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The effects of energizer, carburizing temperature and time on the mechanical properties of hardened big knives in a pack carburizing process

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Abstract

The purpose of this research is to study the effects of energizer, carburizing temperature and time on the mechanical properties of hardened big knives in a pack carburizing process. The mechanical properties of carburized and hardened big knives were compared to those of commercial hardened big knives made from leaf-spring steel that were forged, ground and quenched following traditional processes. The experiment was conducted by forging big knives made from low carbon steel (grade AISI 1010). The first group of them was then pack-carburized using 10 wt% of calcium carbonate with 90 wt% of eucalyptus charcoal. The second group used 10 wt% of egg shells with 90 wt% of eucalyptus charcoal. The carburizing temperatures were 900, 950 and 1,000 °C, with carburizing times of 30, 60 and 90 minutes followed by air cooling. The austenitizing temperature was 780 °C with a holding time of 20 minutes, followed by quenching in water. Finally, the big knives were tempered at 180 °C for 1 hour. Micro-Vickers hardness testing, impact testing and microstructure inspection were carried out. The results of this experiment showed that the hardness of hardened big knives increased with increasing carburizing temperature and time, while its impact value decreased. The hardness derived from using $CaCO_3$ was slightly more than that using egg shells, however, the impact energy was higher when using egg shells compared to using $CaCO_3$.

Keywords: Pack carburizing, Calcium carbonate, Egg shells, Carburizing temperature, Hardened big knives

1. Introduction

Forging of agricultural knives is a process that has been used for a long time. Examples of agricultural knives are big knives and sugar cane cutting knives. Normally, big knives are made from leaf-spring steel, as it has high hardness after quenching. However, the limitations in using leaf-spring steel are that it is difficult to forge and shape the knife, as well as being expensive. It would be useful to the agricultural community if these problems could be solved.

The pack carburizing technique is one of several heat treatment processes used in the metal-working industry. It is a simple process with low investment costs. This process can increase the surface hardness of low carbon steel by increasing carbon content in the surface of steel. The atoms of carbon are from coal and wood charcoals that are activated by energizers. The energizers are composed of carbonate, such as barium carbonate ($BaCO_3$), sodium carbonate (Na_2CO_3) and calcium carbonate ($CaCO_3$). CO_2 gas from the decomposition of energizers reacts with carbon in charcoal and produces CO gas. The CO gas then reacts with the surface of steel and diffuses into the surface as follow [1-3]:

$$3Fe + 2CO \rightarrow 3Fe + C_{(\text{dissolve in } \gamma)} + CO_2 \qquad (1)$$

The carbonate energizers can be classified as synthesis and natural carbonates. Natural carbonate can be found in carbonate materials such as limestone and egg shell. Egg shell is composed of 97% calcium carbonate [4]. A carbonate material such as limestone contains 80-98% $CaCO_3$, while dolomitic limestone contains 42.8-57% $CaCO_3$ [5]. Ihom A. P. et al investigated the possibility of utilizing egg shell waste as an energizer in the case-hardening of mild steel [6]. The results showed that egg shell containing carburizing material produced higher case hardness in steel than carburizing materials without egg shell. Thammachot N. and Homjabok W. used the egg shell as the natural energizer in increasing carbon content on the surface of hardened big knives by the pack carburizing process [7]. This study fixed the carburizing temperature at 950°C and carburizing times of

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30, 60 and 90 minutes. The carburizing temperature strongly affects the effective case depth in the carburizing process, as is well-known [1-3, 8]. This work continued to examine the effect of carburizing temperatures and times on the hardness of hardened big knives using calcium carbonate and egg shell as energizer in the pack carburizing process. This paper differs from the previous papers in varying the carburizing temperature (900, 950, 1,000°C), and holding times (30, 60, 90 minutes), and applying the pack carburizing process for hardening big knives by using egg shell as the natural energizer.

2. Materials and methods

2.1 Material preparation

The commercial hardened big knives used as specimens were made from leaf-spring steel ordered from a knife forging shop. Their size and shape were the same as commercial big knives. These knives were forged, ground and quenched the same way as in the traditional knife forging process. The knives were cut into specially-shaped specimens for hardness tests, impact tests, and microstructure examination.

As for the knives that were hardened by the pack carburizing process, a big knife was made by forging low carbon steel (grade AISI 1010). The size and shape of the big knife were the same as a commercial big knife. The big knife was then cut into parts as shown in Figure 1. Carburizing compound was prepared by crushing eucalyptus wood charcoal into powder. The charcoal powder was screened by a pan with 2 mm grids. Egg shell was also crushed into powder and screened by a pan with 1 mm grids. The 90% by weight of charcoal powder was then mixed with 10% by weight of $CaCO_3$ powder for the first condition. The second condition used 10% by weight of egg shell powder with 90% by weight of eucalyptus charcoal. The $CaCO_3$ powder in this study was a commercial grade which is generally sold in scientific material stores. The back titration technique for determining the purity of $CaCO_3$ was used. The results indicated that the commercial calcium carbonate contained 99.39% $CaCO_3$ while the egg shell contained 94.12% $CaCO_3$.

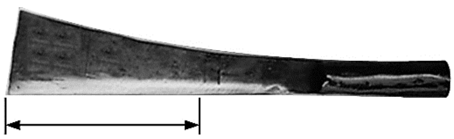


Figure 1 Part of a big knife for pack carburizing

2.2 Carburizing and quenching processes

A part of the big knife was embedded with carburizing material in a steel box as shown in Figure 2. The steel box was filled with carburizing material until it covered the part of the big knife. The lid of the carburizing box was then placed and sealed with clay paste to avoid air ingress so that oxidation would not take place.

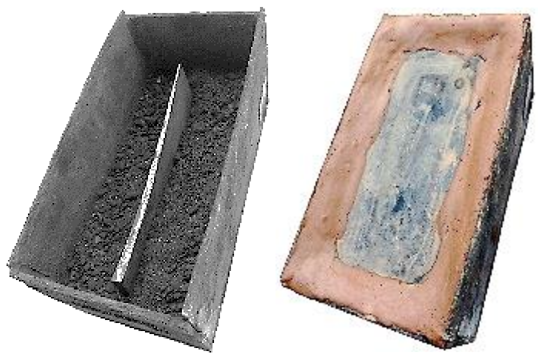
The carburization operation was carried out using an electrical resistance furnace at temperatures of 900, 950 and 1,000°C, and holding times of 30, 60 and 90 minutes. The carburizing box was taken from the furnace after the holding time was reached and the part of the big knife was removed from the carburizing box for air-cooling. Following this, a hardening process was carried out at an austenitizing temperature of 780°C, with a holding time of 20 minutes. Quenching was done in water immediately after removal from the furnace to avoid temperature drop. The tempering was carried out at 180°C, with a holding time of 1 hour.

2.3 Hardness test

Both hardened big knives made from low carbon and leaf-spring steel were tested in order to determine their hardness. A part of the hardened big knife was cut off and mounted with resin for easy handling. The specimens were ground with grits of 240-1200 and were polished on a finishing disc of 0.5 and 0.03 micron alumina paste. The hardness of the knife was measured using a Micro-Vicker hardness test machine with a load of 300 g. Figure 3 shows the positions where hardness measurements were carried out. The specimens' hardness was measured at the sharp edge of the knife. Along the sharp edge of the knife, hardness was measured 0.1 mm from the edge, at intervals 0.5 mm from the first point.

2.4 Impact test

The impact test was used to determine the impact energy of a big knife. The specimen was not tested as the standard specimen since the present study intended to test the specimen under the original condition (shape and size) of the hardened big knives. A hardened big knife (low carbon and leaf-spring steel) was cut to be a specimen for impact testing as shown in Figure 4 (a). The specimen was 70 mm in length. The impact test was performed using the Charpy test and the result after testing is shown in Figure 4 (b).



(a) (b)

Figure 2 (a) A part of the big knife embedded in a steel box (b) The lid of the carburizing box was sealed using clay

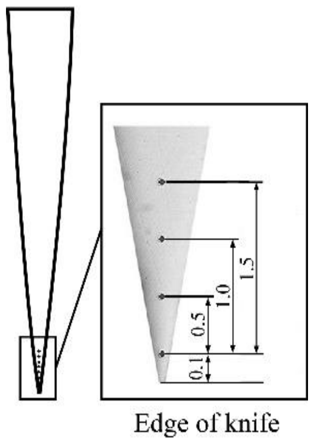


Figure 3 Hardness test positions on the sharp edge of the knife (Unit: mm.)

Table 1 Chemical composition of specimens

	Chemical Composition (% by weight)						
Steel	**C**	**Mn**	**Cr**	**Ni**	**Mo**	**Si**	**V**
Untreated specimen	0.129	0.456	0.053	0.091	0.012	0.062	<0.0005
Leaf-spring steel	0.582	0.802	0.816	0.043	0.016	0.269	0.012

(a) (b)

Figure 4 (a) Length of impact test specimen (b) Specimen after impact test

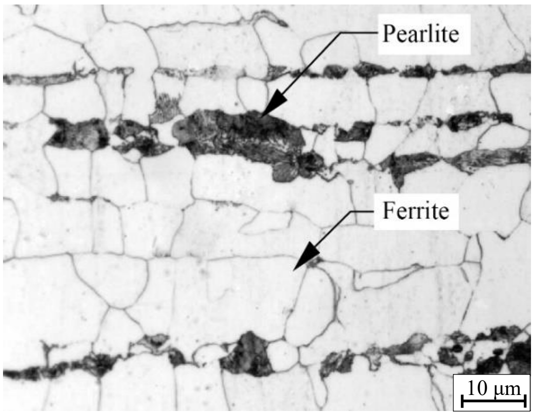


Figure 5 Microstructure of untreated specimen

2.5 Chemical composition and microstructure examination

The untreated specimens were checked for chemical composition by using the spark emission spectrometer (brand name SPECTROMAXx). Both the untreated specimens and hardened big knife were examined for their microstructure. A hardened big knife (low carbon and leaf-spring steel) and untreated specimens were cut, mounted, and ground by a disc grinding machine with grits of 240-1200. These specimens were then polished on the polishing disc using 0.5 and 0.03 micron alumina. A 2% nital solution was used to etch the specimens. A photomicrograph was then taken using an optical microscope.

3. Results

3.1 Chemical composition and microstructure of untreated specimens

The untreated specimens were checked for chemical composition by using the spectrometer. The results are shown in Table 1. The percentages of carbon and manganese in the untreated specimens are in a range of chemical composition standard (0.08-0.13% C, 0.30-0.60% Mn) [9], which is equivalent to carbon steel grade AISI 1010. The leaf-spring steel has 0.582% C, 0.802% Mn, and 0.818% Cr. This chemical composition is in a range of spring steel grade JIS SUP9A, which is equivalent to alloy steel grade AISI 5160 (0.56-0.64%C, 0.75-1.00% Mn, 0.15-0.30% Si, 0.70-0.90% Cr) [9-10]. The microstructure of the untreated specimens is shown in Figure 5. The microstructures of the untreated specimens consist of ferrite and pearlite.

3.2 Comparison of hardness

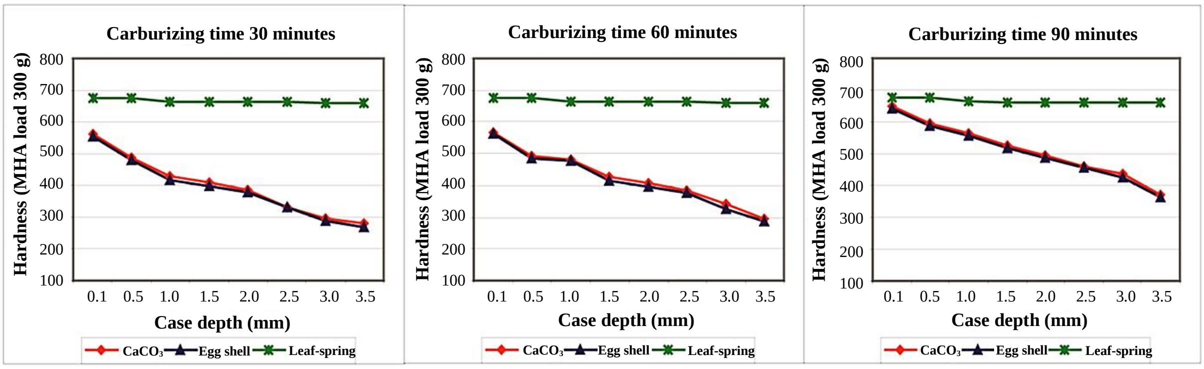
The comparison of hardness at the sharp edges of knives that used egg shell and $CaCO_3$ as an energizer with carburizing temperatures of 900, 950 and 1,000°C is shown in Figure 6. The hardness of the knives is increased with increased carburizing temperature and time. As for the carburizing time of 900 °C, the hardness of the knives is lower than the hardness of leaf-spring steel. The hardness resulting from carburizing temperatures of 950 and 1000°C with carburizing times of 30 and 60 minutes is nearly the same as that of leaf-spring steel at the case depth of 2.5 mm. While at the carburizing temperature of 950 and 1000°C with the carburizing time of 90 minute, the hardness of knives that used using egg shell and $CaCO_3$ is higher than that of leaf-spring steel. The interesting thing is that the hardness of the specimens that used $CaCO_3$ is nearly the same as the specimens that used egg shell, at all carburizing temperatures and times. The results of hardness comparison indicated that the carburizing temperature and time have an effect on the diffusion of carbon. Also, the egg shell as natural energizer has an efficiency nearly the same as that of commercial energizer ($CaCO_3$).

3.3 Comparison of impact energy

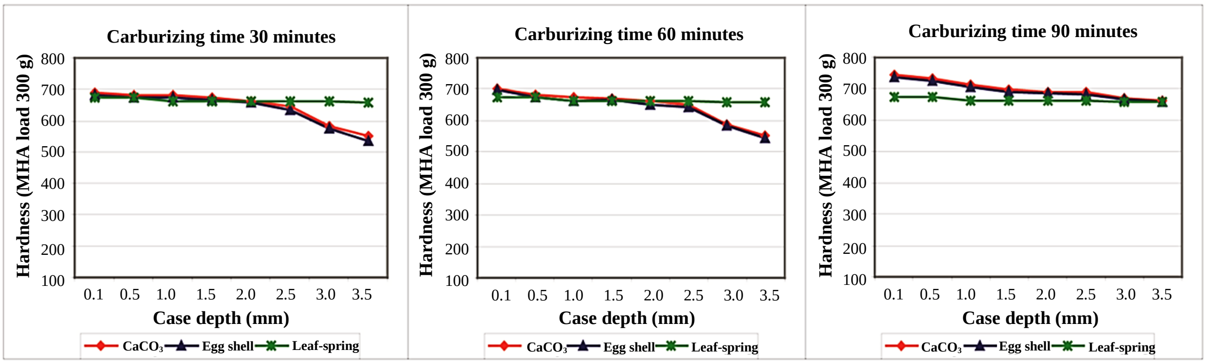
Figure 7 shows the comparison of impact energy of several carburizing temperatures and times. The results indicated that increasing carburizing temperatures and times resulted in a decrease in impact energy. It was also found that the impact energy decreased with an increase in hardness. The impact energy of $CaCO_3$ was found to be lower than that of leaf-spring steel at the carburizing temperatures of 950 and 1000°C with the carburizing times of 60 and 90 minutes. An increase in carburizing temperature and carburizing time results in an increase in hardness which makes the knife more brittle. However, it was illustrated that the impact energy of egg shell is higher than that of leaf-spring steel with all carburizing temperatures and times.

3.4 Microstructure

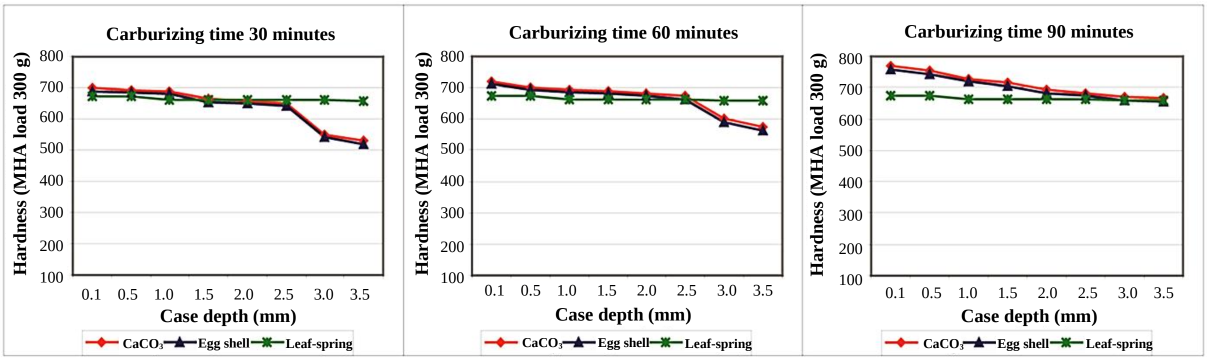
Microstructures of hardened big knives are shown in Figure 8. The selected microstructures were at the carburizing temperature of 950°C and with a carburizing time of 60 minutes. The hardness of the selected microstructure under these conditions was found to be nearly the same as that of the leaf-spring steel, while the impact value was higher than that of leaf-spring steel. The hardness resulting from the carburizing temperature of 900°C was lower than that of leaf-spring steel, while the hardness resulting from a carburizing temperature of 1,000°C was higher. These microstructures were taken at the position of 0.5, 2.0 and 5.0 mm from the sharp edge. The microstructure at the position of 0.5 mm of both $CaCO_3$ and egg shell consist of martensite matrix (Figure 8 (a, b). In the case of $CaCO_3$, some carbides and spheroid carbides dispersed in the



(a) Carburizing temperature 900 °C

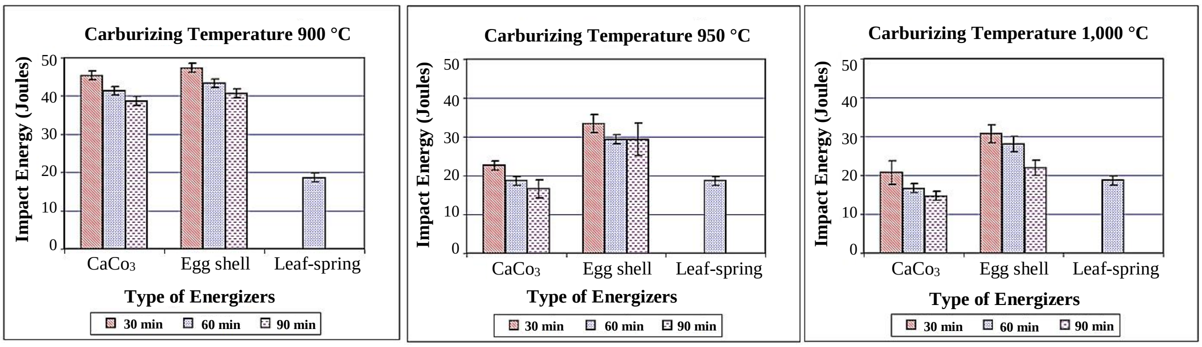


(b) Carburizing temperature 950 °C



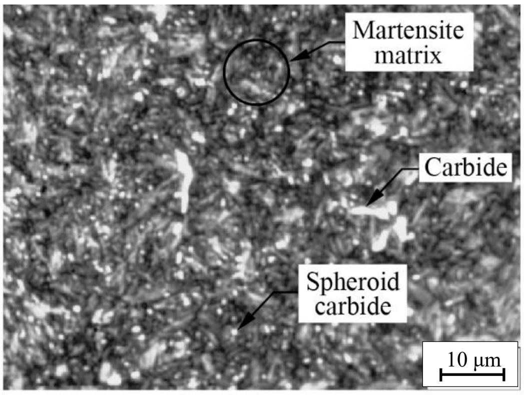
(c) Carburizing temperature 1,000 °C

Figure 6 Hardness of sharp edges of knives for several carburizing temperatures and times

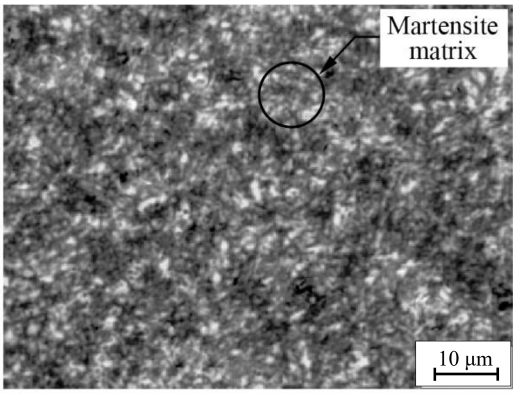


(a) Carburizing temperature 900°C (b) Carburizing temperature 950°C (c) Carburizing temperature of 1,000°C

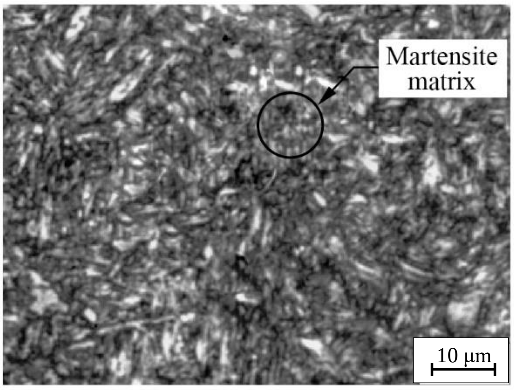
Figure 7 Impact energy of knives for several carburizing temperatures and times



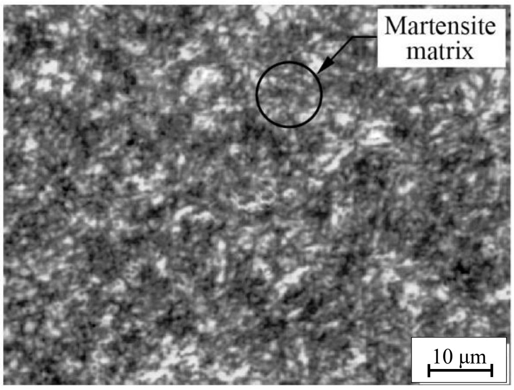
(a) $CaCo_3$, case depth 0.5 mm.



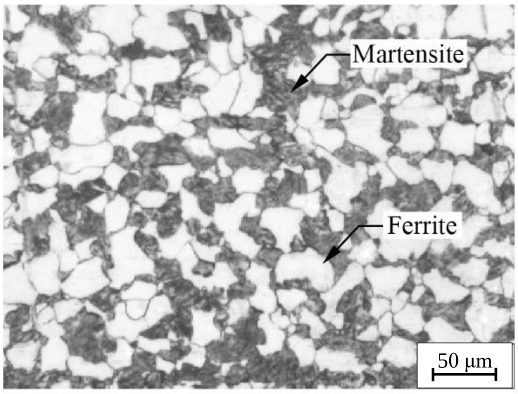
(b) Egg shell, case depth 0.5 mm.



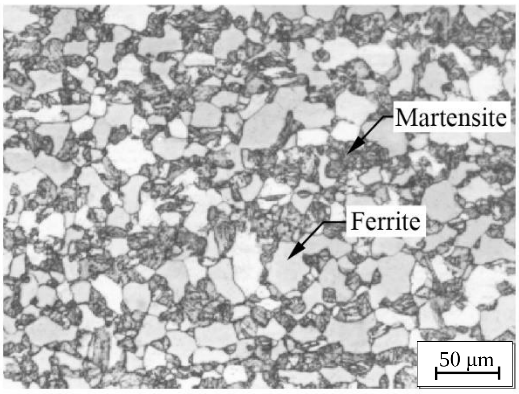
(c) $CaCo_3$, case depth 2.0 mm.



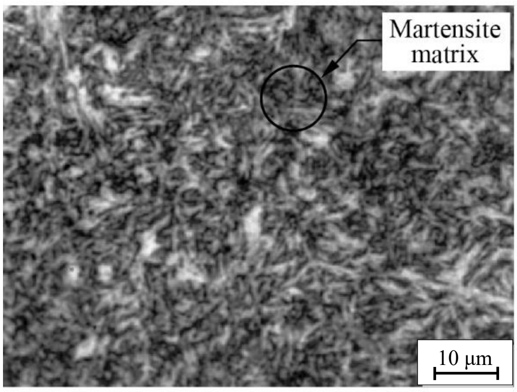
(d) Egg shell, case depth 2.0 mm.



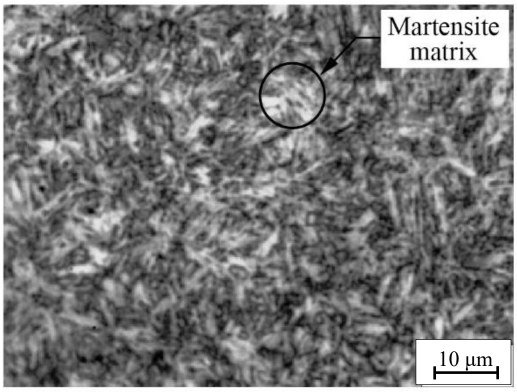
(e) $CaCo_3$, case depth 5.0 mm.



(f) Egg shell, case depth 5.0 mm.



(g) Leaf-spring steel, case depth 0.5 mm.



(h) Leaf-spring steel, case depth 2.0 mm.

Figure 8 Microstructure of hardened big knives at several positions martensite matrix as seen in Figure 8 (a) which leads to slightly increased hardness when compared to that of egg shell. The microstructures at a case depth of 2.0 mm are still martensite matrix. At the position of 5.0 mm, the microstructure consists of martensite and ferrite. Because few carbon atoms diffused, a large amount of ferrite occurred, leading to a very low level of hardness at this position. The microstructure of leaf-spring steel as shown in Figure 8 (g, h) consists of martensite matrix.

4. Discussion

The experimental results showed that the two factors of carburizing temperature and carburizing time had dramatic effects on the hardness of the surface of the steel. Increasing both of them led to the diffusion of carbon atoms into the surface of the steel. This can be explained using Fick's law that says the concentration of solute atoms at any point in the material changes with time [8]. Also, increasing the temperature of a diffusion system will increase the diffusion rate. Then, an increase in carburizing temperature (900, 950, 1,000°C) and carburizing time (30, 60, 90 minutes) results in an increase in hardness.

The results of the experiment also showed that the hardness derived from $CaCO_3$ was slightly harder than that of the egg shell. This means that $CaCO_3$ has the ability to activate carbon atoms better than egg shell. Because the commercial energizer had a higher level of purity of $CaCO_3$ than that of the natural egg shell energizer, the hardness derived from the commercial energizer was slightly harder than that of the egg shell. However, the egg shell contains about 94.12% $CaCO_3$, leading to a level of hardness in the big knives using egg shell that is nearly the same as that of the knives using $CaCO_3$. Moreover, the hardness of the big knives using the egg shell is higher than that of the leaf-spring steel in the case of high carburizing temperature and time. Thus, egg shell can be used as a natural energizer in the pack carburizing process for hardening big knives. This is one method of using solid waste that is economical, therein reducing material costs.

If the hardness and impact energy of leaf-spring steel is used as a criterion, the egg shell with a carburizing temperature of 950 and 1,000°C, and all carburizing times, has a higher value than that of leaf-spring steel. $CaCO_3$ offers higher hardness, but the impact energy is lower than that of leaf-spring steel. The reason is that the commercial calcium carbonate has a high purity level of $CaCO_3$ which can activate more carbon atoms for diffusion into the surface of steel. The high amount of carbon contained in the surface produces carbide structures (Figure 8 (a)) which increases the hardness, but also produces brittleness.

Considering the criteria mentioned above, the egg shell used in the carburizing process as an energizer is able to produce both hardness and ductility. The egg shell has a lower level of purity of $CaCO_3$ than that of the commercial calcium carbonate. This leads to a lower ability to activate carbon atoms when compared to that of the commercial calcium carbonate (Figure 8 (b). The lower number of carbide structures results in a lower level of hardness, but higher ductility when compared to the commercial calcium carbonate. The egg shell produces both hardness and ductility, which is one of the most important characteristics of a samurai sword [11], which has high hardness on the surface for providing sharpness, and a soft core for offering elasticity.

5. Conclusions

The results of this study show that the carburizing temperature and carburizing time directly affect the hardness of the surface of hardened big knives. The hardness of the big knives is increased with the increased carburizing temperature and carburizing time. Increasing carburizing temperature and carburizing time can activate more carbon atoms for diffusion into the surface of steel, leading to a higher concentration at the surface of the steel, therein producing carbide structures which increase the hardness, and producing the brittleness that reduces the impact energy. The egg shell can be used as a natural energizer in the pack carburizing process for hardening big knives, which offers both a higher level of hardness and impact energy than that of leaf-spring steel.

6. Acknowledgements

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7. References

[1] Sinha AK. Physical metallurgy handbook. USA: McGraw-Hill; 2003.

[2] Lakhtin YM. Engineering physical metallurgy and heat treatment. Russia: Mir Publishers Moscow; 1990.

[3] Rajan TV, Sharma CP, Sharma A. Heat treatment; principles and techniques. Revise Edition. New Delhi: Prentice-Hall of India Private Limited; 1994.

[4] Daengprok W, Garnjanagoonchorn W, Mine Y. Fermented pork sausage fortified with commercial or hen eggshell calcium lactate. Meat Sci. 2002;62:199-204.

[5] Khorram F, Memarian H, Tokhmechi B, Soltanian-zadeh H. Limestone chemical components estimation using image processing and pattern recognition techniques. J Min Environ. 2011;2(2):126-35.

[6] Ihom AP, Nyior GB, Nor IJ, Ogbodo NJ. Investigation of egg shell waste as an enhancer in the carburization of mild steel. Am J Mater Sci Eng. 2013;1(2):29-33.

[7] Thammachot N, Homjabok W. The efficiency of natural energizers in increasing carbon content on surfaces of big knives in the pack carburizing process. The 6th International Conference on Science, Technology and Innovation for Sustainable Well-Being (STISWB VI); 2014 August 28-30; Siem Reap, Kingdom of Cambodia; 2014. p.186-92.

[8] Smith WF. Principles of materials science and engineering. 3th ed. USA: McGraw-Hill; 1996.

[9] Chandler H. Heat treater's guide; practices and procedures for irons and steel. USA: ASM International; 1995.

[10] Yamada Y. Materials for springs. Berlin: Springer-Verlag Berlin Heidelberg; 2007. p.48-49.

[11] Morimoto M. The forging of a Japanese Katana. Colorado: Colorado school of mines; 2004. p.8-16.