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Potential of Date-Seed/Snail Shells as a Carburizer for Enhanced Mechanical Properties of Mild-Steel

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Abstract. The suitability of date-seed/snail shells as a carburizer for enhanced mechanical properties of mild-steel using the packed carburization technique was investigated in this work. Standard tensile, impact and hardness test samples prepared from mild-steel were subjected to pack-carburization process using mixtures of date-seed and snail shell in the ratio 60:40 respectively at 800, 900, and 1 000 °C for 3 hours. The carburized samples were quenched in water at room temperature and further tempered at 300 °C for 30 minutes for residual stress relief of the quenching effect. The mechanical properties and optical microstructure of carburized specimen were performed. Results indicated an enhanced mechanical property of the carburized mild-steel using date-steel/snail shell as a carburizer compared to un-carburized same steel material. The tensile strength and hardness increased with increasing carburizing temperature, though with an associated decrease in ductility. The peak hardness (32.82 HRB) and tensile strength (521 MPa) with equivalent 31.28 and 51.45 percentage increments respectively were obtained at carburizing temperature of 1 000 °C. Hence, using date-seed/snail shell powder as a carburizer can enhance the mechanical properties of mild-steel.

Keywords: carburization, mild-steel, mechanical properties, date-seed, snail shell.

1 Introduction

In today’s technological world, nearly everyone depends on carbon steels materials. This is due to a wide array of their applications in automotive chassis, body, and component parts, reinforcement of concrete in the structure, fuel, and water tankers, as well as manufacturing of engineering parts (ball bearing, shaft, drill bit, and gear) and equipment for mobility, health, safety and economic well-being of human sustenance [1, 2].

The versatility of mild-steel in engineering applications can be anchored on its moderate yield strength, availability at lower cost, and good toughness and ductility characteristics suitable for various applications. However, the quest for more improved properties of low carbon steel is on the increase for the production of durable machines and structures with high-quality performance and efficiency to meet the present technologically driven-era requirements and attracted researchers’ interest [3–5]. Therefore, improving the mechanical strength of mild steel will enhance the structural integrity and widen its suitability in high precision engineering applications. One of the essential means of achieving this is by heat treatment processes such as carburization. This technique was widely reported to be suitable for improving low carbon steel materials’ mechanical and wear properties [4, 6, 7]. This process can be achieved by either gas, packed, vacuum, or liquid methods. However, the packed carburization technique has gained more attention from researchers due to its cost-effectiveness without compromising the quality of parts.

Pack-carburization is a surface impregnation thermo-diffusional heat treatment technique in which metallic specimen usually steels, exposed to packed carbonaceous materials at controlled elevated temperature, pick-up free-carbon from surrounding furnace atmosphere followed by desirable cooling mode to modify the surface and properties of metal. It is one of the most commonly performed heat treatment methods to enhance hardness, wear, and mechanical properties by impregnating alloys of steel surfaces with carbon [8]. Over the years, carburization was usually performed in a conventional carbon-rich environment (coke, activated carbon, and charcoals) using synthetic barium or calcium carbonate as an energizer. However, recent findings have unveiled the suitability of various agro-wastes, which are readily available, as a carburizer and, in turn, will also help in the maintenance of a clean environment for a healthy life [3, 5, 6, 9–12].

According to Adly et al. [13], the temperature, soaking time, and types of the carburizing atmosphere have a more significant influence on the performance of the carburization process. Consequently, various researchers' findings on the carburization of mild steel under different conditions are well documented in the literature.

Aramide et al. [14] examined the effect of carburizing temperatures (850, 900, and 950 °C) and time 15 and 30 minutes on mechanical properties of mild steel using activated carbon as the carburizing agent. Analysis of their investigation revealed that the carburizing temperature and time significantly influenced the mechanical properties of mild steel. However, the optimum combination of mechanical properties was recorded at 900 °C carburizing temperature followed by quenching in oil.

A similar result was obtained by Olufemi et al. [15], where the best combination of mechanical properties was achieved at 950 °C over a soaking time of 2 hours in carbonized palm kernel carburizing atmosphere.

Furthermore, Umunakwe et al. [6] investigated the suitability of palm kernel shell and coconut shell powders as a carburizer in singular and hybrid forms. It was discovered that tensile strength and hardness properties were better enhanced with mixtures of a carburizer compared to single carburizing media. Furthermore, 80 wt. % of coconut shell and 20 wt. % palm kernel shell hybrid mixtures yielded the peak mechanical properties. In another study [3], charcoal was used as carburizing materials and cow bone as energizer at different weight proportions. The carburization process was carried out at 900 °C for 8 hours in a muffle furnace. Evidence obtained from this experimentation showed an adequate case depth of 2.32 mm with the best hardness profile recorded at 60 wt. % charcoal and 40 wt% cow bone composition, which affirms the usability of cow bone as a suitable energizer for mild steel carburization.

Other wastes explored as carburizing agents for improving mild steel properties include periwinkle snail shells, as reported by Adzor et al. [16]. Prepared mild steel samples were packed in a mixture of 85 % of carbonized periwinkle shell powder and 15 % barium carbonate and were fired at 850, 900, and 950 °C using an electric furnace under different soaking times followed by tempering. The results revealed that hardness increased with increasing carburizing temperature and dwelling time. However, a decreasing trend in impact strength was recorded with increased carburizing temperature and soaking time. This result corroborated with the recent findings of Adzor et al. [5], where 80 wt. % of snail shell and 20 wt. % melon shell mixture was used as a carburizer.

Undoubtedly, available literature has shown that extensive works had been done on the potential of various agro and animal wastes such as date-seed and African giant snail shells as a carburizer to enhance the mechanical properties of mild steel. However, it was observed that there are still numerous other agro-wastes such as date-seed, whose suitability as an alternative carburizer has not yet been explored in the heat treatment of mild-steel. Date-seeds are discarded parts of a date-fruit after the fleshy parts have been eaten or removed. The challenges of incessant discarding of this seed with no economic value, especially in most Asian countries and northern parts of Nigeria where date-palm fruit are being grown and consumed heavily, are alarming and constituting environmental nuisance [17].

In addition, giant African snail shells are readily available at low or no cost in most tropical parts of Africa and the western region of Nigeria, where they are consumed as meat for food. The use of these wastes (date-seed and African snail shell) as a carburizer are rarely found in the literature despite their discarding consequence on the environment and human health concerns. Hence, this study aims to present the suitability of date-seed and giant African snail shells as a carburizer to enhance the mechanical properties of mild steel.

2 Materials and Methods

2.1 Materials and equipment

The materials and equipment used in this study include mild steel with chemical composition as shown in Figure 1, date-seed wastes, African giant snail shells, Sieving machine, steel boxes, muffle furnace, optical microscope, weighing balance, fired clay, tong and bench-vice, water, Universal tensile testing machine (UTM), impact testing machine and Rockwell hardness tester (HRB).

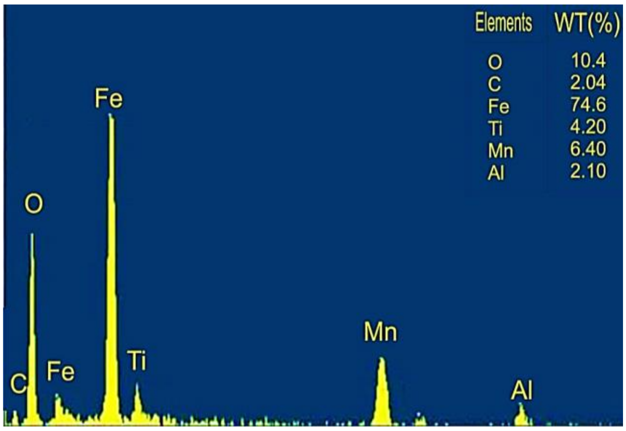
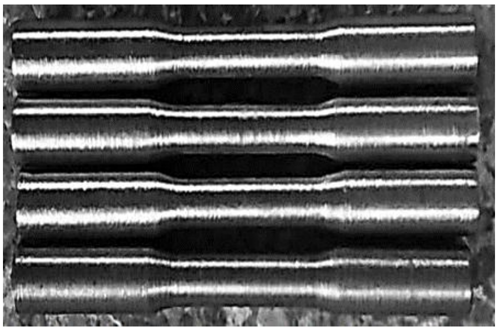


Figure 1 – Chemical composition of mild-steel specimen

2.2 A carburizer and specimen preparation

Date-seed was procured from Ipata market in Ilorin, Kwara state Nigeria, and the snail-shell used was sourced from a DJ restaurant in Osogbo, Osun state Nigeria. To remove moisture, the date-seed was washed and oven-dried at 110 °C for eight hours (8 hours). The dried seed was crushed with hammer mill, pulverized using a disc mill, and sieved down to 200 µm particle size at Land and Water Engineering Laboratory, National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State, Nigeria. A similar procedure was adopted in processing snail shell before it was sieved down to 200 μm sizes. The clay powder retained on 150 μm sieve sizes was used for sealing purposes in this study to prevent oxidation. Each of the sieved samples was kept intact at different air-tight containers before use. This work used a mild steel rod (10232) of dimension 1 000 mm in length and 20 mm diameter with percentage carbon of 0.05–0.25 % procured at Agodi Market, Ibadan Oyo State, Nigeria. Tensile test specimens were machined out of this sample according to ASTME8/E8M-16a standard (see Figure 2 a, hardness (20 mm height by 10 mm diameter) Figure 2 b and impact specimens with 2 mm depth V-notched shape under ASTM D256 specification and as reported by Oluwafemi et al. were used in this work.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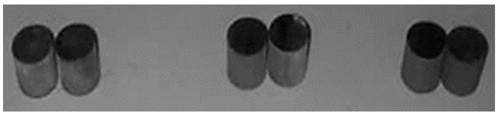
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Figure 2 – Samples of a specimen prepared for tensile (a) and hardness (b) testing

2.3 Carburization heat treatment of mild-steel samples

The calculated and weighed amount of the carburizing ingredients in the ratio 60:40 wt. % of date-seed and snail shells, respectively, were mixed. The mixture (date-seed and snail shell) was then packed around prepared specimens (tensile, impact, and hardness samples) in triplicates inside a rectangular metallic box and covered. All air-openings in the packed box were sealed with sticky, moist clay to prevent oxidation of the samples and placed in the chamber of an electric muffle furnace with the temperature set to 800 °C and fired at a heating rate of 10 °C/min with a dwelling time of one hour. After that, the carburized samples were quenched in water at room temperature, tempered in the furnace at 300 °C for 30 minutes, and air-cooled to room temperature. The same procedure was adopted for the heat treatment of other samples at 900 and 1 000 °C, while the control specimens for the same examination were left without heat treatment.

2.4 Evaluation of mechanical properties and microstructure

In this work, tensile, impact, and hardness tests were used to evaluate the mechanical properties of both carburized and uncarburized standardized samples. The tensile test was carried out at National Centre for Agricultural Mechanization Ilorin, Kwara State Nigeria, under ASTME8/E8M-16a standard on Testometric Universal Testing Machine (0500-10080). The samples were subjected to a uniaxial tensile loading at 10 mm/min machine test speed until failure occurred. Both treated and untreated samples' hardness was performed on Rockwell hardness tester (HRB) with 5 indentations taken from Materials Science and Engineering Laboratory, Malete, Kwara State University. The average of the five indentations was used as the hardness of the sample for each of the variations. Impact strength testing of the V-notched specimen was performed by applying a constant impact force on the Avery Dension Impact testing machine located at the material testing laboratory, University of Ilorin, Ilorin, Nigeria.

Samples for surface morphology examinations were first cut using parting-off tools on the lathe machine. The surface was flattened and smoothened using different sizes of emery paper of 400, 600, 800, and 1 000 μm grit size in that order on a rotating disc grinding machine. The polished samples were etched using 2 % Nital solution, after which surface morphology was viewed using Olympus BX 41M microscope.

3 Results and Discussion

3.1 Tensile strength behavior

The influence of the date-seed/snail shell powder packed-carburizing process on yield tensile strength of mild-steel at 0, 800, 900, and 1 000 °C temperatures are as shown in Figure 3. It was revealed that the yield tensile strength of mild-steel increases with an increase in carburizing temperature though at the expense of ductility, as discernible in Figure 3. The yield tensile strength was lowest in uncarburized mild-steel samples with a magnitude of 344 MPa and 32 % as percentage strain. The yield strength rose to 357 MPa with no significant loss in ductility when carburized at 800 °C. A similar trend was noticed as the carburizing temperature increases to 900 and 1 000 °C with the corresponding yield strength of 514 MPa and 521 MPa, respectively. Hence, the peak ultimate tensile strength was obtained when the mild steel was carburized at 1 000 °C. However, the percentage strain decreases to 30 and 24 % at 900 and 1 000 °C carburizing temperatures, respectively. This implies a loss of ductility as yield strength increases due to increasing carburizing temperatures. The increase in strength observed in this work could be attributed to the increased diffusibility of carbon in date-seed as energized by thermal decomposition of snail shell brought about by carburizing temperature. The increasing carburizing temperature tends to increase the diffusion process for more infiltration of a carbon atom at the interstices of the atomic structure. This, in turn, increases the dislocation density at the surface to a particular depth level of the carburized materials. Consequently, the strength of mild-steel increases. This result was in good agreement with authors [13, 14, 18, 19], where increment in ultimate tensile strength was reported using various types of a carburizer and carburizing parameters.

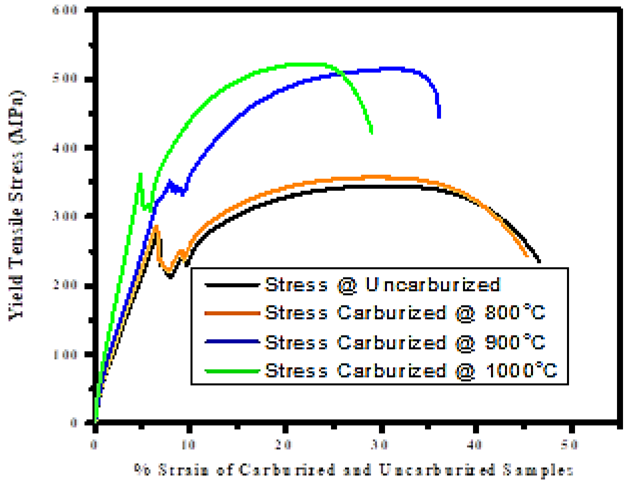


Figure 3 – Influence of carburizing temperature on the yield strength of mild steel

3.2 Impact energy

Figure 4 shows the impact strength of un-carburized and carburized mild-steel at different temperatures (800, 900, and 1 000 °C). It was observed that the carburizing temperature influenced the impact strength of mild steel. The lowest impact strength (96 J) was recorded in uncarburized mild-steel samples. But when it was carburized at 800 °C, the impact strength rose to 133.5 J. Increasing the carburizing temperature to 900 °C only had little influence on the impact strength by increasing it to 137 J. At 1 000 °C carburizing temperature, the impact strength of mild-steel decreases to 133.5 J. The equivalent increase in impact strength carburized at 800, 900, and 1 000 °C respectively is 39, 43, and 40 % compared to uncarburized mild steel. As obtained in this work, these findings indicated a deviation from earlier researchers [11, 14–16], where an increase in carburizing temperature resulted in impact strength reduction of the carburized mild-steels. However, the initial rise in impact strength as presented in this study can be attributed to the case hardening effect of the mild-steel due to carbon depositions below the saturation limit at 800 °C. But as the carburizing temperature increases, more deposition of carbon atoms occurs closer to the saturation limit. This results in increased hardness of the mild-steel, and consequently, brittleness of the mild-steel rises. The high hardness value resulting from increasing carburizing temperature, which in turn translates to brittleness, can be responsible for the 3 % drop in impact strength as discernible in Figure 3 when the carburizing temperature was raised from 900 to 1 000 °C.

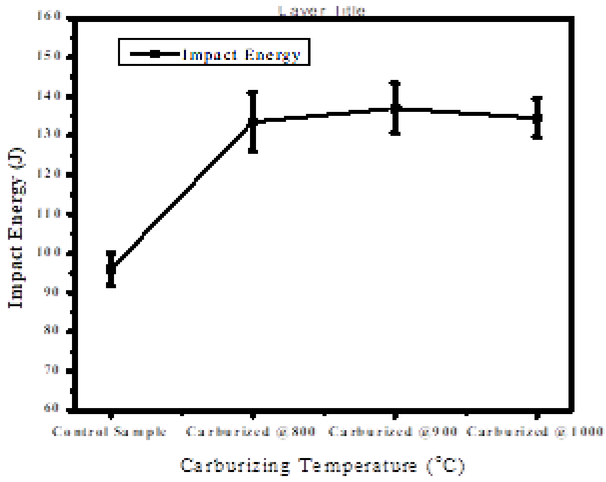


Figure 4 – Impact energy of date-seed/snail shell carburized mild-steel at different temperatures

3.3 Hardness properties of carburized steel

The hardness distribution of uncarburized and carburized mild steels at a distance of 2 mm to the surface are presented in Figure 5. It was observed that the carburizing temperature significantly influences the hardness distributions of samples. The least hardness (25 HRB) was obtained in uncarburized mild steel samples, and when it was carburized at 800 °C, the hardness rose to 27.83 HRB. Similar increment characteristics were recorded at 900 and 1 000 °C. The peak hardness (32.82 HRB) was obtained when carburized at 1 000 °C. This increment is equivalent to 31.32 % relative to uncarburized sample. The increase in hardness with increasing carburizing temperature as obtained in this work follows a typical pattern of results reported by earlier findings [5, 18, 19]. The increase in hardness observed in this work can be attributed to the formation of a well-dispersed hard martensitic phase in all carburized samples, as discernible in Figure 6. The higher carbons content at the surface due to carbon diffusion implies higher hardness on the surface than in the core, as evidenced in Figure 6.

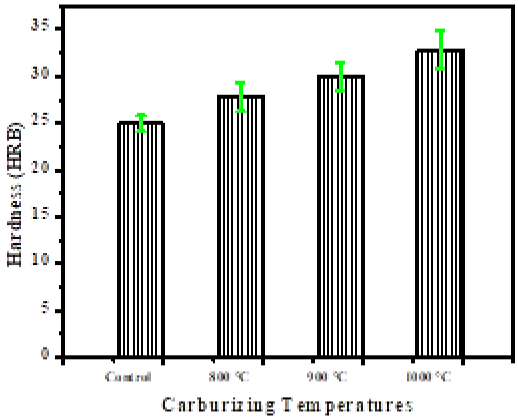
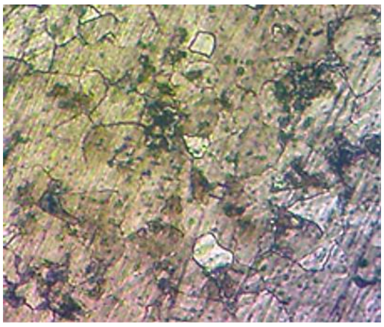


Figure 5 – Hardness behavior of mild-steel at varying carburizing temperatures

3.4 Microstructural examination

Figure 6 shows the optical micrographs of uncarburized and carburized mild-steels at different carburizing temperatures taken at 1 mm from the surface for all specimens. It was evidenced from Figure 6 that morphological transition occurred from uncarburized to carburized mild-steel samples. For uncarburized sample, the micrograph displayed mixtures of coarse ferrite and pearlite microstructure. But when carburized, quenched, and tempered, the morphology of the mild-steel became altered in terms of size and geometries of the pearlite, ferrite, and martensitic structure. The mild-steel carburized at 800 °C, quenched and tempered, shows a reduction in the size of pearlite and ferrite structure with some traces of carbon infiltration in the interstices of pearlite and ferrite.

Further increase in carburizing temperature (900, 1 000 °C) revealed a finer microstructure than un-carburized and 800 °C carburized samples. Black finer particles of carbon which were highest in Figure 6 d, were seen been dispersed in the microstructure of highly dark dense pearlite. This indicated the formation of hard martensitic (Fe_3C) darker structure in carburized samples compared to un-carburized samples, which could be responsible for increased hardness. This finding agrees with the results of Thee and Chaiyawat [20], where the microstructure displayed the formation of the hard phase responsible for the increment in hardness of the carburized samples.



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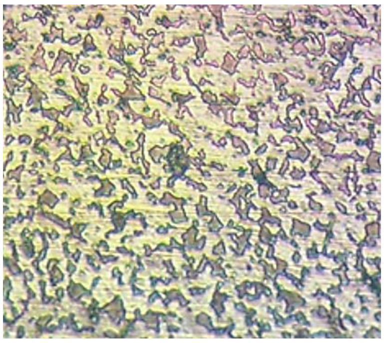

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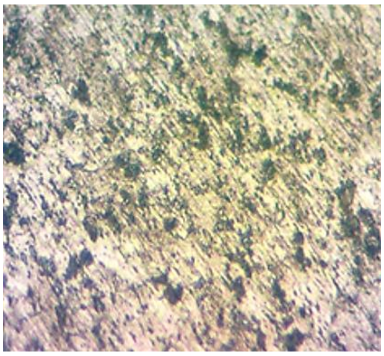

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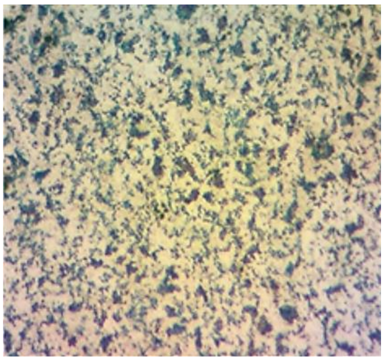

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Figure 6 – Optical micrograph of carburized mild-steel at different temperatures

4 Conclusions

This work carried out the suitability of date-seed/snail shell as a carburizer on the mechanical properties of pack carburized mild steel, and the following deductions were made.

The date-seed/snail shell has good potential to be used as a carburizer for improved mechanical properties of mild-steel.

The parabolic nature of impact strength behavior with an increase in carburizing temperature and least value recorded in un-carburized sample implies that the tempering process after quenching can enhance the toughness of packed date-seed/snail shell carburized mild-steel.

The peak tensile strength (521 MPa) and hardness (32 HRB) were obtained at 1 000 °C carburizing temperature. These values translate to a 52 % and 31 % increase in tensile strength and hardness, respectively, relative to un-carburized samples.

It is recommended that a comprehensive study of carburizing variables such as particles sizes of date-seed in carbonized form, temperature, and soaking time be considered in further studies to determine the carburization parameters that will produce the optimum surface hardness, wear-resistance, and mechanical properties suitable for critical engineering applications.

References

1. Joseph, O. O., Leramo, R. O., Ojudun, O. S. (2015). Effect of heat treatment on microstructure and mechanical properties of SAE 1025 Steel : Analysis by one-way ANOVA. *Journal of Materials and Environmental Science*, Vol. 6, pp. 101-106.
2. Singh, M. (2016). Application of steel automotive industry. I*nternational Journal of Emergence Technology and Advanced Engineering*. Vol. 6, pp. 246-253.
3. Ihom, P. A. (2013). Case hardening of mild steel using cowbone as energiser. *African Journal of Engineering Research*, Vol. 1, pp. 97–101.
4. Alias, S. K., Abdullah, B., Jaffar, A., Latip, S. A., Kasolang, S., Izham, M. F. (2013). Mechanical properties of paste carburized ASTM A516 steel. *Procedia Engineering*, Vol. 68, pp. 525-530, doi: 10.1016/j.proeng.2013.12.216.
5. Abella, A. S., Aondona, I. P. (2018). Utilization of melon and snail shell waste mixtures in the carburization of mild steel. *International Journal of Trend in Scientific Research and Development*, Vol. 2, pp. 1032-1040, doi: 10.31142/ijtsrd11353.
6. Umunakwe, R., Okoye, O.C., Madueke, C.I., Komolafe, D.O. (2017). Effects of Carburization with Palm Kernel Shell/Coconut Shell Mixture on the Tensile Properties and Case Hardness of Low Carbon Steel. *FUOYE Journal of Engineering Technology*, Vol. 2(1), pp. 101-105, doi: 10.46792/fuoyejet.v2i1.83.
7. Blaoui, M. M., Zemri, M., Brahami, A. (2018). Effect of heat treatment parameters on mechanical properties of medium carbon steel. *Mechanics and Mechanical Engineering*, Vol. 22, pp. 909-918, doi: 10.2478/mme-2018-0071.
8. Nwoke, V. U., Nnuka, E. E., Odo, J. U., Obiorah, S. M. O. (2014). Effect of process variables on the mechanical properties of surface hardened mild steel quenched in different media. *International Journal of Scientific and Technology Research*, Vol. 3(4), pp. 388-398.
9. Prime, M. B., Prantil, V. C., Rangaswamy, P., Garcia, F. P. (2000). Residual stress measurement and prediction in a hardened steel ring. *Materials Science Forum*, Vol. 347-349, pp. 223-228.
10. Afolalu, S. A., Oladipupo, S., Edun, Bose, M., Abioye, A. A., Adejuyigbe, S. B., Ajayi, O. O. (2019). Agro waste - A sustainable source for steel reinforcement-review. *Journal of Physics: Confence Series*, Vol. 1378(3), 032032, doi: 10.1088/1742-6596/1378/3/032032.
11. Madu, K. E., Uyaelumuo, A. E. (2018). Parametric effects of carburization time and temperature on the mechanical properties of carburized mild steel. *Research in Material Science*, Vol. 2018, 3209937, doi: 10.2139/ssrn.3209937.
12. Akanji, O., Fatoba, O., Aasa, A. (2015). The Influence of Particle size and soaking time on surface hardness of carburized AISI 1018 steel. *British Journal of Appllied Science and Technology*, Vol. 7, pp. 37-44, doi: 10.9734/bjast/2015/13552.
13. Adly, M., El-Kashif, E., Shash, A.Y., Hamed, A. (2018). Effect of coke size on the mechanical and wear properties of carburized mild steel. *Arabian Journal of Science and Engineering*, Vol. 43, pp. 1083-1092, doi: 10.1007/s13369-017-2724-7.
14. Aramidea, F. O., Ibitoye, S. A., Oladele, I. O., Borode, J. O. (2009). Effects of carburization time and temperature on the mechanical properties of carburized mild steel, using activated carbon as carburizer. *Material Research*, Vol. 12, pp. 483–487, doi: 10.1590/s1516-14392009000400018.
15. Oluwafemi, O. M., Oke, S. R., Otunniyi, I. O., Aramide, F. O. (2015). Effect of Carburizing temperature and time on mechanical properties of AISI/SAE 1020 steel using carbonized palm kernel shell. *Leonardo Electron Journal of Practices and Technologies*, Vol. 14, pp. 41-56.
16. Adzor, S. A., Nwoke, V. U., Akaluzia, R. O. (2016). Investigation of the suitability of periwinkle snail shells as carburizing material for the surface hardness improvement of low carbon steel. *European Journal of Material Science*, Vol. 3, pp. 13-23.
17. Abdulkareem, S., Edache, E. J., Olowosule, I. I., Kolawole, M. Y., Ahmed, I. I., Ajiboye, T. K. (2018). Effect of Date seed particulates on mechanical properties of aluminium alloy. *Acta Technology Corviniensis-Bulletin Engineering*, Vol. 11, pp. 89-94.
18. Negara, D. N. K. P., Widiyarta, I. M. (2019). The study on mechanical properties of pack carburized low carbon steel using $BaCO_3$ as energizer. *IOP Conference Series: Material Science Engineering*, Vol. 673, 012125, 10.1088/1757-899X/673/1/012125.
19. Verma, M., Dhillon, K. S., Verma, M. (2015). Improvement in the wear resistance and mechanical properties of carburized mild steel by varying carburization temperature and constant tempering temperature. *International Journal of Innovation and Scientific Research*, Vol. 15, pp. 379-388.
20. Thee, C., Peeratatsuwan, C. (2020). Microstructure and hardness evolution of carburized mild steel. *Engineering Journal of Research and Development*, Vol. 31(4), pp. 145-152.