

## Corrosion Performance of Mild Steel and Stainless-Steel Alloys in Gangapur Region Soils under Variable Exposure Conditions

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### Abstract

The corrosion of subterranean metallic elements in soil conditions is a significant challenge for pipelines, storage vessels, cable armoring, grounding systems, and structural foundations. This study assesses the corrosion resistance of mild steel, stainless steel 304 (SS304), stainless steel 316 (SS316), and stainless steel 430 (SS430) in soil samples from the Gangapur district of Maharashtra, India. Forty typical soil samples from agricultural and residential areas were utilized as corrosive media. The corrosion behavior was examined using the gravimetric weight-loss method throughout exposure durations of 6, 12, 24, 48, and 96 hours. The corrosion rates were quantified in milligrams per square decimetre per day. The results revealed significant heterogeneity in corrosion response based on alloy type, exposure duration, and soil condition. Mild steel consistently demonstrated the highest corrosion rate across nearly all tested soils, indicating its increased vulnerability in natural soil conditions. Stainless steel grades exhibited significantly reduced corrosion rates owing to the creation of a passive oxide coating. Among the evaluated alloys, SS316 had the highest overall resistance, followed by SS304, with SS430 showing intermediate performance. Corrosion rates were often highest during initial exposure and progressively decreased over time as corrosion products stabilized and passive surface layers formed. A comparative analysis demonstrated that incorporating chromium, nickel, and molybdenum as alloying elements markedly improved resistance to soil corrosion. Soils with elevated salinity, moisture content, and reduced resistivity exhibited higher corrosion values. Agricultural soils were more aggressive than residential soils, reflecting the impact of fertilizer use and irrigation salts. The hierarchy of corrosion resistance is as follows: SS316 > SS304 > SS430 > Mild steel. The study recommends using SS316 for essential subsurface applications, SS304 for moderate-duty installations, SS430 for cost-effective applications, and mild steel only with protective coatings or cathodic protection. The produced outcomes offer valuable foundational data for material selection, corrosion management, and the development of underground infrastructure in semi-arid soil contexts.

### INTRODUCTION

Corrosion is the natural breakdown of metals resulting from interactions with their surroundings and is among the most costly material degradation processes globally. Subterranean structures, including pipelines, fuel tanks, cable sheaths, grounding rods, and foundation reinforcements, are especially susceptible to

damage because soil acts as a natural electrolyte that facilitates electrochemical corrosion. Deficiencies in subterranean systems frequently go unnoticed until leakage, structural degradation, or service interruption occurs, leading to significant economic and safety consequences (Revie and Uhlig, 2008; Fontana, 2005).

Soil corrosion is distinct from atmospheric and aqueous corrosion due to its heterogeneous composition, which includes mineral particles, pore water, dissolved salts, gases, microbes, and organic materials. Fluctuations in oxygen levels, moisture distribution, ionic conductivity, and localized chemistry generate anodic and cathodic regions on metallic surfaces. In anodic regions, metal dissolution occurs, whereas cathodic reactions include either oxygen reduction or hydrogen evolution, depending on aeration conditions (Jones, 1996). Numerous soil characteristics dictate the intensity of corrosion. Moisture content regulates ionic mobility and the continuation of the electrolyte phase. Reduced soil resistivity typically indicates increased conductivity and an elevated risk of corrosion. Chloride ions undermine passive coatings and encourage localized corrosion, while sulfates may engage in both chemical and microbiological corrosion mechanisms. Soil pH affects the solubility of corrosion products and the stability of passive films. Consequently, the corrosion behavior in soil cannot be ascertained from a solitary parameter alone (Romanoff, 1957; NACE International, 2013).

Mild steel is widely used in underground applications due to its affordability and mechanical strength. Nonetheless, it rapidly corrodes in humid and saline soils due to the lack of robust passive layers. Stainless steels have chromium, which generates a protective oxide layer. Nickel boosts corrosion resistance and structural integrity, whereas molybdenum improves resistance to chloride-induced pitting. Thus, stainless steels provide an appealing option for prolonged subterranean applications (Sedriks, 1996). SS304 is the most widely used austenitic stainless steel for both industrial and home applications. SS316 contains molybdenum, which provides enhanced resistance to chloride-laden environments. SS430 is a ferritic chromium stainless steel that offers moderate corrosion resistance at a reduced cost. The comparative performance of these alloys in natural soils is significantly influenced by local environmental factors.

The Gangapur region in Maharashtra comprises agricultural fields, irrigated lands, and residential areas, where subterranean steel structures are widely used. Irrigation methods, fertilizer usage, and household activities can alter soil chemistry and increase corrosivity. While soil characterization data for this location exist, comparative corrosion studies of engineering alloys are scarce. This study investigated the corrosion resistance of mild steel, SS304, SS316, and SS430 in 40 soils from the

Gangapur region under varying exposure durations. The aim was to determine the optimal material for subterranean applications and to establish foundational corrosion data for regional infrastructure planning.

## MATERIALS AND METHODS

Forty soil samples were obtained from agricultural and residential sites in the Gangapur region of Maharashtra, India. Samples were collected at depths of roughly 15–30 cm, corresponding to the burial zone of subterranean metallic constructions. Collected soils were air-dried, homogenized, sieved, and preserved in airtight containers prior to utilization. The physicochemical characterization of soils previously demonstrated moderate variability in pH, conductivity, salinity, moisture content, chloride concentration, and resistivity. Uniformly dimensioned coupons of mild steel, SS304, SS316, and SS430 were fabricated. The specimens were mechanically polished with emery paper, rinsed with distilled water, degreased with acetone, dried, and weighed to the nearest 0.1 mg.

Measured soil samples were positioned in corrosion containers and calibrated to reflect appropriate moisture levels. Individual metal coupons were inserted into each soil sample and exposed for 6, 12, 24, 48, and 96 hours. Following exposure, specimens were extracted, meticulously cleaned to remove loose corrosion products, rinsed, dried, and subsequently reweighed. Weight loss was calculated as the difference between the final and initial masses. The corrosion rate was quantified in  $\text{mg dm}^{-2} \text{ day}^{-1}$  using standard gravimetric techniques. Lower corrosion rates indicate greater corrosion resistance. Statistical analysis was conducted on mean values, comparative rankings, and temporal patterns.

## RESULTS AND DISCUSSION

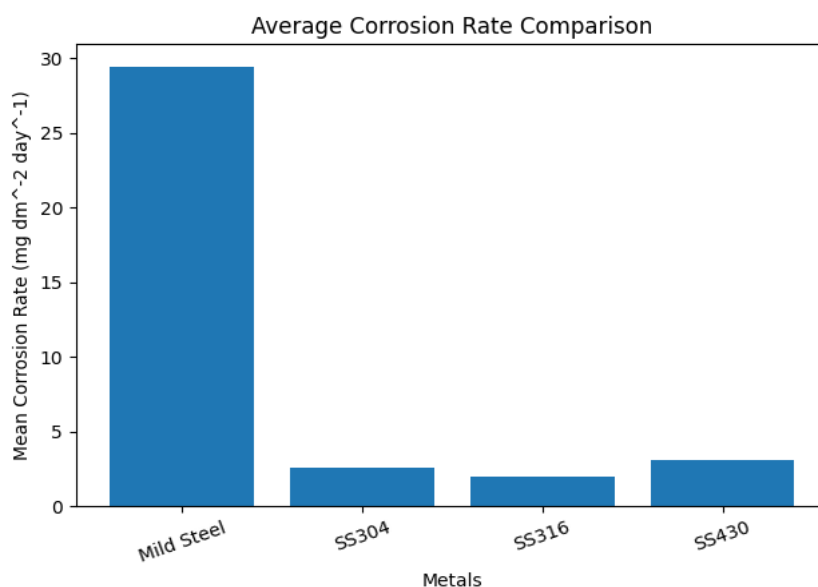
### Descriptive Statistical Analysis of Corrosion Data

The corrosion rate data for mild steel, SS304, SS316, and SS430 from forty soil samples were analyzed using descriptive statistics to assess the general corrosion behavior of each metal. The average corrosion rates for various exposure durations (6, 12, 24, 48, and 96 hours) were computed to assess the relative performance of the alloys. The descriptive analysis clearly reveals substantial differences in corrosion behavior among the examined metals. Mild steel exhibited the highest average corrosion rate ( $29.44 \text{ mg dm}^{-2} \text{ day}^{-1}$ ), approximately 10–15 times that of steel

**Table 1. Average corrosion rate of metals (mg dm<sup>-2</sup> day<sup>-1</sup>)**

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 1. Average corrosion rate comparison of metals**



alloys. This verifies its significant vulnerability to soil corrosion owing to the lack of a protective passive coating. Among stainless steels, SS316 had the lowest average corrosion rate (2.02 mg dm<sup>-2</sup> day<sup>-1</sup>), followed by SS304 (2.62 mg dm<sup>-2</sup> day<sup>-1</sup>) and SS430 (3.12 mg dm<sup>-2</sup> day<sup>-1</sup>). The exceptional performance of SS316 is due to molybdenum, which improves resistance to localized corrosion and stabilizes the passive oxide layer in hostile soil conditions. The bar graph illustrates the substantial disparity in corrosion resistance between mild steel and stainless steel. The trend in corrosion resistance identified using the descriptive analysis is as follows:

SS316 surpasses SS304, which in turn surpasses SS430, followed by Mild Steel. This investigation demonstrates that alloy composition is crucial for regulating corrosion behavior in soil environments. Stainless steels, especially SS316, offer greater durability and are

better suited to subterranean applications than mild steel.

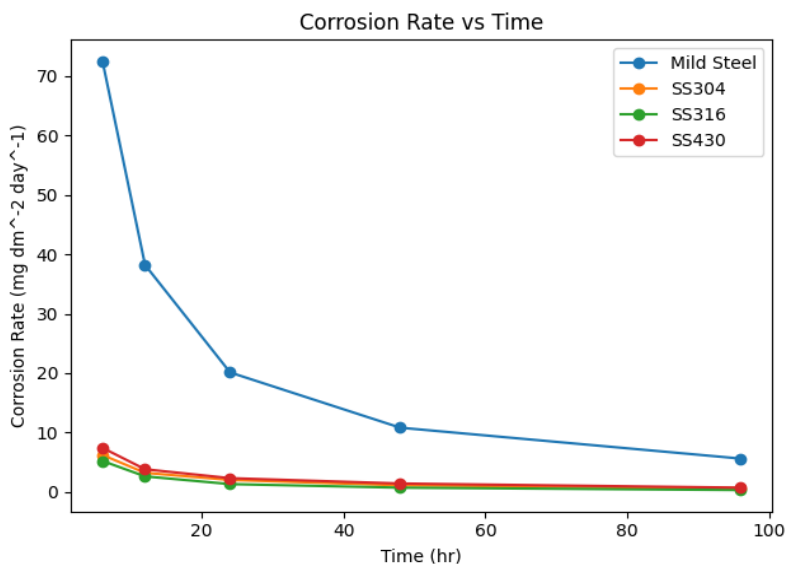
### Time-Dependent Corrosion Behaviour

The variation of corrosion rate with exposure time (6–96 h) was studied for all tested metals to understand the kinetics of corrosion in soil environments. The results indicate a clear decreasing trend in corrosion rate with increasing exposure time. The corrosion rate for all metals was highest during the initial exposure period (6 h) and steadily decreased with time until 96 h. This behavior is characteristic of electrochemical corrosion systems in soil environments. In the initial phase, newly exposed metal surfaces react rapidly with soil electrolytes, leading to elevated corrosion rates. With prolonged exposure, corrosion products develop on the metal surface. These compounds form a partial barrier that reduces direct contact between the metal and its surroundings, thereby inhibiting further corrosion.

Table 2. Average corrosion rate with time ( $\text{mg dm}^{-2} \text{day}^{-1}$ )

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 2. Corrosion rate vs exposure time



This phenomenon is especially pronounced in stainless steels, where stable passive oxide layers form and enhance their protective qualities over time. Among the evaluated metals, SS316 has the lowest corrosion rate across all time intervals, signifying exceptional passivation behavior. SS304 exhibits excellent resistance, while SS430 displays intermediate performance. Mild steel, although exhibiting a declining trend, continues to exhibit markedly higher corrosion values than stainless

steels. This suggests that the corrosion products formed on mild steel lack adequate protective properties, allowing ongoing deterioration.

#### Corrosion Behaviour of Mild Steel

Mild steel exhibited the highest corrosion rate among all tested metals in all soil samples and exposure periods. The corrosion behaviour clearly indicates that mild steel is highly susceptible to soil-induced degradation due to the absence of a protective passive layer.

Table 3. Corrosion rate range of Mild Steel ( $\text{mg dm}^{-2} \text{day}^{-1}$ )

Time (hr)	Minimum	Maximum	Average
6	~55.3	~85.76	72.5
12	~30.7	~45.8	38.2
24	~14.8	~28.3	20.1
48	~6.9	~14.6	10.8
96	~3.5	~7.5	5.6

The corrosion rate of mild steel was significantly elevated during the initial exposure period, with values of around  $85 \text{ mg dm}^{-2} \text{ day}^{-1}$  observed in some soil samples. This indicates rapid electrochemical degradation of iron in the presence of humidity and solubilized salts. With increased exposure duration, the corrosion rate progressively decreased. Nonetheless, even after 96 hours, the corrosion values were markedly higher than those of stainless steel alloys. This indicates that the corrosion products generated on mild steel fail to offer adequate protection against subsequent degradation. The pronounced corrosion behavior of mild steel can be attributed to the following factors:

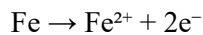
### 1. Lack of Passive Film

In contrast to stainless steels, mild steel does not form a stable protective oxide coating. The

corrosion products, consisting of iron oxides or rust, are porous and weakly attached, facilitating ongoing infiltration of oxygen and electrolytes.

### 2. Electrochemical Reactions

In soil environments, mild steel undergoes anodic dissolution:



Simultaneously, cathodic reactions such as oxygen reduction occur, sustaining the corrosion process.

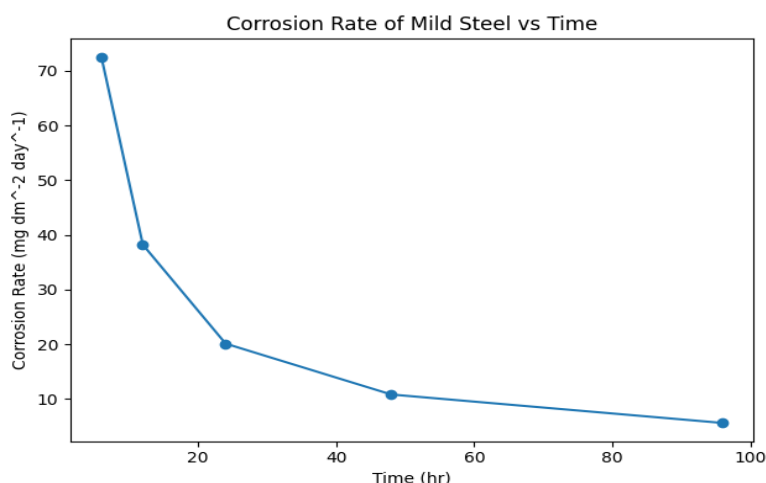
### 3. Influence of Soil Properties

Higher corrosion rates were observed in soils with:

- High moisture content
- High salinity (chloride ions)
- Low resistivity

These conditions enhance ionic conductivity and accelerate electrochemical reactions.

Figure 3. Corrosion rate of Mild Steel vs exposure time



### Corrosion Behaviour of Stainless Steel Alloys (SS304, SS316 and SS430)

The corrosion behaviour of stainless steel alloys (SS304, SS316, and SS430) was evaluated and compared under identical soil conditions and exposure periods. The results indicate that all stainless steels exhibit significantly lower corrosion rates than mild steel due to the formation of passive oxide films on their surfaces. However, noticeable differences were observed among the stainless steel grades depending on their alloy composition.

The comparative analysis clearly shows that corrosion resistance of stainless steels depends strongly on alloy composition. SS316 exhibited the lowest corrosion rates due to molybdenum addition,

followed by SS304 and SS430. The corrosion rate of all stainless steels decreased with increasing exposure time due to stabilization of passive oxide films. However, the rate of decrease and final corrosion values differed depending on alloy chemistry.

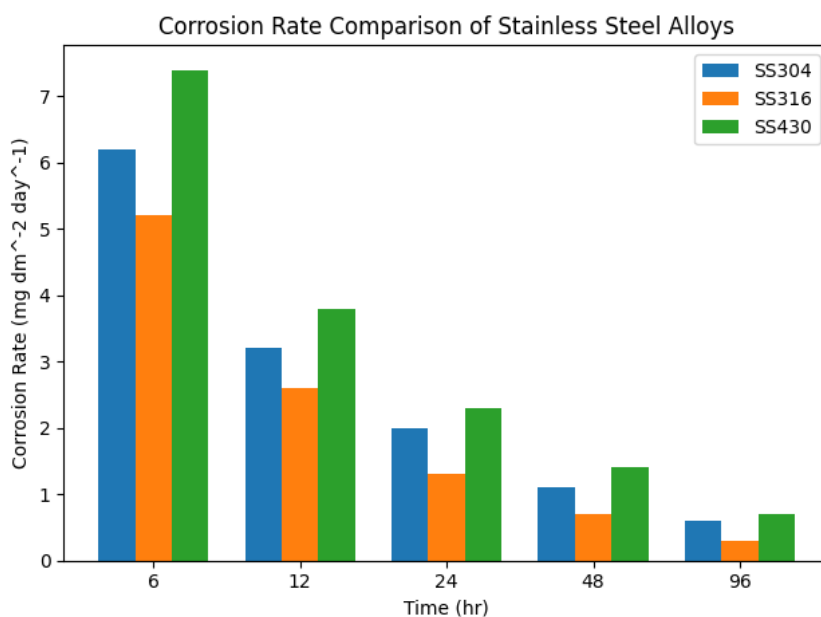
The corrosion resistance order observed is:

$$\text{SS316} > \text{SS304} > \text{SS430}$$

The comparative corrosion behaviour of mild steel, SS304, SS316, and SS430 was evaluated to determine the most suitable material for underground applications in Gangapur soils. The analysis clearly demonstrates significant variation in corrosion resistance among the tested metals.

**Table 4. Corrosion rate range of stainless steel alloys ( $\text{mg dm}^{-2} \text{day}^{-1}$ )**

Alloy	Time (hr)	Minimum	Maximum	Average
SS304	6	~4.6	~7.8	6.2
	12	~2.3	~4.5	3.2
	24	~1.2	~2.6	2.0
	48	~0.6	~1.5	1.1
	96	~0.3	~0.8	0.6
SS316	6	~3.9	~6.9	5.2
	12	~1.9	~3.5	2.6
	24	~0.8	~1.8	1.3
	48	~0.4	~0.9	0.7
	96	~0.2	~0.5	0.3
SS430	6	~5.4	~8.7	7.4
	12	~2.7	~4.8	3.8
	24	~1.3	~2.9	2.3
	48	~0.6	~1.8	1.4
	96	~0.3	~0.9	0.7



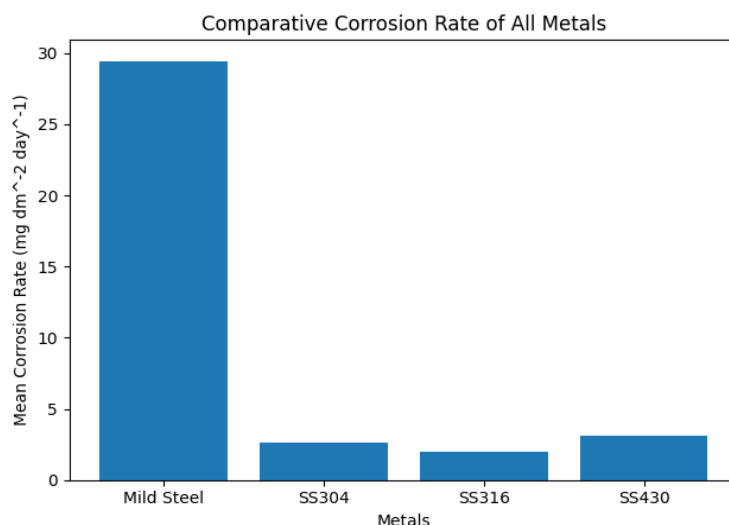
**Figure 4. Comparative corrosion rate of stainless-steel alloys at different exposure times**  
**3.5 Comparative Corrosion Behaviour of All Metals**

**Table 5. Comparative average corrosion rate of all metals ( $\text{mg dm}^{-2} \text{day}^{-1}$ )**

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 findings unequivocally indicate that mild steel exhibits much higher corrosion rates than stainless steel alloys. The mean corrosion rate of mild steel ( $29.44 \text{ mg dm}^{-2} \text{ day}^{-1}$ ) is roughly 10–15 times greater than that of stainless steels, signifying its inadequate resistance in soil conditions. Among stainless steels, SS316 had the lowest corrosion rate ( $2.02 \text{ mg dm}^{-2} \text{ day}^{-1}$ ), followed by SS304 ( $2.62 \text{ mg dm}^{-2} \text{ day}^{-1}$ ) and SS430 ( $3.12 \text{ mg dm}^{-2} \text{ day}^{-1}$ ). The exceptional performance of SS316 is due to molybdenum, which improves resistance to chloride-induced corrosion and stabilizes the passive oxide layer.

SS304 demonstrated excellent corrosion resistance due to its chromium-nickel alloy composition, whereas SS430 showed intermediate resistance because of its lack of nickel, which diminishes the stability of the passive film. The significant disparity between mild steel and stainless steels underscores the critical role of alloy composition in regulating corrosion behavior. Stainless steels form stable passive layers that markedly reduce corrosion rates, while mild steel forms porous rust that facilitates ongoing deterioration.



## CONCLUSION

This study systematically assessed the corrosion behavior of mild steel, SS304, SS316, and SS430 in the soils of the Gangapur region across different exposure durations (6–96 hours). The results unequivocally indicate that corrosion behavior is significantly affected by alloy composition, exposure duration, and soil properties. Mild steel demonstrated the highest corrosion rate across all soil samples, averaging  $29.44 \text{ mg dm}^{-2} \text{ day}^{-1}$ , hence affirming its significant vulnerability to soil corrosion. The lack of a protective passive film and the development of porous rust layers facilitate ongoing electrochemical deterioration. Despite a reduction in corrosion rates over time, mild steel remained highly susceptible throughout the research.

Conversely, stainless steel alloys exhibited significantly lower corrosion rates due to the formation of stable passive oxide coatings. SS316 demonstrated superior corrosion resistance, recording the lowest average corrosion rate of  $2.02 \text{ mg dm}^{-2} \text{ day}^{-1}$ , followed by SS304 at  $2.62 \text{ mg dm}^{-2} \text{ day}^{-1}$  and SS430 at  $3.12 \text{ mg dm}^{-2} \text{ day}^{-1}$ . The exceptional performance of SS316 is due to the

inclusion of molybdenum, which improves resistance to chloride-induced corrosion and stabilizes the passive layer in harsh soil environments. The temporal analysis indicated that corrosion rates diminish with prolonged exposure time for all metals. This behavior is ascribed to the development of corrosion products and passive coatings that mitigate further metal dissolution. The protective effect is markedly greater in stainless steel than in mild steel.

The hierarchy of corrosion resistance determined in this investigation is as follows:

SS316 surpasses SS304, which in turn surpasses SS430, followed by Mild Steel. The findings reveal that soil characteristics, including moisture content, salinity, and resistivity, significantly influence corrosion behavior. Soils with elevated moisture and chloride levels have shown increased corrosivity, expediting metal deterioration. From an engineering standpoint, the results indicate that mild steel is inappropriate for subterranean applications without protective measures such as coatings or cathodic protection. SS430 is suitable for cost-effective use in less corrosive environments, whereas SS304 is ideal for

general-purpose applications. SS316 is the most reliable material for essential underground structures owing to its exceptional corrosion resistance and long-term stability. Overall, the study highlights the importance of material selection in minimizing corrosion-related failures and provides valuable data for the design and maintenance of buried metallic systems in soil environments.

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