

# Effects of Carburization with Palm Kernel Shell/Coconut Shell Mixture on the Tensile Properties and Case Hardness of Low Carbon Steel

<sup>1</sup>Reginald Umunakwe, <sup>2</sup>Obinna C. Okoye, <sup>1</sup>Chioma I. Madueke and <sup>2</sup>Daniel O. Komolafe

<sup>1</sup>Department of Materials and Metallurgical Engineering, Federal University Oye-Ekiti, Ekiti State, Nigeria

<sup>2</sup>Department of Mechanical Engineering, Federal University Oye-Ekiti, Ekiti state, Nigeria

{reginald.umunakwe | obinna.okoye | chioma.madueke | daniel.komolafe}@fuoye.edu.ng

**Abstract** - The effect of using mixtures of palm kernel shell and coconut shell as carburizers for low carbon steel at 950°C on the tensile properties and case hardness was studied. The carburizers were washed, dried, milled and sieved to 150µm particle size. They were mixed in various compositions to serve as carburizers. In each composition, 20wt% of calcium carbonate (CaCO<sub>3</sub>) was added as energizer. Tensile and hardness specimens were machined from low carbon steel. Seven tensile and seven hardness specimens were subjected to pack carburization process with different compositions of the carburizers, and thereafter quenched and tempered at 450°C for forty five minutes in a heat treatment furnace. The tensile and hardness properties show that better properties were obtained with mixtures of the carburizers compared to the use of single carburizing agent.

**Keywords** - Carburization, Low carbon steel, Coconut shell, Palm kernel shell.

## 1 INTRODUCTION

Low carbon steel usually has carbon content less than 0.2%. Low carbon steel has wide applications in areas such as car body panels, tubes, plates, reinforcement for concrete, steel tanks as well as other engineering applications and therefore produced in millions of tones per year (Joseph, et al., 2015). Carbon steels are utilized because of their low cost, ease of fabrication, properties, availability and weldability (Electric Power research Institute, 2007). Low carbon steel is characterized by low tensile strength with little ductility and provides properties that are acceptable for many applications (Al-Qawabah, *et.al.*, 2012). Little variation in the percentage of carbon, heat treatments, materials fabrication, component fabrication and fabrication processes introduce significant differences in strength, hardness, ductility and other properties of low carbon steel (Electric Power research Institute, 2007).

According DIN EN 10052, heat treatment consists of heating and soaking a ferrous metal at specified temperature(s) followed by cooling in a specified manner in order to modify the properties and structure of the metal (European Committee for Standardization, 1993). Heat treatments may also modify the chemical composition of the metal (Brill and Schibisch, 2015). Heat treatment processes consist of thermal (annealing and hardening processes) and thermochemical (diffusion and coating processes) (Brill and Schibisch, 2015). Many heat treatments techniques are used to modify the surface and structural properties of steel ASM International, 1991).

The engineering of the surfaces of components so that they can meet the service requirements is an active research area. Various engineering methods are used for surface hardening of steels and surface hardening has advantage over through hardening because low carbon steel and medium carbon steel can be surfaced hardened with minimal distortion and cracking associated with through hardening of thick sections (Schneider and Chatterje, 2013). Case hardening techniques such as carburizing, boriding, nitriding, etc., are used to improve wears resistance by diffusion of carbon to the surface. DIN EN 10052 explains that carburization is a thermochemical treatment that is applied to ferrous metals in austenite state to allow carbon diffuse to the surface of the metal and thereafter the carburized metal is quenched hardened (European Committee for Standardization, 1993). The ferrous product is heated in a carbonaceous environment to allow carbon diffuse to its surface. Carburizing can take place in a gas, liquid or pack media. Usually, the surface of the product becomes very hard while the interior or "core" of the product retains the toughness of low carbon steel (Oyetunji and Adeosun, 2012).

The mechanical properties of carburized mild steel have been reported to be affected by process parameters such as soaking temperatures and time (Aramide, et al., 2009; Oyetunji and Adeosun, 2012; Aramide, et al., 2010; Ohize, 2009). Various researchers have reported that during carburization, improved properties are obtained between 900 and 950°C (Aramide, et al., 2009, Oyetunji and Adeosun, 2012).

\*Corresponding Author

Many researchers have worked on the utilization of local and cheap materials as carburizers for the case hardening of low carbon steel. Aramide, et al., (2009), investigated the use of activated charcoal as a carburizer to improve the mechanical properties of mild steel and reported that optimal mechanical properties are obtained at temperature of 900°C. Nukman and Chandra, (2013), compared the properties of mild steel carburized with charred goat bone and coconut shell and reported reduced tensile strength and impact energy as a result of carburization with these materials with a more significant reduction in the goat bone carburized mild steel (Nukman and Chandra, 2013). They however reported about 50% improvement in hardness of the goat bone carburized mild steel and 13% improvement in hardness of the coconut shell carburized mild steel (Nukman and Chandra, 2013).

Egg shell was used as an enhancer together with various agricultural wastes (sugar cane, melon shell and araceae flower waste) as carburizers to improve the hardness of mild steel and in each specimen; the hardness was higher when egg shell was mixed with each agricultural waste with the highest hardness of 57HRC obtained with a mixture of araceae flower wastes and egg shells (Ihom, et al., 2013). Oyetunji and Adeosun, (2012) studied and proposed the utilization of animal bone and palm kernel shell to be used on mild steel. It was also reported that palm kernel shell can be used to improve the hardness of mild steel over charcoal and graphite (Alagbe, 2011). Further study was carried out on case hardening of mild steel with a mixture of cow bone and charcoal and it was concluded that a mixture of 60wt% charcoal and 40wt% cow bone improved the hardness of carburized mild steel better as the case depth is higher compared to the mild steel samples carburized with 100wt% charcoal, 70wt% charcoal and 30wt% cow bone, 75wt% charcoal and 25wt% cow bone (Ihom, 2013).

There is still room for further research on the pack carburization of low carbon steel using local carbonaceous materials. The utilization of the mixture of various materials has not been studied extensively. Since coconut shell and palm kernel shell have been reported to have good potential for carburization of mild steel, we therefore evaluated the effect of using various mixtures of these materials as carburizers on the tensile and hardness properties of low carbon steel.

## 2 MATERIALS AND METHODS

### 2.1 Samples Preparation

Palm kernel shell and coconut shell were collected from the local market, washed, dried, crushed with hammer mill, pulverized with a ball mill and sieved to 150µm particle size. 10mm low carbon steel rod with the chemical composition shown in Table 1 was purchased from the open market at Ikole-Ekiti, Nigeria. Tensile specimens were machined from the steel sample in accordance with ASTM E8 with gauge diameter of 5mm and gauge length of 40mm as shown in Fig. 1.

Also, specimens for hardness tests were machined out. The calculated compositions of the carburizing ingredients for each specimen shown in Table 2 were weighed out with a digital weighing balance and mixed together. In each mixture, 20wt% calcium carbonate (CaCO<sub>3</sub>) (20wt% of the composition of the carburizer) was added as energizer to facilitate the dissolution of the carbon in the austenite phase (Okongwu and Paranthaman, 1987). The various mixtures were packed in 5mm thick steel boxes of dimensions 120x30x30mm and covered properly. Each box contained the three specimens for tensile tests and hardness tests and buried in specific composition of the carburizing ingredients shown in Table 2.

Table 1: Chemical composition of the mild steel sample

Element	C	Si	Mn	S	Ni	Cu	Cr	Co	Ca
Average content (%)	0.16	0.118	0.53	0.055	0.026	0.19	0.0622	0.009	0.0001
Element	Al	Sn	W	P	Mo	V	As	Zn	Fe
Average content (%)	0.0027	0.039	0.0053	0.04	0.0016	0.0012	0.0039	0.006	98.75

Table 2: Compositions of the Carburizing Agents Used

Specimen	Palm Kernel Shell Powder (Wt%)	Coconut Shell Powder (Wt%)	Calcium Carbonate (Wt%)	
1	100	00	20	
2	50	50	20	
3	70	30	20	
4	80	20	20	
5	30	70	20	
6	20	80	20	
7	00	100	20	
Control (Not heat treated)		00	00	00

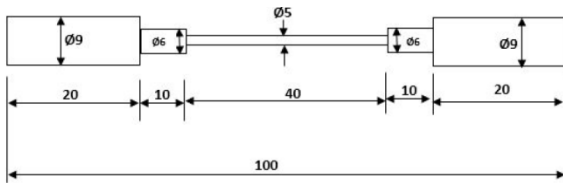


Fig 1: Dimensions of machined tensile test specimen

## 2.2 Carburization of Samples

The seven boxes (specimens 1-7) containing the carburizing powders and the steel samples were placed in the chamber of an electric heat treatment furnace and the temperature rose to 950°C and held for three hours. Thereafter, the steel samples were quenched in water at room temperature and tempered in the furnace by heating them to 450°C, held for forty minutes and brought out to cool in open air at room temperature. The control specimens (sample 8) were not subjected to heat treatments as they served as control to study the effects of carburization.

## 2.3 Mechanical Test

### 2.3.1 Tensile Test

Uniaxial tensile tests were performed on various tensile samples in accordance with ASTM E8 at a strain rate of 10mm/mm using software driven Instron Universal Testing Machine (UTM) connected to a computer. The gauge length and initial diameter of each sample were inputted into the UTM software prior to the commencement of the test and the fracture loads, elongation at break, ultimate tensile strength, modulus of elasticity, percentage elongation and other mechanical properties were measured for each specimen and reported. In order to ensure the reliability of the results, the tensile tests were repeated two more times for each specimen and the average values were reported.

### 2.3.2 Hardness Test

Rockwell hardness tests were carried out on the carburized and tempered samples as well as the control sample to measure the case hardness. For each sample, the indentations were done at three different locations of the case and the average calculated and reported.

## 3 RESULTS AND DISCUSSION

The results of tensile tests are as shown in Figures 2-6 and case hardness (Rockwell, HRA) of the various specimens are shown in Figure 7. In a previous report, coconut shell was reported to increase the carbon content at the surface of low carbon steel after carburization by about 69% as carbon diffused into the steel surface from coconut shell (Nukman and Chandra, 2013). Also, between 900 – 1000°C, carbon has a high tendency to diffuse into steel from palm kernel shell (Oyetunji and Adeosun, 2012). It is expected that the tensile strength of steel will reduce while the ductility will increase after tempering (Fadara, et al., 2011).

The tensile strengths of the specimens are shown in Figure 2. It is observed that the tensile strength increases with more weight percent coconut shell in the carburizing mixture. It appears palm kernel shell must be added to coconut shell to obtain substantially higher values of tensile strength as specimen 7 had lower value of tensile strength compared to specimen 6. Palm kernel shell could be acting as enhancer to make the carburizing effect of coconut shell more marked as can be seen from the result of specimen 6 in Figure 2. The value of tensile strength obtained with 100wt% palm kernel shell carburizer corresponds with the value earlier reported by Oyetunji and Adeosun (2012). It was observed that the best improvement in strengths was obtained with 80wt% of coconut shell and 20wt% of palm kernel shell mixture as carburizers (specimen 6) as shown in Figures 1, 4 and 5.

The modulus of elasticity is a measure of stiffness. The reduced modulus of elasticity of the carburized samples compared to the uncarburized mild steel shown in Figure 6 was due to tempering. Specimen 1 which was carburized with 100% palm kernel shell exhibited the lowest elastic modulus as shown in Figure 6, and this corresponds to the higher percentage elongation exhibited by specimen 1 as shown in Figure 3. The other

specimens carburized with mixture of coconut shell and palm kernel shell did not exhibit the degree of reduction in elastic moduli as observed in the specimen carburized with 100wt% palm kernel shell. The case hardness (Rockwell, HRA) of the various specimens are shown in Figure 7. The diffusion of carbon from the carburizers to the steel resulted to improved hardness of the carburized specimens over the control sample. Specimen 6 carburized with mixture of 80wt% coconut shell and 20wt% of palm kernel shell also exhibited the highest case hardness as shown in Figure 7.

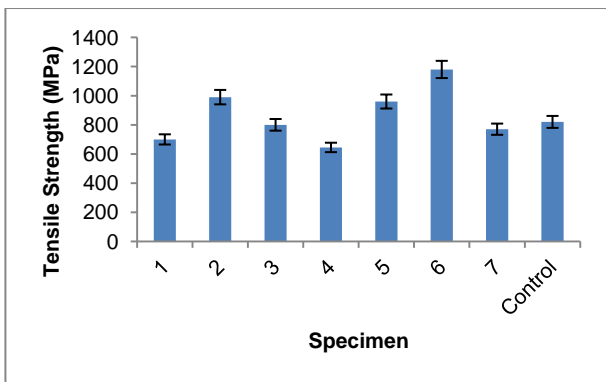


Fig 2 Tensile strengths of various carburized & tempered samples.

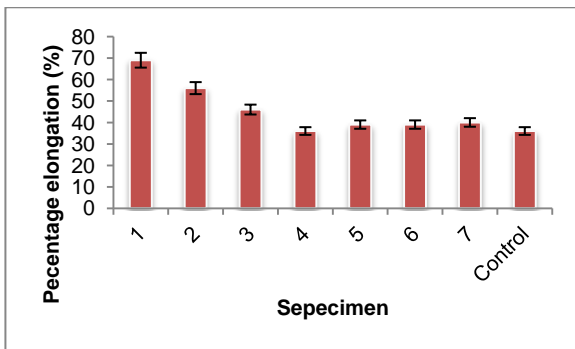


Fig 3 Percentage elongations of the various carburized and tempered samples

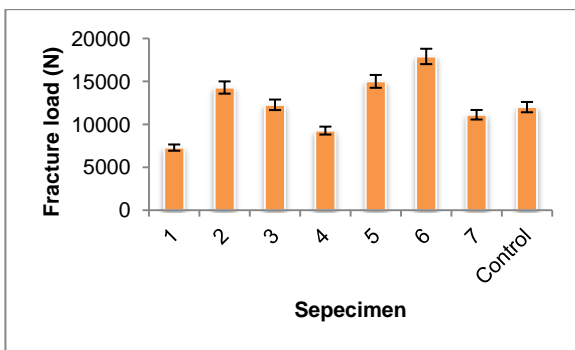


Fig 4 Fracture loads of the various carburized and tempered samples.

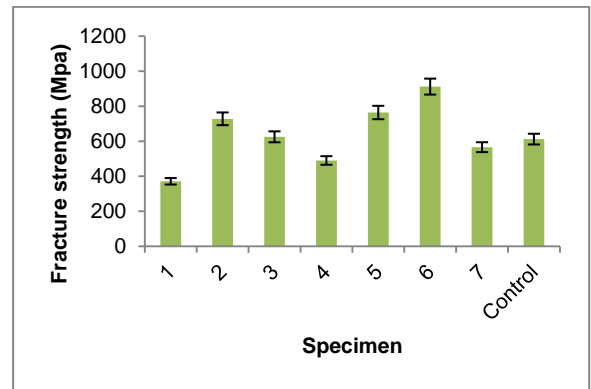


Fig 5 Fracture strengths of the various carburized and tempered samples.

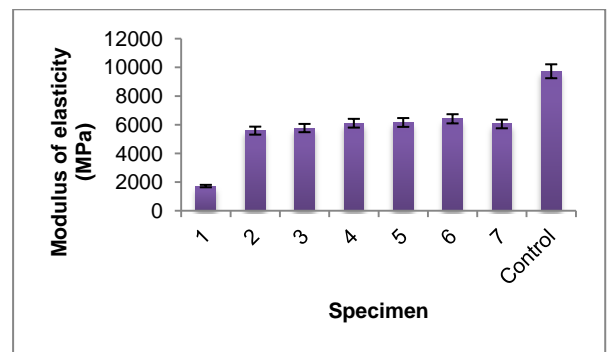


Fig 6 Elastic moduli of the various carburized and tempered samples

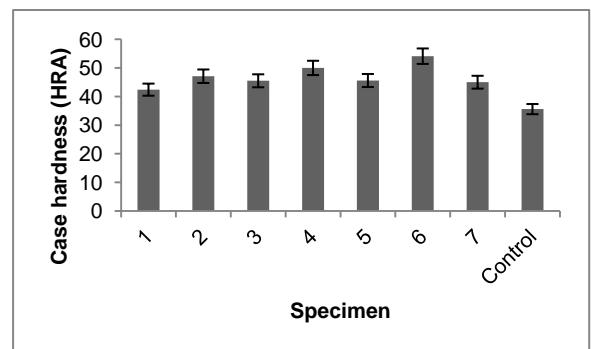


Fig 7 Case hardness of the various carburized and tempered sample

#### 4 CONCLUSIONS

From the results obtained, the following can be concluded;

- a. The use of coconut shell and palm kernel shell as carburizers improved the case hardness of low carbon steel at 950°C.
- b. Better hardness and tensile properties of the carburized low carbon steel were obtained with a mixture of the carburizers.

- c. The best properties were obtained at 80wt% of coconut shell and 20wt% of palm kernel shell mixture as carburizers.

*Materials Science and Engineering*, 1(2), 29-33.  
doi:10.12691/ajmse-1 -2-3

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