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Effects of Cassava Juice on the Corrosion Rate of Mild Steel.

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Abstract

The current global increase in the utilization of cassava root and its products has necessitated a huge demand for cassava processing machines. However, the juice of these roots has a corrosive effect on the components of these machines making them vulnerable to damage. This work studied the effects of cassava root juice on the corrosion rate of mild steel which is commonly used for the fabrication of these cassava processing machines. Mild steel sheet purchased in Ilorin was cut into 90mm long and 20mm wide coupons. The samples were then separately immersed in the juice of a sweet Tropical Manihot Esculenta (TME) 7 (A) and bitter Tropical Manihot Esculenta (TME) 419 (B) varieties of cassava for 30 days (daily group) and 14 weeks (weekly group) respectively. In the daily group, two sets of thirty coupons each of the test samples were immersed in juice A and B and a coupon of the sample was removed daily until the last day. In the weekly group, another two sets of fourteen coupons of the sample were immersed in A and B, with a coupon removed weekly while juice A and B were changed weekly. The total weight loss of each coupon was used to determine corrosion rate while micrographs of their surfaces were taken and analyzed using a Frac347e measurement software. A tensile test of each coupon was also carried out before and after immersion using a Testometric M500-100AT. Mild steel had average corrosion rates of 6.03 mm/y in A and 6.32 mm/y in B for the daily group. In the weekly group, it had an average of 1.54mm/y in A and 1.59mm/y in B. In the daily group, the ultimate tensile strength of mild steel reduced from an average of 251.22 N/mm2 to 166.04 N/mm2 in juice A and from 258.26 N/mm2 to 189.60 N/mm2 in juice B; This study showed that mild steel had higher corrosion rates in the juice of bitter Tropical Manihot Esculenta 419 (B) than in the juice of sweet Tropical Manihot Esculenta 7 (A) varieties of cassava.

1.0. INTRODUCTION

Cassava (*Manihot Esculenta*) is a woody shrub with edible root grown in tropical and sub-tropical areas of the world. Scott *et al*. (2000) described cassava as a tropical root crop that serves as a food security and income generation for many millions of people in the developing world. According to FAOSTAT (2019), Nigeria has remained the highest producer of cassava in the world with about 59 million tonnes turnover in 2017. Michael (2010) reported that cassava's national prominence in Nigeria expanded subsequent to the declaration of a Presidential Initiative in 2002. This programme has since increased the production, processing and utilization of cassava in the country.

Cassava, the widely grown root crop in Nigeria accumulates cyanogenic glocosides, linamarin and lotaustralin. Linamarin produces the toxic compound, hydrogen cyanide (HCN), which is poisonous and has corrosive effects on materials which include metals (Akpofure 2012). In order to improve the palatability of cassava food products, it is essential to eliminate or reduce the level of hydrocyanic acid in the crop by processing it before use as detoxification relies greatly on processing methods. Cassava processing machines and equipment are thus extremely vulnerable to the corrosion effect of the cassava juice as they are usually directly exposed during operations. In addition to production time to maintenance and risk of equipment failure, there is also the risk of product contamination by corrosion products which may cause food poisoning. Most of the metallic materials commonly used in the construction of cassava processing machines most especially mild steel, is thus susceptible to various forms and levels of corrosion.

According to Ofoegbu *et al* (2011) despite the standard recommendation of less corrosive stainless steel, there has been an increase in the local fabrication of cassava processing machines using mild steel, galvanized steel and other grades of steel due to cost and availability. Jekayinfa *et al* (2003) had recognized the corrosion of carbon steel, mild steel and medium carbon steel as a major problem in the food and agro-processing industry. This is as a result of the attack of the aggressive cyanide ions in cassava which causes untimely failures during service. There has been an increase in the local fabrication of cassava processing equipment using carbon steel (coated and uncoated) and galvanized steel in Nigeria due to economic reasons. This is because they are cheap and available despite the fact that stainless steel is recommended for use. This makes carbon steel (coated and uncoated) attractive to the food processing needs of small scale farmers because of cost. According to Alli and Faborode (1993), the cheapest and most readily available metal for the fabrication of machinery in Nigeria is plain carbon steel and mild steel, but medium carbon steel has been recognized as a serious problem in the food and agricultural processing industry.

Corrosion of metals used for constructing cassava processing machines poses a serious challenge in the cassava processing industry. It causes loss of production time for maintenance and replacement of damaged parts as well as risky equipment failure. In addition, corrosion poses the risk of product contamination and thus food poisoning by corrosion products. Corrosion does not only influence the chemical properties of a metal but also generate changes in its physical properties and its mechanical behaviour. Since corrosion reduces metal thickness, it leads to loss of mechanical strength. The presence of a corrosive environment may accelerate fatigue crack propagation in structural steels

In food and agro processing industries however, product quality, health and sanitation issues are of major concerns. The industries does not tolerate corrosion deposits in the manufactured products; therefore material selection for machinery fabrication is essential. There is also the need for information to understand the behavior of cassava processing machines when exposed to cassava fluid. This study thus aimed at investigating the effect of the juice of two cassava varieties on the corrosion rate of mild steel which is commonly used in the construction of cassava processing machines. As well as the effect of its corrosion on the ultimate tensile strength of the metal.

2.0. METHODOLOGY

2.1 Sample preparation

Composition analysis of the mild steel test sample as shown in Table 1 was done at Grand Foundries and Engineering Works Limited Ikeja, Lagos with an optical emission spectrometer. Mild steel sheet purchased at Ilorin metal market was cut in coupon size 20x90x0.67mm with a guillotine machine. A 3mm diameter hole was drilled at the top and a rope attached for labeling, easy hanging and removal from the test medium. These coupons were prepared according to ASTM G1-03 and G4 guidelines. Thereafter, emery cloth of different grades (220, 320, 400,800, 1200) was use to grind the coupon to attain smooth and uniform surfaces. The coupon were then degreased with acetone, washed with distilled water, dried. The dry coupons were thereafter weighed and then immediately kept in a desiccator.

Table 1: Chemical composition of mild steel sample

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co	Ti
Weight(%)	0.112	<0.0001	0.313	0.011	0.018	0.013	0.029	<0.0001	0.0064	0.028	0.0022	0.0007

Element	Nb	V	W	Pb	B	Sn	Zn	As	Bi	Ca	Ce
Weight(%)	0.0072	0.0030	<0.0001	0.0080	0.0004	0.0013	0.0009	<0.0001	0.0009	0.0002	0.0064

Element	Zr	La	Fe
Weight(%)	0.0023	0.0005	99.4

2.2 Corrosion Test Media

The cassava juice was extracted from freshly harvested roots of two (2) species harvested from the National Centre for Agricultural Mechanization (NCAM) research farm. The roots of each cassava variety were pealed, washed, and then grated with NCAM motorized grating machine. The grated cassava mash of the two varieties were pressed from separate permeable polypropylene woven bags. A plastic bowl placed under the press was used to collect juice extracted from the cassava mash. The pH of the test media was taken fresh at the beginning and end of each set of immersion periods.

2.3 Coupon immersion

The weighed samples were immersed separately into transparent bottle jars filled with test corrosion media, the juice of Tropical *Manihot Esculenta* (TME) 7 and TME 419 cassava varieties respectively. They were suspended in the cassava juice by hanging them on aluminum strips placed across the top of the glass jar with the aid of polypropylene strings tied around each coupon. The glass jars were kept open at room temperature. The Coupons were totally immersed in the test media as a total immersion test was intended.

Plate 1: Test samples suspended in glass jars containing corrosion test media

2.4 Gravimetric Analysis

Corrosion test was carried out using the weight loss technique in accordance with ASTM standards (ASTM G31-12a, 2012). The pre-weighed test coupons were totally immersed in the TME 419 and TME 7 cassava juice respectively open at atmospheric temperature. Two groups of setup were used for each corrosion media. They are as follows:

2.4.1 The daily group: Two different sets of thirty (30) coupons of the mild steel test sample were immersed individually in TME 419 and TME 7 (oko iyawo) cassava variety juice respectively. These coupons were removed from the cassava juice after each slated days of immersion.

2.4.2 The weekly group: In this group, two sets of fourteen (14) coupons of the metal sample were immersed individually in TME 419 and TME 7 cassava juice respectively. The cassava juice in each jar was replaced with fresh ones at the end of every week (seven days). This group simulates a situations where cassava processing or handling equipment is intermittently in contact with the cassava juice after regular cleaning. Each metal samples in the two groups were removed on their respective due dates. The experimental set up is shown in figure 2. After the removal of each test coupon from the corrosion medium, they were chemically cleaned to remove corrosion products on their surface as stipulated by ASTM G1 guidelines (ASTM G1. 1999). Each coupon were thereafter dried and reweighed to determine the difference in weight hence, weight loss. From the weight loss, corrosion rate was calculated with the formula;

Corrosion Rate $CR = (K \times W)/(A \times T \times D)$ ……………………….. (*3.1) (ASTM G31)*

Where:

K = a constant (8.76x10^4 for unit mm/y),

T = time of exposure in hours

A = area in cm^2 to the nearest 0.01cm^2

W = weight loss in g

D = density in g/cm^3

2.5 Tensile Testing of Samples

Each immersed coupon before and after corrosion test were subjected to Tensile testing on a 500 KN Testometric M500-100AT installed with a win test analysis 4.2.12 processing software shown in figure 2.2. Properties which include ultimate stress, yield stress, elongation and strain were measured. These tests were carried out at a testing speed of 10.000 mm/min with no pretension as shown in Figure 4.

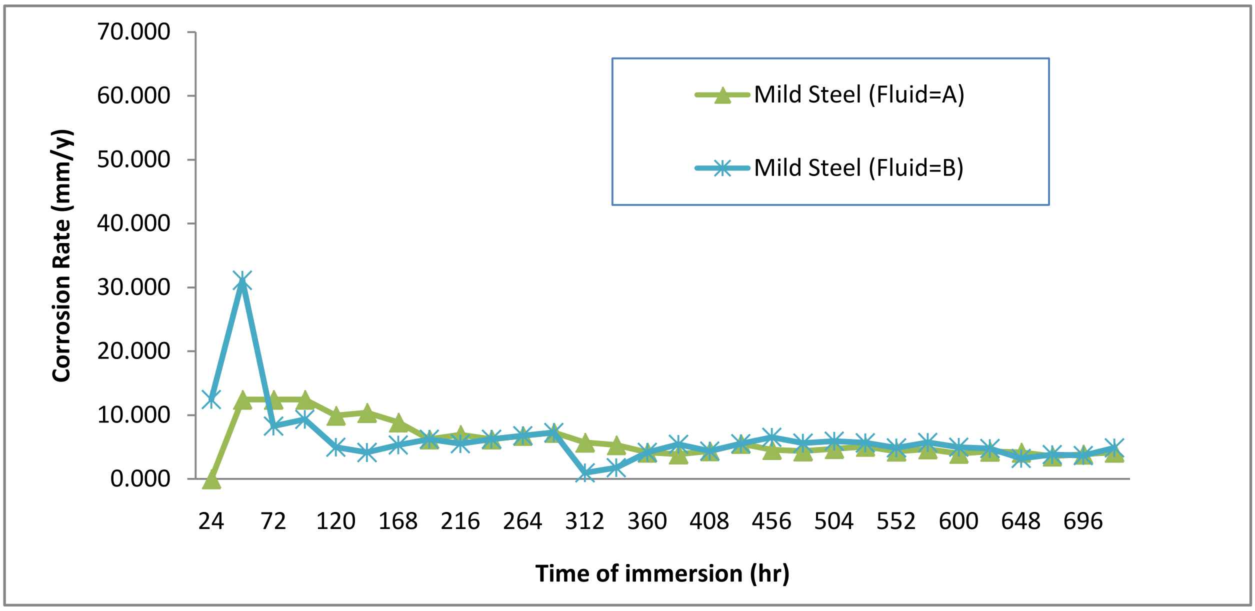
2.6 Fractal Analysis of Samples

The pictures of each sample after removal from the corrosive medium and cleaning were taken with the inverted metallurgical microscope at the metallurgy laboratory of LAUTECH. These images obtained were converted to the bitmap type and reduced to 200x150 mm dimensions. They were thereafter numerically characterized by a fractal measurement Frac347e software, which calculated fractal dimensions by the method of box counting after processing.

3.0. RESULTS AND DISCUSSION

3.1 Effect of time on corrosion rate in the weekly group

Variation of weight loss in the mild steel test sample in the two corrosion media (TME 419 and TME 7) is shown in table….. . The values of the rate of corrosion was observed to be higher in the juice of cassava variety Tropical Manihot Esculenta (TME) 419 [B] than in the juice of cassava variety Tropical Manihot Esculenta (TME) 7 [A]. This showed that corrosion was higher in corrosion media B than in A which is possibly because corrosion media B which is the juice of bitter variety of cassava has a higher level of cyanides according to IITA cassava variety hand book than corrosive medium B which represents the sweet variety with a lower cyanide level. This supports this conclusions of Akpofure (2012).



A-juice of TME 7 "oko iyawo", B-juice of TME 419

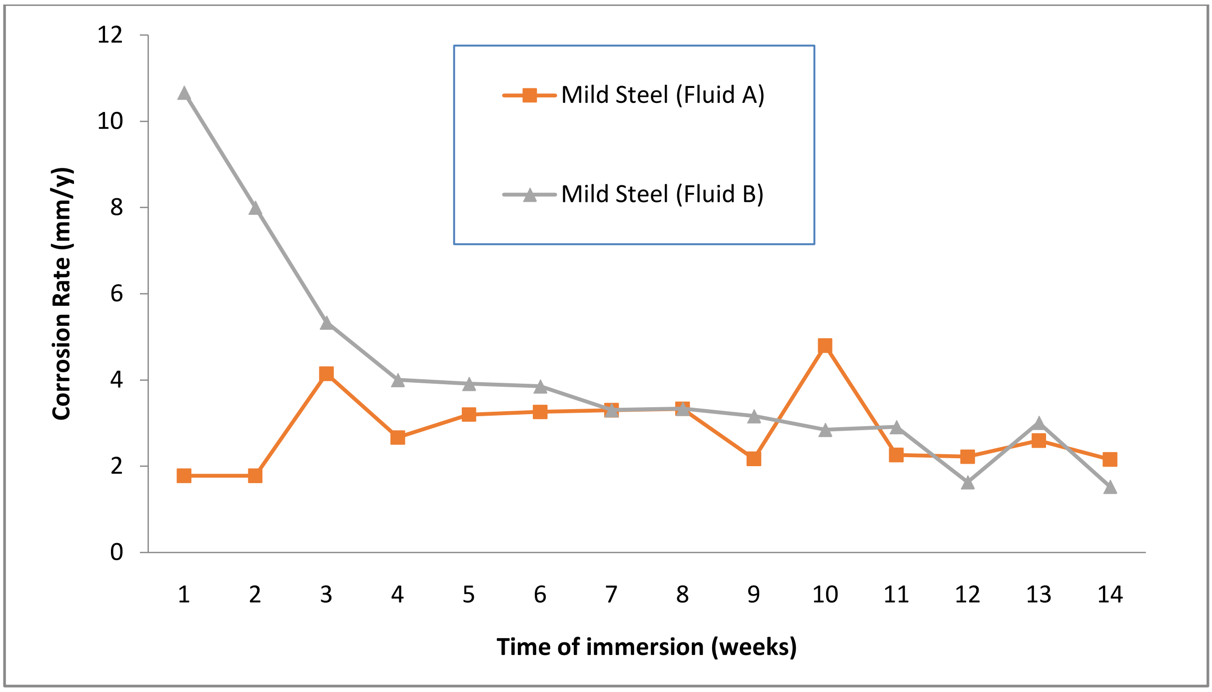
Figure 1: Corrosion rate of Metal sample in Juice A and B against Time (daily group)

The lines defining the corrosion rate of mild steel and galvanized steel in corrosive medium A and B as shown in figure 1 revealed that corrosion rate rose sharply initially before dropping gently for mild steel and galloping for galvanized steel. This might be as a result of the formation of a corrosion inhibitive lactic acid during fermentation of the cassava juice as the immersion time increased. This agrees with the conclusion of Adetunji *et al.* (2011).

Corrosion began in metal sample after 24 hours with corrosion rates rising to peaks within 72 hours (figure 1). The mild steel sample had corrosion rates with the highest value of 32.00 mm/y at time 48 hours in corrosive medium B before dropping to a low of 4.00 mm/y after 720 hours of immersion. In corrosive medium A on the other hand, corrosion rate of Mild steel rose to its peak of 12.00 mm/y in 48 hours before dropping gently to 4.00 mm/y after 720 hours.

3.2 Effect of time on corrosion rate in the weekly group

It can be observed from Figure 2 that corrosion rate of the mild steel within the period of the weekly group study, peaked at the initial week one before decreasing gently till the end. The mild steel in cassava juice sample A, the juice of TME 7 on the other hand, rose to peak in three weeks before it gently declined. Figure 2 also revealed that corrosion rates in the weekly group was lower than it was in the daily group. This might be due to the fact that weekly refreshing of the corrosive medium pushed back microbial activities which resulted in the reduction of corrosion rates as suggested by Akpofure (2012).



A-juice of TME 7 "oko iyawo", B-juice of TME 419

Figure 2: Corrosion rate of Metal sample in Juice A and B against Time (weekly group)

3.3 Effect of corrosion on ultimate tensile strength (UTS) in the daily group

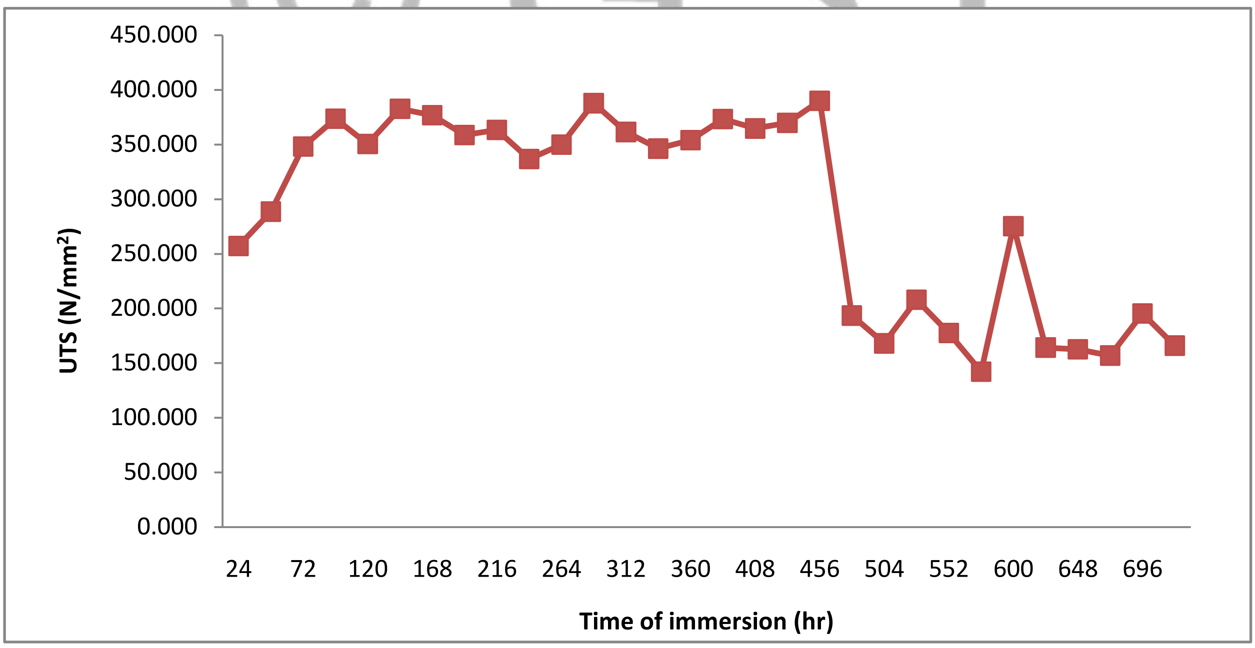


Figure 3: Ultimate Tensile Strength of Metal sample in Juice A against time (Daily Group

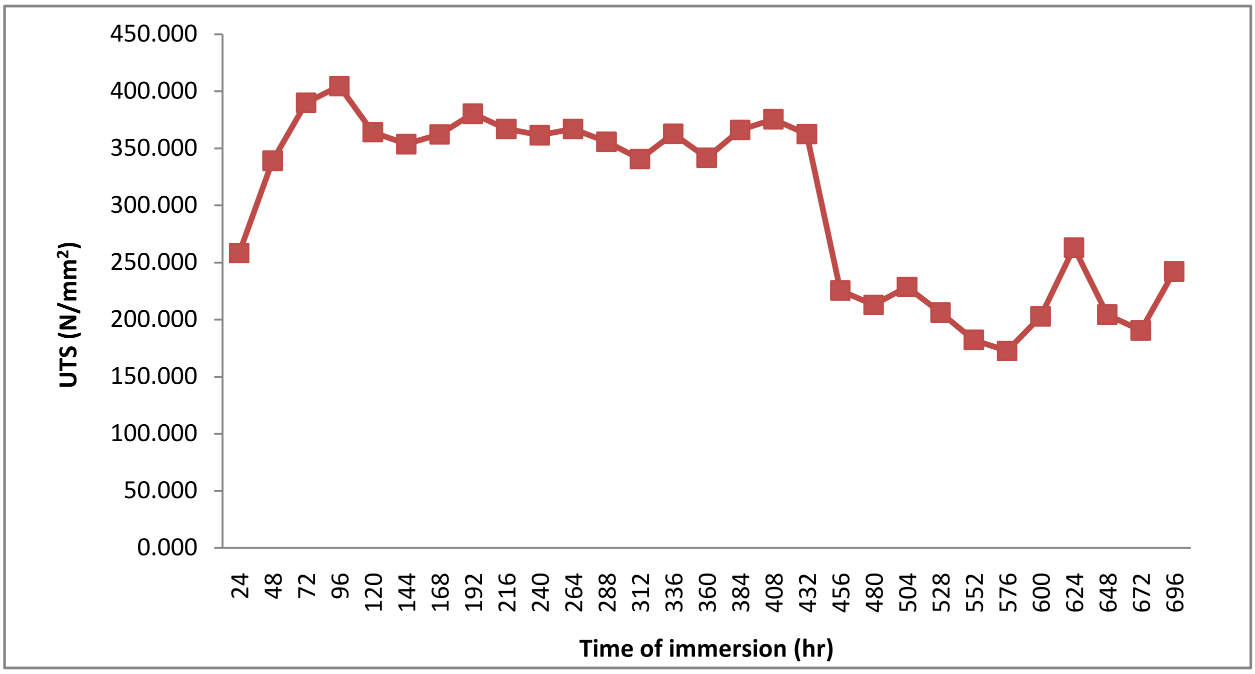
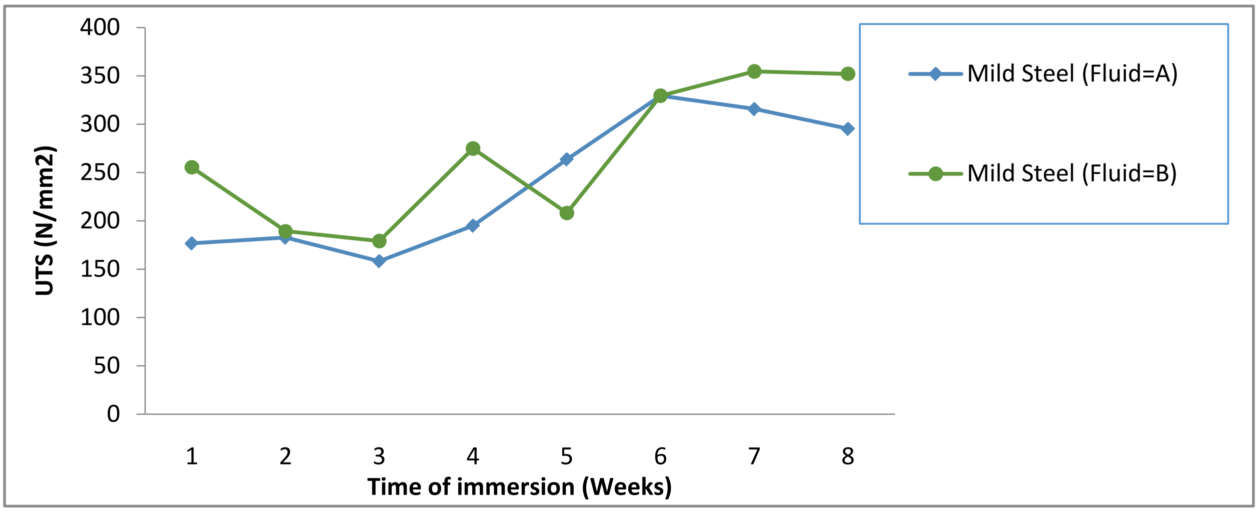


Figure 4: Ultimate Tensile Strength of Metal sample in Juice B against time (Daily Group)

The Ultimate Tensile Strength (UTM) of the metal sample showed a gentle decreasing trend as the immersion time increased in the two corrosion media used for this study. It can be seen from Figures 3 and 4 that the UTM of the metal sample reduced slightly as the time of immersion increased. The decreasing trend in the tensile properties of these metals samples soaked in cassava juice with time could be as a result of the effects of the aggressive cyanide environment on them. This agrees with the conclusions of Adetunji and Adewoye (2010).

In corrosive medium A (juice of cassava variety TME 7), the UTM of the mild steel metal sample reduced from an average of 251.217 N/mm^2 to 166.039 N/mm^2. While in corrosive medium B (juice of cassava variety TME419), the Mild steel metal sample had an UTM decrease from 258.263 N/mm^2 to 189.599 N/mm^2. The reduction in the strength of these metals might have been due to the corrosion of these metal sample leading to its deterioration

3.4 Effect of corrosion on ultimate tensile strength (UTS) in the weekly group



A-juice of TME 7, B-juice of TME 419

Figure 5: Ultimate Tensile Strength of Metal sample in Juice A and B against time (Weekly Group)

As expressed in Figure 5, it can be seen that the ultimate tensile stress of the test metal samples studied in the two corrosion media dropped only slightly within the time of study. This is likely because corrosion rate of the metal samples were lower in the weekly group than in the daily. The corrosive medium were replaced with fresh sample of cassava juice every week in this group, hence microbial activities could have being slowed as a result. This probably reduced corrosion rates as reported by Akpofure (2012). This in turn could have reduced the effect on the ultimate tensile strength.

3.5 Fractal Dimension

For further numerical classification of the corrosion rates of the mild steel metal samples used in this experiment, fractal analysis of their surfaces were done over the time of immersion. An optical microscope was used to observe the sample macro corrosion morphology. The values obtained are presented in appendix A, and the micrographs in appendix B.

The interaction of the fractal dimension with time in the two corrosive medium used in this experiment are plotted as shown in Figures 6 and 7.

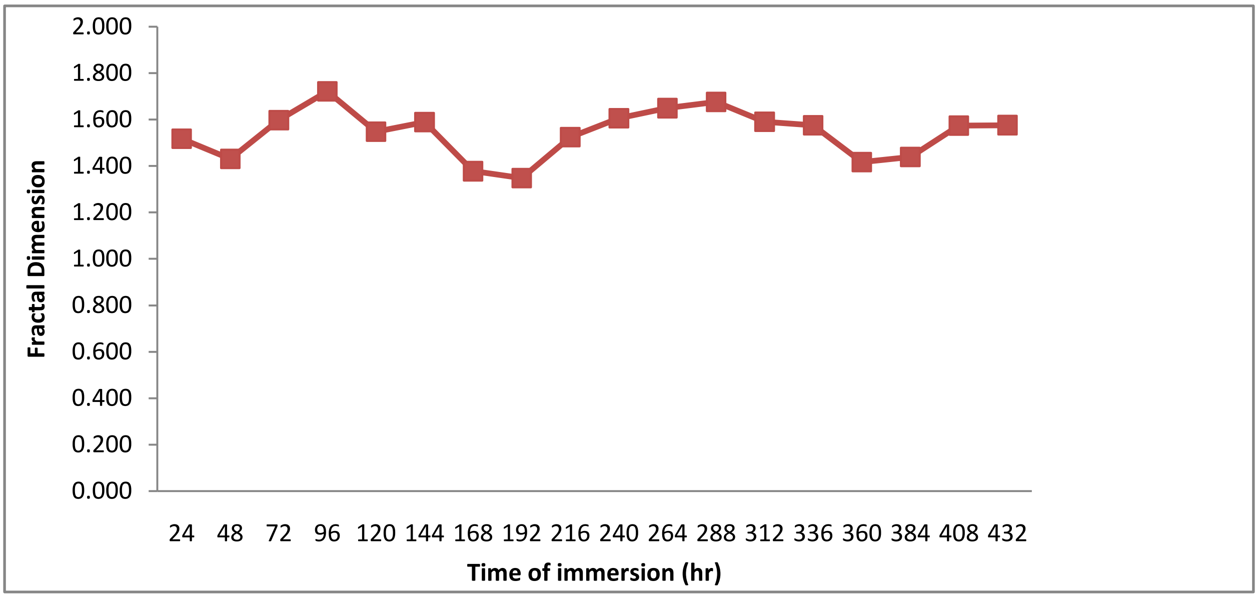


Figure 6: Fractal dimensions of test Metal in Juice A against time

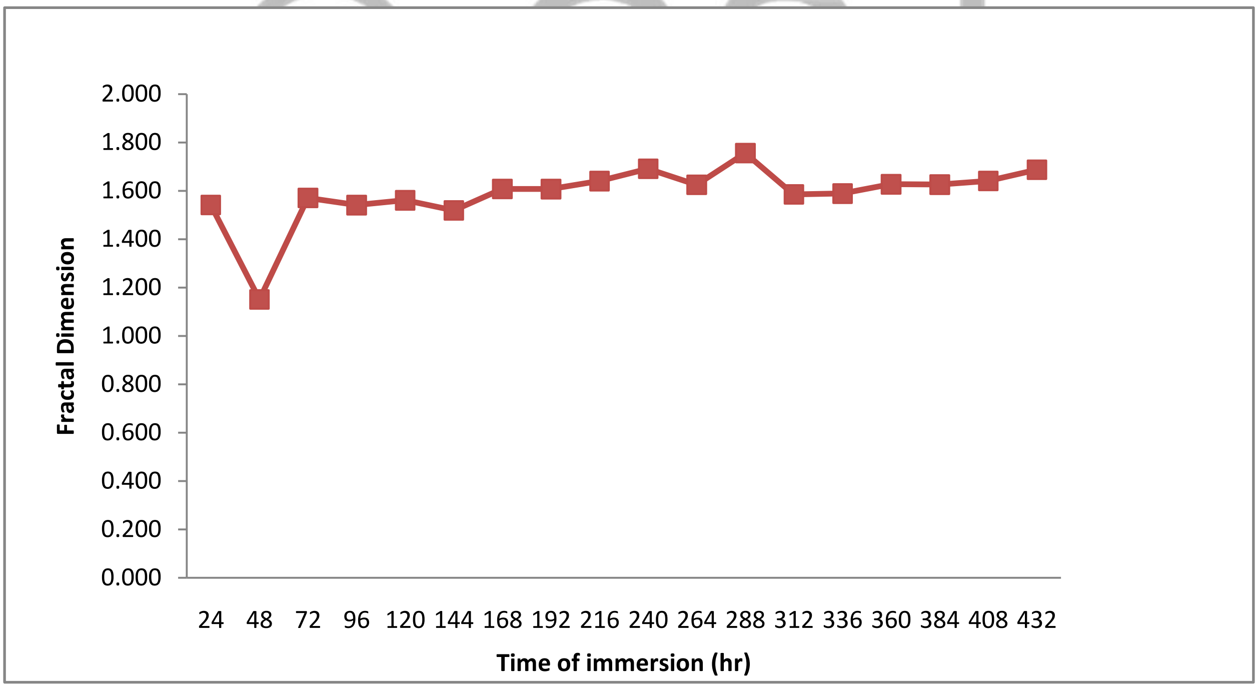


Figure 7: Fractal dimensions of test metal in juice B against time

From Figures 6 and 7 it can be observed that the fractal dimensions of the metal sample increased sharply for the first 48 hours, but later decreased gently as time increased. This corresponds to the trend of the corrosion rate of these metals. Figures 6 and 7 shows variations in the curves of the fractal dimensions. According to Xiang *et al.* 2010, the larger the fractal dimension, the rougher and more irregular the surface of the image of the sample, which implies that the more irregular the image surface, the larger the fractal dimension. They further stated that the more the level of corrosion, the greater the fractal dimension, although sometimes fractal dimensions do not increase with the increase in corrosion rate due to unaccounted uniform corrosion on surfaces.

The trend of variations in the fractal dimension curves in Figures 6 and 7 can be said to have a similar trend with the weight loss of the test metals which showed that the fractal dimension of their surface corrosion morphology could well reflect the variation of the corrosion rate of the test metals. This is in line with the conclusions of Wang *et al*. (2013). It can thus be implied that corroded surfaces are fractal in nature.

4.0. CONCLUSIONS

This study investigated the corrosion rate of mild steel in the juice of a sweet and bitter variety of cassava respectively. The surface morphology of the metal were also examined by fractal analysis to quantify corrosion rates. The effect of corrosion on the tensile strength of this metal was further examined with respect to the two corrosion medium used. Analysis of results obtained led to the following major conclusions.

1. That cassava juice with its aggressive hydrocyanic content is corrosive to mild steel while Corrosion rate was higher in the juice of cassava variety TME 419 which is a bitter variety than in the juice of cassava variety TME 7 a sweet variety.
2. Mild steel had higher corrosion rates when immersed over time in an un-replaced cassava juice medium than when the cassava juice was refreshed intermittently. This

implies that regular cleaning of metal surfaces before further contact with a fresh cassava juice medium can reduce corrosion rate.

3. Mild steel gradually decrease in tensile strength when immersed in bitter and sweet variety of cassava juice over time. Although the rates of decrease are low, Weight loss rate and fractal dimension also have curves of similar variations trend which shows that fractal dimension of metal surface corrosion morphology can reflect the variation of the corrosion rate of the metal but uniform corrosion may not show very serious effects. The higher the rate of corrosion, the more irregular and rougher the surface of the metal image thus, the greater the fractal dimension.

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