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EFFECT OF CHEMICAL COMPONENTS ON THE TENSILE STRESS OF EMBEDDED MILD STEEL IN FRESHWATER, SEAWATER AND SEA SAND

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Abstract
The effect of the chemical components of Ibedu Lekki seawater on the tensile stress of embedded mild steel in three selected environments; fresh water, seawater and sea sand was investigated. Water analysis test was carried out on sample of seawater collected from Ibedu Lekki, Lagos State and fresh water collected from tap water from kwara state polytechnic, Ilorin. Samples of 12mm diameter (varied) mild steel were cut into 0.288m-0.352m lengths, surface cleansed with emery cloth and immersed in the various environments. The samples were taken to with the laboratory for corrosion rate test and tensile strength test. Corrosion rate test was carried out at 2 days interval for 10 days while tensile strength test was repeated subsequently for 42 days at 7 days interval. The results reveals that chemical properties of seawater such as Temperature °C ,pH, magnesium Mg^{2+}, chloride, Total Alkalinity, mg/L, Total dissolved solids, TSA, mg/L have their results greater than the permitted level which keeps the level of corrosion rate higher and faster. The corrosion rate and tensile strength test results shows that the loss of weight over time is more apparent in sea sand than in seawater and fresh water respectively. More also, the ultimate tensile strength reduces sharply with time in sea sand environment than seawater environment and fresh water environment being $377N/mm^2$, $439N/mm^2$ and $458N/mm^2$, respectively *due to the corrosion effect of the chemical components which could be the major cause of structural failures in buildings located in saline areas. A proper measure should be put in place if mild steel must be used in seawater and underground environment that might contains traces of ions that can easily react to produce acidic medium.*

Keyword: *Structural Steel, Seawater, Chemical Components, Corrosion, Environment.*

INTRODUCTION

One of the widely used building materials in the construction industry is steel (Akinkurolere, 2013). The behavior of structural steel is subject to various standards and codes established by agencies that define its specific shape, cross-section, chemical composition and mechanical properties. Steel's primary purpose in the building industry is to form a skeleton that holds everything together. Structural steel is mainly used as a reinforcement material to counter concrete's low tensile strength. Structural steel under prolonged influence of operational factors such as pressure, temperature, radiation and environment can lead to embrittlement as a result of thermal aging and fatigue as well as corrosion damage which leads to the degradation of the mechanical properties and eventually failure.

Mild steel is a low carbon steel where the carbon content is in the 0.004-0.3% range. Mild steel (iron containing a small percentage of carbon, strong and tough but not readily tempered), also known as plain-carbon steel and low-carbon steel is now the most common form of steel because it price is relatively low while it provides material properties that are acceptable for many applications. Mandal, (2015)

When a material is under tension it is known as tensile. The forces that are acting along the axis of force are responsible for the stretching of the material. The external force per unit area of the material resulting in the stretch of material is known as tensile stress. Tensile stress is the resistance of an object to a force that could tear it apart. Tensile stress measures the strength of a material; therefore, it refers to a force that attempt to pull apart or stretches a material. The maximum stress a material can stand before it breaks is called the breaking stress or the ultimate tensile stress. Many mechanical properties of a material can be measured by a tensile test. (www.physicsnet.co.uk, John, et al. (1999)). The resulting force-elongation graph (or stress-strain graph) for a steel specimen displays three distinct regions that represent the three different types of tensile strength: yield strength, ultimate strength and fracture strength. (www.physicsnet.co.uk)

Not only is steel affordable, readily available and safer, its intrinsic properties, such as strength, versatility, durability and 100% recyclability allow for improved environmental performance across the entire life cycle of buildings.(constructsteel.org). The advanced high-strength steels used in steel-plate applications also find uses in a number of related industries. Offshore oil rigs, bridges, civil engineering and construction machines, rail carriages, tanks and pressure vessels, nuclear, thermal and hydroelectric plants – all these applications benefit from the attributes of modern steel.

Saline water (more commonly known as salt water that contains a high concentration of dissolved salts mainly sodium chloride, chlorine, calcium, magnesium, potassium and sulfate. Salt water is an electrolyte which conducts ions, speeding up rusting. Akinkurolere, 2013 reported that salt solution acts as an electrolyte (any substance containing free ions that allows the substance to conduct electricity) allowing iron to lose electrons more easily and so speeds up the rusting process. Olutoge and Amusan, (2014) who further gave a distinction between fresh and sea water defines fresh water as 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.

The reduction in the tensile strength of structural steels (reinforcement) in a saline area have being attributed to action of the chemical components of salty water. This term is called corrosion according to Sundjono, et al.(2018). The earth surface is covered with about 80% ocean (Olutoge and Amusan, 2014). This implies that a large number of structures are exposed to seawater with high salinity especially structures in the coastal region. Salt can enter building materials in a variety of ways, including the gypsum and alkali sulphates present in cement, mineralized ground water that can permeate building materials caused by salt water supplies or by salt water tables that have risen close to the soil surface.

According to Salt (1999), increase in water tables usually bring moisture and salt close to the foundation of the building. The chemical reaction of salt on most reinforcements leads to corrosion. According to Sundjono, et al. (2018) 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) explains that raising 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 thereby causing reduction in the tensile strength. 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, especially the reinforcements in foundations used in this area Olutoge and Amusan, (2014).

Seawater is a relatively uniform saline solution consisting predominantly mixture of 96.5% water, 2.5% salts and small amount of other substances; sodium and magnesium chlorides dissolved in water (www.Britannica.com). Although many other soluble minerals are present in very small quantities, both the individual and cummulative effects of these minerals are so greatly overshadowed by the effect of the dominant chlorides that seawater can be considered equivalent to a 0.5N sodium chloride solution. Keith, (2008) .At this concentration, a sodium chloride solution is at a peak in corrosivity, acting more aggressively toward steel than at either higher or lower concentrations. Factors other than chloride concentration that affect corrosion in seawater include oxygen concentration, biofouling, water velocity and water temperature. Much of the world's magnesium is recovered from seawater, as are large quantities of bromine. In certain parts of the world, sodium chloride (table salt) is still obtained by evaporating seawater. Akinkurolere, (2013)

The six most abundant ions of seawater are chloride (Cl^-), sodium (Na^+), sulfate (SO_2^{4-}), magnesium (Mg^{2+}), calcium (Ca^{2+}), and potassium (K^+). By weight these ions make up about 99 percent of all sea salts. The amount of these salts in a volume of seawater varies because of the addition or removal of water locally (e.g., through precipitation and evaporation). The salt content in seawater is indicated by salinity (S), which is defined as the amount of salt in grams dissolved in one kilogram of seawater and expressed in parts per thousand. Salinities in the open ocean have been observed to range from about 34 to 37 parts per thousand (0/00 or ppt), which may also be expressed as 34 to 37 practical salinity units (psu).(Duxbury, et al. 2011)

Inorganic carbon, bromide, boron, strontium, and fluoride constitute the other major dissolved substances of seawater. Of the many minor dissolved chemical constituents, inorganic phosphorus and inorganic nitrogen are among the most notable, since they are important for the growth of organisms that inhabit the oceans and seas. Seawater also contains various dissolved atmospheric gases, chiefly nitrogen, oxygen, argon, and carbon dioxide. Some other components of seawater are dissolved organic substances, such as carbohydrates and amino acids, and organic-rich particulates. These materials originate primarily in the upper 100 metres (330 feet) of the ocean, where dissolved inorganic carbon is transformed by photosynthesis into organic matter. Duxbury, et al. (2011), Keith, et al. (2008)

Corrosion is a natural process that converts a refined metal into a more chemically stable form such as oxide, hydroxide, carbonate or sulfide. It is the gradual destruction of materials (usually a metal) by chemical and/or electrochemical reaction with their environment. In the most common use of the word, this means electrochemical oxidation of metal in reaction with an oxidant such as oxygen or sulfates. Corrosion degrades the useful properties of materials and structures including strength, appearance and permeability to liquids and gases. Duxbury, et al. (2011).

Wilson (2003), Tony,et al. (2001) 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. Sundjono, et al. (2018) 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 (Mokhtar and Swarmy, (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).

METHODOLOGY

Materials

12mm diameter samples of ild steel (samples varied between 0.288m-0.352m length and 9.5mm-11.20mm diameter), Weighing balance, Seawater, Fresh water, Sea sand, Plastic Containers, Measuring tape, Universal Testing Machine etc

Experimental Methods

Two tests were carried out on the 12mm samples of Mild steel:

1. Corrosion Rate Test
2. Tensile Strength Test

- **Corrosion Rate Test**

  The steel standard utilized was the ASTM G31: This standard is the recommended practice for laboratory immersion corrosion testing of metals. This recommended practice is based on NACE standard TM - 01 -69 "Test Method - Laboratory Corrosion Testing of Metals for the Processing Industries" which describes the procedures used for specimen preparation, apparatus, test conditions, methods of cleaning specimens, evaluation of results and calculations and reporting of corrosion rate.

  The shape of the mild steel rod is cylindrical, therefore, the surface area of a cylinder;

$$A=2\pi rL+2\pi r^2 \quad (1)$$

12mm Mild steel rod of the same dimensions were exposed to three environments; fresh water, seawater and sea sand. The samples were taken out, dried and weighed after 48 hour for 10 days. The weight loss for each sample was obtained using the weighing balance. While the difference in weights for each sample was then calculated. That is, the difference between the weights of each mild steel before and after each 48 hours of immersion of the samples in the different environments. (**Plate 1.0-2.0**)

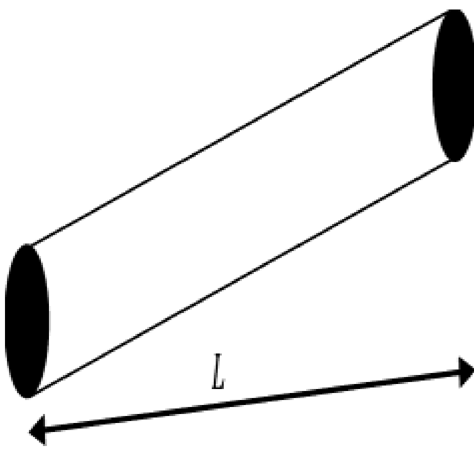

Plate 1.0: Shape of mild steel.

Plate 2.0: Measurement of Weight Loss

The most common method for estimating a corrosion rate from mass loss is to weigh the corroding sample before and after exposure and divide by the total exposed area and the total exposure time making sure that appropriate conversion constants are used to get the rate in the required units. The method in mm/yr can be represented by the equation **(2)**;

Final weight – Initial weight **(2)**

To provide minimum uncertainty in the corrosion rate, this method implicitly assumes: the corrosion rate does not vary with exposure time, the area does not change as mass is lost to corrosion, the projected and actual surface areas are the same, the penetration rate is uniform over the entire surface, the weight is unaffected by corrosion product removal.

Even assuming that the above criteria are fulfilled, errors can still be propagated because of the uncertainty in the measurement of time, mass, and dimensions.

The results obtained were then used for the analysis on the rate of corrosion.

- **Tensile Strength Tes**

The surfaces of the 12mm samples of Mild steel were finished with emery , measured and was immediately weighed. The samples were immersed into the different environments with ropes tied to them for means of easy identification. On each string and test bowl, a masking tape with labeled name of environment was pasted. The fresh water was gotten from tap water, Kwara State Polytechnic, Ilorin.

At 7 days interval for 42 days, the samples were taken out of the various environments. Tensile strength test was conducted using the Universal Testing Machine and readings were obtained. The difference between the initial length and final length before yield point or breaking point was recorded and used for the basis of our calculation. Such as tensile strength, peak load, elongation, tensile modulus and yield as shown in plate 3.0 and 4.0.

Plate 3.0: Samples embedded in Fresh water, Seawater and Sea sand.

Plate 4.0: Samples tested with Universal Testing Machine.

The results were obtained using equation **(3) as** follows:

Tensile stress= P/A **(3)**;

Where, P is the force
A is the area

RESULTS AND DISCUSSIONS

Physio-chemical analysis results of the seawater obtained from Ibedu Lekki, Lagos is as presented on Table 1.0. Corrosion rate of 12mm mild steel in fresh water, seawater and sea sand is presented on Figure 1.0, the Percentage Elongation Measurement of Steels in Length and Mass is presented in Tables 2.0-4.0 and the effect of fresh water, sea water and sea sand on the tensile stress of embedded mild steel is as presented on Figures 2.0-4.0.

Table 1.0: Water Analysis of the Chemical Components of Seawater Obtained from Ibedu Lekki ,Lagos State.

S/No	Parameters	Analytical Results Raw	Analytical Results Raw	Permitted level (NIS) 977:2017
1.	Temperature °C	**26.8**	**26.8**	-
2.	Color(units)	1.2	1.2	3
3.	Turbidity (N.T.U)	2.0	2.0	5
4.	Taste	Objectionable	Objectionable	Unobjectionable
5.	Odor	Odorless	Odorless	Odorless
6.	Electrical conductivity, us/cm	**1950**	**1950**	1,000
7.	pH	**8.21**	**8.21**	6.5-8.5
8.	Total dissolved solids, TSA, mg/L	**1170**	**1170**	500
9.	Filterable solids, mg/L	53.6	53.6	500
10.	Total Hardness, mg/L	**188**	**188**	100
11.	Total Alkalinity, mg/L	**142**	**142**	100

12.	Chloride, mg/L	**106**	**106**	100
13.	Sulphate, mg/L	52	52	100
14.	Nitrate, mg/L	2.6	2.6	10
15.	Nitrate, mg/L	0.03	0.03	0.02
16.	Sodium, mg/L	-	-	100
17.	Manganese, Mn^{3+} ,mg/L	-	-	0.1
18.	Manganese Mg^{2+}	**6.4**	**6.4**	2.0
19.	Iron, mg/L	0.4	0.4	0.3
20	Copper, Cu^{2+}, mg/L	Nil	Nil	1.0
21	Lead, pb^{2+}, mg/L	Nil	Nil	0.01

As presented on Table 1.0, certain parameters like Temperature °C ,pH, magnesium Mg^{2+}, chloride, Total Alkalinity, mg/L, Total dissolved solids, TSA, mg/L have their analytical results greater than the permitted level.

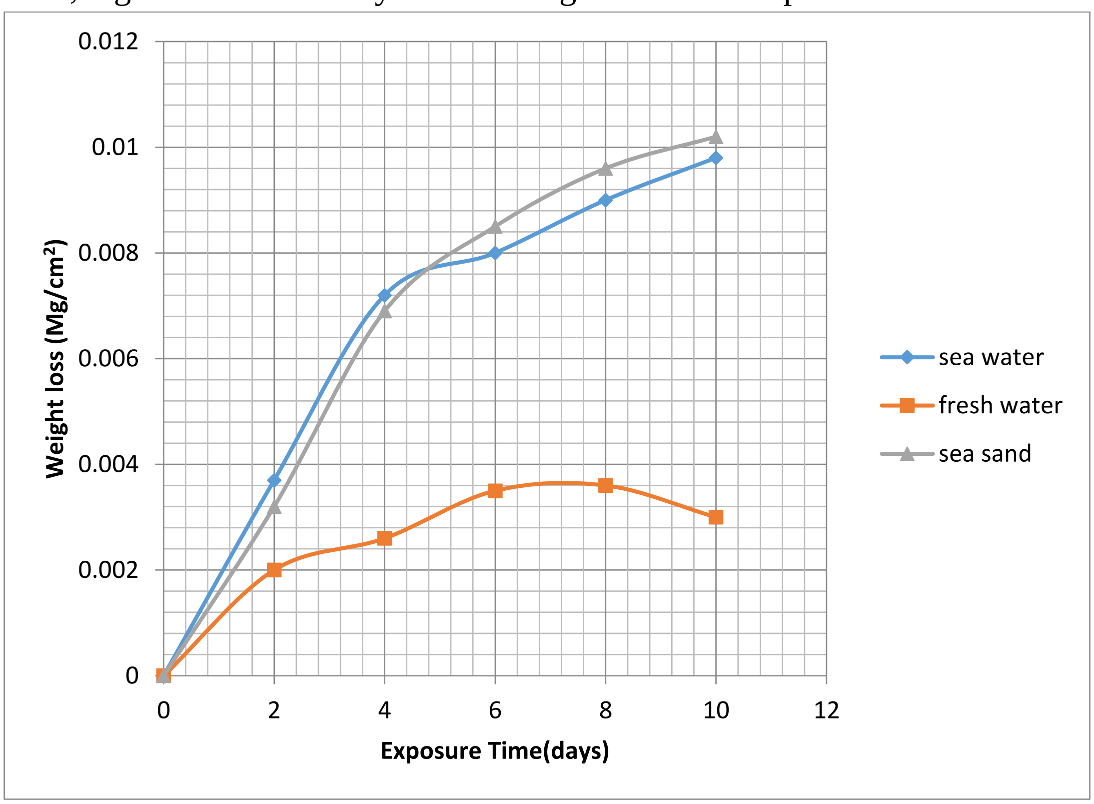

Fig.1.0: Corrosion Rate of 12mm Mild steel in Fresh water, Seawater and Sea sand.

Table 2.0: Percentage Elongation Measurement of Steels in Length and Mass (Fresh Water)

Mass(kg)	Length (m)	$\frac{mass}{length}$	Computed Area	Diameter (mm)
0.265	0.358	0.740	94.2	10.9
0.275	0.354	0.777	98.9	11.2
0.260	0.342	0.760	96.0	11.1
0.255	0.349	0.731	93.1	10.9
0.263	0.355	0.741	94.3	10.9
0.211	0.355	0.594	75.6	9.8
0.211	0.352	0.599	71.2	9.5
0.207	0.351	0.590	75.1	9.8
0.269	0.353	0.762	97.0	11.1
0.264	0.341	0.774	98.5	11.2
0.225	0.291	0.773	98.4	11.2
0.218	0.288	0.757	96.4	11.1
0.296	0.349	0.771	98.2	11.2
0.273	0.355	0.769	97.9	11.2

Table 3.0: Percentage Elongation Measurement of the Steels in Length and Mass (Seawater)

S/N	Mass(kg)	Length (m)	$\frac{mass}{length}$	Computed Area	Diameter(mm)
1.	0.270	0.352	0.767	97.7	11.1
2.	0.262	0.336	0.780	99.3	11.2
3.	0.212	0.350	0.606	77.2	9.9
4.	0.216	0.354	0.610	77.7	9.9
5.	0.269	0.349	0.771	98.2	11.2
6.	0.213	0.350	0.609	77.5	9.9
7.	0.251	0.353	0.711	90.5	10.2
8.	0.272	0.350	0.777	98.9	11.2
9.	0.275	0.344	0.799	101.7	11.4
10.	0.222	0.353	0.629	80.1	10.1
11.	0.275	0.356	0.772	98.3	11.2
12.	0.217	0.353	0.615	78.3	9.9
13.	0.269	0.347	0.775	98.7	11.2
14.	0.251	0.352	0.611	77.8	9.9

Table 4.0: 1st Yield Stress and Ultimate Yield Stress of 12mm Mild Steels in Fresh Water, Seawater and Sea Sand.

Environment	Fresh water		Seawater		Sea sand	
Time (days)	1st yield stress (N/mm^2)	Ultimate yield stress (N/mm^2)	1st yield stress (N/mm^2)	Ultimate yield stress (N/mm^2)	1st yield stress (N/mm^2)	Ultimate yield stress (N/mm^2)
1	224.6	356.66	273.85	374.6	315.4	**377.47**
7	258.05	368.76	361	**439.0**	260.75	347.58
15	317.75	374.70	310	377.13	315.4	377.47
21	356.1	**458.8**	291	430.1	260.75	332.45
28	273.7	365.65	296.4	390.4	315.4	330.47
35	261.5	374.73	299.6	423.17	260.75	258.66
42	275.35	377.36	311.6	436.72	315.4	252.47

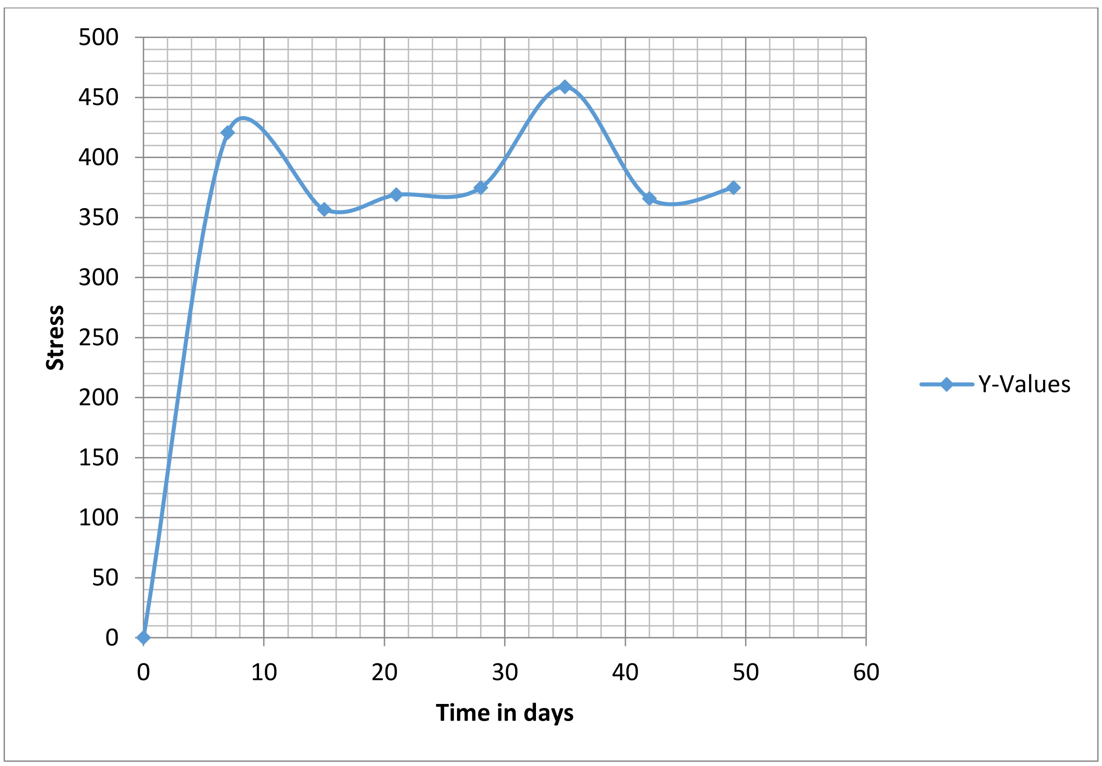

Fig 2.0: Effect of Fresh Water on the Ultimate Tensile Stress of Embedded Mild Steel

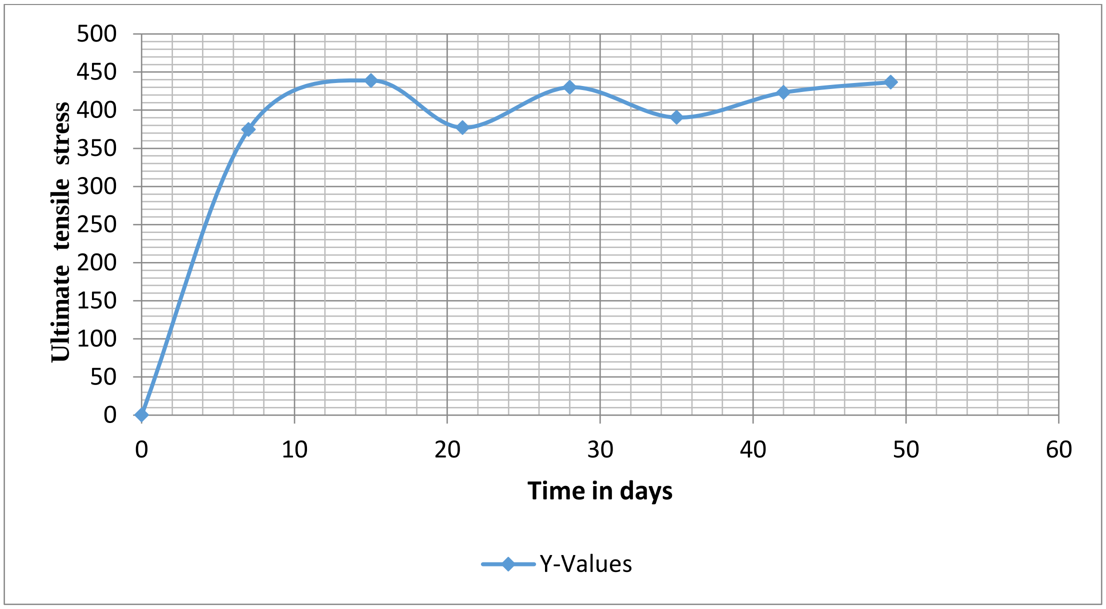

Fig 3.0: Effect of Seawater on the Ultimate Tensile Stress of Embedded Mild Steel

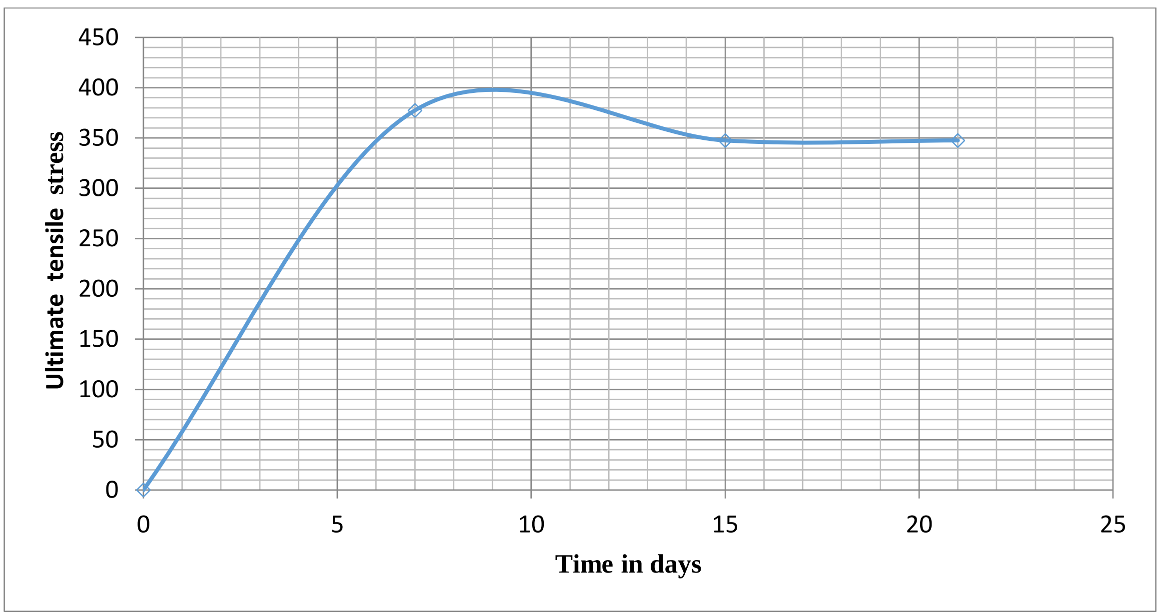

Fig 4.0: Effect of Sea Sand on Ultimate Tensile Stress of Embedded Mild Steel

Discussion of Results

Physical changes were observed on the behavior of mild steel during the experiment for corrosion rate test and tensile strength test. The samples exhibited different features in terms of color changes, surface texture changes, surface appearance changes, type and size of the corrosion products on the metal. The behaviors observed in the different environments are as follows;

Fresh Water

Within the range of seven days to fourteen days, the mild steel rod showed patches of grey corrosion products with light brownish water color. Also, the mild steel rod had shinny smooth grey surfaces with black patches at the edges. Within twenty-one days to twenty-eight days, the water appeared dark yellow with brown corrosion patches at the bottom of the bowl.

Seawater (Salt Solution)

By the end of the first seven days, the mild steel rod showed patches of grey and black on its surface. Between twenty-one days to twenty-eight days about 50 -80% of the surface became rough, with a hard brownish corrosion product, which when washed off left the surface with more black patches than the grey patches. Towards the end of the experiment, circular bumps were formed on the surface which when washed off exposed circular pits inside. The base of the pits was grey in color. The remaining surface was black. Generally by the end of the twenty-eighth days, the water appeared dark yellowish brown with brown particles at the bottom.

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Sea sand

The sample appears to have high corrosion rate starting from twenty-eighth days to thirty-five days when compared to the first twenty-eight days of the experiment.

The results of the corrosion rate loss obviously showed that corrosion occurred in the entire environments because weight losses were evident. The rate of corrosion for the various specimens varied increasingly in the following trend:, Fresh water, Seawater and Sea sand. The specimen in Seawater experienced chloride aggressiveness. The presence of halide ions break down any passive films available and can sometimes prevent passive films from forming on the mild steel rod. From fig.4.1, the mild steel in the sea sand also experienced high corrosion rates towards twenty-one days of immersion because of the presence of anaerobic bacteria and available oxygen accounted. It was observed that in the first fourteen days, the presence of micro-organisms made available the necessary corrosive media combined with the available oxygen, seawater pH while corrosion increased at a rapid rate. The corrosion rate observed for the samples in the fresh water was considerably low.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on this research work, the following conclusions were made;

- Physical appearance of mild steel is altered as the effect of corrosion is seen visibly in sea sand and seawater environments. Corrosion rate of mild steel will proceed at a faster rate in the presence of ions. The rate of corrosion is proportional to the time of exposure. Fig 1.0
- Organisms by their metabolic activities tend to provide corrosion stimulating ions especially in swampy areas and hence increases corrosion rate, hence the rate of corrosion of mild steel is faster in sea sand due to micro organisms by their metabolic activities, followed by sea water and fresh water.
- The chemical compositions of the sea water from (Table 1.0) presents like pH, Manganese, chloride, iron mg/L having their analytical results greater than the permitted level which keeps the level of corrosion rate higher and faster.
- Ultimate yield strength of mild steel in fresh water is higher than sea water & sea sand being 458N/mm^2, 439N/mm^2 and 377N/mm^2 respectively. (Fig 2.0-4.0) and Table 4.0

Recommendations

The following recommendations are hereby made;

- Mild steel should not be used in an environment with traces of high salinity.
- Mild steel tends to be suitable in fresh water but should be coated to achieve a useful service life and with minimum maintenance.
- Therefore, for the purpose of corrosion control, a proper measure should be put in place if mild steel must be used in seawater and underground environment that might contains traces of ions that can easily react to produce acidic medium.

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