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APPLICATION

Unveiling high-performance carburized mild steel using coconut shell ash and $CaCO_3$ nanoparticles derived from periwinkle shell

Oyewole Adedipe[1] · Victor Sunday Aigbodion[2,3,4] · Nicholas Agbese Agbo[5] · Sunday Albert Lawal[1] · Oyebola Wahab Akanni Oyeladun[6] · James Baba Mokwa[7] · Emmanuel Toi Dauda[8]

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Abstract

The surface hardening of mild steel by carburization using periwinkle shell nanoparticles (PWSnp) and coconut shell (CS) was investigated. The carburization was done at 850, 900, and 950 °C with a ratio of PWSnp:CS of 1:9, 2:8, and 3:7. The case depth, hardness values, wear, and corrosion rates were determined. A 114.1% increment in the hardness values, a corrosion protection efficiency of 92.58%, and a 45.67% wear resistance of the mild steel were obtained at 3:7 PWSnp: CS and 950 °C. The development of a passive layer that enveloped the sample and shielded it from further corrosion assaults was responsible for the excellent protection efficacy of the carburized sample. It was established that waste periwinkle shell and coconut shell can be used for surface hardening of mild steel.

Keywords Mild steel · Coconut shell · Periwinkle shell · Corrosion rate · Wear · Hardness values · Microstructure

1 Introduction

To improve the service life of steel parts of military and civilian equipment, it is recommended that they be made to possess not only hard and wear-resistant surfaces but tough and impact-resistant cores [1]. A low-carbon steel of approximately 0.1% carbon is typically tough, whereas a high-carbon steel of about 0.9% C or more has appreciable hardness with low toughness [2]. To possess both a hard and wear-resistant surface and a tough inner core, steel parts require the carburization treatment so as to alter the configuration of the surface by increasing the hardness while retaining the toughness and softness of the core [3]. Carbon diffusivity in austenite is affected by carbon concentration and carburizing temperature [4, 5], because carbon concentration is determined by its activity in austenite and a finite repulsive relationship exists between neighboring carbon atoms in octahedral sites. Carbon diffusivity has been modelled by Babu and Bhadeshia [6] in accordance with the kinetic and thermodynamic behavior of carbon in austenite, whereas Siller and McLellan [7] believe that repulsive forces between neighboring carbon atoms affect carbon diffusivity by reducing the possibility of interstitial site occupancy in the neighborhood already occupied by carbon atoms. Hence, in a concentration gradient, a carbon atom engaging in random motion experiences a high difference in the number of available sites, which improves carbon diffusion down the concentration gradient.

Kolawole et al. [8] investigated the carburization of mild steel using date seed and snail shell as an environmentally friendly carburizer. Results obtained showed that date seed

✉ Oyewole Adedipe
oyewolemech2022@gmail.com;
oye.adedipe@futminna.edu.ng

1 Department of Mechanical Engineering, Federal University of Technology, Minna, Nigeria

2 Department of Metallurgical and Materials Engineering, University of Nigeria Nsukka, Nsukka, Nigeria

3 ACE, Africa Centre of Excellence, SPED University of Nigeria Nsukka, Nsukka, Nigeria

4 Faculty of Engineering and Built Environment, University of Johannesburg, Auckland Park, P. O. Box 534, Johannesburg, South Africa

5 Defence Industries Corporation of Nigeria (DICON), Kaduna, Nigeria

6 Department of Mineral and Petroleum Resources Engineering, Kaduna Polytechnic, Kaduna, Nigeria

7 Department of Mechanical Engineering, Federal Polytechnic Bida, Bida, Nigeria

8 Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria, Nigeria

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and snail shell were highly eco-friendly carburizing agents for mild steel. At 1000 °C carburizing temperature, a tensile strength of 521 MPa and hardness of 32 HRB were measured. In comparison to the uncarburized sample, these were equivalent to 52% and 31% increases in tensile strength and hardness, respectively. In another study, Oluwafemi et al. [9] used carbonized palm kernel shell as a carburizer in the carburization of mild steel. It was observed that a carburizing temperature of 950 °C and a soaking time of 2 h gave the optimum mechanical properties of the carburized mild steel. Umunakwe et al. [10] studied the appropriateness of palm kernel shell and coconut shell powders as carburizing agents for mild steel. It was observed that the tensile strength and hardness of the mild steel were enhanced more with the mixture of the two carburizers than using them separately. The mild steel's mechanical properties were optimized by combining 80% coconut shell and 20% palm kernel shell. Negara et al. [11] worked on the pack carburization of low carbon steel using a temperature of 950 °C and a soaking time of 240 min in a carburization mixture of charcoal gotten from bamboo stems, goat bone charcoal, and barium carbonate as the energizer. The case hardening depth obtained was in the range of 0.5–1 mm, and the hardness decreased toward the steel core. Negara et al. [12] conducted carburization of low-carbon steel at a temperature of 950 °C and soaking times of 2 h, 4 h, and 6 h consecutively. The carburizer was charcoal produced from coconut shell fibers, while the energizer was barium carbonate. They were mixed in a ratio of 80:20. Water was used to cool the carburization process. The hardness and wear resistance improved as the soaking time increased. The best properties were obtained with a soaking time of 6 h. Hesham [13] reported on the carburization of mild steels at temperatures between 850 and 950 °C. The findings showed that the carburization process significantly enhances the mechanical and wear properties, such as tensile strength, hardness, and wear resistance, and that these properties increase with an increase in the carburization temperature. Aramide et al. [14] reported on the carburization of mild steel at 850, 900, and 950 °C, soaked at those temperatures for 15 and 30 min. It was revealed that the carburizing temperature and soaking duration had a significant impact on the mechanical characteristics of mild steels. It was determined that the ideal combination of mechanical qualities is obtained at 900 °C for 30 min. The study of process variables in metals during heat treatment has garnered a lot of interest. However, relatively little work has been done on process variables during the surface hardening process of mild steel using periwinkle nanoparticles and coconut shell ash as carburization materials for the enhancement of corrosion rate, wear, and hardness values of mild steel. Hence, this work will report for the first time the effect of carburizing variables on the corrosion, wear, and hardness characterization of mild steel carburized using periwinkle nanoparticles and coconut shell ash. It is our belief that the use of periwinkle nanoparticles as energizers will enhance the rate of movement of carbon onto the steel surface.

2 Materials and method

2.1 Materials

The periwinkle shells (PWS) utilized in this investigation were from Nigeria's Rivers State, and the coconut shell used in this work was obtained in Edo State, Nigeria. The mild steel was obtained from Ajaokuta Steel, Nigeria. The chemical analysis of the mild steel utilized in this study is shown in Table 1.

2.2 Method

The PWSnP was produced using the sol–gel technique. The raw periwinkle shells were cleaned by washing and drying for 24 h in order to remove the membranes. After being thoroughly cleaned, the periwinkles were calcined for three hours at 1200 °C in a muffle furnace to obtain $CaCO_3$. PWSnPps production process was covered in detail elsewhere [15]. The raw coconut shells (CS) were cleaned by washing and drying for 24 h in order to remove the impurities. After being thoroughly cleaned, the CS was carbonized for 6 h at 1400 °C in a muffle furnace. The carbonized CS was then pulverized with the aid of a ball mill and sieved using a sieve shaver for 20 min to obtain a particle size of 63 µm. Before the carburization process, the mild steel was grounded and polished using metallographic grit sheets and alumina paste and soaked in 10% HCl solutions for 10 min. It was then washed with deionized water and dried. The prepared mild steel samples were cut into a 5 cm by 4 cm size.

The mild steel samples were packed in a carburization box. For the carburization process, PWSnp:CS ratios of 0:0, 1:9, 2:8, and 3:7 were used. These ratios were made possible after a preliminary investigation. The carburization box, including the mild steel and the varied ratio of PWSnp:CS, was put inside a muffle furnace. The carburization was done at 850, 900, and 950 °C for 2 h. The samples were then taken out, cooled in water, and then tempered at 200 °C for 1 h. The energizer (PWSnp) breaks down to CaO and CO_2 during

Table 1 Chemical composition of mild steel (wt%)

Elements	C	Mn	Si	P	S	Zn	Al	Ni	Fe
%	0.16	0.35	0.15	0.0031	0.021	0.034	0.005	0.075	Balance