Global Scientific JOURNALS

GSJ: Volume 10, Issue 6, June 2022, Online: ISSN 2320-9186
www.globalscientificjournal.com

Corrosion Inhibition of Austenitic 316Ti Steel: Mini Review

Olayemi Odunlami[1]*, Toluwalase Fernandez[1], Muyiwa Fajobi[2], Francis Elehinafe[1]

[1]Department of Chemical Engineering, Covenant University, Ota, Ogun state, Nigeria

[2]Department of Mechanical Engineering, Covenant University, Ota, Ogun state, Nigeria

*Corresponding Author e-mail olayemi.odunlami@covenantuniversity.edu.ng

Abstract. Stainless steels have many applications in the industries and for engineering works because of their excellent properties. They are frequently confronted with corrosion attacks during the applications, which had always been their most difficult challenge. Corrosion inhibition is one significant way in which materials are protected from being corroded. The toxic nature of inorganic inhibitors has brought about the use of green inhibitors. Green inhibitors are readily available, renewable, degradable, cheap, and environmentally friendly due to the absence of heavy metals and toxic compounds in them. This review outlined the properties of Titanium (Ti) stainless steel and the use of green inhibitors for corrosion control for a sustainable environment.

Keywords: Corrosion inhibition; stainless steel; green inhibitors austentic 316Ti steel

Introduction

Metals have a high energy state when they are not combined; they tend to go back to a lower energy state when energy is being released. Corrosion is the surface deterioration that occurs in metals when exposed to reactive conditions. It is a gradual destruction of metals due to their reactions with the environment [1,2]. The economic risks of corrosion are very high, with so much money being spent on corrosion protection and repair. It is estimated that 5 per cent of the revenue of a developed country is spent on direct corrosion costs. Examples of metals that corrode are Stainless Steel, Aluminium, Copper, Zinc, Iron, Carbon Steel, Nickel, Lead, Titanium, Tin, Brass, Cadmium, and Cobalt [3,4].

Corrosion inhibitors are substances applied or added to the corrosive medium in small concentrations on metal surfaces, thereby minimizing the potential to be damaged by corrosion. These inhibitors are used in several media to prevent the destruction of metals in corrosion-favourable environments. Current techniques take advantage of organic compounds which act as corrosion inhibitors for exhibiting outstanding metal surface resistance properties. Such organic corrosion inhibitors include: chitosan [5], phenylmethanimine [6], imidazoline [7], and ionic liquid derivatives [8]. These organic compounds help to replace the conventional (inorganic) corrosion inhibitors because of their toxicity. Highly effective corrosion inhibitors have been achieved through these compounds, which are derived from renewable, biological and environmentally safe materials, with a special category being plant extracts [9,10] Stainless steels products have a high ability to resist corrosion because the chromium present in the stainless steel forms a passive film coating of chromium-rich oxide in the presence of oxygen at lower temperatures; stainless steel products have a strong corrosion resistance capacity [11] Harsh environments could potentially cause damage to this barrier. Over the years, research has shown that natural honey, onions, gums of flowers, gelatin, leaves, potatoes, roots, and seeds are suitable inhibitors of metals like steel and nickel. Hence, this review enumerates the use of green corrosion inhibitor on 316 Ti stainless steel in an acidic medium.

Corrosion Inhibitors

Chemical compounds capable of reducing the rate of corrosion of a metal is known as a corrosion inhibitor [12] Corrosion inhibitors have several applications in reducing or controlling the corrosion process of metals and alloys used in industries. These inhibitors prevent corrosion by adsorption of ions on metal surfaces, reduction of the diffusion rate for reactants to the metal surface, reduction of the electrical resistance of the metal surface, and reducing or increasing the anodic or cathodic reaction. Corrosion inhibitors can be from either organic or inorganic sources. Organic inhibitors reduce corrosion by adsorption techniques, while inorganic corrosion inhibitors retard corrosion by reacting with the anodic or cathodic parts of the process [13-16]

Organic Corrosion Inhibitor

Green corrosion inhibitors have been frequently used by researchers for corrosion prevention. Organic Inhibitors are associated with heteroatoms. O, N, and S are the active centres for the process of adsorption on the metal surface. Toxic compounds and heavy metals are absent in green corrosion inhibitors, unlike inorganic corrosion inhibitors. The inhibition mechanism, occurs through adsorption. It primarily depends on the properties of the inhibitor and the physicochemical reaction. The adsorption mechanism is dependent on several factors like the functional group of the inhibitor, the electron density of the atom donor; the degree of ionic forces; the p-orbital character; as well as and the properties of the metal surface [17-21].

Inorganic Corrosion Inhibitor

Inorganic corrosion inhibitors contain heavy metals that scrape at the cathode cell of the unprotected metal surfaces when mixed with corrosive solution. The corrosion inhibitors reduce the proportion of hydrogen ion exchange by forming iron sulfide on the steel and acids. The inorganic inhibitors work better at high temperatures for more extended periods than the organic inhibitors. Yet, they lose their grip in acid solutions stronger than 17% hydrochloric acid, are more difficult to combine. They release toxic gases as the product of corrosion, which adversely affect man and his environment [22-24].

Stainless steel

Any alloy having 10 to 30% chromium is referred to as stainless steel. Chromium resists corrosion and heat as a result of its low carbon content. Nickel, molybdenum, titanium, aluminium, copper, sulphur, and phosphorus could be added to boost the resistance of corrosion. Stainless steel comes in over a hundred different grades. Stainless steels are of these five types: austenitic, ferritic, martensitic, duplex, and precipitation-hardening. Most stainless steels are melted in electric-arc or basic oxygen furnaces first, then refined in a separate steelmaking vessel to remove the carbon content. During the argon-oxygen decarburization process, a mixture of oxygen and argon gas is poured into liquid steel. By altering the ratio of oxygen and argon, it is feasible to remove carbon in controlled amounts by oxidizing it to carbon monoxide without simultaneously oxidizing and losing precious chromium. As a result, lower-cost raw materials like high-carbon ferrochromium might be used in the first melting process [25-31].

Austenitic 316Ti stainless steel

Stainless steels are iron-base alloys with at least 12% Cr, which is required for preventing rust formation in an unpolluted environment. The titanium-stabilized form of 316 molybdenum-bearing austenitic stainless steel is 316Ti (UNS S31635). Compared to other stainless steels, this austenitic chromium-nickel stainless steel contains molybdenum, which aids corrosion resistance, especially at high temperatures. Despite possessing many general qualities as Type 304, it is more heat resistant [32]. Alloy 316Ti has qualities comparable to alloy 316, except that due to the Titanium addition, 316Ti can be utilized at higher sensitization temperatures above 800°C, preventing carbide formation at grain boundaries and safeguarding the metal from corrosion. Sulfuric, hydrochloric, acetic, formic, and tartaric acids, acid sulfates, and alkaline chlorides improve corrosion resistance. This type of stainless steel is commonly used in oil and gas, petrochemical, brewery, food processing, automotive, wine, and chemical industries. It can be used in chemical processes, at high temperatures, in control lines, etc. It is also used in architectural panelling and balustrading along the coast, chemical transport containers, medical implants, boat fittings, and heat exchangers [33-36].

General Properties

The titanium-stabilized version of Type 316 molybdenum-bearing austenitic stainless steel is ATI 316Ti. The Type 316 alloys outperform traditional chromium-nickel austenitic stainless steels like Type 304 in general corrosion and pitting/crevice corrosion resistance. They also have increased creep, stress-rupture, and tensile strength at high temperatures. Sensitization - the development of grain boundary chromium carbides at temperatures between 900 and 1500 °F (425 to 815 °C) – can occur in Type 316 stainless steel, resulting in fast corrosion. Carbon emissions are lower. Although Type 316L is resistant to sensitization, prolonged exposures in this temperature range will eventually cause even the low carbon grade to become sensitized. Sensitivity resistance is accomplished in Type 316Ti by adding titanium to the structure to stabilize it against chromium carbide precipitation, which is the source of sensitization. Intermediate-temperature heat treatment is used to achieve this stability, during which the titanium interacts with carbon to generate titanium carbides. Reducing the development of chromium carbides, considerably minimizes the sensitivity to sensitization in service. As a result, the alloy can be utilized at high temperatures for long periods without losing its corrosion resistance [37-39]. Table 1 shows the chemical compositions of 316 Ti.

Table 1: Chemical Composition of 316 Ti [40]

Element	% by weight
S	0.00-0.03
P	0.00-0.05
C	0.00-0.08
Si	0.00-1.00
Mn	0.00-2.00
Ti	0.40-0.70
Mo	2.00-2.50
Ni	10.50-14.00
Cr	16.50-18.50
Fe	Balance

Case Studies On 316Ti Stainless Steel

Loto (2019) studied the corrosion resistance of austenitic 316Ti, martensitic GX4CrNiMo16-5-1 (EN 1.4405), and ferritic 444 stainless steels in 1 M sulfuric acid solution with a 0-6 percent NaCl addition and concluded that 316Ti is less resistant to acidic solutions when chloride ions are present [41].

In acidic (250 ppm Cl, pH = 4, t = 30°C) and alkaline (4 percent Cl, pH = 9, t = 80°C) electrolytes, Lorsbach and Schmitz (2018) found that agitation rate had a substantial impact on the corrosion rate of SS 316Ti [42].

After various heat treatments in 0.5 M H_2SO_4 + 0.01 M KSCN solution at 30°C, Pardo et al., 2007 studied the influence of Ti, C, and N concentrations in SS 316Ti and SS 321 on intergranular corrosion and discovered that adding titanium to stainless steel increases intergranular corrosion resistance by causing TiC to precipitate, hereby reducing the development of chromium-rich carbides. They also found that stainless steel 316Ti has superior intergranular corrosion resistance over SS 321 [43].

Zhao et al., 2019 investigated the microstructure and intergranular corrosion resistance of 316Ti stainless steel in 0.5M H2SO4 + 0.01M KSCN at 25^{o}C. They found that intergranular corrosion resistance increased with increasing ageing temperature [44].

Finsgar and Milosev (2010) examined the corrosion behaviour of stainless steel 304, 316, and 316Ti in methanesulfonic acid aqueous solutions and discovered that these grades of stainless steel have similar corrosion characteristics [45].

Conclusion

Metals are essential for the production of equipment used in various industries, and they serve a variety of purposes. This is due to their excellent properties like durability, high corrosion resistance, high elevated temperature, good thermal conductivity, and high strength. Stainless steel is a type of metal that, when compared to carbon steel, has a higher corrosion resistance. 316Ti stainless steel is a type of stainless steel used in engineering structures because of its high performance, alloying elements, and high sensitization temperature. Researches had shown that green inhibitors are perfect for the corrosion inhibition of austenitic 316Ti stainless steel in corrosive environments like HCl, H_2SO_4, and H_3PO_4.

References

[1] Rani, B., & Basu, B. (2011). Green inhibitors for corrosion protection of metals and alloys: An Overview . *Int. J. Corros.*

[2] Odunlami, O. A., Loto, R. T., Fajobi, M. A., Olomukoro, O. T., Akande, I. G., Oke, M. A., & Oladimeji, T. E. (2021). Data on the corrosion Inhibition Property of Rosemary on High Carbon Steel in dilute sulphuric acid, citric acid and sodium chloride solution. *Chemical Data Collections*, *32*, 100660.

[3] Rani, B. E., & Basu, B. B. J. (2012). Green inhibitors for corrosion protection of metals and alloys: an overview. *International Journal of corrosion*, *2012*.

[4] Odunlami, O. A., Fayomi, O. S. I., Tijani, S., & Fayomi, J. O. (2021). Chemical Adsorption Data's, Temperature Effect and Structural Properties of Artemether-Lumefantrine Corrosion Inhibition Properties on Structural Steel in 0.62 M NaCl. In *Key Engineering Materials* (Vol. 886, pp. 143-155). Trans Tech Publications Ltd.

[5] Zhao, Q., Guo, J., Cui, G., Han, T., & Wu, Y. (2020). Chitosan derivatives as green corrosion inhibitors for P110 steel in a carbon dioxide environment. *Colloids Surf. B Biointerfaces*, 194.

[6] Machado Fernandes, C., Pina, V., Alvarez, L., de Albuquerque, A., dos Santos Júnior, F., Barrios, A., . . . Ponzio, E. (2020). Use of a theoretical prediction method and quantum chemical calculations for the design, synthesis and experimental evaluation of three green corrosion inhibitors for mild steel. *Colloids Surf. Physicochem. Eng. Asp*, 599.

[7] Munis, A., Zhao, T., Zheng, M., Rehman, A., & Wang, F. (2020). A newly synthesized green corrosion inhibitor imidazoline derivative for carbon steel in 7.5% NH4Cl solution. *Sustain. Chem. Pharm*, 16.

[8] Verma, C., Ebenso, E., & Quraishi, M. (2017). Ionic liquids as green and sustainable corrosion inhibitors for metals and alloys: An overview. *J. Mol. Liq.*, 403-414.

[9] Olawale, O., Bello, J., Ogunsemi, B., Uchella, U., Oluyori, A., & Oladejo, N. (2019). Optimization of chicken nail extracts as corrosion inhibitor on mild steel in 2 M H2SO4. *Heliyon*, 5, e02821.

[10] Odunlami, O. A., Abatan, O. G., Busari, A. A., Alao, G. T., Loto, R. T., & Olomukoro, O. T. (2021). Electrochemical control of high carbon steel corrosion using rosemary oil in citric acid medium. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1036, No. 1, p. 012051). IOP Publishing.

[11] Potgieter, J., Adams, F., Maledi, N., Van Der Merwe, J., & Olubambi, P. (2012). Corrosion resistance of type 444 ferritic stainless steel in acidic chloride media. *J. Chem. Mater. Sci.*, 37-48.

[12 Hubert Gräfen, Elmar-Manfred Horn, Hartmut Schlecker, Helmut Schindler "Corrosion" Ullmann's Encyclopedia of Industrial Chemistry, Wiley-VCH: Weinheim, 2002. doi:10.1002/14356007.b01_08

[13] Umoren, S.; Obot, I.; Madhankumar, A.; Gasem, Z. Performance evaluation of pectin as ecofriendly corrosion inhibitor for X60 pipeline steel in acid medium. Carbohydr. Polym. 2015, 124, 280–291. [CrossRef]

[14] Tiu, B.D.B.; Advincula, R.C. Polymeric corrosion inhibitors for the oil and gas industry: Design graphic and mechanism. React. Funct. Polym. 2015, 95, 25–45. [CrossRef]

[15] Herle, R., Shetty, P., Shetty , S., & Kini, U. (2011). Corrosion inhibition of 304 SS in hydrochloric acid solution by N – Furfuryl N'- phenyl thiourea. *Portugaliae Electrochim.*, 69-78.

[16] Nasrin, S., Nahid, T., Maryam, K., Mohammad Reza, J., & Ahmad, M. (2012). Green approach to corrosion inhibition of 304 stainless steel in hydrochloric acid solution by the extract of Salvia officinalis leaves. *Corrosion Science*, 122-135.

[17] Fajobi, M. A., Loto, R. T., & Oluwole, O. O. (2021). Austenitic 316L Stainless Steel; Corrosion and Organic Inhibitor: A Review. *Key Engineering Materials*, *886*, 126-132.

[18] Eddy, N. O., Odoemelam, S. A., & Odiongenyi, A. O. (2009). Ethanol extract of Musa species peels as a green corrosion inhibitor for mild steel: Kinetics, adsorption and thermodynamic considerations. *Electronic Journal of Environmental, Agricultural and Food Chemistry, vol. 8*, 243–255.

[19] Gholamhosseinzadeh, M., Aghaie, H., Zandi, M., & Giahi, M. (2019). Rosuvastatin drug as a green and effective inhibitor for corrosion of mild steel in HCl and H2SO4 solutions. *J. Mater. Res. Technol.*, 5314–5324.

[20] Fouda, A., El-Morsy, M., El-Barbary, A., & Lamia, E. L. (2016). Study on corrosion inhibition efficiency of some quinazoline derivatives on stainless steel 304 in hydrochloric acid solutions. *Int. J. Corros. Scale Inhib.*, 112–131.

[21] Ehsani, A., Mahjani, M., Hosseini, M., Safari, R., Moshrefi, R., & Mohammad Shiri, H. (2017). Evaluation of Thymus Vulgaris plant extract as an eco-friendly corrosion inhibitor for 304 stainless steel in an acidic solution by means of electrochemical impedance spectroscopy (EIS), electrochemical noise analysis and density functional theory. *Journal of Colloid and Interface Science*, 444-450.

[22] Al-Otaibi, M.; Al-Malouf, A.; Khan, M.; Mousa, A.; Al-Mazroa, S.; Alkhathlan, H. Corrosion inhibitory action of some plant extracts on the corrosion of mild steel in acidic media. Arab J. Chem. 2014, 7, 340–346. [CrossRef]

[23] Ferengi, H.; Jazdzewska, A.; Kurtay, M. A comprehensive evaluation of mimosa extract as a corrosion inhibitor on AA6060 alloy in acid rain solution: Part I. Electrochemical AC methods. J. Adhes. Sci. Technol. 2015, 29, 36–48. [CrossRef]

[24] Odunlami, O. A., Loto, R. T., Fajobi, M. A., Akande, I. G., Oladimeji, T. E., & Olomukoro, O. T. (2021). Rosemary oil as a Corrosion Inhibitor on High Carbon Steel in Citric Acid and Sodium Chloride: Weight Loss Study. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1107, No. 1, p. 012153). IOP Publishing.

[25] Swinbourne, D. R., Kho, T. S., Langberg, D. A. V. I. D., Blanpain, B., & Arnout, S. (2010). Understanding stainless steelmaking through computational thermodynamics Part 2–VOD converting. *Mineral Processing and Extractive Metallurgy*, *119*(2), 107-115.

[26] Das, S. K., Mehrotra, S. P., & Godiwalla, K. M. (2010). Technological advances in Refining and Processing of stainless Steel-A brief overview.

[27] Grigorovich, K. V., & Komolova, O. A. (2020). Effect of Nitrogen on the Plasma Decarburization of Chromium-Containing Steel. *Russian Metallurgy (Metally)*, *2020*(11), 1300-1307.

[28] Saqlain, M., Owais, M., Järvinen, M., Visuri, V. V., & Fabritius, T. (2018). Desphosphorization in ironmaking and oxygen steelmaking.

[29] Gopi, D., Manimozhi , S., Govindaraju , K., Manisankar , P., & Rajeswari , S. (2007). Surface and electrochemical characterization of pitting corrosion behaviour of 304 stainless steel in groundwater media. *J. Appl. Electrochem.*, 439-449.

[30] Behpour, M., Ghoreishi, S., Soltani, N., & Salavati-Niasari, M. (2009). The inhibitive effect of some bis-N,S-bidentate Schiff bases on corrosion behaviour of 304 stainless steel in hydrochloric acid solution. *Corrosion Science* , 1073–1082.

[31] Femiana, G., Kartika, A. M., Firman Mangasa, S., Andoko, A., Hastono, W., & Fredy, K. (2019). Corrosion Inhibition of Honeycomb Waste Extracts for 304 Stainless Steel in Sulfuric Acid Solution. *Materials*, 2120.

[32] Davis, J. R. (Ed.). (2000). *Alloy digest sourcebook: stainless steels*. ASM international.

[33] Grgur, B. N. (2020). Corrosion of the stainless steel 316Ti in 10% hydrochloric and sulfuric acid. *Zaštita materijala*, *61*(4), 339-345.

[34] Selvakumar, P., Karthik, B., & Thangavelu , C. (2013). Corrosion inhibition study of stainless steel in acidic medium – an overview. *Res. J. Chem. Sci.*, 87-95.

[35] Mieczyslaw, S., & Joanna, T. (2013). Adenine as an Effective Corrosion Inhibitor for Stainless Steel in Chloride Solution. *Int. J. Electrochem. Sci.*, 9201-9221.

[36] Albrimi, A. Y., Addi, A. A., Douch, J., Souto, R., & Hamdani, M. (2015). Inhibition of the pitting corrosion of 304 stainless steel in 0.5 M hydrochloric acid solution by heptamolybdate ions. *Corrosion Science*, 522-528.

[37] Ahmed, A. A. (2017). *Coating and surface treatment for novel biomedical implants and their corrosion resistance* (Doctoral dissertation, Technische Universität Clausthal).

[38] Was, G. S., Busby, J., & Andresen, P. L. (2006). Effect of irradiation on stress-corrosion cracking and corrosion in light water reactors. *ASM Handbook*, *13*, 386-414.

[39] Was, G. S., & Ukai, S. (2019). Austenitic stainless steels. *Structural alloys for nuclear energy applications*, 293-347.

[40] AZO Materials (2022) Grade 316 Stainless Properties, Fabrications and Applications. https://www.azom.com/article.aspx?ArticleID=2868

[41] Loto, R. T. (2019). Corrosion resistance and morphological deterioration of 316Ti austenitic, GX4CrNiMo16-5-1 martensitic and 444 ferritic stainless steels in aqueous corrosive environments. *Results in Physics*, *14*, 102423.

[42] Lorsbach, B., & Schmitz, E. (2018). Influence of test parameters of potentiodynamic current density measurements on the determination of the pitting corrosion resistance of austenitic stainless steels. *Materials and Corrosion*, *69*(1), 37-43.

[43] Grgur, B. N. (2020). Corrosion of the stainless steel 316Ti in 10% hydrochloric and sulfuric acid. *Zaštita materijala*, *61*(4), 339-345.

[44] Grgur, B. N., Trišović, T. L., & Rafailović, L. (2020). Corrosion of stainless steel 316Ti tank for the transport 12–15% of hypochlorite solution. *Engineering Failure Analysis*, *116*, 104768.

[45] Finšgar, M., & Milošev, I. (2010). Corrosion behaviour of stainless steels in aqueous solutions of methanesulfonic acid. *Corrosion science*, *52*(7), 2430-2438.