Corrosion Behavior of Nickel Plated Medium Carbon Steel in Cocoa Liquor.

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ABSTRACT

This research work investigated the corrosion resistance of nickel plated medium carbon steel in cocoa liquor. It simulated the effect of continuous use of the material in a cocoa liquor environment where corrosion products are left in place. Medium carbon steel samples were nickel electroplated at 4V for 20, 25, 30, and 35 mins. using Watts solution. The plated samples were then subjected to a cocoa liquor environment for 30 days. The electrode potentials mV (SCE) were measured every day. Weight loss was determined at intervals of 5 days for the duration of the exposure period. The result showed maximum corrosion rate on the nickel-plated steels to be 0.05mm/yr throughout the 30 days duration of the test while corrosion rate in the un-plated steel was observed to be 0.36mm/yr at the end of 30 days. Generally, it was observed that the thicker the nickel coating, the lower the corrosion rate. The pH of the cocoa liquor was acidic throughout the thirty days test duration. Nickel plating is suitable as a protective coating for medium carbon steels in cocoa liquor environment.

(Keywords: corrosion resistance, nickel plating, low carbon steel, cocoa liquor)

INTRODUCTION

Corrosion has been established in uncoated mild steel used in machinery for agro-processing [1, 2]. Previous work on zinc plating on steel used for fermented cocoa fluid processing machinery showed that zinc plating did not offer protection because of the presence of ethanoic acid in the fluid during processing [3]. Corrosion rates were observed to be as high as 0.99mm/yr in the zinc plated steel with the highest coating on the fifth day of exposure [3].

The term "cocoa liquor" is used to describe finely ground unfermented cocoa beans. During grinding, the mill gets hot and the ground cocoa beans become very fine in particle size until the cocoa butter becomes liquid; in short the finely ground cocoa beans are liquid when they exit the mill. When cocoa liquor is cooled and becomes solid, it is the same as unsweetened baking chocolate. Cocoa liquor has no alcoholic content. Cocoa liquor is one of the key components of chocolate. Cocoa liquor is contained in dark chocolate with high content of cocoa products [4].

At present, most of the cocoa beans are used in the production of cocoa products such as chocolate, cocoa powder (for drink, coloring and flavoring agents), chocolate syrup, and other product enrobed with chocolate. Utilization of cocoa beans (for cocoa powder and cocoa butter production) is only 10% of the gross weight of the cocoa pod. This means that 90% of the total pod weight is discarded as cocoa waste. Since a large proportion of the cocoa pod is thrown away, a lot of effort is going into converting the husk and sweating into beneficial by-products. By-products capable of being produced include cocoa juice, jam and jelly from cocoa mucilage; pectin, animal feeds and biogas from pod husk; as well as biochemical products such as alcohol, acetic acid, and esters from cocoa sweating. Cocoa pulp extracted from fresh cocoa beans using 'Cocoa Depulper' is suitable for conversion into economic products [5].

MATERIALS AND METHOD

Material

The material used in this investigation was medium carbon steel. The chemical composition is presented in Table 1.

Table 1: Chemical Composition of Medium Carbon Steel.

Element	Composition (%)
C	0.27588
Si	0.21646
S	0.06229
P	0.08671
Mn	0.52829
Ni	0.09356
Cr	0,07784
Mo	0.00932
V	0.00110
Cu	0.19824
W	0.01037
Ti	0.00132
Sn	0.2547
Co	0.00789
Al	0.00022
Nb	0.00078
Fe	98.4063

Method

Preparation of Specimens (Surface): The samples were cut into pieces of 37mm length and 8.4mm diameter. The sample surfaces were subjected to grinding and polishing procedures [3] to get the surfaces ready for electroplating. They were rinsed in distilled water and then in acetone before drying*.* The prepared sample were then stored in desiccators until they were needed for the experiments.

Preparation of the Cocoa Liquor: Fresh cocoa pods were procured and the cocoa beans were ground into a paste until the cocoa butter became liquid. Average cocoa liquor analysis is presented in Table 2.

Table 2: Cocoa Liquor Properties (Average).

Properties	Average
Fat Content (%)	52.0%
pH	5.8
Moisture (%)	2.0
Shell Content (%)	1.75

Samples Pre-Treatment before Electroplating Operations: The samples were removed from the desiccators in turn and pickled in 0.5M H_2SO_4 for 2 minutes, then rinsed in distilled water before degreasing in an 100 liter electrolytic degreasing tank containing 200g KOH and 100g NaOH in distilled water for 2 minutes, after which the samples were rinsed in distilled water. The samples were weighed using a digital weighing balance Metler Toledo Pb153 of $\pm$0.001g accuracy and the weight was recorded as the initial weight.

Electroplating Operation: The surfaces of the samples were activated with acid solution. The samples were then dipped into the nickel plating bath using Watts solution [6] at a temperature of 60^0C. The electroplating rectifier was switched on using a current of 4 Volts. Four of the samples were electroplated at different plating times ranging from 20mins – 35mins, while the fifth sample was kept un-plated. The electroplated samples were then dried and their weights recorded.

Corrosion Monitoring in Cocoa Liquor: The nickel electroplated samples were immersed in cocoa liquor for duration of 30 days, including an un-plated sample as control. Electrode potential (mV) measurements between the sample surface and the corrosive environment were done at regular interval of 24 hours 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 [7]. Weight loss measurement method was used to determine the corrosion rate [1, 3, 8, 9]. The corrosion samples removed from the corrosion environment were properly cleaned in distilled water and dried with cotton wool. The dried samples were weighed with a digital chemical weighing balance and recorded and this continued at regular intervals of five days.

RESULTS AND DISCUSSION

Results

The nominal chemical composition of the steel samples used is presented Table 1 while Table 2 shows the average properties of cocoa fluid. The electroplating weight gains, and corresponding coating thicknesses values, for the nickel plated steel sample at various times are shown in Table 3 and in Figure 1.

Table 3: Weight Deposited and Coating Thickness of Nickel Deposited on Medium Carbon Steel at 4Volt and Various Plating Times.

Sample Numbers	Time, min	Weight gain, g	Coating mass per unit area mgcm^{-2}	Coating Thickness µm
1	20	0.002	0.18	0.2
2	25	0.0035	0.31	0.4
3	30	0.006	0.54	0.7
4	35	0.0045	0.4	0.5

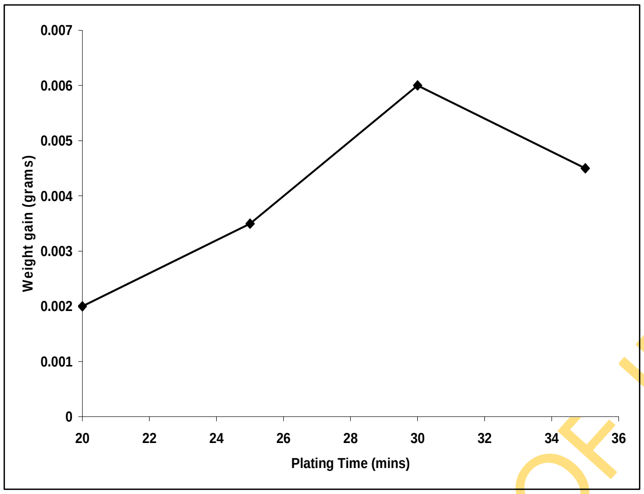

Figure 1: Plot of Weight-Gained During Electroplating Versus Plating Time for Nickel-Plated Medium Carbon Steel.

It could be seen that the resulting nickel coating thickness varied effectively linearly with coating time till 30 mins plating time after which the weight decreased at 35 mins plating time. The coating thickness varied from about 0.2 µm to 0.7 µm.

Fig. 2 shows the variation in pH values for cocoa liquor during the corrosion test period. It showed the pH of the corrosive fluid remaining acidic throughout the test duration.

Figure 3 shows the variation in the electrode potential in mV obtained for un-plated and nickel plated medium carbon steel samples at various electroplating times. All the samples started with electrode potential values consistent with that of nickel and moved to values consistent with the exposure of steel, although not necessarily over the entire metal surface. Generally, the measurement of potential with time under these conditions resulted in data that appeared to be indistinguishable experimentally from each other.

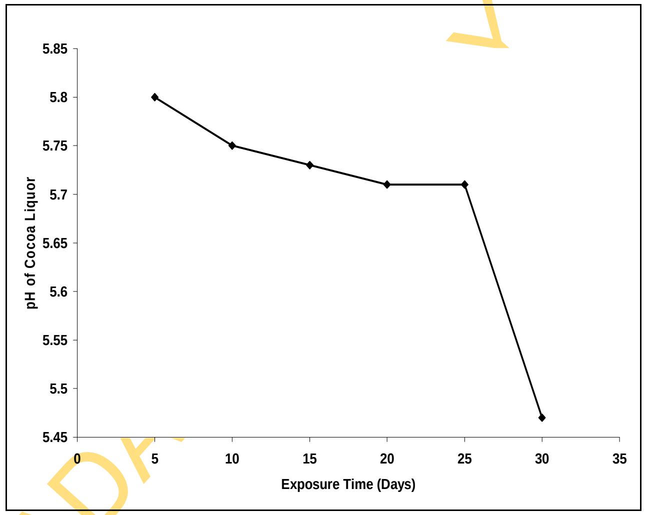

Figure 2: Changes in pH Values during Corrosion Test.

Figure 4 shows the variation of corrosion rate in mm/yr for the various nickel plated medium carbon steel samples as well as the corrosion rate of the un-plated sample immersed in cocoa liquor (control sample). It showed no corrosion on the nickel plated steels in the first 5 days of immersion while corrosion rate of bare steel was already 0.02mm/yr. Generally, it was observed that the thicker the nickel coating, the lower the corrosion rate. Corrosion did not start in the steel nickel-plated for 35 min until after the tenth day.

DISCUSSION

Effect of Exposure Time on Potential

With the exception of the un-plated sample, which showed a fairly constant potential characteristic of bare steel (-550mV, SCE) within three days of immersion, the plated samples showed high negative potential in the sixth and tenth days showing higher corrosion rates which may not necessary be corrosion over the whole specimen surface.

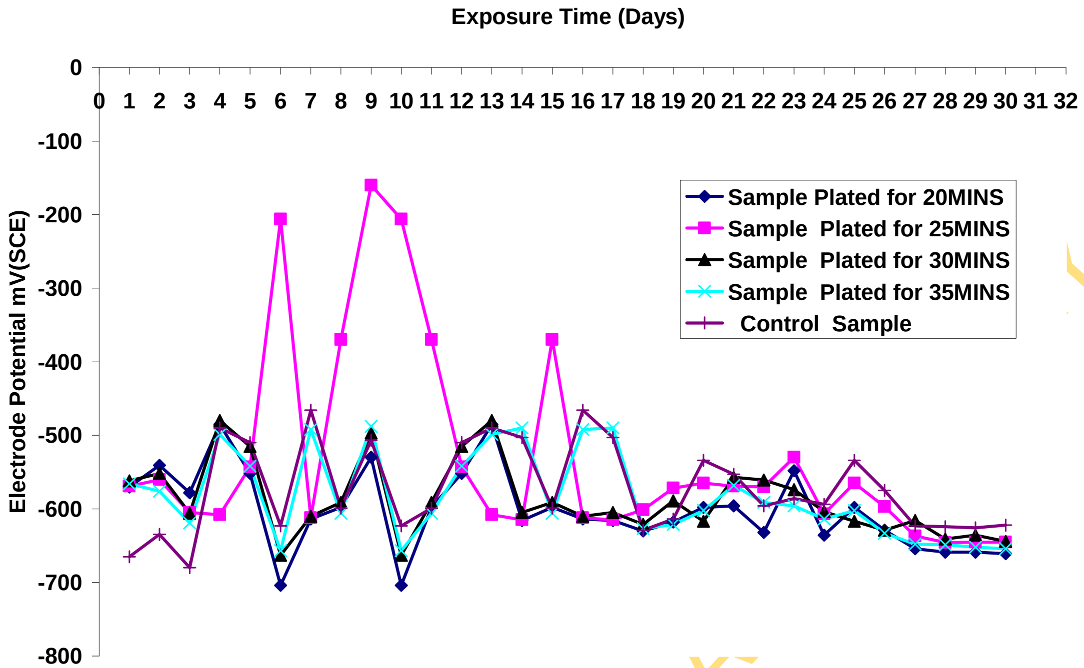

Figure 3*:* Plot of Electrode Potentials Versus Exposure Time for Nickel-Plated Medium Carbon Steels Immersed in Cocoa Liquor.

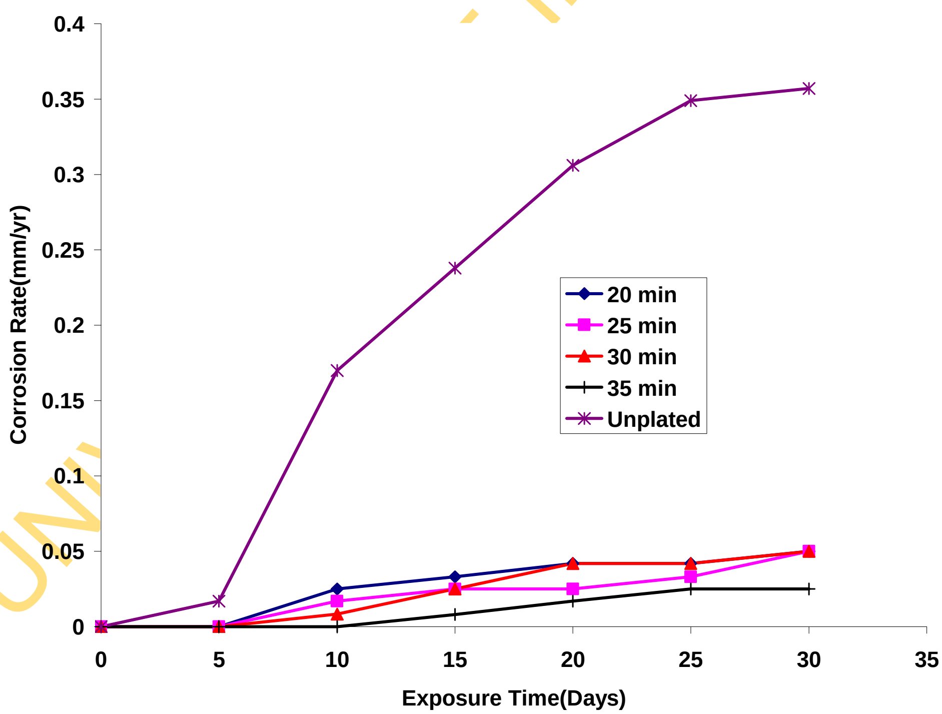

Figure 4: Plot of Corrosion Rate against Exposure Time for Nickel-Plated Medium Carbon Steel Samples Immersed in Cocoa Liquor.

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 thickness did not affect the variation in potential with time.

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 [9]. In the cocoa liquor environment, the corrosion rates of all the samples increased with time showing increasing acidity of the environment. This can be attributed to the fermentation process which has started occurring without preservatives [10]. The highest corrosion rate observed in the nickel plated steel was 0.05mm/yr while the lowest was 0.025mm/yr. In the un-plated steel the maximum corrosion rate of 0.357mm/yr was reached on the 30^{th} day of exposure. This is higher than 0.1mm/yr of which lesser values are considered satisfactory for service conditions [11].

Suitability of Nickel coatings in a Cocoa Liquor Environment

It is evident that uncoated steel is unsuitable for construction material for cocoa liquor processing. The use of nickel plating is a good protection for steels in cocoa liquor environment. Increasing nickel coating was observed to reduce further corrosion rate in medium carbon steels.

CONCLUSION

1. Uncoated medium carbon steel has been found to be unsuitable for use in cocoa liquor processing due to its relatively high corrosion rate.

2. Nickel plating was tried as a possible corrosion protective coating for steel in cocoa liquor. Nickel was found suitable for use in protecting steel in cocoa liquor processing equipment.

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