International Journal of ISSI, Vol. 21(2024), No. 2, pp. 21-30

Online ISSN: 2981-0396 Print ISSN: 2981-0388

International Journal of Iron & Steel Society of Iran

Journal Homepage: https://journal.issiran.com/

Research Article

Enhancing Atmospheric Corrosion Resistance of Shot-Peened A36 Steel in Humid Environments: The Impact of Carbon Monoxide and Surface Treatments

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ARTICLE INFO

Keywords:

A36 Steel, Atmospheric Corrosion, Electrochemical Impedance Spectroscopy, Shot Peening, Carbon Monoxide.

Article history:

Received 28 October 2024
Received in revised form 11 December 2024
Accepted 22 February 2025

ABSTRACT

A36 steel is a widely used construction material, appreciated for its low carbon content and excellent weldability. However, it is prone to atmospheric corrosion, particularly in humid and polluted areas like Tehran with its high carbon monoxide level. This study examines the corrosion behavior of shot-peened A36 steel in both a 3.5% NaCl solution and the same solution with 9 ppm CO to mimic real-world conditions. Electrochemical Impedance Spectroscopy (EIS) and potentiodynamic polarization were performed on samples immersed for 1, 24, 48, 72, and 96 hours as well as 1 and 2 weeks. The results showed that longer immersion times significantly altered the corrosion mechanisms in the Nyquist plots. Notably, shot peening improved the steel resistance to charge transfer and diffusion. After two weeks in the CO-rich solution, the corrosion current density of shot-peened samples dramatically decreased from 45.7 µA/cm² to 6.5 µA/cm², exhibiting an impressive reduction of 85.5%. Carbon monoxide reacts with water to form carbonic acid which lowered the pH, accelerating the cathodic reactions in more acidic medium. Additionally, shot peening applied compressive stresses on the steel surface that limited corrosive ion penetration. Fourier Transform Infrared Spectroscopy (FTIR) analysis confirmed the formation of iron hydroxide compounds on the surface of shot-peened samples, enhancing their corrosion resistance by restricting the diffusion of corrosive agents.

1. Introduction

A36 steel is a cornerstone material in the construction industry, prized for its low carbon content, offering excellent weldability and versatility. With a carbon composition typically ranging from 0.26% to 0.29%, A36 steel achieves a favorable balance between strength and ductility, making it ideal for various applications, including beams, columns, and plates used in buildings and bridges. Its mechanical properties are impressive, featuring yield strengths of 248-400 MPa and tensile strengths of 400-552 MPa, which contribute to its reliability in structural contexts [1-2]. A36 steel can be used without protective coatings in low-risk environments, such as indoor structural applications with minimal exposure to moisture and corrosive agents. Despite its widespread applications, A36 steel is vulnerable to atmospheric corrosion, especially in environments marked by high humidity and pollution. The risk of deterioration is significantly elevated in urban areas like Tehran, where industrial activities and seasonal weather fluctuations cause

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DOI: http://10.22034/IJISSI.2025.2044477.1307
Published by ISSI (Iron & Steel Society of Iran)

corrosive conditions. The presence of chloride ions and other corrosive agents in the atmosphere is one of the key and influential factors of the corrosion behavior of A36 steel. These elements can penetrate the protective oxide layers on the steel surface, accelerating corrosion processes [3-5]. Furthermore, carbon monoxide of urban environments can react with moisture to form carbonic acid, lowering pH, causing a more aggressive environment for corrosion [6-7].

Although A36 steel is not typically recommended for uncoated use in humid and corrosive environments, this study aims to investigate whether surface modification of A36 through treatment can render it suitable for these challenging conditions [3-5]. This approach may enable the effective use of A36 steel without protective coatings in environments such as Tehran that would normally compromise its performance. To mitigate these issues, surface treatment methods such as shot peening have gained increasing attention.Based on Walczak et al., shot peening improves surface integrity, a vital factor in reducing corrosion susceptibility of metals. While shot peening has been shown to enhance the mechanical properties and fatigue resistance of various steels, including stainless steel, its effects on corrosion behavior of A36 steel are not yet fully understood. Their study suggests that this treatment could significantly bolster the resistance of steel to atmospheric corrosion, especially in humid conditions [8]. Similarly, Świetlicki et al. discuss the positive effects of shot peening on metallic surfaces. Based on their report, optimization of treatment parameters can substantially improve corrosion resistance, particularly, against aggressive agents such as carbon monoxide [9]. Furthermore, Zhang et al. explored the combined effects of shot peening and laser-shot peening on medium carbon steel. They reported that such synergistic treatments can enhance microstructural properties and fatigue performance [10]. Indeed, shot peening involves bombarding the steel surface with small metallic balls to induce compressive residual stresses to enhance mechanical properties and improve corrosion resistance. This process not only strengthens the surface but also helps limit the penetration of corrosive agents. The compressive stresses act as a barrier against crack propagation, thus, reducing the probability of stress corrosion cracking (SCC), offering an effective strategy for extending the lifespan of A36 steel in harsh environments [11-13].

Actually, important gaps are highlighted in the understanding of A36 steel behavior when exposed to atmospheric corrosion, particularly in urban settings like Tehran with significant humidity and pollution. The combined impact of chloride ions and carbon monoxide on corrosion rates has been overlooked in most of previous studies, especially on the shot-peened A36 steel. This study, thus, aims to explore the atmospheric corrosion behavior of shot-peened A36 steel under real-world-simulating conditions.The performance of A36 steel was examined in both a 3.5% NaCl solution and a 3.5% NaCl solution containing 9 ppm CO to understand the influence of prolonged exposure on corrosion mechanisms. The novelty of this article lies in its thorough examination of these interactions within a controlled environment that simulates real-world corrosive conditions. This study also investigates the role of shot peening surface treatment to identify effective strategies for enhancing the durability of A36 steel structures. The insights gained from this research will be invaluable for improving the resilience of A36 steel in challenging environments like Tehran.

2. Materials and Methods

A36 steel samples were prepared according to the ASTM E3-11 (2017) standard. The samples were sourced from commercially available sheets and cut into standardized dimensions of 10 mm ×10 mm × 5 mm. To achieve a smooth surface finish, they were cleaned and polished using a range of sandpapers, from 220 to 2500 mesh, followed by further refinement with diamond paste to decrease the roughness to 0.3 µm. To improve their surface properties, the samples were treated by a shot peening process utilizing steel balls with a diameter of 0.5 mm, propelled at a velocity of 50 m/s. The corrosion tests were carried out according to the ASTM G59 and ASTM G106 standards. To this end, two immersion solutions were created: one consisting of a 3.5% NaCl solution and the other a 3.5% NaCl solution with 9 ppm of carbon monoxide (CO) to simulate the urban atmospheric conditions of Tehran. The carbon monoxide (CO) used in this study was provided from a commercial supplier, classified as Grade 3.5, with a purity of 99.95%. Before immersion, each sample was thoroughly cleaned with acetone to eliminate any surface contaminants that could affect the results. The samples were then divided into two groups: one group was shot-peened while the other received no treatments. Each group was immersed in the respective solutions for different durations (e.g. 1, 24, 48, 72, and 96 hours and 1 and 2 weeks) for a comprehensive assessment of their corrosion behavior over time. Before electrochemical tests, the samples underwent an initial stabilization period of 30min to establish a stable open circuit potential (OCP). The electrochemical analysis was performed by a three-electrode system comprisingthe A36 steel sample, a saturated calomel electrode, and a platinum electrode as the working, reference, and counter electrodes, respectively. Electrochemical Impedance Spectroscopy (EIS) was performed across a frequency range from 1 mHz to 100 kHz to assess charge transfer resistance and potentiodynamic polarization and determine the corrosion current density. After immersion, Fourier Transform Infrared Spectroscopy (FTIR) analysis was performed on the shot-peened samples to identify corrosion products.

3. Results and Discussion

The corrosion behavior of shot-peened A63 steel in polluted environments, especially those with carbon monoxide (CO), is vital for evaluating the performance of materials in practical applications. As urban settings expose structural materials to harsh contaminants, it is important to understand the impact of shot peening on the corrosion resistance. While this surface treatment can improve mechanical properties, it may also change the electrochemical responses under corrosive conditions. The corrosion behavior of shot-peened A63 steel was explored in CO-rich environments to further assess its engineering applications and durability.

3.1. EIS Study

Fig. 1. illustrates the Nyquist plots of A36 steel and shot peened A36 steel in 3.5 % NaCl solution and 3.5 % NaCl solution containing 9 ppm CO for different immersion times. According to Fig. 1a. when A36 steel is immersed in a 3.5% NaCl solution for up to 48 hours, the single semi-circle observed in the Nyquist plot evolves into two distinct semi-circles, signifying the formation of corrosion products with protective effects on the surface of A36 steel. Typically, these products consist of iron oxides and hydroxides, which act as a barrier against penetration of corrosive ions [14-15]. However, a decline can be observed in the protective effectiveness of these products for longer immersion times up to 1 week. Such a reduction likely results from corrosive ions and oxygen infiltrating the protective layer, leading to its degradation after 2 weeks of immersion. Interestingly, an increase can be detected in n_{dl} as extending the immersion time of A36 steel in the NaCl solution. n_{dl} is a parameter associated with double layer capacitance. Such an increase can be attributed to the accumulation of ions on the metal surface and the formation of an electric double layer, hindering the penetration of corrosive ions. This double layer comprises a positive or negative charge on the surface and a second layer of mobile ions adsorbed onto that [16-17]. Over time, however, n_{pro} of the corrosion products decreased. Such a decline is often due to the non-uniformity and instability of these products, which may form unevenly on the surface. Such irregularities can increase surface roughness and ultimately reduce the value of n_{pro}. A delicate balance can be seen between the formation and degradation of protective layers over time, significantly influencing both the corrosion behavior and electrochemical performance of A36 steel.

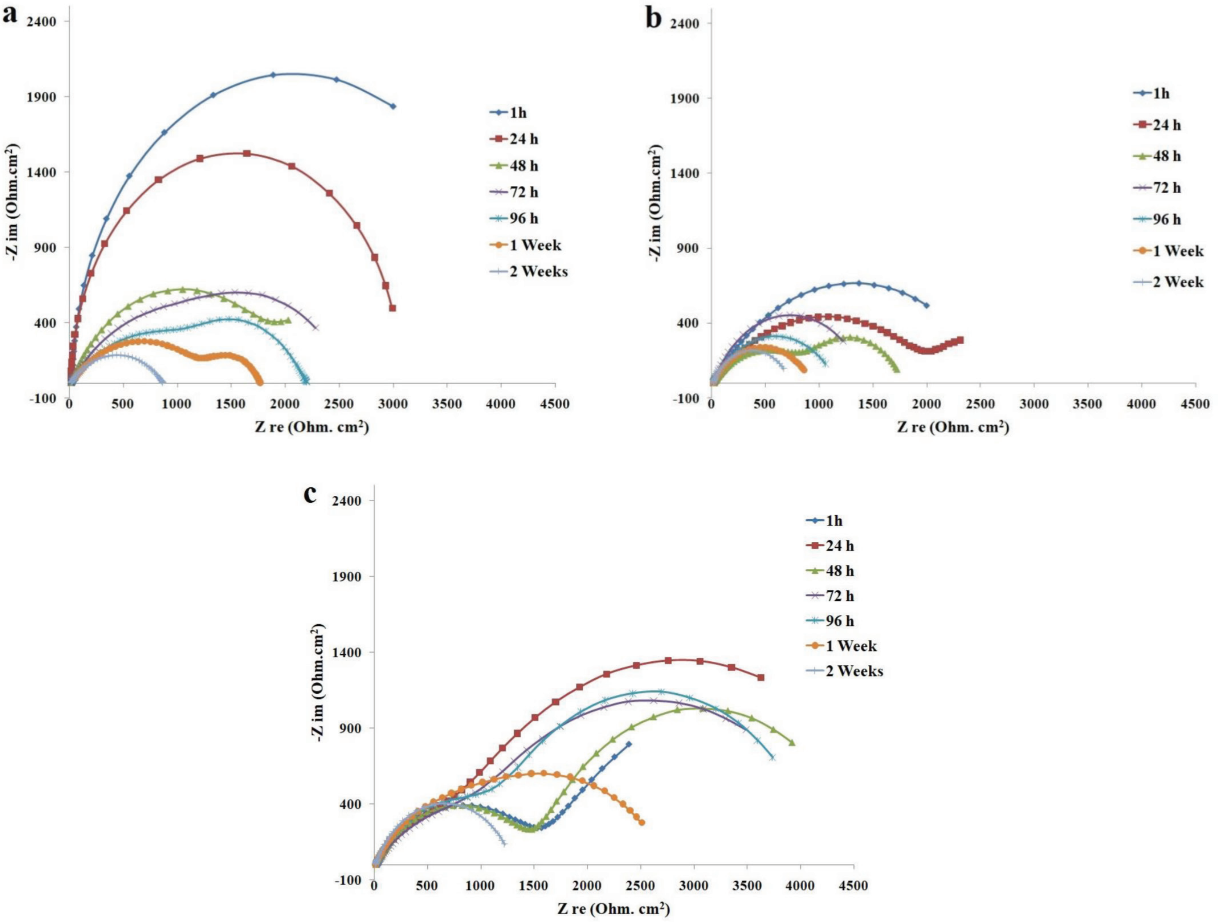

Fig. 1. Nyquist plots of, a) A36 steel in 3.5 % NaCl solution, b) A36 steel in 3.5 % NaCl solution containing 9 ppm CO, and c) shot peened A36 steel in 3.5 % NaCl solution containing 9 ppm CO at different immersion times, 1 h, 24 h, 48 h, 72 h, 96 h, 1 week and 2 weeks.

Moreover, a notable escalation can be seen in corrosion processes when carbon monoxide gas (9 ppm) is introduced into the 3.5% NaCl solution (Fig. 1b). The protective performance derived from corrosion products diminishes after just 24 hours of immersion and completely fades by 48 hours. The corrosion rates rise sharply as immersion time extends to two weeks. The presence of carbon monoxide (CO) not only facilitates the formation of formic acid (HCOOH) but also contributes to a decrease in n of the electric double layer. Such a reduction can be traced back to the adverse effects of CO on the electrochemical properties of A36 steel surface. By increasing CO concentration, chemical reactions produce carboxylic acids which lower the pH of the solution and boost hydrogen ion (H^+) concentration. This rise in hydrogen ions accelerates oxidation reactions while weakening the protective layers and causing non-uniform conditions on the surface—ultimately leading to a decrease in ndl. Furthermore, formic acid has reducing properties, further compromising the protective layers [18-20].

Based on Fig. 1c. the Nyquist plot of the shot-peened A36 steel reveals a significant increase in ring diameters alongside changes in corrosion process mechanisms. The appearance of two semi-circles from early immersion indicates the formation of the effective protective layers by corrosion products which successfully prevent corrosive ions and oxygen from penetrating the steel surface, maintaining their protective capabilities for up to 1 week. However, after 2 weeks, this protective ability diminishes due to further degradation caused by the increased infiltration of corrosive ions and oxygen under CO-induced acidic conditions. In conclusion, shot peening not only enhances the corrosion resistance but also supports the formation of effective protective layers, improving the performance of A36 steel in aggressive environments. By generating compressive stresses on the surface, shot peening improves adhesion between corrosion products and metal surfaces, effectively blocking corrosive ions and oxygen from infiltration into the metal structure. Additionally, this process cleanses the surface by removing impurities and oxides, further enhancing adhesion for hydroxide-based protective layers. For longer immersion time, ions and corrosion products accumulate on the metal surface leading to an increase in n_{pro}—indicating the formation of a stronger electric double layer due to the presence of positive and negative charges at both surfaces and within the solution. Over time, this protective performance may, however, diminish due to infiltration by corrosive ions and degradation from corrosion products. Thanks to their compressive stress and larger surface area, shot-peened samples showed greater capacitive capacity for electric double layers compared to the unshot-peened samples which were more vulnerable to corrosion and degradation due to tensile stresses and ineffective protective layers.

An equivalent circuit model was utilized to better understand the corrosion behavior of shot peened A36 steel and evaluate the protective performance of shot-peened steel in a solution containing 9 ppm of carbon monoxide [21-22]. As depicted in Fig. 2. this model effectively illustrates the corrosion mechanisms and their variations for different immersion times in a 3.5% NaCl solution in the presence/absence of CO. The findings of this simulation are summarized in Tables 1-3. which align with the equivalent circuits shown in Fig. 2. R_{sol} and R_{pro} respectively refer to the resistance of the solution and corrosion products; while R_{ct} pertains to the charge transfer resistance. Meanwhile, CPE_{pro} and CPE_{dl} denote the capacitance of the layer formed by corrosion products and the charge transfer capacitance, respectively. Additionally, n is an indicator of surface roughness and uniformity, providing insight into the overall conditions of the surface.

Tables 1 and 2. shed light on how well A36 and shot-peened A36 steel perform upon immersion in a 3.5% NaCl solution in the presence or absence of carbon monoxide (CO). Notable changes can be seen in the corrosion behavior of the steel by raising the immersion time due to its interaction with the NaCl environment. For A36 steel in NaCl without CO, the immersion time of 48 hours shows moderate corrosion rates, thanks to the formation of protective oxide layers. As the immersion extends to 1 week, the aggressive nature of chloride ions appears, increasing the corrosion rates. By 48 hours, the buildup of corrosion products starts to compromise these protective layers, resulting in a rougher surface. The situation dramatically changes upon introduction of carbon monoxide (9 ppm) to the NaCl solution, even after 24 hours of immersion, CO begins to interfere with the formation of the protective layers. By 48 hours, corrosion accelerates significantly due to the generation of corrosive species like formic acid. This trend continues as immersion time increased, with corrosion rates hitting critical levels by the

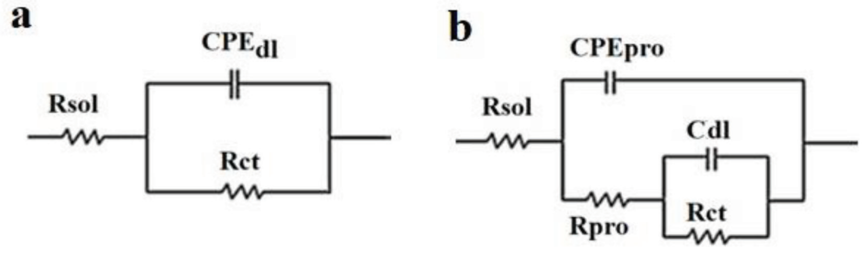

Fig. 2. Electrical equivalent circuits for, a) single loop Nyquist plot, and b) two-ring Nyquist plot.

two-week mark. On the other hand, the protective benefits of the shot-peened A36 in the 3.5% NaCl solution containing 9 ppm CO start to wane. Although it shows initial advantages after just 1 hour of immersion, by 24 hours, the corrosive effects of CO take over. The protective effect of layers decreased by time. By two weeks, a significant corrosion damage can be detected due to the combined impact of chloride ions and CO. Interestingly, the presence of 9 ppm CO not only accelerates corrosion but also shifts the corrosion mechanism from being primarily resistive—where protective layers fend off corrosive elements—to a more capacitive nature [21-23].

Fig. 3. depicts the polarization curves of A36 steel in 3.5 % NaCl solution, A36 steel in 3.5 % NaCl solution containing 9 ppm CO, and shot peened A36 steel in 3.5 % NaCl solution containing 9 ppm CO after immersion time of 2 weeks; whose results were summarized in Table 4.

Table 1. EIS analysis parameters for A36 steel in 3.5 % NaCl solution for different immersion times, 1 h, 24 h, 48 h, 72 h, 96 h, 1 week and 2 weeks.

Samples	Immersion time	R_{sol} (Ω. Cm^2)	R_{pro} (Ω. Cm^2)	CPE_{pro} (F.cm^{-2}.s^{n-1})	n_{pro}	R_{ct} (Ω. Cm^2)	CPE_{dl} (F.cm^{-2}.s^{n-1})	n_{dl}	Chi- Squared
A 36 in 3.5 % NaCl Solution	**1 h**	35	-	-	-	4101	0.241	-	0.00491
	24 h	22	-	-	-	20247	0.084	-	0.00624
	48 h	19	1981	0.021	0.71	890	2.151	0.67	0.00431
	72 h	20	1847	0.018	0.62	751	0.263	0.83	0.00734
	96 h	18	1537	0.002	0.51	658	0.007	0.87	0.00261
	1 Week	18	1307	0.008	0.53	452	0.038	0.72	0.00372
	2 Weeks	16	-	-	-	856	0.006	0.52	0.00649

Table 2. EIS analysis parameters for A36 steel in 3.5 % NaCl solution containing 9 ppm CO at different immersion times, 1 h, 24 h, 48 h, 72 h, 96 h, 1 week and 2 weeks.

Samples	Immersion time	R_{sol} (Ω. Cm^2)	R_{pro} (Ω. Cm^2)	CPE_{pro} (F.cm^{-2}.s^{n-1})	n_{pro}	R_{ct} (Ω. Cm^2)	CPE_{dl} (F.cm^{-2}.s^{n-1})	n_{dl}	Chi- Squared
A 36 in 3.5 % NaCl Solution with 9 ppm CO	**1 h**	21	-	-	-	3610	0.032	-	0.00173
	24 h	19	2085	0.019	0.51	834	0.713	0.71	0.00825
	48 h	19	962	0.002	0.52	806	0.047	0.72	0.00629
	72 h	16	-	-	-	14271	0.078	0.72	0.00861
	96 h	16	-	-	-	1152	0.024	0.63	0.00237
	1 Week	16	-	-	-	915	0.032	0.61	0.00218
	2 Weeks	16	-	-	-	723	0.082	0.69	0.00372

Table 3. EIS analysis parameters for shot peened A36 steelin 3.5 % NaCl solution containing 9 ppm CO for different immersion times, 1 h, 24 h, 48 h, 72 h, 96 h, 1 week and 2 weeks.

Samples	Immersion time	R_{sol} (Ω. Cm²)	R_{pro} (Ω. Cm²)	CPE_{pro} (F.cm⁻².sⁿ⁻¹)	n_{pro}	R_{ct} (Ω. Cm²)	CPE_{dl} (F.cm⁻².sⁿ⁻¹)	n_{dl}	**Chi- Squared**
Shot peened A 36 in 3.5 % NaCl Solution with 9 ppm CO	**1 h**	22	1608	1.8E-3	0.57	4372	0.17	0.62	0.00419
	24 h	20	1208	8.7E-3	0.62	3920	0.81	0.73	0.00783
	48 h	20	1547	6.2E-4	0.59	3083	0.16	0.74	0.00521
	72 h	18	1623	6.8E-3	0.52	2920	0.21	0.76	0.00822
	96 h	18	1503	4.7E-3	0.63	2718	0.25	0.83	0.00694
	1 Week	16	1405	6.3E-3	0.63	1340	0.05	0.61	0.00398
	2 Weeks	16	-	-	-	1295	0.09	0.71	0.00994

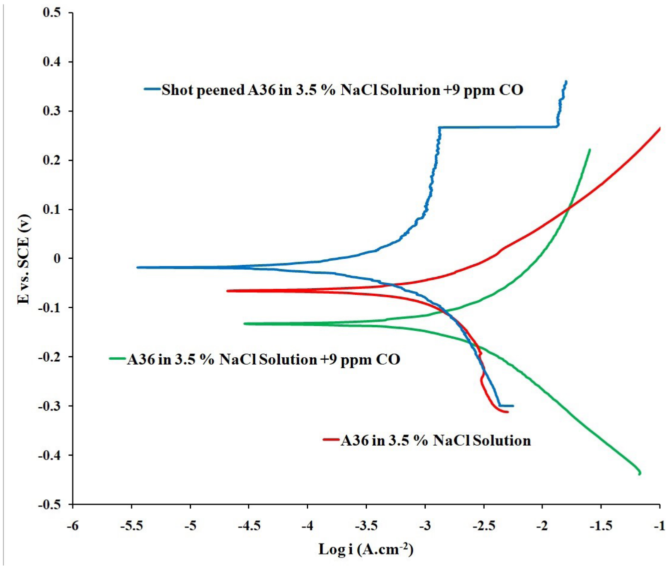

Fig. 3. Potentiodynamic curves of A36 steel in 3.5 % NaCl solution, A36 steel in 3.5 % NaCl solution containing 9 ppm CO, and shot peened A36 steel in 3.5 % NaCl solution containing 9 ppm CO at immersion time of 2 weeks.

Table 4. Polarization analysis parameters of samples after immersion time of 2 weeks.

Sample	E_{corr} (mV)	i_{corr} (μA/cm^2)	**Corrosion rate (mpy)**	**protection efficiency (%)**
A36 in 3.5 % NaCl solution	-67±6	26.5	52.3	-
A36 in 3.5 % NaCl solution + 9 pmm CO	-133±8	45.7	86.8	-
Shot peened A36 in 3.5 % NaCl solution + 9 pmm CO	-19±3	6.5	13.2	85.8

The corrosion current density (i_{corr}) is derived by extrapolating the cathodic branch of the polarization curves to the OCP as the anodic curves do not possess distinct Tafel regions. The corrosion rate (υ_{corr}) can be calculated by Eq. (1) [24-25]:

$$Corrosion\ Rate\ (mpy) = \frac{i_{corr}.K.EW}{\rho.A} \qquad \text{Eq.(1)}$$

where the constant, K = $1.288*10^{-5}$defines the corrosion rate (mpy), i_{corr} shows the corrosion current density in μA. cm^{-2}, ρ denotes the density of the corroding material (7.87 g.cm^{-3}), and EW shows the equivalent weight (55.85 g/mol).The protection efficiency [26] can be determined by Eq.(2):

$$\eta = \frac{I_{corr(shot\ peened\ A36)} - I_{corr(\ A36)}}{I_{corr}(A36)} * 100 \ \text{Eq.(2)}$$

where $I_{corr(shot\ peened\ A36)}$ and I_{corr} represent the corrosion current densities of the bare sample and shot-peened A36, respectively. Table 4 .lists the protection efficiency and polarization parameters after immersion for 2 weeks.

Analysis of the polarization curves offers valuable insights into the corrosion behavior of A36 steel. A significant increase can be seen in corrosion current density, from 26.5 to 45.7 μA/cm^2, alongside a shift in the corrosion potential toward more negative values, changing from -67 mV to -133 mV. As the immersion time increases, the protective capabilities of the surface fade. Conversely, shot peening resulted in a remarkable decrease in corrosion current density in the 3.5% NaCl solution, dropping from 45.7 to 6.5 μA/cm^2. Additionally, the corrosion potential positively shifts to -19 mV. Such a substantial reduction demonstrates a dramatic enhancement in the corrosion resistance of the steel by shot peening through improving its surface characteristics and promoting the formation of protective oxide layers, resulting in an impressive efficiency enhancement of 85.5%. This improvement not only highlights the effectiveness of shot peening but also emphasizes its role in the formation of a more robust barrier against aggressive environmental factors. By refining the surface and enhancing the adhesion of protective layers, shot peening plays a crucial role in increasing the overall durability and longevity of A36 steel in corrosive environments.

The anodic branch of the polarization curve for the shot-peened sample reveals a distinct anodic region, indicating the formation of a protective layer by corrosion products interacting with water ions on the surface. This layer not only reduces further corrosion but also alters the electrochemical behavior of the steel, transitioning from a primarily capacitive mechanism—where protective layers effectively block corrosive elements—to a resistive mechanism as immersion time continues. These protective layers may become compromised as immersion persists, particularly in environments contaminated with pollutants such as 9 ppm carbon monoxide (CO). This can lead to increased corrosion rates and shifts in polarization behavior. The presence of CO exacerbates these effects by promoting the formation of aggressive species which threaten the integrity of the protective oxide layer.

Fig. 4. displays the FTIR spectra of the samples after two weeks of immersion, indicating the presence of iron hydroxide compounds and magnetic materials. The FTIR spectrum of γ-FeOOH show the most prominent peak at 1021 cm^{-1}while additional bands can be seen at 892, 748cm^{-1} and a strong band at 473 cm^{-1}. The FTIR spectrum of α-FeOOH, reveals strong characteristic peaks at 903and 797 cm^{-1} whereas the FTIR spectrum of Fe_3O_4shows a strong peak at 569 cm^{-1}. The peak at 1620 cm^{-1} also indicates the presence of adsorbed water (H_2O). The main rust products found on the A36 steel included γ-FeOOH, α-FeOOH, and Fe_3O_4 [27]. These observations support previous studies reporting these compounds as the key constituents of rust on steel surfaces.

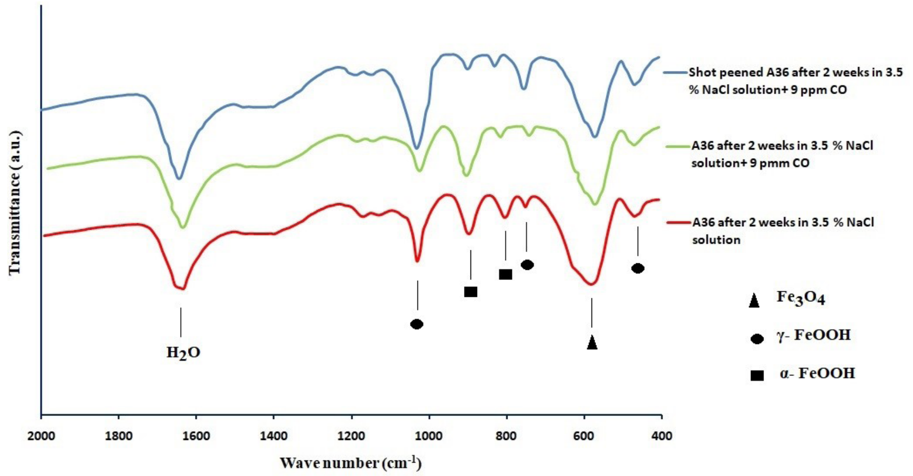

Fig. 4. FTI R spectra of A36 steel in 3.5 % NaCl solution, A36 steel in 3.5 % NaCl solution containing 9 ppm CO, and shot peened A36 steel in 3.5 % NaCl solution containing 9 ppm CO for immersion time of 2 weeks.

As depicted in Fig. 4. Fe_3O_4 is the main corrosion product on the surface of A36 steel after 2 weeks of immersion in 3.5 % NaCl solution, along with iron hydroxides such as γ-FeOOH and α-FeOOH, as indicated by the peak intensities. Interestingly, the presence of CO in the 3.5 % NaCl solution caused a notable rise in α-FeOOH intensity. Concerning the shot-peened A36 steel after 2 weeks of immersion in 3.5 % NaCl solution containing 9 ppm CO, the intensity of γ-FeOOH significantly increased compared to Fe_3O_4, while the intensity of α-FeOOH exhibited a considerable decrease. The changes in corrosion products can be explained by several key factors. The presence of Fe_3O_4 as the main corrosion product suggests a typical response of A36 steel to saline environments, where it tends to form a stable phase under corrosive conditions. The increase in the α-FeOOH intensity due to carbon monoxide indicates the significant impact of environmental pollutants on the corrosion processes, promoting the formation of certain hydroxides [27-29]. On the other hand, shot peening alters the surface properties of the steel, by its compressive stress that enhance the resistance to corrosion. This treatment seems to favor the formation of γ-FeOOH over Fe_3O_4, likely because it improves surface reactivity and encourages the development of protective layers. The decrease observed in α-FeOOH intensity in shot-peened samples suggests that these modified surface conditions may help stabilize γ-FeOOH, ultimately reducing susceptibility to corrosion. These findings emphasize the intricate relationship between environmental influences and surface treatments in the corrosion behavior.

According to the results of Nyquist and polarization curves and FTIR spectra, the presence of carbon monoxide in the 3.5% NaCl solution, and the effects of shot peening, iron atoms react with oxygen and chloride ions to produce iron oxides like FeO and Fe_2O_3. These oxides can then transform into iron hydroxides (Fe $(OH)_2$ and Fe $(OH)_3$), with some levels of protection but can break down quickly under harsh conditions. The introduction of carbon monoxide as an environmental pollutant significantly influences the corrosion process by increasing the formation of α-FeOOH, which is more prone to corrosion compared to other products. This is particularly problematic in environments rich in chlorides, where corrosive ions can lead to pitting, a localized form of corrosion that can severely weaken the steel. On the other hand, shot peening improves the surface properties of A36 steel by creating compressive residual stress to enhance its corrosion resistance. This treatment seems to favor the formation of γ-FeOOH over Fe_3O_4, indicating better protective qualities. However, this shift also results in a reduction of α-FeOOH intensity, suggesting a change in the types of corrosion products. Electrochemical analyses using the Nyquist and polarization curves show that these surface changes and environmental factors significantly affect the overall corrosion behavior of A36 steel. The intricate relationship between these elements highlights the need for effective strategies to manage corrosion in structural applications. Understanding the interaction of pollutants like carbon monoxide with corrosion processes can lead to the development of protective measures and better material performance in challenging environments. Ultimately, these insights emphasize the importance of considering both environmental factors and surface treatments when tackling corrosion issues in engineering materials.

4. Conclusions

The present study reveals the notable enhancements in corrosion resistance of A36 steel upon treatment with shot peening in urban-simulating conditions characterized by high humidity and carbon monoxide. The shot peening process significantly bolstered the ability of steel to resist charge transfer and diffusion. Over a two-week period in a carbon monoxide-rich solution, the corrosion current density of the shot-peened samples dramatically dropped from 45.7 to 6.5 μA/cm², marking an impressive reduction of 85.5%. The interaction of carbon monoxide with water results in the formation of carbonic acid, which lowers the pH and fosters a more acidic environment which accelerates cathodic reactions. Fourier Transform Infrared Spectroscopy (FTIR) analysis indicated an increase in protective iron hydroxides, particularly γ-FeOOH, within the shot-peened samples. Additionally, elevated levels of α-FeOOH were observed due to the presence of carbon monoxide, underscoring its corrosive impact. The changes in the distribution of corrosion products highlight the intricate relationships between environmental conditions and surface treatments. The findings of this research highlight the critical role of corrosion management strategies in improving the durability and performance of structural materials, particularly shot-peened A36 steel. This treatment can significantly enhance corrosion resistance in urban environments with high humidity and carbon monoxide exposure, potentially eliminating the need for additional protective measures like painting. By reducing dependence on such coatings, manufacturers can not only save costs but also adopt a more sustainable maintenance approach for urban infrastructure projects.

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