# TEMPERATURE-DEPENDENT CORROSION OF AISI 1020, AL 1050, AND RIVETED JOINTS IN LANDFILL LEACHATE

**GUNAWAN, QOMARUL HADI*, MUHAMMAD IQBAL RAMADHANI**

*Department of Mechanical Engineering, Faculty of Engineering, Universitas Sriwijaya, Indralaya, 30662, Sumatera Selatan, Indonesia*
**Corresponding author: qoma2007@unsri.ac.id*

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***ABSTRACT:*** Corrosion is a critical degradation mechanism for metallic materials operating in aggressive environments such as landfills, where chloride-rich leachate, high moisture, and fluctuating temperatures accelerate electrochemical reactions. This study investigates the corrosion behavior of AISI 1020 carbon steel, Al 1050 aluminium, and their riveted joints under simulated landfill conditions at 30 °C, 40 °C, and 50 °C using the weight-loss method in accordance with ASTM G31-72. The landfill leachate used in this research contained high chloride, BOD, and COD levels, representing a chemically and biologically aggressive medium. Results show that AISI 1020 and Al 1050 experienced the highest corrosion rate at the early immersion stage (day 2), followed by passivation and a significant rate reduction by days 4 and 6. Increasing temperature accelerated initial corrosion for all materials, with Al 1050 showing greater susceptibility due to chloride-induced breakdown of its passive film. Riveted joints displayed much higher and less stable corrosion rates than single-material specimens, especially at elevated temperatures. Galvanic coupling between steel and aluminium, combined with crevice geometry at the rivet interface, intensified localized attack and disrupted protective oxide films. The most severe corrosion occurred in Al 1050 with riveted joints at 50 °C, reaching 0.523 mm/year on day 2. These findings highlight the combined roles of galvanic and crevice corrosion in riveted assemblies under landfill conditions and emphasize the need for careful material selection and joint design in waste management systems.

*KEY WORDS: Corrosion rate; Landfill leachate; Galvanic corrosion; Crevice corrosion; Temperature effect*

## 1. INTRODUCTION

Corrosion is a critical degradation process in metallic materials, governed by complex electrochemical reactions between a metal surface and its surrounding environment. Environmental factors such as high humidity, aggressive pollutants, and reactive gases significantly accelerate this phenomenon, leading to progressive loss of mechanical integrity, reduced service life, and compromised structural reliability across various applications, including infrastructure, transportation, and industrial systems [1]. Beyond aesthetic deterioration, corrosion poses severe safety and operational performance risks, making its understanding and mitigation an essential engineering challenge.

In the context of sustainable waste management, landfills remain indispensable for the disposal of non-recyclable waste; however, the operational environment within landfills is highly aggressive toward metallic materials. Landfill conditions combine elevated humidity, corrosive gases generated by organic decomposition, and the percolation of chemically aggressive leachate, collectively creating an environment that accelerates corrosion [2, 3].

Leachate is a highly complex and variable fluid containing high concentrations of chloride ions ($Cl^{-}$), ammonia, sulfates, and heavy metals, which can readily penetrate protective oxide films and promote localized corrosion such as pitting [4, 5]. Microbial activity in leachate has also been reported to induce microbially influenced corrosion (MIC), further exacerbating material degradation. Additionally, temperature fluctuations within landfills — caused by exothermic microbial decomposition — increase the conductivity of the medium and accelerate electrochemical kinetics, thus intensifying both uniform and localized corrosion [6].

Carbon steels such as AISI 1020 and commercially pure aluminium (Al 1050) are widely used in landfill-related structures and equipment due to their favorable mechanical strength and cost-effectiveness. Nevertheless, both materials are inherently corrosion-resistant in chloride-rich, microbially active environments. Carbon steel typically undergoes uniform and localized attack under acidic or chloride-bearing leachate. At the same time, aluminium relies on a thin passive oxide film that is vulnerable to chloride-induced breakdown, resulting in severe pitting and intergranular corrosion [7]. Therefore, protective coatings, inhibitors, or surface modifications are often required to extend their service life in such environments.

An additional engineering challenge arises when these metals are joined in landfill infrastructure. Dissimilar joints, such as riveted assemblies of steel and aluminium, are particularly prone to galvanic corrosion, where the more active aluminium becomes the anode and corrodes preferentially when electrically coupled to steel in the presence of an electrolyte [8]. Riveted joints also create crevice geometries that trap leachate, reduce oxygen concentration locally, and promote crevice corrosion. Elevated temperature further intensifies galvanic and crevice corrosion by increasing ionic conductivity, accelerating electrochemical reactions, and destabilizing protective oxide films [9].

Although galvanic corrosion in dissimilar metal joints has been widely studied — particularly in automotive, aerospace, and marine industries — most research has focused on saline or atmospheric exposures. Studies addressing landfill environments, where chloride-rich leachate, microbial activity, and temperature fluctuations act simultaneously, remain limited. Moreover, experimental investigations on riveted steel–aluminium joints under landfill leachate conditions are scarce, and little is known about how temperature variation modulates galvanic and crevice corrosion mechanisms in such assemblies. This lack of systematic studies represents a critical research gap.

The present study addresses this gap by experimentally investigating the corrosion behavior of AISI 1020 steel, Al 1050 aluminium, and their riveted joints in simulated landfill environments. Weight-loss corrosion tests were conducted in real landfill leachate under controlled temperatures (30 °C, 40 °C, and 50 °C). Findings from this study aim to provide practical insights for material selection, protective strategies, and joint design for landfill-related equipment and waste management systems operating under aggressive environmental conditions.

## 2. MATERIALS AND METHODS

Before immersion testing, specimens were prepared from AISI 1020 steel and 1050 aluminum per ASTM G31-72 Standard Practice for Laboratory Immersion Corrosion Testing of Metals. The specimens, cut to dimensions of 2.5 cm × 5 cm (½ inch), were classified into three types with variations in temperature and immersion time, as summarized in Table 1.

Table 1: Specimen code

| No. | Material | Code |
|---|---|---|
| 1 | AISI 1020 | AISI-X |
| 2 | Aluminum 1050 | AL-X |
| 3 | AISI 1020 riveted | AISI+R-X |
| 4 | Aluminum 1050 riveted | AL+R-X |

X = Soaking duration (days)

Leachate samples were collected from the Sukawinatan landfill, Palembang, South Sumatra, and subsequently analyzed at the Environmental Laboratory of the Provincial Government of South Sumatra to determine their chemical composition and potential influence on corrosion behavior. Dimensional measurements of the specimens were carried out with a caliper (accuracy: 0.02 cm) to obtain precise surface area data, while thickness was measured using a digital micrometer. Initial weights were recorded before riveting and immersion, using a digital balance with an accuracy of 0.001 g, as required for weight-loss corrosion testing under ASTM G31-72. Conditions were strictly maintained within ±1 °C for immersion tests involving temperature variation and monitored hourly using a calibrated thermometer. Specimens were carefully removed post-immersion using plastic gloves to minimize mechanical damage, following ASTM G48 recommendations.

Subsequent cleaning procedures were conducted according to ASTM G1-90. For carbon steel, the C.3.3 chemical cleaning method was employed, involving immersion in a solution of 1000 mL distilled water, 20 g zinc granules, and 200 g NaOH, heated to 80–90 °C for 30–40 minutes. The C.1.2 procedure was applied for aluminum, using nitric acid immersion at 25 °C for 1–5 minutes. Metallographic examinations were further performed in compliance with ASTM E407 (2015) to evaluate microstructural features, porosity, and corrosion morphology.

## 3. RESULT AND DISCUSSION

The chemical composition of AISI 1020 steel and 1050 aluminum is presented in Table 2 as follows:

Table 2: AISI 1020 steel and Aluminum 1050 chemical composition

| Material | C | Si | Mn | S | P | Cu | Mg | Al | Fe |
|---|---|---|---|---|---|---|---|---|---|
| AISI 1020 | 0.20 | 0.24 | 1.07 | 0.03 | 0.02 |  |  |  | Rest. |
| Alumnium 1050 |  | 0.25 | 0.05 |  |  | 0.05 | 0.05 | Rest. | 0.4 |

The Environmental Laboratory of South Sumatra tested the composition of leachate collected from the Sukawinatan landfill (Table 3).

Table 3: Results of leachate composition

| No. | Parameter | Unit | Result | Method |
|---|---|---|---|---|
| 1 | pH |  | 8.17 | SNI 6989.11:2019 |
| 2 | BOD | mg/L | 3301 | SNI 6989.72.2009 |
| 3 | COD | mg/L | 12461 | SNI 6989.2:2009 |
| 4 | Chloride | mg/L | 545 | SNI 6989.19:2009 |

The leachate analysis revealed elevated concentrations of chlorides along with other corrosive components, including Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Both parameters are regulated under the Indonesian Government Regulation 82 of 2001 (PP RI No. 82/2001) as indicators of organic and inorganic contamination. A permissible BOD concentration is 20 mg/L, while the COD threshold is 300 mg/L. The measured values exceeded these limits, reflecting poor water quality and high microbial activity. Elevated BOD and COD correlate with reduced dissolved oxygen levels, further exacerbating corrosive conditions.

Chloride ions are particularly aggressive, inducing localized corrosion such as pitting on passive materials like aluminum and stainless steel. At initial exposure, higher $Cl^-$ concentrations accelerate corrosion; however, the corrosion rate decreases over extended immersion periods. This behavior is associated with the formation of green rust (GR), a partially oxidized iron compound that is highly reactive due to its electron deficiency. As illustrated in Fig. 1, GR formation is promoted in chloride-rich environments and has been widely reported in previous studies [10, 11].

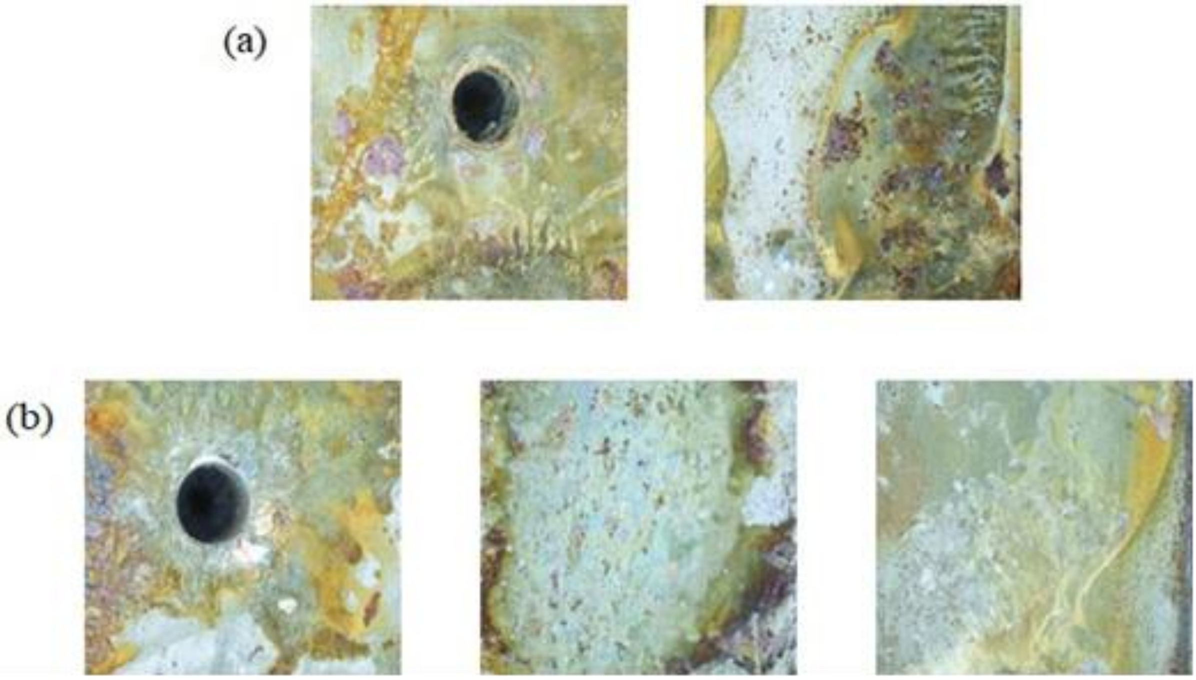
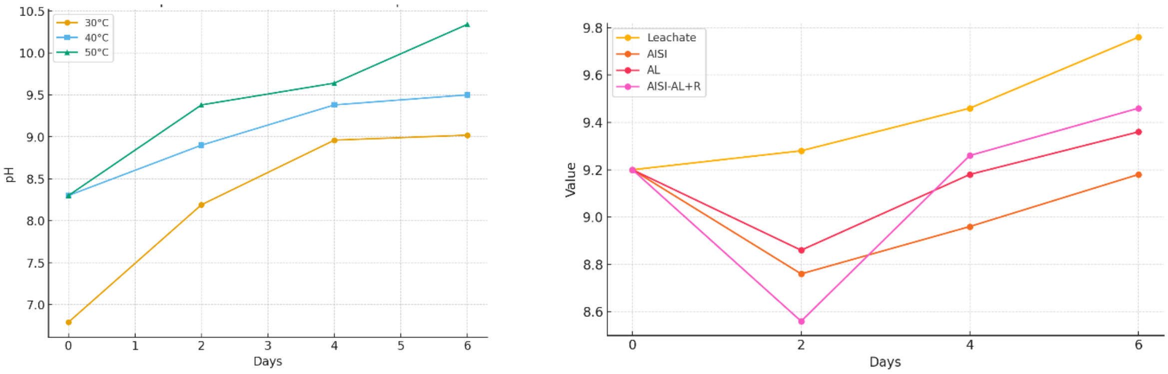


Fig. 1. Green rust formation at (a) 40 and (b) 50 °C

GR is favored under neutral to slightly alkaline conditions (pH 8–11), which aligns with the characteristics of leachate samples collected in this study. Temperature and microbial activity further accelerate GR formation, as the elevated BOD values indicate substantial microbial populations [11]. Beyond its occurrence as a corrosion product, GR has also been identified as a functional material capable of transforming toxic inorganic and organic pollutants and adsorbing contaminants from soil [12].

The pH behavior of leachate under controlled temperatures (30 °C, 40 °C, and 50 °C) is presented in Fig. 2.a. The results show a gradual shift toward alkalinity during anaerobic degradation, primarily due to the consumption of volatile fatty acids by methanogenic bacteria. Additional pH monitoring with test specimens revealed an initial decrease in pH on day 2 across all variations, followed by an increase toward alkalinity on days 4 and 6. These changes are closely linked to electrochemical processes at the metal interface. Upon contact with $H_2O$, $O_2$, and $Cl^-$ ions, anodic and cathodic reactions generate $OH^-$, $Fe^{2+}$, and $Fe^{3+}$ ions, interacting with $Na^+$ and $Cl^-$ to form NaOH and hydrated ferrite species. Depending on the microenvironment, such interactions create localized zones of elevated alkalinity or weak acidity.

The corrosion rate results further confirm the relationship with pH variations. As shown in Fig. 2b, all specimens without rivets exhibited the highest corrosion rate on day 2, after which passivation occurred and corrosion rates declined significantly on days 4 and 6. Aluminum specimens consistently demonstrated lower corrosion rates than AISI 1020, attributable to the protective aluminum oxide film that limits further oxidation.



(a) (b)

Fig. 2. Leachate pH changing during experiments

Conversely, riveted specimens showed unstable corrosion trends due to galvanic effects from material heterogeneity at the joints. The interfacial regions facilitated electrolyte entrapment, which intensified localized electrochemical activity and led to fluctuating corrosion rates. It underscores the importance of joint design and material compatibility in environments characterized by aggressive leachate exposure.

The corrosion rate tests in leachate water at 30 °C, 40 °C, and 50 °C show that temperature accelerates metal degradation. For AISI 1020 (Fig. 3.a), the corrosion rate at 30 °C is low and decreases steadily from 0.088 mm/year on day 2 to 0.020 mm/year on day 6, indicating the formation of a stable passive film. When the temperature is raised to 40 °C and 50 °C, the initial rate rises to 0.155 and 0.180 mm/year, respectively. Although it still drops over time, the protective layer appears less stable under hotter conditions.

Aluminum 1050 (Fig. 3.b) also shows low corrosion at 30 °C ($\leq$ 0.057 mm/year) due to its natural aluminium oxide film, but its early-stage corrosion increases at 40 °C and 50 °C (0.110 and 0.151 mm/year on day 2), suggesting partial breakdown of the oxide at elevated temperature followed by repassivation as immersion continues. Adding riveted joints significantly worsens the temperature effect. For AISI 1020 with a riveted joint (Fig. 3.c), corrosion remains low at 30 °C but rises sharply at 40 °C, peaking at 0.475 mm/year on day 4, and stays high at 50 °C (0.268 mm/year on day 4). This behavior indicates strong crevice and galvanic effects around the rivet that become severe as the temperature increases.

Fig. 3.a shows that at 30°C, corrosion rates were lower than at 40°C and 50°C. Higher temperatures increase system energy, accelerate ion and metal mobility, and enhance

electrochemical reaction probability [7]. However, unlike previous findings, this study revealed that the average corrosion rate of riveted specimens decreased at 50°C. As reported by [3], temperature may affect corrosion differently depending on the environmental system. Generally, increasing solution temperature enhances ionic solubility and precipitate formation. Due to its high surface reactivity, iron (Fe) strongly influences contaminant mobility and degradation. Under oxic conditions, Fe minerals adsorb various organic and inorganic pollutants [8]. This behavior is closely associated with the formation of green rust (GR), a potent reducing agent capable of transforming toxic organic contaminants, with its nanocrystalline structure providing a high density of reactive sites for oxyanion binding, such as chloride.

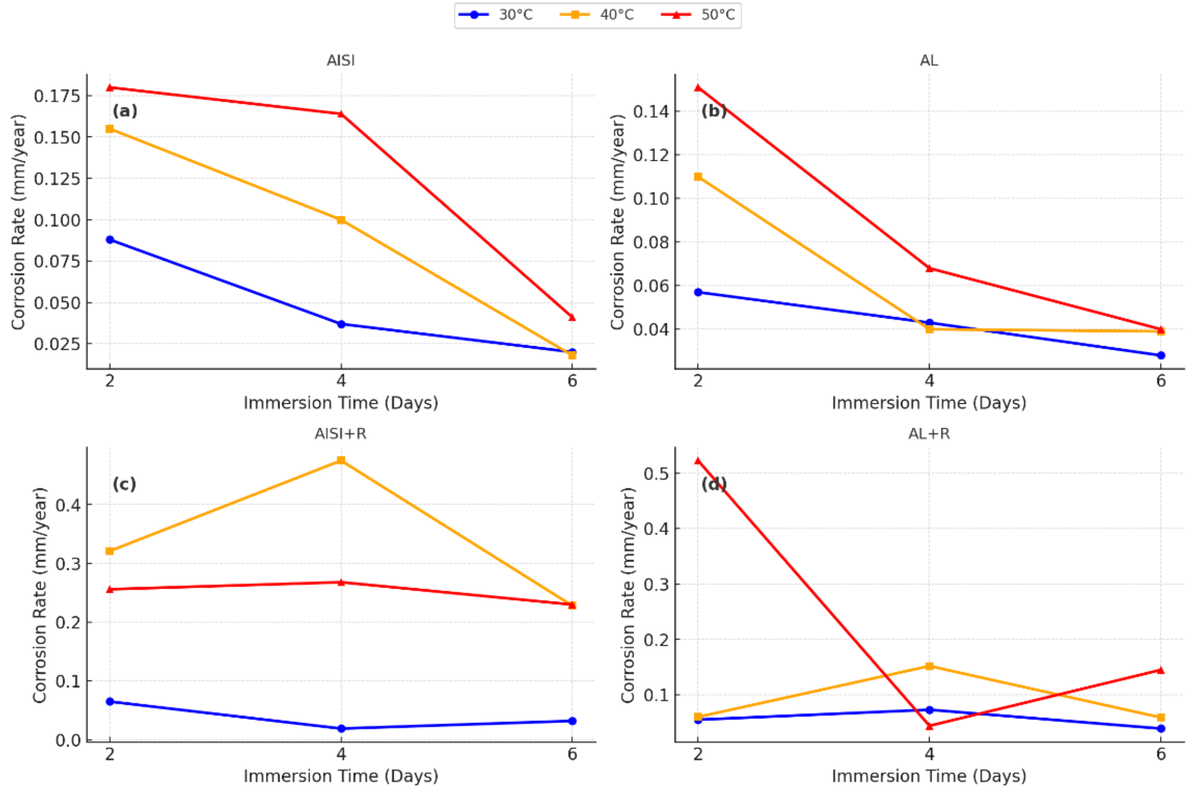


Fig. 3. Corrosion rate at various temperatures of (a) AISI1020, (b) Al1050, (c) AISI1020+Riveted joint, (d) Al1050+Riveted joint

In riveted AISI 1020 specimens, the lower corrosion rate at 50°C was attributed to pollutant adsorption and the accumulation of precipitates, especially within crevice regions, which acted as barriers to further corrosion. In contrast, Al 1050 showed increased corrosion at elevated temperatures, as the attached precipitates facilitated localized attack on its surface. For single specimens, the corrosion rate of aluminum increased significantly with temperature, while for AISI 1020, the increase was less pronounced between 40°C and 50°C. It was due to surface precipitates acting as corrosion inhibitors for AISI 1020. However, aluminum underwent rapid anodic oxidation in humid or corrosive media, accelerating corrosion.

The most aggressive attack occurs on Al 1050 with a riveted joint (Fig. 3.d); while rates at 30 °C remain moderate (≤ 0.073 mm/year), the initial corrosion at 50 °C soars to 0.523 mm/year on day 2, far exceeding that of plain aluminium. Overall, higher temperature accelerates early corrosion in leachate water for all materials, reduces the stability of passive films, and makes riveted joints especially vulnerable to crevice and galvanic corrosion under warm, chemically aggressive conditions.

A possible explanation for the significant increase in corrosion observed in the riveted specimens, especially at higher temperatures, is galvanic and crevice corrosion. In the case of AISI 1020 with riveted joints, the contact between the base steel plate and the rivet material can create a galvanic couple if their electrochemical potentials differ in the leachate environment. Schematic galvanic couple depicted in Fig. 4. The more active material (anode) will corrode faster, while the more noble metal (cathode) is protected. Elevated temperatures increase ionic conductivity and reaction kinetics, making galvanic effects stronger and accelerating the anodic dissolution of the less noble component.

Additionally, the crevice geometry between the rivet and the base metal creates a confined region where the leachate can stagnate. The oxygen content decreases rapidly within such crevices compared to the surrounding bulk solution, creating a differential aeration cell. The oxygen-depleted crevice interior becomes anodic, while the oxygen-rich outer surface acts as the cathode. This crevice corrosion mechanism is intensified by chloride and other aggressive ions in the leachate, which migrate into the crevice and break down passive films. Higher temperatures further accelerate this process by increasing the mobility of aggressive ions and reducing the stability of protective oxides on both steel and aluminium [13].

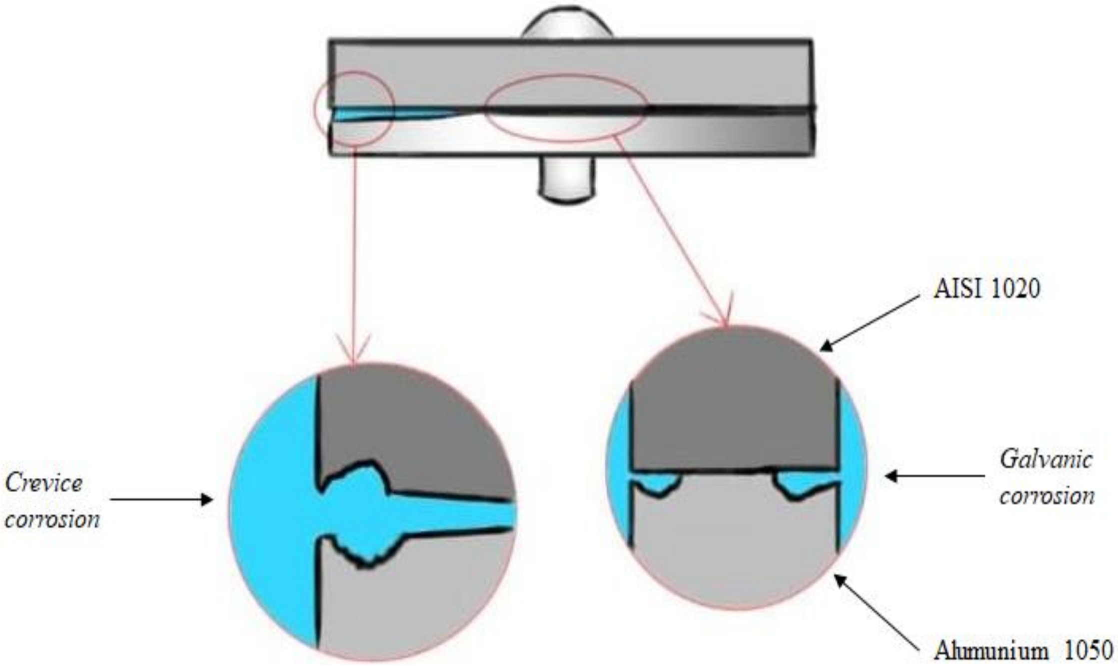
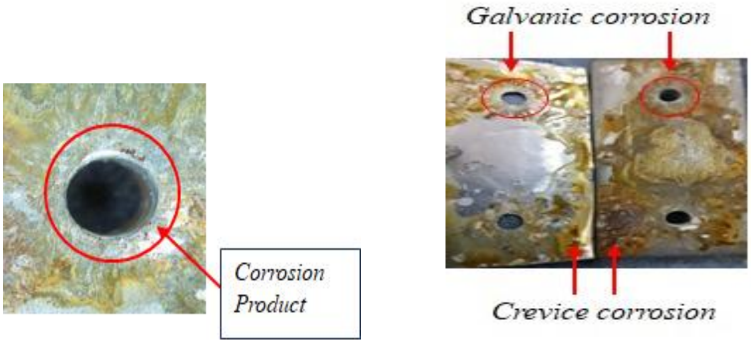


Fig. 4. Schematic galvanic couple

In Fig. 5.a corrosion products of aluminum adhering to AISI specimens can be observed. White corrosion deposits localized near the rivet region confirm that areas farther from the joint experienced different corrosion mechanisms. Previous studies [14] have reported that galvanic and crevice corrosion occur at the interface between aluminum alloys and steel. White corrosion deposits primarily accumulated at the aluminum surface near the rivet, whereas the edge zones of the AISI/Al interface served as favorable sites for crevice corrosion.



(a) (b)

Fig. 5. Galvanic corrosion on a) riveted joint, b) interface of riveted joint

Consequently, more severe damage was observed along the edges, as shown in Fig. 5.b. It suggests that, in addition to galvanic effects, crevice corrosion significantly contributes to overall degradation in riveted AISI/Al joints [2]. The quality of riveting plays a critical role in determining corrosion behavior. Wider crevices from poor riveting promote crevice corrosion, while tighter joints between AISI 1020 and Al 1050 enhance galvanic effects. In the latter case, aluminum acts as the sacrificial anode, leading to a higher corrosion rate in Al 1050 than AISI 1020. Fig. 5.b. Further shows that localized attacks near gaps between overlapping surfaces initiated crevice corrosion. The oxygen concentration gradient was highest at the crevice edge, which corroded faster than the inner region [15]. Thus, crevice corrosion was more severe at the edges, while galvanic corrosion was restricted to areas closer to the rivet Fig. 5.a [16]. The presence of aluminum corrosion products localized at rivet interfaces further indicates the dominance of crevice corrosion in riveted specimens. Meanwhile, self-corrosion mechanisms dominated most surface areas, except those shielded by the rivet head and tail.

## 4. CONCLUSION

This study demonstrates that temperature is a key factor accelerating corrosion in landfill leachate environments, especially during the early stages of immersion. Both AISI 1020 steel and Al 1050 aluminium initially corrode faster at higher temperatures, but plain specimens tend to passivate after prolonged exposure. In contrast, riveted joints experience severe and unstable corrosion due to the synergistic action of galvanic coupling and crevice effects at the metal interfaces. Elevated temperature increases electrolyte conductivity and ion mobility, enhancing galvanic currents and accelerating passive film breakdown, while the crevice geometry created by rivets fosters oxygen depletion and chloride accumulation. Al 1050 with riveted joints exhibited the highest vulnerability among all tested materials, showing a rapid corrosion spike at 50 °C. These results indicate that using dissimilar riveted joints in landfills poses a high corrosion risk, particularly under warm and chloride-rich conditions. Alternative joint designs, protective coatings, or the avoidance of steel–aluminium galvanic couples should be considered when selecting materials for landfill-related infrastructure and waste management systems to extend service life.

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