperature capacity of 1 Ton with about 3000^{o}C was used to melt the materials of recycled carbon steel (Crankshaft and rod) at melting temperature of about 1500^{o}C. It gives clean melt thereby kept about 0.05 max of phosphorus and sulphur at barest minimum because they are dangerous to steel and cast iron. After hardening treatment of the sample the treated carbon steel was machined into 20 pieces each of 199 mm x 12 mm x 12 mm and 20 mm x 12 mm x 12 mm. The sizes were designed base on the capacity of the muffle furnaces

Heat treatment by carburization was carried out at Engineering Materials and Development Institute, Akure (EMDI). The prepared 20 samples each for long and short sizes were inserted in the pulverized palm kernel shell shown in Plate 20 with 20% proportion of Barium trioxocarbonate (v) salt ($BaCO_3$) as an energizer. The carburizer was weighed as shown in Plate 19 and packed inside steel boxes of density 700 g/cm3 and tightly filled up with powdered palm kernel shell cover to prevent the CO from escaping and prevent unwanted furnace gas from entering the steel box during heating.

The muffle furnace was loaded per one prepared box, temperature of the furnace was adjusted to the required temperature (800, 850, 900 and 950 °C) for each stages respectively and the loaded steel box was charged into the muffle furnace one after the other. When the furnace temperature reaches the required carburizing temperature, it was then held/soaked at the temperature for the required time (60, 90 and 120 minutes). After the material was held at the specified time, the steel pot was removed from the furnace and the material was quenched in engine oil (which was initially at the ambient atmospheric temperature). Each sample was carburized base on proportion to specific holding time and temperature as scheduled.

The micro hardness and surface hardness test were carried out on the treated cutting tools produced using Rockwell hardness tester. The result shown in Figures 1 to 13 indicated the effects of carburization on both surface and core layers of the tool.

The Microstructural Studies were carried out on each carburized sample cutting tools after metallographic preparations. These involved the grinding and polishing of each sample on emery papers of 60, 180, 240, 600, 800 and 1200 grits. The mirror-like surface of each polished carburized sample was etched and viewed using the Olympus microscope.

3 Results

3.1 Composition of the recycled tool steel

The composition of the material was analyzed after selection before casting to actualize what the recycled carbon steel contain and the result is shown in Table 1. Melt correction with alloying was done to compensate the elements that loss out during melting as a result of oxidation reaction that took place during melting and the results is shown in Table 2.

3.2 Micro hardness and surface hardness of the cutting tools produced

The results for micro and surface hardness test carried out on carburized cutting tool using micro hardness tester and are shown in Tables 3 to 5. These shown the degree of hardness in both the surface and core of the cutting tools.

3.3 Micro structural analysis

The results of the microstructural analysis are shown in figures 6 to 21.The interface in each micrograph depicts the boundary across which the carbon diffusion travels from the case to the core. The hardness and strength of martensite structure increased sharply with increase in carbon content. Contribution to the strength arises from the carbon in solid solution, carbides precipitated during the quench, dislocations introduced during the transformation, and the grain size. Each micrograph shows the case, interface between the case and the core.

Table 1. Composition of materials selected before charging to furnace

Elements	Composition (%)
C	0.560
Si	0.852
Mn	0.516
P	0.040
S	0.049
Cr	0.382
Ni	0.210
Mo	0.206
Al	0.022

Table 2. Composition obtained after melt correction with alloying.

Element(s)	Composition (%)
C	0.65
Si	1.22
Mn	0.334
P	0.026
S	0.036
Cr	4.34
Ni	0.16
Mo	0.890
W	1.67
V	0.393
Co	0.012
Al	0.010

Table 3. Summary of Micro hardness test at different temperature and holding time

SAMPLE(S)	TEMPERATURE ^{o}C	HOLDING TIME (MINS)	MICRO HARDINESS (HR)
A	800	60	38.0
B	800	90	35.5
C	800	120	29.1
D	850	60	25.1
E	850	90	42.5
F	850	120	40.7
G	900	60	31.0
H	900	90	38.1
I	900	120	39.1
J	950	60	35.3
K	950	90	45.2
L	950	120	47.9
Control			46.1

Table 4. Surface hardness test at different temperature and holding time

SAMPLE (S)	TEMPERATURE ^0C	HOLDING TIME (MINS)	SURFACE HARDNESS (HR)
A	800	60	36.9
B	800	90	49.9
C	800	120	52.3
D	850	60	55.7
E	850	90	56.4
F	850	120	57.7
G	900	60	59.0
H	900	90	59.7
I	900	120	61.1
J	950	60	63.5
K	950	90	65.7
L	950	120	76.8
Control			76.3

Table 5. Summary of micro hardness and surface hardness test.

SAMPLE (S)	TEMPERATURE ^0C	HOLDING TIME (MINS)	MICRO HARDINESS(HR)	SURFACE HARDNESS (HR)
A	800	60	38.0	36.9
B	800	90	35.5	49.9
C	800	120	29.1	52.3
D	850	60	25.1	55.7
E	850	90	42.5	56.4
F	850	120	40.7	57.7
G	900	60	31.0	59.0
H	900	90	38.1	59.7
I	900	120	39.1	61.1
J	950	60	35.3	63.5
K	950	90	45.2	65.7
L	950	120	47.9	76.8
Control			46.1	76.3

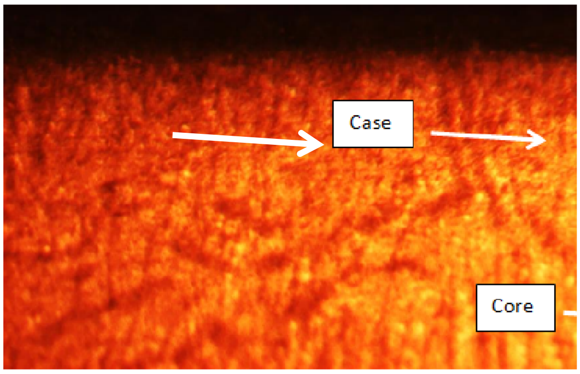

Figure 1: Control, micro hardness 46.1 HR and surface hardness 76.3 HR

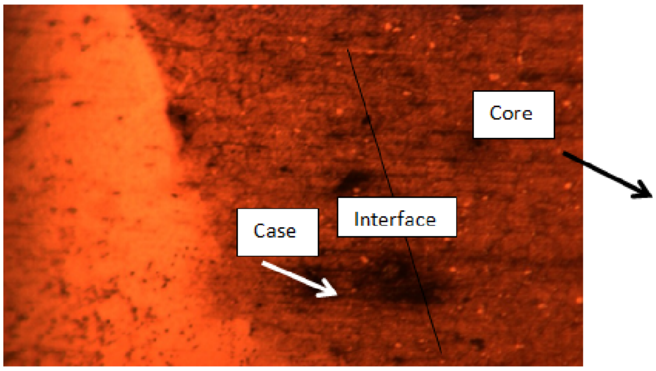

Figure 2: Sample A: Carburized at 800°C held for 60 minutes, micro hardness 38.0 HR surface hardness 36.9 HR

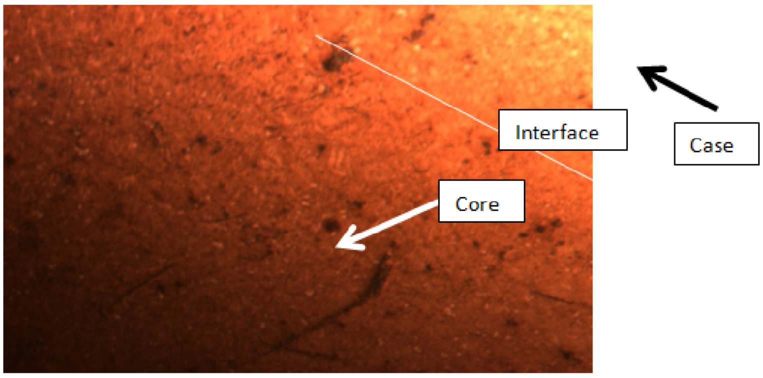

Figure 3: Sample B Carburized at 800°C held for 60 minutes of micro hardness 35.5 HR surface hardness 49.9 HR

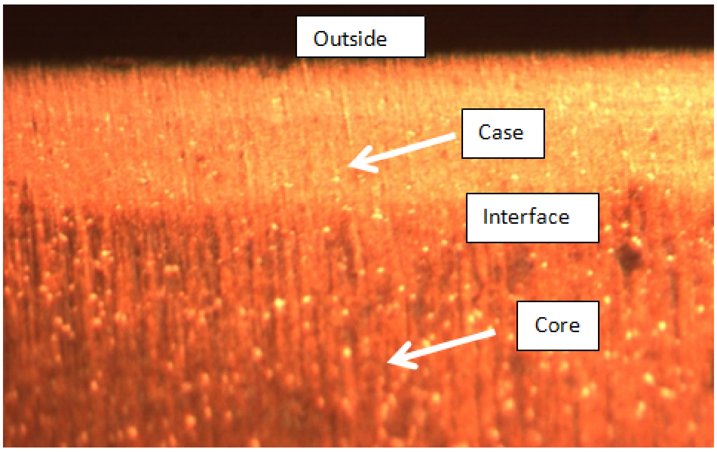

Figure 4: Sample C Carburized at 800°C held for 120 minutes, micro hardness 29.1 HR surface hardness 52.3 HR

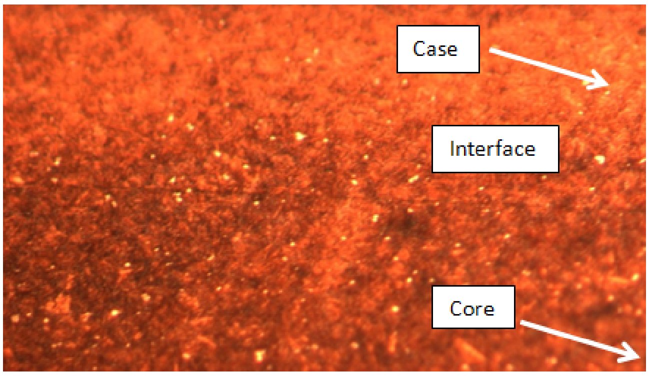

Figure 5: Sample D Carburized at 850°C held for 60 minutes, micro hardness 25.1 HR surface hardness 55.7 HR

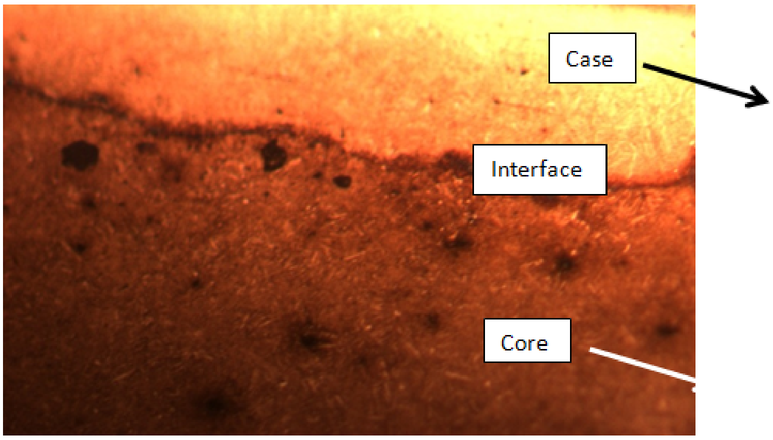

Figure 6: Sample E Carburized at 850°C held for 90 minutes, micro hardness 42.5 HR and surface hardness 56.4 HR

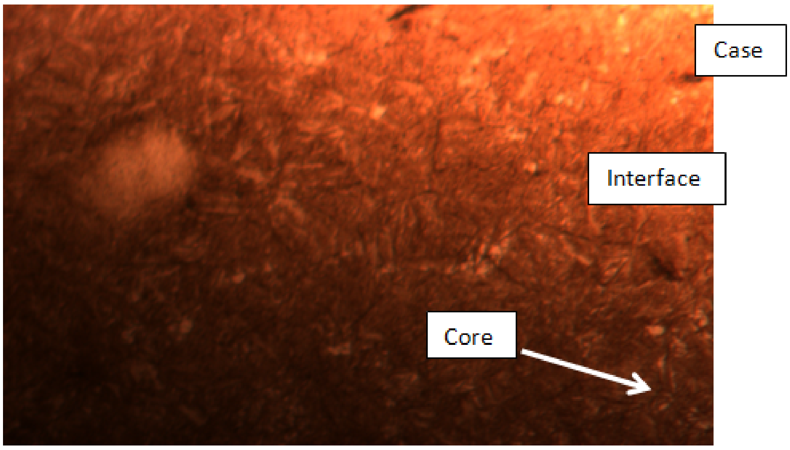

Figure 7: Sample F Carburized at 850°C held for 120 minutes, micro hardness 40.7 HR and surface hardness 57.7 HR

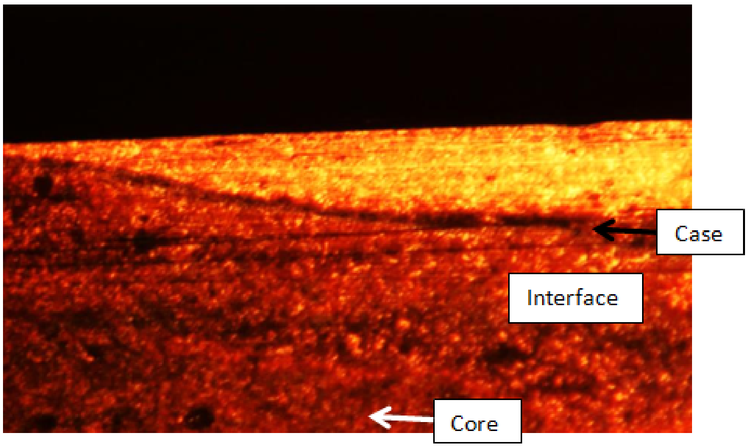

Figure 8: Sample G: Carburized at 900°C held for 60 minutes, micro hardness 31.0 HR surface hardness 59.0 HR

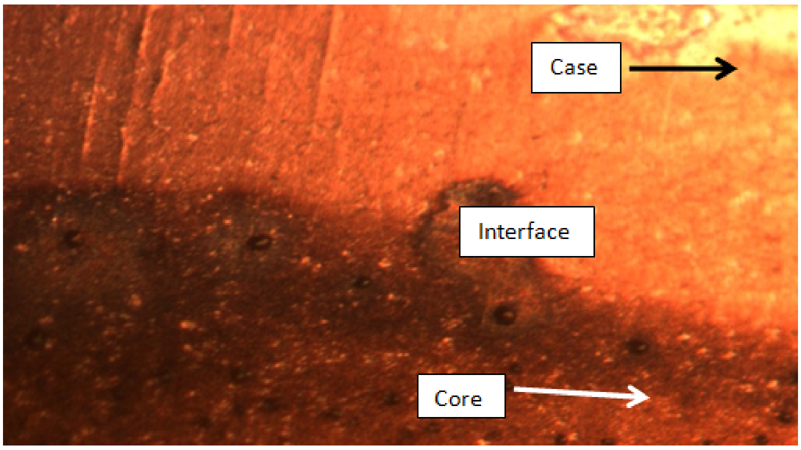

Figure 9: Sample H Carburized at 900°C held for 90 minutes, micro hardness 38.1 HR surface hardness 59.7 HR

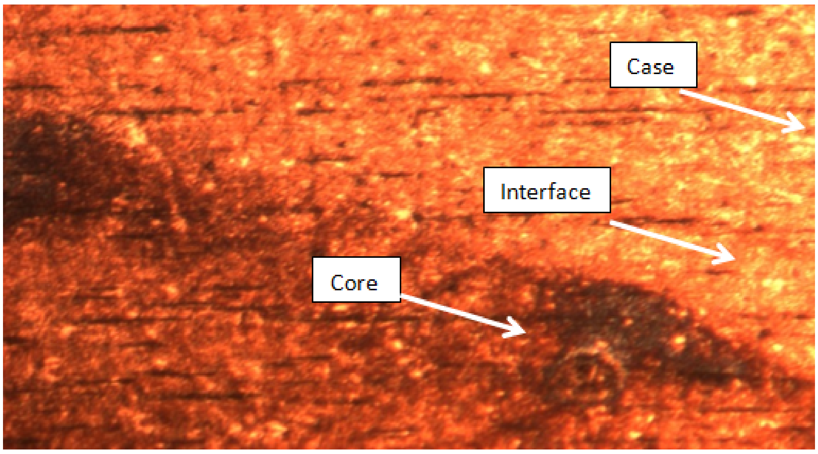

Figure 10: Sample I Carburized at 900°C held for 120 minutes, micro hardness 39.1 HR surface hardness 61.1 HR

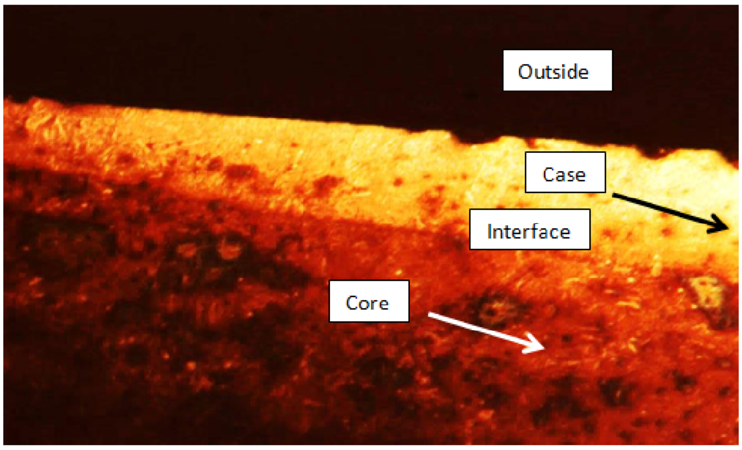

Figure 11 Sample J Carburized at 950°C held for 60 minutes, micro hardness 35.3 HR surface hardness 63.5 HR

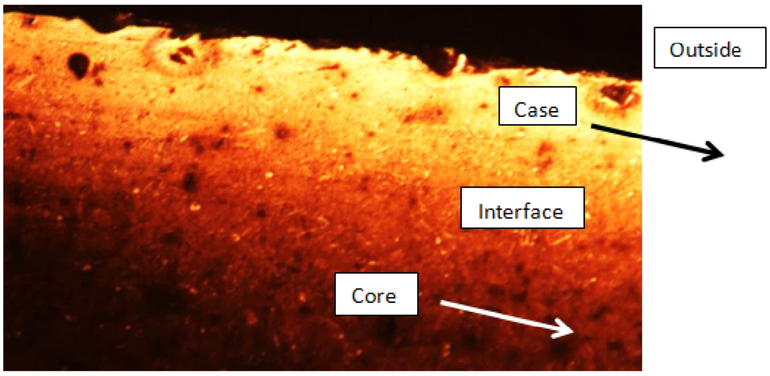

Figure 12: Sample K Carburized at 950°C held for 90 minutes, micro hardness 45.2 HR surface hardness 65.7 HR

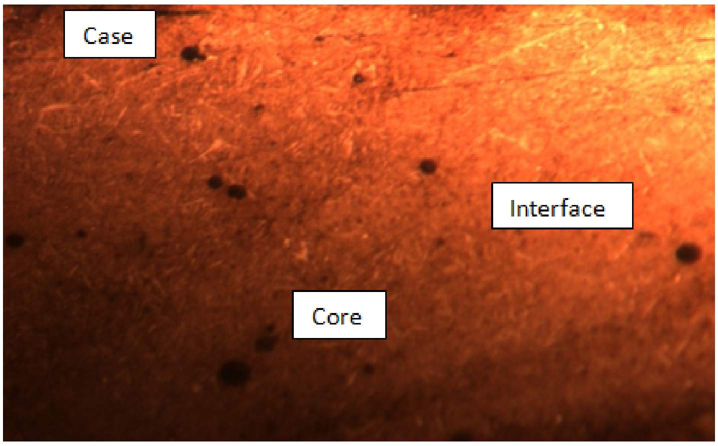

Figure 13: Sample L Carburized at 950°C held for 120 minutes, micro hardness 47.9 HR surface hardness 76.8 HR

3.4 DISCUSSION OF RESULT

The project utilized recycled steel (crankshaft and connecting rod) for casting using palm kernel shell as carbon additive to develop cutting tools of best optimum performance. During the selection of materials the composition analysis for carbon was 0.560 but after the melting of the materials their percentage drop to 0.450 as a result of oxidation reaction that took place during melting. Melt correction was done by adding alloying elements in its pure form to increase the percentage of carbon to 0.65 of HSS range. This result was in agreement with earlier reports as found in

Carburizing the samples enhance the modification of the microstructure and increase in its hardness, wear resistance of both surface and core layers of the cutting tool. The used of energizer Barium trioxocarbonate (v) ($BaC0_3$) in 20% proportion increased the rate of carbon penetration into the layers of the tools. It was observed in Table 5 that the sample carburized at 950^{o}C held for 120 minutes has the highest surface hardness of 76.8HR and micro hardness of 47.9HR, , this show that the higher the carburizing temperature with longer holding time the higher the hardness of both core and layer in agreement as in [10].

The micro- hardness (core) of the carburized samples are L>Control>>K>E>F>I>H>A>B>J>C> G>D while Surface hardness (case) are L>control>k>J>CI>H>G>F>E>D>C>B>A .The cutting tools developed has highest micro hardness and surface hardness that shown the significant of the tools produced in cutting operation. Increase in hardness value is effective as a result of palm kernel shell has enough proportion of carbon to penetrate into the layers of the tools. This agreed with research carried out as in[10].

It was observed that the sample carburized at 800^{o}C held for 60minutes as shown in figures 6, 19 and 20 having higher micro hardness than sample carburized at 800^{0}c held for 120 minutes, in this case low carburizing temperature with less holding time will some cases have higher hardness than with more time if the amount of carbon in the carburizer and energizer has been exhausted, in such case prolonging the holding time at higher temperature may not much significant effects on the cutting tool.

Metallographic studies of the samples of cutting tools shown in Figures 1 to 13 represent the micro structural analysis of the twelve samples with one control it can be observed from the result that the interface in each micrograph depicts the boundary across which the carbon diffusion travels from the case to the core.

The hardness and strength of martensite structure increased sharply with increase in carbon content. Contribution to the strength arises from the carbon in solid solution, carbides precipitated during the quench, dislocations introduced during the transformation, and the grain size. Fig 18 gave clear traits of diffusion of carbon into the center of the sample which led to increased volume fraction of carbides that formed in the material. This is also responsible for the highest micro-hardness and surface hardness of 47.9 HR and 76.8 HR respectively as established in [4].

The volume of carbide here is highest in sample L. Hence sample L is the choice sample because it has the best combination of treatment parameters and can be recommended for use in tools steel applications. More diffusion of carbon into the center of the sample C which led to increase in volume fraction of carbides which were formed in the material. This is also responsible for a higher surface hardness of 52.3 HR. The volume of carbide here is more than in sample B [2].

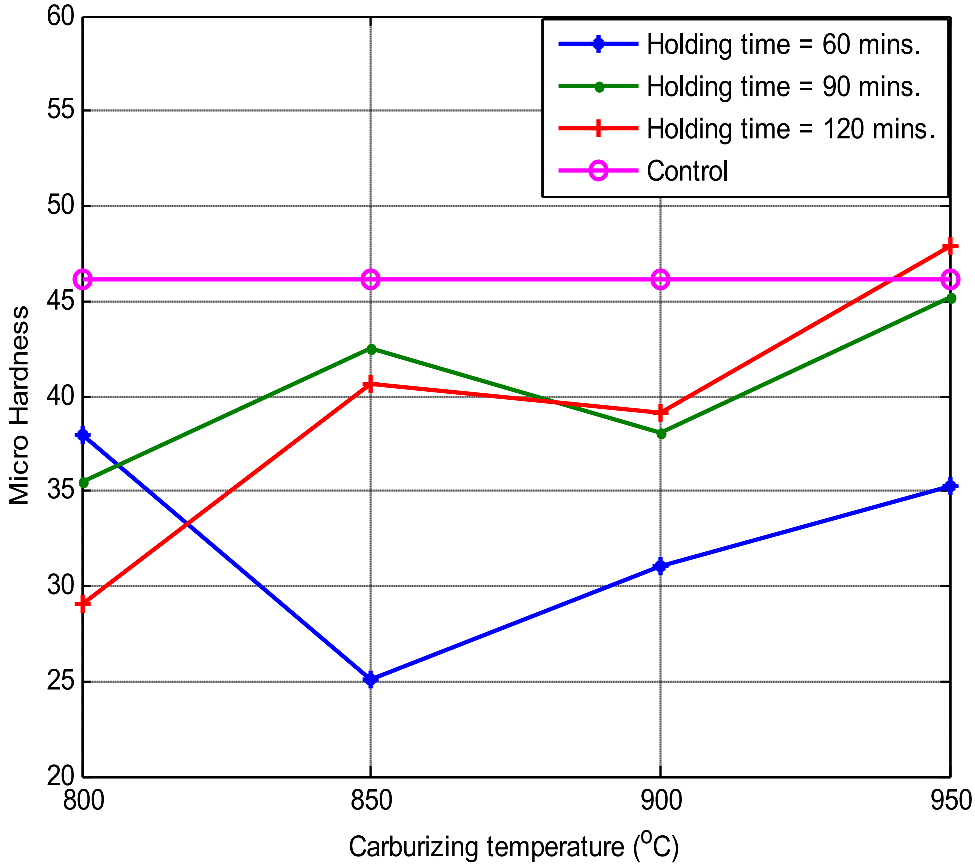

Figure14: Effects of holding time and carburization temperature on the material micro hardness at 10 minutes machining time

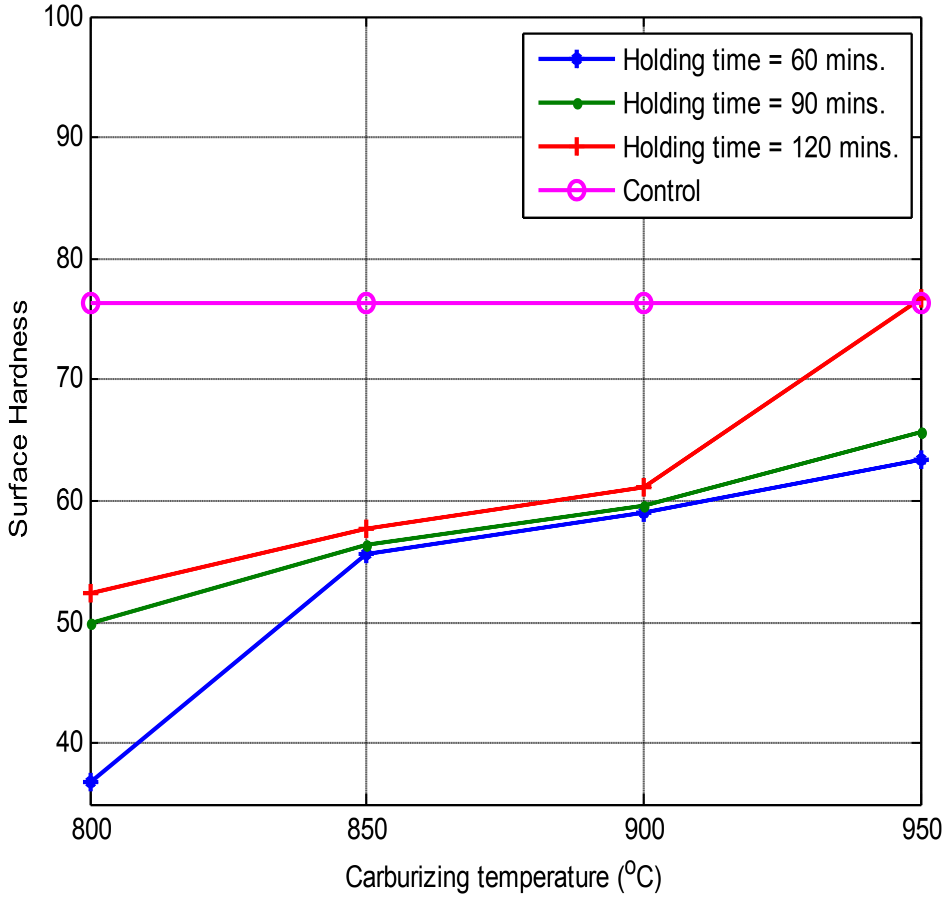

Figure 15: Effects of holding time and carburization temperature on the material energy absorbed at 10 minutes machining time

4 Conclusion

Production of cutting tools from recycled steel using palm kernel shell as shown a significant improvement in hardness and wear resistance with highest micro-hardness and surface hardness of 47.9 HR and 76.8 HR over the imported type (HSS).

The simulation of the model gave the best optimal cutting tools parameters which were applicable in the production of the cutting tools especially in the area of selection of materials, melt correction, casting, carburization and experimental analysis. The carburized mild steel showed higher value in hardness, wear resistance and tensile strength with better performance in cutting operation as cutting a tool. The ability of the developed cutting tool to cut low and medium carbon steel materials indicates the value of high speed in the steel metal. The hardness and strength of martensile structure increased sharply with increase in carbon content as a result of carbides precipitated during the quenching with oil that introduced dislocation during the transformation.

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