Use of Accelerated Tests to Estimate Corrosion Rates of Roofing Sheets

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Abstract

Roofing materials are important assets of our society however no material lasts forever. Atmospheric corrosion phenomenon leads to deterioration of materials. The objective of this study was to estimate the corrosion rate of metallic coated or pre-painted roofing sheets using accelerated testing method as compared to natural exposure. Accelerated tests were performed in ultraviolet light followed by salt spray at concentrations of 0.07% NaCl and 0.28% $(NH_4)_2SO_4$ while in natural exposure the sheets were placed on racks under cyclic conditions of corrosive environment. The gloss and fade variations of pre-painted sheets were determined using spectroguide. Variations occurred within 10.5 days for accelerated tests and 90 days for natural conditions. Correlation analysis on gloss and fade variations under accelerated and natural conditions showed that for gloss $R^2 = 0.994$ while fade $R^2 = 0.831$. Mass loss for galvanized and galvaluminized materials was determined using Shimadzu XRD-7000. Mass loss occurred within 10.5 days for the accelerated tests and 90 days under the natural conditions. High correlation indicates that accelerated tests can be used to estimate corrosion rates of roofing sheets under different corrosive environments.

Key words: Accelerated test; corrosion rate; salt spray; ultraviolet light.

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1. Introduction

Steel roofing sheets are common roofing materials used in Kenya due to their low cost, high tensile strength and ease of fabrication. However, their major limitation in terms of mechanical properties is corrosion. Corrosion causes huge economic losses which accounts for a quarter of the world's production annually [1]. Corrosion causes severe structural damage to metal structures, and impacts on public safety, maintenance plans and requires extensive repair and replacement of corroded structures or parts. Since corrosion is thermodynamically spontaneous, it can only be reduced but not prevented. Different metallic materials will either corrode slowly or faster, depending on the corrosive environment in which they are used [2]. For instance, aluminum coated steel corrodes faster in severe marine environment conditions, while galvanized sheets corrode faster in industrial environments. Several attempts have been made to reduce corrosion for economic, industrial production and public safety.

Aluminum-zinc(AZ) alloy coated and galvanized (GI) steel sheets are widely used in a number of outdoor applications such as roofing, underground pipelines, under sea water structures, frames for building houses, automotive body parts, telecommunication industry, power transmission lines, and thermal power plants [3, 4]. Zinc (Zn) coating provides barrier and galvanic protective effect [5]. Aluminum provides anodic protection to the underlying steel sheet substrate (metal). On both AZ and GI steel sheets atmospheric corrosion begins with an electrochemical process when the surface is made wet by dew, rain or mist [6].

In Mariakani area in the coastal region of Kenya, roofing systems in most houses use galvanized (GI), galvaluminized (AZ) and pre-painted steel sheets. Hence in this study the rate of corrosion of the roofing materials was investigated based on the color change without considering the type of paint or the components. The roofing materials in Mariakani are frequently painted to prevent corrosion. A typical corroded roof in Mariakani is shown in Figure 1.

Figure 1: Corroded galvanized roofing sheets close to the Mariakani-Mombasa highway. The iron nails have turned reddish.

The presence of moisture on the surface of the metal is known to initiate corrosion by acting as an electrolyte [6]. A typical example of droplets of moisture on the surface of a roofing panel is shown in Figure 2.

Figure 2: A Sky Blue pre-painted roofing sheet panel showing rain droplets during the time of wetness. The time of wetness is an important parameter since it directly determines the duration of electrochemical corrosion process.

Temperature has effect on atmospheric corrosion and hence as it increases, it stimulates corrosive attack by increasing the rate of electrochemical reactions and diffusion processes. A rise in temperature leads to an enhanced corrosion rate at a constant humidity. However, when the temperature increases, relative humidity decreases causing rapid evaporation of surface electrolyte [2]. This reduces the time of wetness and ultimately reduces the corrosion rate.

Sunlight hitting the roofing sheet surfaces has a range of wavelengths between 295 and 4000nm. However, the harmful portion of the spectrum to paints (color) coatings is the UV range of less than 380nm. Different paint systems have different absorption peaks. During energy absorption by the roofing sheets, photodegradation of paint coatings occurs [7]. The UV energy absorbed by some chromophoric groups of the paint turns it to an excited state.

The enhanced atmospheric corrosion rates evident at the coastal areas of Kenya could be attributed to the amount of chloride in the environments. Apart from enhancing surface electrolyte formation through hygroscopic salts such as NaCl and $MgCl_2$, it has been reported that chloride ions directly participate in the electrochemical corrosion reactions [8]. On bare steel sheets, chloride anions compete with hydroxyl ions when combining with ferrous ions produced in the anodic reaction. Hydroxyl ions will then tend to form stable species, while iron chloride complexes tend to form soluble and unstable products. The formation of iron

chloride complexes simulates the corrosive attack.

During combustion of sulfur containing fossil fuels, sulfur dioxide (SO_2), is formed as the main product.

In urban and industrial type atmospheres, SO_2 has been observed to play an important role in atmospheric corrosion [9].

While SO_2 may be adsorbed on metal surfaces, it can also dissolve in surface moisture films in which it tends to form dilute sulfuric acid. The oxidation of sulfur dioxide occurs according to equation 1.

$$SO_2 + O_2 + 2\ e\text{-} \longrightarrow SO_4^{2-} \tag{1}$$

The electrons needed in the equation above originate from the anodic dissolution reaction of iron in steel when forming ferrous ions.

On steel, the formation of sulfate ions is due to the accelerating effect of sulfur dioxide. The presence of sulfate ions leads to the formation of iron sulfate ($FeSO_4$).

Iron sulfate is a common corrosion product in industrial atmospheres which forms layers on the steel surfaces as was shown in Figure 2. Iron sulfate is usually hydrolyzed according to equation 2 [10].

$$FeSO_4 + 2H_2O \longrightarrow FeOOH + SO_4^{2-} + 3H^+ + e\text{-} \tag{2}$$
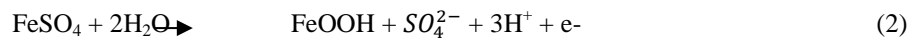
According to equation 2, the sulfate ions are regenerated, leading to an autocatalytic attack on iron.

The general objective of this study was to estimate corrosion rate of pre-painted roofing sheets using accelerated tests as compared to outdoor exposure tests.

The corrosion rate was evaluated in terms of gloss and fade variations for pre-painted roofing sheets while for galvanized (GI) and galvalumized (AZ) roofing products, corrosion rate was evaluated in terms of mass loss.

2. Materials and Methods

The effect of parameters such as salt concentration on corrosion of pre-painted, galvanized (GI) and galvaluminized (AZ) roofing sheets were investigated under various corrosive environments at the Mariakani study site.

Mariakani town lies in Kilifi County, about 30 km from Mombasa along the Mombasa Nairobi highway. In terms of corrosivity category, Mariakani represents an industrial marine environment.

It is at an altitude of 203 metres above sea level, longitude 39^0 27'E and latitude 03^050'S.The GI, AZ and pre-painted steel sheets measuring 150mm $\times$ 75mmwere used in the accelerated tests as shown in the set up in Figure 3.

Figure 3: Arrangement of samples during salt spray (Fog) process

The samples were placed under ultraviolet light (Figure 3) followed by salt spray at concentrations of 0.07% NaCl and 0.28% $(NH_4)_2SO_4$. Color changes were observed within a complete cycle of 10.5 days after which the samples were cleaned with detergent, washed with acetone and dried. Spectroguide (BYK Gardner 82638, GMBH) was then used to measure gloss loss (ΔG) in % and fade (ΔE) in Hunter units for the pre-painted roofing materials.

The samples for the outdoor exposure test were taken from a similar batch measuring 190mm $\times$ 130mm in size and were cut using a shear cutting machine. The samples having a thickness of 0.20mm to 0.50mm were placed on the exposure rack as shown in Figure 4.

Figure 4: The pre-painted samples fastened on an exposure rack at Mariakani corrosion test site.

After 90 days of exposure, the mass loss of the coated GI and AZ samples was determined using XRD-7000 [Japan, Model EDX-7000 ROHS ASSY].

3. Results and Discussions

After 10.5days in the accelerated test chambers and 90 days on outdoor exposure racks, the estimated change in gloss (% ΔG) and fade (Hunters units) for the red, green and blue pre-painted samples were recorded as presented in Table 1.

Table 1: Averages of exposure results for the pre-painted (color coated) samples for accelerated and outdoor exposures

Color of roofing material	Accelerated test exposure		Outdoor exposure	
	Average gloss (%)	Average fade (Hunters Units)	Average gloss (%)	Average fade (Hunters Units)
Red	-5.7± 4.0	3.41±0.54	-6.4±0.6	2.47±0.84
Green	-1.0±0.9	2.91±0.13	-0.7±0.4	3.01±1.94
Blue	-12.2±9.2	1.99±0.74	-11.7±1.2	0.79±0.29

The results computed as averages for each colored sample under accelerated tests and outdoor exposures are given in Table 1. The results showed that different color coatings had various degrees of gloss and fade variations. The values for red, green and blue roofing sheets showed that there was a correlation between accelerated and outdoor exposures. For instance, average gloss loss and fade for red roofing sheets were -5.7± 4.0 % and 3.14 ± 0.54 Hunters units for accelerated tests compared to -6.4 ±0.6 % and 2.47 ±0.84 Hunters units for the outdoor exposure tests. Generally, the gloss was within a range of ±5% and the fade was within a range of less than 0.1 Hunters units, which is recommended for industrial measurements [11]. The coating mass loss, which was taken as corrosion rate for galvanized (GI) and galvaluminized (AZ) roofing sheets is presented in Table 2.

Table 2: Results for the galvanized (GI) and galvaluminized (AZ) samples for accelerated and outdoor exposures.

Sample type	Accelerated test exposure		Outdoor exposure	
	loss of Al (g/m^2)	loss of Zn (g/m^2)	loss of Al (g/m^2)	loss of Zn (g/m^2)
GI	0.147 ±0.127	8.532± 3.801	0.278± 0.022	9.921±1.768
AZ	2.180±1.860	1.877±0.082	2.417±1.058	1.821±0.223

Correlation analysis was performed on the mass loss of the sample types in Table 2 under the accelerated and the outdoor exposure tests. The results showed that R^2 was equal to 1.00. This indicated that coating mass loss under accelerated test could be used to predict the mass loss under outdoor exposure.

It was observed that (Table 2) the mass loss for Al is 0.147$\pm$ 0.172 g/m^2 and Zn is 8.532$\pm$ 3.801 g/m^2 compared to Al, 0.278 $\pm$ 0.022 g/m^2 and Zn, 9.921 $\pm$ 1.768 g/m^2 for GI under accelerated and outdoor exposures respectively. For the galvaluminized (AZ) samples, estimated coating mass losses were 2.180$\pm$1.860 g/m^2 (Al) and 1.877$\pm$0.082g/m^2 (Zn) compared with 2.417$\pm$1.058g/m^2 (Al) and 1.821$\pm$0.223g/m^2 (Zn). The predicted mass losses could be used to calculate the corrosion rate in millimeters per year (mmpy) of galvanized (GI) and galvaluminized (AZ) samples using equation 3.

$$\text{Corrosion rate } = \frac{K \times W}{ATD} \tag{3}$$

where, K is a conversion constant that depends on the units of measurement. When the measurement is in cm, K $= 3.65 \times 10^3$

W= Mass loss in grams

A= Area in cm^2

T= Time of exposure in days

D= Density in g/cm^3.

4. Conclusion

The study on the accelerated and outdoor exposures for the corrosion of galvanized (GI), galvaluminized (AZ) and pre-painted steel roofing sheets showed that corrosive environments could be simulated to represent the natural environments when determining the corrosion rate of roofing materials. The various colored brands of roofing materials sold in Kenya, showed different corrosion resistance which could be attributed to the composition of the paint. The study showed that corrosion rates vary among roofing materials and the salt spray could be used as a quality control method. Further, the study revealed that under accelerated tests, corrosion rate of the roofing sheets could be estimated in terms of coating mass loss for the GI and AZ sheets gloss and fade for the pre-painted sheets after10.5 days while under outdoor exposure, the corrosion rate could be estimated after 90 days. The mass loss under accelerated tests was highly correlated with mass loss under natural environment ($R^2 = 1.00$). Hence one can use the value obtained under accelerated to predict the mass loss under natural environment.

5. Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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