Corrosion of mild steel in cassava juice

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AN INVESTIGATION has been made into the corrosive properties of cassava juice obtained from the root tubers of the cassava plant genus manihot (esculenta crantz) by electrochemical and non-electrochemical (weight-loss) methods. The results showed extensive corrosion of mild steel by the plant's juice. Separate coating of the steel specimen with two different kinds of paints could not provide effective protection. The CN^- ions from the hydrocyanic acid content of the root's juice are believed to be the reacting species that caused the corrosive chemical interfacial reactions.

Introduction

Cassava is a tropical plant of genus manihot (*esculenta crantz/utilissima*) with tuberous starchy roots from which major staple foods are extracted in West African and other tropical countries. Other uses of cassava include the manufacture of ethyl alcohol, as an animal feed and as a binder in making tablets. Another anticipated large-scale industrial use of the cassava root flour is as a component of wheat flour for bread making.

Some major problems of severe corrosion have been reported from many local and industrial cassava root processing industries, particularly in respect of agricultural implements, machinery and storage facilities. Such material degradation has led to damage and machine failures. There has been no known corrosion research work carried out in respect of cassava other than the present work carried out in our laboratory in which corrosion of steel was observed[1].

This investigation is aimed at the corrosion behaviour of mild steel by electrochemical and non-electrochemical (weight-loss) means and the protection afforded by paint in an extracted cassava juice environment. This is part of research efforts to select corrosion-resistant alloys and means of protection for machines and storage facilities for cassava root processing.

Experimental procedure

2.1 Preparation of specimens

The mild steel used was the hot-rolled product obtained from the RST 37-2 standard billet which was locally manufactured at the Delta Steel Company Ltd, Aladja, Warri, Nigeria. This steel is used in manufacturing agricultural equipment and tools; its average chemical composition is 0.15%C, 0.23%Si, 0.50%Mn, 0.04%P, 0.04%S, 0.025%Cu, 0.1%Cr, 0.011% Ni, 0.05%Sn and the balance Fe. The 16-mm diameter hot-rolled bar was cut into 20-mm lengths which were then ground in a grinding machine using different types of abrasive papers ranging from 120 to 600 grits. This was done to

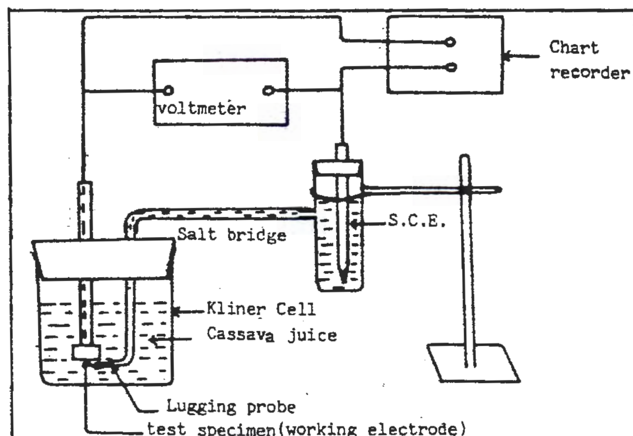

Fig. 1. Arrangement for the potential measurement of mild steel in cassava juice extract (note: SCE = saturated calomel electrode).

examine the effect of final surface preparation with particular attention to paint adhesion. Some of the samples ground (with 600-grit abrasive paper) were later polished using 1.0μ alumina and 0.5μ alumina solutions in a rotating wheel mounted in the polishing machine containing emery cloths. Some of the polished specimens were etched with 2% Nital, and the microstructure was observed under an optical metallurgical microscope.

Two types of paints were used to paint some of the test specimens all over their surfaces for the weight-loss experiment. These were an ICI zinc-rich epoxy and a red Dulux epoxy paint. Some of the specimens were mounted with *met-set* resin and each of the exposed specimen's surfaces was also painted. Those specimens mounted with the resin were used for the experiments described in section 2.4 below; the exposed surfaces of each of two of the samples mounted with the resin were further coated with 1, 2 and 3 coats of the paints. These coated specimens were used for the experiment described in section 2.5. The paints were carefully applied to the specimen's surface with brushes and the samples were left to dry.

2.2 Preparation of cassava juice

The cassava juice used as the test medium was obtained from the cassava tubers from the

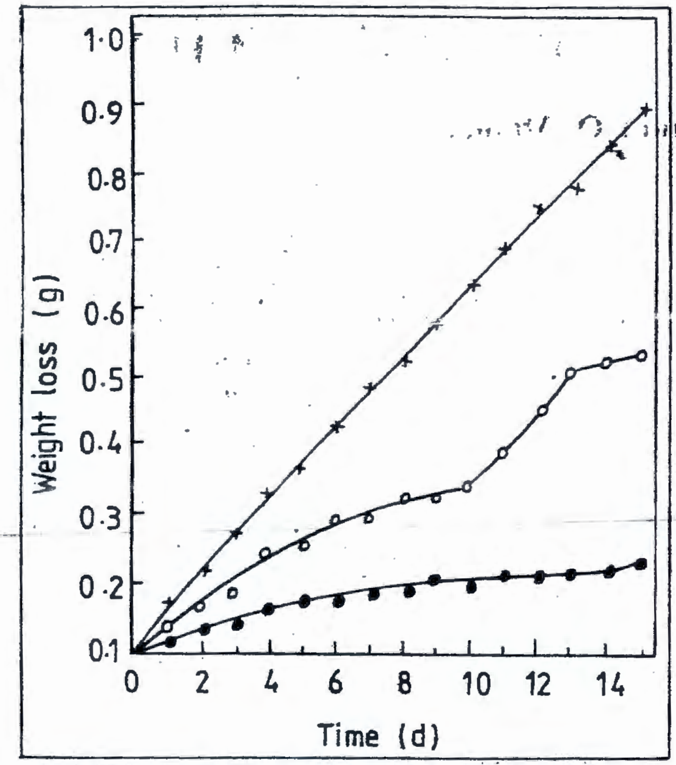

Fig. 2. Weight-loss vs. time curves for mild steel immersed in extracted cassava juice. Key: x = unpainted specimen; o = red Dulux painted specimen; • = zinc-rich painted specimen.

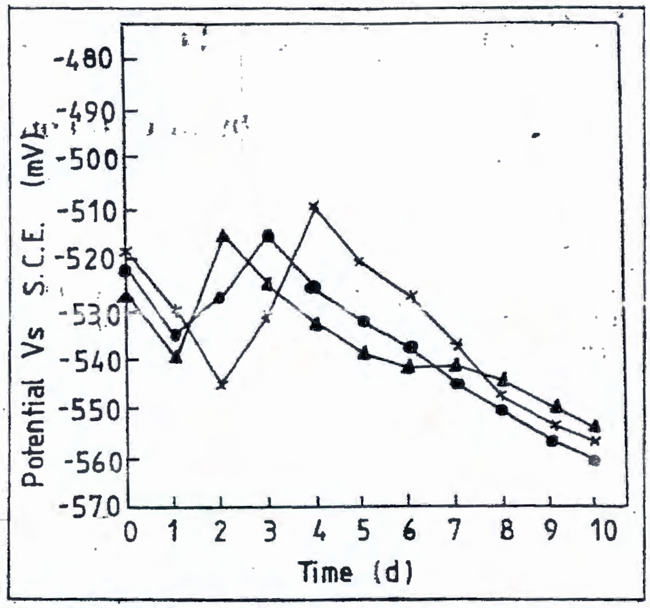

Fig. 3. Variation of potential with time for the mild steel specimens painted with red Dulux paint and immersed in cassava juice. Key: x = samples prepared with 320 grit abrasive paper; • = machined samples; Δ = samples prepared with 120 grit abrasive paper.

University's agricultural farm. The tubers are of genus *esculenta crantz*, and were peeled, washed and sliced to pieces. The pieces were then crushed using a *stephan* machine, the crushed pieces being compressed to extract the juice which was collected, filtered and stored in a clean 5li bottle and kept in a refrigerator. The pH of the juice was immediately recorded.

2.3 Weight-loss experiment

Three samples painted with zinc-rich paint, three with *Royal Red* Dulux paint and three unpainted specimens were used for the weight-loss experiment. The specimens were immersed in extracted cassava juice in different containers (beakers) and the weight loss was measured daily for 15 days.

2.4 Potential measurements

The specimens, both painted and unpainted, were each suspended in turn in the prepared cassava juice. The suspended specimen's potential readings at the steel/solution interface were obtained by using a digital voltmeter and a chart recorder (Fig. 1). A saturated calomel electrode was used as the reference electrode. The partially-immersed test specimen was connected to the voltmeter; a pvc tube (serving as a salt or electrolyte bridge) was used to connect the cassava juice in the corrosion cell to the calomel reference electrode which was held in an electrode holder. The electrochemical measurement was carried out at ambient temperature and under free corrosion potential. Potential readings were taken for 10 days for each specimen.

2.5 Determination of the effect of number of coats of paint

The specimens with different numbers of paint coatings were separately immersed in the cassava juice for 10 days. They were removed and the surfaces were both visually observed and observed under an optical metallurgical microscope.

Experimental results

3.1 Weight-loss measurements

Fig. 2 shows the weight-loss versus time curves for the specimens immersed in cassava juice. The unpainted specimen had the greatest loss of weight relative to time and the relationship is linear. This is followed by the red dulux-painted specimen, while the zinc-rich epoxy painted specimen had the least weight loss.

The zinc-rich painted specimen (as shown in Fig. 2) seems to be more protected (as it has the lowest weight loss or corrosion rate among the three differently-prepared test specimens) than that coated with the red dulux paint. Throughout the 15-day period of the experiment, the total weight loss of the specimen painted with zinc-rich epoxy paint and immersed in the cassava juice was 0.135g. The specimen painted with red dulux paint and immersed in the same medium and for the same period had a total weight loss of 0.432g. The unpainted specimen had a total weight loss of 0.791g within the same period and in the same test environment. Further visual observation showed that while the red dulux paint began to strip from the steel specimen's surface after the 6th day, it started to strip off after the 10th day for the

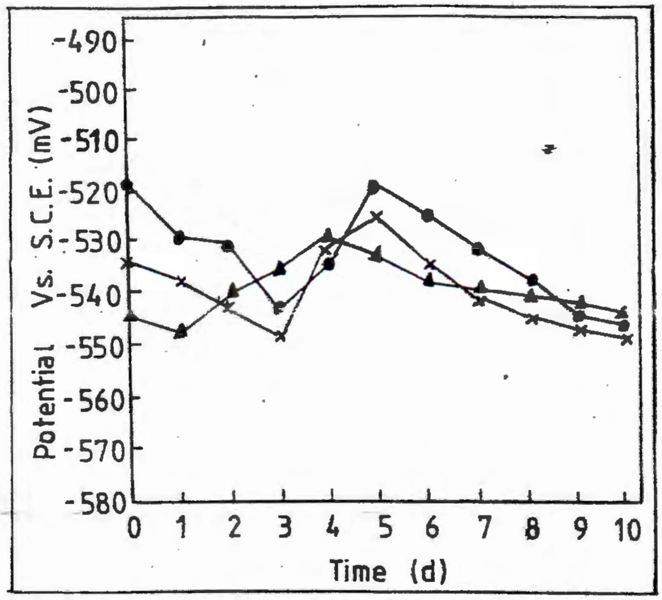

Fig. 4. Variation of potential with time for mild steel specimens painted with Zn-rich paint and immersed in cassava juice. Key as for Fig.3.

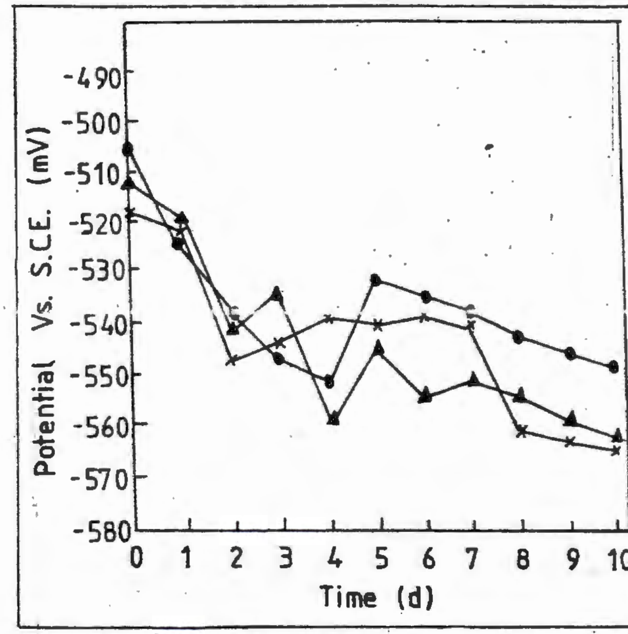

Fig. 5. Variation of potential with time for unpainted specimens immersed in cassava juice. Key: x = machined samples; • = samples prepared with 120 grit abrasive paper; Δ = samples prepared with 600 grit abrasive paper.

specimens painted with the zinc-rich epoxy paint. The stripping appeared to be due to under-film corrosion.

3.2 Potential measurements

The results obtained for the potential/time measurements for the unpainted and painted specimens immersed in cassava juice are shown in the curves in Figs 3, 4 and 5. The potential/time curves for the specimen painted with red dulux paint for the three differently-prepared surfaces are shown in Fig. 3. There was a decrease in potential immediately after immersion of the test specimens that continued for one to two days (for different specimens). After this, there was an increase in potential for about two days following which it started to decrease steeply to lower potentials until the end of the experiment.

The potential/time curves for the specimens painted with the zinc-rich paint (Fig. 4), show similar trends to those painted with red dulux paint. Nevertheless, the initial decrease of potential was more gradual. The positive (cathodic) rise of potential was similar to that for the red dulux painted specimen. However, there was an immediate fall of potential which remained very gradual to the end of the experiment on the 10th day.

For the unpainted specimens, the potential/time curves, Fig. 5, show a more continuous decrease of potential with increase in time. The decrease of potential started after the immersion of the specimens.

3.3 Effect of number of coats of paint

The number of coats of paint applied to the surface of the specimens which were inserted in cassava juice did not show any significant difference in coating adhesion. The surface of the specimen coated with one layer of paint was attacked within 5 days of its contact with the corrosive medium. The surface coated twice had its paint fail, and thereby lost its adhesion. The surface with three coatings, though comparatively more adherent, also lost its adhesion in some parts of the specimen surface within 10 days of its contact with the juice.

Discussion

4.1 Weight-loss measurements

Obviously, the highest weight loss shown by the unpainted specimens must have been due to the more intense chemical reactivities and corrosion processes of the anodic and cathodic reactions occurring at the unprotected specimen/solution (cassava juice) interface. The more intense corrosion reactions here might have been enhanced by the mild steel's heterogeneous microstructure, which basically consists of two phases (ferrite and pearlite) and some inclusions. The chemical compositions of the two phases are different, and hence anodic and cathodic areas are established. When immersed in the juice, the anodic sites corroded. The inclusions further served as stress raisers and hence formed areas of higher energy. This led the inclusion areas to be more susceptible to chemical/corrosion reactions.

The zinc content of the zinc-rich epoxy paint must have contributed to its more protective tendency when compared with that of the red Dulux paint. This is because zinc functions as an anodic material to provide cathodic protection of steel at those areas where the reacting species of the test medium (CN^-) have penetrated the coating (through pores, scratches etc.). These probable defects, particularly the tiny holes, could serve as sites for the commencement of the localized corrosive attack. This is because the defects could set up the anodic and cathodic reaction processes within the test environment which would, invariably, enhance the corrosion of the steel by anodic dissolution and paint stripping by underfilm corrosion.

4.2. Potential measurements

From the above-described results, it could be explained that the immediate decrease in potential after immersion might be due to the chemical reactions occurring at the specimen/solution (cassava juice) interface. The reacting species in the juice, by diffusion process, seems to have set up a chemical reaction with the epoxy paints and penetrated through pores to the metal surface immediately after the immersion of the specimens. This probably caused some of the paint stripping from the specimen's surface by underfilm corrosion. The unpainted specimens were immersed immediately after grinding or machining. This meant that an almost bare fresh surface had been exposed to the test environment. The effect then was that of immediate anodic dissolution reaction at the specimen/solution interface. The observed trend for all the specimens mentioned above at this initial stage was that of active corrosion, though it was more pronounced with the unpainted specimens, as expected.

As indicated in Figs 3-5, the overall corrosion behaviour profile was that of increasing negative potential with some repassivating potential fluctuations probably caused by unstable corrosion deposits. The acidic nature of the test environment, with a pH of 3.90, appeared to have prevented the passivation of the test specimens' surface by corrosion deposits or hydroxyl-formed film.

4.3. Effect of number of coats of paint

It is very difficult to say precisely why there has been loss of adhesion and consequent coating failure on the specimen surface in contact with the cassava juice, despite the varied number of applied paint coatings. However, some of the explanation given earlier in sections 4.1 and 4.2 are considered to be reasonable explanations of this phenomenon.

Conclusion

1. The cassava juice, with its hydrocyanic acid content, is very corrosive to the mild steel. The CN^- ion reacting species could penetrate the air/ hydroxyl-formed oxide film and/or penetrate through defects in the painted surfaces by a diffusion process to initiate corrosion reactions.
2. The zinc-rich epoxy paint is more protective on the steel's surface than the red Dulux paint. This is believed to be due to the zinc content of the paint that protects the steel cathodically.
3. In this investigation, the overall protective effect of the paints on the steel's surface in the cassava juice environment was minimal, particularly from the red Dulux paint which was less protective.

References

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