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EFFECTS OF ADDITION OF CARBON BLACK TO PALM KERNEL SHELL AS CARBURIZER ON THE MECHANICAL PROPERTIES AND CASE STRUCTURE OF LOW CARBON STEEL

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Abstract: This study investigated the influence of the addition of carbon black to palm kernel shell, as the carburizing media, on the mechanical properties and case structure of low carbon steel. The particle size of the carburizers used was 150 µm. Various compositions of the carburizing media were used, and carbon black was added to palm kernel shell to a maximum of 10 wt% of the total weight of the carburizer. For each composition, 20 wt% of calcium carbonate was added as energizer. Samples for tensile test, hardness test and microstructural examination were carburized at 950^{0}C for 3 hours. The samples were then tempered at 450^{0}C for forty minutes. The best combination of mechanical properties was obtained for the sample carburized with 95 wt% palm kernel shell and 5 wt% carbon black.
Keywords: low carbon steel, carburization, palm kernel shell, carbon black, mechanical properties

INTRODUCTION

Low carbon steel, also known as mild steel, has carbon content of less than 0.30% [1]Typical applications of low carbon steel are in: rivets, seam welded pipes, structural steels, plates, nuts, screws, bolts, sheets, and parts of machines which do not demand high – strength requirement [2, 1]. When the carbon content in a steel is varied, in conjunction with using a suitable heat-treatment method adequate for that particular amount of carbon, a myriad of mechanical properties can be obtained. No other metallic alloy has this unique feature of carbon steel. In addition, carbon steel in comparison with non-ferrous alloys, is not expensive, thus steel is largely the most important engineering alloy [2].

Steel undergoes heat treatment in order to harden it, and to increase its strength, ductility and toughness. The carbon content and the intended use of the steel determine the kind of heat treatment the steel will undergo (Higgins, 1993). The types of heat treatment are as follows: normalising, tempering, annealing, isothermal transformations and hardening [2, 3].

Carburization is the process of adding carbon to the exterior of low-carbon steels mainly at temperatures of between 850^{0}C and 980^{0}C [4]. Within this temperature range, austenite which has high solubility for carbon, is the crystal structure which is stable. Hardening is obtained by quenching the high-carbon exterior of the steel to form martensite. Thus, the martensitic case which has high carbon content (having good wear and fatigue resistance) is laid over a tough core that is low in carbon content [5, 4] .The carburizing method used may be solid, liquid or gaseous [5, 2, 4]. These methods have their merits and demerits [5, 4], and the kind and extent of the work to be done by the metal will determine the best carburizing method to be used [2]. The most frequently used method for high-volume production is gas carburizing, since it is precisely regulated and needs much reduced special handling [5, 4] .

Researchers have investigated the use of cheap and locally available carbonaceous materials as carburizing agents in pack carburization.

[6] experimentally studied the effect of coal, bone charcoal and wood charcoal on the hardness, tensile strength and impact strength of mild steel. He found out that each carburizing medium increased the hardness and tensile strength of mild steel with carburizing time, while each medium decreased the impact strength of mild steel with carburizing time. The results of the hardness tests he obtained had reasonable agreement with those available in literature. He suggested that with the addition of energizers to the local carburizing media, better results could be obtained in less time. He further reported that wood charcoal gave the highest values of mean hardness and mean tensile strength, while coal gave the least values. [7] studied the effect of the variation in carburizing temperature and time on the mechanical properties of mild steel quenched in oil, and tempered at 550^{0}C for one hour. For their experimental conditions, they reported that the best blend of mechanical properties was obtained at carburizing temperature and time of 900^{0}C and 30 minutes respectively, with quenching in oil and tempering for an hour at 550^{0}C following the carburization process.

[8] studied the effect of varying carburizing temperature and carburizing time on the mechanical properties of mild steel using pulverized bone as carburizer. They reported a strong connection between the properties and carburization process, carburization temperature and soaking time at a particular temperature. In particular, they noted that the best results were obtained for the samples carburized at 900^{0}C and 15 minutes, and at 850^{0}C and 30 minutes, as they both had a hard case with a softer core.

[9] investigated the effects of using graphite, charcoal, palm kernel shell and mixed carburizer on the case hardness of low carbon steel. Impact tests and microstructural examination were also conducted on the steel samples. The sample

carburized with palm kernel shell had the highest hardness value, while that carburized with graphite had the highest impact energy. [10] investigated pack carburization of mild steel using seashell, palm kernel shell and animal (cow) bone in the temperature range of 700 to 1100^{0}C. They reported that palm kernel shell and animal (cow) bone were better carburizing media compared to seashell. [11] studied pack carburization of mild steel using charcoal with bone as energizer. The compositions of the carburizing compounds that were used were 100 wt% charcoal, 75 wt% charcoal/25 wt% cowbone, 70 wt% charcoal/30 wt% cowbone and 60 wt% charcoal/40 wt% cowbone. The best hardness value reported was for the 60 wt% charcoal/40 wt% cowbone composition. [11] set out to determine whether egg shell waste could be used as an energizer using sugar case waste, aracaceae flower droppings and melon shell as the carburizing media. They concluded that egg shell waste was a good energizer as it increased the hardness values of the samples, as compared to when the samples were carburized without it. [12] conducted experimental investigation on the effectiveness of locally available carbonate minerals as energizers in pack carburization of mild steel using charcoal as the carburizing medium. The minerals they studied were marble, limestone and dolomite, and they compared the efficacy of these minerals with that of barium carbonate. They reported that marble or limestone is a suitable replacement for most of the barium carbonate used as energizer in pack carburization of mild steel. They showed that the best result, in terms of effective case depth and relative efficacy of the energizer, was obtained using 15% marble and 5% barium carbonate. They noted that this composition of energizer seems to be more effective than using 20% barium carbonate. They reported that dolomite is not an energizer and that in fact, it seems to slow down carburizing action.

More research work is needed, especially in the comparative analysis of carburizing media, to determine suitable local carburizing media for pack carburization of mild steel. Palm kernel shell is a readily available waste product in Nigeria, and it has been shown to have a high carbon potential. However, its efficacy as a carburizing medium has not been extensively investigated. In this work, mild steel will be carburized using palm kernel shell with the addition of carbon black to a maximum of 10 wt% carbon black. 20 wt% calcium carbonate was used as energizer, since it has been shown in the literature to be effective, and is in abundant supply in Nigeria. The effects of various compositions of the carburizing media on the hardness, tensile properties and microstructure of mild steel will be studied

Table1. Chemical composition of the low carbon steel

Element	Al	Si	P	S	Ti	V	Cr
Composition (%)	0.1478	0.3113	0.0369	0.0025	0.9355	0.0097	0.1808
Element	Mn	C	Fe	Ni	Cu	As	Mo
Composition (%)	0.5071	0.14	97.4118	0.0865	0.1806	0.0032	0.0463

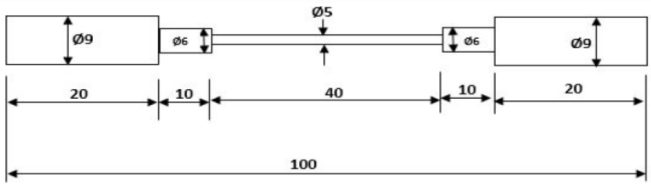

Figure 1. Dimensions of tensile test sample

MATERIALS AND METHODS

— Preparation of Samples

Palm kernel shells were obtained, washed and dried. Thereafter they were crushed with hammer mill, and pulverized using a ball mill. The powder was then sieved to particle size of 150 μm. Grade 330 carbon black was purchased and used for the work. A 10 mm mild steel rod was used for the work.

The chemical composition of the rod is presented in Table 1. Specimens for the tensile test were machined from the rod according to ASTM E8 (refer to Figure 1).

The samples for the hardness test and microstructural examination were also cut out. Four boxes measuring 120 x 30 x 30 mm were constructed using 5 mm thick steel plate. The composition of the carburizing media was measured out for each sample as shown in Table 2. For each composition of carburizer, 20 wt% of calcium carbonate, that is 20 wt% of the carburizer's total compositon, was included as energizer. The samples for the tensile and hardness tests and those for microstructural examination were buried in the carburizer and then the boxes were properly sealed.

Table 2: Compositions of the carburizing media used

Sample	Palm kernel shell powder (wt%)	Carbon black (wt%)	Calcium Carbonate ($CaCO_3$) wt%
1	100	0	20
2	90	10	20
3	95	5	20
4	99	1	20
5 (control sample)	0	0	0

— Carburization of the Samples

The sealed boxes were then placed in an electric heat treatment furnace and the temperature of the furnace was set to 950^{0}C. When the temperature of the furnace attained 950^{0}C, the time was taken. The samples were then held in the furnace on attainment of 950^{0}C for 3 hours. After this time, the samples were quenched in water at room temperature. Afterwards, the samples were tempered in the furnace at 450^{0}C for forty minutes, and were cooled in air at room temperature. The control sample (Sample 5) did not undergo heat treatment.

TESTS CONDUCTED

— Tensile Test

Uniaxial tensile tests were conducted on the tensile specimen according to ASTM E8 using an Instron Universal Testing Machine, at a strain rate of 10 mm/mm. Before beginning the tests, the gauge length and initial diameter of the specimens were entered into the software. The ultimate tensile strength, fracture strength, modulus of elasticity, percentage elongation and fracture load were determined for each of the specimens.

— Hardness Test

Hardness tests were performed using a digital Brinell hardness testing machine.

— Microstructural Examination

The microstructures of the cases of samples 1, 2 and 5 (control sample) were examined using a Phenom scanning electron microscope.

RESULTS AND DISCUSSION

The tensile test results of the samples are presented in Figures 2 to 6, while the hardness test results are presented in Figure 7.

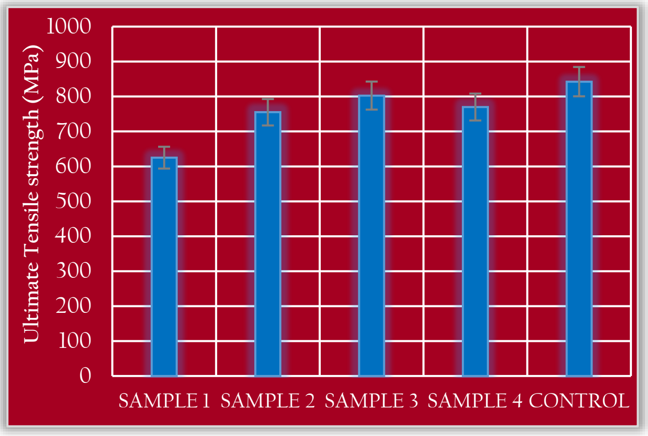

Figure 2: Ultimate tensile strength of the samples

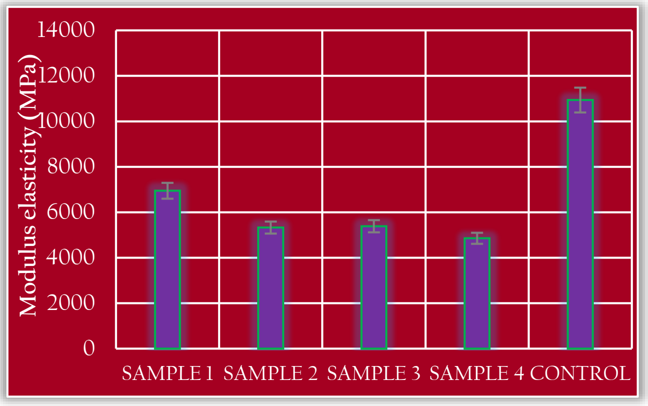

Figure 3: Modulus of elasticity of the samples

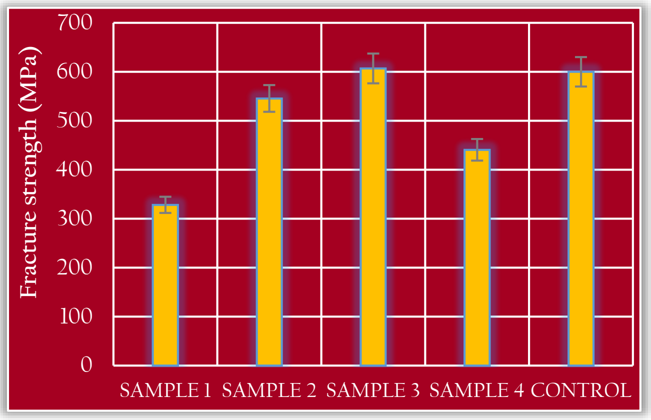

Figure 4: Fracture strength of the samples

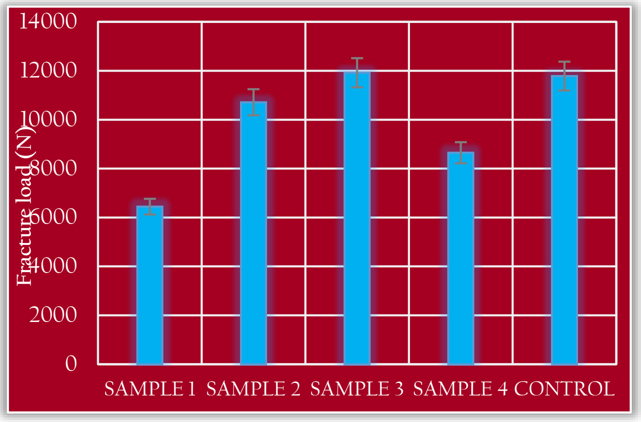

Figure 5: Fracture load of the samples

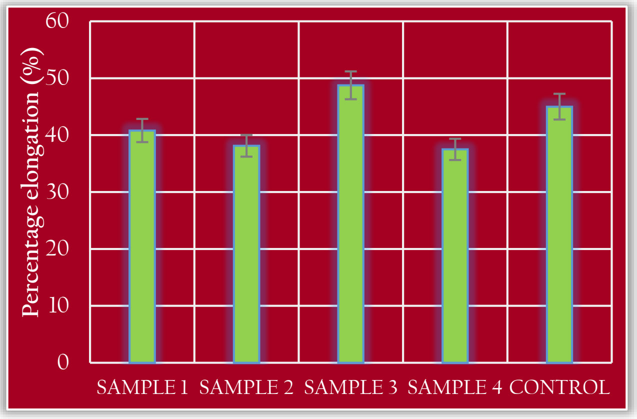

Figure 6: Percentage elongation of the samples

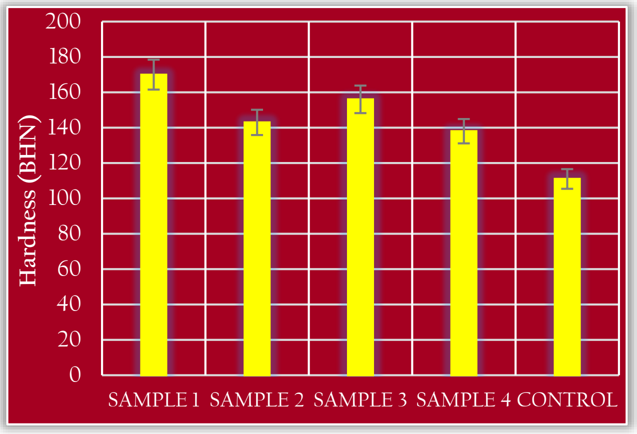

Figure 7: Hardness of the samples

From the results of the tensile test, it can be seen that generally there is a reduction in the values of the ultimate tensile strength and the modulus of elasticity of the heat-treated samples. This is due to the fact that the hardened steel was tempered [2, 1].

From Figure 2, there is a reduction in the ultimate tensile strength of the heat-treated samples. Also, there was a reduction in the modulus of elasticity of the heat-treated samples as shown in Figure 3. As expected, there was an increase in the fracture strength, the fracture load and the percentage elongation of the samples that were subjected to heat treatment. This is because tempering improves the toughness and the ductility of carbon steels [2, 13].

From Figure 7 it can be seen that the hardness values of the heat-treated samples increased significantly as compared to the control sample. This suggests that palm kernel shell is indeed a good carburizing medium as can be seen from sample 1 (Figure 7). From Figures 2 to 7, it can be seen that sample 3 had the highest values, compared to other heat-treated samples, of ultimate tensile strength, fracture strength, fracture load and percentage elongation. However, its modulus of elasticity and hardness values are lower than those of sample 1. Thus sample 3 has the best combination of tensile properties and hardness value.

The photomicrographs of samples 5, 1 and 2 are presented in Figures 8, 9 and 10.

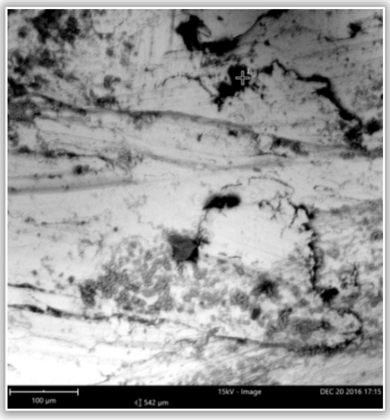

Figure 8: Photomicrograph of the case of sample 5 (control sample)

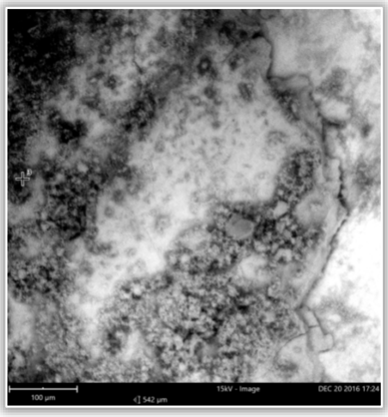

Figure 9: Photomicrograph of the case of sample 1

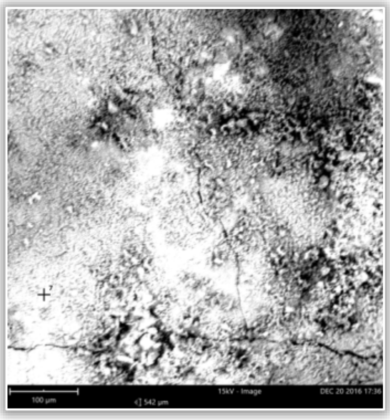

Figure 10: Photomicrograph of the case of sample 2

The photomicrograph of the control sample (Figure 8) shows the typical structure of mild steel, that is ferrite (light areas) and pearlite (black areas) [13, 14].

In Figure 9, coalesced globules of cementite can be seen in the ferrite matrix. Cementite was precipitated from the martensitic structure on tempering [2]; while Figure 10 shows a more even distribution of spheroid cementite in the matrix of ferrite.

The presence of cementite in Figures 9 and 10 indicates carbon enrichment of the steel surface. The ultimate tensile strength, fracture strength and fracture load of sample 2 are greater than those of sample 1 as seen from Figures 2, 4 and 5 respectively.

The modulus of elasticity and hardness of sample 2 are lower than that of sample 1 (Figures 3 and 7) while the percentage elongation of sample 2 is slightly lower than that for sample 1 (Figure 6). It appears that the addition of 10 wt% of carbon black to palm kernel shell increased its toughness.

From the results of this study, sample 3 gave the best combination of mechanical properties. This suggests that carbon black has some effects on the improvement of the mechanical properties of steels carburized with palm kernel shell.

CONCLUSIONS

The following conclusions can be drawn from this study:

- Palm kernel shell is a good carburizing agent as it has very high carbon potential, and gave the highest case hardness value.
- The addition of carbon black to palm kernel shell as carburizing media helps to improve the toughness of low carbon steel.
- The best combination of mechanical properties was obtained with a composition of the carburizing media containing 95 wt% palm kernel shell and 5 wt% carbon black.
- The findings of this work will be useful to the following companies in Nigeria: Integrated Steel PLC, Osogbo; Nigeria Machine Tools Limited, Osogbo; Ajaokuta Steel Company Limited, Ajaokuta; Delta Steel Company, Ovwian – Aladja as well as similar companies in Nigeria and across the world.

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