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PARAMETRIC ANALYSIS OF THE EFFECTS OF CARBURIZING PROCESS ON THE MECHANICAL PROPERTIES OF CARBURIZED MILD STEEL

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ABSTRACT
The suitability of using palm kernel shell, and animal bone (cattle bone) materials as carburizers for case hardening of 0.078%C mild steel was evaluated in this work. The mild steel sample used in this study sourced from universal steel company, Ikeja Lagos Nigeria was cut into suitable sizes using hacksaw machine for tensile and hardness tests. The carburizing media used were milled into fine powder while barium trioxocarbonate (vi) ($BaCO_3$) was used as an energizer in the carburizing process. The carburizing temperatures varied between 700 - 1100^{0}C while the holding time varied between 1-5 hours. The boxes and its contents were allowed to cool down to room temperature in the furnace after carburization. All samples were heated to 850^{0}C after been soaked for 30 minutes at this temperature and oil quenched. Ten (10) of these samples were further tempered at 350^{0}C for 2hours to relieve the stress built up during quenching. Hardness test,and tensile strength tests were carried out on the samples. Observations shows that the hardness values of the untempered samples are superior to the tempered ones at carburizing temperatures of 700^{0}C, 800^{0}C and 900^{0}C. Conversely, the tensile strengths of the tempered samples are higher relative to the untempered samples at carburizing temperatures of 700^{0}C, 1000^{0}C and 1100^{0}C. The results of the carbon analysis show that palm kernel shell and animal bone are potentially suitable to be used as a carburizing media at high temperatures (above 1000^{0}C) with holding time above 1 hr.

KEYWORDS: Carburizers, Hardness, Tensile, Carburizing Time and Temperature.

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INTRODUCTION

Many different types of heat treatment processes are used to modify the surface and structural properties of engineering components as reported by Child (Child, 1980). The engineering of surfaces of components to improve the life and performance of parts used in automobiles and aerospace is an active area of research. Suitable thermal / mechanical / thermo mechanical surface engineering treatments are known to produce extensive re-arrangements of atoms in metals and alloys and a corresponding marked variation in physical, chemical and mechanical properties. Among the more important of these treatments are heat treatment processes such as immersion hardening, induction hardening and case carburizing as studied by Child (Child, 1980). The service condition of many steel components such as cams, gears and shafts make it necessary for them to possess both hard and wear-resistant surfaces at the same time with tough and shock-resistant cores. In plain carbon steels, these two different sets of properties exist only in alloy steels. Higgins (Higgins, 1991) reported that low carbon steel, containing approximately 0.1 %C, will be tough and soft, whilst a high carbon steel of 0.8%C or more will be hard and brittle. Case carburizing involved the diffusion of carbon into the surface layers of low carbon steel by heating it in contact with a carbonaceous material. The principle of case hardening was used centuries ago in the conversion of wrought iron to steel by 'the cementation process. This ancient case hardening process make use of the fact that carbon will diffuse into the iron provided the iron is in the Face Centered Cubic (FCC) gamma form which exists above 910°C. Prime, *et al.*, Prime *et al*, (2003) reported that carburizing is one of the most commonly performed steel heat treatments. Over the years it was performed by packing the low carbon wrought iron parts in charcoal, then raising the temperature of the pack to red heat for several hours.

The entire pack, charcoal and iron parts, was 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. Craig (Craig, 2006) defined carburizing as a diffusion controlled process, so the longer the steel is held in the carbon-rich environment, the greater the carbon penetration will be and the higher the carbon content. The carburized section will have carbon content high enough so that it can be hardened again through flame or induction hardening. The objective is to produce a hard, wear-resistant case which will be resistant to both bending and contact fatigue whilst still maintaining its toughness and ductility of the low carbon core as studied by Stephen and Edward (Stephen and Edward, 1991).

Surface hardening processes are influenced by heat treatment temperature, rate of heating and cooling, heat treatment period, quenching media and temperature as investigated by Schimizu and Tamura[6]. Post heat treatment and pre-heat treatment processes are the major influential parameters, which affect the quality of the part surface hardened. Harden ability is essentially the ease of forming martensite and reflects the ability of steel to be hardened to a specified depth as found in prior's works of Kirkaldy and Feldman (Schimizu and Tamura 1997 and Rudnev*et al*, 2003). While Rakhit, Rudnev*et al.* and Smith (1993), studied the factors that increase hardenability and they found those factors as dissolved elements in austenite (except CO), coarse grains of austenite, and homogeneity of austenite. Automobile components such as rack and pinion, gears, cam, valve, rocker, shafts and axles, which require high fatigue resistance, are normally case hardened by carburizing. The carburizing furnaces are either gas fired or electrically heated. The carburizing temperature varies from 870 to 940 °C while the gas atmosphere for carburizing is produced from liquid or gaseous hydrocarbons such as propane, butane or methane as reported by Rajan, *et al*., (1994). The study of process parameters in metals during heat treatment studied by Denis (1987), Leblond (1989), Wang, *et al*., (1997) and Liu, *et al*., (2003) has been of considerable interest for some years but there has been relatively little work on process variables during the surface hardening process reported by Xu and Kuang (1996) since controlling parameters in carburization is a complex problem as stated by Aramide, *et al*. (2009). The major influencing parameters in carburization are the holding time, carburizing temperature, carbon potential and the quench time in oil as reported by Shewmon (1963).

EXPERIMENTAL METHODOLOGY

The as-received mild steel rod of 16 mm diameter was analyzed using spectrometric analyzer and it chemical composition is shown in Table 1. The various carburizing media – palm-kernel shell, and animal bone were obtained and pulverized in ball milling machine into fine powder to increase the surface area. Two stainless steel boxes were fabricated to accommodate the carburizing media, as-received mild steel rod samples, and the energizer ($BaCO_3$) of 65% purity level. These mild steel rods were cut and machined into tensile and hardness tests pieces. The surfaces of the samples were polished into mirror-like before the carburization process began. The fabricated stainless steel boxes have its density as 700g/cm^3. The weight of the carburizer was calculated from the volume of the container used and a known weight of each of the carburizer was packed into the stainless steel box with 20 wt % of Barium trioxocarbonate (vi) salt ($BaCO_3$). The 20 wt % $BaCO_3$

Table 1: Chemical Composition of Mild Steel Rod

Element	C	Ca	Zn	Si	S	P	Mn	Ni	Cr	Mo	V	Cu	W	As	Sn	Al	Co	Fe
% comp	0.078	0.0001	0.005	0.15	0.06	0.05	0.58	0.13	0.11	0.02	0.001	0.38	0.007	0.005	0.04	0.003	0.01	98.24

is 140g and was thoroughly mixed with each carburizer in each of the boxes. The $BaCO_3$ act as energizer and also promotes the formation of carbon (iv) oxide (CO_2) gas, which in turns react with the excess carbon in the media to produce carbon (ii) oxide (CO). This CO reacts with the low carbon steel surface to form atomic carbon which diffuses into the steel. Then the prepared samples were buried completely in the palm kernel shell, and animal bone in the respective boxes. The two boxes contained the carburizing powder and the steel samples were placed in the heat treatment chamber of the heat treatment furnace show in (1a), where they were heated to predetermined temperatures and held at these temperatures for a predetermined time as shown in Table 2. At each temperature and holding time, the furnace was allowed to cool down before the samples were all removed. Hardening treatment was carried out on all the samples by heating them to a temperature of 850^0C for 30 minutes and then quenched in oil. The oil quenchant physical properties are shown in Table 3.

Table 2: Pack Carburizing Processes Done At Different Temperatures and Times

Treatment temperature (°C)	700	800	900	1000	1100
Holding time (hrs)	5	4	3	2	1

Ten (10) of these quenched samples were tempered at 350^0C for 2 hours to relieve internal stresses built up during quenching and to increase the toughness of the specimens while the remaining 15 samples were untempered after hardening.

Table 3: Typical Characteristics of the Quenching Oil

Characteristics	Values
Viscosity of cSt @ 40 °C	14.0
Viscosity of cSt @ 100 °C	3.2
Viscosity of SUS @ 100 °F	74
Viscosity of SUS @ 210 °F	37
Flash Point, °C/ °F	173/343
Ramsbottom Carbon Residue, Mass%	0.2
Quench Time, seconds	
Nickel Ball	16
Chromized Nickel Ball	19

Chemical Analysis

The chemical analysis of the as-received mild steel samples and after carburizing processes were carried on the carburized mild steel by sparking using spectrometric analyser. The results were shown in Tables 1 and 4.

		% carbon at Various Tempering Temperature (^{0}C)				
S/No	Carburizer	700	800	900	1000	1100
1	Palmkernel Shell	0.004	0.066	0.102	0.151	0.53
2	Animal Bone	0.078	0.084	0.127	0.131	0.425
Sample as received: 0.078C						

Mechanical Test

In each case, test was conducted on two test samples and the mean value was taken. The tensile tests were performed on various tensile samples using Tensometer. The fracture load for each sample was noted as well as the diameter at the point of fracture and the final gauge length. The initial diameter and initial gauge length for each sample was noted before applying load. The sample was subjected to uniaxial load, at a fixed crosshead speed of 10 mm/min. This test was performed in accordance with standard used by Aramide*et al.*, [17].Rockwell hardness test was carried out on carburized, tempered mild steel samples. For each of the sample case the test was conducted 3 times andthe average value was taken. The test was performed in line with Oyetunji and Alaneme [19] previous work.

RESULTS

The mechanical tests results are as presented in Figures (1-4).

DISCUSSION

From the hardness responses shown in Figures 1 and 2 the tempered samples have values which are inferior to the untempered ones at 700^{0}C, 800^{0}C and900^{0}C. This is because tempering reduces the hardness and increases the toughness of the samples. The tensile strength results shown in Figures 3 and 4 revealed that samples carburized at 700^{0}C, 1000^{0}Cand 1100^{0}C in palm kernel shell carburizer have the tensile strength values for the tempered samples which are higher than the untempered ones due to increase in toughness resulting from tempering. While for animal bone carburizer, the steel samples show improved tensile strengths at 700^{0}C over untempered samples. Thus at higher temperature the tensile strengths of samples in the animal bone carburizer declines.

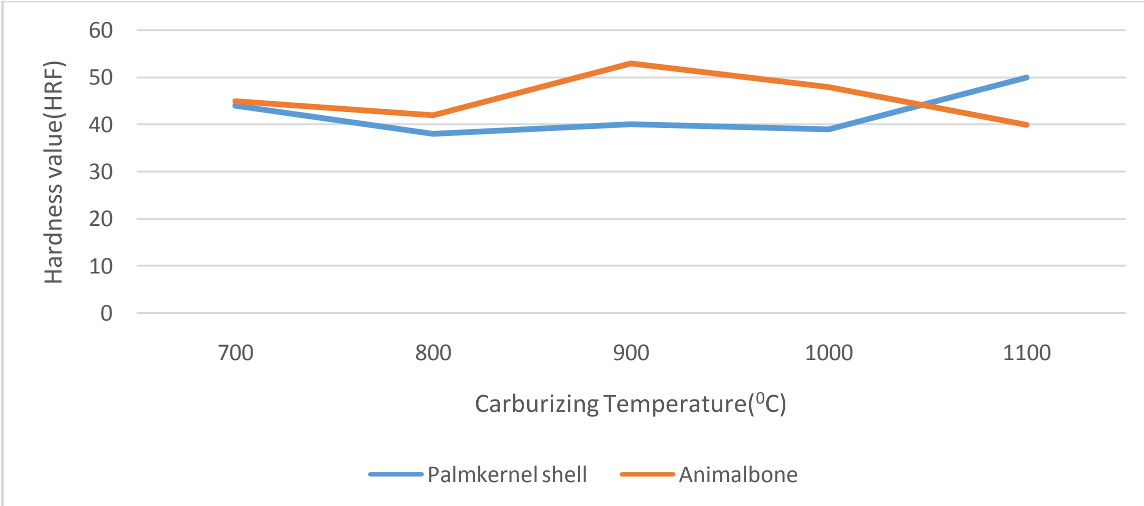

Figure 1: Hardness responses of quenched and tempered samples with carburizing temperature.

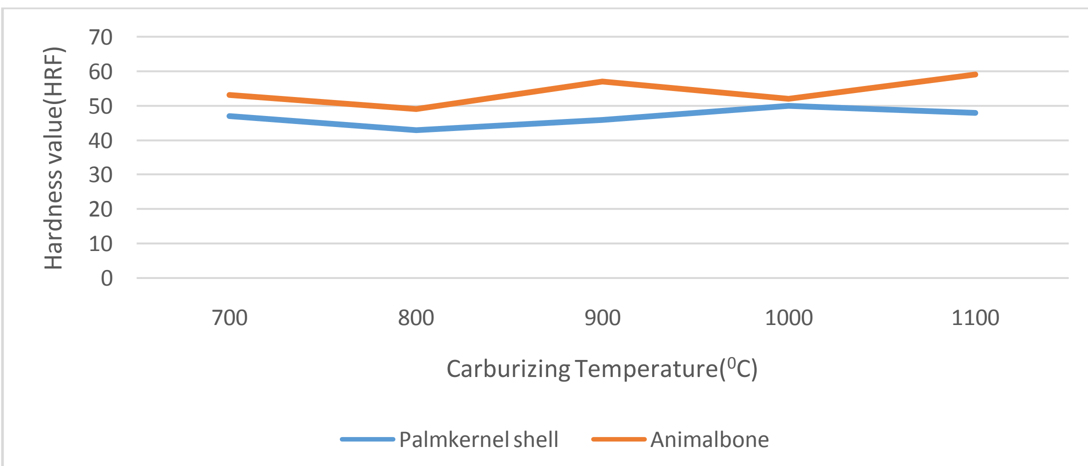

Figure 2: Hardness responses of quenched and untempered samples with carburizing temperature.

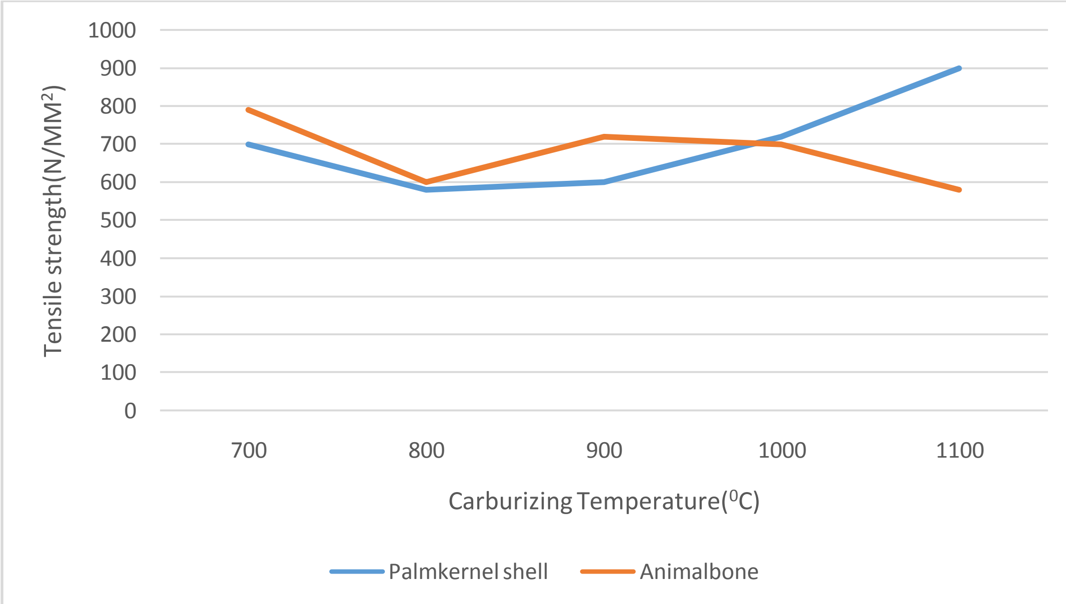

Figure 3: Tensile strengths of carburized, quenched and tempered steel samples with carburized temperature.

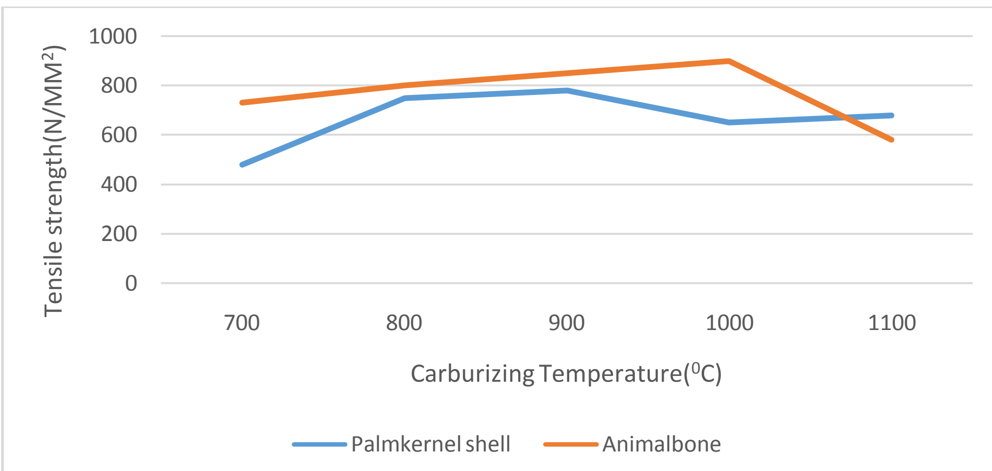

Figure 4: Tensile strengths of carburized, quenched and untempered steel samples with carburizing temperature.

The result of the chemical analysis shown in Table 4 indicates that only palm kernel shell and animal bone have the potential to be used as carburizing media. These carburizers show considerable increase in percentage carbon released into the steel sample matrix at 900^0C, 1000^0C and 1100^0C when compared to carbon percentage of the as-receive samples. The presence of martensite in quenched steel, while greatly increasing its hardness and tensile strength, causes the material to be brittle as its formation is accompanied by severe matrix distortions. 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 (Stephen and Edward, 2008). The quenching stresses can be relieved and some of the carbon can precipitate from the super saturated solid solution to a finely dispersed carbide phase, through careful controlled tempering treatment. In this way, the toughness of the steel can be vastly improved with very little detriment to its hardness and tensile properties. The properties of the tempered steel are primarily determined by the size, shape, composition and distribution of the carbide that forms with a relatively minor contribution from the solid solutions hardening of the ferrite. These changes in microstructure usually decrease hardness, tensile strength and yield strength but increase ductility and toughness (Stephen and Edward, 2008).

CONCLUSIONS

The following deductions can be made from the results obtained:

- The hardness of the untempered samples carburized in palm kernel shell and animal bone showed higher values than the tempered samples.
- Palm kernel shell and animal bone carburizers have good potential to be used as a carburizerfor mild steel.
- The tensile strengths of the samples carburized in powdered palm kernel shell at 1000^0C and1100^0C and tempered showed higher values than the untempered ones.
- For the samples carburized using powdered palm kernel shell and animal bone, the carbon content in solid solution increases as temperatures increased from 800^0C-1100^0C.

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