Zinc-Plated Roofing Sheets and the Effect of Atmospheric Pollution on the Durability of the Sheets.

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Abstract

This study was conducted in an area of Jos, in North Central Nigeria, where the main sources of atmospheric pollution were due to emissions from high vehicular traffic on the Jos-Zaria road, automobile repairs and welding shops, and burning of rubber materials, and waste automobile tyres. This work took into consideration an earlier work which has shown that there has been a considerable amount of H_2S, CO, and particulate matter in the environment around this area under study. The study was extensively carried out, and the building structures assessed, were those constructed from 2001 to 2013 covering a period of thirteen (13) years. The study has shown that there is a relationship between atmospheric pollution and the rusting of zinc plated roofing sheets indicated by brown and reddish spots. Building structures for the period 2001-2005 showed serious corrosion problems which were indicated by large reddish rust spots all over the structures. Further test on various brand symbols of galvanized steel sheets used in the structures studied revealed that the corrosion resistance of the galvanized steel sheets increases with increase in coating mass of the galvanized steel sheets.

Keywords: Galvanized, Zinc-plated, Durability, Roofing sheets, Atmospheric pollution, Corrosion and Red rust.

1. Introduction

Excessive release of air pollutants in the atmosphere by anthropogenic activities disturb the dynamic equilibrium in the atmosphere and thereby affect man and his environment (Dara, 2007). According to US Public Health Services, ‘’ Air pollution may be defined as the presence in the outdoor atmosphere of one or more contaminants or combination thereof in such quantities and of such duration as may be, or may tend to be injurious to human, plant or animal life, or property, or which unreasonably interfere with the comfortable enjoyment of life, or property, or the conduct of business’’ (Bhatia, 2008).

The atmosphere is a dynamic system, which steadily absorbs various pollutants from natural as well as man-made sources, thus acting as a natural sink. Gases such as CO, CO_2, H_2S, SO_2, and NO_2 as well as particulate matter, such as sand and dust, are continually released into the atmosphere through natural activities such as forest fires, volcanic eruptions, decay of vegetation, winds and sand or dust storms. Man-made pollutants e.g. CO_2, NO_x, SO_2, CO, hydrocarbons, particulates etc. are also released into the atmosphere. These have surpassed the pollutants contributed by nature thousand-fold (Dara, 2007, Bhatia, 2008). The magnitude of the problem of air-pollution has increased alarmingly due to population explosion, industrialization, urbanization, automobiles, and other human proclivities for greater comfort.

There has been no time in history than now that the world has come to live with the stack reality of the effects of air pollution like climatic change, global warming and its resultant effects, acid rains, photochemical smog and others. The damage to life and property as a result of this global menace cannot be quantified (Dara, 2007, Bhatia, 2008, Torsten,1995, Ola et al, 2013). A recent WHO (2014) report has revealed that air pollution has become worse in many cities around the world in recent years, especially in Africa and South-East Asia. The UN agency's report showed that nearly 90 per cent of the world population breathes air that is markedly above the limits recommended by the WHO. Experts from the agency identified car traffic, the burning of coal, oil and gas as well as badly insulated houses as the main culprits. The UN agency had said in April that polluted air killed 3.7 million people under the age of 60 in 2012.

This research work is meant to assess the impact of air pollution on the roofs of building structures made of zinc plated roofing sheets in an area of Jos where the main sources of air pollution are from automobiles, generators, burning of rubber, old tyres, plastic wastes, and other wastes. A study was conducted in the area by Ola et al (2013) and the levels of pollutants in the air around the vicinity were noted. The researchers observed that CO was 6-110ppm. This range was above acceptable limit of 50ppm – 55ppm. H_2S was 1.0-3.6ppm and particulate matter was 0.1 to 0.6 mg/m^2 these peak level concentrations were however, within acceptable limits (Ola, et al 2013). The atmospheric air contains 0.1 to 0.12ppm of carbon monoxide. Automobiles exhaust accounts for 60% of CO in the atmosphere. The concentration of CO in city air is about 55ppm. The atmospheric background concentrations of N_2O, NO, and NO_2 are 0.25ppm, 0.1 to 2ppm, and 0.5 to 4ppm respectively. Although the concentration of N_2O is more in the atmosphere, NO and NO_2 are more significant from air pollution point of view and they are usually represented together as NO_x. The NO_x from man-made sources may be 10 to 100 times more in urban areas, as compared to rural areas. Even in urban areas, the ambient NO, levels vary with sunlight and traffic density at any given point of time. Most of the man-made So_x pollution is concentrated in urban and industrial area (Dara, 2007, Bhatia, 2008, Torsten, 1995, Ola et al, 2013).

Galvanized iron/steel sheets with nominal thickness 0.35-1.0mm and with coating mass designation of Z25 and Z27 (corresponding to coating thickness of 0.049mm and 0.054mm) normally used for building structure roofing. The base metal thickness is between 0.25 – 3.2 mm. however, in Nigeria the common range is nominal thickness of 0.155 – 0.35mm. The specification may however, vary depending on customer demand (NSC, 2007, NIS, 2003). For roofing sheets both sides of the sheets (triple-spot-method) are normally coated (NSC, 2007, NIS, 2003). Iron /steel is generally regarded as a product susceptible to ''rust (corrosion)''. However, rust in steel can be greatly inhibited by galvanizing (NSC, 2007, NIS, 2003, Fasuba, 2011). The reason for this is that electro-chemical protection (galvanic) action that works between steel and zinc is effective and the zinc itself is highly weather resistant. The electro-chemical or sacrificial protection offered by zinc on the steel base is effective even in an uncoated area up to 5mm (JIS, 2007). While the zinc on the galvanized steel sheet protects the base metal steel sheet of the galvanized sheet from corrosion by means of galvanic action, this is not the reason why galvanized sheets are in common use. Rather, it is due to the high corrosion resistance peculiar to galvanized sheets-in the case of outdoor applications, galvanized sheets offer corrosion resistance that is several times or even tens of times greater than ordinary steel sheets. When exposed to ordinary atmosphere, zinc is slow to dissolve and difficult to corrode (NSC, 2007, NIS, 2003, Fasuba, 2011, JIS, 2007)

Research has been conducted for many years on the outdoor service life (the period of time before red rust appears) on galvanized sheets. In the case of galvanized sheets with a coating mass of 350 g/m^2, the approximate service life is 15-18 years in rural areas and 3-8 years in industrial areas (NSC, 2007, NIS, 2003, Fasuba, 2011, JIS, 2007). This clearly shows how long galvanized sheets can remain in use, compared to uncoated bare steel sheets. Results of weather resistance tests by outdoor exposure have clearly shown that the corrosion of galvanized steel sheets is 5-30 times slower than that of steel sheets (NSC, 2007, NIS, 2003, Fasuba, 2011, JIS, 2007). Galvanized steel sheets remain completely free of corrosion for a very long time in appropriate application environments. There were tests results in which galvanized sheets showed no corrosion loss for several years in atmosphere of low humidity (NSC, 2007, NIS, 2003, Fasuba, 2011, JIS, 2007). This is thought to be due to the formation of a tight extremely thin oxide film on the surface of galvanized sheets that becomes inactive under appropriate conditions (in fact, an extremely basic zinc carbonate is produced through interaction between water, carbon dioxide and air) (NSC,2007, Aigbodion et al, 2007, Okonkwo et al, 2012). Research has also shown that as the coating mass increases, the corrosion resistance of the galvanized sheets is improved, thereby protecting the base steel for longer periods (NSC, 2007, NIS, 2003, Fasuba, 2011, JIS, 2007). It has also been proved by Nippon Steel Corporation (NSC) (2007) that post treatment of galvanized sheets is important in improving white rust resistance it has been proven that chromium coating mass treatment improves white rust resistance (NSC, 2007)

The objective of the work is to investigate the effect of atmospheric pollution on the durability of galvanized roofing steel sheets in semi industrial and high vehicular traffic area of Jos, a city located in the North Central region of Nigeria.

2. Materials and Method

2.1. Materials

The materials used for this work included; roofed structures made of galvanized steel sheets, details shown in Table 1. Industrial salt and result of pollution level in the area. Salt spray chamber was the equipment used for assessing five brands of galvanized steel sheets used in the study.

Table 1 Details of the Galvanized Roofing Steel Sheets Studied

S/No	Brand symbol	Nominal thickness (mm)	Gauge	Mass of zinc coating (on both sides) g/m^2
1	Swan	0.155	G38	120
2.	Star	0.170	G38	150
3	Elephant	0.180	G35	160
4	Hand	0.200	G35	170
5.	Star (big)	0.350	G28	200

2.2 Method

This study was conducted in an area of Jos, in North Central Nigeria, where the main sources of atmospheric pollution were due mainly to emissions from high vehicular traffic on the Jos-zaria road; automobile repair and welding shops; generators; and burning of waste organic materials of rubber, tyres and plastic origin. The work took into consideration an earlier work which was conducted in the area the result of which is shown in Table 2. This study was conducted in an area called NEPA which is a semi-industrial area. The study was conducted for thirteen (13) years starting from 2001 to 2013. Only buildings with the following brand symbols were monitored; swan, star, elephant, hand and star (big). The five brands are all produced according to Nigerian Industrial standard NIS 180:2003 specification with reference to JISG0303 2000, JIS G 3302 1998, and JIS Z 8401 1999 for galvanized corrugated steel sheet. The monitoring of the structure for the first reddish rust spot started from the day the roofing was done and a total of thirteen houses were monitored using nondestructive testing method of visual inspection. Because of the slowness in the development of red rust spot, the interval between assessments was five months. The time the first rust spot appears on the different brands was always noted. It was actually difficult to make satisfactory comparison because the houses located close to the road and the industrial area showed earlier signs of reddish rust spots than the houses that were located at a distance, because of this to understand the individual corrosion resistance of the individual brands a salt water spray test was carried out on the five brands according to JIS Z 2371 (NSC, 2007, JIS, 2007) test conditions. The test was carried out at the corrosion laboratory of the National Metallurgical Development Centre Jos.

Table 2 Peak Concentrations of Some pollutants at NEPA Area of Jos

S/No	Air pollutant	Nov,2006	Jan,2007	Feb,2007	Aug,2007
1	Carbonmonoxide	51 ppm	110ppm	81 ppm	30 ppm
2.	Hydrogen sulphide	2.6 ppm	1 ppm	2.2 ppm	1.6 ppm
3.	Particulate matter	0.4 mg/m^3	0.4 mg/m^3	0.4 mg/m^3	0.3 mg/m^3

Source: Ola et al, (2013)

3. Results and Discussion

3.1 Results

After thirteen years of the corrosion study, the result of the work was collated and is here presented. Table 3 shows the condition of galvanized roofing sheets in a thirteen year study. Table 4, shows emergence of reddish spot on five brand symbols of galvanized roofing sheets, figure 1, is the brand symbols and time until red rust occurrence and plates 1-6 shows the condition of the roofs monitored at various periods.

Table 3, Condition of Galvanized Roofing Sheets in a Thirteen Year Study

S/No	Year of roofing	Present condition (2013)	Emergence of first reddish rust spot (years)
1.	2001	Brown rust on sheets	7 no pitting hole seen
2.	2002	Brown rust on some sheets	6 No pitting hole seen
3.	2003	Brown rust on some sheets	5 No pitting hole seen
4.	2004	Brown rust on some sheets	4 No pitting hole seen
5.	2005	Brown rust on some sheets	4 No pitting hole seen
6.	2006	Brown rust on some sheets	4 No pitting hole seen
7	2007	Brown rust on some sheets	4 No pitting hole seen
8	2008	Dull ($ZnCO_3$ formation) scanty red rust	4 No pitting hole seen
9	2009	Dull ($ZnCO_3$ formation) scanty red rust	3 No pitting hole seen
10	2010	Dull ($ZnCO_3$ formation) scanty red rust	2 No pitting hole seen
11	2011	Dull ($ZnCO_3$ formation) white rust	7 months
12	2012	Dull ($ZnCO_3$ formation) white rust	7 months
13	2013	Dull ($ZnCO_3$ formation) white rust	7 months

Table 4 Emergence of reddish Rust Spot on Five Brand Symbols of Galvanized Steel Roofing Sheets

S/No	Brand Type	Time until Red rust Appears (years)
1.	Swan	2
2.	Star	3
3.	Elephant	4
4.	Hand	4
5.	Star (big)	5

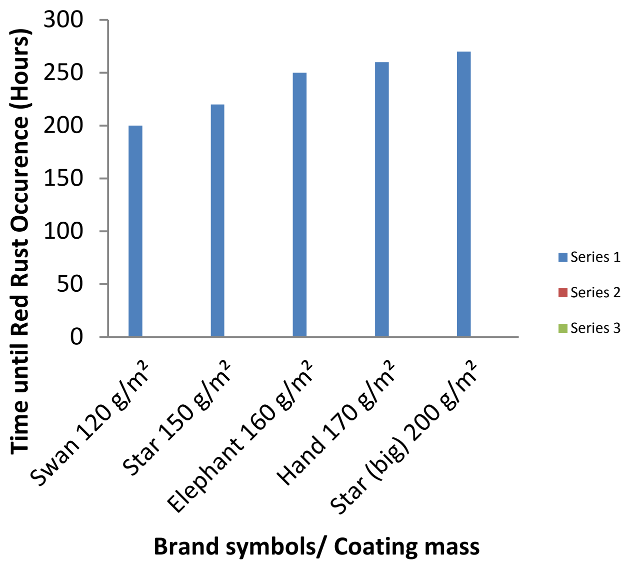

Figure 1 Brand Symbol and Time until Red Rust Occurrence (Salt water test: 5% salt water)

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Plate 1: Buildings Close to the Main Road and Roofed in the Year 2001 had Shiny Roofs but have now (2013) turned Completely Reddish Brown

Plate 2: Building roofed in 2003 showing Light- Brown Rust Spot uniformly on the Zinc-plated roofing Sheets

Plate 3: Building roofed in the Year 2004 showing Reddish- Brown Rust Spots

Plate 4: Two Buildings the First from the left was Roofed in Year 2007 and the Second Was Roofed in 2004. Rust has taken Away the Shining Beauty of the Second Roof

Plate 5: Building Was Roofed in Year 2010; Dulling of the Surface has Already Taken Place

Plate 6: Building was Roofed in the Year 2013, still Shining in some Areas but getting Dull in Others.

Plates 1-6 indicates the state of some of the building structures studied during the research work.

3.2 Discussion

Table 3 shows the conditions of galvanized steel roofing sheets in a thirteen year study. Houses roofed as from 2001 – 2013 were selected and monitored as reflected in the table. The result as collated in 2013 showed that 2001-2007 roofs had various degrees of red rust. 2008 – 2010 roofs had scanty red rust spots. It was generally observed in all the roofs that dulling of the roofs occurred after seven months of roofing. The shining nature of the roofing sheets disappears with a characteristic whitish dust on the surface of the sheets. This is referred to as white rust. It is formed as a result of reaction between the zinc coating, water, carbondioxide and air (NSC, 2007, Obi et al, 2007, Ogundare et al, 2007). According to a publication by Nippon Steel Corporation (2007) this is thought to be due to the formation of a tight, extremely thin oxide film on the surface of galvanized steels that becomes inactive under appropriate conditions (in fact an extremely thin basic zinc carbonate is produced through interaction between moisture, CO_2 and air) (NSC,2007, Ogundare et al, 2011). The rate at which this takes place is faster if the level of pollutants in the atmosphere is high. Table 2 above confirms why the surface of the roofing sheets dulls very fast (Ola et al, 2013, Aigbodion et al, 2007). Table 3 also indicates when reddish spots were first sighted on the surface of the roofing sheets. It took seven (7) years to sight a red rust spot on the 2001 roofed structure. This was not the case with subsequent roofs as the number of years kept decreasing. This trend can be attributed to the fact that pollution of the environment kept increasing with increased use of generators as source of power supply, increased in number of automobiles, and burning of industrial and organic wastes. Table 2 above also confirms this with peak value concentrations of CO reaching 110 ppm (Dara, 2007, Bhatia, 2008, Torsten, 1995, Ola et al, 2013). No pitting hole was observed in any of the roofs monitored for the thirteen years. It however has to be categorically stressed that the aim of using the galvanized roofing sheets is not only for the prevention of rains and wind getting into the building, but it is also for aesthetics. Red rust on top of the roof takes away the beauty of the building and disfigures it, so the absence of pitting hole does not mean that corrosion of the roof was not a problem (see plates 1-6)

Table 4 shows the emergence of reddish rust spot on five brand symbols of galvanized steel roofing sheets. The table indicated that the time until red rust appears on the surface of the five brand symbols increased from 2 years for swan brand to 5 years for star (big). This variation has to do with the variation in coating mass of the brands. The elephant and the hand brand has a close coating mass value, this is reflected in the fact that they all have 4 years in the table. When compared with standard and ideal conditions of corrosion resistance of galvanized steel sheet. The number of years indicated for the emergence of first rust spots on the galvanized steel sheets in the table is indeed low. This is also confirmed by ref. (NSC, 2007). Air pollution has become a global problem having devastating effect on properties including corrosion of galvanized roofing sheet. According to Dara (2007) emissions such as CO, CO_2, H_2S, NO_2, undergo reactions stated below in the atmosphere resulting in what is called acid rain which are very corrosive to buildings and other things.

$$4NO_2+2H_2O+O_2 \longrightarrow 4HNO_3 \qquad (1)$$

$$\text{Alternative Mechanism for nitric acid formation} \left\{ \begin{array}{l} a)\ O_3+NO_2 \longrightarrow NO_3 + O_2 \\ b)\ NO_3+NO_2 \longrightarrow N_2O_3 \\ c)\ N_2O_3+H_2O \longrightarrow 2HNO_3 \end{array} \right\} \quad (2)$$

$$\left. \begin{array}{l} SO_2 + O_3 \longrightarrow SO_3 + O_2 \\ SO_3+H_2O \longrightarrow H_2SO_4 \longrightarrow (H_2SO_4)n \end{array} \right\} \quad (3)$$

$$CO_2+H_2O \longrightarrow H_2CO_3 \qquad (4)$$

Dara (2007) further said that ''as beautiful and refreshing as rain can be; in these last few decades, simple rainfall has taken on a threatening complexity in some parts of the world. In most localities, rain pass through an atmosphere polluted with oxides of sulphur (So_x) and oxides of Nitrogen (NO_x). The falling rain and snow react with these oxide pollutants to produce often a mixture of sulphuric acid, nitric acid and water. This is known as acid precipitation or acid rains''. This explanation by Dara no doubt explains early appearance of red rust on the various brand types of galvanized steel sheets in Table 4. The work of Ola et al (2013), in the same area of this study also confirms the role of pollutants in the early appearance of rust spots on the roofs. Ola et al (2013) observed that the peak concentration of pollutants in dry season was higher than in raining season, and their explanation was that in raining season the pollutants are washed away by the rains. This acidic rains now falling on roof tops, corrode the galvanized steel roofing sheets, resulting in red rust spots in very severe or concentrated areas of attack. This takes us to figure1, which explains the importance of a thick coating mass in a corrosive area.

Figure 1 shows brand symbols and time until red rust occurrence. The figure showed the time taken for red rust to appear on different brand symbols with different coating mass. The figure shows that as coating mass increases the time until red rust occurrence also increases. With a coating mass of 120g/m^2 the time until red rust occurrence came up to 200hours. The number of hours increased to 270 hours corresponding to a coating mass of 200g/m^2. These observations agree with other works in refs (NSC, 2007, JIS, 2007). It therefore means that for corrosive environments, galvanized steel sheets with high coating mass should be preferred to offer better corrosion resistance.

Plates 1-6 indicate the state of the roofing sheets at various stage of the study. The plates support the results in Tables 3 and 4. The plates clearly show the roofs and corrosion products and other features. It can be clearly seen that the rust do not only reduce the service life of the zinc-plated roofing sheets that it also steals away its beauty.

4. Conclusion

In conclusion the study which spaced through thirteen years has studied the impact of atmospheric pollution on the durability of zinc –plated roofing sheets popularly called galvanized steel roofing sheets and the following have been drawn from the study

1. Evidence exists from the study that excessive release of air pollutants in the atmosphere by anthropogenic activities in the studied area have led to the early occurrence of red rust spot on galvanized steel roof sheets.
2. The various brand symbols of roofing galvanized steel sheets in the market have different corrosion resistance due to the thickness of the coating applied.
3. Investigation using salt spray test revealed that the corrosion resistance (time until red rust appears) depend on the coating mass or thickness of the coating on the surface of the steel sheet.
4. For corrosion-prone area the study advised that galvanized steel sheets with thick coating mass should be used.
5. The study also observed that the aim of roofing with galvanized steel sheet is not only for protection from rain and wind but also for aesthetics. The red rust on galvanized steel sheets therefore disfigures the building. Hence the effect of the corrosion as a result of pollution therefore goes beyond durability of the roofing sheets.

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