Exploring Salt Reaction on Buildings along Coastal Area in Lagos State, Nigeria – A Review

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Abstract

Over the years studies have revealed that location and environmental impact are important factors to be considered in building materials selection. These have become major criteria in selection of appropriate building materials especially in the coastal regions of the world. In Nigeria, Lagos State has a close proximity with the Atlantic Ocean and the saline air present in this Ocean have been discovered to cause physical and chemical damages to the nature of the building materials used in this area. Hence, in order to curb these effects, understanding the impact of this saline air on building materials and the way towards improving the resistance of buildings within this area to salt reaction is necessary. This study present the result gotten from the review of literature on the effect of salt on buildings in coastal areas and the possible ways of ensuring a reduction of the negative effect of this salt reaction with building materials. Findings revealed that salt attack on concrete and steel reinforcements leads to structural failure in buildings. Also, moisture penetration leads to blistering, chalking, and peeling of paints, which leads to constant re-painting of buildings. Cracking of walls, deterioration of floorboards and wood degradation are some of the effect of salt on buildings within the coastal areas.

Keywords

Building Materials, Saline Environment, Salinity, Corrosion, Defibration

1. Introduction

In construction, several factors affect the choice of materials used in building construction one of which is the building location (Ogunkah and Yang, 2012). According to the World Bank (2009), the coastal area as a building location has grown to be the most developed areas in most parts of the world today. However, in more recent times these part of the world has been affected by the tremendous climatic change, which according to Susmita *et al*. (2014) can lead to increased salinity from sea water, loss of wetland, a flood from as a result of the rise in sea level, and storm damage. The impact of salinity on building materials is not a truth farfetched among buildings in Lagos state, Nigeria. This part of the country is located around the Atlantic Ocean which according to Oyewo *et al.* (1982) and Folorunsho (2004) experience low and high sea tides on a daily basis which leads to release of salt into the area. Folorunsho and Ahmad (2013) further stated that buildings with close contact with the Atlantic Ocean in Lagos state are affected by the impact of saline air from the ocean.

The effects of increased salinity from sea water and inundation due to sea level rise have been a threat to buildings around the coast today. Thus, the Federal Emergency Management Agency (FEMA, 2005) explained that the durability of any home around the coastal area depends on the type of building materials used in constructing it. Fabio (2014) opined that salt crystals are often the reason why buildings show signs of aging at an early stage. This is because these salts crystallize inside the building materials making them crack and crumble. Wilson (2003) has earlier stated that in some cases, cracked bricks or stone, mortar turning into dust, and cement render flaking off on internal and external walls can be seen when salt crystals come in contact with these building materials. Department of Environment and Climate Change (2008) affirmed that when building materials are exposed to seawater they are prone to physical and chemical damages; these damages can be in the form of deterioration of mortar and bricks, corrosion of metals and decay of wood.

Lagos State located along coordinates 6°35' N 3° 45'E and with a land area of 3,577 square kilometers, it is currently the smallest state in Nigeria but arguably the most economically important state in the country. Lagos is the largest city located on the Atlantic oceans and about 787 square kilometers is made up of lagoons and creeks. The close proximity of the State to the Atlantic Ocean opens her buildings to deterioration from saline air from the Atlantic Ocean. Studies have shown that one of the causal factors of building collapse in areas around the Lagoon in Lagos State is salt reaction with reinforced concrete which causes brittleness of concrete and corrosion of reinforcement, hence leading to degradation of reinforced concrete which in turn causes structural failure in buildings (Akande *et al.*, 2016; Awobodu, 2009; Tinuade and Qouzeem, 2016). Folorunso and Ahmad (2013) further attributed the reason for paint chalking in this area to salt spray and this causes such buildings to be exposed to continuous repainting when compared to buildings in other tropical regions. Akande *et al.* (2016) further opined that other noticeable defects in structurally defective buildings in the study area include an erosion of mortar joints, defective plastered rendering and floorboards, cracking of walls, roof defects caused by corroded nails and salt crystallization in building materials are contributing factors to these issues. Thus, due to problems arising from the destructive effect of salt crystallization and penetration within building materials, the need to proffer solutions to such problems using salt resistant building measures has become necessary.

2. Building Materials

Building material is any material required for a construction purpose (Jana, 2014). It can simply be referred to as a material used in constructing a building. They usually occur in form of natural material such as clay, sand, wood, stones or man-made materials such as glass, Poly Vinyl Chloride among several others. Folorunso *et al.* (2017) explained that it is necessary for buildings materials to perform environmentally. This performance can be ascertained through an assessment of the compatibility of the material with the environment where such construction is to be executed. In determining this compatibility, the function, durability, and mechanical performance of such material are considered. Therefore, based in the inherent responsibilities of architects and other similar professionals in the specification appropriate materials for construction, it can be deduced that it is imperative for professionals to know the characteristic behaviour of the chosen building materials and their compliance with the environment before they are selected. Venkatarama and Jagadish (2003) have earlier submitted that materials and technologies chosen for construction of buildings should considerably satisfy the felt needs of the user and the society without impact on the environment negatively. Duggal (2008) asserted that building materials play very important roles in modern-day construction of buildings and building construction in turn currently requires and consumes between 30-50% of raw materials worldwide (Sustainable Design Assessment in the Planning Process, 2012). The realization of a building project cannot be achieved without the proper selection of the necessary building materials. Nevertheless, the required materials to be selected are determined by a number of factors.

2.1 Factors affecting the choice of building materials

The choice is regarded as the mental process of judging the advantages of several options and selection of the most preferred is usually a topic of discourse. Folorunso *et al* (2017) opined that choosing a particular material out of the available options could be challenging. According to Ogunkah and Yang (2012), the numerous number of building material options has made the selection of building materials a daunting task for most construction participants. However, Van Kesteren *et al*. (2005) have earlier highlighted some possible factors to consider in material selection and these include; product-personality, use, function, material characteristics, shape, and manufacturing processes. Fernandez (2006) opined that architects select materials based on performance attributes of the required material. Nevertheless, this has the disadvantage of impeding the vital qualities inherent in the materials. Cagan and Vogel (2002) asserted that six factors are basically important in the materials selection process. These are emotion, aesthetic, product identity, ergonomics, core technology, and quality.

Ogunkah and Yang (2012) provided a framework for determining the factors which affect the selection of building materials. The six factors identified are site factors, environmental factors, economic factors, sensorial factors, socio-cultural factors, and technical factors. The research showed that location and environmental impact which are subsets of site factors and environmental factors respectively are important factors to be considered in building materials selection. This becomes necessary due to the need to determine the necessary impact the immediate environment will have on a building when it is sited in a particular location. Thus, the need to study the necessary effect of locating a building around a saline environment, the impact salinity has on building materials and the means of reducing such effects using appropriate building materials becomes cannot be overemphasized.

3. Salinity and Saline Environment

According to World Ocean Atlas (2009), salinity is basically described as the saltiness or dissolved salt content of a body of water**.** Pawlowicz (2013) explains that in large water bodies like lakes, rivers and ocean salinity can be described as the quantity of dissolved salt content of water. Osei (2000) observed that most parts of the earth's surface are covered by body of water and about 71% of these bodies of water reaches to a depth of more than ten kilometers (10km). Preeti *et al.* (2014) further gave a distinction between fresh and sea water. Freshwater is a purified body of water which is free from any form of impurity while sea water is that body of water containing high percentage of Sodium Chloride. Anati (1999) further explains that seawater is created to have a salinity level of 35g/L and this reduces near the coast. According to Olutoge and Amusan (2014), 97.5% of the earth's water body are sea water and these contain a complex solution of many salts containing living matter, suspended silt, dissolved gases, and decaying organic material. Also, Akinkurolere *et al.* (2007) explain that chemical constituent such ions of chloride, magnesium, calcium, and potassium are present in seawater and they are fairly uniform in chemical composition which is characterized by the presence of about 3.5 percent soluble salts by weight. The concentration of major salt constituents of seawater are given in weight percentage of salt as 78%NaCl, 10.5% MgCl2, 5% MgSO4, 3.9% CaSO4, 2.3% K2SO4, and 0.3% KB**.** Nevertheless, the ionic concentrations of Na+ and Cl**-** are the highest, in the Atlantic Ocean which typically contains 11000 and 20000mg/liter respectively.

3.1 Salt in Buildings

According to Olutoge and Amusan (2014), the earth surface is covered with about 80% ocean. This implies that a large number of structures are exposed to seawater with high salinity. Sena da Fonseca *et al*. (2013) opined that the issue of sea spray affecting buildings has been a major issue experienced in the coastal regions today**.** Salt can enter building materials in a variety of ways, including through the gypsum and alkali sulphates present in cement, mineralized groundwater that can permeate building materials, seawater spray, and de-icing agents that seep into building materials near the ground. Also, various coatings or treatments may also add to the type and quantity of salts present in a building material. When salts are added to some building materials, corrosion of metals and reinforcement within the building starts to appear (Department of Environment and Climate Change, 2008)**.**

Sena da Fonseca *et al.* (2013) explains that most cases of salt deterioration of buildings have been attributed to rising dampness from soils. Wilson (2003) further explains that the impacts of salinity on infrastructure in urban settings are broadly divided into two, these are; those caused by saline water supplies and those caused by saline water tables that have risen close to the soil surface. The use of building materials from such environment is also a source of impact in buildings (Folorunso, 2014). According to Salt Action (1999) increase in water tables usually bring moisture and salt close to the foundation of buildings. When this occurs periodically, it causes rising damp through capillary action especially when the areas are made of brick, stone or cement. Also, the severity of a rising damp problem will depend on the materials used, the amount of moisture and salt present, the amount of evaporation, and the effectiveness of the damp-proof barrier (Wilson, 2003).

Hill (1999) identified numerous factors that influence salinity on a building. These factors are; the intensity of use and rainfall, groundwater level, salinity concentration, and soil type. Department of the environment and climate change (2008) opined that amount of available water, the rate of evaporation and permeability of the building materials are three main factors driving the rate of water and salt entering a building. The amount of available water is influenced by the depth to the water table; the amount of water leaking from sewer and stormwater systems; the over watering of gardens; as well as the timing, distribution, and intensity of the rain. The rate of evaporation, on the other hand, is dependent on ventilation, temperature, relative humidity and the amount of building surface exposed to evaporative processes while the permeability of the building material depends on the size, distribution and continuity of the pores within a building material

3.2 Reaction of salt on building materials

Wilson (2003) explains that dryland salinity and rising saline water tables have long been recognised as a significant and worsening problem across many rural areas in the world today as this reduces agricultural production and damage the natural environment. However, the impact of salinity has been greatly felt in the built environment in recent times as it affects landscapes and public and private infrastructure. Jeannette (2011) explains that the issue of rising sea levels combining with fresh water resources has been a major issue of the coastal and saline environment.

This has proven to be a reason for the deterioration of buildings after a long period of time. As a result of this several coastal and offshore structures are continuously exposed to the action of physical and chemical deterioration processes. Department of environment and climate change (2008) asserts that when salt concentrates in water are absorbed by building materials, they are prone to physical and chemical damages. These effect ranges from mortar and bricks deterioration, rusting and corrosion of metals, the decay of wood among several others and this is a major problem existing in countries and places existing in the coastal regions of the world. Hence, in order to curb these effects, salt resistant building materials are manufactured today and these can be integrated into the modern building designs right from its conceptualisation and implemented during the course of construction. Also, the issue of a rising damp problem is one of the problems affecting buildings along the coast. As the building materials around these areas undergo periodic wetting and drying cycles, salt crystals often grow within their confined pore spaces. This might lead to the foundations of structures deteriorating rapidly causing a breakdown of their base and the deterioration of their surfaces (Hamilton, 1995).

Salt Reaction on Concrete

The presence of salt ions such as Na+Cl- or common salts usually affects the quality of concrete when mixed with sea water (Jordan, 2014). Preeti *et al.* (2014) explain that when water contains a considerable amount of chlorides, persistent dampness and surface efflorescence are bound to occur, hence, such water is not suitable for works that have to do with appearance such as plaster finishes. Olutoge and Amusan (2014) report that after exposing concrete cylinder to seawater, the part of the concrete remaining above high-tide lines would be vulnerable to cracking. This report was in line with Tibette (1968) research which reported that a huge number of structures made from concrete in United States, Canada, Cuba and Panama close to seawater are exposed to chemical deterioration. Akinkurolere *et al.* (2007) asserts that when one side of a concrete of a permeable solid is in contact with the salt solution and the other side is subjected to loss of moisture by evaporation, such concrete has a high tendency to deteriorate. This is due to the stresses caused by the crystallization of salts in the pores. Gopal (2010) further explains that due to the effects of chemical reaction of seawater constituents with cement hydration, crystallization pressure of salts within concrete especially when one face of the structure is subject to wetting and others to drying, frost action in cold climates, corrosion of reinforced steel embedded within the concrete and physical erosion due to wave action, may lead to deterioration of concrete structures.

Salt Reaction on Metal

The chemical reaction of salt on most metals leads to corrosion, According to Petrica *et al.* (2010) corrosion is a complex phenomenon which depends on the composition and structure of the metallic material, the nature and composition of the environment due to the chemical and electrochemical reactions and the conditions permitting the reaction to take place. Wilson and Laurie (2002) explain that rising level in saline water table has been the major cause of cast iron, brass, copper and galvanized iron water pipes corroding. Also, salt-laden moisture entering reinforced masonry through cracks, defects, or a thin masonry can cause the steel reinforcement to corrode and loss of strength. As a result of this, the choice of reinforcement material to be used in such a building project is important. Wilson and Laurie (2002) explain that an increase in the level of corrosion of metals has led to an increase in maintenance cost of such metals and also reduce their useful operating life over time. Among other metals, cast iron still remains the most corrosive and thus, limiting its usage in coastal areas.

Salt Reaction on Clay Bricks and Roof Tiles

Sena da Fonseca *et al.* (2013) asserts that materials derived from clay such as roof tiles and bricks when exposed to severe salt spray especially in coastal areas lead to degradation of such materials and this, in turn, leads to functional, aesthetic, economic and safety problems. Department of environment and climate change (2008) explains that in buildings faced with bricks, evaporation is likely to occur on the outside wall of the building and increase in evaporation will lead to greater concentration of salts within that part of the wall and leads to deterioration especially when there is continuous supply of water to such part of the wall. Also, salt solutions have the capacity to move through bricks and other silicate materials at different speeds leading to building up of the fluid in these materials and as such increase their damage (Bates, 2007).

Salt Reaction on Wood

Jones *et al.* (2011) explained that over time wood degradation occurs due to high salt concentration and this is usually regarded as salt killed wood or defibration. The initial and gradual deterioration of these woods is usually due to the presence of chlorine in the salt solution. This is further accelerated by the increase in salt concentrations, high moisture levels, high temperatures, mechanical abrasion, sunlight, pressure washing, and wave action. Techline

(2011) observes that as heating and drying of the salt solution occur due to exposure to direct sunlight, the water evaporates and this leads to the formation of salt crystals within the wood cells. Further physical forces exerted by the salt crystals on the wood leads to pushing of the wood fiber apart, thus, leading to the formation of a fuzzy wood.

The salt damage on wood can be reduced when oily preservatives such creosote are used as surface coats on them (Techline, 2011). This is because the oil acts as a barrier to salt movement within the wood. The use of chemicals such as creosote, bitumen, and creosote-coal tar solutions can effectively prevent the fuzzy of wood from taking place (Jordon, 2014). FEMA (2005) explains that after application of wood finishes in form of preservative chemicals such as wood should be prevented from direct contact with moisture and this better achieved by preventing the end grain cuts from being exposed as they absorb water 30 times faster than the sides of a wood member. However, the use of surface coats has not been fully considered effective in reducing the effect of salt damage on woods (Jones *et al*, 2011). This is because it is difficult to get a quality bond between the surface coating and the wood surface and also, salt water will continue to move upward within the wood structure, thus leading to deterioration of the wood underneath the coating. Thus, for effective resistant wood, proper kiln drying of wood is used in combination with a surface coating.

Salt Reaction on Paint

Painting of building is majorly to give the immediate environment a beautiful look and at the same time showcase the level of civilization, taste, and fashion of the people within that environment. However, more recent findings have proven that the application of paint on a building has the tendency to increase the lifespan of such building on buildings. This is possible due to some characteristic properties of paint and some modern additives that are included at the production stage of paints (Folorunso and Ahmad, 2013). Folorunso and Ahmad (2013) further explained that a continuous action of ocean wave at the coastal line of the Atlantic Ocean increases the humidity of the area and this means that buildings around the ocean are exposed to the constant influence of moisture. With the prevalent saline air and high humidity, the paint used on the external walls will gradually begin to absorb moisture while salt crystallization takes place. The action of salt crystallization and humid air combined will increase the rate at which the paint used on the surface absorbs the moisture which will lead to deterioration. Also, using paints as the exterior finish is subject to the stresses of the climate such as sun and rain and these causes quick deterioration of paint. However, the existence of saline air and endogenic salt in substrates in any environment will increase the rate of failure and frequency of repainting of building's exterior wall (Folorunso and Ahmad, 2014). It had been reported that deposit of salt on walls reduces the rate of evaporation and increases dampness (Viitanen and Ritschoff, 2011; Olaf, 2011) and causes the growth of efflorescence on painted walls (Hoang, Kinney, Corsi and Szaniszib 2010; Olaf, 2011). Hinks and Cook (2003) further asserted that moisture penetration which is a common feature in the coastal area is responsible for the loss of adhesion between the paint film and substrates and this leads to other defects such as blistering, cissing, blooming, chalking, bittiness, efflorescence growth, decolouration and peeling.

4. Resisting Salt Reaction on Building Materials

According to Techline (2011), the salt damage on wood can be reduced when oily preservatives such creosote are used as surface coats on them. This is because the oil acts as a barrier to oil movement within the wood. Jordan (2014) further asserted that the use of chemicals such as creosote, bitumen, and creosote-coal tar solutions can effectively prevent fuzzy wood from taking place. FEMA (2005) explains that after application of wood finishes in form of preservative chemicals such wood should be prevented from direct contact with moisture and this better achieved by preventing the end grain cuts from being exposed as they absorb water 30 times faster than the sides of a wood member. However, the use of surface coats has not been fully considered effective in reducing the effect of salt damage on woods (Jones *et al*., 2011). This is because it is difficult to get a quality bond between the surface coating and the wood surface and also, salt water will continue to move upwards within the wood structure, thus leading to deterioration of the wood underneath the coating. Thus, for effective resistant wood proper kiln drying of wood is used in combination with a surface coating (Jones *et al*., 2011).

The use of concrete in coastal areas has proven to be destructive, however, it is possible to minimise this problem during the course of building construction. According to the Department of environment and climate change (2008), one of the ways of improving the resistance of concrete to the salt reaction is the concrete duration and procedure. Preeti *et al.* (2014) explain that there is always an increase in strength in concrete if salt water is used for its casting and curing. An experiment carried out by Olutoge and Amusan (2014) proved that casting and curing mass concrete with seawater increases it compressive strength. However, Wegian (2010) submitted that the compressive strength of concrete mixed and cured in seawater increased at early ages up to 14 days, while a definite decrease was noticed for ages more than 28 days and up to 90 days. This reduction in strength increases with an increase in exposure time, which may be due to salt crystallisation formation affecting the strength gain. This implies that despite the increased early strength observed in concrete produces using seawater, there is a high tendency of failure due to a decrease in strength that is experienced over time when salt crystallisation starts to form within such concrete. To solve this problem, Cady (1986) earlier suggested the use of the lowest water/cement ratios mixtures in designing concrete structures to minimise stresses from thermal expansion and shrinking by using vapour barriers and coatings on concrete would help in decreasing the intensity of its damage from the salt action. Wegian (2010) further affirmed this suggestion by stating that Cement content in concrete mixes has a great effect on concrete strengths and durability and the increase of cement content can help improve the resistance of concrete to deterioration from seawater and salty solutions. It was further stated that the use of Sulphate Resisting Cement (SRC) will considerably help resist damage of concrete exposed to seawater.

The type of metal used in construction determines its resistance to corrosion. According to Jordan (2014) rate of corrosion in steel reduces with time while that of aluminum increases with time. This makes steel especially galvanized or stainless steel preferable in construction works than aluminum. Titanium still proves to be the most resistant metal to corrosion nevertheless, it is very expensive to purchase while lead does not corrode when moisture is added. Also, the application of protective coating such as epoxy and paints can be used in improving the resistance of metals to corrosion Jordan (2014). FEMA (2005) recommended the use of 0.75m thick G90 zinc coating to be applied on each face of metals to be used for construction works. Furthermore, in the construction of Reinforced concrete for suspended floors and other structural members, increasing the amount of concrete cover over steel reinforcement is necessary to reduce its exposure to corrosion (Department of environment and climate change, 2008).

The use of Polyethylene sheet and Poly Vinyl Chloride (PVC) are also effective salt controlling materials. A damp proof membrane helps in providing a layer that resists the upward movement of the salt water into the building from the ground. According to Department of environment and climate change (2008) for moisture control and prevention of salt attack on building a high impact polyethylene sheet of 0.2mm thickness should be laid under the floor slab of the building. This should also be laid around the footings of the building to the ground level. When Poly Vinyl chloride (PVC) is used as surface finishes they tend to prevent the absorption of moisture through them and this makes them useful in resisting salt. PVC of 5mm thickness is usually applied on surfaces of metal doors to prevent its corrosion. They are also useful in the construction of ceilings for buildings.

5. Lessons Learnt

Based on the review of existing literature, finding prove that one of the reasons for the degradation and deterioration of building materials around the Atlantic Ocean is due to the prevailing presence of saline air in the area. This could result in failure of the building materials used in the construction of such buildings (Akinsola *et al.*, 2012). Previous research has shown the possibility of concrete and metals deteriorating when in contact with saline air (Preeti *et al*, 2014; Olutoge and Amusan 2014; Akinkurolere *et al.*, 2007; Gopal, 2010). This study discovered that one of the possible reasons for structural failure in buildings present in areas around the coastline is the deterioration of reinforced concrete caused by a salt attack on concrete and steel reinforcements. This has become a contributing factor in the collapse of building structures experienced in some of these areas like in the case of Lagos State Nigeria (Awobodu, 2009; Tinuade and Qouzeem, 2016). This situation can be addressed through the use of SRC and low water/cement ratios mixtures in designing concrete structures. Increasing the cement content will improve the resistance of concrete to deterioration from seawater and salty solutions (Cady, 1986; Wegian, 2010).

Also, the moisture penetration which is a common feature in coastal areas is responsible for the loss of adhesion between the paint film and substrates and this leads to defects such as blistering, chalking, peeling among several others (Hinks and Cook, 2003). This definitely leads to the constant painting and repainting of buildings within these areas (Bliss, 2006; Folorunso and Ahmad, 2014). Salt crystallization in building materials has the tendency to cause structural failures in buildings, cracking of walls and deterioration of floorboards which at the end leads to building collapse in buildings along the coastline (Akande *et al.*, 2016). This assertion correlates with Bates (2007) submission on the effect of salt crystallization in masonry walls and Jones et al (2011) conclusion of the possibility of wood degradation due to salt- wood reaction. The effect of saline air on wood can be reduced through the use of oily preservatives such as creosote (Techline, 2011). Also, PVC can be used to control salt penetration into buildings by using them as surface finishes (Department of environment and climate change, 2008).

6. Conclusion and Recommendation

This study through a review of literature assessed the effect of salt on buildings along the coastlines and the possible ways of ensuring a reduction in the negative effect of this salt movement. The effect of salt on concrete, clay brick and tiles, metal, wood and paint were investigated in this study. Based on the findings, the study concludes that the prevailing presence of saline air within areas along the Atlantic Ocean is a major reason for the degradation and deterioration of building materials in the area. The salt attack on concrete and steel reinforcements leads to structural failure in buildings. Also, moisture penetration leads to blistering, chalking, and peeling of paints, which leads to constant re-painting of buildings within these areas. Cracking of walls, deterioration of floorboards and wood degradation are some of the effect of salt on buildings within the coastal areas. The study, therefore, recommends that if building in the coastal areas of Lagos State, Nigeria are to achieve better resistance to salt reaction within the area, then proper consideration should be given to environmental factors as they have a role to play when choosing the right building materials for buildings around the coast and this provides prior knowledge of the reaction of the building materials to salt. The use of SRC and low water to cement ratios mixtures in designing concrete structures will help improve the resistance of concrete to deterioration from seawater and saline air. Oily preservatives such as creosote should be used on woods to prevent the effect of saline air on them while PVC can be used to control salt penetration into buildings by using them as surface finishes.

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