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Research article

Corrosion resistance of galvanized roofing sheets in acidic and rainwater environments

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ABSTRACT

The galvanization of steel sheets for building roofs and construction of additional structures has been a valued solution to the challenges faced by the deterioration of roofing steel sheets in an unfavourable surroundings. This research was conducted on galvanized roofing sheets obtained from the open market in Nigeria. The samples were cut to a small size (5 cm by 4 cm) and immersed in sulfuric acid (H_2SO_4) and hydrochloric acid (HCl). As the control medium for the experiment, rainwater was used. The experiment was performed over 1200 hours; each sample was removed every 240 hours, thoroughly washed, dried, and weighed again. Based on the reacting media, variations in the weights of the samples were obtained. According to ASTM G1-03 standard practice, Corrosion rates were calculated for preparing, cleaning, and evaluating corrosion test specimens. Scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) was also carried out. Although some samples resisted corrosion, other samples corroded. It is predicted that the green-coated samples are more resistant to corrosion in rainwater and H_2SO_4 and thus more stable.

1. Introduction

The corrosion results are numerous, and the impacts on the protected materials are dependable on the corrosion agents [1]. From findings, it is a reality that consumption decreases the thickness of the metal, bringing about loss of mechanical quality and degradation of the structure [1]. Material depreciates around us when we take a critical look at numerous metallic materials we use daily. For instance, corrosion may sometimes be severe, resulting in the breakdown of constructions such as maritime hardware, underground lines, dams, etc. It is therefore risky to human life expectancy. Billions of dollars are reportedly lost every year owing to material depletion [2, 3]. Corrosion happens when defensive instruments have been neglected or broken down, leaving the metal powerless against assault [4]. Lately, numerous disappointments due to the utilization of metallic structures in contact with watery and non-fluid media have been recorded due to erosion. Even though the aluminum can shape a stable slim oxide film that shields it from deterioration, it goes through erosion while being in contact with forceful media, for example, hydrochloric acid [5, 6].

Galvanized steel has been widely used due to its extensive applications in various manufacturing companies. Its choice is due to its low cost, ruggedness, and durability. Its production is by hot-dip coating process due to the flexibility of the techniques. Ungalvanized steel will corrode shortly and is never economical to install [7]. The research by [8] hinges on selected grades of roofing materials such as aluminum, galvanized steel, plastic, and asbestos. They were cut to size and dipped in various media, namely acidic, alkaline, Seawater, and Rainwater. Some of the sheets corroded, while others resisted corrosion. The samples' weights and respective corrosion rates were changed based on the reacting media. The values obtained were used to determine the corrosion rates. The authors recognized that the coated samples were resistant to corrosion and long-lasting than the uncoated sheets in the media. Aluminum was recommended because it maintains its shiny lustre in rainwater used as the control throughout the long days of the experiment.

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Plastic wasn't recommended despite resistance to corrosion due to its brittleness, thermal expansion, low-temperature resistance, flame friendliness under harsh atmospheric conditions. Aluminum sheet was observed to be highly reactive in an alkaline medium, so not advisable to be installed in an alkaline-prone environment. Steel sheet conversely reacts highly in an acidic environment. Therefore it should be coated and free of crack to inhibit exposure to acids. A part solution to steel corrosion is to galvanize it with zinc which will not eventually survive an acidic environment such as industrialized areas.

The authors [9] present a methodical technique for identifying grooved asbestos-cement roofing sheets and gauging the degradation of the asbestos fiber, which causes cancer named asbestosis. The paper provides the government with a planning process that can project the occupancy of lethal AC roofing sheets. Their study will allow for decisions on effective intervention policies such as roofing materials to be discontinued or treated. The results of [10] revealed that XRD analyses could provide government authorities with an efficient, quick, and repeatable ecological mapping technique that can offer evidence about the position of dangerous asbestos roofing sheets. X-ray diffraction studies of pulverized asbestos roofing sheet samples reveal that harmful fibre of chrysotile has been spotted in most commercially available asbestos roofing sheet samples.

The usage of corrugated asbestos sheets may be a potential hazard for humans in the future in the country. However, the radium's radiation values such as 40 K, 238 U, and 232 Th are within internationally acceptable values and don't pose any significant radiation hazard. The authors suggested that an asbestos management plan will help manage the material, but an alternative to the asbestos roofing sheets is advisable.

The work of [11] studied the corrosion behaviour of Al_3O_3 and galvanized steel roofing sheets in solutions of sodium carbonate and sodium chloride media and was subjected to different environments for a month days. Their results revealed a higher corrosive impact of NaCl on galvanized roofing sheets than $NaCO_3$ solution, while it's the opposite for aluminum sheets. Also, galvanized steel roofing corroded more than aluminum roofing in both carbonate and chloride environments, which was continuous and therefore not recommendable in these environments or industrial atmospheres with these alkaline compounds. The behavior of galvanized steel and aluminum can be predicted using the previous solutions but further on the electrochemical mechanism of corrosion.

The corrugated iron sheet are galvanized to curb corrosion as it is the most widely used material for making the roof of low-cost houses. There exist in the market, the material has varied thicknesses. The researcher investigated the effect of coating this materials with zinc of different thicknesses. The test was carried out in different environments such as fresh water, sea water, and brine exposed for long hours. The authors [12] discovered that corrosion was minimized with an increase in thicknesses of zinc coating.

The galvanization of steel has emerged as a technique that minimizes sulfide penetration and chloride ion pollution. It is a technique that is appropriate for the full spectrum and application of steel coatings. Roofing sheets are continuously exposed to rainwater and other atmospheric harsh conditions, resulting in physical, chemical, and structural deterioration. It causes a loss of value and requires replacement after a while. Hence, there is a need to study the responses of galvanized roofing sheets to these agents to know their corrosion resistance abilities.

An enhanced coated roofing sheet can be achieved at low cost but with high durability. An example is cobalt aluminate ($CoAl_2O_4$) blue pigments due to their noteworthy shade of blue colour. Its minor demerit is the high cost and poor solar reflectance. Therefore, a retrofit pigment is developed that achieves viable blue colorants with less Co content and enhanced solar reflectivity, which is $NaZn_{0.9}Co_{0.1}PO_4$. The synthesized blue pigment is said to be a capable representation for producing a multipurpose economical paint that can give a primer less anticorrosive cool outward coat [13].

The difference in human psychological taste for aesthetics contributes to the vastness of colour mixing. Colour stimulates a response from human beings and impacts people's emotions. It has been used to check human brain alertness in the medical field. Architects play an essential role in the proper colour selection for building to achieve a green and aesthetic environment. Its misuse can cause thermal discomfort, thereby raising the temperature of the environment and eventually global warming. The authors recommended the constant use of silver and red colour aluminum roofing sheets due to their high surface reflectivity while they discouraged the use of beige and green colours with low surface reflectivity because they retained heat and increased surface temperatures. Dark brown and blue colours were downplayed for application. Bright color roofs can reflect heat and light from sunrays, reducing heat around buildings compared to dark color roofs [14].

The selection of appropriate roofing materials, insulation, and coating will help curb excessive heat transferred through the roof, which causes thermal discomfort in tropical regions. Such material can be further enhanced by using light colours for the roof surface [15].

This study examines the corrosion resistance of galvanized roofing sheets in acidic and rainwater environments. It will be achieved by determining the corrosion rates of galvanised roofing sheets in acidic and rain water environments, the impact of exposure time on corrosion resistance of galvanised roofing sheets in acidic and rain water environments, and the study of morphological changes through scanning electron microscopy. The primary metallic material that is being utilized in this work is aluminum and zinc-covered material sheets.

This material is exposed to various media, such as hydrochloric acid, sulfuric acid, and rainwater. The perceptible change achieved by the environmental response to the material under study was examined.

2. Methodology

2.1. Materials and apparatus

The materials used during the experimental procedure were Sulphuric Acid (H_2SO_4), Hydrochloric Acid (HCl), Rain Water, Distilled Water, Green, and Cream Corrugated Roofing Sheet. Apparatus utilized include; Ohaus weighing balance, Beakers (25 mL, 50 mL, 250 mL, 600 mL, and 1000 mL), Funnel, Spatula, Cleaning materials (detergent, paper towels/tissue paper), Masking tape and Cello-tape, Vice and hacksaw, Latex Gloves, Nose mask, and Ziplock.

2.1.1. Preparation of metal roofing sheet

The various metal roofing sheets investigated were obtained from the open market in Nigeria. They are green and cream corrugated roofing sheets. These sheets were cut into dimensions of 5 cm × 4 cm with holes drilled at one end and suspended by a rope thread in each of the solutions.

2.1.2. Collection of rain water

Rainwater was accumulated directly from the atmosphere in an open environment. The samples were collected a few minutes after the beginning of the rainfall into containers. This is done solely to minimize pollution due to atmospheric sources.

2.1.3. Acid preparation

0.5 M of sulfuric acid (H_2SO_4) and 0.5 M hydrochloric acid (HCl) prepared each in 1000 ml of distilled water were used as the corrosion medium.

The formula for acid preparation:

$$V_O = \frac{MVC_O}{10Pd} \tag{1}$$

Where,

V_o = required volume
M = molecular weight
C_o = required concentration
P = percentage purity
d = density or specific gravity, d = 1.49 g/cm^2
V = volume needed

2.2. Weight loss measurement

Weighed test specimens were totally immersed in each test media contained in a 200 ml plastic container. The plastic container was covered with a lid to prevent evaporation of the solution over time. Removal of the specimen was effected after 240 hours, 480 hours, 720 hours, 960 hours, and 1200 hours to determine a change in colour, shape, and mass over time. Experiments were performed with 0.5 M sulfuric acid test solution, 0.5 M hydrochloric acid solution, and rainwater. Test specimens were taken out of the test medium every 10 days, washed with distilled water, air-dried, and then weighed to determine the weight losses during the whole experimental period.

The corrosion rate was calculated from the formula in Eq. (3) [16] concerning the initial and final weight after each required period.

The weight loss is calculated by:

$$\text{Weight Loss} = \text{Initial Weight} - \text{Final weight} \tag{2}$$

The corrosion rate in (mm/yr.) is calculated with the formula;

$$\text{C.R.}(\text{mm}/\text{yr.}) = 87.6 \times \left(\frac{W}{DAT}\right) \tag{3}$$

Where;

W = Weight loss in milligrams (mg)
D = Metal density (g/cm^3)
A = Exposed area of sample in cm^2
T = Time of exposure of the in hours metal sample (hours)

2.3. SEM/EDX analysis

Energy-dispersive X-ray spectroscopy (EDS or EDX) is a method of microchemical analysis used with a High-Resolution Scanning Electron Microscope (HDR-SEM). Surface morphology before and after corrosion was investigated via a JSM-7600F Schottky Field Emission Scanning Electron Microscope coupled with EDS. This machine has robust specimen analysis packages such as cross-section imagery, analysing the surface, testing for fatigue and corrosion, evaluations of the field, analysis of failure, characterization of materials, inspection and measurement of micro-scale and nano-scale, chemical surface identification, assessment of corrosion, analysis of the structure of the coating and others. It was used for surface characterization of the samples after the corrosion tests.

3. Results and discussion

3.1. Data results and corrosion rate

The results of the weight loss and corrosion rate at time intervals of each sample when taken out of the solution after every 240 hours are given in Figures 1, 2, and 3.

3.1.1. Corrosion rate of different roofing sheet samples immersed in rain water

Results of corrosion rate results obtained from the recorded weight loss experiment calculations for the specimen immersed in rainwater solution at different time intervals are presented in Figure 1. The corrosion rate was varied with the exposure time (1200 hours in total). The graph shows that the cream roofing sheet had the highest corrosion rate in the first ten days (240 hours), which decreased to 480 hours. The possible cause of the decrease is passivation [17, 18]. Between 720 and 1200 hours, there was alternating rise and fall in corrosion rate, possibly due to depassivation and passivation. Depassivation occurs when the protective oxide film is broken, rendering the anodic metal surface at that point.

On the other hand, the green roofing sheet showed a preliminary low corrosion rate at 480 hours, indicating passivation. However, at 720 hours, there was a rise in corrosion rate followed by a gradual decrease until the end of the experiment. This observation is in agreement with the literature [17]. In rainwater, the green roofing sheet was the least affected, with lower corrosion rate values. Hence, it can be inferred that the cream roofing sheet samples with the higher corrosion rate values were the most affected in the rainwater solution.

3.1.2. Corrosion rate of different roofing sheet samples immersed in 0.5 M sulfuric acid (H_2SO_4)

Results of corrosion rate obtained from the calculations of the recorded weight loss experiments values for the specimen immersed in 0.5 M H_2SO_4 solution at separate time intervals are presented in Figure 2.

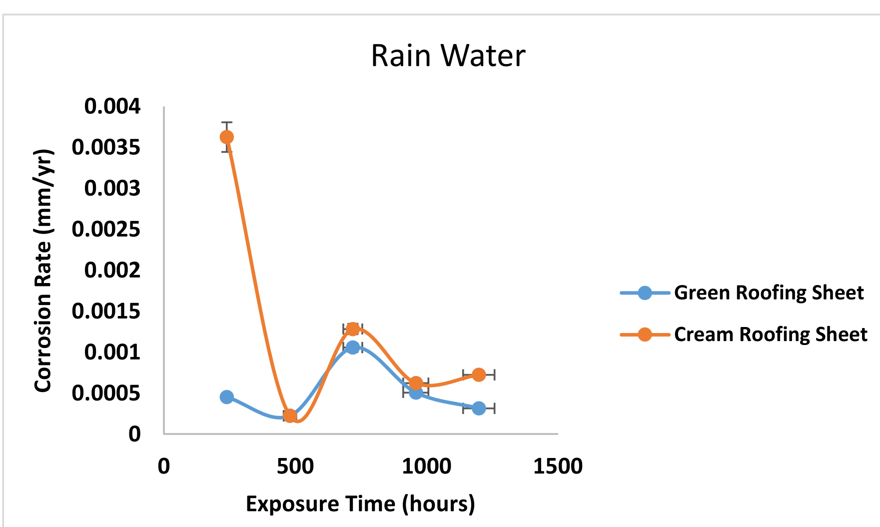

Figure 1. Corrosion rate of roofing sheets against exposure time in rain water.

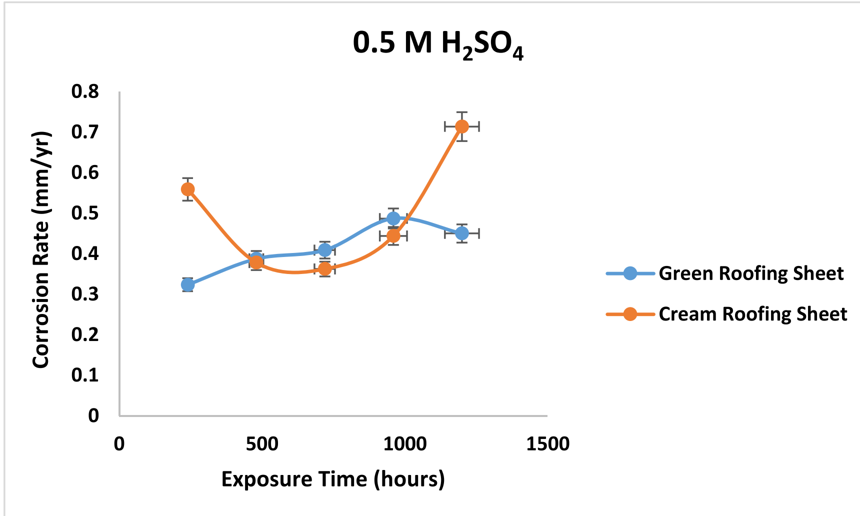

Figure 2. Corrosion rate of different roofing sheets against exposure time in 0.5 M sulfuric acid.

The graph shows that the effects of sulfuric acid solution on the cream roofing sheet are at the highest and peak corrosion rate at 0.71 mm/yr at 1200 hours. In a sulfuric acid environment, green roofing sheet was the least affected, with a low corrosion rate value of 0.45 mm/yr at 1200 hours. Therefore, the samples with the highest corrosion rate over the exposure time, the cream roofing sheet, were the most affected in sulfuric acid solution.

3.1.3. Corrosion rate of different roofing sheet samples immersed in 0.5 M hydrochloric acid (HCl)

Results of corrosion rate obtained from the calculations of the recorded weight loss values for the specimen immersed in HCl solution at different exposure times are shown in Figure 3. The graph shows that in hydrochloric acid solution, the green roofing sheet has the highest corrosion rate of 0.47 mm/yr at 1200 hours. Cream roofing sheet was the least affected at the end of 1200 hours exposure period, with the corrosion rate of 0.39 mm/yr. Hence, the highest corrosion rate overexposure sample was the green roofing sheet, which was more corrosive in the hydrochloric acid solution.

3.2. Results of scanning electron microscope (SEM) and energy dispersive X-Ray spectroscopy (EDS)

The red circled portion signifies the region where the energy dispersive x-ray spectroscope is taken from the sample to characterize the analyzed volume's elementary structure and components.

3.2.1. SEM and EDS analysis for hydrochloric acid (HCl)

Figure 4 shows the surface morphology and EDS of green roofing sheets exposed to HCl for 480 hours.

In Figures 4 and 5, the surface elemental content of the sample before 20 days exposure and after 50 days exposure as shown reveal a higher percentage composition of the base element of aluminum as 60.20 % and 75.20 %, respectively, with a short percentage composition of the galvanizing elements (zinc, iron, manganese, and magnesium). The EDS shows the presence of oxygen and chloride ions which would have assisted in the corrosion process. The results were due to the formation of an impermeable protective oxide film on the surface of the roofing sheet samples causing a general corrosion attack [19, 20, 21].

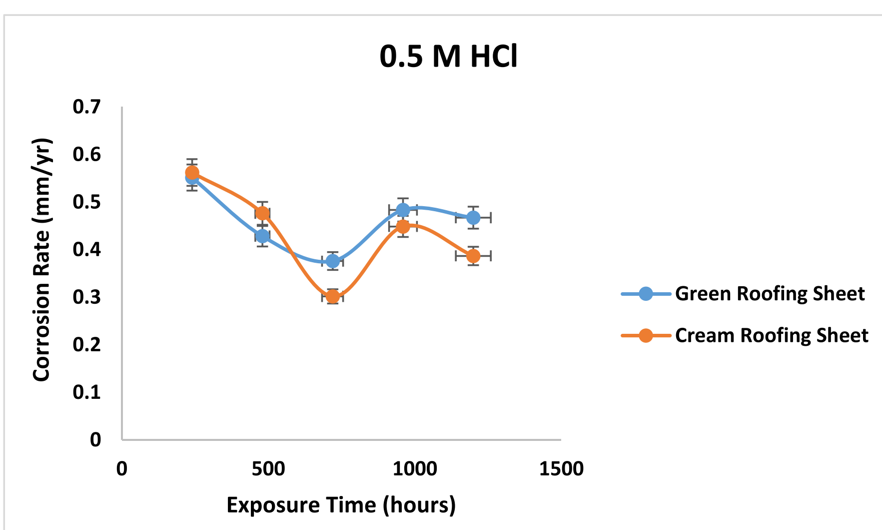

Figure 3. Corrosion rate of different roofing sheets against exposure time in 0.5 M Hydrochloric acid.

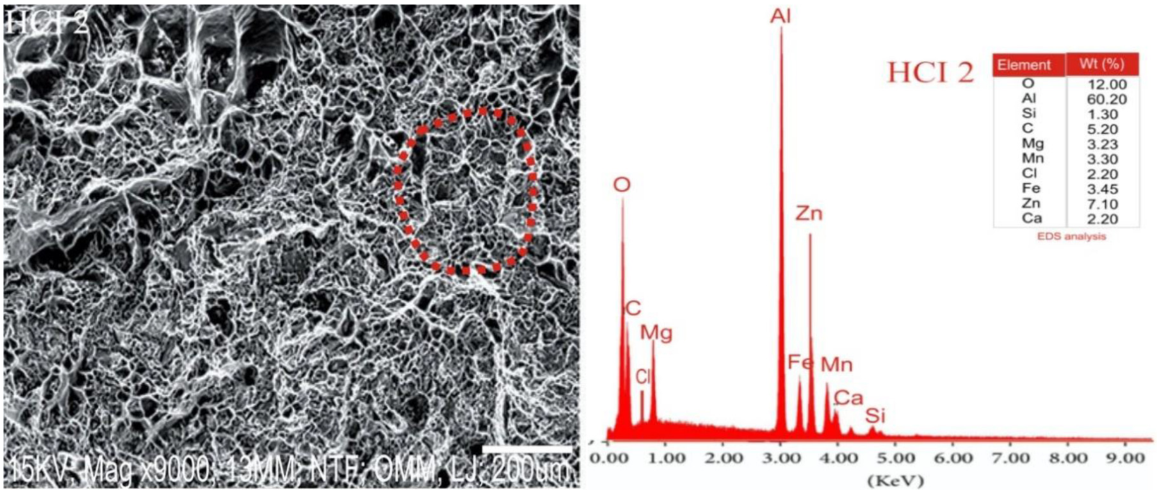

Figure 4. Surface morphology of exposed green roofing sheet sample in HCl for 480 hours.

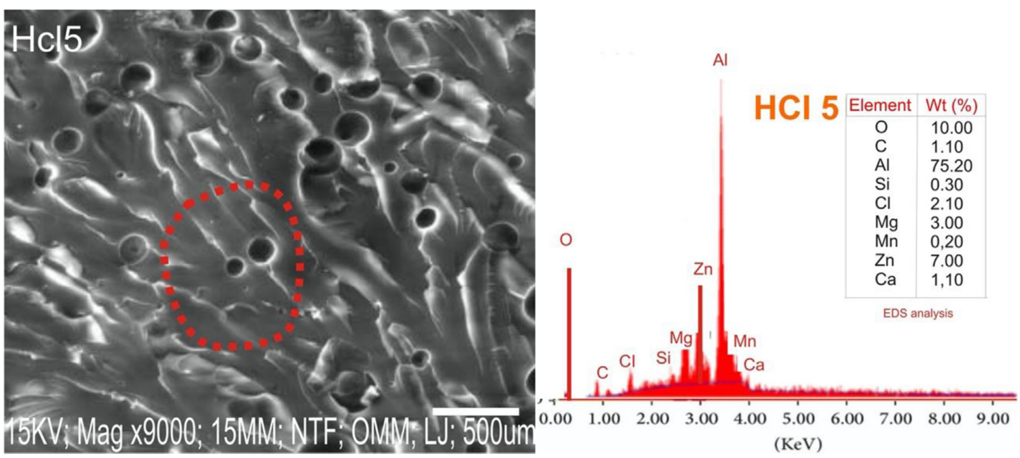

Figure 5. Surface morphology of exposed green roofing sheet sample in HCl for 1200 hours.

3.2.2. SEM and EDS analysis for green roofing sheet in sulfuric acid (H_2SO_4)

In Figures 6 and 7, the surface elemental content of the sample before 20 days exposure and after 50 days exposure are shown, which revealed a higher percentage composition of the base element of aluminum of 65.35 % and 72.30 %, respectively, with a very low percentage composition of the galvanizing element of zinc, manganese, calcium, and magnesium. The coatings and galvanizing elements were exposed due to oxygen and sulphur from the sulphuric acid environment.

3.2.3. SEM and EDS analysis for roofing sheets in rain water

In Figures 8 and 9, the surface elemental content of the sample after 20 days exposure and after 50 days exposure reveal a higher percentage composition of the base element of aluminium of 50.20 % and 70.70 %,

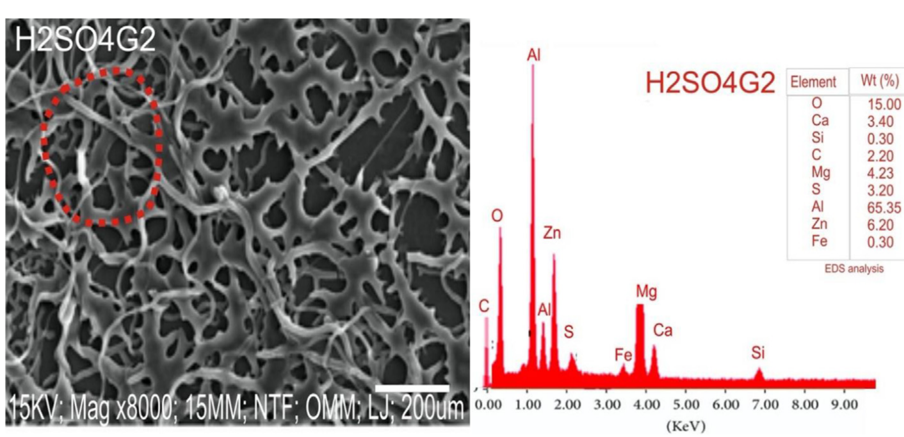

Figure 6. Surface morphology of exposed green roofing sheet sample in H_2SO_4 for 480 hours.

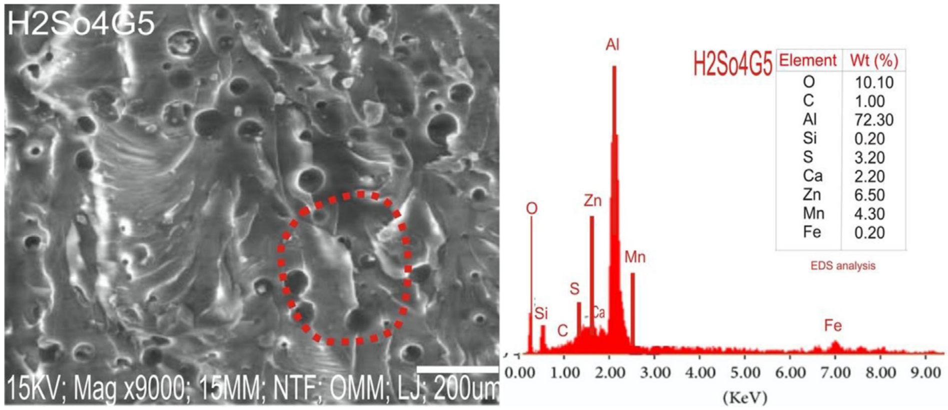

Figure 7. Surface morphology of exposed green roofing sheet sample in H_2SO_4 for 1200 hours.

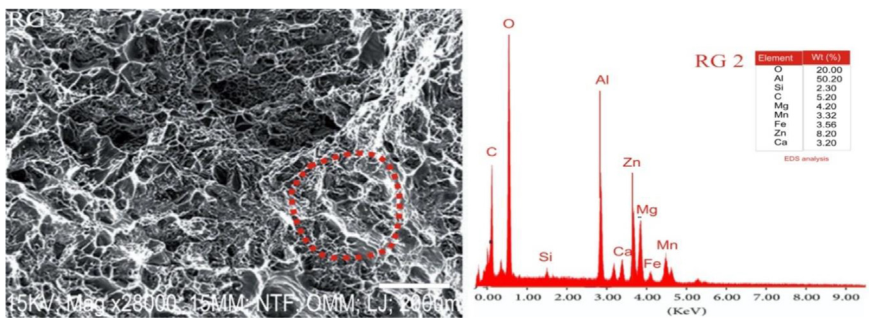

Figure 8. Surface morphology of exposed green roofing sample in Rain Water for 480 hours.

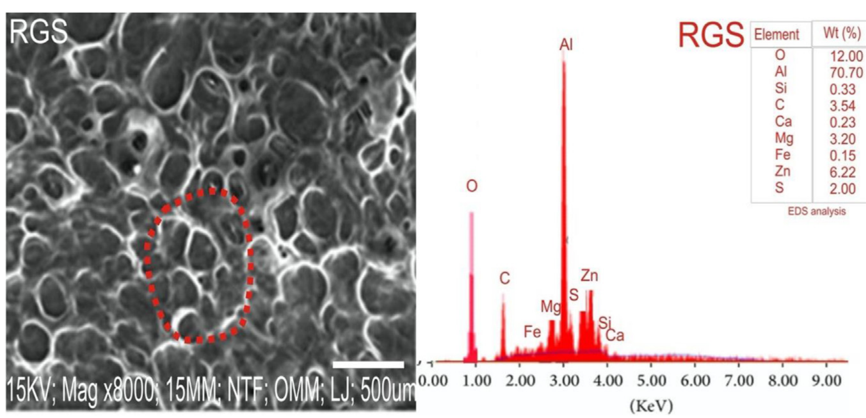

Figure 9. Surface morphology of exposed green roofing sheet sample in Rain Water for 1200 hours.

respectively, with a shallow percentage composition of the galvanizing element of zinc, iron, silicon, and magnesium. It is also seen that the coatings and the galvanizing element were exposed due to the presence of carbon dioxide in the solution.

4. Conclusion

From the experiments carried out and careful corrosion analysis and comparisons of the various roofing sheet samples against the concentrations and exposure time, the following conclusions were made;

The green roofing sheet was the least affected in the rainwater weight-loss experiment, with lower corrosion rate values. In addition, the lowest corrosion rate values were observed in the rainwater experiments compared with the acidic environment tests.

In sulfuric acid (H_2SO_4) solution weight-loss experiments, the cream roofing sheet has the top corrosion rate value while the green roofing sheet has the minimal value.

In hydrochloric acid (HCl) solution weight-loss experiments, the green roofing sheet recorded the maximal corrosion rate compared to the cream roofing sheet. However, the green roofing sheet was least affected by rainwater and H_2SO_4 medium and should be habitually demanded in buildings because of their moderate-length life span and durability.

Declarations

Author contribution statement

Olufunmilayo O. Joseph: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Olakunle O. Joseph & Joseph O. Dirisu: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Ayinoluwa E. Odedeji: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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