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Evaluation of Metal Coupons Corrosions in Fresh Water Environment at Different Water Depths Using Finite Element Analysis

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Abstracts

This research addressed the effects of water depths and quality on corrosion of submerged metal structures in the water body considering environmental conditions. The depths considered were 30cm to 150cm. Four different metal coupons were selected (Mild Steel, Copper Steel, Carbon Steel and Stainless Steel] Galerkin`s finite element techniques was applied to evaluate the relationship between diffusion and weight loss, also velocity and weight loss at different water depths. The results reviewed that increase in corrosion rate followed the order 30cm <60cm < 90cm < 120cm <150cm for a specific time. Between 30 and 90 cm, mild steel decayed at the fastest rate, whereas stainless steel corroded at the slowest rate in that same range. The rate of copper coupon corrosion peaked between 120 and 150 cm. Galerkin's finite element method showed that the primary mediators of metal corrosion in the aqueous medium were diffusion and velocity.

Keywords: Metal coupons, fresh water environment, water depth, finite element analysis, corrossion

INTRODUCTION

Background of the Study

Corrosion damages a single metal layer when most or all of the protons on that surface become iodized. Iodization, which happens when metals lose electrons to oxygen and other molecules in the ground, air, or water, is a common occurrence for most metals. It lowers its oxygen and gets an electron. It creates an oxide by joining the metal. The complex process of copper, carbon, mild, and stainless steel corrosion in aquatic settings is influenced by a wide range of elements. Because of the physiochemical connection that exists between the metal and its surroundings, several of these conditions are known to induce corrosion of elements linked with aquatic environments [1-3].

When metals and the environment they inhabit interact, a process dubbed electrochemical decline takes place, which lowers a refined metal back to the original ore [4–7]. The technique may decrease the metal's utilitarian in addition to its strength. The degree of effect on the corrosion process can be altered by both living and nonliving biotic and abiotic microorganisms. Metals naturally corrode when they combine with oxygen to form metal oxides, in addition to dissolving in water that has very little dissolved salt. Water-borne ion dissolution is a term for this process. This process causes plumbing materials to incrementally disintegrate.

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Because corrosion impacts Nigeria's aquatic environment, atmosphere, and industrial processes, it has drawn a lot of scientific and engineering interest. In fact, the corrosion issue has become worse. The components and techniques used in industrial operations on natural water as well as the environment can cause metals to produce unstable forms involving oxide, hydroxide, and sulphite [8–14].

The Finite Element Method (FEM) has been applied in many engineering applications and analyses for both structural and non-structural slab issues. It may be used to study and evaluate the corrosion process of metal coupons in a water environment [15]. Before construction begins, it allows the designers to analyze both non- linear and linear issues based on the study's findings and assess any modifications using models. Among the many benefits of finite element approaches are their ability to regulate various load conditions and represent shapes that are odd.

Finite element method is a technique that allows numerically solve mathematical model of complex geometry, it is achieved by starting the governing equation and boundary conditions of the model in their integral form, the element of relative simple geometry are divided as model domain. The model's equation numerically solved for simple elements and the solution for whole model domain is then reconstructed as the addition of the contribution of each elemental environment properties. It can be defined independently for each element. Finite element method handles much more versatile approach, for modeling heterogeneous and dynamic environment. [16-18] Finite Element Analysis (FEA) is the method of forecasting and comprehending how an item could respond under different physical situations by using simulation, models, and mathematical calculations.

[19-20] demonstrated a Finite Element Method-based model in which the Laplace Equation was used as the governing equation with Butler-Volrner kinetics describing the electrochemical boundary conditions to calculate dimensionless potential and cathode shape changes during electrode corrosion.

[21-22], carried out a research work on finite element modeling of steel corrosion on concrete structures, and note that in the study a nonlinear finite element analysis program was developed called V.T- Multiphase. This program will enable multi-physics simulations, analysis of chloride-induced corrosion includes constitutive laws, element formulation and solution schemes that will allow the analysis of steady state and time dependent problems, that involve multiple coupled processes like mechanical deformation, heat transfer, mass flow and chemical reactions with adventive and diffusive transport of the various species. It was revealed that the analysis based on the streamline up wind Petrov-Galerkin method, also implemented to address spatial instabilities which characterize analysis of advection-dominated transport. Set of analyses was use to verify the capabilities of VT-Multiphase to conduct different type of simulations and reproduced cloud form analytical solution of simple cases. It further noticed that concrete failures is as a result of chloride – induced corrosion on steel in the concrete, chloride induced in concrete is a multi-physics phenomenon that is affected by water environment exposure conditions like ambient temperature, chloride transport across the surface of the concrete structure and humidity (Duo. 2010).

In conclusion a non-linear finite element analysis program (VT-Multiphasic) was used in the simulation of chloride induced corrosion in concrete structures, it was also proposed to be adopted as modeling scheme for heat conduction, chemical diffusion, moisture transport and also for preliminary verification, validation analysis finite element analysis was capable and satisfactorily proving to be good techniques.

[23-27] studied finite element simulation and prediction of mechanic electrochemical behavior on crevice corrosion in sheet pile of steel. In his study, finite element method was used for modeling crevice corrosion effect on sheet pile steel through a multi physics field coupling techniques, it was noted that why a tensile strain enhanced stress uniformly through the sheet pile steel, and increased depth of physics corrosion result in a concentrated stress of localized corrosion. If crevice corrosion is under an

elastic deformation, there will be no effect of mechanical/electrochemical interaction on corrosion and when the tensile strain is applied on the side of crevice, corrosion is enough to produced plastic deformation, corrosion activities will increased. It was concluded that finite element model developed to study mechanical/electrochemical effect of corrosion crevice of sheet pile steel through multi physics coupling simulation, the model enable simulations of the synergies of the stress concentration and localized corrosion on the sheet pile steel, increased longitudinal tensile strain and depth of crevice corrosion enhance local stress on the sheet pile steel but they do not similarly effect on the stress distribution, when the corrosion depth is under local elastic deformation, there is no apparent mechanical-electrochemical interaction affecting local corrosion. Increase depth of corrosion defect result in the concrete stress as crevice corrosion, if load is applied on the side of the geometry of the corrosion defect, more severe to cause a plastic deformation at crevice corrosion.

Helle, et al., developed a thorough finite element analysis using a Laplace approach for a galvanic corrosion system and indicated that Finite Element Method-based method showed advantages computational flexibility and accuracy over the discrete sink-source method in terms of general 2D and axisymmetric 3D cells. Forrest and Bicicchi as demonstrated the application of Finite Element Method for the design of the cathodic protection of bronze propeller: the Laplace equation based approach used boundary conditions of constant current density along the anode and linear polarization behaviour along the cathode to determine the optimized number and positions of sacrificial anodes needed for protection while minimizing power dissipation. [28-33] also used Finite Element Method-based Laplacian approach to give different examples of the uses of Finite Element Method modeling for design and analysis of cathodic protection in offshore or marine structures. He explicitly used a well-controlled, laboratory-scale corrosion cell to determine the accuracy of Finite Element Method modeling for calculating the potential distribution along a galvanic system. He and his co-workers later extended the Laplace Equation approach by defining a 'diffusional potential (Φ_i)" caused by concentration gradient together with existed electrolyte potential by electrostatic field. In order to calculates ions concentration distributions in the corrosion system, considering the diffusional potential. Laplace's Equation can be used for Finite Element Method development instead of full N-P Equation of the early Finite Element Method modeling efforts focused on galvanic interactions relevant to large marine/offshore infrastructure or lab-scale corrosion cell. There had been little numerical work focusing on the macro- or even micro scales relevant to localized corrosion such as pitting, crevice corrosion. Alkire, early work extended the use of Finite Element Method to the 2D shape change that occurs during electrode position, which is essentially corrosion in reverse, and noted that Finite Element Method would be useful for modeling of multiple reactions taking place in corrosion, though Finite Element Method was used in the electrode position study in 1989. Developed comprehensive Finite Element Method-based model to predict active pit and crevice propagation of carbon steel in a moderate concentration of sodium chloride solution; this model utilized a N-P based method to study the electrochemical distributions along the pit/crevice length and its changes over a long time period with the consideration of the effect of solution chemistry and electrochemistry. The work is a framework used to solve the complex set of N-P based equation rather than the Laplace Equation, and the comparison of model results to those from an experimental test. Later, there have been a great number of Finite Element Method-based modeling studies focusing on the modeling of pit or crevice corrosion initiation or propagation for better understanding of localized corrosion mechanisms. In addition, during 1990s, a number of studies considered the importance of the effect of electrode kinetics or surface properties as boundary conditions on the modeling prediction accuracy for pitting/crevice corrosion [34-40].

Vijay 2022, published a research work on finite element analysis (FEA) and it was defined as the process of using mathematical calculation models and simulations to understand and analyze. To predict the behavior of an object, parts or structure under various physical conditions, the article observes finite element analysis in details, the uses and how it works with the use of software to enables engineer uses finite element analytic. That model physical forces that helps to identify vulnerabilities in the design of their product prototypes, it enable engineers to localize design problems and optimize the components, thereby streamlining the design phase of the product, potential design may revert to identifying overheating parts, weak sports or area of tension, technically finite element analysis is used to breakdown the structure of an object into multiple elements and manageable portions, which are reconnected through point called nodes finite element methods generate a series of algebraic equations that engineers, scientist and designers use to performs that finite element analysis of any structure. Finite element analysis use in mathematical context physical features of a product such as structural appearance fluid behavior, or thermal coefficient are illustrated by employing partial differential equations (PDE), finite element analysis enable computer and machines to find solutions for linear and nonlinear differential equation and also its offer numerical approach in handling partial differential equation and the capabilities of finding approximate result. It significantly reduces the number of experiments performed and prototypes created that are necessary to optimize the design product component [41-45].

The overall goal of this study can be achieved through the following objective:

- Determine and examine the functional parameters that influence metal corrosion in fresh water environment using Galerkin's finite element techniques
- Determine the weight loss of the metals coupon at different water depths and calculate corrosion rate.
- Examine and evaluate the rate of metal corrosion at different depth

The assessment of metal corrosion is a critical task in the oil and gas sectors. Predicting metal corrosion at varying depths in aquatic environments requires a solid understanding of the corrosion process.

MATERIALS AND METHODS

The experimental work is to study the evaluation of metals corrosion rate in fresh water environment at different water depths. Four metals were selected (Carbon Steel, Stainless Steel, Mild Steel and Copper Steel), The experiment was carried out at normal room temperature (28 ± 0.5) and precautions were taken to obtain excellent result, based on the understanding of the research work.

Materials

The materials needed were Carbon Steel, Stainless Steel, Copper Steel, Mild Steel, boat, life vest, analytical balance, brush or sponge, reagents, fresh water environment at different depths (30cm, 60cm, 90cm, 120cm and 150cm).

Metal sample

The selected metals (carbon steel, mail steel, copper steel and stainless steel) used for this investigation were purchased from Mile 3 Building Market and was transported the Department Chemical/Petrochemical Engineering Laboratory for preparation and taken to site for the field submerged

Experimental set - up

The experimental were set – up in accordance to the design concept of weighing the materials and introducing them into the various water depths in the fresh water environment. The experimental set up were to meet with the aims and objectives to check and observes the following.

1. Metals Corrosion
2. Weight loss
3. Corrosion rate determination

Methodology

The metals were cut into sizes and rectangle in shapes, the thickness of the metals were considered, in the variation from 1mm to 2mm the metals were smooth file and sand paper as to dress the edges, a medium to removed rough filling to avoid accelerate corrosion.

Each metal was washed thoroughly in distilled water and brush and dried, all metal is store in plastic bags, a hole was made at the edge of each metal as to insert a rope and take to the site for immersion in the fresh water at different depths. The metals will be brush and wash with the water at site for field experiment, every month, three (3) months interval, the metals will be retrieved from the water with use rope attached to metals, and the weight will be check and recorded, these will be repeated for duration of eighteen (18) months. All metals were weighed to check their initial weight this was done using analytical weight balance, the readings were recorded accordingly. The weight of each metal coupon were recorded,

Arrangements for corrosion check experiment. Each metal was suspended in the fresh water at various depths at site, through a supporting rope and tight to a stopper, since the water has current (Tidal water) ensure uniform contact of the water for proper submerge as shown in the picture.

The fresh water was at The New Calabar River, Choba in Obio/Akpor Local Government Area of Rivers State, with the coordinate of 4.8121192; 6.8452748. The metals coupons were introduced in the fresh water at different depths with a supporting rope as to suspend it for immersion and removal.

The initial mass, volume and densities of the selected metals i.e. Carbon Steel CBS-D, Stainless Steel SST-C, Mail Steel MS-B and Copper Steel CPS-A, will be determined and recorded before the experiment

The following parameters will be observed and analyzed:

- Metals weight loss: the change in weight of metal at the time will be observed and a model will be used to predict the corrosion rate.
- Rate of corrosion: the change in weight of metal and surface area change will be analysed as metals exposed per unit using the equation.

$$C_R = \frac{534\Delta W}{\rho \text{At}} \tag{1}$$

Where:
C_R = Corrosion rate (mm/day)
W_O = Initial weight of material (gm)
W_t= Instantaneous weight of material (gm)
Þ= Density of material (gm/mm^3)
A = Cross sectional area of materials (mm^3)
t = Time

Calculation of Corrosion Rate

Corrosion rate is best expressed in terms of thickness or weight loss where the surface of the metal corrodes uniformly across the area that has been exposed.

It can be expressed as:

$$R = \frac{d}{E}\left(\frac{min}{y}\right) \tag{2}$$

But this work can be expressed as weight loss $\frac{g}{m^2}$

Corrosion rate from metal loss data

$$R_{corr).mm/yr)} = \frac{87.6\ x\ w}{DHT} \tag{3}$$

Where
W_L = Weight loss in milligrams

D = Metal density in g/cm^3
H = Area of sample in cm^2
T = Time of exposure of the metal samples in hours

Alternatively,

$$C_R(mpy) = \frac{10\ x\ 365}{A\ x\ T\ x\ D} \quad (4)$$

Where
W = Weight loss,
A = Area
D = Density
T = Time

Application of Finite Element Analysis Using Galarkin's Model Concept

Using experimental data analysis, in order to obtain a numerical solution to differential equation using Galerkin's finite element method (GFEM), the domain is subdivided into finite elements, the function is approximated piecewise trial functions over each of these elements.

The Galerkin's deals with mass transfer of functional Parameters with the use of finite element techniques. The Gelerkin's finite element approach was adopted in the work due to the determination of the linear shape characteristics of the various metals considered in this investigation. Linear shape characteristics techniques were used for the formulation based on the Galeikin's approach, the mathematical expression is shown as

$$C_R(x) = N_{i+1}^e C_{Rei} + N_i^e C_{ei+1} = [N]C_{RR} \quad (5)$$

Where, N_i^e is shape function or approximation function where

Where

$$N_i^e = 1 + \frac{W_{Lt}}{W_L} \quad (6)$$

As well as

$$N_i^e + 1 - \frac{W_{Lt}}{W_L} \quad (7)$$

It is necessary to examine the linear shape functions of element (e), at $i + 1$

The weighted approach was used develop the element equation using the Galerkin's weighted resistant method. This technique was the mechanism used in resolving the mathematical expression of equation (5). Therefore applying the concept into equation (5) we have

$$\int_0^{WL} N^T \left(D_y \frac{d^2 C_{Re}}{dx^2} - u_x \frac{d^2 C_{Re}}{dx} - \frac{dC_R}{dt}\right) dx = 0 \quad (8)$$

where N^T is –transpose shape function, or inverse domain transpose Parameters using the technique o£ finite element [46].

Development of Corrosion Rate Model and Functional Parameters using Galerkin's Finite Element Techniques

Mathematical model was developed to predict the corrosion rate and functional parameter concentration and their contribution towards the process. The individual terms of equation (8) will be evaluated using the line shape functions, finite element approach which can be sub-divided into three groups as state as:

Group 1: Evaluation (Diffusion)

$$\int_0^{W_L} N^T \partial y \frac{d\mathrm{C}_{Re}{}^2}{dx} = \int_0^{WL} N^T \partial y \, d\mathrm{C}_{Re} \left(\frac{dc_{Re}}{dx}\right) = 0 \tag{9}$$

$$= \int_0^{WL} N^T \partial y \; \frac{d\mathrm{C}_{Re}}{dx^{e^{dx}}}$$

Inline $dx^e = \frac{dx^2}{d\mathrm{C}_{Re}} or \; {}^{dx}/_{dx^e} = \frac{dc_{Re}}{dx}$

$$\therefore \int_0^{W_L} N^T \partial y \frac{d\mathrm{C}_{Re}}{dx^e} dx = \partial y \int_0^{WL} N^T \frac{d\mathrm{C}_{Re}}{dx^e} dx$$

$$Dy \int_0^{WL} N^T dx \; \frac{dc_{Re}}{dx^e}$$

$$= \mathrm{Dy}\int_0^{W_L} N^T \, dx \; \int_{\mathrm{C}_{Re_1}}^{\mathrm{C}_{Re_2}} \frac{d\mathrm{C}_{Re}}{dx^e}$$

Inline $N^T = I_n(x)$

$$\therefore \int N^T = \left[{}^{1}/_{x}\right]_0^{WL}$$

$$= \frac{\partial y}{WL} \int_{\mathrm{C}_{Re_1}}^{\mathrm{C}_{Re_2}} \frac{d\mathrm{C}_{Re}}{dx^e} = \frac{\partial y}{WL} \int_{\mathrm{C}_{Re_1}}^{\mathrm{C}_{Re_2}} \frac{1}{\Delta x_e} d\mathrm{C}_{Re}$$

$$= \frac{\partial y}{WL} [\Delta x^e]_{\mathrm{C}_{Re_1}}^{\mathrm{C}_{Re_2}}$$

$$= \frac{Dy}{WL} \begin{bmatrix} \mathrm{C}_{Re_1} - \mathrm{C}_{Re_2} \\ \mathrm{C}_{Re_2} - \mathrm{C}_{Re_1} \end{bmatrix}$$

$$= \frac{dy}{WL} \begin{bmatrix} \mathrm{C}_{Re_1} - \mathrm{C}_{Re_2} \\ \mathrm{C}_{Re_1} + \mathrm{C}_{Re_2} \end{bmatrix}$$

$$= \frac{dy}{WL} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} \mathrm{C}_{Re_1} \\ \mathrm{C}_{Re_2} \end{bmatrix} \tag{10}$$

Group 2: Evaluation (velocity rate)

Evaluation of Group 2

$$\frac{d^2\mathrm{C}_{Re}}{dx^2} \longrightarrow 0 \; \& \; \frac{d\mathrm{C}R}{dt} \rightarrow 0$$

$$\therefore \int_0^{W_L} N^T \left(\partial y \frac{\partial^2 \mathrm{C}_{Re}}{\partial x^2} Ux \; \frac{d\mathrm{C}_{Re}}{dx} - \frac{d\mathrm{C}_{Re}}{dt} \right) dx$$

$$= \int_0^{W_L} N^T \left(-Ux \; \frac{d\mathrm{C}_{Re}}{dx} \right) dx = Ux \int_0^{W_L} -N^T \left(\frac{dx}{dx^e} \right) dx \tag{11}$$

$$= -Ux \int_0^{W_L} N^T dx \int_{\mathrm{C}_{Re_1}}^{\mathrm{C}_{Re_2}} {}^{1}/_{dx^e} \, dx$$

$$= U_x \int_0^{W_L} N^T dx \int_{\mathrm{C}_{Re_1}}^{\mathrm{C}_{Re_2}} {}^{1}/_{\Delta x^e} \, d\mathrm{C}_{Re}$$

$$= \frac{Ux}{2}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}\begin{bmatrix} C_{Re_1} \\ C_{Re_2} \end{bmatrix} \quad (12)$$

Evaluation for Group 3: (corrosion concentration)

Let $\frac{\partial^2 C_{Re}}{dx^2} \rightarrow 0$ & $\frac{dC_{Re}}{dx}\, Ux \rightarrow 0$

$$\therefore \int_0^{W_L} N^T \left(\partial y \frac{\partial^2 C_{Re}}{\partial x^2} - Ux\, \frac{dC_{Re}}{dx} - \frac{dC_{Re}}{dt}\right) dx$$

$$= \int_0^{W_L} N^T \left(\frac{-dCR}{dt}\right) dx \; when \frac{dCR}{dt} = \frac{L}{6}\left(C_{Re_2} + {}^{1}/_{\Delta x^e}\right)$$

$$= \int_0^{W_L} N^T = \int_{C_{Re}}^{C_{Re_2}} {}^{L}/_{\sigma} \left({}^{1}/_{\Delta x^e}\right) dx$$

$$= - {}^{L}/_{6} \int_0^{W_L} N^T dx \int_{C_{Re_1}}^{C_{Re_2}} \left(C_{Re_2} + {}^{1}/_{\Delta x^e}\right) dx$$

Let $\int_0^{W_L} N^T dx \rightarrow 1$

$$= -{}^{L}/_{6} \int_{C_{Re_1}}^{C_{Re_2}} \left(C_{Re_2} + {}^{1}/_{\Delta x^e}\right) dx$$

$$= -{}^{L}/_{6} \begin{bmatrix} C_{Re_2} + C_{Re_2} + C_{Re_1} \\ C_{Re_1} + C_{Re_2} + C_{Re_1} \end{bmatrix}$$

$$= -{}^{L}/_{6} \begin{bmatrix} 2C_{Re_2} + C_{Re_1} \\ C_{Re_2} + 2C_{Re_1} \end{bmatrix}$$

$$= -{}^{L}/_{6} \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}\begin{bmatrix} C_{Re_1} \\ C_{Re_2} \end{bmatrix} \quad (13)$$

Combining equation (3.10) and (3.12) we have the mathematical expression stated in equation (13)

$$\frac{D_t}{W_L}\begin{bmatrix} 1 & -1 \\ -1 & 2 \end{bmatrix}\begin{bmatrix} C_{Re1} \\ C_{Re2} \end{bmatrix} - \frac{u_t}{2}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}\begin{bmatrix} C_{c1} \\ C_{c2} \end{bmatrix} + \frac{L}{6}\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}\begin{bmatrix} C_{Rc1} \\ C_{Rc2} \end{bmatrix} = 0 \quad (14)$$

Considering $K_1 = K/v$ and $K_2 = \frac{Ux}{2}$ that is, the rate of corrosion is dependent of diffusion and velocity of influence factors, where $V = dw/dt, K = v/t, K2 = K/2.$

Using Gauss Elimination; Consider the finite element concept. The matrix is in the form

$$\begin{bmatrix} a_{11} & a_{12} & a_{13}\, a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23}\, a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33}\, a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43}\, a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53}\, a_{54} & a_{55} \end{bmatrix}\begin{bmatrix} C_{e1} \\ C_{e1} \\ C_{e1} \\ C_{e1} \\ C_{e1} \end{bmatrix} = \begin{bmatrix} WL_1 \\ WL_2 \\ WL_3 \\ WL_4 \\ WL_5 \end{bmatrix}$$

Let equation (1) be represented as

$$[x][y] = [\, z \,]$$

Where:

$$\therefore [x] = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & 1 & 1 & 1 & 1 \\ a_{41} & 1 & 1 & 1 & 1 \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix}$$

Where:

$a_{11} = K_1 + K_2,\ a_{12} = K_1 - K_2,\ a_{13} = a_{14} = a_{15} = 0$

$a_{21} = -K_1 + K_2,\ a_{22} = 2K_1,\ a_{23} = -K_1 - K_2,\ a_{24} = a_{25} = 0$

$a_{31} = a_{35} = 0, a_{32} = -K_1+K_2,\ a_{33} = 2K_1,\ a_{34} = -K_1+K_2$

$a_{41} = a_{42} = 0, a_{43} = -K_1+K_2\ a_{44} = 2K_1,\ a_{45} = -K_1+K_2$

$a_{51} = a_{52} = a_{53} = 0, a_{54} = -K_1+K_2,\ a_{55} = -K_1 - K_2$

$[x][y] = [Z]$ become

$$\begin{bmatrix} a_{11} & a_{12} & 0 & 0 & 0 \\ a_{21} & a_{22} & a_{23} & 0 & 0 \\ 0 & a_{32} & a_{33} & a_{34} & 0 \\ 0 & 0 & a_{43} & a_{44} & a_{45} \\ 0 & 0 & 0 & a_{54} & a_{55} \end{bmatrix} \begin{bmatrix} C_{e1} \\ C_{e1} \\ C_{e1} \\ C_{e1} \\ C_{e1} \end{bmatrix} = \begin{bmatrix} WL_1 \\ WL_2 \\ WL_3 \\ WL_4 \\ WL_5 \end{bmatrix}$$

The details were in appendix N
Therefore, The Galerkin's concept for Homogeneous

$$\begin{vmatrix} K_1 + K_2\ K_1 - K_2\ 0\ 0\ 0 \\ -K_1 + K_2\ 2K_1\ -K_1 - K_2\ 0\ 0 \\ 0\ -K_1 + K_2\ 2K_1\ -K_1 + K_2\ 0 \\ 0\ 0\ -K_1 + K_2\ 2K_1 - K_1 + K_2 \\ 0\ 0\ 0\ -K_1 + K_2 - K_1 - K_2 \end{vmatrix} \begin{vmatrix} C_{e1} \\ C_{e2} \\ C_{e3} \\ C_{e4} \\ C_{e5} \end{vmatrix} = 0 \tag{15}$$

where K_1 is the relationship between Diffusion and weight loss contributed upon the influence of the physiochemical parameters and K_2 is the relationship between velocity divided by 2 obtained from-the integration of second term of evaluation of group 2 upon the-influence of the physicochemical parameters.

The relationship in terms of weight loss leading to corrosion interaction can be expressed mathematically as heterogeneous.

$$\begin{vmatrix} K_1 + K_2\ K_1 - K_2\ 0\ 0\ 0 \\ -K_1 + K_2\ 2K_1\ -K_1 - K_2\ 0\ 0 \\ 0\ -K_1 + K_2\ 2K_1\ -K_1 + K_2\ 0 \\ 0\ 0\ -K_1 + K_2\ 2K_1\ -K_1 + K_2 \\ 0\ 0\ 0\ -K_1 + K_2 - K_1 - K_2 \end{vmatrix} \begin{vmatrix} C_{e1} \\ C_{e2} \\ C_{e3} \\ C_{e4} \\ C_{e5} \end{vmatrix} = \begin{vmatrix} WL_1 \\ WL_2 \\ WL_3 \\ WL_4 \\ WL_5 \end{vmatrix}$$

C_{Re} is the corrosion concentration of the sample upon the influence of the environment *investigated.*

RESULTS AND DISCUSSIONS

The results obtained from the investigation of metals corrosions (copper steel, mild steel, carbon steel and stainless steel) evaluation at different water depths in fresh water environment (the new Calabar River) were presented in graphs and tables. All experimental data were shown in Appendices. But due space it were reduced

Weight lost Analysis Result of Metals Coupons in Different Water Depths in Fresh Water Environment over Period of Exposure

Analysis of weight loss were over 18 months period at interval of three months, Figures 1 to 4 contained the graphs which showed the trend of metals coupon decrease in weight loss.

Figure 1 below shows the relationship between the weight loss of various metals coupon and time (months) or period of exposure in fresh water environment at 30cm depth, while Figure 2 below shows the illustration in relationship between the weight loss of various metals coupon and time (months) or period of exposure in fresh water environment at 60cm depth. The increase in weight loss of the metals coupons increased with increased in period of exposure, it indicated that there is reaction at the interface where the metals and fresh water environment contact and the more the contact the corrosion increase. The decrease in the weight of metals with increased time of exposure could also be attributed to the actions of physiochemical properties in the fresh water at 30cm depth which also revealed the variations in the concentration of the physiochemical parameters and their interactions the environment. It is also important to note that temperature, electrical conductivity density and pH of the water influence the corrosion of metals.

The regression curve for each of the metal coupon are respectively obtained as $Y = 0.1323x - 0.4349$, with coefficient determination as $R^2 = 0.8637$. $Y = 0.2597x - 0.7051$, with the coefficient determination as $R^2 = 0.8637$. $Y = 0.0591x - 0.2413$, with the coefficient determination as $R^2 = 0.9458$. $Y = 0.1365x - 0.6347$, with the coefficient determination as $R^2 = 0.9137$. Respectively for CPS-A, MS-B, SST-C, CBS-D. The weight loss as shown were in order of MS > CBS>CPS >SST. The R^2, showed that the equations fitted well with experimental results.

The questions of the curve for Figure 2 obtained from each metals corrosion at 60cm as influence on the period of exposure are express as CPS-A: $y = 0.0963x - 0.3312$, with the coefficient of the best fit given as $R^2 = 0.9496$, MS-B: $y= 0.2287x - 0.9193$, with the coefficient of the best fit given as $R^2 = 0.9614$, SST-C: $y = 0.0351x - 0.189$ with the coefficient of the best fit given as $R^2 = 0.7643$, CBS-D: $y = 0.0915x - 0.3922$, with the coefficient of the best fit given as $R^2 = 0.8869$

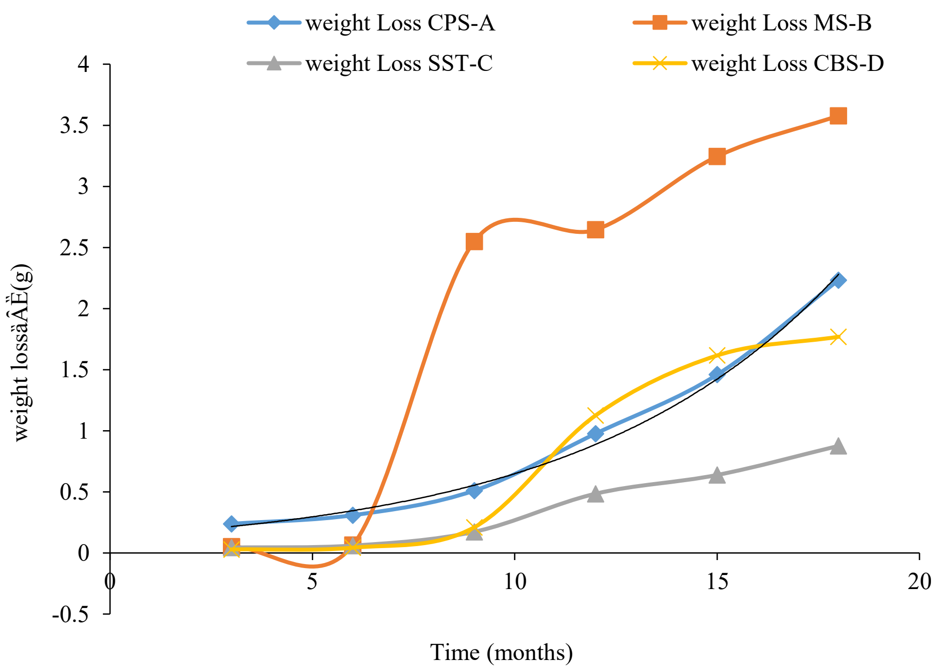

Figure 1. Trend of metals coupon decrease in weight loss (30cm).

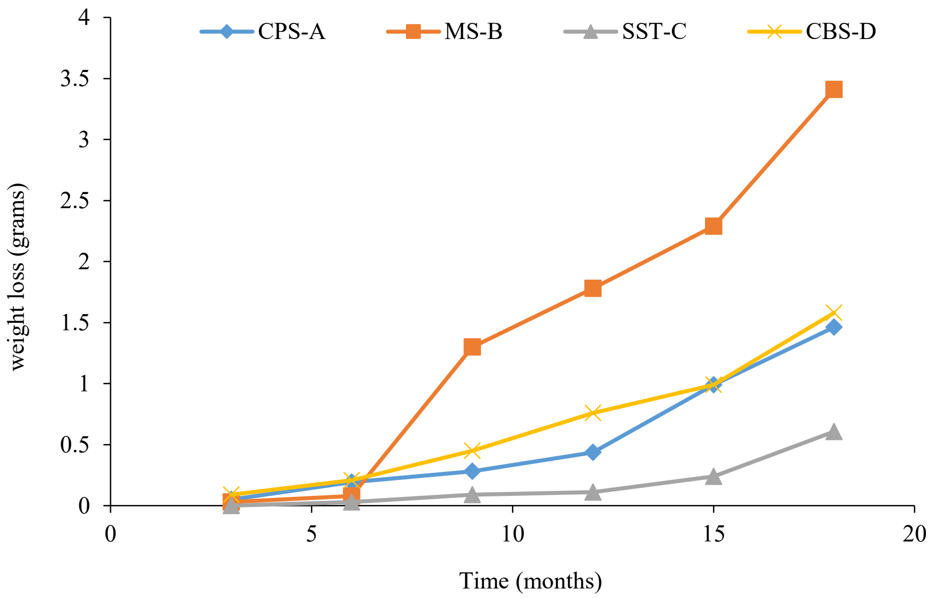

Figure 2. Trend of metals coupon decrease in weight loss (60cm).

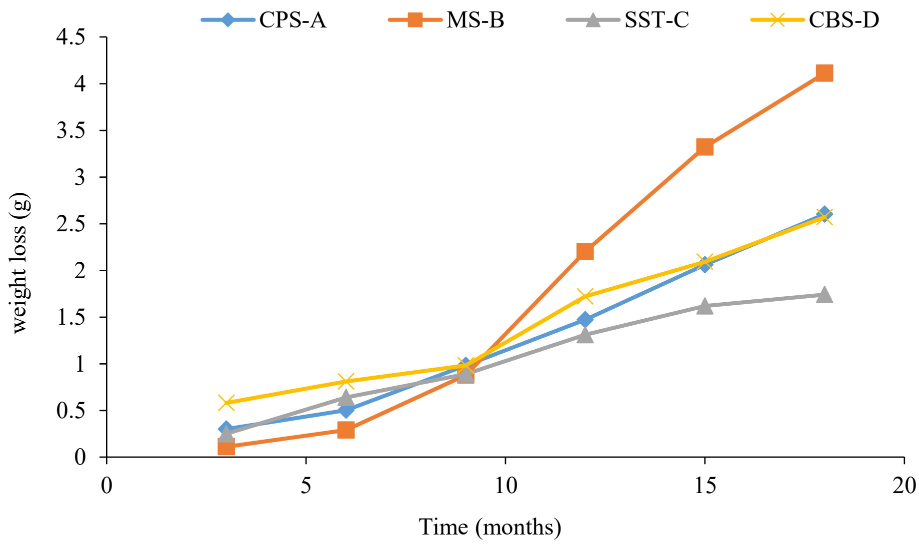

Figure 3. Trend of metals coupon decrease in weight loss (90cm).

The weight loss as shown were in order decrease of MS >CPS >CBS >SST. The R^2 showed the model fitted well with experimental result. Figure 3 illustrates the profile relationship between the weight loss of various metals coupons and time (months) or period of exposure in fresh water environment at 90cm depth. Figure 4 Illustrate the profile relationship between the weight loss of various metals coupons and time (months) of exposure in fresh water environment at 120cm depth. From the analysis it can be seen that water quality decreases with decrease in depth. At 120cm depth there was rapid corrosion of carbon steel, copper steel and mild steel and the weight losses were higher than stainless steelThe result showed that 90cm depth the corrosion of stainless steel, carbon steel and copper steel were faster than that of mild steel between three (3) and six(6) months. The reduction in weight of the metals coupons was gradual for the four metals between three (3) to nine (9) months, with the increase in period of exposure. The rapid corrosion on mild steel between ten (10) and eighteen (18) months resulted in an increase weight loss of mild steel. This result shows that there was reaction in the interface between metals and fresh water environment. The weight loss was observed to increase as the period of exposure increased under the influence of fresh water environment. The four materials copper steel, mild steel, carbon steel and stainless steel, experienced reductions in weight as the months of immersion in fresh water environment increased. The decrease in the weight of metals as increased time of exposure could be attributed to the variation in the fresh water environment. The actions of physiochemical properties in the fresh water influenced the corrosion of the various metals at 90cm depth, which also revealed, the variations in the concentration of the physiochemical parameters and their interactions. The temperature, electrical conductivity, density and pH of the water influenced the corrosion of metals, thereby resulting to their weight losses. The activities of microorganisms as characterized from the various depths of fresh water sample revealed the contribution of microbial action on metals corrosion. The change in weight loss was attributed to the time of exposure. The weight loss increased with the time of exposure increased. The questions of the curve obtained from each metals corrosion as influenced by the period of exposure are expressed as CPS-A: $y = 0.1587x - 0.3473$, with the coefficient of the best fit given as $R^2 = 0.9835$, MS-B: $y= 0.2896x - 1.2227$, with the coefficient of the best fit given as $R^2 = 0.9582$, SST-C: $y = 0.103x - 0.006$, with the coefficient of the best fit given as $R^2 = 0.9828$, CBS-D: $y = 0.1384x + 0.0053$ with the coefficient of the best fit given as $R^2 = 0.9655$. The weight loss as shown were in order decrease of MS >CPS >CBS >SST. The R^2 showed the simulation fitted well with experimental result

Corrosion Rate Analysis of Various Metals Coupons Versus Period of Exposure at Different Depths

The corrosion rate of various metals material sampled and the period of exposure in fresh water environment were observes, the graphs below demonstrate the effects of water quality and properties at different depths (Figures 5–8). Showed the corrosion rate of four (4) metals coupons sampled at the depth of 30cm, 60cm, 90cm and 120cm respectively. exposure for period of time ranging from three (3) months to eighteen (18) at interval of three(3) months. The corrosion rate increased with increase in period of exposure. It was observed that for three (3) months the corrosion rate was slow, however, as the immersed period increased, it was observed that the corrosion rate increased. The variation in behavior was as a result of the physiochemical properties interactions with the metals coupons in the water environment. The results obtained revealed that the variations in the concentration of water quality and physiochemical parameters of the water at different depths affected metals corrosions. The activities of microorganism at different depth and different concentration contribute to electron loss from the metals. The variations of time or the period of exposure induced on the water environment results in increase in rapid corrosion rate. Temperature variation, electrical conductivity and density influenced, the pH of the water at various time of exposure, therefore increased corrosion rate of metals coupons sampled. The metals corrosion rate investigated, as shown in the graph above indicates that stainless steel was resistance to corrosion and the corrosion rate were in order of MS > CPS > CBS > SST.

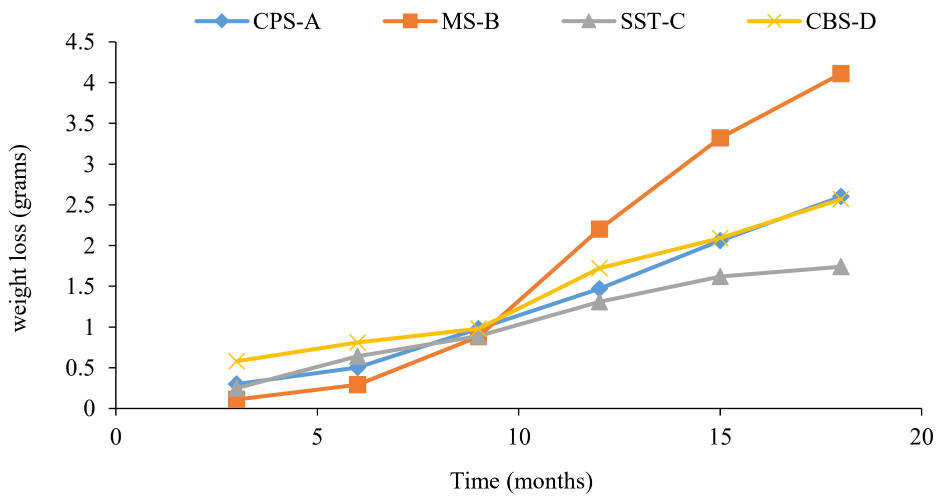

Figure 4. Trend of metals coupon decrease in weight loss (120cm).

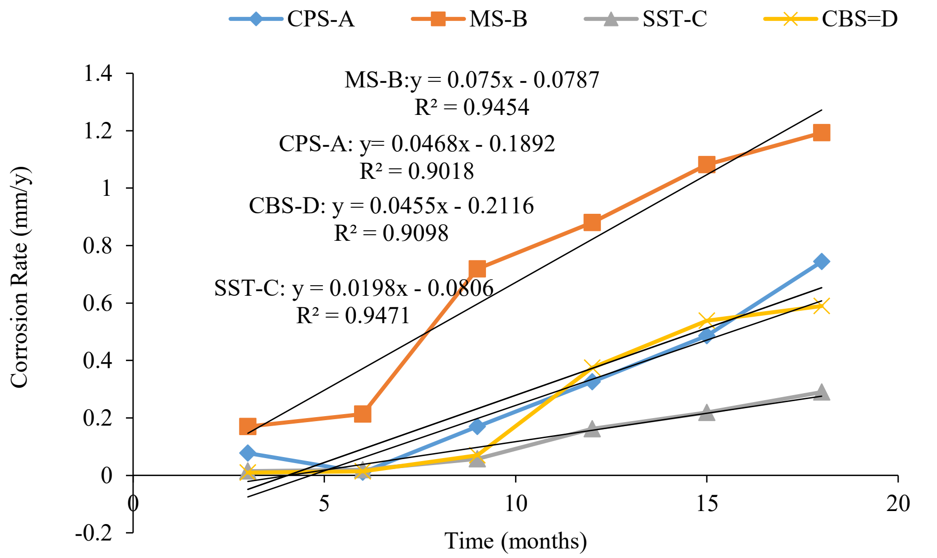

Figure 5. Comparison of corrosion rates over time for different coating systems.

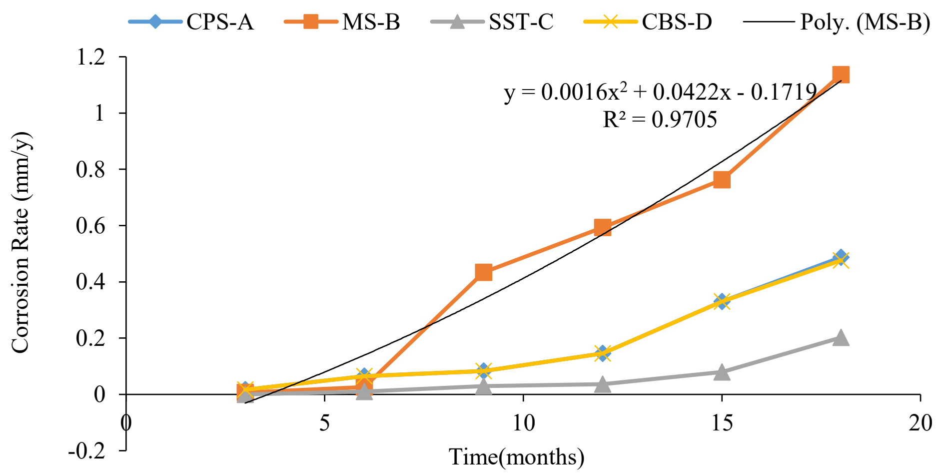

Figure 6. Polynomial fit of corrosion rate vs. time for different coating systems.

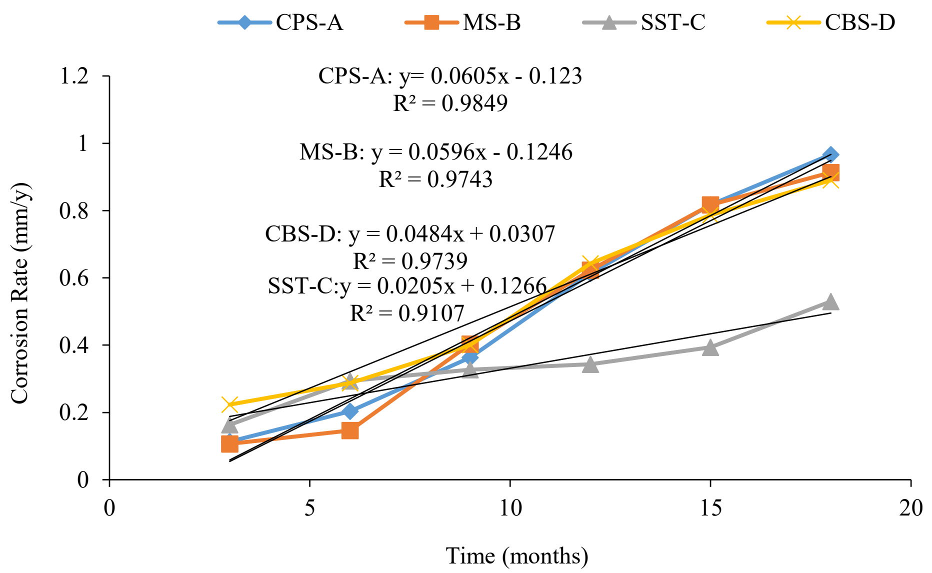

Figure 7. Linear regression analysis of corrosion rates for different coating systems over time.

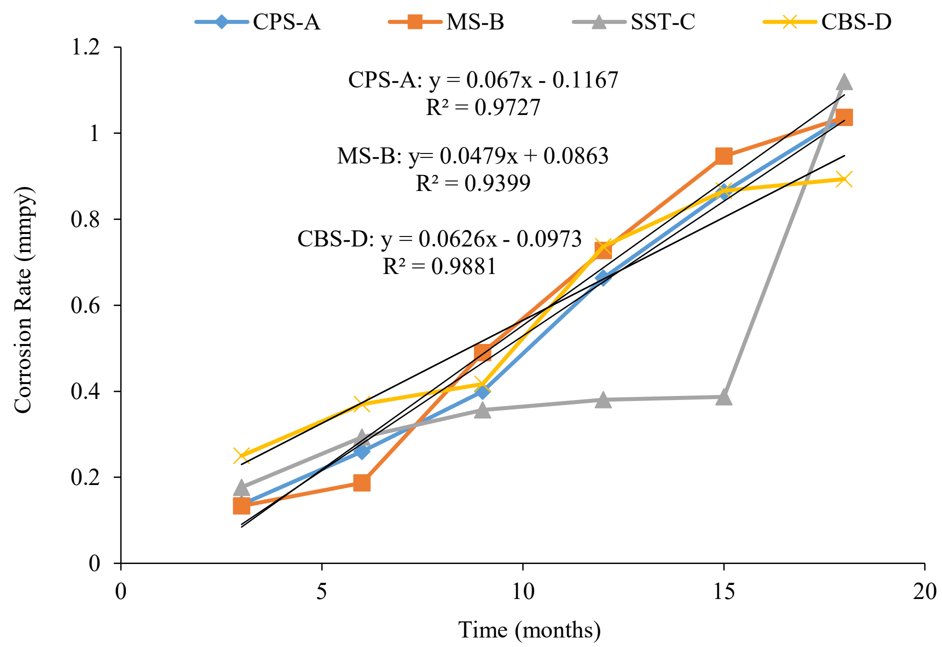

Figure 8. Comparative linear regression of corrosion rates for coating systems over time.

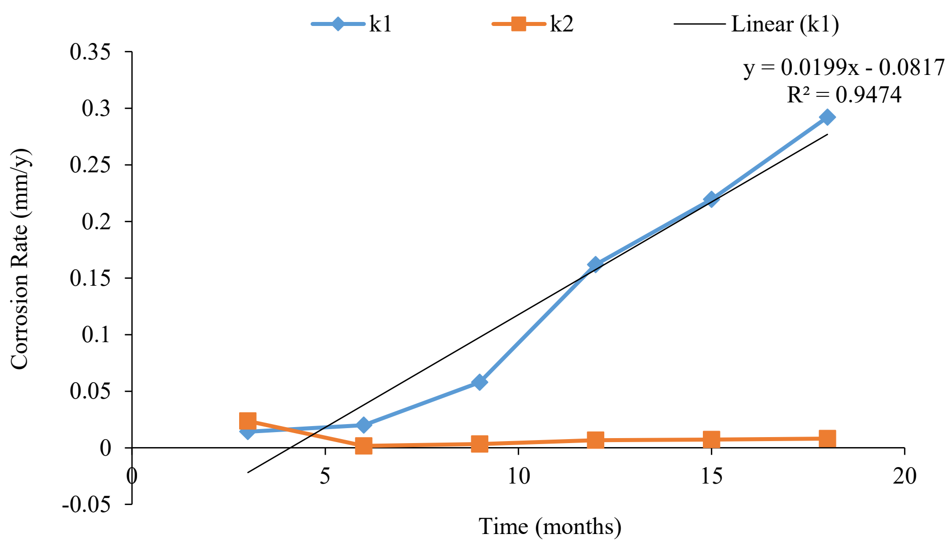

Figure 9. Copper steel CPA-A 30cm.

Functional Parameter for Corrosion Rate Using Galerkin's Finite Element Techniques

Functional parameters**,** diffusion and velocity were the influence factor k_1 is the relationship between diffusion and weight loss, while k_2 is the relationship between velocity rate and weight loss, this coefficient factors influences physiochemical parameter, the integration as second term in the evaluation contribute to corrosions of metals in the medium. K_1 and k_2 were functional coefficient parameter which determinant the corrosion rate and weight loss using finite Element method.

Change in the localized chemistry of the medium, mass transport were as a result diffusion migration and natural convections which occurs in the water environment and its affects the dissolved oxygen, oxygen concentration was controlled by the gas adsorption and dissolution process of the water medium and the interface [47], the diffusions most times limits the currant density, k_1 and k_2 were used to describe the coefficient physiochemical parameters under the influence of electric conductivity in the system and all their contributions on corrosion rate in the water environment.

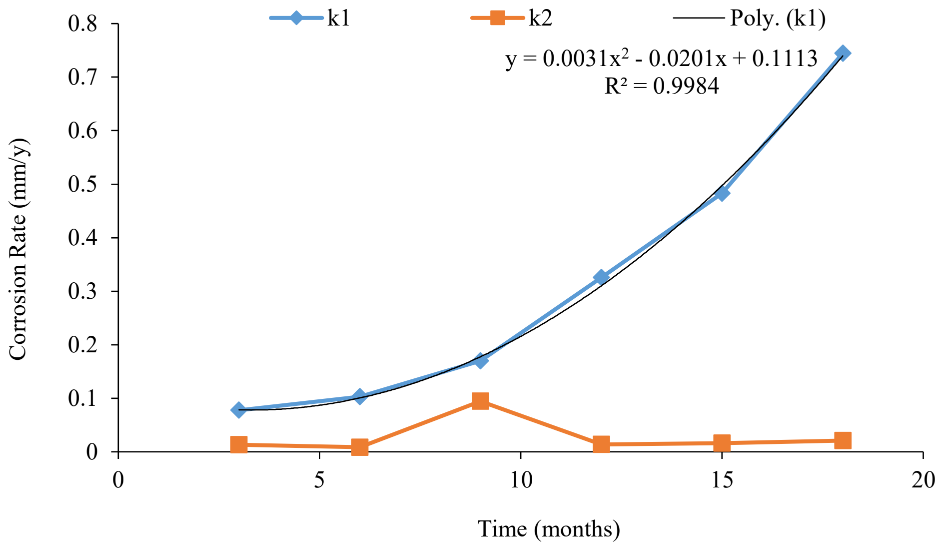

Figure 10. Mild steel MS-B; at 30cm depth.

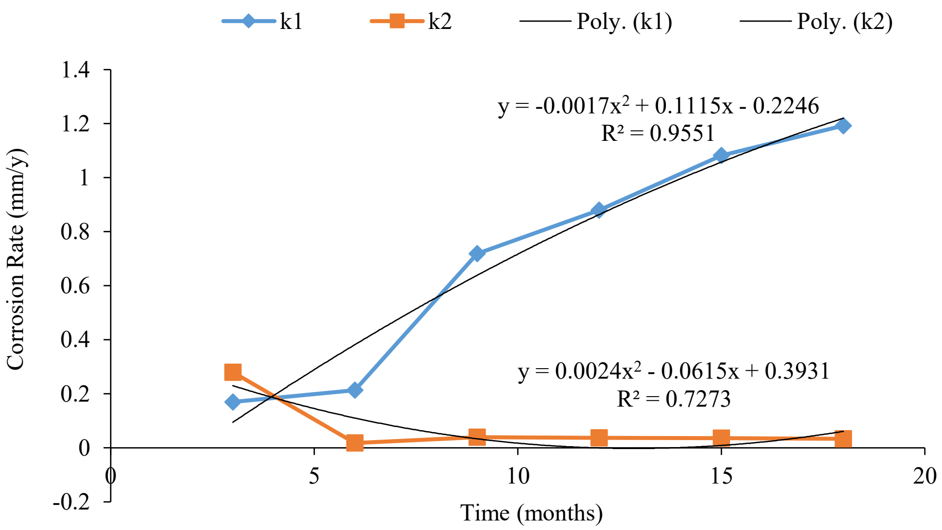

Figure 11. Stainless steel, SST-C at 30cm depth.

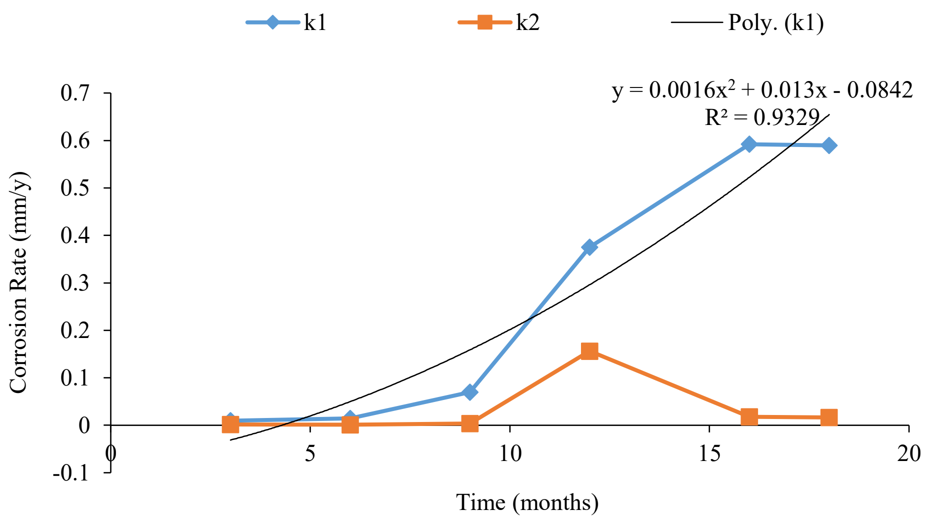

Figure 12. Carbon steel CBS-D; at 30cm depth.

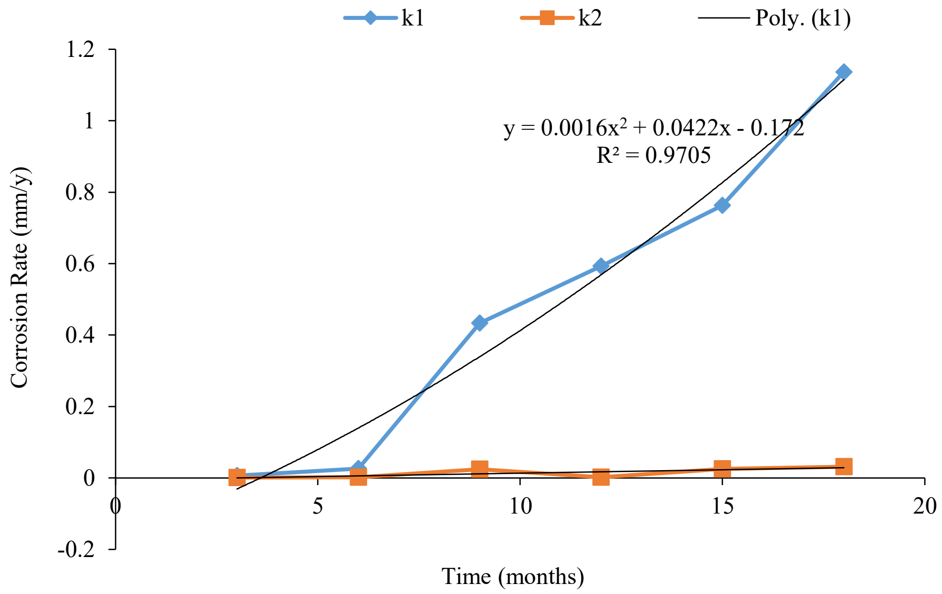

Figure 13. Mild steel MS-B at 60cm depth.

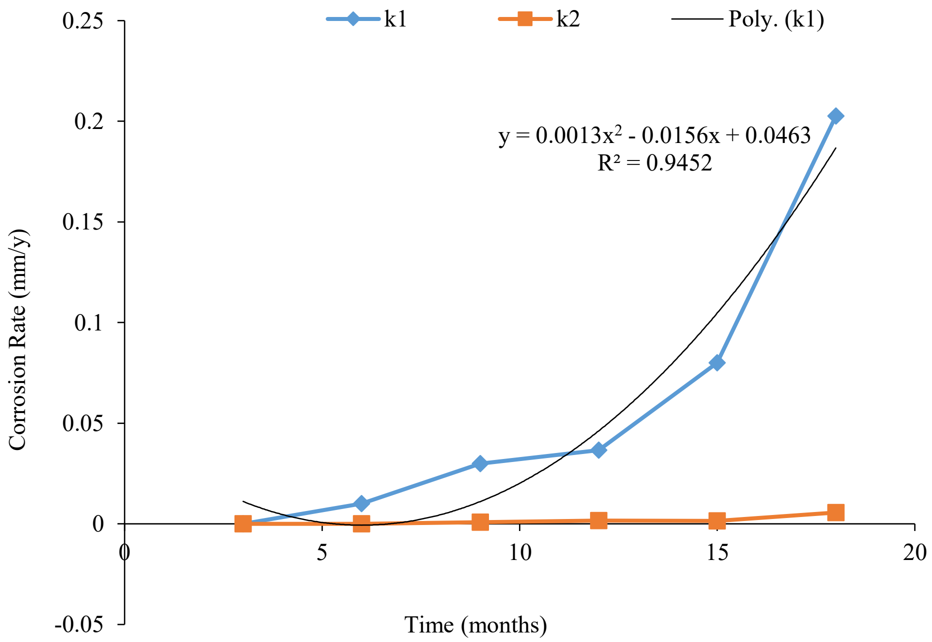

Figure 14. Stainless steel SST-C at 60cm depth.

The graphs below illustrate the trend that shows their contributions K1 increased as the exposure time increased while K2 was slightly stable. Diffusion (K_1) increased across the depths of the water environment therefore makes it possible for dissolve oxygen to get in contact with metals coupon.

The presence of dissolved oxygen in water, as water is exposure to atmosphere oxygen it absorb oxygen, hydrogen sulfide and carbon dioxide, the concentration can vary due to biological activities and the rate of mixing with surface thereby given variations in corrosion rate of the metal coupons present at different depths at various time of exposure, Water quality index and physiochemical parameters at different depth of the fresh water affects corrosions rate in different ways and forms as shown on the graphs above. Polluted water has low dissolved oxygen due high oxygen up take by microorganism in a low oxygen water corrosion rate may be reduced

CONCLUSION

The research was carried out to demonstrate the effect of water depths and the contribution functional parameters that K1 and K2. Using Galerkin's finite element technique.

The functional parameters influence metal corrosion in fresh water environment. Using Galerkin's finite element technique it was revealed that the behavior of K_1 which is diffusion in relationship to weight loss of metal coupon and K_2 is the velocity of the water environment medium were the determinant factors for metals corrosion and weight loss.

The influence of k_1 and K_2 contribute to the deterioration of metal, and their contribution as showed on the graphs Figures 4.17 to 4.36. K_1 and K_2 were determinant factors, for corrosion rate and weight loss. Mass transfer and transport were determined by K_1 which is the diffusion. The dispersion in fresh water at different water depths influences metal corrosion and weight loss. The transfers from solid phase to liquid phase within the water medium contribute to metals deterioration.

The diffusion in fresh water environment affects current density, which influence electric conductivity in the system, all this contribute to corrosion rate and metal weight loss. K_2 is the velocity and weight loss relationship, the velocities at all depths over the period exposed remains stable just slightly variation due microorganism activities, the variations do not influence changes in the physiochemical properties at any depths. However it contributes to corrosion rate and weight loss. From the results obtained Stainless Steel were more resistance to velocity (K_2), its corrosion rate were observed to be low.

Determination of weight loss of metal coupon at different depths and the calculation of corrosion rate revealed that at 30cm depth, The loss were in decrease order of MS > CBS > CPS >SST; For 60cm weight loss were in order of MS > CPS > CBS > SST; For 90cm the decrease were MS > CPS > CBS > SST; For depth of 120cm MS > CPS > CBS > SST; For the depth of 150cmMS > MS > CPS > CBS > SST; The depth of 150cm we have MS > CPS > CBS > SST; These were the order of decrease, in all the depths chosen for the research work. Stainless steel (SST) showed more resistance to weight loss. The model used for the analysis fitted well with the experiment result. Also the calculation of corrosion rate were as done for various depths, at the depth of 30cm; the rate revealed a decrease as MS > CPS > CBS > SST; For the depth of 60cm the decrease were MS > CPS > CBS > SST; AT 90cm decrease were CPS > MS > CBS > SST; At the depth of 120cm decrease resistance were as followed CPS > MS > CBS > SST; FOR 150cm the decrease were CPS > CBS > MS = SST. At 150 cm depth the exposure of 18 months, metals corrosion of stainless steel and Mail steel were the same.

Comparison of the weight loss at various depths revealed that 30cm. The loss were in decrease order of MS > CBS > CPS >SST; For 60cm weight loss were in order of MS > CPS > CBS > SST; For 90cm the decrease were MS > CPS > CBS > SST; For depth of 120cm MS > CPS > CBS > SST; For the depth of 150cmMS > MS > CPS > CBS > SST; The depth of 150cm we have MS > CPS > CBS > SST; These were the order of decrease, in all the depths chosen for the research work. Stainless steel (SST) showed more resistance to weight loss.

Comparison for corrosion rate were as done for various depths, at the depth of 30cm; the rate decrease as MS > CPS > CBS > SST; For the depth of 60cm the decrease were MS > CPS > CBS > SST; AT 90cm decrease were CPS > MS > CBS > SST; At the depth of 120cm decrease resistance were as followed CPS > MS > CBS > SST; FOR 150cm the decrease were CPS > CBS > MS = SST. At 150 cm depth the exposure of 18 months, metals corrosion of stainless steel and Mail steel were the same.

The examination and evaluation carried out showed that metals coupon weight loss ere more at the depth of 150cm over the period of 18 months of exposure, The comparison of the weight loss of various metals coupons at different depths immersion for a period revealed that, the decrease observed were as 150cm >120cm >90cm >30cm > 60cm.

The comparison of metal coupon with respect to the environmental conditions, revealed that at the depth of 150cm all the four (4) metals coupon showed higher corrosion rate at the period of 18 months exposure and it indicate that weight loss were also higher value. The weight loss of all the selected metals used for experiment, after exposed at various depths in fresh water environment proofs that stainless steel is more resistance to corrosion at various depths considered in this research

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APPENDIX A

Weight Loss Analysis of Selected Metals Coupons due to Corrosion at different Depth of Fresh Water over Exposure

Table 4.1. Weight analysis result of metals in fresh water medium new calabar river (Under Choba Bridge) at the depth 30cm.

Time (months)	0	3	6	9	12	15	18
CPS-A	29.61	29.372	29.301	29.1	28.633	28.151	27.37
MS-B	32.47	32.411	32.406	30.315	29.825	29.224	28.892
SST-C	21.99	21.946	21.93	21.817	21.505	21.35	21.114
CBS-D	31.83	31.801	31.787	31.62	30.704	30.214	30.061

Table 4.2. Weight analysis result of metals in fresh water medium new calabar river (Under Choba Bridge) at the depth 60cm.

Time (months)	0	3	6	9	12	15	18
CPS-A	29.61	29.56	29.417	29.33	28.174	28.62	28.148
MS-B	32.47	32.44	32.39	31.17	30.69	30.18	29.06
SST-C	21.99	21.99	21.96	21.9	21.88	21.75	21.363
CBS-D	31.83	31.74	31.622	31.381	31.07	30.84	30.25

Table 4.3. Weight analysis result of metals in fresh water medium new calarba river (Under Choba Bridge) at the depth 90cm.

Time (months)	0	3	6	9	12	15	18
CPS-A	29.61	29.31	29.107	28.63	28.14	27.55	27.01
MS-B	32.47	32.36	32.18	31.59	30.27	29.15	28.36
SST-C	21.99	21.74	21.35	21.1	20.68	20.37	20.25
CBS-D	31.83	31.25	31.02	30.85	30.11	29.74	29.26

APPENDIX B

Weight lost Results Analysis of Metals Coupons in Different Depth in Fresh Water Environment

Table 4.1.1. Determination weight loss for metals coupons at the depth of 30cm in fresh water medium.

Time (months)	3	6	9	12	15	18
CPS-A	0.238	0.309	0.51	0.977	1.459	2.233
MS-B	0.059	0.064	2.155	2.645	3.245	3.578
SST-C	0.044	0.06	0.173	0.485	0.638	0.876
CBS-D	0.029	0.043	0.21	1.126	1.616	1.769

Table 4.2.2. Determination weight loss for metals coupons at the depth of 60cm in fresh water medium.

Time (months)	3	6	9	12	15	18
CPS-A	0.05	0.193	0.28	0.436	0.99	1.462

MS-B	0.03	0.08	1.3	1.78	2.29	3.41
SST-C	0	0.03	0.09	0.11	0.24	0.607
CBS-D	0.09	0.043	0.449	0.76	0.99	1.58

Table 4.3.3 Determination weight loss for metals coupons at the depth of 90cm in fresh water medium.

Time (months)	3	6	9	12	15	18
CPS-A	0.3	0.503	0.98	1.47	2.06	2.6
MS-B	0.11	0.29	0.88	2.2	3.32	4.11
SST-C	0.25	0.64	0.89	1.31	1.62	1.74
CBS-D	0.58	0.81	0.98	1.72	2.09	2.57

Table 4.4.4. Determination weight loss for metals coupons at the depth of 120cm in fresh water medium.

Time (months)	3	6	9	12	15	18
CPS-A	0.34	0.61	1.09	1.87	2.45	2.87
MS-B	0.32	0.44	1.21	1.99	3.29	3.08
SST-C	0.49	0.88	0.98	1.03	1.18	1.59
CBS-D	0.67	0.86	1.2	1.93	2.36	2.68

Table 4.5.5. Determination weight loss for metals coupons at the depth of 150cm in fresh water medium.

Time (months)	3	6	9	12	15	18
CPS-A	0.41	0.78	1.2	1.99	2.59	3.11
MS-B	0.4	0.56	1.47	2.18	2.84	3.36
SST-C	0.53	0.88	1.07	1.14	1.16	1.24
CBS-D	0.75	1.11	1.25	2.21	2.58	2.68

APPENDIX C

Analysis of Various Metals Corrosion Rate Exposure at different depth over time.

Analysis Result of Corrosion Rate of Metal Coupons in Fresh Water Medium at Different Depths

Table 4.6. Depth of 30cm.

Corrosion Rate (mmpy) Metals							
Time	**0**	**3**	**6**	**9**	**12**	**15**	**18**
CPS-A	0	0.0777	0.0103	0.17	0.3256	0.4863	0.7443
MS-B	0	0.17	0.2133	0.7183	0.88	1.0816	1.1927
SST-C	0	0.0147	0.02	0.0577	0.161	0.2193	0.292
CBS-D	0	0.0097	0.0143	0.07	0.3753	0.5387	0.5897

Table 4.7. Depth of 60cm.

Corrosion Rate (mmpy) Metals							
Time	**0**	**3**	**6**	**9**	**12**	**15**	**18**
CPS-A	0	0.0167	0.0643	0.0833	0.1453	0.33	0.4873
MS-B	0	0.0067	0.0267	0.4333	0.5933	0.7633	1.1367
SST-C	0	0	0.01	0.03	0.0367	0.08	0.2023
CBS-D	0	0.0167	0.0643	0.0833	0.1453	0.33	0.4873

Table 4.7. Depth of 90cm.

Corrosion Rate (mmpy) Metals							
Time	**0**	**3**	**6**	**9**	**12**	**15**	**18**
CPS-A	0	0.1	0.1677	0.3267	0.49	0.6867	0.8666
MS-B	0	0.0367	0.0967	0.2933	0.7333	1.1067	1.37
SST-C	0	0.0833	0.2133	0.2967	0.4367	0.54	0.58
CBS-D	0	0.1933	0.27	0.3266	0.5833	0.6967	0.8567

APPENDIX D

Functional Coefficient Determination of Corrosion Rate in Fresh Water Environment

Table 4.10. Computation of functional coefficient for the determination of the corrosion rate for fresh water environment at depth of 30cm: CPS-A.

$Time(t)$ $months$	$Weight\ loss$ (g)	dw	dt	$v = \frac{dw}{dt}$	$k = \frac{v}{t}$	$\tau = \frac{1}{t}$	$k_1 = \frac{k}{\tau}$	$k_2 = \frac{k}{2}$
0	29.61	0	0	0	0	0	0	0
3	29.56	0.23	3	0.07766	0.02588	0.33333	0.0776	0.012944
6	29..417	0.309	3	0.10300	0.017167	0.16666	0.1030	0.008583
9	29.33	0.51	3	0.17000	0.01889	0.11111	0.1700	0.009445
12	29.174	0.977	3	0.32560	0.02713	0.08333	0.3256	0.013565
15	28.62	1.459	3	0.48630	0.03242	0.06666	0.4829	0.01621
18	28.148	2.233	3	0.74430	0.04135	0.05555	0.7444	0.020675
$K_{1(t)}$ =1.9035 $k_{2(t)}$=0.081422 $K_{2(m)}$= 0.2719285 $k_{2(m)}$ =0.01163171								

Table 4.11. Computation of functional coefficient for the determination of the corrosion rate for fresh water environment at depth 30cm: MS-B.

$Time(t)$ $months$	$Weight\ loss$ (g)	dw	dt	$v = \frac{dw}{dt}$	$k = \frac{v}{t}$	$\tau = \frac{1}{t}$	$k_1 = \frac{k}{\tau}$	$k_2 = \frac{k}{2}$
0	32.47	0.00	0	0.00	0.00	0.00	0.00	0.00
3	32.411	0.51	3	0.17	0.05666	0.3333	0.16999	0.2833
6	32.406	0.64	3	0.2133	0.03555	0.1666	0.21338	0.01777
9	30.315	2.155	3	0.7183	0.079811	0.1111	0.71830	0.03990
12	29.825	2.645	3	0.88	0.073333	0.08333	0.87999	0.03666
15	29.224	3.245	3	1.082	0.072106	0.06667	1.08153	0.03605
18	28.892	3.578	3	1.19267	0.06625	0.05555	1.1926	0.033125
$K_1(t)$= 4.25579 $k_2(t)$=0.4468 $K_1(m)$=0.60797 $k_2(m)$=0.0638293								

Table 4.12. Computation of functional coefficient for the determination of the corrosion rate for fresh water environment at Depth 30cm: SST-C.

$Time(t)$ $months$	$Weight\ loss$ (g)	dw	dt	$v = \frac{dw}{dt}$	$k = \frac{v}{t}$	$\tau = \frac{1}{t}$	$k_1 = \frac{k}{\tau}$	$k_2 = \frac{k}{2}$
0	21.99	0.00	0	0.00	0.00	0.00	0.00	0.00
3	21.946	0.044	3	0.014667	0.00472	0.3333	0.014161	0.0236
6	21.930	0.06	3	0.0200	0.00333	0.1666	0.020006	0.0016665
9	21.817	0.173	3	0.057669	0.0064076	0.1111	0.0576689	0.0032038
12	21.505	0.485	3	0.16167	0.013472	0.08333	0.161677	0.006736

15	21.350	0.658	3	0.21933	0.014622	0.06666	0.219330	0.007311
18	21.114	0.876	3	0.29200	0.016222	0.05555	0.292025	0.008111
$K_{1(t)}=0.764868$ $k_{2(t)}=0.0506211$ $K_{1(m)}=0.1092668$ $k_{2(m)}=0.0072316$								

APPENDIX E

Determination of the Functional Coefficients Using Gaterkin's Finite Element Parameters or Metals Coupons, For Depths of 30cm ($K_1$and K_2) and Simulation Result. The tables were about 20 for all metal coupons for various depths considere.

Table 4.29. CPA-A.

K1	K2	K1+K2	K1-K2	2K1	(-K1+K2)
0	0	0	0	0	0
0.0776	0.012944	0.090544	0.064656	0.1552	0.090544
0.103	0.008583	0.111583	0.094417	0.206	0.111583
0.17	0.009445	0.179445	0.160555	0.34	0.179445
0.3256	0.013565	0.339165	0.312035	0.6512	0.339165
0.4829	0.01621	0.49911	0.46669	0.9658	0.49911
0.7444	0.020675	0.765075	0.723725	1.4888	0.765075

A					B	
0.112	0.094417	0	0	0	WL1	0.309
-0.16	0.34	-0.179445	0	0	WL2	0.51
0	-0.312035	0.6512	-0.312035	0	WL3	0.977
0	0	-0.46669	0.9658	-0.46669	WL4	1.459
0	0	0	-0.723725	-0.765075	WL5	2.233
A^{-1}					X	
5.703	-2.264725	-0.741973	-0.164519	0.1003551	CR1	-0.13355
3.851	2.6764754	0.8768712	0.1944297	-0.118601	CR2	0.430545
2.194	1.524782	2.3253011	0.5155919	-0.314507	CR3	0.777353
0.728	0.5056614	0.7711365	0.8815823	-0.537759	CR4	1.321526
-0.69	-0.478332	-0.729459	-0.833935	-0.798367	CR5	1.41687

Table 4.30. MS-B.

K1	K2	K1+K2	K1-K2	2K1	(-K1+K2)	(-K1-K2)
0	0	**0**	0	0	0	0
0.16999	0.2833	**0.45329**	-0.11331	0.33998	0.45329	-0.79327
0.21338	0.01777	**0.23115**	0.19561	0.42676	0.23115	-0.65791
0.7183	0.0399	**0.7582**	0.6784	1.4366	0.7582	-2.1948
0.87999	0.03666	**0.91665**	0.84333	1.75998	0.91665	-2.67663
1.08153	0.03605	**1.11758**	1.04548	2.16306	1.11758	-3.28064
1.1926	0.033125	**1.225725**	1.159475	2.3852	1.225725	-3.61093
A					**B**	
0.231	0.19561	0	0	0	**WL1**	0.309
-0.68	1.4366	-0.7582	0	0	**WL2**	0.51
0	-0.84333	1.75998	-0.84333	0	**WL3**	0.977
0	0	-1.04548	2.16306	-1.04548	**WL4**	1.459

0	0	0	-1.15948	-1.225725	**WL5**	2.233
A^{-1}					X	
2.753	-0.53603	-0.27456	-0.07346	0.0626561	**CR1**	0.341798
1.859	0.633419	0.324442	0.086805	-0.07404	**CR2**	1.175776
1.059	0.36087	0.860397	0.2302	-0.196349	**CR3**	1.249332
0.351	0.119695	0.28538	0.393609	-0.335729	**CR4**	0.973004
-0.33	-0.11323	-0.26996	-0.37234	-0.498261	**CR5**	1.08003

