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The effect of carbonate energizer on pack carburizing ASTM A36 steel

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Abstract

Pack carburizing process of carbon steel, energizer plays an important role in the changes in surface hardness, carburized layer and microstructure of carbon steel. A study has been conducted on changes in surface hardness and microstructure of ASTM A36 low carbon steel due to the pack carburizing process with variations of energizer. The pack carburizing treatment process was carried out at a temperature of 900 °C and soaking time of 2 hours. The carburizing media was a mixture of charcoal powder and energizer with a ratio of 70: 30 weight percentage, with heating carried out in an electric furnace. The energizer used was carbonate energizer in the form of $CaCO_3$, $BaCO_3$, and Na_2CO_3. The results of the study surface hardness, microstructure and thickness of carburized layer of ASTM A36 steel specimen after pack carburizing treatment are influenced by energizer. The use of $CaCO_3$ energizer has the greatest impact on increasing surface hardness, microstructure and thickness of carburized layer of ASTM A36 steel specimen, which was pack carburized.

Keywords: ASTM A36; Energizer; Pack carburizing; Surface hardness

1. Introduction

ASTM A36 steel material is low carbon steel, with a content of around 0.25–0.29% C. This steel is very commonly used in construction and manufacturing because of its easy to form and weld properties, as well as resistance to deformation at moderate pressure. The general use of ASTM steel, as building structures (beams, columns, frames), bridge components, tanks and containers, and light machine components. Carbon structural steel products, the relative products are round bar steel, angle bars, and steel sections such as I-beams, H-beams, angles, and channels. Hot-rolled ASTM A36 has a rough surface on the final product, easy to further process such as machining. The characteristics of ASTM A36 steel are very soft to facilitate forming, machining, welding. Current research activities are focused on improving mechanical properties and corrosion properties to expand the application fields of ASTM A36 low carbon steel. This improvement can be done by coating, painting, and surface hardening. Surface hardness is directly proportional to the wear resistance of ASTM A36 steel.

In the study [1] the experimental method of the pack carburizing process of AISI 1020 steel samples, charcoal powder carburizing media, at a carburizing temperature of 900 °C, soaking time of 4 hours with variations of Na_2CO_3 and $CaCO_3$ catalysts. The process is continued with quenching using distilled water cooling media. The results of the study showed that AISI 1020 steel that was pack carburized using Na_2CO_3 energizer had a significant microstructural transformation which would affect the increase in the highest hardness value (505.4 HV) and the decrease in the lowest wear rate (0.00821 mm^3/min).

A study to examine the effect of variations in cooling fluids on the heat treatment of S45C carbon steel, especially its hardness and microstructural changes, has been conducted [2]. Pack carburizing was carried out at a temperature of

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850 ᵛC for 30 minutes, followed by cooling using different fluids, namely water, ice water, and oil. The results showed that faster cooling caused an increase in hardness. The hardness numbers were 697 HV, 481 HV, and 248 HV, respectively. The phase changes observed on the surface of the specimens showed the dominance of martensite.

In the study [3] low carbon steel specimens ASTM A36 were pack carburized at a temperature of 950 °C, soaking time variations of 1, 2 and 3 hours. The carburizing media used was a mixture of coconut shell charcoal powder and goat bone powder (Capra aegagrus hircus) with a grain size of 100 mesh. The variation of the weight percentage between goat bone powder and coconut shell charcoal was 10%: 90%, 20%: 80%, and 30%: 70%. The conclusion of the highest surface hardness figure was 854.734 kg/mm^2 at soaking time of 3 hours with a carburizing media composition of 10%: 90%.

Gas carburizing significantly improves the surface properties of low alloy gear steel, such as microhardness, layer thickness, carbon content, and better mechanical properties [4]. Gas carburizing is a thermochemical process that is better than nitriding and carbonitriding, which have limitations in core properties and hardening depth. Gas carburizing is ideal for applications in the automotive, aerospace, and manufacturing industries. In this study, samples were gas carburized for 4, 6, or 8 hours. The results showed significant improvements: the microhardness increased from about 140 HV to more than 819 HV, and the surface layer thickness grew by more than 41%, from 1166 µm to 1576 µm. In addition, the carbon content in the surface layer increased by more than 450%, reaching up to 0.94 wt%.

The study [5] on vacuum carburizing of four steel grades, according to European standards 1.7243, 1.6587, 1.5920, and 1.3532. Nickel content ranged from 0 to about 3.8 wt.%. As a reference for comparison, gas carburizing was also carried out on grade 1.3532, which has the highest nickel content. The results of the study showed that the resulting carburized layer had an effective thickness of about 0.8 to 1.4 mm, a surface hardness in the range of 600 to 700 HV, and an estimated retained austenite content of 10 to 20 vol%. The fatigue strength values observed for the layer varied in the range of 1000 to 1350 MPa. The vacuum carburizing processing method improves fatigue properties more than gas carburizing, which causes internal oxidation phenomena.

The effect of alloying elements on carbon penetration and diffusion on steel surface during vacuum carburizing has been conducted [6]. The test specimens were steels (AISI 1020, AISI 8620, AISI 4120) with the same carbon content and different Cr contents. The carbon mass increase with carburizing time was measured using a microbalance, and the average carbon flux, which is an indicator of carbon penetration rate, was calculated using the measured weight as a variable. The outer surface of the carburized specimens was observed by scanning electron microscopy (SEM) and Raman spectroscopy (RS), and the equilibrium carbon content was calculated by Thermo-Calc. The overall carbon distribution and the distribution of alloying elements on the outer surface were quantitatively analyzed using electron probe microanalysis (EPMA). The results of the study on the surface of AISI 1020 and AISI 4120 specimens, graphite and grain boundary carbide layers were formed during the carburization process, which inhibited the carburization rate, while no abnormal layers were observed on the surface of AISI 8620 carburized specimens, so the overall carburization results were very good.

Low temperature plasma carburizing and nitriding heat treatment can improve the hardness and corrosion resistance of austenitic stainless steel through the formation of S-phase expanded austenite [6]. The single plasma carburizing process was carried out for 4 hours and continuous plasma nitriding for 3.5 hours, with carburizing temperatures of 400 and 450 C. The deposited composite layer contains solid solution carbon and eutectic carbide due to the thermal decomposition of tungsten carbide during laser metal deposition. The nature of eutectic carbide inhibits carbon diffusion, while the original solid solution carbon contributes to the formation of S phase, resulting in a thick S phase layer. The plasma carburizing and nitriding processes are effective in improving the Vickers surface hardness and corrosion resistance.

Research [7] studied the effect of double-luminescence low-temperature plasma carburizing technology on the fretting wear mechanism of AISI 316L steel, which was affected by different normal loads and displacements. The results showed that the maximum surface hardness was 897 ± 18 HV0.2, four times higher than that of the matrix (273 ± 33 HV0.2). In addition, the surface roughness increased approximately twofold. However, the wear thickness, wear rate, and frictional dissipation energy coefficient of the carburized layer were significantly reduced.

Research activities to improve the surface hardness and microstructure of ASTM A36 steel are still very limited. In this study, the pack carburizing process was carried out with variations of energizers, with the aim of increasing the surface hardness and microstructure

2. Material and methods

The ASTM A36 steel research specimen is cylindrical with dimensions of 50 mm x 20 mm. ASTM A36 steel is a medium carbon steel with a chemical composition: (C) 0.25–0.29%, (Cu) 0.20%, (Fe) 98.0%, (Mn) 1.03%, (P) 0.04%, (Si) 0.280%, and (S) 0.050%, The energizer used is carbonate $CaCO_3$, $BaCO_3$, Na_2CO_3, with a purity of 98% (Aldrich Co, ASC grade reagent). As a carbon source is charcoal powder with a grain size of 100 mesh. The manufacture of charcoal powder using a Zegvary type attritor. The carburizing medium is a mixture of charcoal powder and energizer with a weight proportion of 70:30.

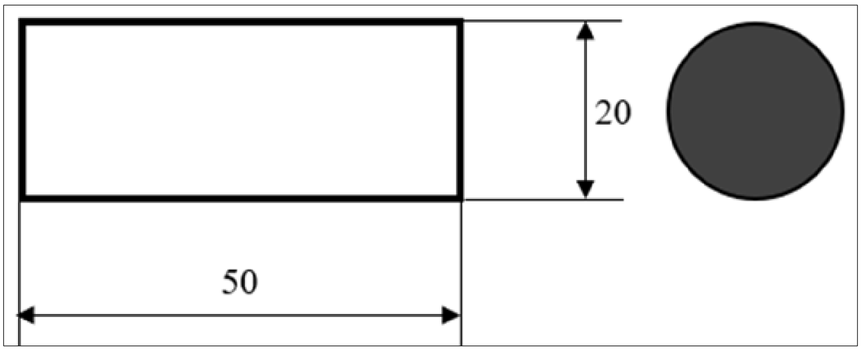

Figure 1 Specimens for Pack Carburizing

Pack carburizing treatment is carried out in an electric chamber furnace (Brand ST 1200 7818). The carburizing pack temperature is 900°C, with a soaking time of 2 hours and cooled with water cooling media to room temperature. To determine the effect of energizer variation on ASTM A36 steel that is pack carburized, surface hardness test, carburized layer thickness, and metallographic analysis were carried out to determine changes in the microstructure of the specimen. The surface hardness test used the Vickers method according to ASTM E 384 and SAE J423 standards. Surface hardness measurement at the layer depth by the Vickers method, using a Reichert hardness tester. The tool is equipped with a four-sided diamond pyramid press. A load force of 50 gf and a dwell time of 10 s were applied during the test. The indentation mark size ranged between 7 and 15 lm

The thickness of the carburized layer was studied and measured using the ASTM G79-83 standard with the help of a trinocular microscope and a Moticam 2300 camera. Metallographic analysis was prepared according to the ASTM E3 standard and etched in 2% nital solution. An olympus IX70 optical microscope and a JEOL JSM6700F scanning electron microscope (SEM) were used for microstructural observation.

3. Result and Discussion

3.1. The effect of carbonate energizer on surface hardness of pack carburizing

3.1.1. ASTM A36 steel

Surface hardness testing of ASTM A36 specimens after pack carburizing treatment, using ASTM E 384 and SAE J423 standards. This standard is a standard that covers various methods of testing the mechanical properties of steel, including Brinell and Vickers hardness testing. The results of the surface hardness test, measured by the Vickers method, are shown in Figure 2. The results showed that the lowest average surface hardness value was at a depth of 800 µm. The hardness value at that depth for the use of $CaCO_3$, $BaCO_3$, Na_2CO_3 energizers, respectively, was around 200, 195, 190 HV. The highest average surface hardness value was up to a depth of 50 µm. The hardness values at that depth for the use of energizers $CaCO_3$, $BaCO_3$, Na_2CO_3, respectively, are around 760, 690, 520 HV. The use of $CaCO_3$ energizer in the pack carburizing process of ASTM A36 steel, gives the highest surface hardness results at a depth of 50 µm around 760 HV, while the use of Na_2CO_3 energizer gives the lowest surface hardness results around 520 HV.

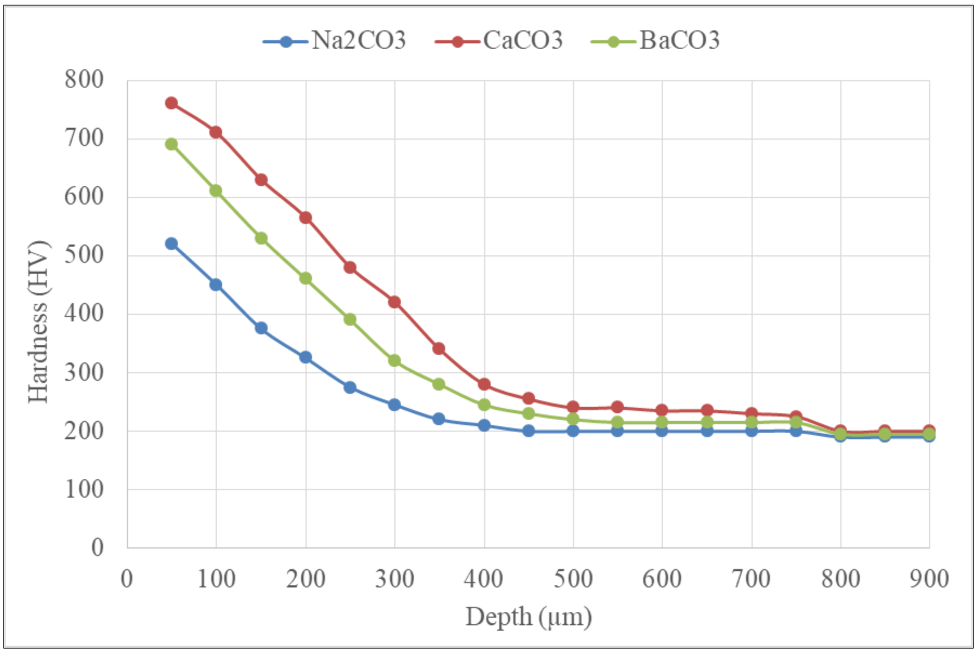

Figure 2 Surface hardness of ASTM A36 steel after pack carburizing treatment

Based on Figure 2, the surface hardness value decreases monotonically at a depth of 50 µm towards the center of the sample, around a depth of 800 µm. This is because the surface of the specimen up to a depth of 50 µm contains the martensite phase. The hardness of martensite generally ranges from 525 to 900 HV. This hardness can be higher, even reaching 1791 HV in steel with a higher carbon content. In general, martensite is known as a very hard and brittle material, in line with research results [7].

The above phenomenon shows that, the energizer $CaCO_3$ here is producing carbon monoxide (CO) gas when decomposed at high temperatures. This CO gas helps to bring carbon to the steel surface more effectively. The chemical reactions that occur are as follows:

$$CaCO_3 \rightarrow CaO + CO_2$$

$$C + CO_2 \rightarrow 2CO$$

The CO gas resulting from this chemical reaction can penetrate into the steel, enriching the carbon content in its outer layer, resulting in a significant increase in the surface hardness of the specimen.

3.2. The effect of carbonate energizer on microstructure of pack carburizing

3.2.1. ASTM A36 steel

Variation of energizer used in pack carburizing ASTM A36 specimens, affects the microstructure formed, as shown in Figure 3. Pack carburizing using Na_2CO_3 energizer, the microstructure is as shown in Figure 3a. The microstructure is still dominated by ferrite and pearlite, although martensite has formed, the carburized layer with the lowest percentage so that the surface hardness number is the lowest at around 520 HV to a depth of 50 µm from the specimen surface. Figure 3b presents the microstructure of the specimen treated with pack carburizing using $BaCO_3$ energizer after being held for 2 hours, the martensite microstructure formed, the carburized layer is thicker compared to Na_2CO_3 energizer. The thickness of the carburized layer was about 25 µm . The martensite microstructure with the largest percentage and the highest thickness of around 30 µm, was obtained in the pack carburizing process with $CaCO_3$ energizer, as shown in Figure 3c.

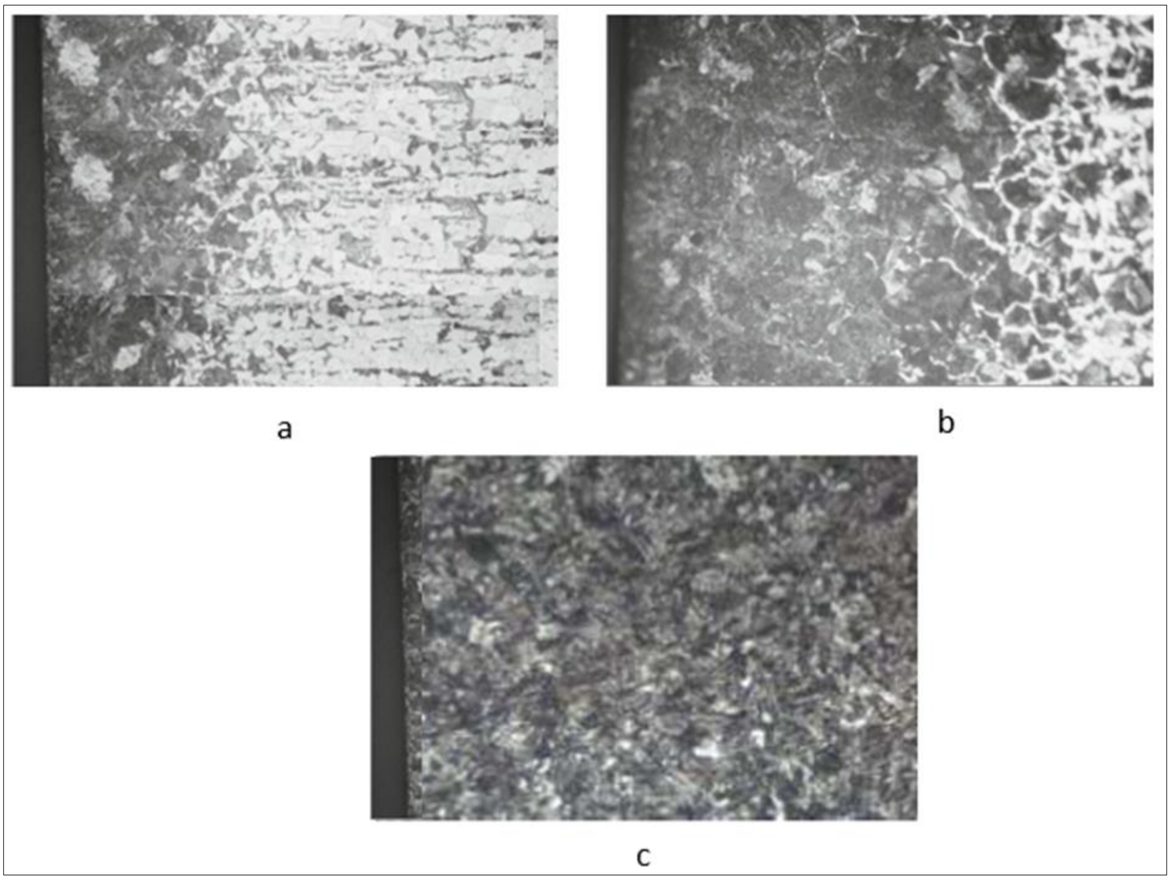

Figure 3 Microstructure of ASTM A36 steel after pack carburizing treatment. a. Energizer Na_2CO_3, b. Energizer $BaCO_3$, c. Energizer $CaCO_3$

Microstructure changes due to differences in energizers used in the pack carburizing process according to the study results [8]. The effect of the energizer type is seen from the change in the thickness of the carburizing layer. The layer has a maximum thickness of 410 µm for the use of $CaCO_3$ energizer.

4. Conclusion

The lowest average surface hardness value was at a depth of 800 µm. The hardness value at that depth for the use of $CaCO_3$, $BaCO_3$, Na_2CO_3 energizers, respectively, was around 200, 195, 190 HV. The highest average surface hardness value was up to a depth of 50 µm. The hardness values at that depth for the use of energizers $CaCO_3$, $BaCO_3$, Na_2CO_3, respectively, are around 760, 690, 520 HV. The use of $CaCO_3$ energizer in the pack carburizing process of ASTM A36 steel, gives the highest surface hardness results at a depth of 50 µm around 760 HV, while the use of Na_2CO_3 energizer gives the lowest surface hardness results around 520 HV.

Surface hardness, microstructure and thickness of carburized layer of ASTM A36 steel specimen after pack carburizing treatment are influenced by energizer. The use of $CaCO_3$ energizer has the greatest impact on increasing surface hardness, microstructure and thickness of carburized layer of ASTM A36 steel specimen, which was pack carburized.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] A. Karim, I. Azmy, S. Q. Khoiriah, and C. Bintoro, "Microstructure and Mechanical Properties of Pack Carburized AISI 1020 Steel Using Na2CO3 and CaCO3 Catalysts," J. Renew. Energy Mech., vol. 5, no. 02, pp. 52–59, 2022, doi: 10.25299/rem.2022.vol5.no02.9965.

[2] R. W. Rochmad Winarso, Slamet Khoeron and Darmanto, "Effect of cooling media on hardness and microstructural changes in S45C carbon steel during heat treatment process," Polimesin, vol. 20, no. 2, pp. 121–127, 2023, [Online]. Available: https://e-jurnal.pnl.ac.id/polimesin/article/view/3626/3230

[3] S. Sujita, I. D. K. Okariawan, and L. Hakim, "Characteristics of ASTM A36 steel mechanical properties in pack carburizing with carburizing agent coconut shell charcoal and goat bone powder mixed," Din. Tek. Mesin, vol. 13, no. 1, p. 57, 2023, doi: 10.29303/dtm.v13i1.619.

[4] H. Boumediri et al., "Effect of carburizing time treatment on microstructure and mechanical properties of low alloy gear steels," Mater. Res. Express, vol. 11, no. 7, 2024, doi: 10.1088/2053-1591/ad5cd6.

[5] P. Kochmański et al., "Influence of Chemical Composition on Structure and Mechanical Properties of Vacuum-Carburized Low-Alloy Steels," Materials (Basel)., vol. 17, no. 2, 2024, doi: 10.3390/ma17020515.

[6] G. H. Kwon, H. Park, Y. K. Lee, and K. Moon, "Influence of Alloying Elements on the Carburizing Behavior in Acetylene Atmosphere," Metals (Basel)., vol. 14, no. 1, 2024, doi: 10.3390/met14010029.

[7] E. Santoso, F. Fatkhurrohman, A. R. Firmansyah, and S. C. Putra, "Hardness and Microstructural Characterization of Pack Carburizing AISI 1020 Low-Carbon Steel by Temperature and Holding Time Variations," Adv. Sustain. Sci. Eng. Technol., vol. 6, no. 1, pp. 2–9, 2024, doi: 10.26877/asset.v6i1.17583.

[8] A. González-Angeles, J. López-Cuevas, and N. Pitalúa-Díaz, "Comparison of CaCO3 from natural sources and artificial carbonates as activators of solid-phase carburizing of low-carbon steel," Met. Sci. Heat Treat., vol. 55, no. 7–8, pp. 355–357, 2013, doi: 10.1007/s11041-013-9634-4.