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Review Article

Corrosion Behaviour of Mild Steel and Stainless-Steel Alloys in Semi-Arid Soils of Aurangabad District, India

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Abstract

The corrosion behavior of mild steel, SS304, SS316, and SS430 in the agricultural and industrial soils of Aurangabad district, Maharashtra, India. Forty typical soil samples served as corrosive media in a controlled laboratory environment. Corrosion investigations were conducted employing the gravimetric weight-loss technique for exposure durations of 6, 12, 24, 48, and 96 hours. The findings indicated that corrosion behavior is significantly influenced by alloy composition, soil characteristics, and exposure time. Mild steel displayed the highest corrosion rate due to the lack of a solid passive coating, while stainless-steel alloys showed markedly enhanced corrosion resistance owing to the creation of a chromium-rich oxide layer. The examined alloys, SS316 had the highest corrosion resistance, followed by SS304 and SS430. Corrosion rates progressively diminished with extended exposure time due to the stabilization of corrosion products and passive oxide coatings. The observed order of corrosion resistance was SS316 surpasses SS304, which in turn surpasses SS430, followed by Mild Steel. The results demonstrate that stainless-steel alloys, especially SS316, are more appropriate for subterranean applications under corrosive soil conditions, whereas mild steel needs protective coatings or cathodic protection systems for prolonged utilization.

INTRODUCTION

The corrosion of metallic materials in soil environments is a significant engineering and economic challenge for underground pipelines, storage tanks, cable armoring, irrigation systems, transmission towers, grounding networks, and reinforced foundations. Soil corrosion is considerably more complex than atmospheric or aqueous corrosion because soil is a heterogeneous medium consisting of mineral particles, moisture, dissolved salts, gases, microorganisms, and organic matter. The interaction between buried metals and surrounding soil creates electrochemical cells that initiate gradual material deterioration, reduction in service life, leakage problems, structural failure, environmental contamination, and increased maintenance costs (Revie and Uhlig, 2008; Fontana, 2005).

Corrosion is globally recognized as one of the major causes of infrastructure degradation and industrial losses. Reports indicate that corrosion-related damage contributes significantly to the gross domestic product of many developing and industrialized countries. Underground corrosion is particularly difficult to detect because buried structures often remain hidden for long periods before visible failure occurs. Therefore, understanding the corrosive behavior of soil environments is essential for designing durable underground systems and selecting suitable corrosion-control strategies such as protective coatings, cathodic protection, corrosion inhibitors, and corrosion-resistant alloys (Koch et al., 2002; Romanoff, 1957).

The corrosive nature of soil is controlled by several physicochemical parameters, including electrical conductivity, salinity, moisture content, chloride concentration, sulfate concentration, pH, organic matter, and soil resistivity. Among these parameters, soil resistivity is considered one of the most reliable indicators of underground corrosion behavior because low-resistivity soils facilitate the electrical current required for electrochemical corrosion reactions (NACE International, 2013). High electrical conductivity and dissolved salt concentration accelerate ionic mobility within the soil matrix, thereby increasing corrosion susceptibility. Aggressive ions, such as chlorides and sulfates, are particularly harmful because they destabilize passive oxide films and promote localized corrosion processes, such as pitting and crevice corrosion (Sedriks, 1996).

Moisture content and soil texture also play important roles in underground corrosion. Water acts as an electrolyte, supporting ionic transport and electrochemical activity at the metal–soil interface. Clay-rich soils generally retain higher moisture and dissolved salts, resulting in lower resistivity and greater corrosion tendency, whereas sandy soils exhibit comparatively lower water-retention capacity and reduced corrosive behavior (McNeill, 1979). Soil pH also affects corrosion product stability and metal solubility. Acidic soils generally accelerate metal dissolution, while neutral or mildly alkaline soils may support the formation of partially protective oxide layers depending on environmental conditions (Evans, 1960).

Mild steel is widely used in underground engineering applications due to its low cost, ease of fabrication, and favorable mechanical properties. However, mild steel undergoes rapid corrosion in moist, saline environments due to the absence of a stable passive protective layer. Stainless steels contain chromium, which forms a protective chromium oxide film on the surface, thereby improving corrosion resistance considerably. Alloying elements such as nickel and molybdenum further enhance passive-film stability and resistance against chloride-induced attack (Jones, 1996; Sedriks, 1996).

SS304 is one of the most commonly used austenitic stainless steels for industrial and engineering applications because of its good corrosion resistance and mechanical strength. SS316 contains molybdenum, which improves pitting resistance and provides superior protection in chloride-rich environments. SS430 is a ferritic stainless steel possessing moderate corrosion resistance at comparatively lower cost. Comparative evaluation of these alloys under soil conditions is important for selecting suitable materials for underground applications.

Aurangabad district in Maharashtra includes agricultural lands, industrial areas, irrigation systems, and underground utility networks, where buried metallic structures are extensively used. Soil salinity, fertilizer application, irrigation practices, industrial contamination, and dissolved ionic species may substantially influence underground corrosion behavior. However, systematic comparative studies on the corrosion performance of engineering alloys in regional soils remain limited.

The present investigation was therefore undertaken to evaluate the corrosion behavior of mild steel, SS304, SS316, and SS430 in agricultural and industrial soils of Aurangabad district using gravimetric weight-loss analysis under different exposure conditions. The study aims to establish the comparative corrosion resistance of commonly used engineering alloys and to assess the influence of soil physicochemical properties on underground corrosion susceptibility.

MATERIALS AND METHODS

2.1 Soil Sampling

Forty representative soil samples were obtained from agricultural and industrial sites in Aurangabad district, Maharashtra, India. Soil samples were collected at depths of 15–30 cm, reflecting subterranean burial conditions. The gathered soils were air-dried, homogenized, sieved, and stored in airtight containers. The physicochemical analysis of soils included assessment of pH, electrical conductivity, salinity, moisture content, chloride concentration, sulfate concentration, and soil resistivity using standard analytical techniques.

2.2 Preparation of Metal Specimens

Homogeneous samples of mild steel, SS304, SS316, and SS430 were fabricated for corrosion analysis. The metal coupons were mechanically polished with emery paper and cleaned with distilled water, degreased with acetone, dried, and precisely weighed using an analytical scale. The chemical compositions of the examined alloys are presented in Table 1.

Table 1. Composition of Investigated Metallic Alloys

Alloy	Major Composition
Mild Steel	Fe–C
SS304	Fe–Cr–Ni
SS316	Fe–Cr–Ni–Mo
SS430	Fe–Cr

2.3 Corrosion Studies

Individually prepared specimens were immersed in soil samples under regulated moisture conditions and subjected to exposure durations of 6, 12, 24, 48, and 96 hours. After exposure, the specimens were extracted, meticulously cleaned to remove corrosion products, rinsed, dried, and reweighed. Weight loss was calculated as the difference between the final and initial masses. The corrosion rate was determined using the gravimetric weight-loss method and represented in mg dm^{-2} day^{-1}.

RESULTS AND DISCUSSION

3.1 Statistical Evaluation of Corrosion Data

The corrosion rate data for mild steel, SS304, SS316, and SS430 in various soil situations were statistically evaluated to assess the overall corrosion behavior of the examined alloys. Significant variation in corrosion rate was observed across alloy composition, exposure period, and soil physicochemical characteristics. The results obtained unequivocally demonstrate that alloy composition is crucial for regulating subterranean corrosion behavior. Mild steel consistently had the highest corrosion rate among all examined materials due to the absence of a stable passive protective coating. Stainless-steel alloys exhibited markedly enhanced corrosion resistance owing to the development of chromium-rich passive oxide layers. The statistical research indicated that SS316 demonstrated the lowest average corrosion rate, followed by SS304 and SS430. The findings further indicated that soils with higher conductivity, moisture content, and chloride concentration, and lower resistivity, produced somewhat higher corrosion rates for all examined alloys.

3.2 Comparative Corrosion Behaviour of Metals

The corrosion behavior of mild steel, SS304, SS316, and SS430 showed a strong dependence on alloy composition and ambient soil conditions. Mild steel consistently showed the highest corrosion rate across all examined soil settings, while stainless-steel alloys displayed relatively enhanced corrosion resistance due to the creation of a passive coating. The mean corrosion rate of mild steel was roughly 10 to 15 times higher than that of stainless-steel alloys. This behavior unequivocally demonstrates the mild steel's inability to withstand electrochemical deterioration in hostile soil environments. The rust layer on mild steel was porous and non-protective, permitting ongoing transport of oxygen, moisture, and dissolved salts to the metal surface.

Stainless-steel alloys exhibited markedly reduced corrosion rates due to the formation of a stable chromium oxide passive layer by the chromium in the alloy composition. This passive layer serves as a protective barrier, reducing direct contact between the metal surface and the surrounding soil electrolyte.

Table 2. Average Corrosion Rate of Metals (mg dm^{-2} day^{-1})

Metal	6 hr	12 hr	24 hr	48 hr	96 hr	Mean
Mild Steel	72.5	38.2	20.1	10.8	5.6	29.44
SS304	6.2	3.2	2.0	1.1	0.6	2.62
SS316	5.2	2.6	1.3	0.7	0.3	2.02
SS430	7.4	3.8	2.3	1.4	0.7	3.12

The examined alloys, SS316 exhibited superior corrosion resistance. The enhanced performance of SS316 is due to molybdenum, which increases pitting resistance and improves passive-film stability in chloride-rich environments. SS304 demonstrated superior corrosion resistance owing to its chromium-nickel composition, while SS430 showed relatively modest performance due to the lack of nickel and diminished passive-film stability.

The results indicate that alloy chemistry is a critical factor influencing underground corrosion resistance. The addition of chromium, nickel, and molybdenum markedly enhances the durability of stainless-steel alloys in harsh soil environments.

The corrosion resistance order observed during the investigation was:SS316 > SS304 > SS430 > Mild Steel

The corrosion behavior of mild steel, SS304, SS316, and SS430 exhibited significant variance based on alloy composition and soil properties. Mild steel displayed the greatest corrosion rate across all examined soil conditions, while stainless-steel alloys showed markedly enhanced corrosion resistance. The elevated corrosion vulnerability of mild steel is due to the lack of a stable passive oxide layer. The corrosion products on mild steel are porous and weakly attached, facilitating ongoing infiltration of moisture, oxygen, and dissolved salts. Conversely, stainless steels develop protective chromium oxide coatings that markedly diminish electrochemical corrosion. Among the examined alloys, SS316 exhibited the lowest corrosion rate due to the incorporation of molybdenum, which enhances passive-film stability and resistance to chloride-induced corrosion. SS304 demonstrated superior corrosion resistance due to its chromium-nickel alloy composition, while SS430 exhibited very modest performance due to the lack of nickel.

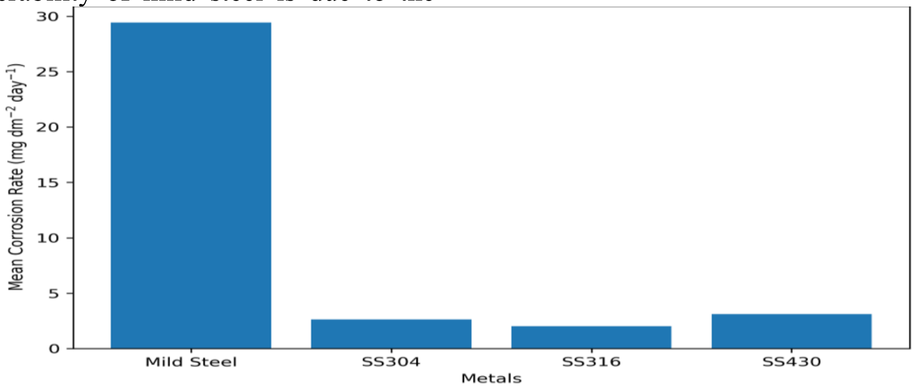

Figure 3: Comparative Average Corrosion Rate of Investigated Metals

3.3 Time-Dependent Corrosion Behaviour

The corrosion rate declined consistently across all examined metals over 6 to 96 hours of exposure. The peak corrosion values occurred during the initial exposure phase due to direct interaction of freshly exposed metallic surfaces with soil electrolytes containing dissolved salts and aggressive ions. In the initial phase of exposure, the electrochemical dissolution of metal occurs swiftly due to the bare metallic surface. As exposure duration increases, corrosion products progressively build up on the metal surface, thereby diminishing further electrochemical attack by creating diffusion barriers. This feature was especially important for stainless-steel alloys, as stable passive oxide layers formed progressively with extended exposure duration. The passive coatings significantly reduced additional interaction between the metallic surface and the surrounding soil electrolyte. Mild steel showed a progressive decline in corrosion rate over time; however, the corrosion products formed on it were porous and loosely adhering. As a result, corrosion persisted despite extended exposure. The observed temporal behavior demonstrates that the passivation and stabilization of corrosion-product layers significantly influence underground corrosion dynamics.

Table 2. Average Corrosion Rate of Metals (mg dm^{-2} day^{-1})

Metal	6 hr	12 hr	24 hr	48 hr	96 hr	Mean
Mild Steel	72.5	38.2	20.1	10.8	5.6	29.44
SS304	6.2	3.2	2.0	1.1	0.6	2.62
SS316	5.2	2.6	1.3	0.7	0.3	2.02
SS430	7.4	3.8	2.3	1.4	0.7	3.12

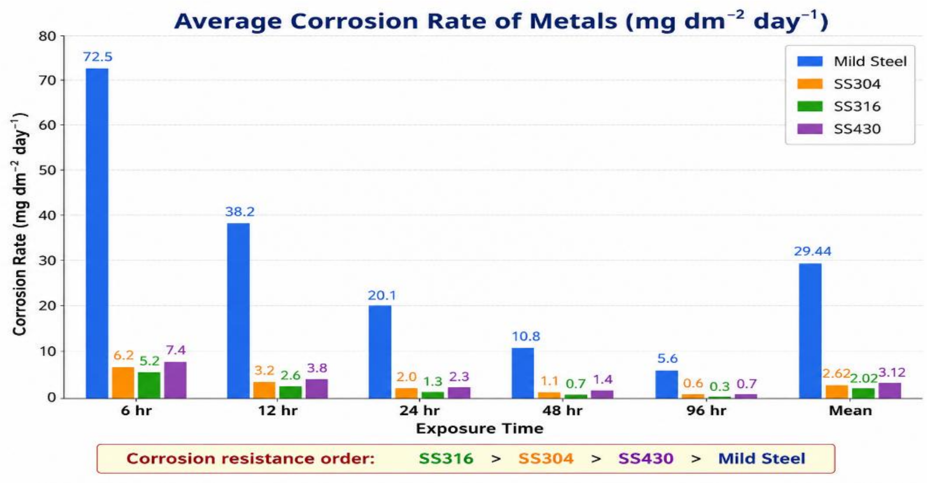

Figure 2: Comparative Average Corrosion Rate of Investigated Metals

3.4 Correlation Between Soil Properties and Corrosion Behaviour

The analyzed soils showed significant differences in conductivity, salinity, moisture content, chloride levels, sulphate levels, and resistivity. The physicochemical changes significantly affected the corrosion behavior of the examined metals. Electrical conductivity demonstrated a robust inverse correlation with soil resistance, indicating that soils with higher ionic concentrations are more conductive and electrochemically aggressive. Chloride concentration also showed a positive relationship with corrosion rate, as chloride ions destabilize passive films and accelerate localized electrochemical attack.

The moisture content markedly affected corrosion behavior, since water serves as an electrolyte that enhances ionic mobility and charge transport. Soils rich in clay, which retain more moisture and dissolved salts, typically exhibit lower resistivity and a greater propensity for corrosion than sandy soils.

Table 3. Corrosion Rate Variation with Exposure Time (mg dm^{-2} day^{-1})

Time (hr)	Mild Steel	SS304	SS316	SS430
6	72.5	6.2	5.2	7.4
12	38.2	3.2	2.6	3.8
24	20.1	2.0	1.3	2.3
48	10.8	1.1	0.7	1.4
96	5.6	0.6	0.3	0.7

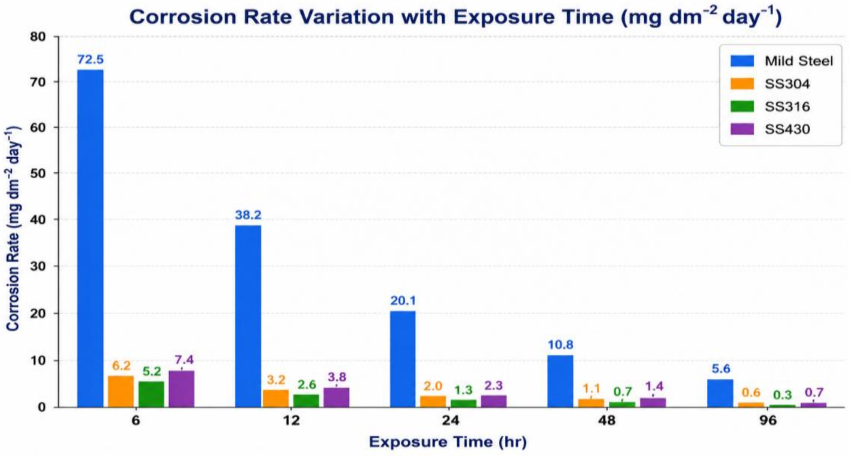

Figure 5: Corrosion Rate vs Exposure Time

Table 4. Correlation Between Major Soil Parameters and Corrosion Behaviour

Parameter	**Effect on Corrosion**
Electrical Conductivity	Increases corrosion
Moisture Content	Increases corrosion
Chloride Concentration	Strongly increases corrosion
Sulphate Concentration	Moderately increases corrosion
Soil Resistivity	Reduces corrosion
Sandy Texture	Reduces corrosion
Clay Texture	Enhances corrosion

4. CONCLUSION

This study evaluated the corrosion behaviour of mild steel, SS304, SS316, and SS430 in agricultural and industrial soils of Aurangabad district using the gravimetric weight-loss method. The results showed that alloy composition, exposure duration, and soil physicochemical properties strongly influence underground corrosion behaviour. Soils with high conductivity, salinity, moisture content, chloride concentration, and low resistivity exhibited greater corrosion aggressiveness. Among the investigated alloys, mild steel showed the highest corrosion rate, whereas stainless-steel alloys demonstrated significantly better corrosion resistance due to chromium-rich passive-film formation. SS316 exhibited the best corrosion resistance followed by SS304 and SS430 because of its stable molybdenum-enhanced passive layer in chloride-rich environments. The corrosion resistance order observed was:

SS316 > SS304 > SS430 > Mild Steel

Corrosion rates gradually decreased with increasing exposure time due to stabilization of corrosion products and passive oxide films. The findings suggest that stainless-steel alloys, particularly SS316, are more suitable for underground applications in aggressive soil environments, while mild steel requires protective protection systems for long-term durability.

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