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Effect of zinc plating of low carbon steel on corrosion resistance in cocoa fluid environment

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Abstract

This work investigated the corrosion resistance of zinc-plated low carbon steel in cocoa fluid. Low carbon steel samples were zinc electroplated at voltages between 0.5 V and 0.9 V for 5–20 min. The plated samples were then subjected to a cocoa fluid environment for 30 days. The electrode potentials mV (SCE) were measured every day. Weight loss was determined at intervals of 5 days for the exposure period. The result showed corrosion attack on the zinc-plated steel, the severity increasing with the increasing weight of zinc coating on substrate. The result showed that thinly plated low carbon steel generally did not have any advantage over unplated steel. Heavily zinc plated steel was observed to offer some form of protection for the plated steel as passivation was observed to occur on the nineth day of corrosion leading to almost nil corrosion rate. The pH of the cocoa solution which initially was acidic was observed to progress to neutral after 5 days, contributing to the near nil corrosion rates in the plated samples after 15 days. It was observed that electroplated steel plate at 0.8 V for 5 min and the more heavily plated steel at 0.9 V for 10 min gave the best resistance to cocoa fluid corrosion attack in the 30 days test period. Unplated steel was found to be unsuitable for the fabrication of cassava processing machinery without some form of surface treatment.

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1. Introduction

The cheapest and most rapidly available metal for machinery fabrication in Nigeria is plain carbon steel. Metallic corrosion especially that of carbon steel, mild steel and medium carbon steel has been recognized as a problem in the food and agriculture processing industry [1,2]. This is a result of some aggressive ions present in raw agricultural and food products, which may attack the steel components of processing machinery, resulting in their untimely failure in service. It is therefore very necessary to identify and solve these problems in relation to materials selection for machine component parts before any attempt to provide mechanical assistance in the on-farm processing of cocoa is embarked upon.

Cocoa is one of the most widely grown tropical plants. After harvest, the wet contents of the pods are fermented for 4–7 days. During the first 86 h the temperature rises and yeast develop which convert the sugars in the pulp to alcohol and carbon dioxide. Further increases in temperature occur and the alcohol is oxidized to ethanoic acid. The different primary processing operations of cocoa require the use of machinery of varying sophistication through which corrosion problems are likely to be encountered. Corrosion problems in cocoa fluid becomes more pronounced as the cocoa pods are broken into pulps and thereafter left to ferment naturally by yeast in which the sugars in the pulp is convert to alcohol and later oxidized to ethanoic acid [3]. The average analysis of cocoa fluid is as shown in Table 2.

The objective of the research is to investigate the corrosion of zinc-plated low carbon steel in cocoa fluid.

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2. Materials and method

2.1. Materials

The material used in this investigation is a low carbon steel substrate of length 1 m and 20 mm diameter. It was obtained from Nigeria Machine Tools Limited, Oshogbo, with batch number "DL 150", part number "01-160-61". The chemical composition of the steel is shown in Table 1.

2.2. Methods

2.2.1. Preparation of specimens' surface

The low carbon steel was used in as received condition. The samples were machined into cylindrical pieces of 20 mm diameter and 20 mm long. The sample surface were treated by abrading them through successive grades of silicon carbide papers of grades 60, 120, 320, 400 and 600 grit, and finally on the 0.05 μm cloth grade. They were rinsed in distilled water and then in acetone before drying. The prepared samples were stored in desiccators until when used for the experiments.

2.2.2. Preparation of the cocoa fluid

The environment under study is cocoa fluid. Fresh cocoa pods were procured and then broken into two parts and there after the fluid was manually squeezed out from the beans in the pods and stored in a 10 l gal-lon and then labeled. The chemical composition of each of the cocoa fluid was carried out at the Crop, Soil and Pest's departmental laboratory of the Federal University of Technology, Akure (FUTA). The result is tabulated in Table 2.

2.2.3. Samples pre-treatment before electroplating operations

The samples were removed from the desiccators in turns and pickled in 0.5 M H_2SO_4 for 2 min and then rinsed in distilled water before degreasing in the electrolytic degreasing tank for 2 min and then rinse in distilled water. The samples were weighed using a digital weighing balance model Scout Pro SPU402 and the weight recorded as initial weight.

2.2.4. Electroplating operation

The laboratory zinc electroplating bath was stirred with the aid of a stirrer for 1 min. The sample already attached to the flexible copper wire was then hanged on the cathode arm of the zinc electroplating bath and there after the electroplating rectifier was switched on. The electroplating rectifier was regulated to obtain 0.5 V. The steel sample was allowed to stay in the plating bath for 5 min and there after taken from the plating bath, passivated, dried in air and reweighed. This procedure was repeated for 10, 15 and 20 min of electroplating time. This procedure was repeated using voltages of 0.6, 0.7, 0.8 and 0.9 V and varying electroplating times for 5, 10, 15 and 20 min.

Table 1
Chemical composition (wt%) of the low carbon steel substrates

Alloy elements	Composition (wt %)
Carbon	0.180
Silicon	0.100
Sulphur	0.031
Phosphorus	0.038
Copper	0.230
Chromium	0.100
Tin	0.008
Vanadium	0.006
Iron	99.31

Table 2
Cocoa fluid properties (average)

Composition	Percent (average)
pH	4.19
Humidity	97.12
Ash	1.15
Protein	1.55
Lipid	0.10
Carbohydrate	0.08
Acidity	1.29
Fibre	–
HCN (mg/c)	–

Table 3
Electroplating weight (g) values of zinc-plated low carbon steel sample at various voltage and time

Samples numbers	Voltage (V)	Time (min)	Initial weight before plating (g)	Final weight after plating (g)	Weight gained after plating (g)
1	0.50	5.0	46.36	46.37	0.01
2	0.50	10.0	46.16	46.19	0.03
8	0.50	15.0	46.28	46.34	0.06
14	0.50	20.0	46.16	46.33	0.17
9	0.60	5.0	47.61	47.64	0.03
3	0.60	10.0	47.61	43.91	0.08
5	0.60	15.0	45.17	45.27	0.10
15	0.60	20.0	45.92	46.14	0.22
11	0.70	5.0	46.20	46.24	0.04
7	0.70	10.0	47.56	47.67	0.11
4	0.70	15.0	45.75	45.88	0.13
16	0.70	20.0	47.95	48.30	0.35
10	0.80	5.0	43.45	43.51	0.06
6	0.80	10.0	47.90	48.03	0.13
12	0.80	15.0	45.01	45.24	0.23
13	0.80	20.0	45.44	45.83	0.39
18	0.90	5.0	47.47	47.55	0.08
19	0.90	10.0	43.08	43.27	0.19
17	0.90	15.0	49.18	49.51	0.33

Table 4
Weight loss (mg), for zinc-plated low carbon steel samples at various voltage and time and control sample immersed in cocoa fluid

Exposure time (days)	0.5 V 5 min	0.6 V 10 min	0.7 V 15 min	0.5 V 20 min	0.8 V 5 min	0.9 V 10 min	Control sample
0	–	–	–	–	–	–	–
5	40.00	80.00	160.00	180.00	50.00	200.00	20.00
10	10.00	30.00	10.00	10.00	10.00	10.00	10.00
15	20.00	20.00	20.00	10.00	0.00	0.00	10.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	10.00	10.00
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5
Corrosion rate (mg/cm^2/yr) values for zinc-plated low carbon steel samples at various voltage and time, and control sample immersed in cocoa fluid

Exposure time (days)	0.5 V 5 min	0.6 V 10 min	0.7 V 15 min	0.5 V 20 min	0.8 V 5 min	0.9 V 10 min	Control sample
0	–	–	–	–	–	–	–
5	154.83	309.65	619.30	696.71	193.53	774.13	77.41
10	19.35	58.06	19.35	19.35	19.35	19.35	19.35
15	25.80	25.80	25.80	12.90	0.00	0.00	12.90
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	7.74	7.74
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6
Electrode potential values mv (SCE) for zinc-plated low carbon steel samples at various voltages and time and control sample immersed in cocoa fluid

Exposure time (days)	0.5 V 5 min	0.6 V 10 min	0.7 V 15 min	0.5 V 20 min	0.8 V 5 min	0.9 V 10 min	Control (unplated) sample
1	−694	−520	−600	−480	−635	−580	−512
2	−530	−520	−675	−630	−504	−713	−530
3	−534	−553	−711	−694	−542	−626	−535
4	−528	−527	−529	−538	−536	−599	−542
5	−521	−502	−512	−524	−534	−548	−537
6	−528	−522	−515	−529	−534	−526	−540
7	−544	−542	−549	−550	−552	−547	−552
8	−537	−545	−544	−547	−544	−543	−550
9	−384	−412	−429	−418	−425	−423	−427
10	−380	−299	−312	−298	−288	−280	−240
11	−510	−530	−540	−534	−536	−538	−545
12	−525	−537	−554	−535	−543	−535	−547
13	−488	−498	−536	−524	−527	−528	−544
14	−505	−525	−556	−536	−537	−541	−550
15	−529	−543	−580	−551	−544	−549	−551
16	−537	−531	−566	−537	−530	−543	−536
17	−523	−553	−578	−548	−505	−556	−526
18	−533	−536	−566	−541	−527	−559	−537
19	−485	−472	−532	−494	−451	−491	−470
20	−547	−530	−549	−531	−523	−550	−530
21	−491	−535	−543	−534	−525	−531	−536
22	−549	−527	−532	−554	−561	−534	−564
23	−553	−504	−521	−515	−487	−489	−484
24	−587	−574	−563	−575	−556	−530	−546
25	−598	−570	−558	−548	−559	−558	−551
26	−565	−530	−561	−535	−559	−519	−578
27	−589	−530	−555	−503	−535	−595	−562
28	−580	−530	−555	−511	−507	−506	−574
29	−557	−522	−516	−493	−548	−508	−590
30	−584	−577	−492	−544	−605	−555	−629

2.2.5. Determination of corrosion resistance in cocoa fluids (electrode potential and weight loss)

The corrosion environment for examining the corrosion protection performance of the zinc electroplated samples is the cocoa fluid. The zinc electroplated samples were immersed in the cocoa fluid for the duration of 30 days, including three (3) unplated samples as control. The investigation involved the potential (mV) measurement between the sample surface and the corrosive environment (medium) at regular interval of 24 h using DT8300D digital multimeter. Zinc electrode was used as a reference electrode. Values obtained were converted to saturated calomel electrode (SCE) values.

Weight change determination was used due to its simplicity [4,5]. The investigation involved periodic weight loss measurement. The corrosion samples were removed from the corrosion environment with the aid of a tong after which the samples were properly cleaned in distilled water and then dried with a cotton wool. The dried samples were weighed with a chemical weighing balance and recorded and this continued at regular intervals of 5 days.

3. Results and discussion

3.1. Results

Table 3 shows data of weight gained (in grams) by the steel plate samples after electroplating at various electroplating voltages and times.

Table 4 shows data for weight loss (in mg) for unplated and zinc-plated low carbon steel samples at various electroplating voltages and times. The table shows that corrosion stopped in the steel zinc electroplated at 0.8 V for 5 min. Corrosion was observed have occurred again in unplated steel and the zinc-plated steel electroplated at 0.9 V for 10 min on the 25th day.

Table 5 shows the corrosion rate (in mg/cm²/yr) for unplated and zinc-plated low carbon steel samples at vari-

ous electroplating voltages and times in cocoa fluid environment.

Table 6 shows the electrode potential data in mV (SCE) obtained for unplated and zinc-plated low carbon steel samples at various voltages and electroplating times in the cocoa juice environment.

Table 7 shows the variation in pH values for cocoa fluid during the corrosion test period. It shows the pH of the corrosive fluid changing from acidic to neutral during the corrosion test.

Fig. 1 shows the plot of the weight gained against electroplating time at different electroplating voltages. It shows increasing weight gained with increasing voltage and electroplating time.

Figs. 2–7 show the plots of the electrode potential in mV (SCE) obtained for corrosion of unplated and zinc-plated low carbon steel samples in cocoa fluid.

Fig. 8 shows the electrode potential versus exposure time plots for the entire electroplated and unplated sample in cocoa fluid environment superimposed on a graph. It shows the low negative potential of the unplated steel plate

Table 7
Variation in pH values for cocoa fluid during the test period

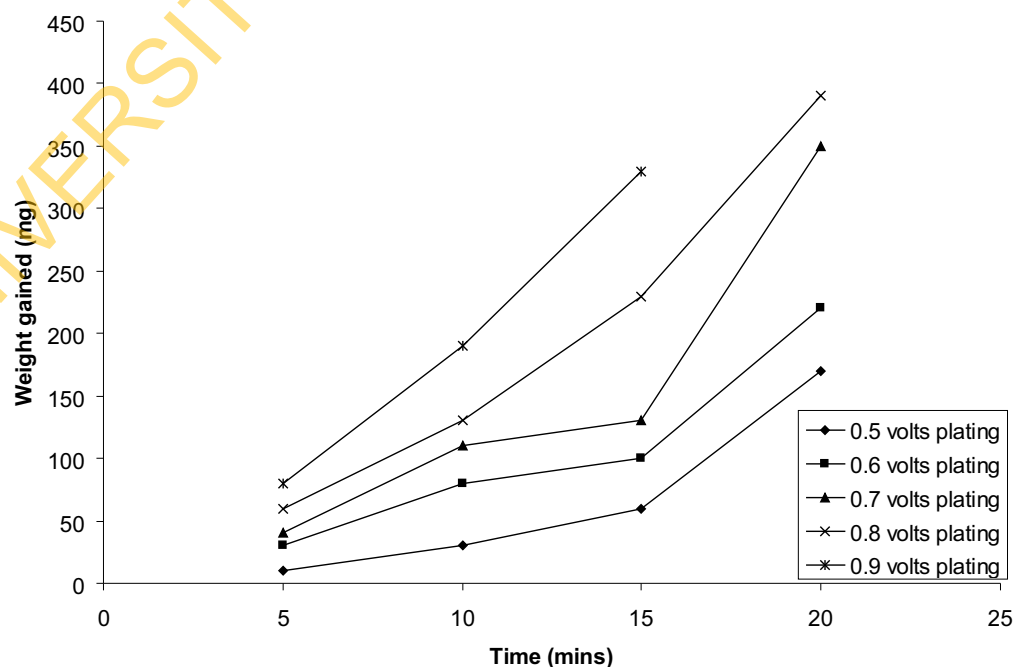| Exposure time (days)	Change in pH
0	–
5	3.18
10	3.63
15	3.67
20	3.89
25	4.57
30	5.21

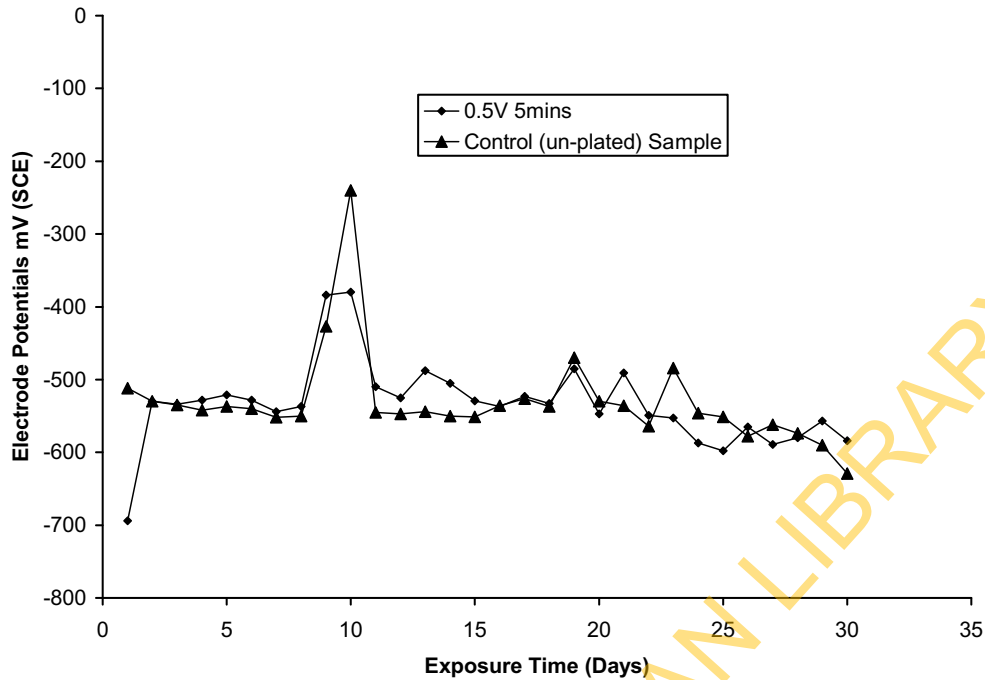Fig. 1. Plot of weight gained against time for zinc-plated low carbon steel samples at various voltages.

Fig. 2. Plot of electrode potential against exposure time for unplated and zinc-plated low carbon steel sample at 0.5 V and 5 min.
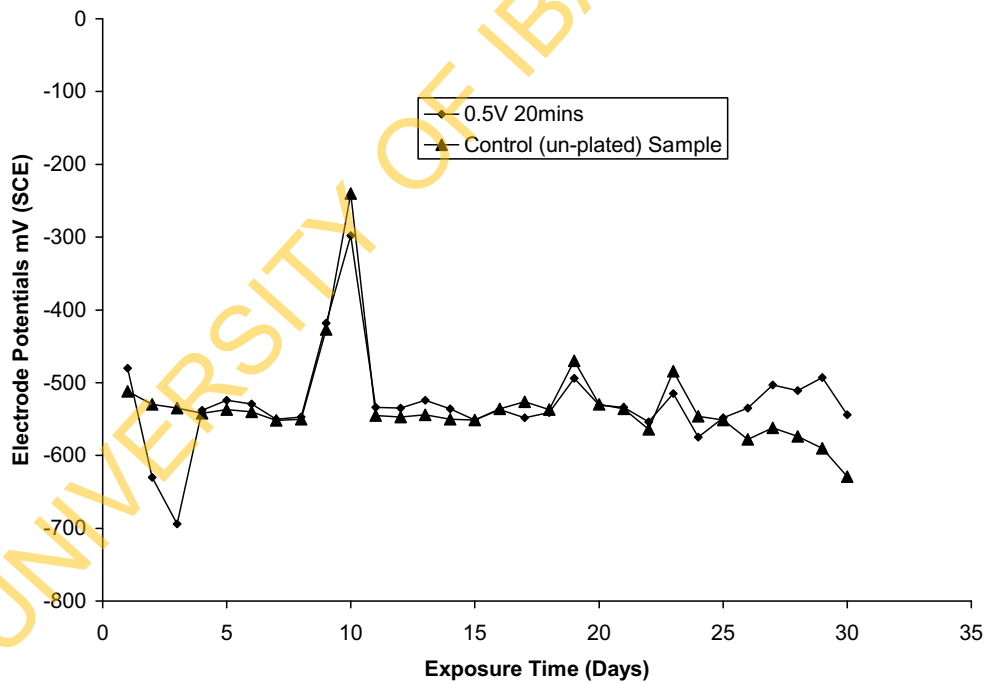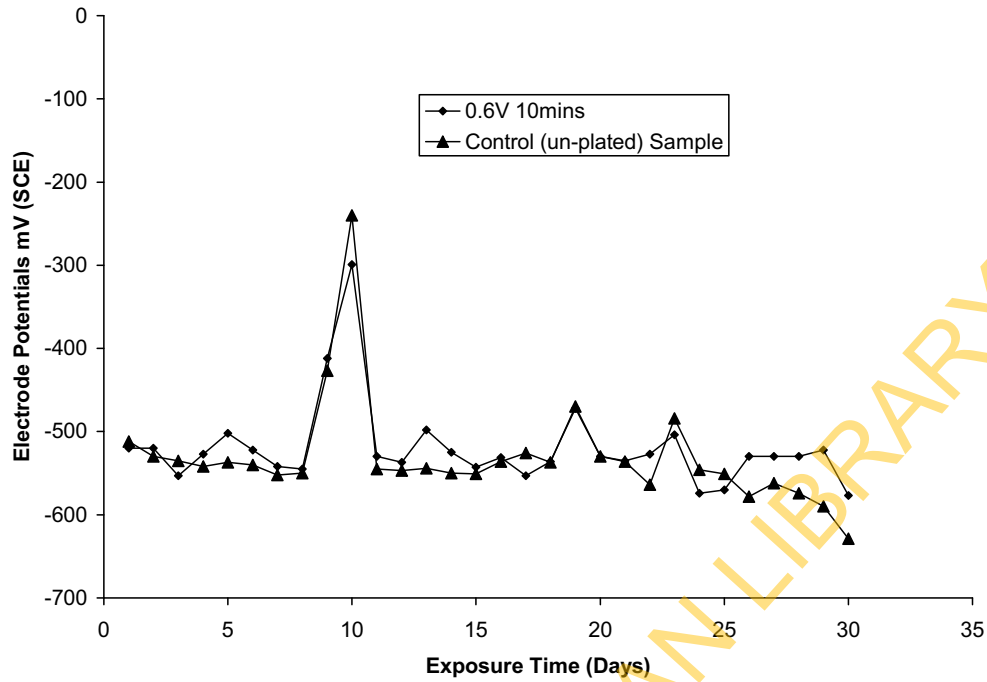

Fig. 3. Plot of electrode potential against exposure time for unplated and zinc-plated low carbon steel sample at 0.5 V and 20 min.

at the early days of corrosivity to be lower generally than the potential of the zinc-plated samples.

Fig. 9 shows the plot of corrosion rate in mg/cm^2/yr for zinc-plated low carbon steel samples at various voltages and electroplating time, as well as the corrosion rate of the unplated sample immersed in cocoa fluid. It shows

the high corrosion rate experienced in the zinc-plated steel in the first 5 days. Corrosion rate was observed to be highest in the plates with the highest amount of zinc plating.

Fig. 10 shows the effect of weight of zinc plating on corrosion resistance of zinc-plated low carbon steel. This fig-

Fig. 4. Plot of electrode potential against exposure time for unplated and zinc-plated low carbon steel sample at 0.6 V and 10 min.
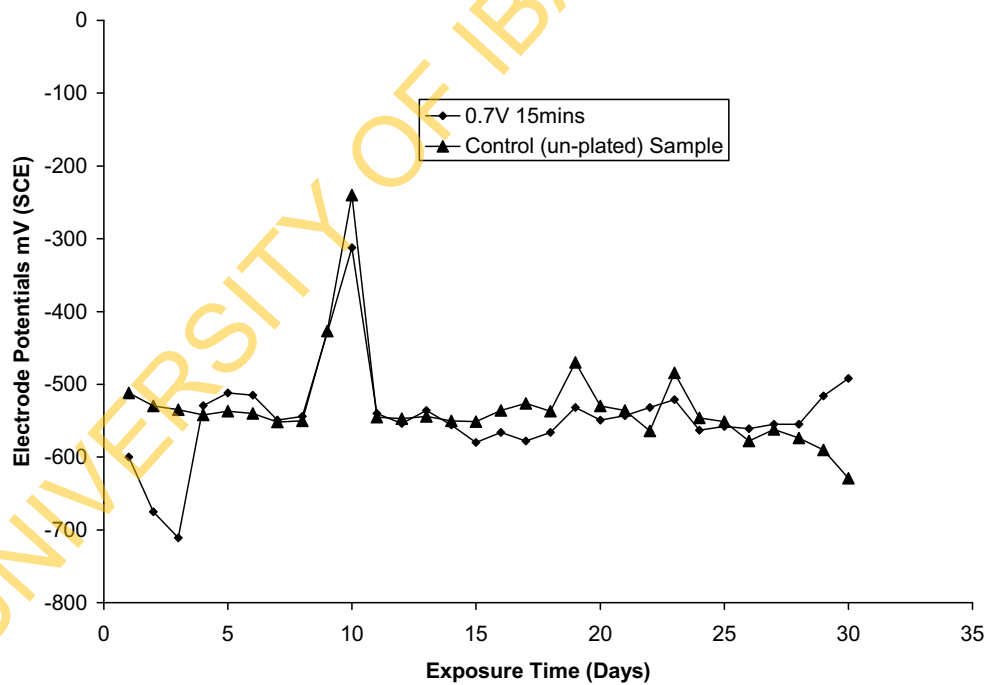

Fig. 5. Plot of electrode potential against exposure time for unplated and zinc-plated low carbon steel sample at 0.7 V and 15 min.

ure shows that all the thinly plated steels with the exception of the plated steel at 0.8 V for 5 min were quickly stripped off the zinc coating and corrosion. It showed that all the electroplated samples with the exception of that electroplated at 0.9 V for 10 min. had been stripped off their zinc plating in the first 5 days. Corrosion had started eating into

the steel substrate of most of the samples even by the fifth day. This might be attributed to very thin plating and uneven plating. By corrosion had begun eating into the steel substrate of all the samples with the exception of the plate with the very thick plating and only one with thin coating.
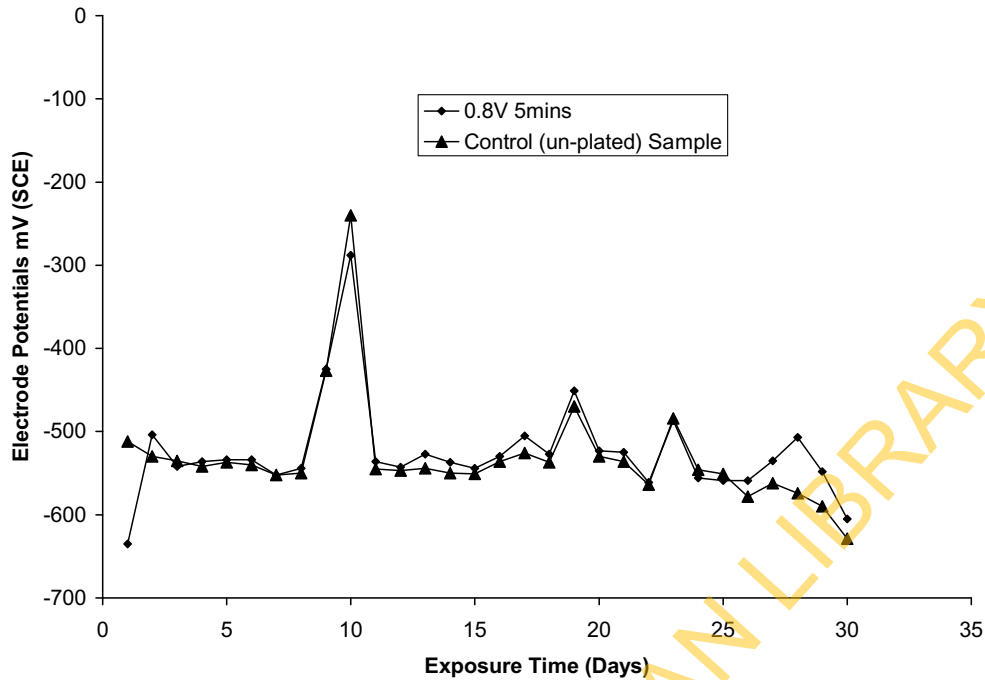
Fig. 6. Plot of electrode potential against exposure time for unplated and zinc-plated low carbon steel sample at 0.8 V and 5 min.
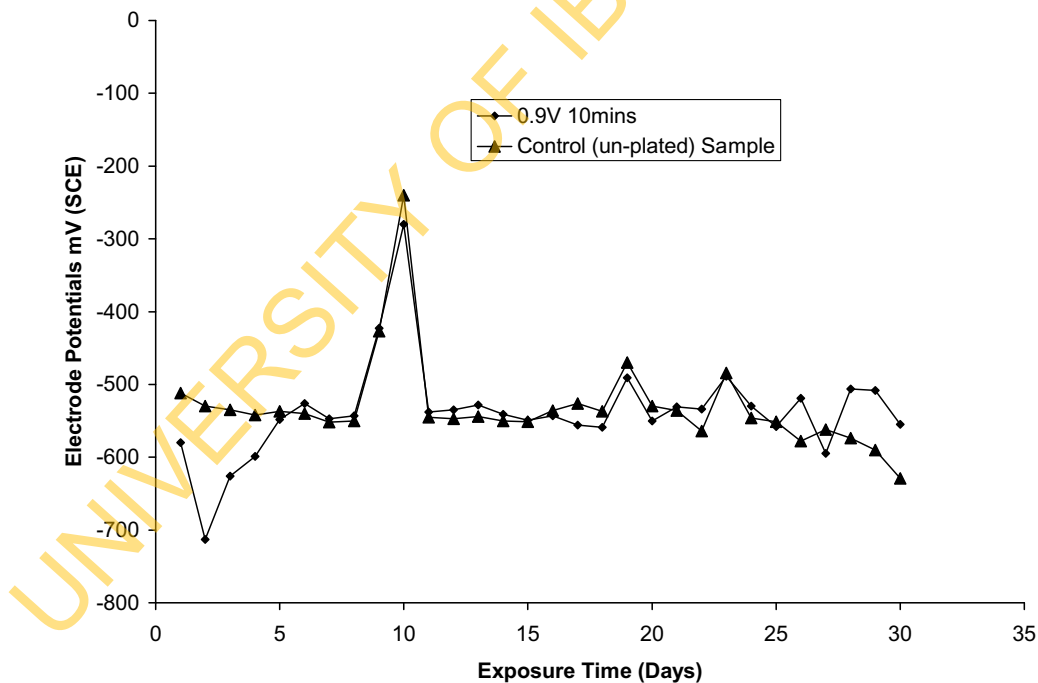

Fig. 7. Plot of electrode potential against exposure time for unplated and zinc-plated low carbon steel sample at 0.9 V and 10 min.

3.2. Discussions

3.2.1. Effect of exposure time on potential

A general increase in negative potential indicated susceptibility of the unplated sample and the zinc-plated low carbon steel samples to active corrosion during the first day of immersion in the corrosion medium. There was an initial chemical reactivity of anode dissolution at the specimen/solution interface within the first 24 h of the experiment [6]. The decrease in the negative potential during
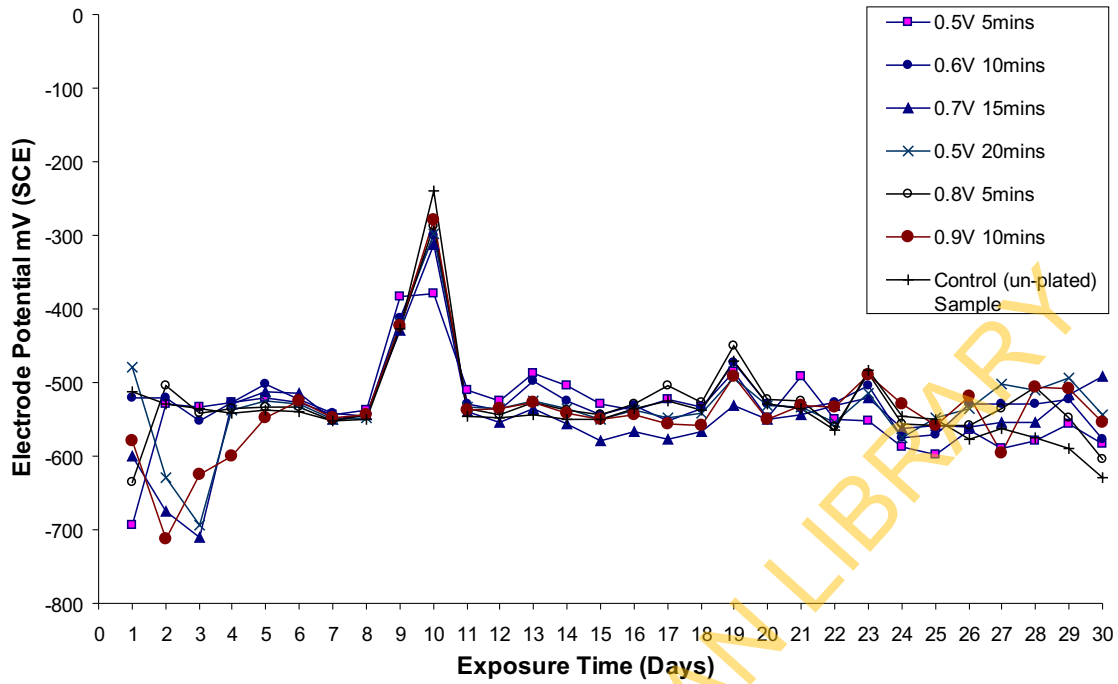
Fig. 8. Plot of electrode potential against exposure time in cocoa fluid for unplated and zinc-plated low carbon steel samples electroplated at various voltages and times.
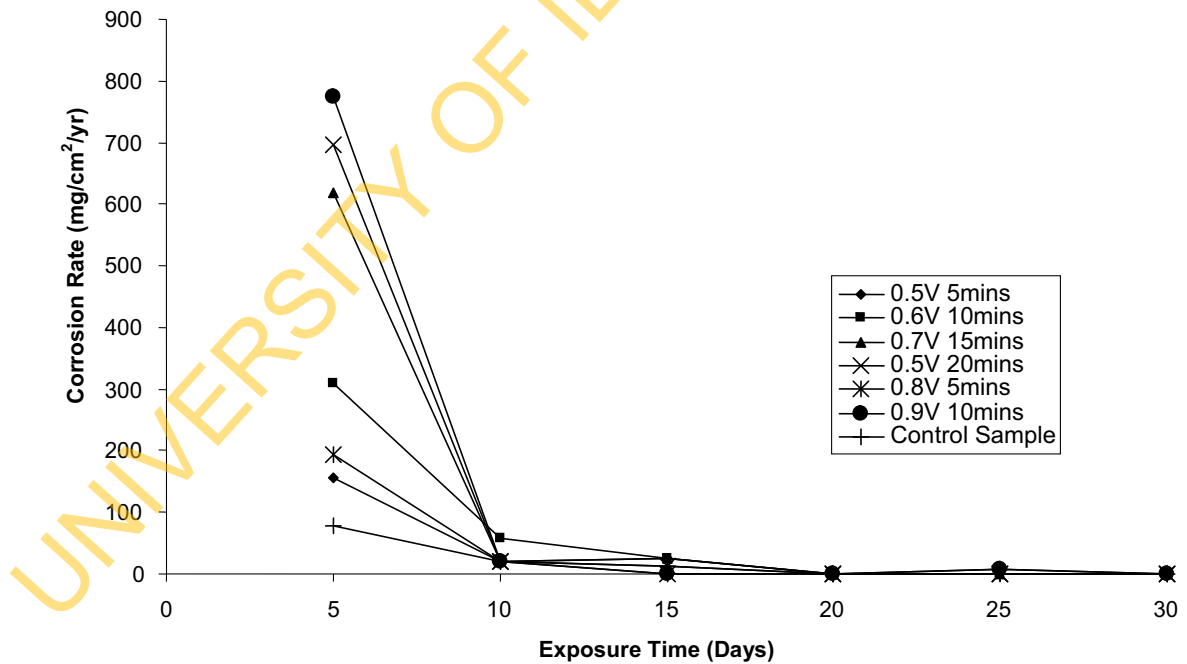

Fig. 9. Plot of corrosion rate against exposure time in cocoa fluid for unplated and zinc-plated low carbon steels electroplated at various voltages and time.

the experiment showed that the unplated sample and zinc-plated low carbon steel samples were in a state of progressive passivation which was at its peak between 9 and 10 days. The change in pH of the corrosion environment from acidic to neutral aided in slowing down corrosion considerably. The increase in negative potential again observed after day 10 may be attributed to film breakdown as a result of cleaning of the metal surface; this quickly heals
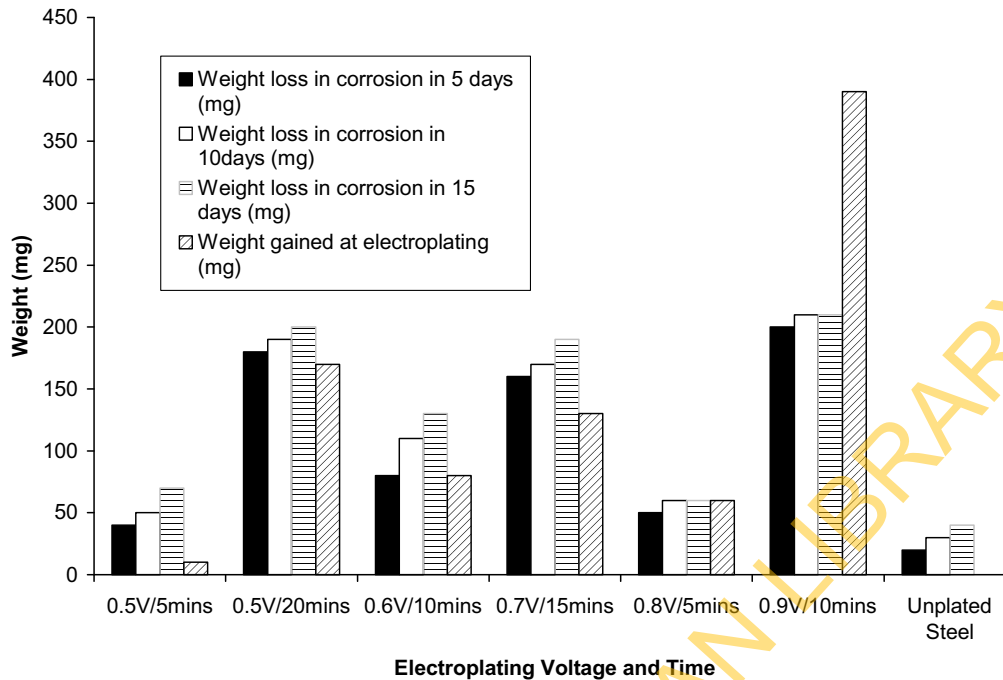
Fig. 10. Plot showing effect of weight of zinc plating on corrosion resistance of zinc-plated low carbon steel in cocoa fluid.

up owing to oxygen diffusion towards the metal surface. The material electrode potential after day 10 exposure period could be said to be in a passive state and in a state of dynamic equilibrium of film potential breakdown and repair.

3.2.2. Effect of exposure time on corrosion rate

Corrosion rates were observed to decrease sharply with the exposure time in this order: 0.9 V/10 min, 0.5 V/20 min, 0.7 V/15 min, 0.6 V/10 min, 0.5 V/20 min, 0.5 V/5 min, for zinc-plated low carbon steel samples. The unplated sample showed the smallest decrease in corrosion rate with exposure time. The sharp decrease in the corrosion rate of the samples between the periods of 5 and 10 days can be attributed to the aggressiveness of the chemical reactivity and the changing pH of the corrosive species in the medium [6]. All the corrosion rates tend to zero after 10 days of the exposure periods. This may be attributed to the formation of passive films at the sample/solution interface.

4. Conclusion

The 0.8 V/5 min zinc-plated low carbon steel sample was observed to give the best corrosion resistance in cocoa fluid. However, it could be generated stated that very thick coating would prevent steel corrosion for some time before corrosion sets in. The 0.8 V plated for 5 min was not studied for a longer time and should form the focus of a future research.

The unplated low carbon steel samples are found to be unsuitable for the fabrication without some form of surface protection.

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