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The Influence of Particle Size and Soaking Time on Surface Hardness of Carburized AISI 1018 Steel

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Authors' contributions

This work was carried out in collaboration between all authors. Author OSF designed the study, wrote the protocol, wrote the first draft of the manuscript and managed analyses of the study. Author ASA analysed, verified and quality checked the data used in the results and discussion. Author OLA gathered the materials needed to write the review, initiated the literature review of this study and analysed the experimental procedure. This work was proofread and accepted by all authors before submitted for publication. All authors read and approved the final manuscript.

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ABSTRACT

This work examines the effect of process variables on the mechanical property of carburized AISI 1018 steel quenched in water and oil for improved performance. A carburizer consisting of charcoal was used for research with sea shell as energizer. Samples were carburized using weight percent of seashell (10, 20, 30 and 40%) with particle sizes of 212 µm, 425 µm and 600 µm respectively. The process was carried out at carburizing temperature of 950°C, soaked for 4, 6, and 8 hours and quenched in oil and water. The samples were further tempered at 200°C for 1hour to relieve the stress built up during quenching. Hardness test was carried on the steel samples. The results of the study showed that hardness values of the carburized and tempered steel increased with influence

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of soaking time, volume fraction and particle sizes of energizer. The optimal carburizing effect was achieved at 90% charcoal and 10% seashell (energizer) of 212 μm particle size at 8 hrs soaking time when quenched in water.

Keywords: Energizer; soaking time; cooling media; particle size; hardness.

1. INTRODUCTION

The failure of engineering materials is undesirable for several reasons, which include loss of human lives, injuries, economic losses and interference with availability of products and services. The usual causes are improper selection and processing of materials and inadequate design and misuse of component [1]. Various forms of steel are used in the manufacture of both major and minor machine parts. Bolts, cams, nuts and cutting tools are among the essential engineering components usually made out from steel. The service condition of many steel components demands that they possess both hard, wear-resistant surfaces and tough shock resistant cores.

Mild steel, due to its dominance and workability among the classes of steel [2], has found a broad relevance in the production of engineering components like gears, keys, pinions, handtools, shafts, agricultural equipment on the account of its low cost and easy fabrication [3]. These components require the mechanical properties of impact strength, tensile strength and hardness for their safe and tough purposes. Rapid penetration of the surface of steel can only be effective if the solute element dissolves interstitially. Once dissolved, the elements increase the hardness of the surface by forming interstitial carbides, nitrides or borides depending on the diffusion atoms [4].

Nwoke et al. [1] reported that carburizing is one of the most commonly performed steel heat treatments. Over the years, it was performed by packing the low carbon iron parts in charcoal, then raising the temperature of the pack to red heat for several hours. The resulting interstitial solid solution is harder than the base material, which improves wear resistance without sacrificing toughness [5]. Optimum structural material is a huge concern in manufacturing environments, where high performance in mechanical properties such as toughness and hardness is in high demand [6]. Increase in concentration of carbon dissolved in austenite prior to quenching during hardening heat treatment leads to increase in hardness and other mechanical properties of steels [6,7], through the transformation from austenite to martensite, while the core remains soft and tough as a ferrite and/or pearlitic structure [8,9].

The potential of using sea shell as energizer in carburized steel was investigated by Ogo and Ette [10]. From their results, the addition of sea shell (Oyster shell) to charcoal produced a significant increase in the carburization rate, tensile strength and hardness of carburized steel [11-13]. As reported by them, local seashell also compared favorably with imported $BaCO_3$ as energizer, giving relative efficiency of 72.5%. However, there is limited report on the effect of grain size of energizer on the hardness of carburized steel.

The study of process parameters in metals during heat treatment has been of considerable interest for some years [14-17] but there has been relatively little work on process variables during the surface hardening process [18] since controlling parameters in carburization is a complex problem. The major influencing parameters in carburization are the soaking time, carburizing temperature, carbon potential and the quenching media [19].

The work is aimed at determining the potential use of seashell as steel energizer mixed with charcoal and the influence of energizer particle sizes on the mechanical properties of carburized AISI 1018 steel by optimizing weight percent and particle size of energizer.

2. EXPERIMENTAL PROCEDURE

2.1 Materials and Methods

A flat bar of mild obtained was analyzed and its nominal chemical composition is given in Table 1.

Table 1. Chemical composition of AISI 1018 mild steel (Eldorado Steel Industry, Lagos, Nigeria

C	Si	Mn	P	S	Fe
0.18%	0.215%	0.51%	0.022%	0.005%	Balance

Pack carburizing process was carried out in a muffle furnace. Seashell and Charcoal were obtained and grinded in a ball milling machine into powder to increase the surface area. The seashell powder was sieved using 212 µm, 425 µm and 600 µm sieve sizes respectively. Charcoal powder was mixed properly with an energizer (seashell) in the proportion of 9:1, 8:2, 7:3 and 6:4 as shown in Table 3. The seashell which contains $CaCO_3$ act as energizer and promotes the formation of carbon (iv) Oxide (CO_2 gas) which reacts with the excess carbon in the media to produce carbon (ii) Oxide (CO gas). This CO reacts with the mild steel surface to form atomic carbon which diffuses into the steel. The prepared samples were polished into mirror-like before carburization process began. The prepared steel samples were embedded inside a rectangular steel box, which was first filled with appropriate mixture (Charcoal/Seashell) which was then tightly sealed with clay mixed with moderate water in order to make the box air tight and to prevent unwanted furnace gas from entering the steel box during heating. The loaded steel carburizing box was charged into the furnace and then allowed to heat to temperature of 950°C. When the furnace temperature reaches the required carburizing temperature, it was then soaked at the temperature for the required time (4, 6 and 8 hours) respectively. The samples were held at the specified time, the steel carburizing box was removed from the furnace and the samples were quenched in water and oil at room temperature. The oil quenchant physical properties are shown in Table 2. The carburizing process was carried out in various batches in accordance with volume fraction of Charcoal/Seashell combination.

The carburized steel samples were tempered at a temperature of 200°C held for an hour and then cooled in air. Vickers hardness test was conducted on the carburized, tempered mild steel samples by using a Matsuzawa Seiko Vickers micro-hardness tester model MHT-1 with a Vickers diamond indenter. An indenting load of 100 kg, spacing of 50µm and a 10 second dwell time was used for each hardness indent action. The hardness of a sample is indicated by the penetration of the indenter on the said sample and displaced by the machine. For each of the sample, tests were carried out 5 times, and the average of all the samples was taken as the observed values in each case. The diamond shape of the indenter which is characterized by two diagonals remains on the surface of the sample after allowing dwelling for 10 seconds.

Table 2. Compound ratio of charcoal/seashell used for the carburizing process

Samples	Charcoal (wt. %)	Seashell (wt. %)
A	100	0
B	90	10
C	80	20
D	70	30
E	60	40

Table 3. Typical characteristics of the quenching Oil (As specified by the producer: Petro-Canada)

Characteristics	Values
Viscosity of cSt @ 40°C	14.0
Viscosity of cSt @ 100°C	3.2
Viscosity of SUS @ 100°F	74
Viscosity of SUS @ 210°F	37
Flash Point, °C/°F	173/343
Ramsbottom carbon residue, mass %	0.2
Quench Time, seconds	20
Nickel Ball	16
Chromized Nickel Ball	19

3. RESULTS AND DISCUSSION

From Fig. 1, after heat treating for 4 hours at 950°C, the steel sample quenched in water and heat treated with solid carburizing media of particle size 212 µm had the highest value of 300 HV at a composition ratio of 60% charcoal and 40% seashell. Particle size of 425 µm produced hardness value less than 212 µm and the least hardness value was obtained with particle size 600 µm. It shows that the finer the grain size of the energizer the better the hardness of the sample. According to Stephen and Edward et al. [20] changes in microstructure of tempered steels usually decrease hardness, tensile strength and yield strength but increase ductility and toughness. Tempering treatment of the carburized samples was carefully controlled in order for the quenching stresses to be relieved. Precipitation of carbon from supersaturated solid solution to a firmly dispersed carbide phase leads to great improvement in the toughness of steel with very little detriment to its hardness [21]. It shows that the lower the particle size, the higher the hardness value of the carburized and tempered samples. Particle size 425 µm compared favourably with 212 µm at soaking time of 4 hrs when quenched in water. Particle size of 600 µm showed half the values of hardness recorded by both 212 µm and 425 µm particle sizes.

From Fig. 2, with soaking time of 4hrs and temperature of 950°C, steel samples quenched in oil and heat treated with particle size of 212 µm still had the optimum hardness value of 270 HV which was low compared to water quenched samples. The hardness measurements presented in Fig. 1 show that water quenched samples had higher hardness number compared to oil quenched samples in Fig. 2. This may be due to the fast cooling rate of water resulting in highest free carbon in martensite as reported by Gunduz et al. [22]. Moreover, the presence of fine dispersion of small particles in the pro-eutectoid ferrite and pearlitic ferrite, which hinders the dislocation movement, may have also contributed to the higher hardness number of the water quenched samples as shown in Fig. 1. Particle size of 212 µm showed a sinusoidal curve. At 30% wt. of energizer, the hardness value dropped by 18% and increased in values with decreased weight percent of seashell. 425 µm particle size showed a regression curve with decreased volume fraction of seashell. Samples quenched in water gave better hardness improvement as compared to samples quenched in oil. The finer grain size had influence on the hardness of steel with increase carburizing time [19].

From Fig. 3, after heat treating for 6 hours with carburizing temperature of 950°C, the steel sample that was quenched in water with particle size of 425 µm had the highest value of 269 HV at a composition ratio of 80% charcoal and 20% energizer. After this, the hardness decreased with increased volume fraction of energizer. Particle size 212 µm gave the lowest hardness value at 100% wt of charcoal. This shows the influence of energizer and its particle size on the hardness property of carburized and tempered samples. Particle size of 600 µm showed no improvement even at higher soaking time when quenched in water.

From Fig. 4, after heat treating with the same condition as Fig. 3, but quenched in oil, particle size of 600 µm picked at value of 301 HV at a volume fraction of 80% charcoal, 20% energizer, although there was a drastic decrease in hardness values at some other composition ranges. 212 µm particle size started slowly and peaked at 265HV before decreasing with an increased volume fraction of energizer. The least hardness value was obtained from 425 µm particle size. By comparing Figs. 3 and 4, samples quenched in oil with particle size of 425µm showed drastic decrease in hardness value as shown in Fig. 4 compared to the values displayed by the same particle size when quenched in water.

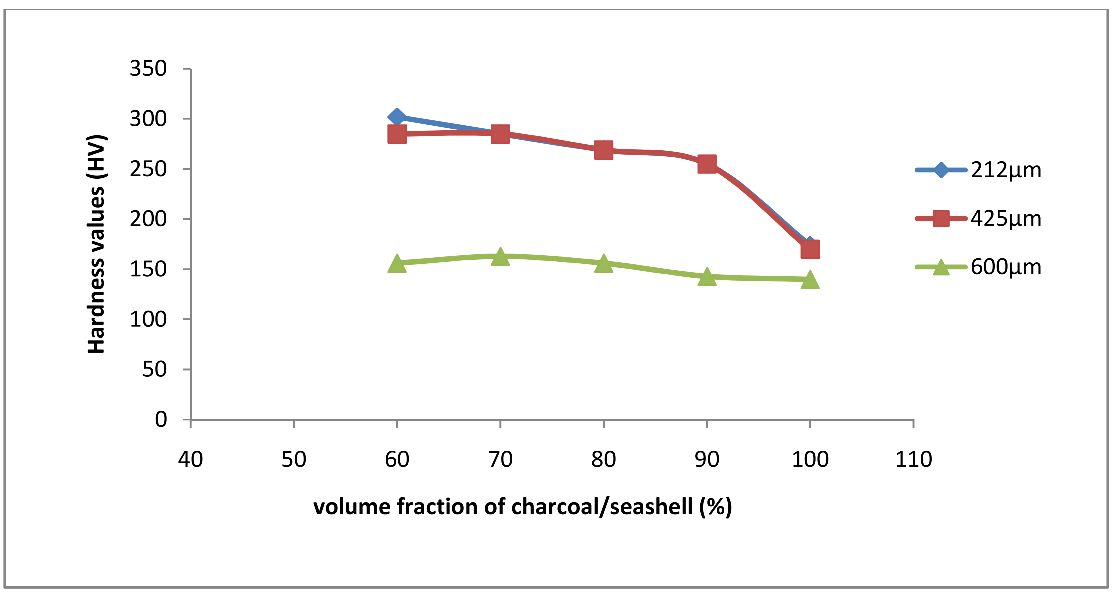

Fig. 1. The relationship between hardness and particle sizes of energizer after 4hrs at 950ºC. (Water quenched)

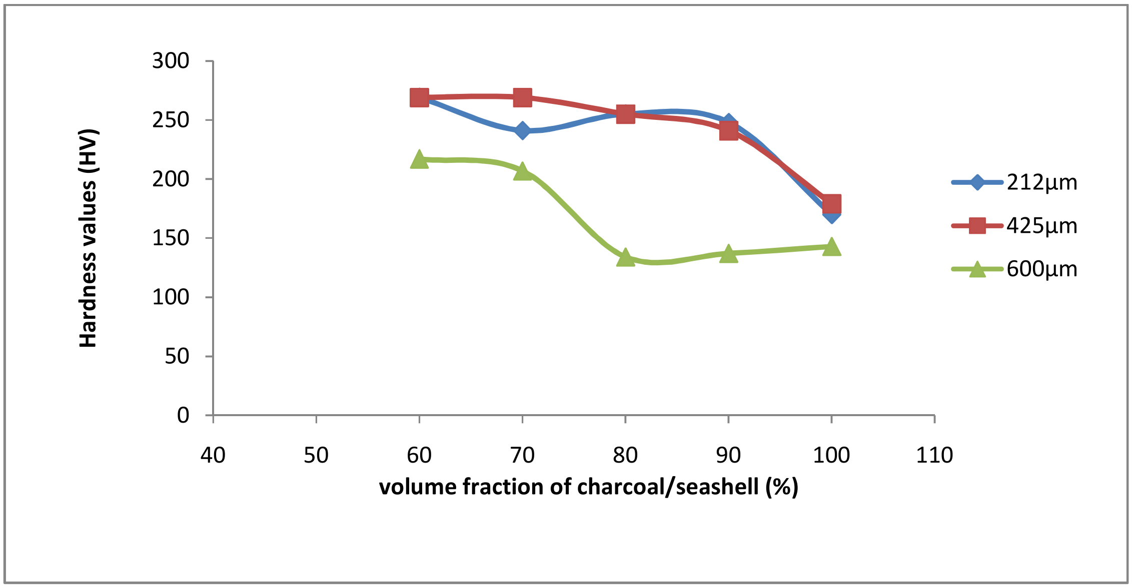

Fig. 2. The relationship between hardness and particle sizes of energizer after 4 hrs at 950ºC. (Oil quenched)

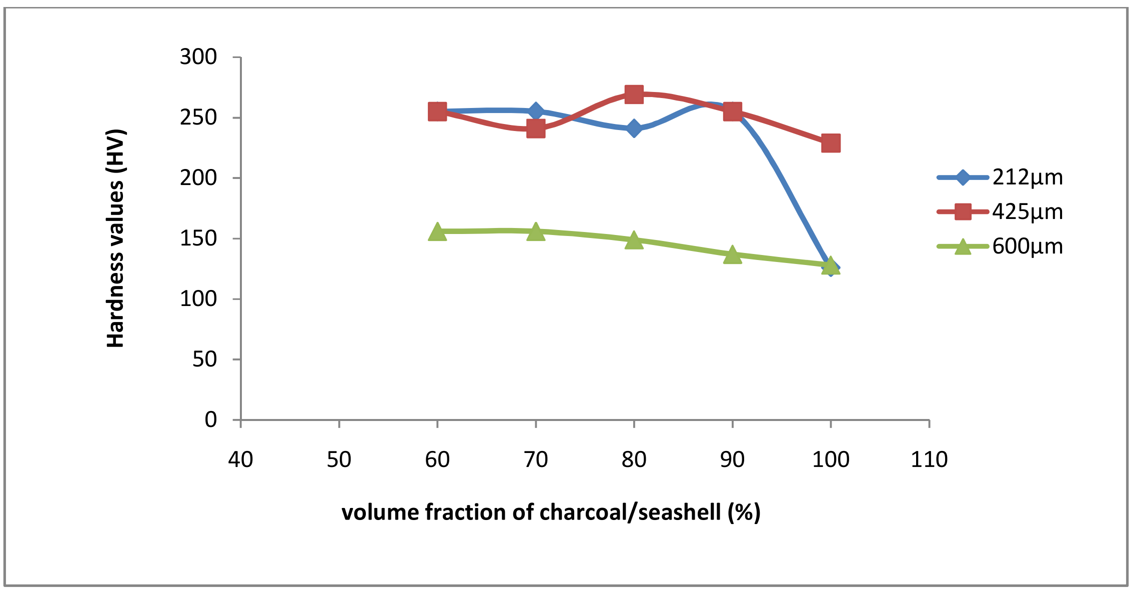

Fig. 3. The relationship between hardness and particle sizes of energizer after 6 hrs at 950ºC. (Water quenched)

Fig. 5 produced the optimum hardness value of 310 HV with particle size of 212 µm at volume fraction of 90% charcoal, 10% seashell. Particle size 425 µm had a slight increase in hardness value while 600 µm had a decrease in hardness values with an increased volume fraction of energizer respectively. The difference in hardness values displayed by 212 µm was twice the values displayed by both 425 µm and 600 µm respectively. Therefore, particle size of 212 µm yielded the optimum hardness values of 310 HV at volume fraction of 90% charcoal and 10% seashell. It implies hardness increases with decreasing particle size. Moreover, seashell will serve as a potential steel energizer in carburizing process as reported by Fatoba et al. [13].

From Fig. 6, after heat treating for 8 hours with a furnace temperature of 950°C, the steel sample was quenched in oil. Particle size of 212 µm had hardness values of 280 HV far above the other particle sizes at a volume fraction of 90% charcoal and 10% energizer addition. The 212 µm particle size increased in hardness value with increased weight percent of energizer but decreased in value at 30% addition of energizer and slightly improved at 40% addition of energizer. With 600 µm particle size, the highest hardness value was achieved at 10% addition of seashell.

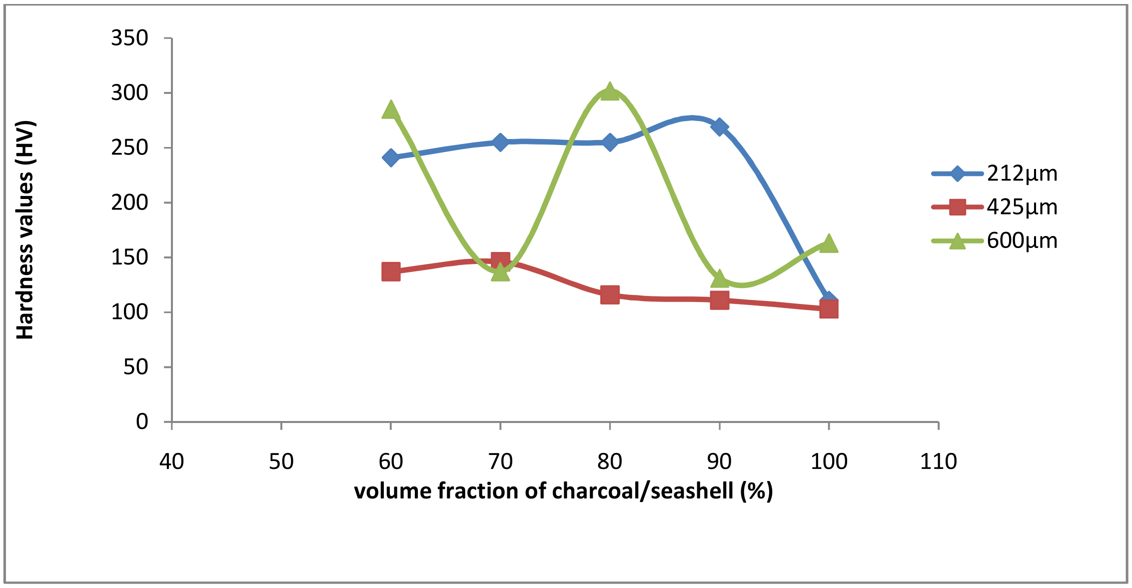

Fig. 4. The relationship between hardness and particle sizes of energizer after 6 hrs at 950ºC. (Oil quenched)

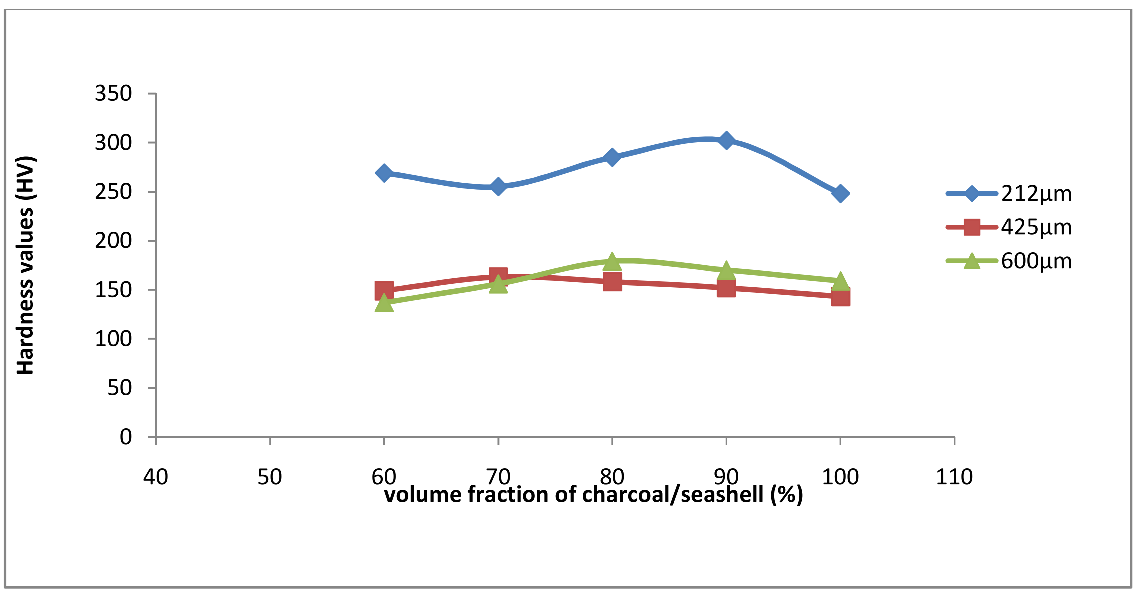

Fig. 5. The relationship between hardness and particle sizes of energizer after 8 hrs at 950ºC. (Water quenched)

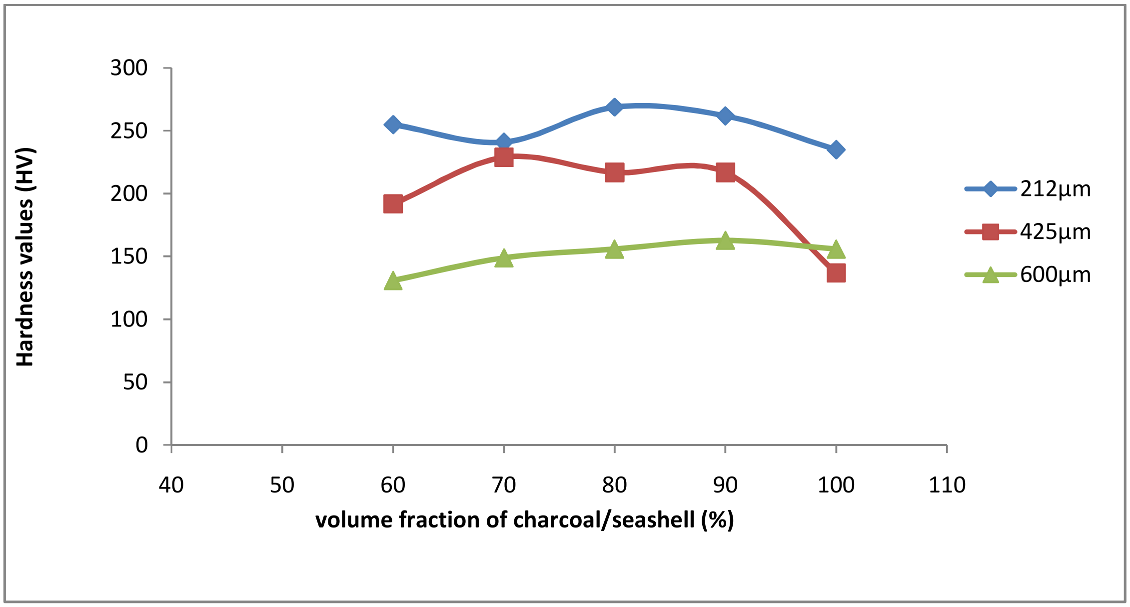

Fig. 6. The relationship between hardness and particle sizes of energizer after 8 hrs at 950ºC. (Oil quenched)

4. CONCLUSION

The followings can be deduced from the results:

- There is a significant increase in the carburization rate of low carbon steel by the addition of seashell to charcoal. This can be seen in the difference between the hardness values of carburized steel for 100% charcoal (as received) and samples which had sea shell energizer added for equal soaking time, particle size and quenching media. The 100% charcoal samples had lowest hardness values than the energized samples.
- The optimal carburizing effect was achieved at 90% charcoal and 10% seashell for 212 µm particle size at 8hrs soaking time when quenched with water. This yielded optimum hardness values of 310 HV. It implies hardness increases with decreasing particle size. It indicates the best condition under which sea shell should be used as an energizer for the carburization of mild steel.
- Better efficacy might be derived using longer furnace holding times and finer grain sizes of seashell. The longer holding times suggest longer periods for the carbon diffusion to occur in the furnace which will increase the case depth and hence hardness of the carburized samples. The finer grain sizes on the other hand, indicate a larger surface area which is a precursor for a faster reaction rate.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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