

# Corrosive environments in municipal waste composting facilities: mechanisms, corrosivity and protection strategies

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## Abstract

Although composting is a mature and economically favorable waste treatment technology, the controlled aerobic biodegradation of organic waste generates physicochemical conditions that are highly aggressive toward metallic and cementitious materials. This paper examines the corrosive environment in municipal solid waste composting facilities and its implications for material degradation and structural durability. Appropriate corrosion protection strategies were proposed based on the obtained results.

The corrosivity of composting atmospheres arises from both chemical and microbiological processes. Elevated temperatures (40–70 °C), persistent high relative humidity (>90%), and the presence of condensates enriched with organic acids, ammonia, carbon dioxide, and reduced sulfur compounds create an environment conducive to accelerated corrosion. Operational factors, including condensation–evaporation cycles and acid-laden runoff, accelerate corrosion kinetics and compromise protective coatings.

Given the limited empirical data on composting-specific atmospheric corrosivity, the corrosion rate of steel and zinc was determined under the conditions of a real operating composting plant according to the methodology described in the ISO 12944-2 standard and the appropriate corrosivity categories were defined. Based on this, optimized anti-corrosion systems were developed for new and renovated municipal solid waste composting facilities.

## Keywords

corrosion, composting facilities, corrosivity category, anti-corrosion coatings

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## 1. INTRODUCTION

Industrial environments and those associated with municipal infrastructure are often highly corrosive to structural materials due to their specific characteristics. It is therefore essential to implement appropriate protection methods. The first step in this process is to understand the composition, properties, and parameters of the environment, as well as its corrosivity as a key factor influencing the expected durability of the structure.

This paper is based on our practical experience with municipal composting facilities and builds on our portfolio of completed corrosion risk assessments and corrosion protection projects across various sectors, including the energy industry (Drozda and Miszczyk, 2022; Miszczyk and Darowicki, 2002; Miszczyk and Darowicki, 2012), museums and national heritage sites (Miszczyk et al., 2016; Szociński et al., 2019), oil installations (Miszczyk et al., 2026; Orlikowski et al., 2024), and municipal water networks (Orlikowski et al., 2014).

The article outlines comprehensive steps for effectively protecting municipal organic waste composting facilities against corrosion. Due to insufficient understanding of the corrosive conditions present in such environments, many facilities deteriorate rapidly, leading to costly and disruptive repairs or reconstruction (Pajura, 2024).

Traditional waste treatment or disposal methods include composting (Avramidou et al., 2013; Hassen et al., 2001), anaerobic digestion (Abad et al., 2019; Jain et al., 2015), and landfilling (Behrooznia et al., 2018; Lee et al., 2017). Nontraditional technologies encompass incineration (Sharifah et al., 2013; Panepinto and Zanetti, 2018), pyrolysis (Lu et al., 2020; Yang et al., 2018), gasification (such as plasma gasification) (Lopes et al., 2018; Zhang et al., 2012), and hydrothermal processing (Anthraper et al., 2018; Peng et al., 2016).

Composting supports the circular economy by turning organic waste, such as food scraps and plant material, into nutrient-rich compost that improves soil quality. Instead of being discarded, organic waste is transformed into a valuable resource and returned to agricultural production. This process closes the environmental loop, reduces waste, and lessens environmental impact by sustainably reusing natural resources (Munir et al., 2021; Pajura, 2024; Pecorini et al., 2026).

Composting is a quite advanced technology for processing municipal solid waste. It has benefits like low initial costs, available land, lower contamination risks, and profitability from composted products (Ayilara et al., 2020; Gajalakshmi and Abbasi, 2008; Kumar, 2011; Lee et al., 2017). However, municipal waste composting facilities represent one of the most aggressive corrosive environments encountered in civil and industrial infrastructure (Agnew and Leonard, 2003;



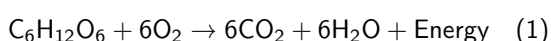
De Belie et al., 2000; Richard et al., 2002). These facilities are designed to accelerate the biological degradation of organic waste through controlled aerobic composting processes. But at the same time, the biochemical and physicochemical conditions that enable rapid biodegradation also create severe corrosion hazards for structural materials, mechanical equipment, and protective systems. Premature deterioration of steel and reinforced concrete elements has been widely reported in enclosed composting halls, tunnels, and bio-reactors, leading to increased maintenance costs, operational downtime, and, in extreme cases, structural safety concerns.

The corrosive environment in composting plants arises from a combination of high humidity, elevated temperatures, acidic and alkaline condensates, and biologically generated corrosive agents (Epstein, 1997; Rynk, 2022). Organic waste decomposition produces large quantities of water vapor, carbon dioxide, ammonia, organic acids (e.g., acetic, formic, and lactic acids), and reduced sulfur compounds. These substances accumulate in confined spaces and condense on cooler structural surfaces, forming aggressive electrolytes capable of attacking both metallic and cementitious materials.

A central question in the corrosion science of composting facilities concerns the role of biochemical reactions driven by compost-processing microorganisms. While corrosion itself is an electrochemical process, microbial activity is a primary upstream cause of corrosivity. Aerobic bacteria and fungi metabolize organic matter, releasing carbon dioxide and organic acids that lower local pH. In parallel, localized anaerobic microenvironments within compost piles can foster sulfate-reducing and sulfur-oxidizing bacteria, leading to the formation of hydrogen sulfide (H<sub>2</sub>S). Subsequent oxidation of H<sub>2</sub>S, either chemically or biologically, can produce sulfuric acid, a well-known agent of severe concrete degradation. This mechanism closely resembles microbiologically influenced corrosion (MIC) observed in wastewater infrastructure, although composting environments are typically more heterogeneous and transient.

The chemical processes that occur during composting include (Epstein, 1997; Epstein, 2011; Rynk, 2022):

- Decomposition of organic matter
  - Hydrolysis: Organic polymers such as cellulose, lignin, proteins, and fats are broken down into smaller molecules by enzymes secreted by microorganisms.
    - \* Cellulose → Glucose
    - \* Proteins → Amino Acids
    - \* Fats → Fatty Acids and Glycerol
  - Hydrolysis products become available for further metabolism by microorganisms.
- Degradation of Carbon Compounds
  - Aerobic Respiration: Microorganisms consume oxygen to oxidize carbon compounds into carbon dioxide (CO<sub>2</sub>) and water (H<sub>2</sub>O), releasing energy.



- Anaerobic Processes (in the absence of oxygen): Gases such as methane (CH<sub>4</sub>), hydrogen sulfide (H<sub>2</sub>S), and organic acids are produced.
- Decomposition of sulfur compounds: The decomposition of sulfur-containing proteins (e.g., cysteine) leads to the formation of hydrogen sulfide (H<sub>2</sub>S) and sulfates (SO<sub>4</sub><sup>2-</sup>).
- Organic acid production
  - Short-chain organic acids, such as acetic, butyric, and lactic acids, are formed as intermediate products in the fermentation process.
- Humification
  - Decomposition products, such as phenols, alcohols, and organic acids, are converted into stable humic compounds. This process involves:
    - \* Polycondensation of aromatic compounds.
    - \* Formation of stable organic complexes.
- Heat release
  - The decomposition of organic matter is an exothermic process. Due to the intense respiration of microorganisms, the compost temperature can rise to 60–70 °C, which helps eliminate pathogens and weed seeds.
  - Mineralization: Elements such as phosphorus, potassium, calcium, and magnesium are released in plant-available forms, making compost an excellent fertilizer.
- Gas release
  - During decomposition, gases such as carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and ammonia (NH<sub>3</sub>) are released, depending on aerobic or anaerobic conditions.

These chemical and biological processes work together to create nutrient-rich and stable compost. Maintaining the appropriate conditions (e.g., oxygen, moisture, temperature) is crucial for the process to proceed effectively.

Operational conditions within municipal composting facilities further exacerbate corrosion risk. Internal air temperatures commonly range from 40 to 70 °C, with localized compost core temperatures reaching up to 75 °C during thermophilic phases. Relative humidity is persistently high, often above 90% and frequently approaching saturation, particularly in enclosed or tunnel-based systems. These conditions promote continuous condensation–evaporation cycles on structural surfaces, which accelerate corrosion kinetics and undermine the long-term performance of protective coatings.

Due to the processes described above, the chemical and physical parameters of the composting environment change. Figure 1 schematically illustrates the changes in the following parameters: temperature and pH of the environment as a function of composting time, as well as the involvement of bacteria and fungi at various stages of the process (Epstein, 1997; Rynk,

2022). As the figure shows, in the initial period, bacteria are active, resulting in an increase in temperature and a decrease in the pH of the environment to approximately 5. In the second stage, the intensity of decomposition due to bacterial activity decreases, the temperature decreases, and fungi grow more intensively, leading to an increase in pH to approximately 8.5.

To mitigate these risks, composting facilities employ a combination of material selection, structural design, and corrosion protection systems. Load-bearing frameworks are typically constructed from structural carbon steel and reinforced concrete, while ancillary components may incorporate stainless steels (e.g., AISI 304L or 316L), aluminum alloys, or polymer-based materials such as high-density polyethylene (HDPE), polypropylene (PP), and fiber-reinforced plastics (FRP). In highly exposed zones, non-metallic materials are increasingly favored due to their inherent resistance to moisture and chemical attack.

Protective strategies for steel and concrete surfaces rely heavily on coating systems engineered for high humidity and chemically aggressive atmospheres. Common solutions include multi-layer epoxy systems, epoxy-phenolic coatings, polyurethane topcoats, and vinyl ester or novolac epoxy linings. Typical dry film thicknesses range from 300 to 500  $\mu\text{m}$  for atmospheric protection and may exceed 1000  $\mu\text{m}$  for heavy-duty linings in areas exposed to condensate runoff or leachate. For concrete structures, polymer-modified cementitious coatings, epoxy coatings, and chemically resistant membranes are applied to limit acid ingress and moisture penetration.

Current best practice recommends an integrated anti-corrosion approach combining environmental control (ventilation and condensate management), robust coating systems, corrosion-resistant materials, and rigorous inspection and maintenance regimes. Early involvement of corrosion engineers during the design phase, along with adherence to relevant standards and exposure classifications, is critical for achieving an acceptable service life in these demanding environments.

Experience in this area is relatively limited, so principles developed earlier for industrial environments are applied here. To apply this approach, it is necessary to determine the corrosiveness of the atmosphere in various zones, and such data are lacking.

Composting plant design must be resistant to changing conditions. High humidity and air temperature must be properly considered in closed composting systems. The temperature inside the composting system is usually higher than the ambient temperature. Therefore, moisture in the air condenses on all surfaces, and the condensate contains aggressive acids and ammonia. The pH of the condensate changes from approximately 5 to 8.5 during the process. Typical anti-corrosion measures are ineffective in the composting process. Since these conditions are quite specific, it is necessary to perform measurements of the corrosive aggressiveness of the atmosphere in the composting plant, in accordance with the [ISO 12944-2](#) standard, in order to propose an appropriate protection system.

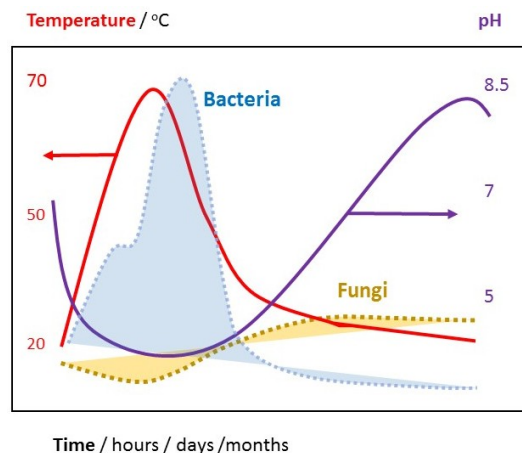


Figure 1. Schematic representation of changes in temperature and pH of the environment and the intensity of bacterial and fungal activity as a function of time in the composting process.

Based on this, it was decided to first characterize the chemical environment in the composting plant, then determine the corrosivity categories in different areas of the composting plant and, based on the data, propose protective systems necessary for proper protection of the structure in the conditions of the new and previously existing (renovation) composting plant structure. The research concerned composting plants processing municipal organic waste in Polish conditions.

## 2. EXPERIMENTAL DETAILS

The compost factory consists mainly of three halls that perform the functions necessary to carry out the entire process (Figure 2):

- Waste reception hall.
- Operational connector composting hall.
- Maturing and finishing hall.

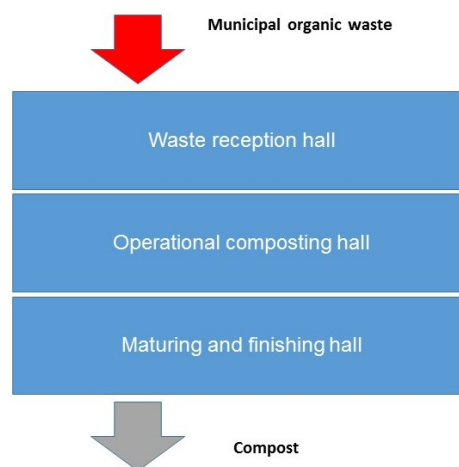


Figure 2. Schematic representation of the structure of the composting installation

Corrosivity categories were assessed based on [ISO 12944-2](#). They are determined based on the corrosion rate of mild carbon steel and/or zinc over a period of 1 year as shown in Table 1.

Table 1. Standard corrosion rates for mild steel and zinc in atmospheric conditions for different corrosivity categories.

| Corrosivity |             | Corrosion rate [ $\mu\text{m}/\text{year}$ ] |                       |
|-------------|-------------|----------------------------------------------|-----------------------|
| Category    | Description | Mild steel                                   | Zinc                  |
| C1          | Very low    | $\leq 1.3$                                   | $\leq 0.1$            |
| C2          | Low         | $> 1.3$ to $\leq 25$                         | $> 0.1$ to $\leq 0.7$ |
| C3          | Medium      | $> 25$ to $\leq 50$                          | $> 0.7$ to $\leq 2.1$ |
| C4          | High        | $> 50$ to $\leq 80$                          | $> 2.1$ to $\leq 4.2$ |
| C5          | Very high   | $> 80$ to $\leq 200$                         | $> 4.2$ to $\leq 8.4$ |
| CX          | Extreme     | $> 200$ to $\leq 700$                        | $> 8.4$ to $\leq 25$  |

### 3. AIR COMPOSITION ANALYSIS IN THE INTERIORS OF COMPOSTING BUILDINGS

The contents of organosulfur compounds, hydrogen sulfide ( $\text{H}_2\text{S}$ ), ammonia ( $\text{NH}_3$ ), oxygen ( $\text{O}_2$ ), carbon monoxide ( $\text{CO}$ ), carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ ), and hydrogen ( $\text{H}_2$ ) were determined inside the hermetic composting facility. Measurements were taken in the waste reception hall, the operational connector, and the maturation and finishing hall. The following equipment was used to determine the above-mentioned compounds: a MODEL WT8811 multigas concentration monitor, a Gas Data GFM Series multigas concentration monitor, and a Clarus 580 gas chromatograph (PerkinElmer, USA) with an ELITE-1MS capillary column (dimensions:  $60\text{ m} \times 0.32\text{ mm} \times 1.0\text{ }\mu\text{m}$ ) and an FPD flame photometric detector. The measurement results are presented in Table 2.

In addition to the total organosulfur compounds, which reached 6.36 ppm in the operational connector hall, qualitative determinations of the detected compounds were also made, identifying the presence of carbon disulfide, dimethyl sulfide, isopropyl mercaptan, and propyl mercaptan.

Analysis of the obtained results in terms of corrosion hazards led to the following observations:

- The carbon dioxide content in all composting halls was approximately 0.4%. This value is approximately one order of magnitude higher than that of atmospheric air (0.03%). The presence of carbon dioxide increases the corrosiveness of the environment, as  $\text{CO}_2$  combined with water (moisture in the air) forms carbonic acid ( $\text{H}_2\text{CO}_3$ ). This is an inorganic acid, relatively weak and unstable. However, due to the high carbon dioxide concentration and

high humidity inside the composting halls, its formation in large quantities can pose a significant corrosion hazard. The highest carbon dioxide content was recorded in the operational connector hall, which translates into the greatest corrosion risk in this part of the composting plant.

- Carbon monoxide, whose higher concentrations were detected in the waste reception hall and connector hall compared to the maturation and final processing hall, is an inert gas (it does not form acids or hydroxides in the presence of moisture) and does not pose a corrosive threat to metals at atmospheric pressure ( $\text{CO}$  contaminated with sulfur compounds and combined with moisture can cause stress corrosion cracking under elevated pressure).
- The oxygen content in all composting halls remains at approximately 19%, which is lower than the oxygen content in outdoor atmospheric air. Oxygen is an essential element of the corrosion reaction (it participates in the cathodic reaction of the corrosion process), so its lower concentration in composting buildings does not increase the corrosion risk.
- The remaining compounds determined were present at concentrations below the detection limit of the measurement and analytical equipment used, meaning that their impact on the corrosiveness of the atmosphere inside the composting halls is negligible.

Table 2. Results of air composition measurements inside the hermetic composting facility.

| Compound                                                     | Waste reception hall | Operational composting hall | Maturing and finishing hall |
|--------------------------------------------------------------|----------------------|-----------------------------|-----------------------------|
| $\text{O}_2$ [%]                                             | 18.9                 | 18.8                        | 18.7                        |
| $\text{CO}$<br>[ $\mu\text{mol}/\text{mol}$ of air]          | 16                   | 17                          | 3                           |
| $\text{H}_2\text{S}$<br>[ $\mu\text{mol}/\text{mol}$ of air] | $< 0.1^*$            | $< 0.1^*$                   | $< 0.1^*$                   |
| LEL<br>(explosive gases) [%]                                 | $< 0.1^*$            | $< 0.1^*$                   | $< 0.1^*$                   |
| $\text{CO}_2$ [%]                                            | 0.4                  | 0.5                         | 0.4                         |
| $\text{CH}_4$ [%]                                            | $< 0.01^*$           | 0.2                         | $< 0.01^*$                  |
| $\text{H}_2$ [ppm]                                           | $< 1^*$              | $< 1^*$                     | $< 1^*$                     |
| $\text{NH}_3$ [ppm]                                          | $< 1^*$              | $< 1^*$                     | $< 1^*$                     |
| Total volatile organosulfur compounds<br>[ppm]               | $< 0.1^*$            | 6.36                        | $< 0.1^*$                   |

\*means the detection limit of a given compound using the measuring equipment used

#### 4. CORROSIVITY INSIDE COMPOSTING HALLS

A study was conducted to determine the corrosivity category in composting halls. For this purpose, a total of 40 samples made of S235JR carbon steel and steel coated with a  $24.6 (\pm 2.4) \mu\text{m}$  thick hot-dip zinc coating and measuring  $20 \text{ cm} \times 5 \text{ cm} \times 1 \text{ mm}$  were hung in various representative locations under the roof (within the roof structure), Figure 3. Additionally, for comparative purposes, two steel samples were hung in the connecting hall at a height of approximately 2 m from the floor, next to a wall shared with the reception hall. The exposure period was 48 days. After this period, the samples were removed (Figure 4), and the dirt and corrosion products of steel and zinc were removed in appropriate solutions, in accordance with the PN-74/H-04600 standard (10% HCl with 5% hexamine, 5% acetic acid solution, at  $20^\circ\text{C}$ , respectively). The mass losses of steel and zinc were determined and converted into corrosion rates for steel and zinc (in  $\mu\text{m}/\text{year}$ ). Figures 5 and 6 present the results for all galvanized and steel samples in the form of bar graphs to facilitate comparison of the corrosivity of each hall. Figure 7 indicates the corrosion rate averaged over all samples in a given hall.

Based on the conducted research, the corrosivity category for the reception hall and the operational composting hall is CX (extreme corrosivity). The maturation and final processing halls are C5. It should be noted that in some areas of the operational composting hall corrosivity is higher than that specified for CX (based on zinc results), meaning it falls outside the range of the accepted scales. These findings are also confirmed by the results obtained for steel, where the limiting value for this corrosivity category is a steel corrosion rate of  $700 \mu\text{m}/\text{year}$ . This indicates that the initially applied protection, consisting of a  $20 \mu\text{m}$  thick zinc coating, was sufficient for approximately one year. This is due to the range of pH values of condensates formed during the composting process, which vary from 5 to 8.5. As shown in Figure 8, this is the range in which zinc corrosion rates are significantly higher than in a neutral or near-neutral environment (pH around 7). This is facilitated by elevated temperature, high humidity (90–100% relative humidity), and the presence of corrosion stimulants in the form of salts (sulfates, chlorides, nitrates) formed as a result of chemical and biological processes.

Zinc corrosion rate studies have shown that protective layers of corrosion products form within a pH range of 6–12, with a minimum corrosion rate observed in the pH range of 10–12 (Figure 8). Water and increased amounts of organic and inorganic acids, a product of bacterial metabolism, condense under composting conditions on the internal surface of the roof structure, preventing the formation of a protective layer on the zinc surface. This causes accelerated corrosion of the zinc, which, therefore, no longer protects the steel surface after a short period of time. The steel continues to corrode due to the aggressive, corrosive atmosphere at an accelerated rate.



Figure 3. Steel and galvanized samples hung in the composting halls on the first day of exposure (2 steel and 2 galvanized).

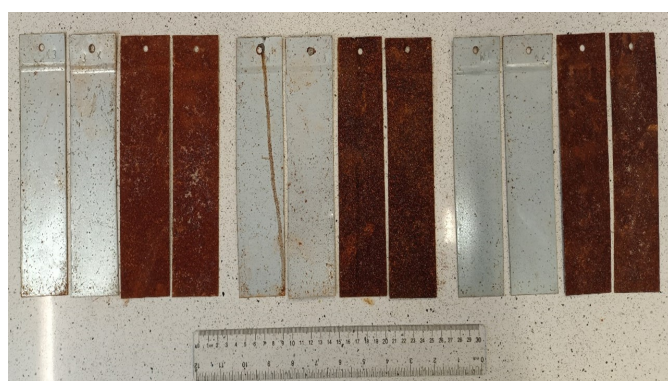


Figure 4. Appearance of some galvanized and steel samples after 48 days of exposure in composting halls.

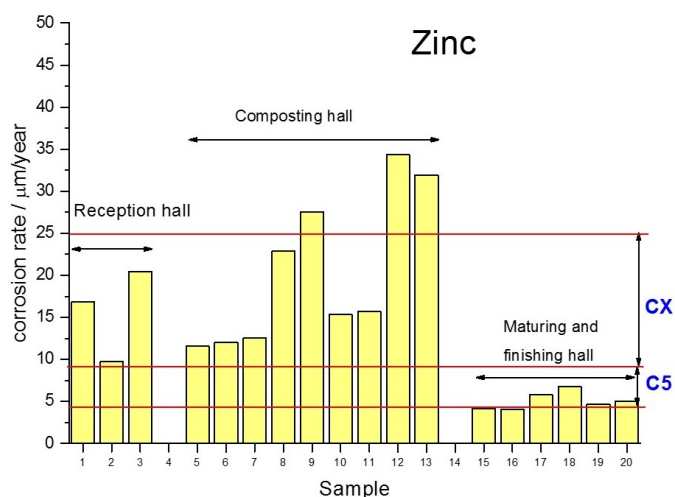


Figure 5. Corrosion rates of galvanized samples in the composting factory halls at different locations in each hall. The CX and C5 corrosivity ranges are marked according to the criteria of the ISO 12944-2 standard.

#### 5. PROTECTION STRATEGIES

Municipal solid waste composting facilities, particularly enclosed (most common in central Europe) or tunnel-based systems, must be designed for a simultaneously aggressive

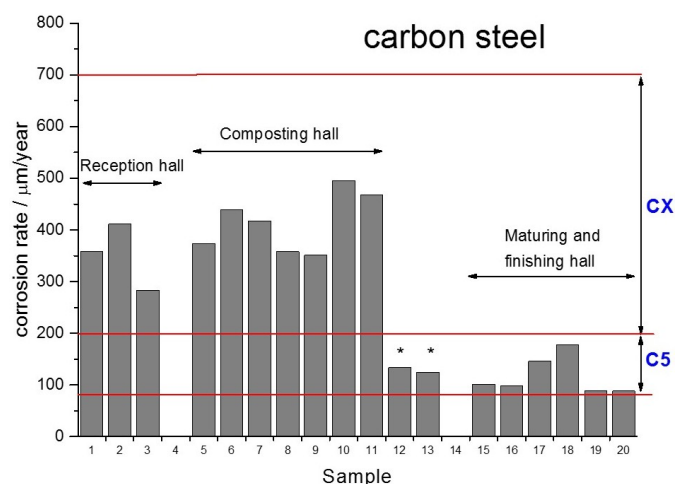


Figure 6. Corrosion rates of carbon steel samples in the composting factory halls at different locations in each hall. The CX and C5 corrosivity ranges are marked according to the criteria of the [ISO 12944-2](#) standard. (\*) refers to the corrosion rate of steel at a height of approximately 2 m above the floor.

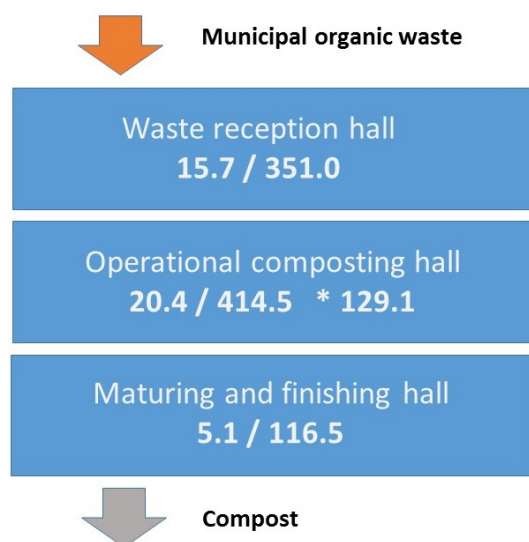


Figure 7. Average corrosion rates of zinc / steel within each hall, expressed in  $\mu\text{m}/\text{year}$ . The average value applies to all samples of a given type exposed in a given hall. The value with an asterisk (\*) refers to the corrosion rate of steel at a height of approximately 2 m above the floor.

chemical, thermal, moisture, and mechanical environment. Structural solutions therefore differ substantially from conventional industrial halls. This is not always noticed, which results in corrosion problems later that are more difficult to repair. Roof design is critical due to:

- Condensation formation.
- Corrosive condensate dripping.
- High humidity exposure.
- Temperature gradients.

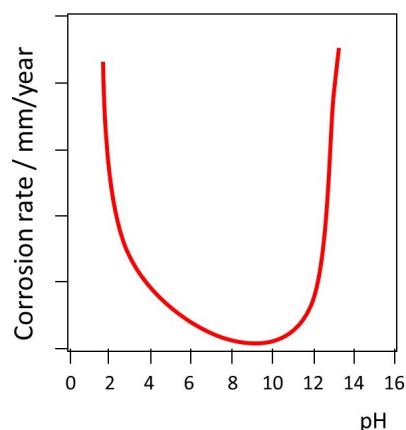


Figure 8. Schematic diagram of the zinc corrosion rate as a function of pH of the aquatic environment (based on [Zhang, 1996](#)).

A typical solution in this case are hot-rolled (Figure 9) or welded steel trusses. Stainless steel is only used selectively (due to cost). Reinforced concrete frames or hybrid steel-concrete structures are sometimes used. Lightweight openwork trusses are common structurally, but they are not "light" from a corrosion perspective, they require substantial protection. Subsections 5.1 and 5.2 propose protective coatings and their application methods appropriate to the conditions in a new composting plant and one requiring renovation, respectively.

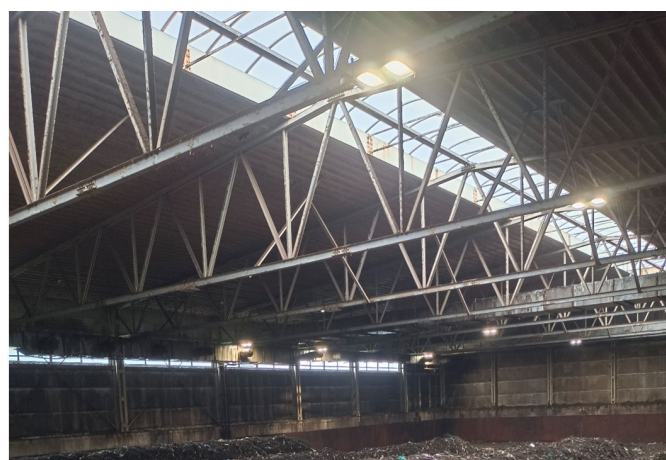


Figure 9. Hot-rolled steel trusses connected with bolts used in one of the composting halls.

Multi-layer coating systems are an indispensable solution for anticorrosion protection, especially in heavy-duty environments, including municipal waste composting facilities. A single layer of any organic coating is not capable of providing an efficient and durable barrier in the long term. Selection of the coating system and its parameters is performed based on the respective standards, namely:

- [ISO 12944-5](#) "Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 5: Protective paint systems", which covers the types of paints

and systems (e.g., alkyd, epoxy, polyurethane) used for protecting steel in environments characterized by different corrosivity classes from C1 to C5.

- [ISO 12944-9](#) "Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 9: Protective paint systems and laboratory performance test methods for offshore and related structures", which relates to carbon steel structures and high-durability paint systems, typically those exposed to harsh environments of corrosivity class CX.

The standards contain the information about the minimum requirements (types of binders suitable for particular application, number of coating layers, dry thickness range for particular layers) for the coating systems for different durability variants. The standards have been created and are periodically updated based on practical experience collected from numerous application fields where organic coatings provide anticorrosion protection, for instance, atmospheric exposure, industrial applications, offshore structures, the transportation sector, etc. While searching for the optimum protection strategy for the municipal waste composting facility, we took into account the recommendations for C5 and CX corrosivity classes included in the ISO 12944 standards, and additionally confined our selection to epoxy- and polyurethane-based coatings. It is due to the specific environment identified inside the composting facility, especially significant variations in the pH that only these binders can withstand in the long-term exposure.

The presented approach is the primary method for designing coating protection. However, it requires knowledge of the corrosivity of the target atmosphere in which the protection is intended, taking into account specific environmental characteristics that may eliminate certain types of coatings (e.g., due to the unusual pH of the environment, most coatings will not guarantee adequate durability). First, the corrosivity of the atmosphere was precisely determined and other parameters of the composting environment that may affect the durability of coatings were examined. The approach presented in this manuscript includes all the necessary steps needed to design appropriate coating protection in accordance with the current state of knowledge.

The organic coating systems presented in the following chapters are typically designated for bare steel substrates. This situation occurs in structures intended for renovation. However, the same systems can be used to provide additional protection for new structures, which are inherently protected by a thin (approximately 25  $\mu\text{m}$ ) zinc coating on the steel elements. This type of protection is sufficient for similar warehouse structures, which are often used as a basis for composting plant halls. In this way, a duplex system is created, which provides even more efficient anticorrosion protection. Composting facilities are characterized by heavily corrosive conditions, in which the zinc layer alone is insufficient for effective protection, and thus application of the duplex systems is beneficial ([van Eijnsbergen, 1994](#); [Yu et al., 2020](#)).

The presented systems were designed to be applied to both steel and galvanized steel surfaces, facilitating their application in different variants due to their versatility.

## 5.1. Anticorrosion protection of steel girders and trapezoidal roof sheet in the variant of erecting a new roof structure

Most frequently, the roof structure of a composting facility consists of trapezoidal steel sheet and steel girders. To ensure long-term durability, they must be adequately protected against corrosion in accordance with the [ISO 12944-2](#) standard: CX for the waste reception hall and the operational connector hall, and C5 for the maturation and post-processing hall.

### 5.1.1. Requirements concerning the preparation of the steel substrate for painting and the conditions for applying coatings

Preparation of the metal substrate is one of the most crucial steps in achieving efficient, long-term anticorrosion protection. To provide good adhesion of paint coatings to the steel substrate, the following should be performed:

- abrasive blast cleaning using grit abrasives to the Sa2½ preparation grade in accordance with [ISO 8501-1](#) standard,
- obtaining an intermediate surface roughness profile,
- washing steel elements with clean water to remove water soluble salts. The salt content on surfaces to be painted, determined according to the Bresle method ([ISO 8502-6](#)), should not exceed 50  $\text{mg}/\text{m}^2$ .

Conditions for applying paint coatings shall comply with the requirements specified in the datasheet of the anticorrosion paints used. Nevertheless, certain conditions must be met regardless of the type of paint employed, such as during application and drying/curing of coatings, the relative air humidity should not exceed 85%, and the dew point temperature should be at least 3 °C higher than the temperature of the painted surfaces. It is recommended to prepare the surface and apply protective coatings to individual elements under controlled climatic conditions (for instance, inside the painting rooms) before their delivery and final installation on the composting plant buildings. It reduces the formation of flash rust after abrasive blasting of elements and provides fully hardened coatings before assembly. After installing the roof structure on the composting plant buildings, painting (using the same coating systems as on the rest of the structure) of the bolted joints should be performed. After final installation, it is recommended to inspect the coatings on the entire roof structure to identify and repair potential damage caused by installation.

#### 5.1.2. Coating protection for the waste reception hall and for the operational connector hall

The minimum requirements for a coating system intended for use in the waste reception hall and in the operational connector hall should meet the CX corrosivity class (offshore) environment:

- the coating system should consist of a minimum of 3 layers,
- the total dry thickness of the coating system should not be less than 350  $\mu\text{m}$ ,
- the dry thickness of the primer coating should not be lower than 60  $\mu\text{m}$ ,
- it is recommended to use paints based on epoxy and/or polyurethane binders,
- it is recommended to apply a topcoat of a fire-retardant coating to prevent cellulose fire,
- the applied and cured coating system, after the conditioning period, should be characterized by an adhesion of not less than 5 MPa, measured with a pull-off test in accordance with [ISO 4624](#) standard.

#### 5.1.3. Coating protection of the maturation and post-processing hall

In the case of coating protection of the maturation and post-processing hall characterized by corrosivity class C5, it is recommended to choose one of the two longest durability periods: long (15–25 years) or very long (over 25 years). The minimum requirements for a coating system intended for use in a C5 corrosivity class environment, for a long life include:

- 1 layer of primer based on epoxy or polyurethane binder,
- the dry thickness of primer from 80 to 240  $\mu\text{m}$ ,
- 1–3 layers of coatings based on epoxy and/or polyurethane and/or acrylic binder,
- the total dry thickness of the coating system should not be less than 300  $\mu\text{m}$ .

The minimum requirements for a coating system intended for use in a C5 corrosivity class environment, for a very long engulf:

- 1 layer of primer coating based on epoxy or polyurethane binder,
- the dry thickness of primer from 80 to 200  $\mu\text{m}$ ,
- 2–3 layers of coatings based on epoxy and/or polyurethane and/or acrylic binder,
- the total dry thickness of the coating system should not be less than 360  $\mu\text{m}$ .

Additionally, in both variants, it is recommended to apply a topcoat of a fire-retardant coating to prevent cellulose fire.

#### 5.1.4. Additional recommendations

Due to possible gaps at the connection points between individual elements of the roof structure, it is beneficial to protect

these places with bridging fillers of high chemical resistance and flexibility. For larger gaps, using a filler with mesh should be considered. Due to the highly corrosive conditions in composting facilities, it is advised to carry out paint inspections of protective coatings once a year to assess the degree of their degradation and detect possible damage. This will enable repairs and renovations to be carried out at an early stage, allowing for lower financial outlays. It is also recommended to periodically, at least once a year, wash the roof structure with water at a pressure not exceeding 10 MPa. This will remove accumulated deposits and contaminants that contribute to the degradation of protective coatings.

#### 5.2. Anticorrosion protection of steel girders and trapezoidal roof sheet in the variant of renovation of the existing roof structure

When renovating an existing roof structure, trapezoidal steel sheet and steel girders must be protected against corrosion in accordance with the atmospheric corrosivity class following the [ISO 12944-2](#) standard: CX for the waste reception hall and the operational connector hall, and C5 for the maturation and post-processing hall. In this situation, the most important elements from the standpoint of obtaining effective and long-lasting coating protection are:

- thorough cleaning of the steel roof structure from corrosion products, deposits, and impurities, especially in difficult-to-access places and with complex geometry,
- ensuring appropriate climatic conditions at the coating application stage,
- ensuring suitable climatic conditions and the time necessary for the individual layers of the coating system to completely dry/cure before being put into service.

These elements become particularly important in a situation where the planned renovation will take place without suspending the technological process of waste processing, only with partial shutdown of parts of the facility for the duration of painting.

##### 5.2.1. Requirements concerning the preparation of the steel substrate before painting and the conditions for applying coatings

In some facilities, due to design errors, the steel sections of the roof structure may have cavities directed towards the top of the structure. Moisture, deposits, and impurities accumulate inside them, causing severe corrosion. After protective coating application, these regions will still be exposed to accelerated degradation. In order to minimize this phenomenon, it is necessary to ensure drainage of these depressions by drilling holes allowing water to evacuate. During the recommended annual inspections of the coatings, the patency of drainage

holes should be checked, and the aforementioned corrosion-sensitive sections should be washed with water at a pressure not exceeding 10 MPa to remove any deposits.

Preparation of steel surfaces to obtain good adhesion of paint coatings should involve:

- abrasive blast cleaning using grit abrasives to the Sa2½ preparation grade in accordance with the [ISO 8501-1](#) standard,
- obtaining an intermediate surface roughness profile,
- it is permissible to clean the surface to the Wa2½ grade by using a high-pressure water jetting (in accordance with the [ISO 8501-4](#) standard),
- the acceptable flash rust intensity cannot exceed M grade in accordance with the [ISO 8501-4](#) standard; it is recommended to apply a primer on the same day as the substrate preparation,
- particular attention should be paid to cleaning and preparing the area with cavities in the roof support structure,
- washing steel elements with clean water to remove water soluble salts. The salt content on surfaces to be painted, determined according to the Bresle method ([ISO 8502-6](#) standard), should not exceed 50 mg/m<sup>2</sup>.

Since the renovation usually takes place without suspending the technological process of waste processing, and only particular fragments of the facility are subjected to a shut-down during the steel substrate preparation, painting, and drying/curing of the coatings, it is recommended to use paints tolerating minimal surface preparation in case the required climatic conditions are not met.

Similarly to protecting new roof structure, conditions for applying paint coatings shall comply with the requirements specified in the datasheet of the anticorrosion paints used. During application and drying/curing of coatings, the relative air humidity should not exceed 85%, and the dew point temperature should be at least 3 °C higher than the temperature of the painted surfaces. Additional coating application should be made locally using a brush in difficult-to-access areas with complex geometry (all edges, corners, structural kinks) to provide good protection. This operation should be performed before applying each layer of the coating system.

#### 5.2.2. Coating protection for the waste reception hall and for the operational connector hall

The minimum requirements for a coating system intended for use in the waste reception hall and in the operational connector hall should meet the CX corrosivity class (offshore) environment:

- the coating system should have a minimum of 3 layers,
- the total dry thickness of the coating system should not be less than 350 µm,
- the dry thickness of the primer coating should not be lower than 60 µm,

- it is recommended to use paints based on epoxy and/or polyurethane binders, tolerating the substrates with minimum preparation (presence of flash rust); the use of paints based on other binders is permitted provided that equivalent protective properties and tolerances of substrate are verified,
- it is recommended to apply a fire-retardant coating as a topcoat to prevent cellulose fire,
- the applied and cured coating system, after the conditioning period, should be characterized by an adhesion of not less than 5 MPa, verified with a pull-off test in accordance with the [ISO 4624](#) standard.

#### 5.2.3. Coating protection of the maturation and post-processing hall

Coating protection intended for corrosivity class C5, which is typical for the maturation and post-processing hall, requires selection between the two longest durability periods:

- long (15–25 years) or,
- very long (over 25 years).

The minimum requirements for a coating system intended for use in a C5 corrosivity class environment, for a long life engulf:

- 1 layer of primer based on epoxy or polyurethane binder tolerating the substrates with minimum preparation (presence of flash rust); the use of paints based on other binders is permitted provided that equivalent protective properties and tolerances of substrate are verified,
- the dry thickness of primer from 80 to 240 µm,
- 1–3 layers of coatings based on epoxy and/or polyurethane and/or acrylic binder; the use of paints based on other binders is permitted provided that equivalent protective properties and tolerances of substrate are verified,
- the total dry thickness of the coating system should not be less than 300 µm.

The minimum requirements for a coating system intended for use in a C5 corrosivity class environment, for a very long durability include:

- 1 layer of primer coating based on epoxy or polyurethane binder tolerating the substrates with minimum preparation (presence of flash rust); the use of paints based on other binders is permitted provided that equivalent protective properties and tolerances of substrate are verified,
- the dry thickness of primer from 80 to 200 µm,
- 2–3 layers of coatings based on epoxy and/or polyurethane and/or acrylic binder; the use of paints based on other binders is permitted provided that equivalent protective properties and tolerances of substrate are verified,
- the total dry thickness of the coating system should not be less than 360 µm.

Additionally, in both variants, it is recommended to apply a topcoat of a fire-retardant coating to prevent cellulose fire.

Figure 10 schematically illustrates an example of coating systems on galvanized steel (a new structure protection option) for environments with corrosiveness classes C5 and CX. This protective system is highly durable, exceeding the combined durability of its components (zinc coating and paint system) by 20–50% (van Eijnsbergen, 1994; Yu et al., 2020). Based

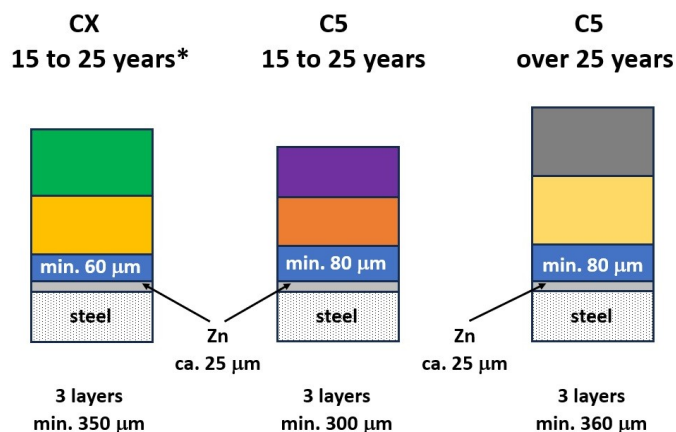


Figure 10. Graphical comparison of the requirements (total dry film thickness and number of layers) for the coating systems employed in corrosivity classes CX and C5. (\*) refers to the durability “High” with expectancy of the first major coating failure between 15 and 25 years from the date of installation.

on the experience contained in the ISO 12944 standard and our own experience in contact with municipal composting plants and industrial environments, it is possible to estimate with great probability the protection effectiveness of the most common protective systems (Table 3). Undoubtedly, the most advantageous protective properties should be demonstrated by a “duplex” system thanks to the synergistic interaction of the zinc coating and the painting system consisting of epoxy and/or polyurethane coatings.

#### 5.2.4. Additional recommendations

Similarly to maintenance of new roof structures, the following recommendations concern the renovated ones:

- it is suggested to protect the connection points between individual elements of the roof structure with bridging fillers of high chemical resistance and flexibility,
- it is advised carry out paint inspections of protective coatings once a year to assess the degree of their degradation and detect possible damage,
- it is recommended to periodically, at least once a year, wash the roof structure with water at a pressure not exceeding 10 MPa to remove accumulated deposits and contaminants; particular care should be taken when cleaning drainage holes and cavities in the roof structure sections.

## 6. CONCLUSIONS

Municipal composting facilities constitute a crucial element of waste management systems in urban and rural areas. The nature of biological and biochemical processes poses a serious risk to construction materials through corrosion degradation. Surprisingly, this problem seems to be underestimated as there are very few literature reports marginally relating to this topic. In this paper, we described a comprehensive approach, in which particular sections of the municipal composting facility were field tested for environment corrosivity class, corrosion rates were determined for steel and zinc, and anti-corrosion protection coating systems were selected for the protection of metal roof structures.

Corrosivity of the environment was determined based on the analysis of the biological and biochemical processes occurring in each part of the composting facility and the composition of ambient air collected in each section. Field exposure of steel and zinc samples inside the facility revealed corrosion rates characteristic of C5 and CX classes corresponding to high and very high corrosion risk, respectively. Then a protection with multi-layer organic coating systems was designed, taking into account two variants – new erected and renovated roof structures. It included the selection of coating types, number of coating layers, description of metal substrate preparation procedures, coating application conditions, and post-application, periodic maintenance recommendations.

The conditions inside the municipal composting facility include high humidity and temperature, presence of acidic and alkaline condensates, corrosion-enhancing microbiological activity, and

Table 3. Estimated approximate durability of anti-corrosion systems in compost factory halls.

| Hall                   | Zinc coating/years | 3-layer painting system*/years | Zinc coating + 3-layer painting system*/years |
|------------------------|--------------------|--------------------------------|-----------------------------------------------|
| Waste reception        | 1–3 (25 µm)        | 15–25 (360 µm)                 | 20–25 ((25 + 360) µm)                         |
| Operational composting | 1–2 (25 µm)        | 15–25 (360 µm)                 | 20–25 ((25 + 360) µm)                         |
| Maturing and finishing | 4–6 (25 µm)        | 10–15 (300 µm) > 15 (360 µm)   | 15–25 ((25 + 300) µm) > 25 ((25 + 360) µm)    |

\*applies to epoxy and/or polyurethane paints

mechanical impacts. To provide durable and efficient anti-corrosion protection of metal structures in these heavy-duty conditions, it is required to:

- perform a thorough metal surface preparation procedure before organic coating application, which will ensure Sa2½ preparation grade, an intermediate surface roughness profile, and water soluble salts concentration lower than 50 mg/m<sup>2</sup>,
- apply at least a 3-layered organic coating system having a dry film thickness not less than 300 µm, depending on location and corrosivity class,
- use the coatings based on epoxy binders since the protection concerns indoor structures with minimal access to sunlight; they exhibit the highest resistance to the aforementioned harsh conditions; in some situations, polyurethane-based coatings are also acceptable,
- ensure high adhesion of the coating systems to the metal substrate equal to at least 5 MPa measured in a pull-off test.

Finally, long-term effective coating protection can be amplified by proper in-service maintenance, including annual washing of the structures with water at a pressure not exceeding 10 MPa to remove accumulated deposits and contaminants, followed by inspection for potential coating defects.

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