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ORIGINAL PAPER

Effect of Silicon Inclusion Carbonaceous Composite Particulate on the Thermal-Ageing Characteristics and Mechanical Performance of Low Carbon Steel

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Abstract

This study focus on the effects of silicon inclusion carbonaceous particulate on the hardness and microstructural properties of carburized low carbon steel, at constant temperature of 900 °C with different holding time from 2 to 5 h. The cow bone and coal dust composite particles were varied with 20% $CaCO_3$ used as the energizer. Hardness and microstructural testing of the various specimens were then carried out using Vickers hardness machine and metallurgical scanning electron microscope. From the result, it was noticed that there was an increase in microhardness performance on both cow bone and coal dust reinforced matrix compared to the as-received samples. For coal dust carburized carbon steel, the hardness value improved from 286 HVN control samples 434.55 HVN in 5 h. It was seen that the introduction of cow bone composite particulate also provides a reasonable mechanical hardness improvement to 418.2 HVN although a little short fall against the coal dust metal matrix. From the microstructure and macrostructure studies highly pearlitic matrix steel was observed with grain refinement of CB and CD found at the interface providing an effective nucleation site along the boundaries.

Keywords Carburizer · Grain refinement · Composite particulate · Heat treatment

1 Introduction

Engineering structural modification of functional part to improve the life and performance of artifact has been of considerable interest of recent [1]. These mechanical structural treatments often produce extensive rearrangements of atoms in metals and alloys and a corresponding marked variation in physical, chemical and mechanical properties were often obtained [2, 3]. Technological advancement has established that appropriate thermomechanical process especially heat treatment processes, immersion hardening, induction hardening and case carburizing has help in various automobile components are used with intention to maintain fatigue life and better mechanical performance [4].

The study of process parameters in metals during heat treatment has been of considerable interest for some years, but there has been relatively little work on process variables during the surface hardening process since controlling parameters in carburization is a complex problem [5]. Carburizing is one of the most surface phenomena perform on steel heat treatment operation. The surface became very hard, while the interior retained the toughness of low carbon steel. Interestingly outside layer of a carbon poor component is enriched with carbon by means of carbon diffusion [6, 7]. The increase of carbon content causes the material to harden at the surface and create a solid crystal. The result is a hard with a tough core that are dependent on the characteristics of the developed carbon,

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Table 1 Spectrochemical analysis of as- received sample

C	Si	Mn	S	P	Cr	Ni	Cu	Nb
0.2210	0.1450	0.6820	0.0590	0.0390	0.0850	0.0800	0.2660	0.0001
Al	B	W	Mo	V	Ti	Fe		
0.0340	0.0001	0.0001	0.0001	0.0001	0.0001	98.3890		

the flowability and the temperature influence. With steel carburized making process, the carburizing process does not harden the steel alone but increases the carbon content to some pre determined depth below the surface to a sufficient level to allow subsequent quench hardening [8, 9].

The major influencing parameters in carburization are the holding time, carburizing temperature, carbon potential and the quench media [9]. Therefore, there has been several considerable work done in the previous years on the possibility of increasing the hardness of a carburized low-carbon steel by varying the carburizing temperature and time on the mechanical properties of steel using carburized palm kernel shell as the carbon rich environment [9, 10].

Recently, a study was aimed at determining the potential of materials such as seashell, palm kernel shell and animal bone as steel carburizers to determine the effects of carburizing process variables such as carburizers, carburizing temperature and holding time on the mechanical and chemical properties of carburized steel [11]. The present work is focused on the effects of selected carbonaceous materials and varying holding time on the mechanical properties of carburized low-carbon steel using pack carburizing heat treatment, coal and cow bone as the carbon rich environment, calcium carbonate as energizer and water as the quenching medium.

2 Materials and Methods

One-meter length of a low carbon steel rod of known chemical composition was obtained from Universal Steel, Ikeja Lagos. Animal bones were procured from butchers in Okene meat market in Okene Kogi State and charred to produce bone charcoal. Coal was sourced from Okaba - Odigbo mining field in Kogi State. The coal and bone charcoal were granulated into powders. Fine powders were sieved off from the granulated materials. Sample of the steel was taken for compositional analysis. The result of the spark spectrometric analysis of the sample was carried out with Hilger Analytical Direct Optical Light Emission Polyvac Spectrometer E980C. The chemical composition of the steels and the carburized composite was described in Tables 1, 2 and 3 respectively using the procedure by [4].

Pack carburizing heat treatment was used with coal and animal bone as the carbon rich environment and calcium carbonate as the energizer. Eight pack boxes measuring 200 mm by 100 mm by 100 mm with lids were fabricated from Standard Wire Gauge (SWG) 18 mild steel sheets bought from Okene market. Equal volumes of granulated coal and bone charcoal were poured into the eight pack boxes each to fill them to about one-third full with addition of about 20% calcium carbonate as energizer. It was ensured that the specimens were completely buried inside the carburizing materials. The lids of the boxes were placed on and sealed with clay to prevent oxygen infiltration.- carburizing temperature of 900 °C was maintained for all samples using a carbolytic heating furnace with a maximum temperature of 1200 °C. Four different carburizing time of 2 h, 3 h, 4 h and 5 h was used for each carburizing mixtures. Water was used as quenching medium after carburizing.

Hardness test specimens were cut from the tensile test specimens after fracture. The hardness specimens were ground and polished after which they were mounted on the Vickers

Table 2 Chemical EDS Elemental Analysis of the Coal Dust (IN WT%)

S/n	Elements	Weight %	Atomic %
1	C	68.34	76.98
2	O	23.18	19.60
3	Al	2.41	1.21
4	Si	3.51	1.69
5	S	0.68	0.29
6	K	0.19	0.07
7	Ba	1.69	0.17

Table 3 Chemical EDS Elemental Analysis of the Cow Bone (IN WT%)

S/n	Elements	Weight %	Atomic %
1	C	5.60	10.10
2	O	43.65	59.10
3	Na	0.93	0.87
4	Mg	0.61	0.54
5	P	17.33	12.12
6	Cl	0.31	0.19
7	Ca	31.58	17.07

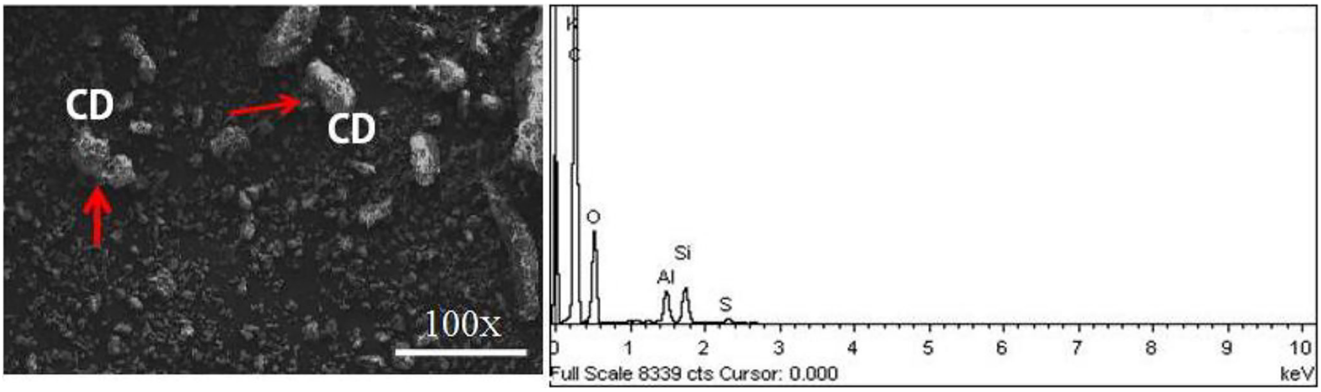

Fig. 1 SEM/EDS analysis of carburized low carbon steel with coal dust (CD)

Hardness Testing machine for hardness measurements. Two hardness indentation were made per specimen after which the average was recorded.

The indentation resisting effect of the reinforcing CSCB and CCCD was compared at the conclusion of the test using Eq. 1

$$HV = \frac{2F\sin\left(\frac{136}{2}\right)}{n^2} = \frac{1.8544F}{n^2} \quad (1)$$

F is the impression load in kgf, n is the average diagonal of the impression in mm.

The Scanning Electron microscope incorporated with Energy – Dispersive x – ray Spectroscopy (EDS) was used to study the surface morphologies of the granulated coal dust and pulverized cow bone so as to give information about their morphologies and topological presentations as well as the elemental analysis or chemical characterization of the samples. These presentations also help provide explanations about the behavior of the studied materials. The SEM - EDS analysis was carried out using a JSM 7600F Joel ultra – high resolution field emission gun scanning electron microscope.

For macro-structural examination, each of the samples was subject to grinding with 204, 320, 400 and 600 grits silicon carbide abrasion paper and polished in accordance with ASTM: E384 Standard as described by [12]. The surface of the polished sample was etched in 2% Nital by swabbing the surface with cotton wool soaked in the etchant. The microstructural examination of the etched surface of the specimens was made under a metallurgical microscope with an in-built camera through which the resulting microstructures were all photographically recorded.

3 Results and Discussion

3.1 Microstructural Analysis

The microstructures effects of carbonaceous CD and CB on low carbon steel are shown in Figs. 1 and 2 respectively. The distributions of the carbonaceous materials are seen at the carbon steel coal dust interface with multiple grains and less large agglomeration. The resulting small grain size of the dispersed coal dust is no doubt as a result of high combustibility nature of coal dust relative to cow bone, that favors increases carbon penetration and diffusion. Study has shown that the nature of particulate refinement is dependent on the holding time and characteristics of the additives [6]. The morphology of the structure changed outrightly after 900oC holding time

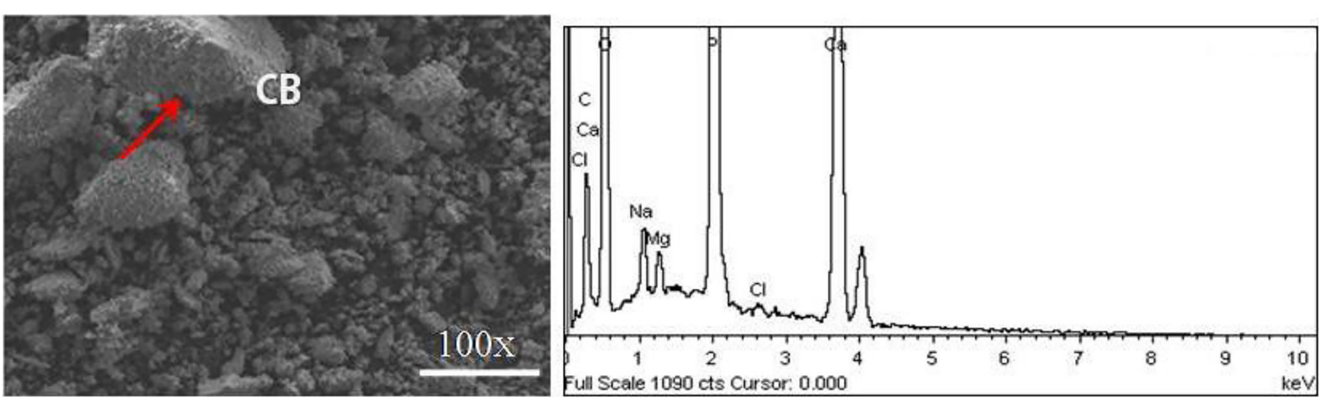

Fig. 2 SEM/EDS analysis of carburized low carbon steel with cow bone (CB)

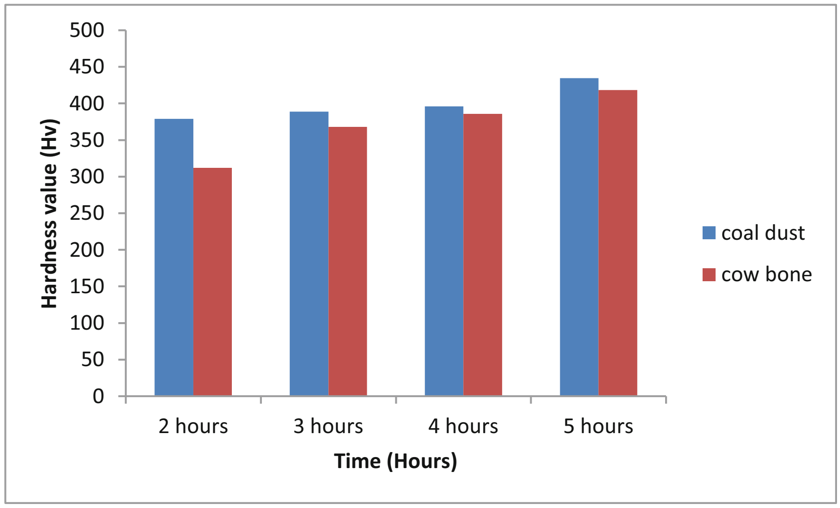

Fig. 3 Effect of selected carbonaceous materials and varying holding time on the hardness value of low carbon steel

for CB. The irregular perlitic phase seen was converted with cow bone like FeC spheroidized C particles heterogeneous distributed in Fe matrix. Similar outcome was reported in literature of stir casting technology of Al6063 [13]. This explains why solid solution improves structural properties and mechanical performance. The energy dispersion spectrometer shows 68.34% carbon as against cow bone with 5.60%.

3.2 Microhardness Analysis

3.2.1 Effect of CD/CB Carbonaceous Materials on the Hardness Potential of LCS

Hardness test specimens were cut to 20 mm length and 10 mm diameter from each sample and were subjected for smooth sur-

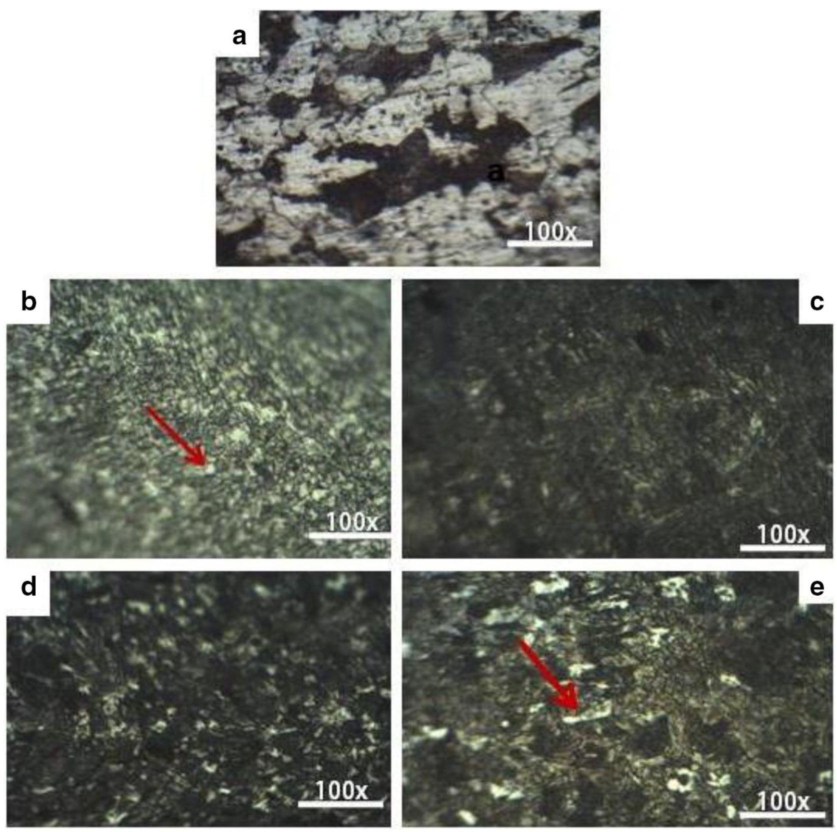

Fig. 4 Microstructure of a) As - received Low Carbon Steel at × 200 b) low carbon steel carburized in coal dust at 900 °C and held for 2 h c) low carbon steel carburized in coal dust at 900 °C and held for 5 h d) low carbon steel carburized in cow bone at 900 °C and held for 2 h e) low carbon steel carburized in cow bone at 900 °C and held for 5 h

face finish for accurate results. The surface was subjected to a standard pressure of 980.7 MN for a standard length of time of 10s by means of a pyramid-shaped diamond. The diagonal of the resulting indention is measured under a microscope and the Vickers Hardness value read. Figure 2 presents the variation of hardness values of low carbon steel when carburized in pulverized coal dust and cow bone. The hardness values formed the basis for comparison, from which the response of low carbon steel to surface hardening can be analyzed with varying carburizing time in hours. The coal dust was activated with 20% $CaCO_3$ and hardness values are obtained in the order of control 286 HVN, 2 h (378.95 HVN), 3 h (388.9 HVN), 4 h (395.85 HVN) and 5 h (434.55 HVN). It was observed that as the carburizing time increases, hardness values also increases. The increase in hardness value is due to the increase in surface carbon content because of surface-hardening. This explained the effective potential of coal dust as an efficient carburizer with highest diffusion and penetrating tendencies.

Similarly, the variation of hardness values of low carbon steel when carburized in cow bone was also seen from Fig. 2. The cow bone was activated with 20% $CaCO_3$ likewise and hardness values are obtained in this order control 286 HVN, 2 h (312.2 HVN), 3 h (368.2 HVN), 4 h (385.8 HVN) and 5 h (418.2 HVN). It was observed that as the carburizing time increases, hardness values as well also increases. However, when compared to coal dust, cow bone has the least diffusion or penetrating power, which makes it less efficient carburizer (Fig. 3).

3.3 Macro-Ageing Behavior of CSCB/CSCD

Metallographic studies of samples produced by pack carburizing have shown in Fig. 4a-e with presence of oxides, fine carbon and decarburization constituent. The analysis shows that there is a variation in microstructures between the control sample and the other samples which are subjected to carburizing treatment with the selected carbonaceous materials. The control sample has flakes of pearlite structure in ferrite matrix and unequal grain size distribution as seen in Fig. 4b-e. No doubt, at the carburizing temperature range of 900 °C, austenite which is formed is unsaturated with respect to carbon. As the CB and CD carburizer comes in contact with the surface of the low carbon steel, it diffuses as attested by [13]. As a result, a very thin layer of extremely fine carbon is deposited on the surface. This carbon is absorbed by the steel till saturation is attained. As the holding time increases up to 5 h, for both cow bone and coal dust, massive pearlite matrix with notable carbide was observed to have formed. Although, this might be as a result of the concentration gradient of carbon which are more noticeable as the holding time increases for each carbonaceous materials. As the steel specimen is water quenched, martensitic and retained austenite grains are produced and concentrated on the surface. This notable change has affirmed by [4, 14].

4 Conclusions

This study affirmed that both coal dust and cow bone are good carbonaceous materials for excellent case hardening progresses for automobile and aerospace application. The influence of carbon diffuses impact on the hardness and microstructural properties at all holding time. The highly pearlite matrix phase observed in most samples has proved to be most significant for application in automobile and aerospace system.

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