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Deterioration of Coating Materials Applied on Roofing Iron Sheets Under Marine Environments in Kenya

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ABSTRACT

Roofing iron sheets are prone to rapid corrosion when exposed to harsh environmental conditions leading to loss of mechanical strength and collapse of structures that results into huge economic loses. The aim of this study was to investigate the effect of marine environmental conditions on deterioration of the coating materials applied to protect roofing iron sheets in Kenya. We studied fading and gloss retention of green and blue coatings applied to roofing iron sheets for a period of 450 days under an outdoor setting at Diani Beach and Mariakani sites representing severe marine and industrial marine environmental conditions respectively. Prepainted roofing sheets obtained from manufacturers MR, MB and CH were cut into130 mm x 190 mm sizes, placed on racks and exposed to the atmosphere. Exposed sheets were removed at predetermined time intervals, cleaned and assessed for glossiness and fading using a Spectro guide BYK Gardner GMGH. Fourier Transform Infrared Spectroscopy was used to determine variations in functional group composition of the coatings. Meteorological data including rainfall, temperature, Ultraviolet radiation and relative humidity were collected during experimental period. Fade variations for green coating followed 0.77-5.00 and 1.33-19.60 for Diani and Mariakani respectively, while blue coating recorded 0.86-5.60 and 1.94-6.86 Hunter units per year for Diani and Mariakani respectively. Percent gloss retention for green coating varied from 30-63% and 18-63% at Diani and Mariakani respectively, while the blue coating varied from 2-77% and 10-82% at Diani and Mariakani respectively. MR coating recorded the highest percentage gloss retention between 75-77 % and the lowest fading at 0.32 - 0.86 Hunter units per year for both green and blue coatings. Mariakani site recorded higher rates of fading compared to Diani attributed to severe marine environmental conditions experienced at the site, characterized by higher levels of chloride, relative humidity- 81%, ultraviolet radiation-12 mW/cm^2 and temperature -27 $^{\circ}$C. High ultraviolet radiation increases photo-oxidative reactions and significant degradation of the binding material in the pigments. Fourier Transform Infrared Radiation results revealed dominance of esters, polybasic acid, and phthalate O-CH_2 groups and pigments, and the disappearance of some of functional groups due to photodegradation. Based on the data obtained, high chloride levels from the ocean coupled with high ultraviolet radiation and relative humidity are likely to accelerate fading and loss of gloss in marine environments which may lead to poor performance of roofing sheets under such environments. The findings of this study are of significance in improving the quality of coating materials for roofing sheets applied in marine environments.

1. Introduction

Paints and coatings are widely applied on steel roofing sheets to prevent corrosion [1], increase beauty and heat reflectance, and to enhance absorption or reflection of sun light [2]. Most paints consist of resins made up of polymers, pigments, solvents and additives [3]. Coatings used are broadly classified into organic and inorganic materials [4, 5]. The polymeric materials used in organic coatings involve large cross-linkages in a series of building blocks to increase tensile strength and to enhance crystallinity [6]. However, most polymeric materials are prone to photodegradation by ultraviolet radiation leading to alteration of mechanical and chemical properties of the coatings.

Roofing materials majorly apply modified polyester silicone and polyvinylidene fluoride [7] polymers due to their high durability. Whereas polyesters are less expensive and widely applied in forming hard, scratch-resistant coatings, they are more vulnerable to chalking when exposed to ultraviolet radiation [8]. This makes the choice of polyester with longer chains more preferred since they are more resistant to ultraviolet radiation than those with shorter chains. In addition, polyesters with silicone modification provide chalking resistance and higher gloss retention. Mostly, urethane is applied as the first coat to enhance paint adherence especially in polyvinylidene fluoride coating systems which are readily susceptible to ultraviolet radiation. In inorganic coatings containing titanium dioxide are susceptible to photo-degradation upon photo absorption due to formation of an electron-hole pair in the pigment, and movement of a photo-excited hole to the surface of the particle leading to chemical reaction. According to [9], photo degradation is the major factor that causes surface degradation to coatings exposed to the natural environment.

Ultraviolet radiation and reactive pollutants such as sulphur dioxide, nitrogen dioxide and moisture have been found to affect resins used in coating materials by accelerating their weathering [8, 10]. High solar radiation enhance degradation of coating materials by accelerating chemical reactions, softening polymers and increasing loss of volatile constituents [6,11] . The weathered resin matrix is also prone to erosion by rain and wind, and in combination with accumulated dirt deposits lead to loss of adhesion. Hence weathering and erosion of the coating materials results into overall thinning and fading of the coating film [4]. Fading is a visible loss of color. All prepainted metallic coated roofing sheets are prone to fading and losing their original vibrancy over time. However, the rate at which this occurs is enhanced by environmental factors. [12] Reported fade and gloss in marine environment.

This study investigated colour changes of selected coatings for the pre-painted roofing sheets exposed under marine environments in Kenya.

2. Materials and Methods

The study was conducted at two different atmospheric environments; Dian site located 100 m from the Indian Ocean representing severe marine environment, and Mariakani located

40 km from the Indian Ocean representing Industrial marine environment. Figure 1 shows the locations of the sampling sites.

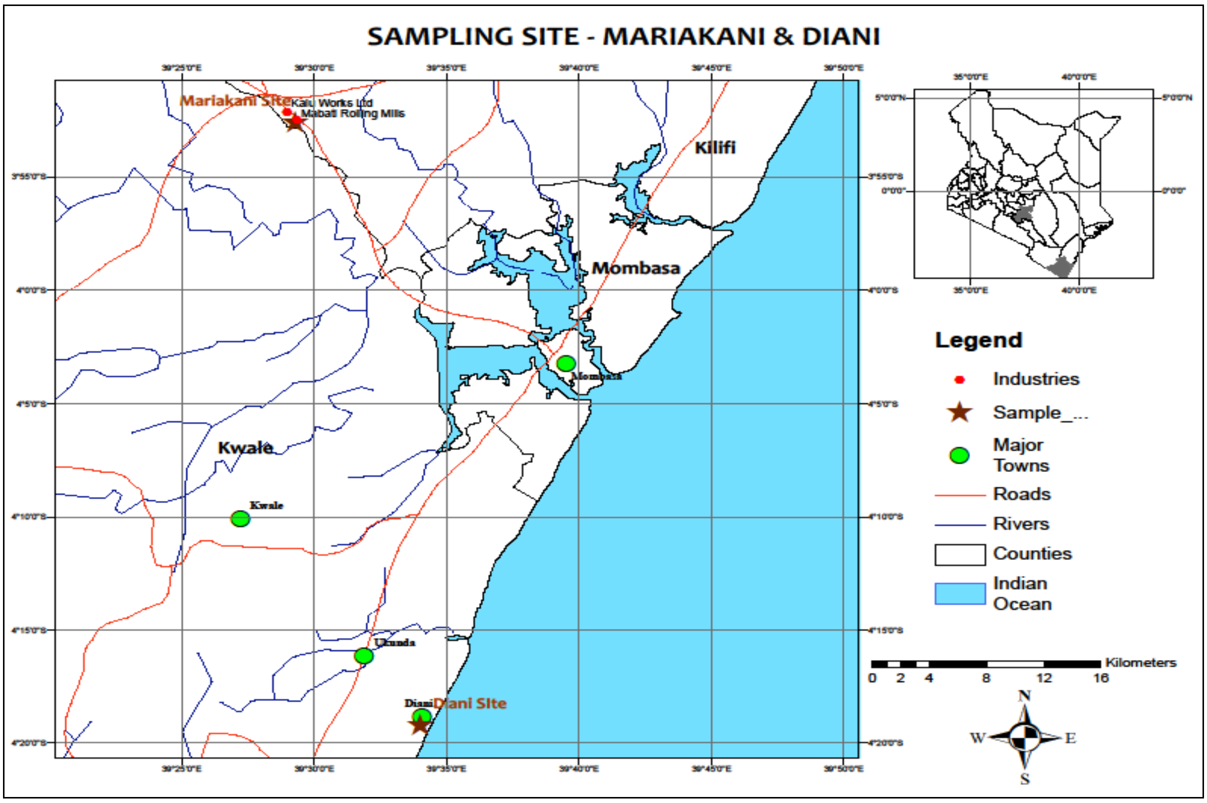

Figure 1: The map of the sampling sites in Diani and Mariakani -Department of Geology University of Nairobi

2.1 Experimental procedure

This study was carried out for a period of 450 days from July 2019 to September 2020. Blue and green prepainted iron sheets produced by Hot dip galvanizing process and rolled through a molten coating containing 55% aluminum and zinc were used. Each sheet had primer coat topped with the selected colour. The experimental sheets were sheared into 130 x 190 –mm coupons with thickness of 0.2 mm and cleaned. The initial fade and glossiness were recorded before the sheets were exposed to the atmosphere on racks inclined at an angle of 45^{o} to act as typical system of roofing sheets in Kenya [13] for a period 450 days (Figure 2). Exposed specimen were collected at predetermined intervals over the experimental period for determination of fading and glossiness.

Figure 2: A set-up for outdoor exposure of prepainted metallic coated sheets at Diani site

2.2 Determination of color change of the specimen samples

The samples were collected and cleaned to remove dust before colour measurement following ISO 7724/2 [14] method, and loss of gloss according to ISO 2813 method, for measurement of specular gloss of non-metallic paint films at 20°, 60° and 85° ISO 2813 [15]. Cleaned specimens were dried and the glossiness and color determined using BYK Gardner GMGH spectroguide spectrophotometer. Fade and glossiness measurements before and after exposure of the specimen were compared to determine the changes over the exposure period based on Equation 1.

$$\Delta E^{*}{}_{CMC} = \sqrt{\left(\frac{\Delta L^{*}}{IS_L}\right)^2 + \left(\frac{\Delta C^{*}}{cS_c}\right)^2 + \left(\frac{\Delta h^{*}}{S_H}\right)^2} \ \ldots \text{ Equation 1}$$

where L* axis = lightness, C* axis = chromaticity of the color and h* = hue angle. The color difference (ΔE) for each sample was calculated using Equation 1. The, S_C, S_L and S_H are factors giving weight for L*, C*, and h*.

2.3 Determination of the composition of paint

The functional groups in the coating materials were analyzed using Fourier transmission infrared technique (FTIR) (Model: Waltham, MA, USA) before and after exposure. Both exposed and control (unexposed) samples were scaned between 650 and 4000 cm^{-1} and at 4 cm^{-1} resolution. Changes in the functional groups of the samples were quantitatively monitored against absorbance of the control sample. The GRAMS software V9.2 (Model: Waltham, MA, USA) was used in the analysis of the spectra.

2.4 Quality assurance and Quality control (QA/QC)

All reagents used were of analytical grade. All apparatus and glassware were cleaned, rinsed and dried at 110 °C for 12 hours before use. Control tests were performed to ascertain the purity of reagents. The FTIR and Spectroguide machine used were calibrated to ensure attainment of suitable working condition. Microsoft Excel 2010 and Statistical Package for the Social Science (SPSS) version 20 for windows were applied in data handling and analysis. All experimental samples were carried out in triplicates to confirm the results of analysis, while blank samples were included in the experimental setup as controls.

3. Results and Discussion

3.1. Fading and gloss retention of green coating at Diani and Mariakani sites:

Table 1: Average meteorological data for Diani and Mariakani sites

Meteorological Parameters	Average Rainfall [mm]	% Relative humidity	UV index [mW/cm^2]	Average Temp °C
Sampling sites/year	2019	2019	2019	2019
Mariakani	62	77	6	27.6
Diani	93	81	12	27.6

Source: www.worldwideweather.com

Experimental data for fading and gloss retention after 450 days of exposure revealed faster fading of the green coating at Mariakani than Diani, while gloss retention was higher at Diani compared to Mariakani.

MR green coating recorded the lowest fading at Diani compared to Mariakani sites with a general manufacturer performance trend of MB>CH>MR, as shown in Fig 3.

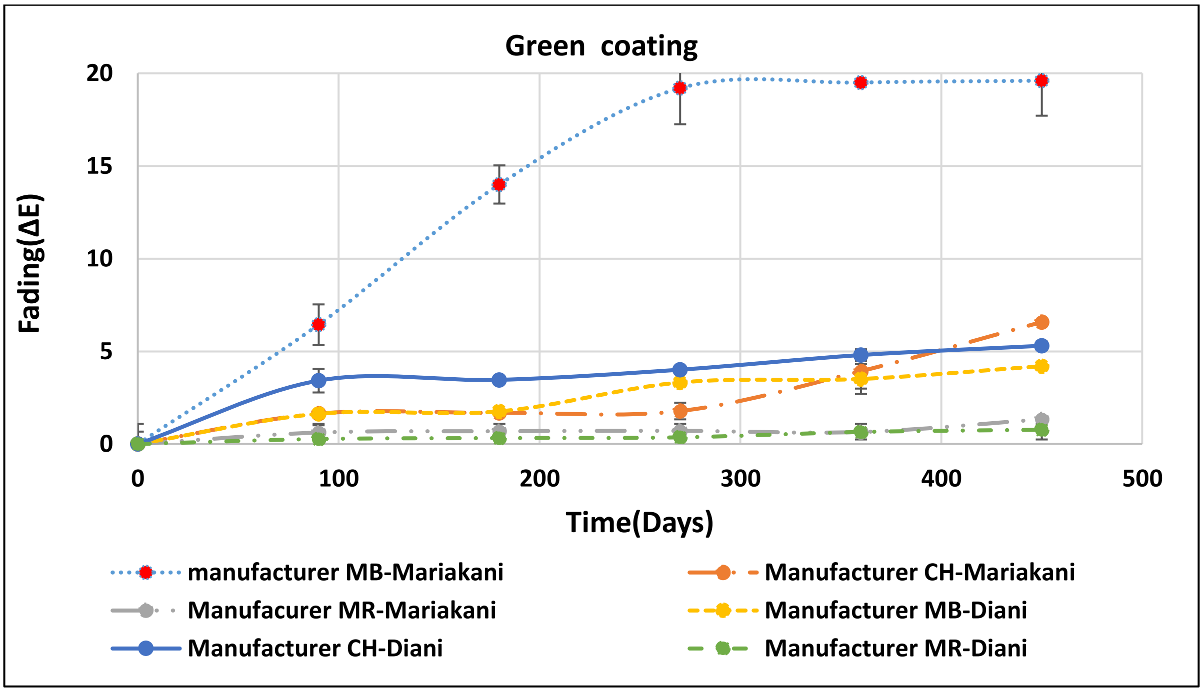

Figure 3: Change in color of green prepainted iron sheets exposed for 450 days.

Both Mariakani and Diani sites are characterized by high UV index and chloride content due to their proximity to the Indian Ocean. The fading of the green prepainted iron sheets at both sites could be attributed to the intense UV radiation experienced at the two sites, with Diani leading at 12 mW/cm^2 compared to Mariakani which registered 7 mW/cm^2 (Table1). However, coupling with the above parameters, Mariakani registered high sulphur dioxide (SOx) and nitrogen dioxide (NOx) concentration which could have enhanced higher fading as compared to Diani. High moisture content and acidic gases react with the coating materials increasing fading.

In addition, previous studies have shown that UV radiation with wavelengths between 280–315 nm absorbed by paint influence thermal, mechanical and esthetical properties of coating materials [16].

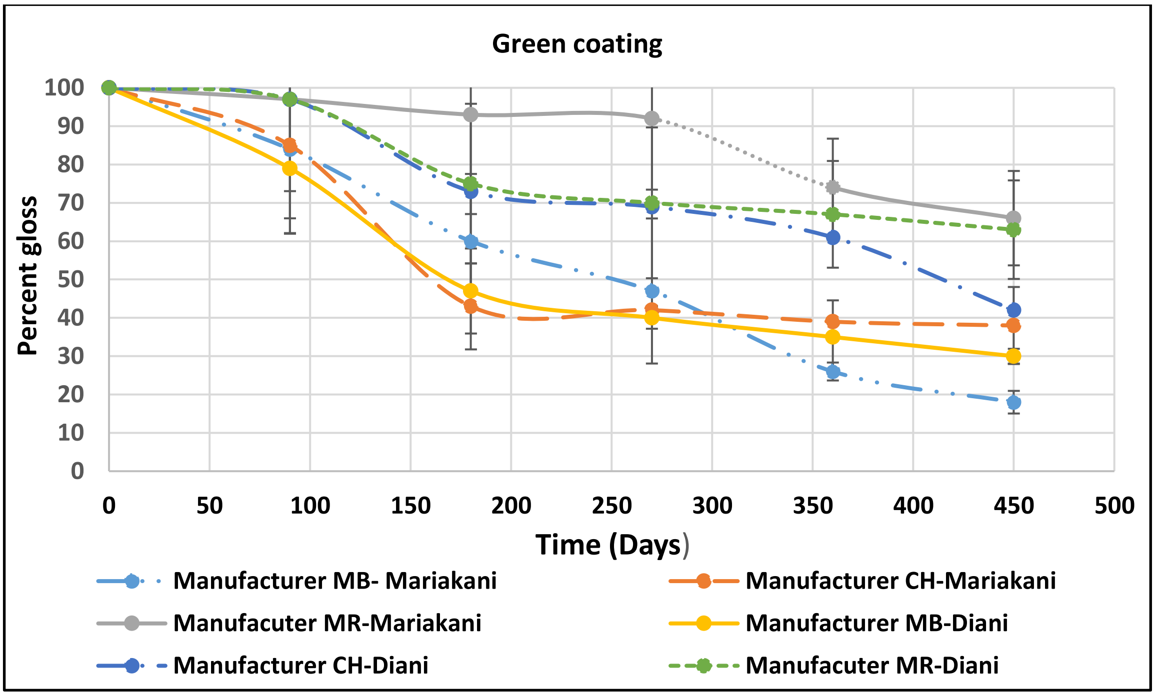

Figure 4: Gloss retention of green prepainted iron sheets exposed for 450 days**.**

Gloss retention followed the order of MB<CH<MR from the lowest gloss retention to highest, in both Diani and Mariakani sites as shown in Fig 4.

Green coated iron sheets exposed to atmospheric conditions at Mariakani experienced more adverse effects compared to those exposed at Diani, which could be attributed to additional effect of chloride attack on the coating materials, agreeing with findings by [17]. Green roofing sheets from MR had the highest percentage gloss retention in both sites (Diani 63.51 ± 12.85 % and Mariakani 66.53 ± 12.31 %).

When a coating degrades, the surface becomes rough, and the gloss reduces. Figure 5 shows pictures of green coated iron sheets from manufacturers CH, MB and MR exposed for 450 days at Mariakani and Diani sites.

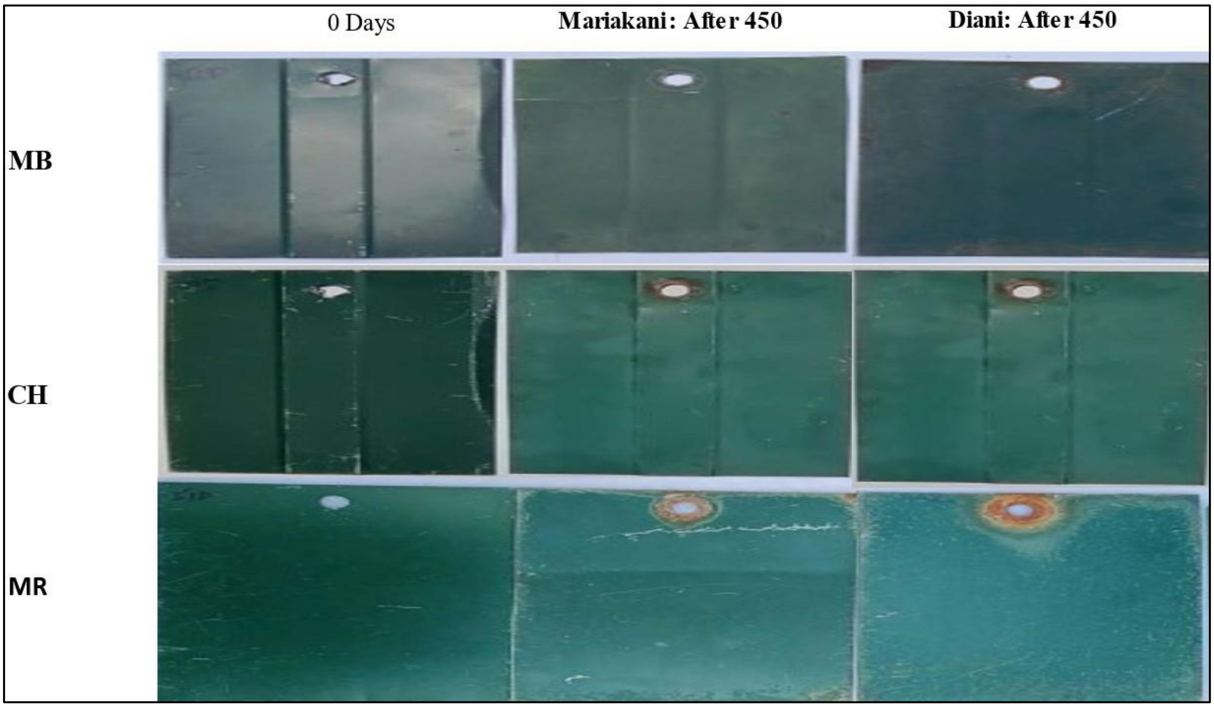

Figure 5: Comparison of green coated iron sheets at Mariakani and Diani after 450 days

3.2 Fading and gloss retention of blue coating at Diani and Mariakani sites

Fading results for blue coated iron sheets revealed faster fading rates at Mariakani compared to Diani site, with an overall manufacturer performance of MR<CH<MB, ranging from the lowest to the highest respectively, as shown in Fig 6.

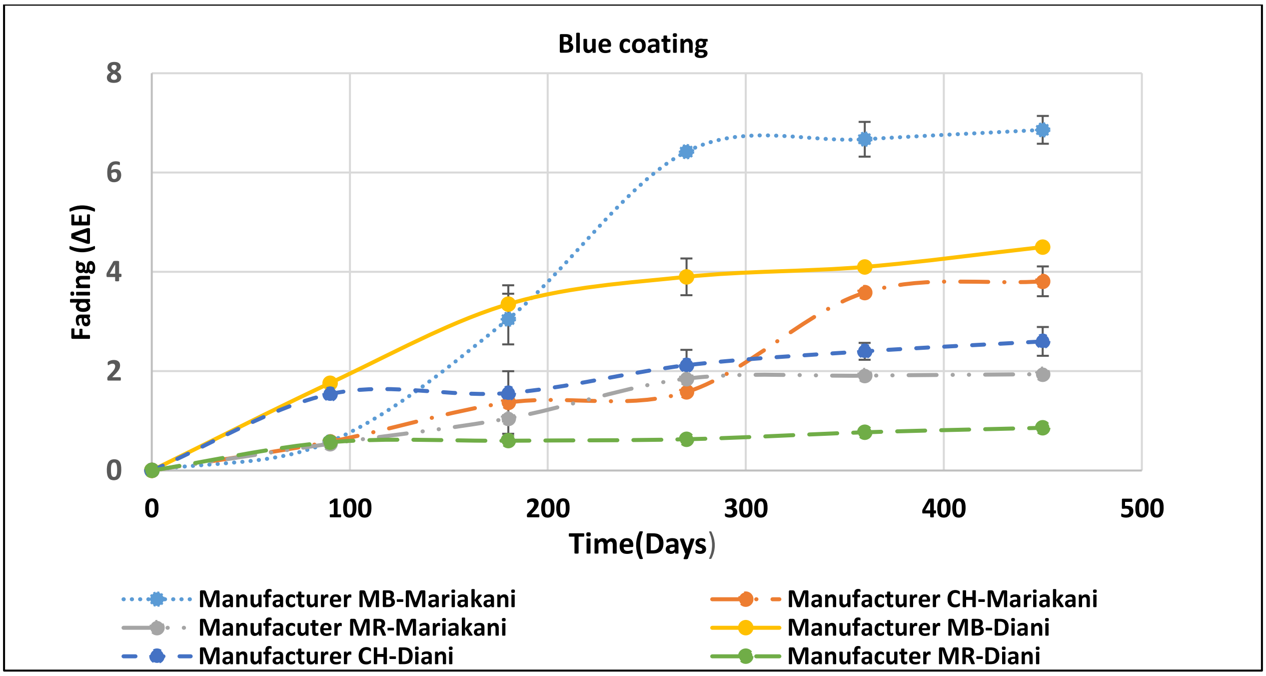

Figure 6: Change in color of blue prepainted iron sheets exposed for 450 days

The fading of the blue pre-painted roofing sheets at the sites was in the order of: MB > CH > MR at Diani and MB > CH > MR at Mariakani. The low fading capacity of the sheets manufactured by MR could be attributed to the properties of the components (resins, solvents, pigments and additives) added to the blue paint during manufacturing process.

Gloss retention was recorded highest for all the blue sheets exposed at Diani beach compared to Mariakani except for blue sheets from manufacturer MR. Generally, MR had highest gloss retention of (77% and 82.7% at Diani and Mariakani respectively) followed by CH, and lowest for MB (49% and 12% at Diani and Mariakani sites respectively), as shown in Fig 7. The poor performance of the blue sheet MB especially at Mariakani could be attributed to poor properties of the paint components used during manufacturing process which could not withstand attack from the aggressive atmosphere at the site. Environmental properties strongly contribute to photochemical degradation of the coating materials [18].

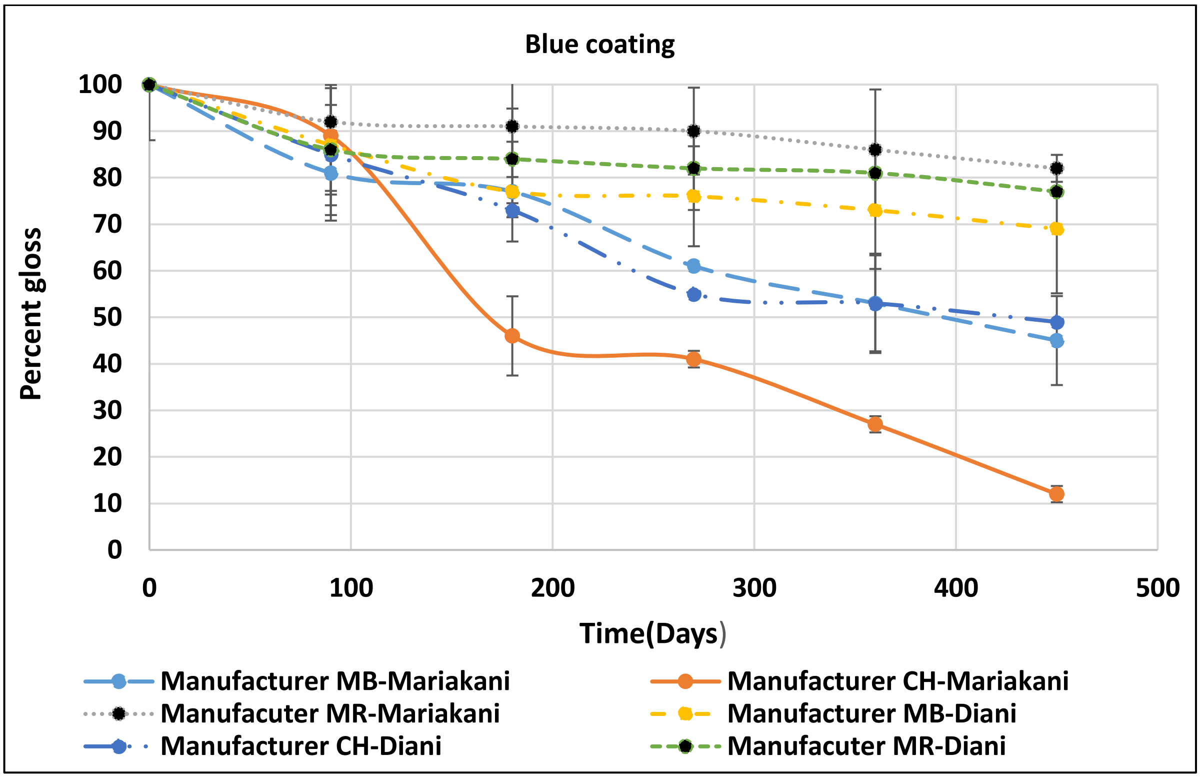

Figure 7: Percent gloss retention of blue prepainted iron sheets exposed for 450 days

High gloss retention means that the roofing sheets will remain unchanged for a long duration which implies better protection and extended shininess of the roofing iron sheets. MB and CH sheets recorded lower percent gloss retention suggesting less resistance to corrosive environment over a long duration compared to MR at both the Diani and Mariakani sites.

Blue prepainted CH sheets experienced highest fading and loss of glossiness when exposed at Diani. However, samples exposed at Mariakani tends to brighten in colour/loss of fade (Figure 8).

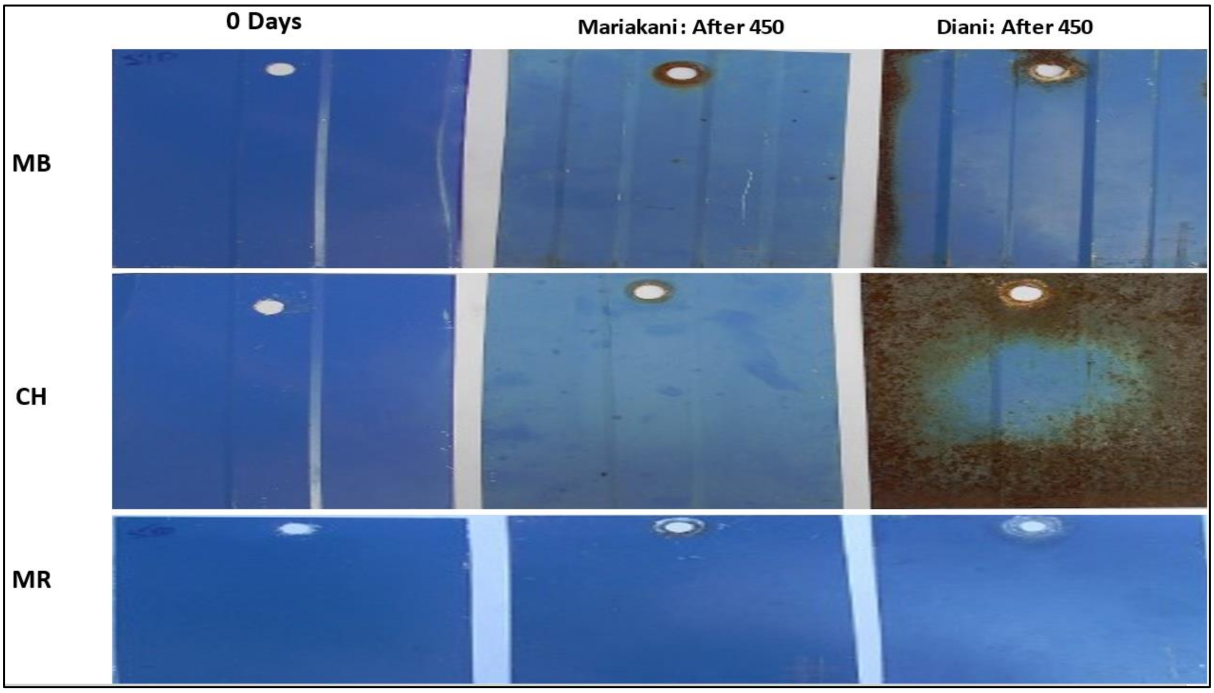

Figure 8: Comparison of prepainted blue samples exposed at Mariakani and Diani test sites after 450 days

3.3 Comparison between blue and green pre-painted iron sheets at both sites

In terms of sites, blue and green sheets exposed at Mariakani were adversely affected with high fade values and low % gloss. Loss of glossiness is associated with degradation of coating that translates into poor durability, while high gloss retention could be attributed to quality of the chemical components in the formulation for coating materials. At Mariakani site blue sheet were more superior product. The fade values were highest for all the green pre-painted sheets exposed, indicating that the green sheets were not suitable for roofing in surrounding location.

The two marine test sites were ranked in order of decreasing corrosiveness beginning with Diani then Mariakani. In terms of order in performance at Diani site, the order of colour loss for the blue roofing sheet was: MB > CH > MR while for green sheets was MB > CH > MR hence green sheets was found to be more superior product than blue.

The study showed that there was a colour loss (fade) in the green and blue prepainted roofing sheets after the exposure in both sites. However the fade varied with the product from the manufacturer and with site of exposure with samples exposed at Diani site having fade values ranging from 1.94-6.86 for blue and 1.33-19.59 Hunter units for green while Mariakani site was 0.86- 5.6 for blue and 0.77- 5.3 for green Hunter units per year. Percent gloss retention values ranged from 2.27- 77 % for blue and 30-63 % for green at Diani while 10-82% for blue and 18-66 % for green at Mariakani site after 450 days of exposure. A comparison of different research done around the world is a bit challenging because of the variations in the shades of paints used. However, the findings were in agreement with the research conducted by [16, 19, 13]. [20, 21] also reported acceleration of paint degradation in marine environments.

3.4 FTIR analysis

Fourier transform Infrared (FTIR) analysis was applied to characterize the surface of atmospherically exposed pre-painted roofing sheets. The FTIR analysis of the paint coatings applied on the pre-painted roofing sheets confirmed that sheets were composed of the following paint components; esters, polybasic acid, and phthalate of O-CH_2 (used as a binder) and pigments composed of $BaSO_4$, TiO_2, SiO_2 and silicones. The difference in composition of the paint was noted between exposed samples and control samples.
After exposure bands 1543, 1473, 1373 cm^{-1} for manufacturer CH and all the bands for manufacturer MB disappeared except band 1105 cm^{-1} in Diani and Mariakani sites (Table 2).

Table 2. Fourier transform infrared spectra of blue pre-painted sheets from different manufacturers before and after exposure.

	Manufacturer CH blue		Manufacturer MB blue		Manufacture MR blue	
Control Specimen [cm-1]	Diani	Mariakani	Diani	Mariakani	Diani	Mariakani
2926	-	-	-	-	-	-
1716	1714	-	-	-	1705	1716
1543	-	-	-	-	-	1535
1375	-	-	-	-	-	-
1253	1259	1261	-	-	1249	1246
1112	1112	1111	1105	-	1112	1116
1060	1056	1051	-	-	1056	-

In Table 2, the spectrum of blue pre-painted samples from manufacturer CH and MB had strong bands in the 2926–2853 cm^{-1} region which corresponded to C–H Stretching (CH_2). After 450 days of natural exposure, the band for blue sheets from manufacturer CH and MB disappeared at the two exposure sites. Disappearance of these peaks after exposure could have been attributed to oxidation of the double bond of the methylene group. Methylene groups are susceptible to degradation by undergoing oxidation at the double bonds due to absorption in the region of CH_2 stretching. Peak at band between 1600-1585 cm^{-1} for blue sheets from manufacturer CH corresponding to an aromatic ring of C = C disappeared after exposure in all the two sites. This could be due to degradation caused by UV radiation. For manufacturer MB, the peak at 1705 cm^{-1}corresponding to C=O stretching disappeared after exposure at all the two sites. This could be due to thermal oxidation of the resin during aging. The polybasic acid for the samples from manufacturer CH is part of the organic paint alkyd resins with band 1375 cm^{-1} corresponding to methyl group (-CH_3) of alkanes which is sp^3 hybridized and after exposure the methyl group degraded. Methyl group undergoes degradation when exposed to air, UV radiation and water [19]. The band at the region 1254–1070 cm^{-1} for manufacturer MB disappeared which could be attributed to vibrations of bonds of organic resin and mineral pigments especially $BaSO_4$ pigments at spectra region between 1174 and 119 cm^{-1}. The study showed that paint coating appearances were affected due to physio-chemical degradation. It was observed that the exposed samples had faded and the gloss changed leading to disappearance of bands. According to [22], paint degradation is mostly due to physiochemical processes which include UV radiation, reaction with water and air [19].

4. Conclusion

Both blue and green sheets from manufacturer MR displayed less fade and good gloss retention in both Diani and Mariakani with highest percentage gloss retention between 75-77 % and the lowest fading at 0.32 - 0.86 Hunter units per year for both green and blue coatings, hence a suitable product in roofing application at marine environment. The better performance of green and blue from manufacturer MR could be attributed to use of better chemical components in the paint's pigments during manufacturing process.

On the other hand, high chloride levels from the ocean are likely to accelerate fading and loss of gloss at Diani, which may lead to poor performance of roofing sheets under severe marine environment. A higher fading and loss of gloss retention was observed where the ultraviolet radiation, relative humidity, sulphur dioxide and nitrogen dioxide were high, leading to paint components degradation. Mariakani site recorded higher rates of fading attributed to higher levels of chloride, relative humidity- 81%, ultraviolet radiation-12 mW/cm^2 and temperature -27 $^{\circ}$C. Higher ultraviolet radiation increases photo-oxidative reactions and significant degradation of the binding material in the pigments. Hence, components used to manufacture prepainted sheets by manufacturer MR should be considered by other companies to minimize fading in such environments. Regardless, marine environment could be an aggressive environment for exposure of prepainted roofing sheets.

Disclosure statement

The authors declare no conflict of interest.

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REFERENCES

[1] Wang, H., Liu, Z., Wang, E., Yuan, R., Gao, D., Zhang, X., and Zhu, Y. (2015) A robust superhydrophobic PVDF composite coating with wear/corrosion-resistance properties. *Applied Surface Science*, *332*, 518–524. https://doi.org/10.1016/j.apsusc.2015.01.213

[2] Hayes, P. A., Vahur, S., and Leito, I. (2014) ATR-FTIR spectroscopy and quantitative multivariate analysis of paints and coating materials. Spectrochimica Acta Part A*: Molecular and Biomolecular Spectroscopy*, **133:**207–213. https://doi.org/10.1016/j.saa.2014.05.058

[3] Abba, Z. Y., Gumel, S. M., Idris, A. A., and Ibrahim, M. A. (2020) Formulation of paint using natural pigment from Lawsonia Inermis Leaves. *International Journal of Advanced Chemistry* **8**: 155-159.

[4] Salla, J., Pandey, K. K., and Srinivas, K. (2012) Improvement of UV resistance of wood surfaces by using ZnO nanoparticles. *Polymer Degradation and Stability*,*97*(4),592–596. https://doi.org/10.1016/j.polymdegradstab.2012.01.013

[5] Kumar, A.; Dixit, U.; Singh, K.; Gupta, S.P.; and Beg, M.S.J (2021) Structure and Properties of Dyes and Pigments. In Dyes and Pigments-Novel Applications and Waste Treatment; Papadakis, R., Ed.; IntechOpen: London, UK.

[6] Tator, K. B. (2015) Coating Deterioration. In K. B. Tator (Ed.), *Protective Organic Coatings* (pp. 462–473). ASM International. https://doi.org/10.31399/asm.hb.v05b.a0006073

[7] Liu, Y., Zhao, Y. J., Teng, J. L., Wang, J. H., Wu, L. S., and Zheng, Y. L. (2018) Research progress of nano self—Cleaning anti-fouling coatings. *IOP Conference Series: Materials Science and Engineering*, *284*, 012016. https://doi.org/10.1088/1757-899X/284/1/012016.

[8] Berdahl, P., Akbari, H., Levinson, R., and Miller, W. A. (2008) Weathering of roofing materials – An overview. *Construction and Building Materials*, **22**(4): 423–433. https://doi.org/10.1016/j.conbuildmat.2006.10.015

[9] Cogulet, A., Blanchet, P., and Landry, V. (2019) Evaluation of the impacts of four weathering methods on two acrylic paints: Showcasing distinctions and particularities. *Coatings*, **9(2):121**. https://doi.org/10.3390/coatings9020121

[10] Vidal, F., Vicente, R., and Mendes Silva, J. (2019) Review of environmental and air pollution impacts on built heritage: 10 questions on corrosion and soiling effects for urban intervention. *Journal of Cultural Heritage*, *37*, 273–295. https://doi.org/10.1016/j.culher.2018.11.006

[11] Joshi, A. A., and Pagni, P. J. (1994) Fire-induced thermal fields in window glass. II—experiments. *Fire Safety Journal*, *22*(1), 45–65. https://doi.org/10.1016/0379-7112 (94)90051-5.

[12] Onyatta, J. O., Yusuf, A. O., & Ooko, J. O. (2016). Atmospheric Corrosion Studies in Kenya: Past, Present and Future. 8.*African Corrosion Journal*.2(1).25-32

[13] Ooko, J. O. (2019) Atmospheric Corrosion Analysis of Metallic Coated and Prepainted Steel Roofing Products in Selected Sites in Kenya. 93. M.Sc. Thesis. University of Nairobi.

[14] International Organization for Standardization (1984) ISO 7724/2. Paints and vanishes –Colorimetry-part 1.Princiles Method for colour measurement, International organization standard, Geneva, Switzerland.

[15] International Organization for Standardization (2014) ISO 2813. Paints and vanishes –Colorimetry-part 1.Princiles Method for measurement of specular gloss of non-metallic paint films a 20^0, 60^0 and 85^0, International organization standard, Geneva, Switzerland.

[16] Driel, B. A., Kooyman, P. J., van den Berg, K. J., Schmidt-Ott, A., and Dik, J. (2016) A quick assessment of the photocatalytic activity of TiO2 pigments—from lab to conservation studio! *Microchemical Journal*, **126**: 162–171.

[17] Rossi, S., Lindmark, H., & Fedel, M. (2020). Colored Paints Containing NIR-Reflective Pigments Exposed to Accelerated Ultraviolet Radiation Aging with Possible Application as Roof Coatings. *Coatings*, *10*(11), 1135. https://doi.org/10.3390/coatings10111135

[18] Guerguer, M., Karim, M., Naamane, S., Edfouf, Z., and Raccurt, O. (2018) Degradation of solar glass mirrors paints at marine outdoor site. *AIP Conference*. pp 1-9. https://doi.org/10.1063/1.5067232.

[19] Hara, S., Kamimura, T., Miyuki, H., and Yamashita, M. (2007). Taxonomy for protective ability of rust layer using its composition formed on weathering steel bridge. *Corrosion Science*, **49**(3): 131–142.

[20] Vashi, R. T., and Kadiya, H. K. (2009) Corrosion study of metals in marine environment. *E-Journal of Chemistry*, **6**(4):1240–1246.

[21] National Renewable Energy Laboratory (NREL) (2018) Corrosion and durability Research. 2017.