World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(RESEARCH ARTICLE)

Check for updates

Influence of Carburizing Chromization Process on Mechanical Properties of ASTM A36 Steel

Sujita Sujita Darmo * and Rudy Sutanto Sutanto

Department of Mechanical Engineering, Faculty Engineering, University of Mataram, Majapahit Street 62, Mataram 83125, Indonesia.

World Journal of Advanced Engineering Technology and Sciences, 2024, 13(02), 258–263

Publication history: Received on 27 September 2024; revised on 10 November 2024; accepted on 13 November 2024

Article DOI: https://doi.org/10.30574/wjaets.2024.13.2.0547

Abstract

Research on changes in microstructure and hardness properties of ASTM A36 steel caused by carburizing-chromization process has been conducted. Carburizing-chromization treatment process was conducted at various temperatures: 850 °C, 900 °C and 950 °C and holding time: 6 hours, 9 hours and 12 hours. Carburizing media in a mixture of solid powder charcoal/BaCO3 and ferrochromium/alumina/NH4Cl, with heating carried out in an electric furnace. The obtained layers were investigated using X-ray and electron diffraction, optical and scanning electron microscopy, and hardness measurements were carried out with micro Vickers, and potentiodynamic measurements. The thickness of the carburizing layers ranged between 50 and 500 μm. In addition to the host c-phase, the layers were mostly composed of carbides (Fe_7C_3, $Cr_{23}C_6$, Cr_7C_3, and Fe_3C) and traces of a¢-martensite. The average hardness value decreases smoothly from 680 HV at the surface of the sample to 200 HV in the center of the sample. Potentiodynamic tests revealed that the chromized samples have lower corrosion resistance compared to the untreated material. For the strong chromization regime, the corrosion rate increases fourfold compared to the untreated material, while the microhardness of the coating is threefold greater. These materials are suitable for use in environments requiring good corrosion resistance and wear properties.

Keywords: ASTM A36; Low carbon steel; Carburizing-chromization; Surface hardness

1. Introduction

ASTM A36 steel is the most widely used hot rolled steel product. As a kind of carbon structural steel product, its relative products are round bar steel, angle bar, and steel sections such as I-beam, H-beam, angle, and channel. Hot rolled ASTM A36 has rough surface on the final product, easy for further processing such as machining. According to chemical analysis ASTM A36 belongs to general low carbon steel, steel products with low carbon content less than 0.3%, very soft for easy forming, machining, welding. Heat treatment has less effect on ASTM A36 steel material. It contains some other elements including alloying elements: manganese, sulfur, phosphorus and silicon. Iron and these elements together form the unique mechanical properties of ASTM A36, unlike stainless steel with nickel and chromium elements, it does not show good corrosion resistance, in order to improve its corrosion resistance, by coating it.

Current research activities are focused on improving mechanical properties and corrosion properties to expand the application field of ASTM A36 low carbon steel. These improvements can be achieved by coating, painting and surface hardening.

The study [1] focused on examining the kinetics of Fe2B layer formation on the surface of ASTM A681 steel during powder boronization process. The study measured the thickness of Fe2B layer at various temperatures and times to determine the growth mechanism of Fe2B layer controlled by diffusion during boronization process. Understanding the

* Corresponding author: Sujita Sujita Darmo

kinetics of boronized layer growth is very important because it can facilitate the optimization and automation of industrial processes. This ensures efficient and consistent production of boronized layers on cutting tools, such as drills and milling cutters, due to their high hardness and wear resistance. X-ray diffraction technique was used to identify the presence of boronized iron phase and tribological studies were also carried out to evaluate the coefficient of friction (COF) of the samples. The results of the study showed that the COF of boronized samples was (0.256) and untreated (0.781). Fe_2B coating can also increase wear resistance up to 300%.

Corrosion protection by the technique of incorporating expensive alloying elements into bulk steel is not of interest, since only its surface is exposed to aggressive environments. The work [2] focused on the development and optimization of a new surface functionalization technology through in situ observation of thermal interactions between metal powders at high temperatures. It was concluded that a Cu-Ni powder mixture, with 12.5 wt% Ni, started to melt at 1099.5 ∘C and melted completely at 1175 ∘C, significantly different from Cu-Ni solid solution and bulk Cu or Ni. As a result of the high temperature reaction, copper penetration up to 35 μm for pure copper and 55 μm for copper-chromium composite coatings occurred due to corrosion of the liquid metal. In contrast, the copper-nickel composite coating showed a cupronickel solution microstructure with FeNi dendrites and a nickel-rich transition layer. This cupronickel coating, with a chemical composition of 89.3 wt% Cu, 6.2 wt% Ni, and 4.5 wt% Fe, showed uniform thickness, good surface morphology, and continuous coverage on the steel substrate.

Gas carburizing significantly improves the surface properties of low-alloy gear steel, such as microhardness, layer thickness, carbon content, and better mechanical properties [3]. 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 [4] 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 [5]. 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 carburization and nitriding heat treatment improves the hardness and corrosion resistance of austenitic stainless steel through the formation of expanded austenite, known as S phase [6]. In the present study, single plasma carburization for 4 h and continuous plasma nitriding for 3.5 h after carburization for 0.5 h at varying temperatures of 400 and 450 C. The deposited composite layer as it occurs contains solid solution carbon and eutectic carbide due to the thermal decomposition of tungsten carbide during laser metal deposition. The eutectic carbide inhibits the diffusion of carbon, while the original solid solution carbon contributes to the formation of S phase, resulting in a thick S phase layer. The plasma carburization and nitriding processes are effective in improving the Vickers surface hardness and corrosion resistance.

The study [7] revealed the effect of double-luminescent low-temperature plasma carburizing technology on the fretting wear mechanism of AISI 316L steel, under different normal loads and displacements. The research results showed that the carburized layer contained a single Sc phase, a uniform and dense structure, and a metallurgical composite matrix. After plasma carburizing, the sample showed a maximum surface hardness of 897 ± 18 HV0.2, four times higher than that of the matrix (273 ± 33 HV0.2). In addition, the surface roughness was approximately doubled. The wear depth, wear rate, and frictional dissipation energy coefficient of the carburized layer were significantly reduced.

Research activities to improve the mechanical properties of low carbon steel are still few. To compensate for the lack of Cr in ASTM A36 low carbon steel and form further carbides need to be done. In this study, the carburizing-chromization process was carried out, with the aim of increasing hardness and better corrosion properties.

2. Material and method

2.1. Materials

The research specimen is ASTM A36 steel. The material is low carbon steel that has good properties, so it is often used in construction and industry. The production method of ASTM A36 steel is by hot rolling or cold drawing. The shape of ASTM A36 steel is rectangular bar, square bar, circular bar, channel, angle, H-beam, and I-beam. The properties of ASTM A36 steel have properties that can be machined, ductile, and strong. This steel also has good welding properties. Chemical composition: contains (C) 0.25–0.29%, (Cu) 0.20%, (Fe) 98.0%, (Mn) 1.03%, (P) 0.04%, (Si) 0.280%, and (S) 0.050%.

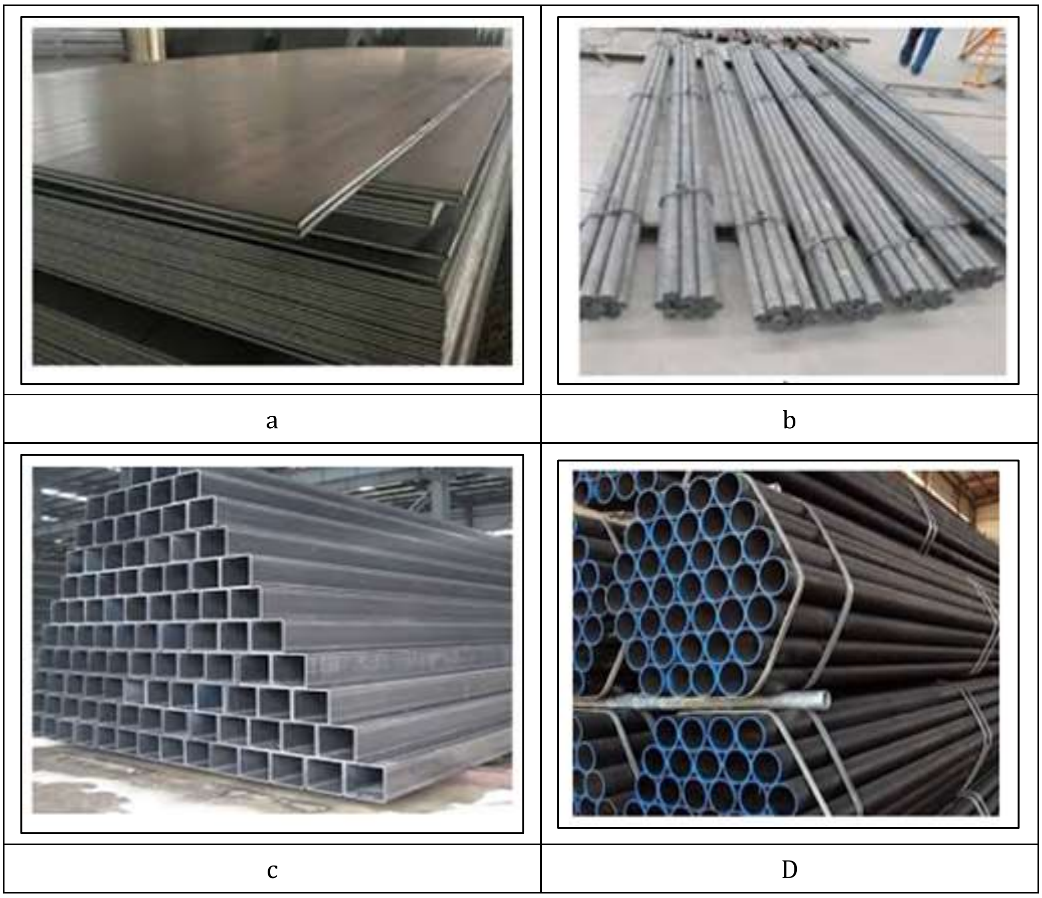

Figure 1 a. Plate ASTM A36, b. Bar ASTM A36, c. Rectangular bar, d. Circular bar

3. Methods

The sample in the form of ASTM A36 steel was first carburized with solid carburizing media (pack carburizing) and then chromatization, commonly referred to as the method. Carburizing-chromization treatment process. Carburization treatment is carried out by placing the prepared ASTM A36 sample in a container filled with solid carburizing. The carburizing media is a mixture of 80 percent charcoal powder (as a carbon source) and 20 percent $BaCO_3$ (as an activator). Various temperatures: 850 °C, 900 °C and 950 °C and holding time: 6 hours, 9 hours and 12 hours. The sample that has undergone carburization is then chromized in a solid environ ment, using a mixture of ferrochromium powder (as a chromium source), ammonium chloride powder (as an activator), and alumina powder (inserted into the mixture with a composition of 76 ferrochromium, 21 percent alumina), and 3 percent NH4Cl. Carburizing-chromization treatment process is carried out in a container made of refractory steel with a diameter of 120 mm and a height of 130 mm, the container is covered with clay under normal atmosphere.

An Olympus IX70 optical microscope and a JEOL JSM6700F scanning electron microscope (SEM) were used for microstructural observation. The SEM microscope equipped with an EDS analyzer was used to determine the chemical composition of the films. The crystal structure and phases present in the films were investigated by X-ray diffraction (XRD) and selected area electron diffraction (SAED). XRD spectra were recorded in h 2h mode using a Bruker D8 Advance diffractometer operating with Cu Ka1 radiation (k = 0.154056 nm) and equipped with a front monochromator. The diffracted beam was energy filtered to remove the fluorescence background. SAED patterns were recorded using a Topcon 002B transmission electron microscope operating at 200 kV.

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.

Tabel 1 Sample Preparation Conditions

Sample	Carburizing Temperature (˚C)	Carburizng Time (h)	Composition (%)		
			Al_2O_3	NH_4Cl	FeCr
PC1	850	6	20	5	75
PC2	900	9	70	5	25
PC3	950	12	25	5	75

4. Result and discussion

4.1. Surface hardness of ASTM A36 steel after carburizing chromization treatment

Hardness testing of ASTM A36 specimens after carburizing-chromatization treatment, using the ASTM A370 test standard. This standard is a standard that covers various test methods for the mechanical properties of steel, including Brinell and Vickers hardness testing. Figure 2.

Surface hardness figures, measured by the Vickers method. The results showed the lowest average surface hardness number value of 200 HV (for all specimens PC1, PC2, and PC3) and the highest was 680 HV in specimen PC2 at a depth of 50 µm. Based on Figure 2, the surface hardness values decrease monotonically at a depth of 50 µm towards the center of the sample, around 500 µm depth. This fact is due to the surface of the specimen until depth of 50 µm contains the martensite phase which is known to exhibit a hardness between 510 and 680 HV. The largest hardness number occurred in specimen PC2, with carbrizing-chromization treatment at 900 temperature for 9 hours, with a composition of 70% Al_2O_3, 5% NH_4Cl and 25% Fe Cr.

Nevertheless, the measured surface hardness values are much lower than those reported [8] in the literature for chromium carbides (C23C6 and Cr7C3 have hardness values of 1700 and 2300 HV, respectively). This is probably due to the fact that the carbides are present essentially at the grain boundaries, and therefore, they are distributed among the austenite grains. In addition their crystal structure is rather poor, and thus, their mechanical properties are also affected. In such cases, the hardness measure gives an average value between austenite (200 HV), martensite (small contribution) and carbide hardness. Such hardness values (between 200 and 650 HV) have been reported in carburized [9]. Finally, it is important to point out that such depth-dependent hardness measurements are a more precise way to evaluate the layer thickness. Figure 2. clearly shows that this the thickness is similar (approx. 400 lm) for all samples, for all considered carbochromization conditions. As also suggested by optical microscopy observations, these measurements emphasize the difficulty in defining clearly the interface between the coating and the substratesince this differentiated layer consists of a variable mixture of different phases. From a structural point of view, this layer is quite inhomogeneous, containing grains of distribution of C-austenite, needles of AC- martensite.

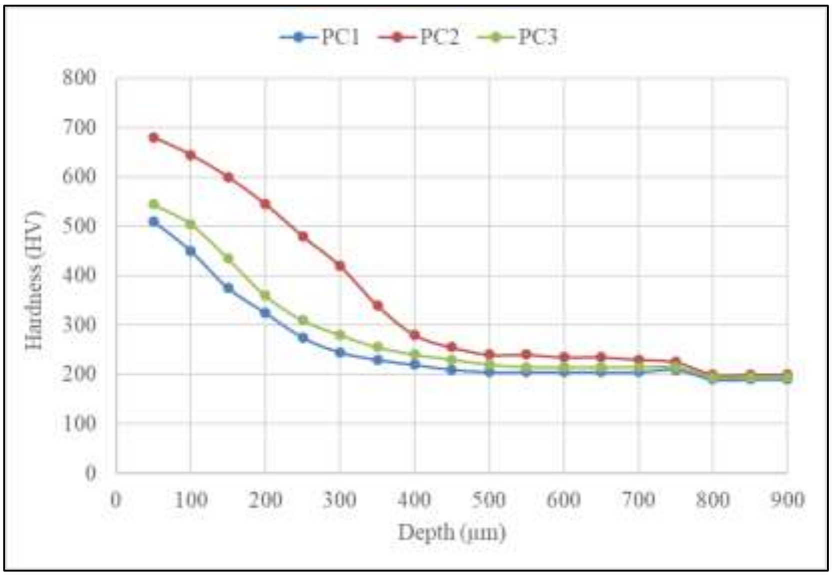

Figure 2 Surface hardness of ASTM A36 steel after carburizing chromization treatment

4.2. Anodic polarization characteristic of ASTM A36 steel

The anodic polarization behavior of the carburizing-chromization treated samples was investigated by potentiodynamic tests. The tests were also conducted on ASTM A36 steel specimens without carburizing-chromization treatment as references. The corrosion parameters determined from the Tafel zone are shown in Table 2. Based on the data in Table 2, it is shown that samples PC1 to PC3 have lower corrosion resistance compared to the initial/untreated ASTM A36 steel specimens. This fact can be caused by two phenomena. First, the formation of iron carbide on the surface of the sample (Fe7C3) can reduce the corrosion resistance. Second, based on EDS analysis, it is shown that the concentration of chromium on the surface of the specimen is lower, compared to the interior of the sample where the precipitation of chromium carbide is more intensive. Since chromium is known to enhance corrosion resistance, the low concentration on the surface of the sample causes the corrosion rate to be 11 to 22 times higher when compared to the untreated specimens. However, PC1 and PC3 specimens, which have the highest amount of chromium, showed corrosion rates only 4 to 11 times greater than the untreated material. In accordance with the results of the study [10]. This observation is in accordance with the SEM data which showed a higher concentration of Cr in the depleted layer compared to the low chromium layer. Various studies have shown that steel improves its corrosion properties after chromium treatment.

Tabel 2 Anodic Polarization Characteristic of The ASTM A36

Specimen	**E Corrosion (V)**	**E Corrosion (µA/cm^2)**	**R (KΩ)**	**Corrosion Rate (mm/year)**
Unpack Carburized	-0.373	0.887	39.27	0.012
PC1	-0.395	10.081	4.82	0.113
PC2	-0.531	19.158	1.61	0.219
PC3	-0.432	3.487	10.53	0.041

Although the chromization process is unable to restore the entire Cr content and save corrosion resistance measured on untreated ASTM A36. material, the difference in corrosion resistance between high and low chromized samples clearly shows the the important role of this process on the final properties of the material. Therefore, ASTM A36 chromated with carbo chrome can be used for applications where better mechanical properties and good corrosion resistance is required.

5. Conclusion

Carburizing-chromization treatment of ASTM A36 steel specimens resulted in, carburized layers with an average thickness of ranging from 50 to and 500 m. Based on the results of surface hardness testing, the thickness of the carburized layer is almost the same for all carburizing conditions. is almost the same for all carburizing-chromization parameter conditions. The layer consists of C-austenite, iron, chromium carbides, and traces of a¢-martensite. Especially chromium carbides are formed at grain boundary regions, The hardness of the coating is about 680 HV at surface and decreases progressively to 200 HV in the the interior of the sample. The increase in hardness inside the coating is mainly related to the presence of carbides and less with the presence of a¢-martensite.

The concentration of chromium on the surface of the specimen is lower, compared to the interior of the sample where the precipitation of chromium carbide is more intensive. Since chromium is known to enhance corrosion resistance, the low concentration on the surface of the sample causes the corrosion rate to be 11 to 22 times higher when compared to the untreated specimens. However, PC1 and PC3 specimens, which have the highest amount of chromium, showed corrosion rates only 4 to 11 times greater than the untreated material.

Compliance with ethical standards

Acknowledgments

The intellectual and moral contributions of Prof. DR. Ir. Rudy Soenoko, Msc.Eng., Prof. DR. Eng. Ir. IGN. Wardana, Prof. Sugiman, ST., MT. among others towards the success of this work are deeply appreciated.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] M. Ortiz-Domínguez, Á. J. Morales-Robles, O. A. Gómez-Vargas, and G. Moreno-González, Surface Growth of Boronize Coatings Studied with Mathematical Models of Diffusion, Metals (Basel)., vol. 14, no. 6, 2024, doi: 10.3390/met14060670.

[2] H. H. Khan et al., In Situ Thermal Interactions of Cu-Based Anti-Corrosion Coatings on Steel Implemented by Surface Alloying, Coatings, vol. 14, no. 6, 2024, doi: 10.3390/coatings14060722.

[3] 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.

[4] 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.

[5] 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.

[6] S. Adachi, T. Yamaguchi, K. Tanaka, T. Nishimura, and N. Ueda, Effects of Solid-Solution Carbon and Eutectic Carbides in AISI 316L Steel-Based Tungsten Carbide Composites on Plasma Carburizing and Nitriding, Metals (Basel)., vol. 13, no. 8, 2023, doi: 10.3390/met13081350.

[7] L. Sun, Y. Li, C. Cao, G. Bi, and X. Luo, Effect of Low-Temperature Plasma Carburization on Fretting Wear Behavior of AISI 316L Stainless Steel, Coatings, vol. 14, no. 2, 2024, doi: 10.3390/coatings14020158.

[8] S. Iorga et al., Influence of the carbo-chromization process on the microstructural, hardness, and corrosion properties of 316l sintered stainless steel, Metall. Mater. Trans. A Phys. Metall. Mater. Sci., vol. 45, no. 7, pp. 3088–3096, 2014, doi: 10.1007/s11661-014-2247-8.

[9] B. Wang, Z. Q. Lv, Z. A. Zhou, S. H. Sun, X. Huang, and W. T. Fu, Combined effect of rapid nitriding and plastic deformation on the surface strength, toughness and wear resistance of steel 38CrMoAlA, IOP Conf. Ser. Mater. Sci. Eng., vol. 89, no. 1, pp. 0–7, 2015, doi: 10.1088/1757-899X/89/1/012046.

[10] A. Oyetunji and S.O. Adeosun, Effects of Carburizing Process Variables on Mechanical and Chemical Properties of Carburized Mild Steel, J. Basic Appl. Sci., vol. 8, no. 2, pp. 319–324, 2021, doi: 10.6000/1927-5129.2012.08.02.11.