

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

O. O. Oluwole¹, D. T. Oloruntoba*² and O. Awcheme²

This research work investigated the corrosion resistance of zinc plated low carbon steel in cassava fluid (i.e. containing hydrogen cyanide). It simulated the effect of continuous use of the material in a cyanide environment where corrosion products are left in place. Low carbon steel samples were zinc electroplated at voltages between 0.5 and 0.9 V for 5 to 20 min. The plated samples were then subjected to a cassava fluid environment for 30 days. The electrode potentials, in mV (SCE), were measured every day. Weight loss was determined at intervals of 5 days for duration of the exposure period. The result showed corrosion attack on the zinc plated steel, the severity increasing with increasing weight of zinc coating on substrate. The result showed that thinly plated low carbon steel did not have any advantage over unplated steel and were quickly stripped of their zinc plating with resultant corrosion of the underlying steel substrate. Heavily zinc plating steel was observed to offer some protection for the steel but not for a long time. The pH of the cassava solution which initially was acidic because of the cyanide content in the cassava was observed to progress to neutrality after 5 days and then became slightly alkaline at the end of the 30 days test (because of corrosion product contamination of the cyanide), contributing to the reduced corrosion rate. Unplated steel was found to be unsuitable for the fabrication of cassava processing machinery without some form of surface treatment, but unfortunately, zinc is not suitable as a protective coating in this environment.

Keywords: Corrosion resistance, Zinc plating, Low carbon steel, Cassava fluid

Introduction

Corrosion in cassava processing machinery especially those made of carbon steel is a common phenomenon in Nigeria's agriculture processing industry. Because most of these firms are small scale and cooperative industries, there is the tendency to use the cheapest and most available metal, i.e. low and medium carbon steel to minimise setup costs.^{1,2}

Cassava is a widely grown root crop which accumulates two cyanogenic glucosides, linamarin and lotaustralin.³⁻⁵ Linamarin produces the toxic compound hydrogen cyanide (HCN) which is corrosive to processing machinery components. The primary processing operations of cassava into any of food products ('gari', 'lafu', flour, etc.) include: peeling, washing, slicing, grating, dewatering, fermentation, sifting, drying/frying, grinding, packaging and storage. All these involve the use of machinery of varying sophistication through

which corrosion problems are likely to be encountered. Corrosion problems in cassava fluid becomes more pronounced as the cassava tubers are broken into pulp and thereafter left to ferment naturally by yeast and other microorganisms in which the sugar in the mash are hydrolysed. The critical issue is the presence of the two cyanogenic glucosides released during cassava processing. The water used in the cassava processing carries a high concentration of these glucosides, which explains the relatively high amounts of these toxic compounds in the residual liquid waste.^{3,6} Linamarin and lotaustralin are hydrolysed in the presence of acid and enzymes to produced CN^- and subsequently, hydrocyanic acid (HCN).^{3,7} The average analysis of cassava liquid is as given in Table 1. The estimated annual global production of cassava between 1998 and 2000 was 168 million tonnes fresh weight out of which about 70% was produced in Nigeria, Brazil, Thailand, Indonesia and Democratic Republic of Congo.⁸ Nigeria's share of the world production of cassava in 2000 was 37 million tonnes. This represents 21% of the total global production and 40% of the total production in Africa.⁸

The general objective of the research is to carry out zinc electroplating on low carbon steel and determine

¹Department of Materials Science and Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria

²Department of Metallurgical and Materials Engineering, Federal University of Technology, Akure, Nigeria

*Corresponding author, email leke_oluwole@yahoo.co.uk

the corrosion effects of the zinc plated low carbon steel in cassava fluid.

Materials and method

Material

The material used in this investigation was a low carbon steel (rod) substrate of 1 m length and 20 mm diameter. It was obtained from Nigeria Machine Tools Limited, Oshogbo, Nigeria with batch number 'DL 150', part number '01-160-61'. The chemical composition of the steel is shown in Table 2.

Method

Preparation of specimens (surface)

The low carbon steel was used in its as received condition. The samples were machined into cylindrical pieces of 20 mm diameter and nominally 20 mm length. The sample surface were treated by abrading them through successive grades of silicon carbide papers of grades P60, P120, P320, P400 and P600 grit, and finally on a 5 μ m 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.

Preparation of cassava fluid

The environment under study is cassava fluid. Fresh cassava tubers were procured, grated, and their fluid was manually squeezed out into a clean bowl and stored in a 10 L gallon container and labelled. The chemical composition of each of the cassava 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 1.

Samples pretreatment before electroplating operations

The samples were removed from the desiccators in turn and pickled in 0.5M H₂SO₄ for 2 min, then rinsed in distilled water before degreasing in a 100 L electrolytic degreasing tank containing 200 g KOH and 100 g NaOH in distilled water for 2 min, after which the samples were rinsed in distilled water. The samples were weighed using a digital weighing balance model Scout Pro SPU402 of accuracy ± 0.01 g and the weight was recorded as the initial weight.

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 after which 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 then removed, 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. This process resulted in a series of zinc coatings of different coating weights on the steel.

Corrosion resistance in cassava fluid

The corrosion environment for examining the corrosion protection performance of the zinc electroplated samples was cassava fluid. The zinc electroplated samples were immersed in cassava fluid for durations up to 30 days, including an unplated sample as control. Electrode potential (mV) measurements between the sample surface and the corrosive environment were carried out at regular interval of 24 h using a DT8300D digital multimeter with a zinc electrode used as a reference electrode. The reference electrode was not left in the cell for the duration of the experiment but used only at time of measurement of potential then afterwards removed. Values obtained were converted to saturated calomel electrode (SCE) values.⁹ It has been reported that among the most widely used corrosion measurement technique, weight change determination was preferred due to its simplicity.¹⁰⁻¹² The investigation involves periodic weight loss measurement. The corrosion samples were removed from the corrosion environment (cassava fluid) 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 digital chemical weighing balance and recorded and this continued at regular intervals of 5 days.

Results

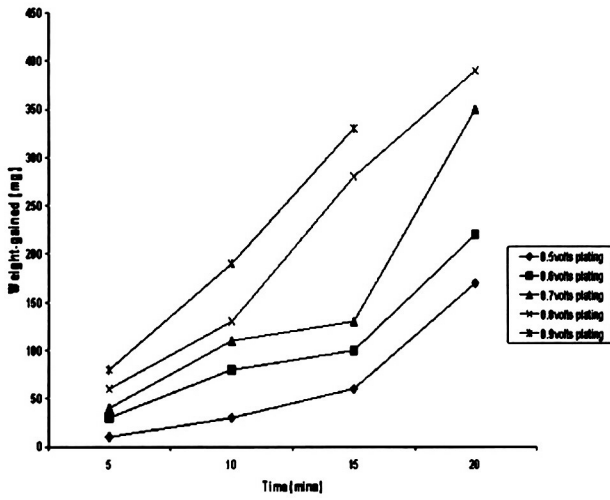
Table 1 shows the nominal chemical composition of the steel samples used while Table 2 shows the average properties of cassava fluid. The electroplating mass gains, and corresponding coating thicknesses value, for the zinc plated steel sample at various voltages and times are shown in Table 3 and in Fig. 1. It can be seen that the resulting zinc coating thickness varied effectively linearly with coating time and increased with coating voltage. The coating thickness varied from about 1 to 30 μ m. Table 4 shows the variation in pH values for cassava fluid during the corrosion test period. It shows the pH of the corrosive fluid changing from acidic to neutrality and then to alkalinity at the end of the corrosion test.

Table 1 Cassava fluid properties (average)

Cassava property	Composition (average)
pH	4.01
Water content, vol.-%	93.71
Ash, vol.-%	2.45
Protein, vol.-%	1.06
Lipid, vol.-%	0.17
Carbohydrate, vol.-%	2.80
Acidity, %	1.63
Fibre	-
HCN, mg c ⁻¹	26.70

Table 2 Chemical composition of low carbon steel substrates, wt-%

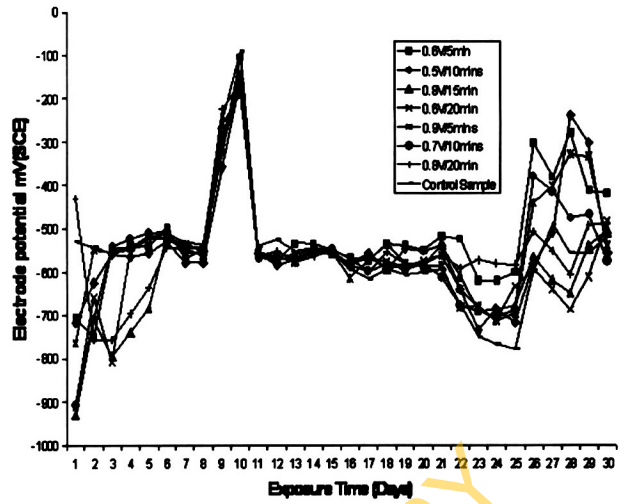
Alloy elements	Composition
Carbon	0.180
Silicon	0.100
Sulphur	0.031
Phosphorus	0.038
Copper	0.230
Chromium	0.100
Tin	0.008
Vanadium	0.006
Iron	99.31



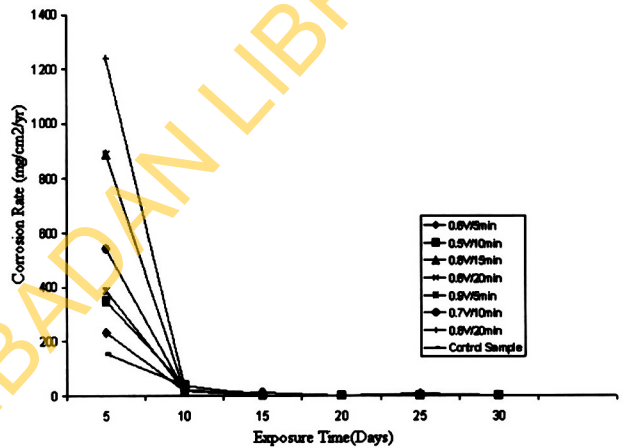
1 Plot of weight gained against time for zinc plated low carbon steel samples at various voltages

Figure 2 shows the variation in the electrode potential in mV obtained for unplated and zinc plated low carbon steel samples at various voltages and electroplating times. For most samples, except those with the thinnest coatings, the electrode potential starts at values consistent with that of zinc and relatively rapidly moves to values consistent with the exposure of steel, although not necessarily over the entire metal surface. An unusual potential excursion occurred for all samples between about 7 and 10 days of exposure but there is no explanation for this, and it must be assumed to be experimental error. Generally, the measurement of potential with time under these conditions resulted in data that appeared to be indistinguishable experimentally from each other.

Figure 3 shows the variation of corrosion rate in $\text{mg cm}^{-2} \text{y}^{-1}$ for the various zinc plated low carbon steel samples as well as the corrosion rate of the unplated sample immersed in cassava fluid (control sample). It shows a relatively high corrosion rate



2 Plot of electrode potential against exposure time for unplated and zinc plated low carbon steel samples at various electroplating voltages and times



3 Plot of corrosion rate against exposure time for unplated and zinc plated low carbon steel samples in cassava fluid environment

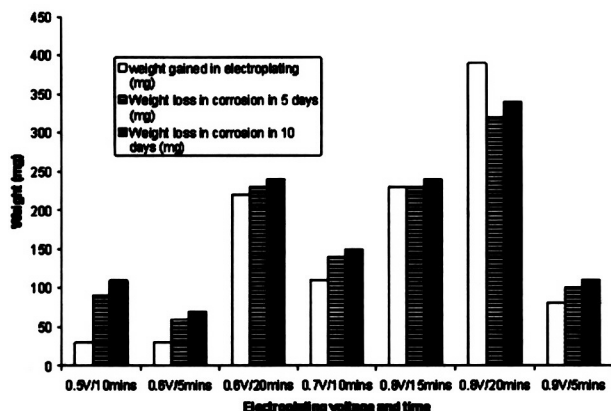
Table 3 Electroplating weight (g) values of zinc plated low carbon steel sample at various voltages and times¹³

Sample number	Voltage, V	Time, min	Weight gain, g	Coating mass per unit area, mg cm^{-2}	Coating thickness, μm
1	0.50	5.0	0.01	0.6	0.8
2	0.50	10.0	0.03	1.7	2.3
8	0.50	15.0	0.06	3.3	4.7
14	0.50	20.0	0.17	9.4	13.2
9	0.60	5.0	0.03	1.6	2.3
3	0.60	10.0	0.08	4.3	6.1
5	0.60	15.0	0.10	5.6	7.9
15	0.60	20.0	0.22	12.2	17.1
11	0.70	5.0	0.04	2.2	3.1
7	0.70	10.0	0.11	6.0	8.4
4	0.70	15.0	0.13	7.3	10.2
16	0.70	20.0	0.35	18.9	26.5
10	0.80	5.0	0.06	3.5	4.8
6	0.80	10.0	0.13	7.0	9.9
12	0.80	15.0	0.23	13.0	18.2
13	0.80	20.0	0.39	21.9	30.6
18	0.90	5.0	0.08	4.4	6.1
19	0.90	10.0	0.19	11.0	15.4
17	0.90	15.0	0.33	17.6	24.6

experienced by the zinc plated steel in the over the first 5 days of immersion. Interestingly, compared with the corrosion of bare steel, the corrosion of zinc was much higher (up to 7 times greater) with greater corrosion observed as the thickness of the zinc coating increased. Figure 4 tabulates the increase in weight caused by initial zinc plating compared with the loss of weight caused by subsequent corrosion. It is quite evident that thin coatings of zinc on steel are not beneficial and do not protect the steel as they are quickly stripped off.

Table 4 Variation in pH values for cassava fluid during test period

Exposure time, days	Change in pH
0	-
5	3.49
10	3.85
15	4.98
20	5.46
25	6.94
30	7.90



4 Plot showing effect of weight of zinc plating on corrosion resistance of zinc plated low carbon steel

Discussion

Effect of exposure time on potential

With the exception of the unplated sample, which showed a fairly constant potential characteristic of bare steel (-550 mV, SCE) from initial immersion, the samples with the lowest coating thicknesses (0.5 V/10 min, 0.6 V/5 min, 0.7 V/10 min and 0.9 V/5 min; i.e. generally less than ~ 7 μm) showed potential moving within 1–2 days into the potential region characteristic of steel. Note that although the pH was changing during the immersion, the extent of the change is deemed to be too small to be significant. An increase in coating weight only marginally affected the variation in potential with time with the rise in potential to that characteristic of steel being delayed for 5–6 days. Eventually, the open circuit potentials of all coating weights lay in the range for that of steel illustrating that exposure of the substrate had occurred. Visible corrosion products for steel (i.e. rust) were apparent from early immersion for the majority of the samples.

Effect of exposure time on corrosion rate

The extent of susceptibility to corrosion in natural fluids depends on the aggressiveness of chemical reactivities, transport properties of environment, concentration of corrosion species in the medium (pH), the metallurgy of the alloy sample and temperature of the corrosion medium.¹⁴ In the cassava fluid, the corrosion rates of all the samples decreased with time tending to relatively low rate after 10 days of exposure (Fig. 3). This can be attributed to the formation of a layer of corrosion product on the sample surfaces from the corrosion products and perhaps to accumulation of zinc (from corrosion of the zinc coating) in the environment, which would act as a cathodic inhibitor and contribute to the observed increase in pH of the environment.

Suitability of zinc coatings in cassava environment

It is evident that uncoated steel is unsuitable for a material of construction for cassava processing equipment and this work tested the use of zinc coatings as a potential protective coating. Unfortunately, and unusually, the zinc also appears to corrode rapidly in this environment and certainly makes low coating thicknesses ineffective. The reason for the relatively rapid corrosion of zinc is undoubtedly due to the easy complexing of zinc as a cyanide species and the consequently more rapid corrosion. Unfortunately, results in zinc being an unsuitable material for the protection of steel in cassava fluid.

Conclusions

1. Uncoated steel has been found to be unsuitable for use in cassava food processing due to its relatively high corrosion rate.
2. Electroplated zinc was tried as a possible corrosion protective coating for steel in cassava fluids. Unfortunately, due to the cyanide content of cassava, zinc had an unacceptably high corrosion rate that was greater than the underlying steel. Thus, zinc is unsuitable for use in protecting steel in cassava processing equipment.
3. An alternative coating material should be sought for the protection of steel cassava processing equipment.

References

1. S. O. Jekayinfa, J. O. Ojadiran and P. O. Okekunle: *Anti-Corros. Methods Mater.*, 2003, **54**, (5), 346–370
2. S. E. Chukwujekwu: Proc. COREN Engineering Assembly, 1998, COREN, Ile-ife, Nigeria, 40–68.
3. M. P. Cereda and M. C. Y. Mattos: *J. Venomous Animal Toxins*, 1996, **2** (1), 1–6.
4. R. O. Cooke: 'Enzymatic assay for determining the cyanide content of cassava and cassava products', 1–14; 1979, Cali, Cassava Information Center-CIAT.
5. E. E. Conn: *Acta Hort.*, 1994, **374**, 31–43.
6. M. P. Cereda (ed.): 'Residuo da industrializacao da mandioca no Brasil', 1–50; 1994, Sao Paulo, Pauliceia.
7. H. J. Williams: *Experiment. Agric.*, 1979, **15**, 393–409.
8. S. O. Jekayinfa, M. A. Waheed, K. A. Adebisi and F. T. Adebisi: *Anti-Corros. Methods Mater.*, 2005, **52**, (5), 286–292.
9. D. B. Hibbert and A. M. Jones: 'Dictionary of electrochemistry'; 1984, London, McMillan Press.
10. D. T. Oloruntoba: 'Effect of fluctuating heat treatment operation on corrosion resistance of austenitic stainless steel samples in sulphuric acid solution', Master's dissertation, FUTA, 2002, 29.
11. J. L. Sodile: *Niger. J. Eng. Res. Develop.*, 2002, **1**, (2), 1–9.
12. K. A. Adebisi, K. A. Hammed and E. O. Ajayi: *J. Eng. Technol.*, 2003, (1), 75–81.
13. O. O. Oluwole, D. T. Oloruntoba and O. Awcheme: *J. Mater. Des.*, 2007, to be published.
14. C. A. Loto and M. A. Adesomo: *Afr. J. Sci. Technol. Ser. A*, 1988, **7**, (1).
15. H. Huang: 'Predominance diagrams', available at: www.mtech.edu/huang/predominance.htm (assessed August 2007).