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Mechanical Properties of Pack Carburized AISI 4340 with Variation Energizer Composition of Barium Carbonate ($BaCO_3$) and Sodium Carbonate (Na_2CO_3)

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Abstract

This research aimed to determine the mechanical strength of American Iron and Steel Institute (AISI) 4340 steel after pack carburizing with a combined variation of barium carbonate ($BaCO_3$) and sodium carbonate (Na_2CO_3) as an energizer. Combination of two variations of energizer materials as an alternative to improve mechanical properties. The various ratios of energizer: 40/60, 50/50, and 60/40% w/w. The mechanical test was conducted to determine tensile (American Society for Testing and Material-ASTM E-8), impact strength (ASTM E-23), Rockwell hardness (ASTM E-18), and microstructure characterization (ASTM E-3). Both type specimens were temperature pack carburized was 950 ℃, and the holding time was 3 hours. Results showed that Specimen C had the lowest ultimate tensile strength mean value of the other specimens, which was 333.43±30.22 MPa. The impact test results showed that the lowest impact energy value was found in Specimen C, which is 4.32 Joules, and the highest impact energy value was found in specimens without treatment, which was 15.80 Joules. The microscope observation indicated that the specimen's microstructure was martensite structure increase, and the results of the hardness test were influenced by the martensite phase.

1 Introduction

Pack carburization has improved the various mechanical properties of metals and alloys. The different temperature ranges of 850 °C, 900 °C, and 950 °C have been studied, and it is found that the simple heat treatment dramatically improves the hardness [1]. The steel industry plays a significant role in supplying raw materials for development in various fields, from providing infrastructure, transportation equipment, and industrial machinery to weapons [2]. Because of its vital role, the existence of the steel industry is very strategic for the prosperity of a country. One of the steels used in industrial activities is AISI 4340 steel. The carburizing process primarily aims to wear the resistance surface on mechanical components by enriching the surface layer with carbon to a concentration from 0.75 to 1.2% [3].

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AISI 4340 is a steel with an alloy of nickel, chromium, and molybdenum. One of the applications of AISI 4340 steel is in gears, shafts, and aircraft landing gear [4,5]. AISI 4340 carbon steel is required to improve its properties, such as hardness, ductility, upper hardness, and resistance to friction. In general, to obtain these properties, it is necessary to carry out a heat treatment process to increase the metal's hardness. The heat treatment of materials of low carbon steel at a diameter of 1588 cm with the pack carburizing at a heating temperature of 850 °C for long-lasting 30 minutes on the size of the mesh 30 and the load used for the suppression of 60 kg with the variation of the percentage of bone charcoal buffalo effect on the hardness [6].

The effect of the carburizing parameter, such as carburizing temperature, carburizing media, immersion time, carburizing composition, and cooling method, affects the hardness value and the depth of the steel layer. The higher the carbon carburized, the more carbon will be diffused, so the higher the surface hardness of the steel [7,8]. Based on the description above, in this study, variations in the composition of the energizer on the carburizing pack will be carried out on the mechanical properties (tensile strength, hardness, and impact strength) and the characteristics formed from the results of these tests. The authors are interested in conducting research with the title "Mechanical Properties Of Pack Carburized AISI 4340 With Variation Energizer Composition of Barium Carbonate ($BaCO_3$) And Sodium Carbonate (Na_2CO_3)".

2 Experimental Methods

2.1 Materials and instruments

This research employed an AISI 4340 steel plate, and the media used was coconut shell charcoal. The necessary tools were such as hanging sieve, muffle furnace, digital caliper, Autodesk Inventor software, Siemens Computer Numerical Control (CNC) milling machine, tensile test equipment (Material Test System) MTS Exceed Model E64, Gotech brand impact tester, Rockwell brand TH500 hardness tester, microstructure characterization instrument Insize Digital Microscope with Stand and ISM-PRO software.

2.2 Methods

The tensile test specimen pattern was adjusted to the ASTM E-8 standard dimensions (130 mm × 10 mm × 5 mm), and the impact test specimen according to the ASTM E-23 standard dimensions (55 mm × 10 mm × 10 mm). After getting the specimen pattern according to each dimension, the next step was to pack carburizing with a variation of the carburizing medium energizer and then quenched it with Society of Automotive Engineers (SAE) 40 oil cooling media. Next, testing the specimen using the tensile, hardness, and impact tests. Specimen preparation refers to several parameters, as in Table 1.

Table 1. Parameters of pack carburizing

Specimen Code	Energizer Variation $BaCO_3$:Na_2CO_3 (% w/w)	Composition Energizer: Activated Carbon (% w/w)	Temperature (°C)	Holding Time (Hour)	Grain Size (Mesh)	Cooling Media
A	40:60	80:20	950	3	28	Oil SAE 40
B	50:50	80:20	950	3	28	Oil SAE 40
C	60:40	80:20	950	3	28	Oil SAE 40

2.2.1 Specimen measurement

The specimen was measured manually by using a caliper with Insize Digital Caliper. The following is how to measure the specimen in Figure 1 below.

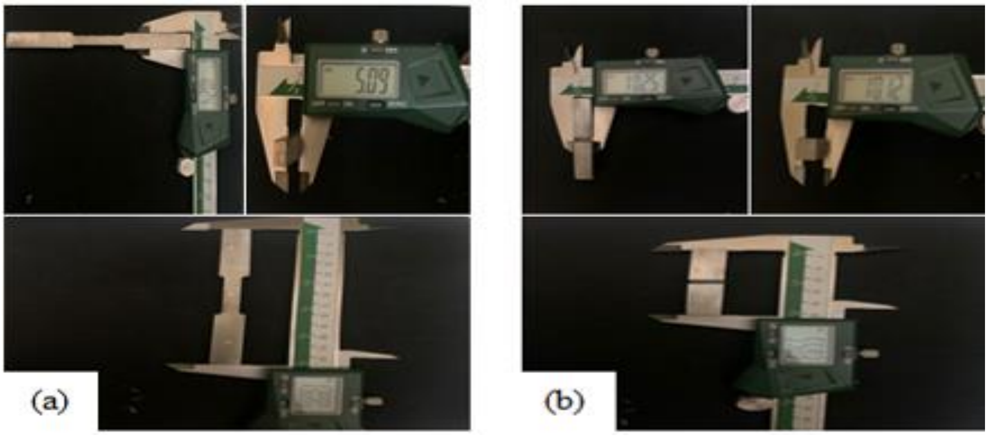


Figure 1. Specimen measurement: (a) ASTM E-8, and (b) ASTM E-23

2.2.2 Tensile test

Tensile testing was used to determine the tensile strength, elongation, yield strength, von-Mises, Poisson ratio, and Young modulus using ASTM E-8 specimens. Tensile test machine MTS Exceed Model E64 with a testing speed was 0.4 mm/s. The following are the specimen dimensions used in the tensile test in Figure 2.

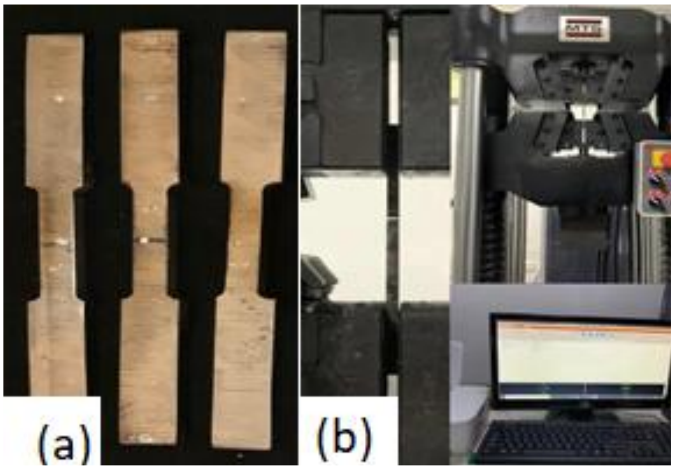


Figure 2. Tensile test: (a) Specimens [9], and (b) Tensile test machine

2.2.3 Impact test

This impact test was carried out to determine the ability of a material to accept impact loads with the size of the energy required to break the specimen. Impact tester with an impact radius of ±0.674 m. The mass of the pendulum used was ±23.87 kg. The angle used was 150°. The following are the specimen dimensions used in the impact test in Figure 3.

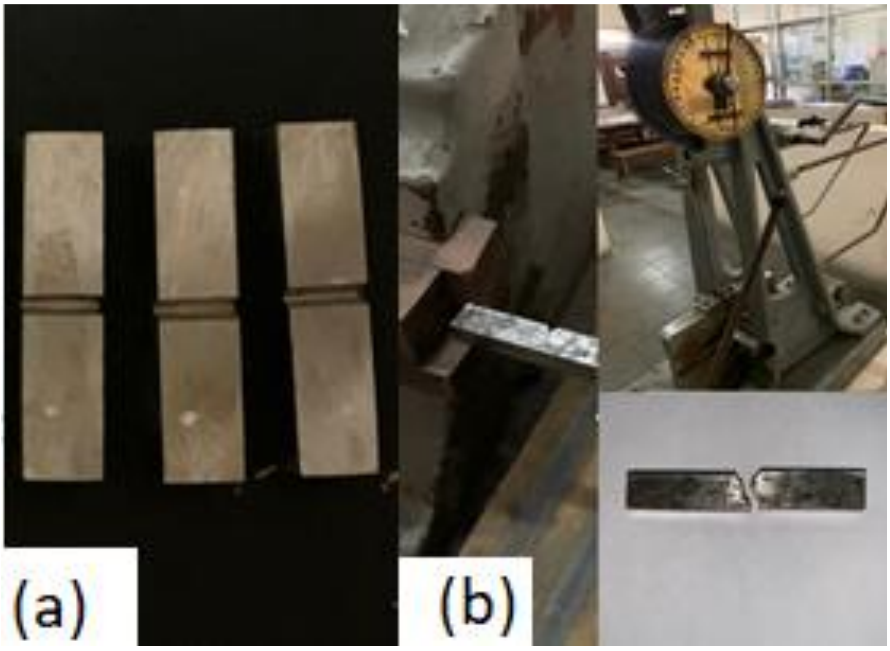


Figure 3. Impact Charpy test: (a) Specimens [10], and (b) Gotech brand impact tester

2.2.4 Hardness test

This Hardness Test used a Rockwell hardness tester with a Rockwell brand TH500 hardness tester. Each specimen was tested with a specimen load of 980 N (100 kg). Diamond cone penetrator with an angle of 120° and performed at three points of emphasis. The specimen used was the tip of the impact test specimen. The following tool used in this study is shown in Figure 4.

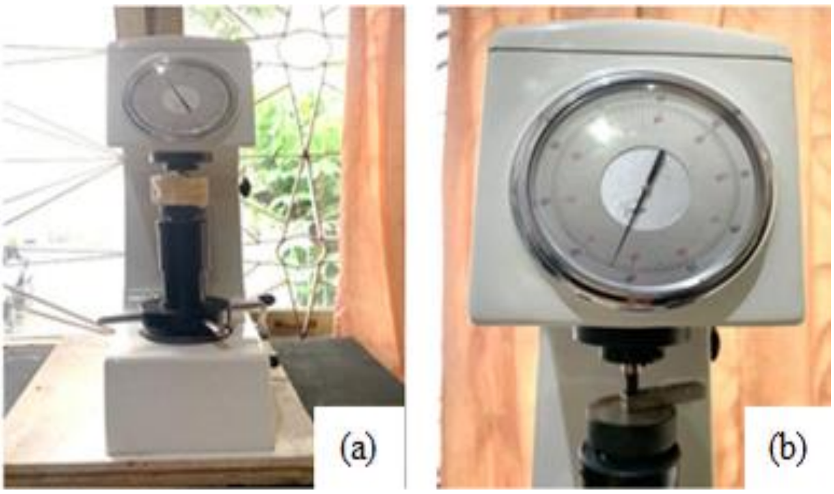


Figure 4. (a) Rockwell hardness tester machine, and (b) Testing specimen

2.2.5 Microstructure characteristics

The purpose of this microstructure was to observe the phase formed from the influence of the energizer. This microstructure analysis used the instrument Insize Digital Microscope with Stand and ISM-PRO software magnifications of 100x and 400x. The following tools used in this study are shown in Figure 5.

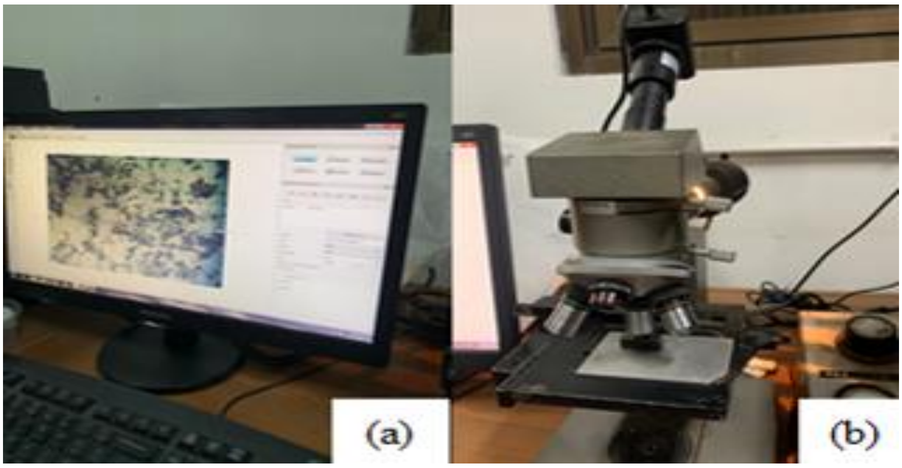


Figure 5. Macrostructural analysis tool: (a) PC, and (b) Metallography microscope

3 Results and Discussion

3.1 Tensile test results

This tensile test used a tensile testing machine with a nominal thickness specimen was ±3.8 mm and a speed of testing of 0.4 mm/s. This tool had a range capacity from 1 kN to 300 kN. Based on the results obtained in the tensile test, in Figure 6, it was known that the raw specimen had a higher ultimate tensile strength compared to other specimens, which was 819.53±0 MPa. In contrast, Specimen A (40:60% w/w) was 441.92±20.24 MPa, Specimen B (50:50% w/w) was 469.29±25.56 MPa, and Specimen C (60:40% w/w) was 333.43±30.22 MPa.

Based on the elongation results in the tensile test, which can be seen in Figure 6, it can be seen that Specimen C (60:40% w/w) had a lower elongation than the other specimens, which was 31.02±0.0 mm. In contrast, for raw specimens, it was 31.59±0 mm, Specimen A (40:60% w/w) was 31.22±0.02 mm, and Specimen B (50:50% w/w) was 31.19±0.01mm. Specimen C (60:40% w/w), which had a low elongation, indicated that the specimen had brittle properties compared to Specimen A (40:60% w/w) and Specimen B (50:50% w/w).

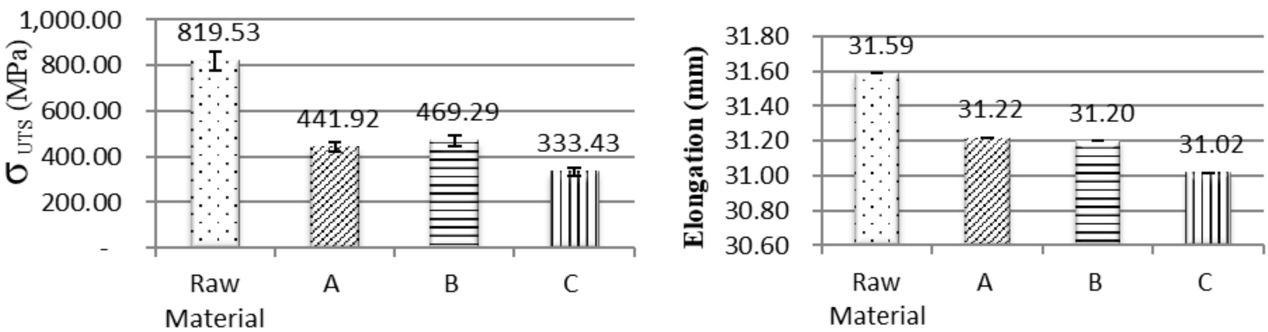
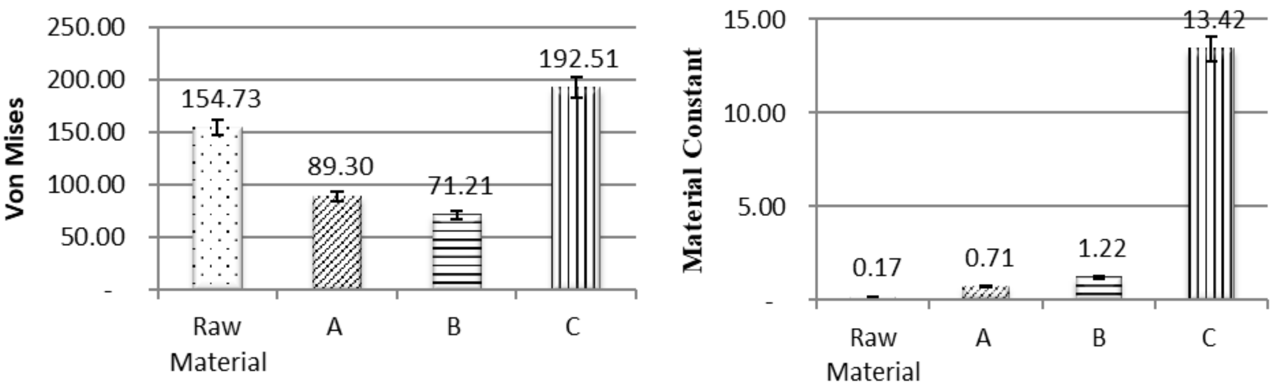


Figure 6. Average value diagram: (a) σUTS, and (b) Elongation

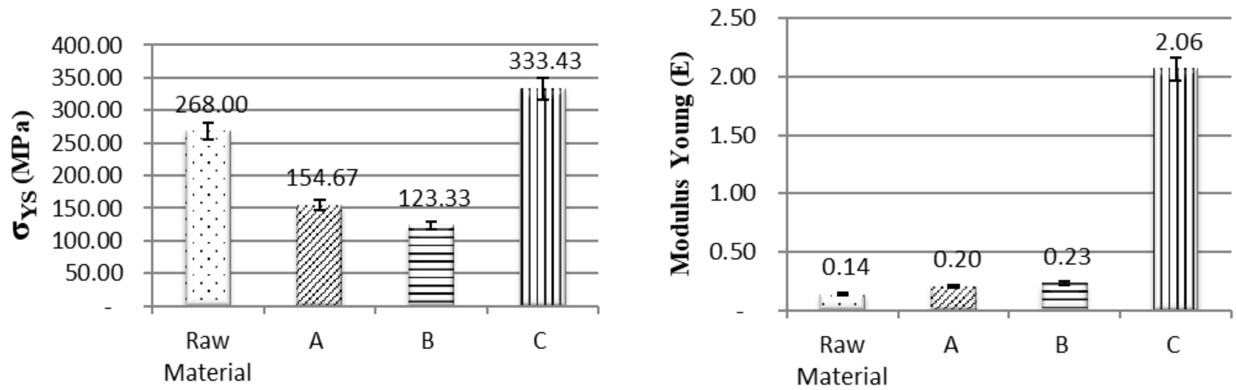
The von-Mises value was the minimum stress that the material had when the material was deformed. In Figure 7 above, it can be seen that the highest von-Mises value was found in Specimen C (60:40% w/w), which was 192.51±17.45 MPa, while for raw specimens, it was 154.73±0 MPa, while for Specimen A (40:60% w/w) it was 89.30±10.14 MPa and for Specimen B (50:50% w/w) it was 71.21±2.19 MPa.



(a) (b)

Figure 7. Average value: (a) Von-Mises, and (b) Poisson ratio

The Poisson ratio also affected the mechanical properties of a material. The Poisson ratio was the ratio between the narrowing of the material to the increase in length due to tension. Poisson ratio can be seen in Figure 8, Specimen C (60:40% w/w) had the highest Poisson ratio of 13.42±3.93 mm, while the raw specimen was 0.17±0 mm, Specimen A (40:60% w/w) was 0.71±0.37 mm, and Specimen B (50:50% w/w) had a value of 1.22±0.39 mm. Poisson ratio describes the increase in the length of a material due to mechanical treatment.



(a) (b)

Figure 8. The average value: (a) Yield strength, and (b) Young modulus

The term yield strength was also found in the stress-strain curve, a material's minimum stress when it lost its elasticity. Based on the yield strength value in the tensile test that had been carried out in Figure 8, it was found that the highest yield strength value was found in Specimen C (60:40% w/w), which was 333.43±30.22 MPa, while for Raw Material was 268.00±0 MPa, while Specimen A (40:60% w/w) was 154.67±17.56 MPa and Specimen B (50:50% w/w) was 123.33±3.79 MPa.

The highest Young modulus (*E*) in this study, Figure 8, was found in Specimen C (60:40% w/w), which was 2.06±0.41 MPa, while the Young modulus with raw specimens was 0.14±0, Specimen A (40:60% w/w) was 0.20±0.02 MPa and Specimen B (50:50% w/w) was 0.23±0 MPa.

3.2 Impact test results

This impact test was carried out to determine the value of the ability of a material to receive impact loads by measuring the amount of energy required to break the specimen. The impact radius was ±0.674 mm. The mass of the pendulum used was ±23.87 kg. The angle used was 150°. Figure 9 shows the comparison of specimen data based on the energizer of each sample. Based on the results of the impact testing that had been carried out, it appearred that the highest energy value was shown by the untreated specimen with an average impact value of 15.802±0 Joules. The lowest average impact energy was shown in Specimen C (60:40% w/w) with a holding time of three hours and a temperature of 950 ℃ with an Impact energy value of 4.32±0 Joules. Impact energy has decreased because, affected by carburizing, toughness has decreased while the temperature of carburizing has increased [11].

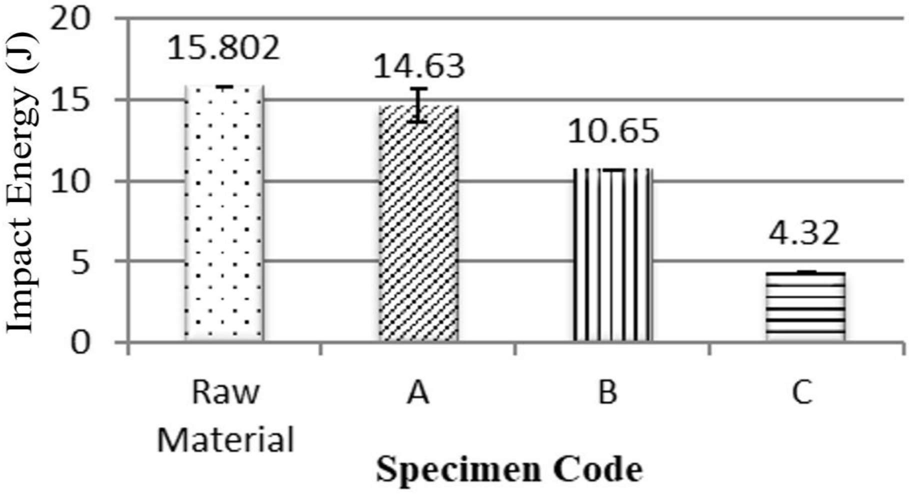


Figure 9. Average value impact energy

3.3 Hardness Rockwell test results

This hardness test was carried out to determine the hardness of material in the form of the material's resistance to the test object, which was emphasized on the surface of the test material. Diamond cone penetrator has an angle of 120°, and it is used to perform at three points of indentation. Hardness testing was carried out on all specimens both in pack carburizing and without pack carburizing. Based on the results obtained in the hardness test, Figure 10, it was known that Specimen C (60:40% w/w) had the highest hardness with a holding time of three hours and a temperature of 950˚C with a hardness of 80.70±1.20 HRC, while the hardness for raw specimens was 56.90 HRC, while Specimen A (40:60% w/w) was 66.97±1.13 HRC, and Specimen B (50:50% w/w) of 72.72±0.81 HRC. This increase in hardness occurred due to the addition of carbon elements on the steel surface, where carbon was evenly diffused into the steel structure, so the price of hardness tends to increase [12]. The surface hardness and tensile strength increased, but the ductility of the specimen decreased, after pack carburizing treatment, in proportion to the increase in temperature of pack carburizing and the content of $BaCO_3$ in the carburizing agent [13].

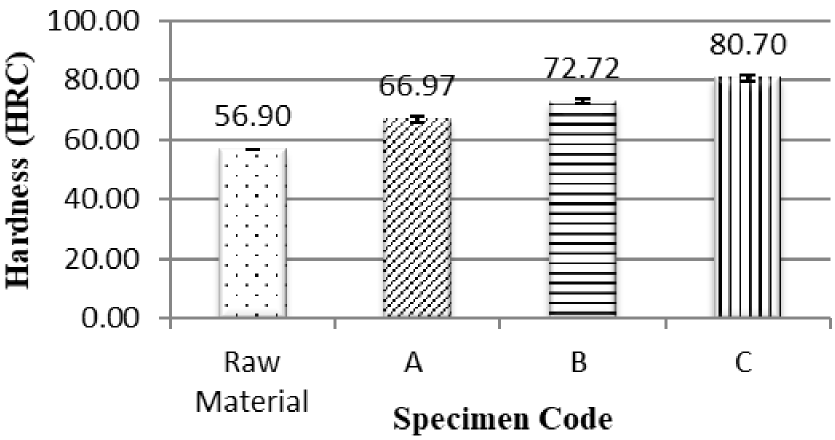


Figure 10. Average value hardness Rockwell C

3.4 Microstructure analysis

Microstructural testing was conducted to determine the phase formed in the specimen. The magnification used in the microstructure characterization used 100x and 400x. The test was carried out twice, namely on specimens without treatment and specimens with treatment, with the highest impact value, namely on Specimen A1 with energizer 40% w/w $BaCO_3$: 60% w/w, Na_2CO_3. The results of the microstructure can be seen in the following figure.

Experiments and results of the microstructure of AISI 4340 steel in the untreated specimen area and based on Figure 12, it can be seen that the microstructure in the Raw Material was ferrite and perlite phases - a large number of perlite phase structures in AISI 4340 steel material results in high material hardness. The ferrite phase structure was not dominant in the material after pack carburizing was carried out in a holding time of three hours. The structure of the ferrite phase was indicated by white circular patterned lines, and the perlite phase was indicated by black or dark circular lines.

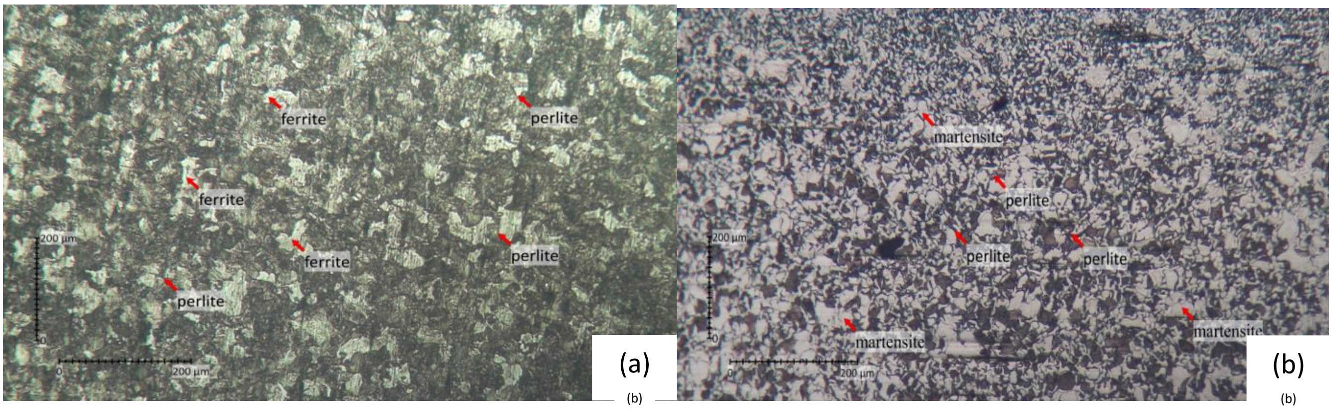


Figure 12. Results of the microstructure observation at 100x magnification: (a) Without treatment, and (b) With treatment

Based on Figure 13, the microstructure of AISI 4340 steel surface with pack carburizing holding time treatment of three hours with a variation of energizer 40% w/w $BaCO_3$: 60% w/w, Na_2CO_3 at 400x magnification underwent a phase change, the phases formed were perlite and martensite with media quick cooling using SAE 40 oil down to 28 ℃ room temperature. The martensite phase structure was characterized by a black color that gathers like needles or plates.

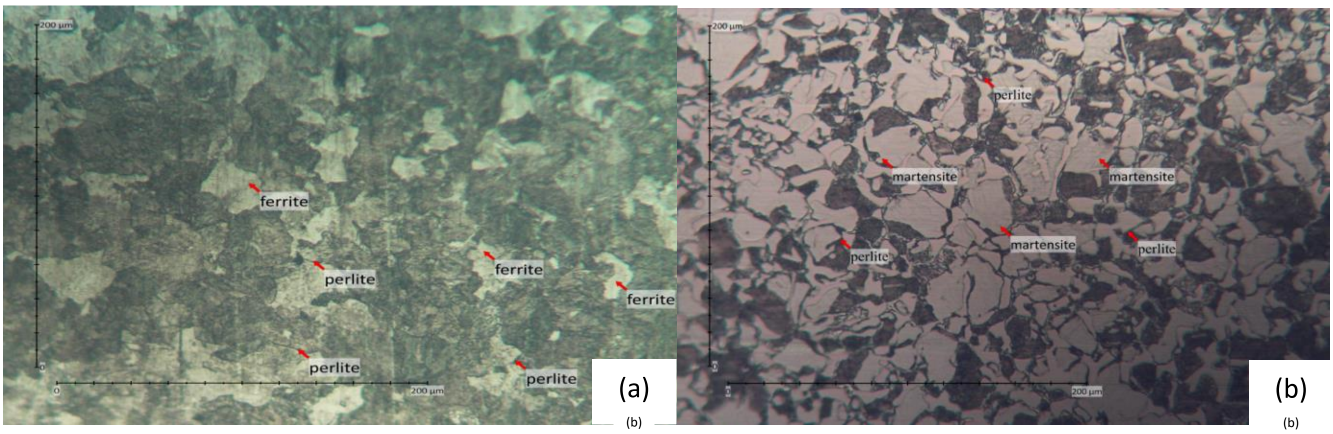


Figure 13. Results of the microstructure observation at 400x magnification: (a) Without treatment, and (b) With treatment

3.5 Cooling rate

Cooling media was used to lower the temperature after heating in the heat treatment process to improve mechanical properties. The cooling media used was fastron brand SAE 40 oil. The specimens were refrigerated for one hour. The following is the result of the cooling rate of the tensile and impact specimen in Figure 14 below.

In Figures 14 and 15, the results of temperature measurements for 60 minutes of immersion with an interval of five measurements every five minutes, from the results of the graph, it can be seen that each variation of the energizer had a different temperature decrease. This means that the cooling medium's cooling rate decreased during immersion. Specimen C, with a higher energizer composition, reached the highest temperature compared to other specimens. As seen in the graph, Specimen A has a more sloping line. This was because the temperature had dropped rapidly, then the temperature of Specimen A began to cool down to air temperature.

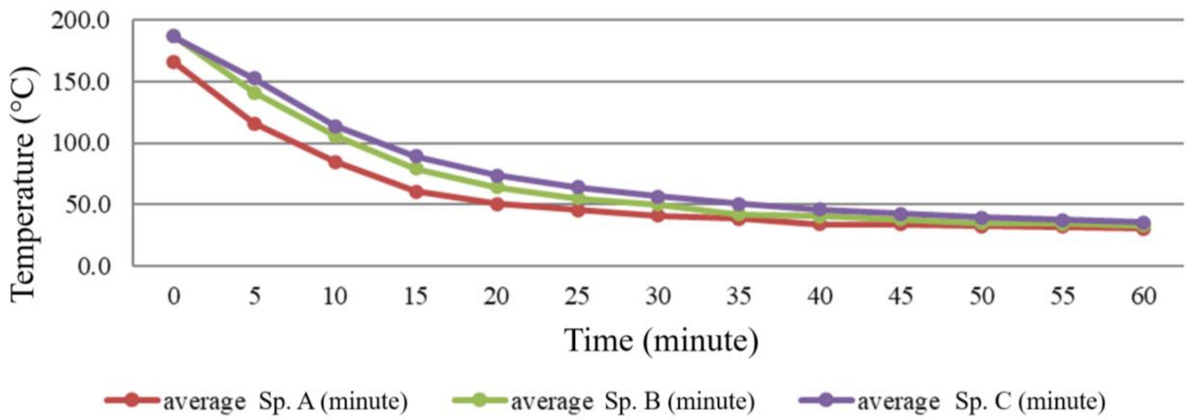


Figure 14. Average value diagram cooling rate tensile

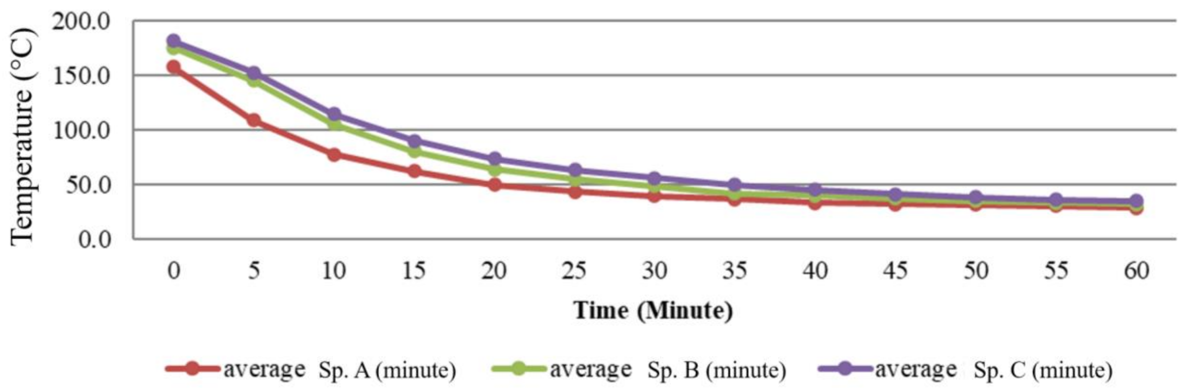


Figure 15. Average value diagram cooling rate impact

4 Conclusions

In this study, it can be concluded that several tests with different energizer variations in the percentage of $BaCO_3$:Na_2CO_3 respectively (40:60% w/w), (50:50% w/w), (60:40% w/w) result of pack carburizing made of AISI 4340 Steel. This study also found that in Specimen C, the tensile test results decreased the average Ultimate Tensile Strength (UTS) value. However, the average yield strength and modulus of elasticity increased significantly at 333.43 MPa and 2.06. Moreover, *d* for the impact test Specimen C had a small energy absorption capacity of 4.32 Joules. This proves that the composition of 60% w/w $BaCO_3$:40% w/w Na_2CO_3 from pack carburizing can increase the average hardness value of

80.70 HRC and formed martensite microstructure, the target was to prove the effect of $BaCO_3$:Na_2CO_3 combination of energizer in pack carburizing with their hardness and microstructure had succeeded.

5 Acknowledgement

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