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EFFECTS OF CASSAVA JUICE ON CORROSION OF MILD AND HIGH YIELD STEEL BARS IN CONCRETE STRUCTURES

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ABSTRACT

Nigeria is the highest producer of cassava in the world and cassava juice is rich in hydrocyanic acid, a by-product from the extraction process. This paper examines the effect of cyanide ions, the reacting ions from hydrocyanic acid on reinforcing bars when cassava tubers are processed on reinforced concrete platforms. Mild and High yield steel reinforcing bars are embedded in concrete cubes cast and cured for 21 and 28 days. These steel bars were used to model the experiment. Half – Cell potential apparatus was used to take potential measurements of both steel bars with concrete cubes immersed in hydrocyanic acid and ordinary water for 32days. Corrosion rates under these different conditions were monitored. The results demonstrated that both steel types will corrode in hydrocyanic acid, however, High yield steel has better corrosion resistance than Mild steel: this is due to the mechanical properties and chemical composition of the steel. It was also observed that with increase in curing age the degree of probability of corrosion decreased.

Keywords: Cassava juice, Corrosion, Mild steel, High yield steel, Half – Cell Potential measurement

INTRODUCTION

Cassava and varieties of its processed products are major sources of staple food in Nigeria and the by-products are either used directly or processed for animal feeds. The country is currently the highest producer of cassava in the world and there is the drive and support given by the government for cassava farmers to produce more with a view for exporting the processed products. Grinding of Cassava tubers is done by machines on reinforced concrete platforms.

In the process of grinding, liquid extracts from cassava called cyanogenic glucisides *linamarin* and *lotausralin* which when hydrolyzed yield cyanide are released (Onwueme, 1978). According to Loto and Atanda (1998) cyanide ions (CN^-) produced from hydrocyanic acid when in solution is believed to be the reacting ions that cause corrosive chemical reaction. Cyanides are known to be corrosive and poisonous when in appreciable concentration. Therefore, Cyanide ions reactions with steel in reinforced concrete platforms are a major source of concern that requires investigation. Corrosion of reinforcement has been established as the predominant factor causing widespread premature deterioration of concrete construction worldwide (Kamaitis, 2002). After initiation of the corrosion process, the corrosion products (iron oxides and hydroxides) are usually deposited in the restricted space in the concrete around the steel. Yoon *et al* (1997) opined that corrosion produces expansive products that generate tensile stresses in the concrete surrounding the reinforcing steel, which may cause concrete cracking. Cracks can reduce the overall strength and stiffness of the concrete structure and accelerate the ingress of aggressive ions, leading to other types of concrete deterioration and resulting in further cracking. Umoru, (2006) observed that concrete surfaces are often characterized by micro cracks and micro pores that provide paths for transport of aggressive ions and corrosion of reinforcing steel depends on the rate of diffusion of ions. Also, corrosion products are highly porous, weak, and often form around reinforcing steel, thus decreasing the bond strength between the reinforcement and concrete. In addition, corrosion reduces the cross-sectional area of reinforcing steel, and may cause stress concentrations in the reinforcing steel, decreasing ductility of the structure, especially when pitting corrosion occurs. This in turn results in progressive deterioration of the concrete. As a result, the repair costs constitute a major part of the recurrent spending on infrastructures. Investigations on the problems of deterioration of concrete and the consequent corrosion of steel in concrete are currently going on all over the world with innovative ways of remediation programme. Properly monitoring the structures for corrosion performance and taking suitable measures at the appropriate time could result in enormous savings on cost of maintenance. The tendency of any metal to react with an environment is indicated by the potential it develops in contact with the environment. In reinforced concrete structures, concrete acts as an electrolyte and the reinforcement will develop a potential depending on the concrete environment, which may vary from place to place. Usually the condition of the structures is monitored by visual inspection and remedial measures are resorted to only when the condition becomes very serious by way of heavy rusting of steel reinforcements followed by cracking and spalling on concrete. As a consequence, Amleh *et al.* (2002) observed that the serviceability, durability and safety of the structure can diminish increasingly as corrosion proceeds. It is desirable to monitor the condition of such reinforced concrete structures right from the construction stage by carrying out periodic corrosion surveys and maintaining a record of data. Song and Saraswathy (2007), discussed various electrochemical and non-destructive techniques of measurement of the corrosion rate of reinforcing steel in concrete. Half –Cell Potential measurement was employed in this work to determine the rate of corrosion of mild steel (RST37-2) and high yield steel (ST60Mn) embedded in concrete specimens cured in water and tested in cyanide (extracted from cassava). The essence of this work is to give basic understanding of the corrosion mechanisms of reinforcing steel under hydrocyanic acid aggressive condition and the associated damage manifestation.

MATERIALS AND METHOD

Mild and High yield steel types used for this work were obtained from the Osogbo Steel Rolling Company (OSRC), Osogbo, Nigeria, and Cassava extracts (Cyanide) used were from Cassava processing sites within Ile – Ife, Nigeria. Elephant Portland cement brand used was purchased from local distributor, granite gravel were from a quarry and river sand was bought locally. Other materials include portable water, $Cu/CuSO_4$ reference electrode and Voltmeter. The chemical composition of steel bars used mild and high yield steel types are presented in Tables 1 and 2. A concrete mix of 1:2:4 by weight was prepared to cast six concrete cubes of 100mm x 150mm x 200mm. Three each, for mild and high yield steel bars, the diameter of steel used is 12mm and length 200mm and pickled in hot dilute hydrochloric acid solution for ten minutes at 60°C. The steel specimens were rinsed in water, dried and then embedded in the prepared concrete cubes to a length of 170mm while 30mm protruded out of the concrete; this is to facilitate connection during the Half-Cell Potential experiment. A set of three concrete specimens were then cured in water for 21 days and another set of three concrete specimens were cured in water for 28 days. Two concrete specimens, one each with mild and high yield steel bars were then removed from the curing environment after 21 days and placed in hydrocyanic acid. Thereafter, potential measurements taken for 32 days at interval of four days. Another set of two specimens one each with mild and high yield bars were taken from the curing environment after 28 days and were placed in hydrocyanic acid solution the Cassava extract aggressive environment under study. Half–Cell Potential experiments were conducted on these samples at same interval of time for the same duration of 32 days. The experiment was conducted on another set of two specimens one each for the two steel bars for same duration of time in ordinary water environment after curing for 21 days. The experiment was conducted with each concrete sample immersed in hydrocyanic acid solution (aggressive medium). A distance is maintained between the exposed end of the steel rods and hydrocyanic acid and the exposed ends are coated with coal tar to ensure that the solution did not make contact with the rods. This is necessary to prevent contact between the steel rods and the hydrocyanic acid solution which may result in reaction, as this would affect the accuracy of the results. . The ASTM standard C876 (1991) gave general guidelines for evaluating corrosion activities in concrete structures using Half-Cell potential. According to the Standard, reading of Cu/$CuSO_4$ less than 200 mV indicates 90% probability of no corrosion; reading between 200 mV and 350 mV indicates an increasing probability of corrosion above 50% while reading greater than 350 mV indicates 90% probability of corrosion. The measurement of the corrosion potential involved a modified fixed base (total field) array. The mobile Cu/$CuSO_4$ non-polarising electrode was connected to the positive terminal of the voltmeter while the steel rod was adopted as the fixed electrode and connected to the negative terminal of the meter. Readings were taken on both sides of the concrete specimen and average potential calculated at four days interval for thirty two days.

RESULTS AND DISCUSSION

i. Results

The results of the average potential measurement readings for Mild and High yield steel rods are presented in Tables 3 to 5. These results are also presented in Figures 1-5. Figure 1 shows the variation in potential values with number of days. For both Mild and High yield steel reinforcements cured in water for three weeks and tested in hydrocyanic acid environment. The Figure shows High yield reinforcement with lower potential for corrosion. Figure 2 shows variation of potential with exposure days for both Mild and High yield steel reinforced concrete cured in water for four weeks and tested in hydrocyanic acid environment. The same trend is noticed for curing for three weeks is observed here, High yield steel showing lower potential for corrosion. Figure 3 2 shows variation of potential with exposure days for both Mild and High yield steel reinforced concrete cured in water for four weeks and tested in ordinary water. The result shows High yield steel with high potential at the beginning of the exposure till sixteenth day after which its potential became lower and stabilized. Potential values for Mild steel reinforcement are higher than that of High yield steel and continue to increase till the twenty fourth day before drop was observed. Figure 4 shows a comparative plot of variation of potential with time for Mild steel reinforcements with curing in water for three weeks and tested in Cassava juice and water for thirty two days. The potential in corrosion was observed to be much more than corrosion in ordinary water. Figure 5 also shows a comparative plot of potential variation with time for High yield steel reinforcement cured in water for three weeks and tested in both Cassava fluid and ordinary water. The figure shows potential for corrosion in Cassava fluid much higher depicting obvious faster rate of corrosion of High yield steel in Cassava fluid.

ii. Discussion

Corrosion Characteristics of RST37-2 and ST60Mn steel types

Figures 1-3 show that corrosion potential of Mild steel are higher than that of High yield steel. This could be explained in terms of their composition and microstructures. As presented in Tables 1 and 2, High yield steel has carbon ranging between 0.35 - 0.42% has less ferrite than Mild steel of carbon content ranging between0.12 - 0.17%. For mild steel Soroka, (1994) observed that galvanic corrosion process is not necessarily conditional on the contact between two dissimilar metals. The formation of anodic and cathodic sites may develop in the same metal, due to local variations in composition, stress level; oxygen supply, e.t.c. Anodic and cathodic sites develop, sometimes, at very short intervals, to give what is usually referred to as galvanic micro cells. Ferrite corrodes preferentially to cementite as it is anodic to cementite, thus, corrosion rate is higher in Mild steel which contains more ferrite and less in High yield steel.

Corrosion of steel types in Cassava juice environment

Steel is protected from corrosion when embedded in dense concrete owing to the formation of passive films. This film is established by the high concentration of hydroxyl ions associated with concrete pore electrolyte, and effectively stifles the anodic dissolution of ferrous ions so that the corrosion rate remains negligibly small. As presented in Figures 1 to 5 early characteristic increase in corrosion rate results from the break down of the passive films by the ingress of aggressive agents in contact with steel surface bringing down the pH level to a point where corrosion can occur. In the next stage it is observed that there is a decrease in corrosion rate probably due to formation of iron oxide layer that temporarily prevents direct attack on the steel. The final stage is characterized by increase in corrosion rate resulting from breakdown of passivity or the initiation of micro cracks.

Effect of curing on the corrosion characteristics of steel types

The effects of curing on the corrosion characteristics of the steel rebars are presented in Figures 1 and 2. It is observed that there is a general decrease in corrosion rate with time of the steel embedded in concrete cubes cured for four weeks when compared to those cured for three weeks.

Comparison of corrosion rates of steel types in Cassava juice and ordinary Water environment

Figures 4 and 5 present comparison of corrosion rates of steel types in Cassava juice and ordinary Water environment. It is observed that corrosion rates in ordinary water are far less than that of Cassava juice environment. This can be attributed to the hyrocyanic effect on steel. The hydrocyanic environment has a lower pH value hence acidic, therefore, accelerate corrosion.

CONCLUSION

From the results obtained, it is evident that Cassava juice constitutes a corrosive medium for reinforcement in concrete principally due to cyanide ions present in it. It is obvious from the results of this work also, that High yield steel has better resistance to corrosion than Mild Steel in the environment under study. Therefore, in reinforcing concrete structures under this environment High yield steel is preferable in order to give longevity to the structures. It is also noted from the research that the longer the curing time the less the possibility of corrosion of reinforcement in concrete. This is because curing time decrease porosity and permeability of concrete.

Table 1: Chemical Analysis of RST37-2 (Mild steel)

Element	Percentage Composition
Carbon	0.12 – 0.17
Silicon	0.18 – 0.28
Manganese	0.40 – 0.60
Phosphorous	0.04
Sulphur	0.04
Iron	98.87 – 99.22

Table 2: Chemical Analysis of ST60Mn (High yield steel)

Element	Percentage Composition
Carbon	0.35 – 0.42
Silicon	0.20– 0.30
Manganese	0.90 – 1.20
Phosphorous	0.04
Sulphur	0.25
Copper	0.10
Chromium	0.10
Nickel	0.10
Iron	97.49 – 97.96

Table 3: Half Cell Potential readings for mild steel RST37-2 and high yield steel ST60Mn cured for three weeks and tested for 32 days in Hydrocyanic acid.

Days	RST37-2 mV	ST60Mn mV
4	273	229
8	247	257
12	312	296
16	325	285
20	321	281
24	323	263
28	288	276
32	286	249

Table 4: Half Cell Potential readings for mild steel RST37-2 and high yield steel ST60Mn cured for four weeks and tested for 32days in Hydrocyanic acid.

Days	RST37-2 V mV	ST60Mn mV
4	257	249
8	247	295
12	268	263
16	275	259
20	253	250
24	269	237
28	287	228
32	296	231

Table 5: Half Cell Potential readings for mild steel RST37-2 and high yield steel ST60Mn cured in water for three weeks a nd tested for 32days Ordinary water environment

Days	RST37-2 mV	ST60Mn mV
4	161	92
8	168	84
12	153	138
16	160	163
20	193	143
24	191	148
28	180	147
32	167	145

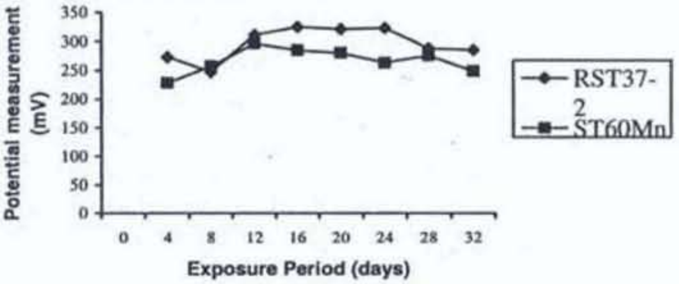

Figure 1: Potential measurement vs Exposure Period for RST37-2 and ST60Mn cured in water for three weeks and tested in Hydrocyanic acid for 32days.

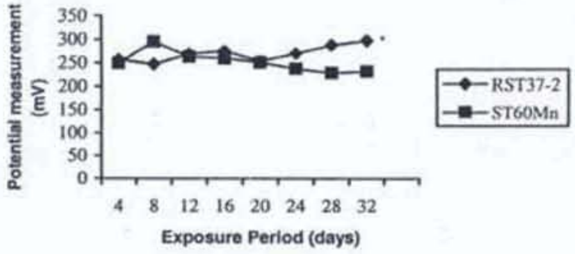

Figure 2: Potential measurement vs Exposure Period for RST37-2 and St60Mn cured in water for four weeks and tested in Hydrocyanic acid for 32 days.

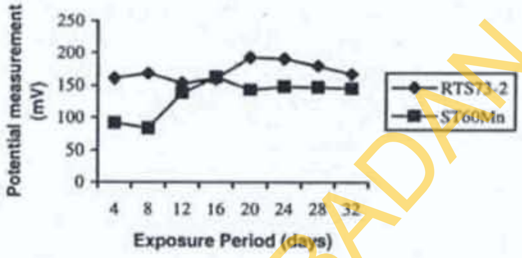

Figure 3: Potential measurement vs Exposure Period for RST37-2 and St60Mn cured in water for four weeks and tested Ordinary water for 32 days.

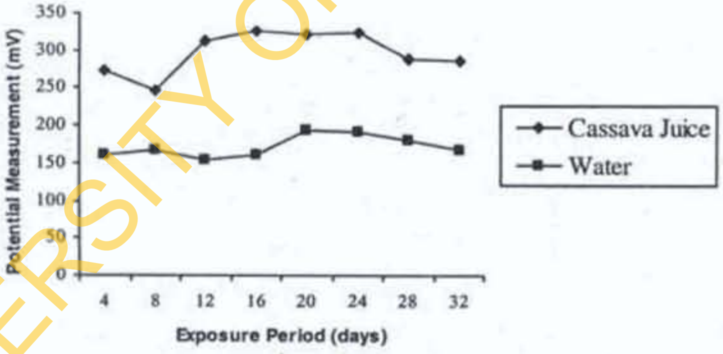

Figure 4: Potential measurement vs Exposure Period for RST37-2 cured in water for three weeks and tested in Hydrocyanic acid and Ordinary water for 32 days.

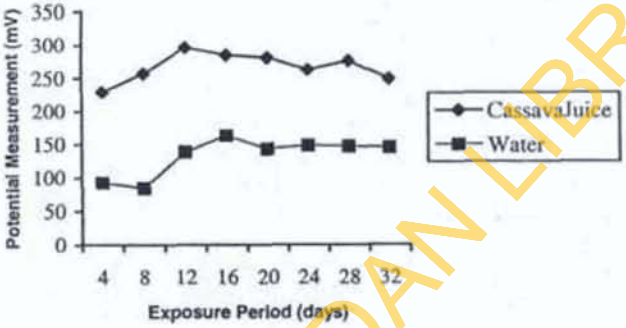

Figure 5: Potential measurement vs Exposure Period for ST60Mn cured in water for three weeks and tested in Hydrocyanic acid for 32 days.

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