Research Paper

Corrosion Resistance of Heat-Treated and Cold-Worked SAE 1030 Mild Steel in Cassava Fluids Media

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ABSTRACT: *The effects of raw cassava tuber slurry (cassava pulp) and raw cassava tuber extract (cassava juice) on corrosion behaviour of variously heat-treated and cold-worked SAE 1030 mild steel sample were investigated. The various heat treatments the samples were subjected to were: annealing, normalizing, hardening and tempering. They were subsequently all cold-worked by forging whereby their thickness was reduced by 25 percent. They were then immersed in the two media, the raw cassava pulp and the raw cassava juice. The samples were exposed in the media by two exposure conditions, the continuous exposure and the intermittent exposure. The unheated (cold-worked) and untreated (as-received) steel samples were used as the experimental controls. The results obtained showed that corrosion rates for the variously heat-treated and cold-worked samples decreased below the corrosion rate of the unheated and untreated samples in the following descending order: unheated > untreated > hardened > normalized > annealed > tempered; unheated 1.421mm/yr, untreated 1.298mm/yr, hardened 0.388mm/yr, normalized 0.340mm/yr, annealed 0.272mm/yr and tempered 0.268mm/yr respectively in medium A. The same corrosion rates trend for the samples were observed for the two media and the two exposure conditions and in medium B, C and D. The results obtained also showed that the corrosion rates of samples immersed in the raw cassava pulp were higher than the of corrosion rates of samples immersed in the raw cassava juice. Finally, the results obtained showed that the corrosion rates of samples exposed continuously in the two media were higher than the corrosion rates of samples exposed intermittently in the two media. The final corrosion rates attained for the unheated and tempered steel samples in medium A were 1.421mm/yr and 0.268mm/yr respectively while the final corrosion rates reached for the unheated and tempered steel samples in medium D were 0.778mm/yr and 0.260mm/yr respectively. Based on the corrosion control method of materials processing and selection, tempered sample offered the highest corrosion resistance in the media, hence isrecommended to reduce the problem of faster corrosion rate of raw cassava tubers processing machines.*
KEYWORDS: *Corrosion Resistance, Heat-treated, Cold-worked, SAE 1030 Mild Steel, Cassava Fluids, Media.*

I. INTRODUCTION

During the fabrication of raw cassava tubers processing machines(cassava peeling, slicing, grating, grinding, pressing, drying and silos) for foods, agro and allied products, the metallic components are subjected to different heat treatments and cold workings process as results of welding and plastic deformation. When these machines are in contact with raw cassava tubers fluids it corrode faster due to the combined effects of mainly the fabrication processes, the aggressive cyanide ions (CN^-) present in form of hydrogen cyanide (HCN) and other corrosion products [1] from the reaction between the metallic surface and the media; minor the forms and types, concentrations, temperatures, and velocity of media; and least the immersion methods and exposure conditions of samples, and atmospheric interference on samples. The resultant effects of the main, minor and least caused a higher corrosion rate of the samples in the media with faster metal deterioration, wastage, and

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damage thereby reduced the optimum capacity and allowable life-span, and increased the untimely failure in service of the cassava plants.

Cassava tubers and cassava processed products are very important for domestic and industrial uses in Nigeria. Due to the products increasing demand, many agro-processing equipment and machinery are rapidly fabricated with mild steel metallic materials which corrode when immersion in this aggressive cassava processing environments. Metallic corrosion, especially, that of plain carbon steels, mild steel and medium carbon steel have been recognized as a major problem in foods and agro-processing industries [1, 2, 3]. Corrosion failures are minimized by appropriate design, proper material processing and selection, and control of metallurgical structure through the use of inhibitors, alloying and heat treatments [4]. Of all these control strategies, heat treatment is the most commonly used due to its cost effectiveness. Heat treatment and alloying of steel are the two particular reasons for its extraordinary versatility and inexpensive [5].

Since Nigeria recently embarked on massive production of foods, agro and allied products with plain carbon steel been the cheapest and most rapidly available metal for agro-processing fabrication of machinery for raw cassava tubers processing [6, 7]. Hence the needs for more researches to reduce the higher corrosion rate of cassava machine through corrosion control measure. Although many related researches have been published on mild steel corrosion using cassava media given below.

[7] Investigated the effect of cassava fluid on corrosion performance of mild steel. The investigation involved periodic weight loss measurements of 0.18 per cent carbon and 0.36 per cent carbon steel rods as they were exposed to cassava fluid. The relationships between loss in weight of the exposed samples and exposure period were determined. Models were developed to relate corrosion rate in each environment with total surface area and exposure period. The results show that 0.36 per cent carbon steel was less affected by corrosion than 0.18 per cent carbon steel, with corrosion intensity in both cases, increasing with duration of immersion. Generally, there was low level of corrosion resistance (high corrosion rate) by the two steel materials. The correlation coefficient between the experimental values of corrosion rates and predicted values (using the developed models) was high. The results of this study indicate that mild steel materials are unsuitable for use in cassava processing without some forms of surface treatment. [8] Investigated the influence of electrode diameter on the corrosion rate of welded mild steel in cassava. This study was carried out to investigate the effect of electrode diameter on this phenomenon. The mild steel samples used in this study were welded with electrodes of gauges 2.5mm, 3.5mm and 4.0mm respectively. Cassava juice was used as corroding medium. An electronic weighing balance was used to take the weights at 4 days interval progressively for 32 days. The least weight loss was obtained in gauge 2.5mm sample (3.45g), followed by 3.5mm (4.96g) and greatest loss was recorded for 4.0mm sample (11.46g). This shows that corrosion rate in cassava processing plant can be minimized through the choice of electrodes. In this case, gauge 2.5mm is recommended for the construction of cassava processing machines. [9] Investigated the role of microorganisms in cassava mill effluent on the corrosion of S45C mild steel. Outcome of this investigation provides opportunities for material selection in the construction of cassava mill. Chemical and biological characterises of cassava mill effluent was also experimentally determined. Corrosion rate has been estimated by weight loss measurements. Results indicate the cassava mill effluent exhibits the necessary qualities of an environment suitable for the promotion and sustenance of microbiologically influenced corrosion. The corrosion rates of S45C mild steel in the cassava mill effluent were 1.37, 1.41, 1.60, 1.85, 1.88mpy at 10, 20, 30 40 and 50days respectively. Pseudomonas sp., Streptococcus sp., Micrococcus sp., Bacillus sp., Neisseria sp., and Lactobacillus sp. were identified in cassava mill effluent.

The main objectives of this research were to control the problem of faster corrosion rate of sample used in fabricating raw cassava tubers processing machine through material processing and selection of the highest offered corrosion resistance sample in the media, and to increase the foods, agro and bye products output through improved optimum capacity, increased allowable life-span, and limited untimely failure in service of the cassava plant fabricated with the mild steel sample. The specific objectives of the research were:

1. To investigate the effects of cassava slurry and extract on corrosion behaviour of samples.
2. To determine the weight loss of differently samples in the raw cassava fluids.
3. To evaluate the corrosion resistance of various samples in the cassava media.
4. To compare the corrosion rate of different samples in the media for corrosion control measure.

The scope and limitation to the study was that heat treatments and cold working were performed on single component of the cassava plant rather than on combined components. Mild steel sample and raw cassava fluids were used for the corrosion experiment instead of other metal samples and other raw agro fluids. Short and long exposure duration (32days) and interval (4days) for samples was used not considering long and short exposure period (98days) and interval (2days) for coupons.

II. MATERIALS AND METHODS

2.1 Chemical Composition Analysis

The SAE 1030 mild steel sheet metal sample 900mm x 480mm x 2mm was obtained from the Universal Steel Limited, Lagos. The chemical composition analyses of the as-received samples were carried out by Optical Emission Spectrometry using AR430 Metal analyzer. The results of elemental analysis conducted via Minipal 4 spectrometer were shown in table 1 below. The materials were used in as-received condition [1].

2.2 Metal Sample Preparation

The main samples were machined into 8 pieces of minor samples of 400mm x 120mm x 2.00mm. 4 samples were heat-treated and cold-worked (annealed, normalized, hardened and tempered) while 1 sample was non-heat-treated but cold-worked (unheated) another 1 sample was non-heat-treated and non cold-worked (untreated). The minor samples were lightly punched and drilled with 3mm drilling bit. The 3mm diameter holes were drilled towards the longitudinal end for easy suspension with rubber thread in the test media.

2.3 Samples Heat Treatment

The lower critical temperature (AC_1) and upper critical temperature (AC_3) were determined by Hougardy empirical formula [10] as presented here.

$$AC_1 \,(^0C) = 739 - 22C - 7Mn + 2Si + 14Cr + 13Mo - 13Ni \tag{1}$$
$$AC_3 \,(^0C) = 902 - 255C - 11Mn + 19Si - 5Cr + 13Mo - 20Ni + 55V \tag{2}$$

The operating temperature of 819.609℃ theoretical value was obtained by the calculation of AC_3 from equation 2 but a practical value 900℃ was used to achieve a homogenized (uniform) austenitic phase.

The 4 minor samples were subjected to 4 different heat treatments methods and procedures- annealing, normalizing, hardening, and tempering in accordance to ASM International Standards, with the operating temperature determined from equation 2 above. The heat treatment methods and conditions are listed in table 2 below.

1. **Annealing (A)**

The samples were heated to austenitic temperature of 900℃ and held or soaked for 60min to ensure complete homogenization, without excessive grain growth and then cooled inside the furnace to room temperature.

2. **Normalizing (N)**

The samples were heated to austenitic temperature of 900℃ and held for 60min to ensure complete homogenization, without excessive grain growth and then taken out of the furnace for air-cooling to room temperature.

3. **Hardening (H) or Quenching (Q)**

The samples were also heated to austenitic temperature of 900℃ and held for 60min to ensure complete homogenization, without excessive grain growth and then quenched in still water at room temperature to ambient temperature.

4. **Quenching (Q) and Tempering (T)**

The samples were heated to 900℃, held for 60min to ensure complete homogenization, without excessive grain growth and then quench in still water at room temperature to ambient temperature. The samples were again re-heated at 550℃ in the furnace for 30min and air-cooled to room temperature.

2.4 Sample Cold Working

The5 treated minor samples were all cold-worked by forging by an amount of 25% of its thickness to a uniform thickness of 1.50mm resulting to 400mm x 120mm x 1.50mm, while the 1 untreated minor sample remained 400mm x 120mm x 2.00mm.The minor samples were then machined into 600 pieces of sub-minor samples of 30mm x 20mm x 1.50mm (treated) and 30mm x 20mm x 2mm (untreated) samples respectively for the overall total samples of the experiments. Average run of 2 samples were used for all the tests.The sharp edges of the machined coupons were smoothened with a hand file. The samples were cleaned with distilled water and then were degreased in acetone before drying. The prepared specimens were then stored in desiccators to dry until they were needed for the experiments.

2.5 Weighing and Suspension

The samples were weighed using a sensitive weighing balance of digital electronic appliance to an accuracy of $1/1000^{th}$ of a milligram and recorded to obtain the initial weight (W_1) of the coupon. The rubber strings were then used to attach coupons for suspension in the prepared rawcassava fluids. The coupons were reweighed and recorded at 4days intervals after immersed and exposure in the media to obtain the final weight (W_2) and these repeated for 32days duration.

2.6 Media Sourcing and Preparation

The environments under study were raw cassava tuber fluids. The cassava tubers were sourced and prepared from freshly uprooted sweet cassava tubers (TME-7) which were obtained from the Federal University of Technology Owerri cassava farm land. The 2 cassava fluids- cassava slurry (cassava pulp) and cassava extract (cassava juice) were prepared by thoroughly peeled and washed 6000g of the freshly harvested cassava and then grinding to fine slurry (pulp) taken care not to lose any water and immediately poured into 4 separate

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500mL rubber containers marked A, B, C and D to matched each of the prepared, measured and labelled samples. A and C were not manually squeezed with rubber sieve; forming the cassava slurry and medium A and C while B and D were manually squeezed with rubber sieve; forming the cassava extract and medium B and D. The cassava fluids chemical compositions and nutritive values were shown below in table3 and table 4 respectively after analysis.

2.7 Samples Immersion and Exposure Test

The total immersion and exposure test method was the experimental procedure used in this research. This method was adopted by [8, 13], because it has a good reproducibility of result. The samples were completely and separately immersed in the 2 different cassava fluids and exposed by 2 different exposure conditions- continuous exposure and intermittent exposure in the measured rubber container at ambient temperature. The corrosion test duration for samples was 32days and measurements were at 4days interval. The 2 immersion cassava fluids and the 2 exposure methods resulted to 4 different media, medium A, B, C and D, the samples were immersed and exposed in:

1 Medium A: raw cassava slurry/pulp at continuous/steady exposure.
2 Medium B: raw cassava extract/juice at continuous/steady exposure.
3 Medium C: raw cassava slurry/pulp at intermittent/interrupted exposure.
4 Medium D: raw cassava extract/juice at intermittent/interrupted exposure.

2.8 Weight Loss Measurement

The differently weighed and suspended samples were submerged in the 4 media for corrosion test by weight loss analysis. The unheated coupons were immersed and exposed into each of the medium with heat-treated and cold-worked coupons while the untreated coupons were immersed and exposed completely and separately in other 4 media, medium A, B, C and D. The coupons were measured and recorded at the 32days duration of each test on 4days interval from medium A and B, for continuous exposure; while medium C and D, for the intermittent exposure, the coupons were measured and recorded on 4days interval before the 32days duration of each test. The coupons taken out from the 4 media, were observed, washed and cleaned thoroughly with distilled running water, and with a rubber bungs to remove corrosion products; degassed in acetone, rinsed with distilled water, and dried in desiccators; and then reweighed to determine the final weight (W_2), from which the weight loss (ΔW), and consequently the corrosion rate (CR) are computed. The initial weight (W_1) and final weight (W_2) recorded were of average of 2 run weights, as shown in figure 12 and figure 13 below.

The plot of weight loss (ΔW) versus exposure time (T) i.e. ($\Delta W/T$) and graphs of corrosion rate (CR) versus exposure time (T) i.e. (CR/T) were plotted respectively. The corrosion rate (CR) from equation3 given below was used to determine the samples corrosion resistance in media, using the formula written by [14] and proposed by [8, 15].The graphical plots were:

1. Weight loss (ΔW) versus exposure time (T) [$\Delta W/T$]
2. Corrosion rate (CR) versus exposure time (T) [CR/T]

Corrosion rate, $CR = \dfrac{K\Delta W}{\rho AT}$ (mm/yr)   (3)

CR is the corrosion rate (mm/yr)
A is the surface exposed area (cm^2)
$\Delta W = W_1 - W_2$ (4)
ΔW is the weight loss (mg)
W_1 is initial weight of specimen before corrosion in milligrams (mg)
W_2 is final weight of specimen after corrosion in milligrams (mg)
ρ is the alloy density (g/cm^3) is $7.859 g/cm^3$
T is exposure time (hr)
K is a constant for unit conversion is 87.6
Surface area of the sample,
$A_1 = 2(L \times B) + 2(L \times t) + 2(B \times t)$ (5)
Where L= length of the sample
B= Breadth (width) of the sample
t= Thickness of the sample
Surface area of the drilled, $A_2 = \dfrac{\pi D^2}{4}$ (6)

$A = A_1 - A_2$ (7)

III. RESULTS AND DISCUSSION

3.1 Chemical Compositions, Heat Treatments, Nutritive Values, Weight Loss and Corrosion Rate.

Table 1: Chemical Composition and Analysis of SAE 1030 Mild Steel Sample.

Run	Fe	C	Si	S	P	Mn	Ni	Cr	Cu	Sn	Mo	V

1	98.184	0.293	0.218	0.057	0.061	0.699	0.098	0.142	0.214	0.027	0.019	0.006
2	98.190	0.312	0.220	0.061	0.061	0.679	0.094	0.106	0.212	0.023	0.019	0.006
Average	98.187	0.302	0.219	0.059	0.061	0.689	0.096	0.124	0.213	0.025	0.019	0.006

Table 2: Heat Treatment Methods and Conditions for Samples.

CONDITIONS	ANNEALED	NORMALIZED	HARDENED	TEMPERED
TEMPERATURE (^{0}C)	900	900	900	550
HOLDINGTIME (min)	60	60	60	30
COOL MEDIUM	Furnace	Air	Water	Air

Table 3: Chemical Composition of Cassava Fluid

Compositions	Percentage (Average)
Humidity	93.71
Protein	0.49
Starch	5.23
Carbohydrate	32
Lipid	0.4
Ash	1.06
Fibers	0.8
pH	4.10
Acidity	2.70
HCN (mg/c)	440.00

Source: [11].

Table 4: Nutritive Values for Cassava at 127 Calories per 100g

Nutrients	Percent (At 127 Calories Per 100g)
Protein	0.8 to 1.0
Fat	0.2 to 0.5
Carbohydrate	32
Ash	0.3 to 0.5
Moisture	65
Fiber	0.8

Source: [12].

Table 5: Weight Loss and Corrosion Rate of Samples in Medium A.

Samples	Unheated				Annealed				Normalized			
T (Days)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)
0	6.863	6.863	0.000	0.000	6.860	6.860	0.000	0.000	6.861	6.861	0.000	0.000
4	6.488	6.093	0.395	3.415	6.852	6.818	0.034	0.294	6.849	6.806	0.043	0.372
8	6.113	5.517	0.596	2.576	6.841	6.774	0.067	0.290	6.792	6.709	0.083	0.359
12	6.912	6.199	0.713	2.055	6.847	6.748	0.099	0.285	6.841	6.719	0.122	0.352
16	6.897	6.139	0.758	1.638	6.849	6.715	0.134	0.290	6.836	6.681	0.155	0.335
20	6.329	5.435	0.894	1.546	6.776	6.608	0.168	0.291	6.720	6.528	0.192	0.332
24	6.688	5.688	1.000	1.441	6.765	6.569	0.196	0.282	6.648	6.424	0.224	0.323
28	6.488	5.490	0.998	1.161	6.801	6.578	0.223	0.275	6.754	6.486	0.268	0.331
32	6.113	4.798	1.315	1.421	6.869	6.617	0.252	0.272	6.674	6.359	0.315	0.340

Samples	Hardened				Tempered				Untreated			
T(Days)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)
0	6.872	6.872	0.000	0.000	6.859	6.859	0.000	0.000	6.877	6.877	0.000	0.000
4	6.797	6.737	0.060	0.519	6.889	6.856	0.033	0.285	6.059	5.744	0.315	2.626
8	6.621	6.515	0.106	0.458	6.823	6.756	0.067	0.290	6.658	6.080	0.578	2.409
12	6.596	6.450	0.146	0.421	6.854	6.756	0.098	0.282	6.684	6.020	0.664	1.845
16	6.626	6.440	0.186	0.402	6.892	6.763	0.129	0.279	6.486	5.783	0.703	1.465
20	6.446	6.223	0.223	0.386	6.797	6.635	0.162	0.280	6.111	5.324	0.787	1.312
24	6.505	6.245	0.260	0.375	6.608	6.416	0.190	0.274	6.910	6.090	0.820	1.112
28	6.632	6.326	0.306	0.378	6.741	6.520	0.221	0.273	6.894	5.789	1.105	1.316
32	6.723	6.364	0.359	0.388	6.988	6.740	0.248	0.268	6.326	5.125	1.201	1.251

Table 6: Weight Loss and Corrosion Rate of Samples in Medium B.

Samples	Unheated				Annealed				Normalized			
T (Days)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)
0	6.836	6.836	0.000	0.000	6.830	6.830	0.000	0.000	6.834	6.834	0.000	0.000
4	6.912	6.664	0.248	2.144	6.866	6.833	0.033	0.285	6.803	6.759	0.044	0.380
8	6.897	6.340	0.557	2.408	6.814	6.749	0.065	0.281	6.825	6.742	0.083	0.359
12	6.329	5.675	0.654	1.885	6.883	6.786	0.097	0.280	6.852	6.730	0.122	0.352
16	6.688	5.983	0.705	1.524	6.894	6.761	0.133	0.287	6.829	6.672	0.157	0.339
20	6.650	5.908	0.742	1.283	6.880	6.717	0.163	0.282	6.846	6.653	0.193	0.334
24	6.376	5.541	0.835	1.203	6.892	6.700	0.192	0.277	6.818	6.591	0.227	0.327
28	6.479	5.358	1.121	1.385	6.895	6.674	0.221	0.273	6.847	6.579	0.268	0.331
32	6.659	5.443	1.216	1.314	6.884	6.636	0.248	0.268	6.836	6.523	0.313	0.338

Samples	Hardened	Tempered	Untreated

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T (Days)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)
0	6.841	6.841	0.000	0.000	6.829	6.829	0.000	0.000	6.864	6.864	0.000	0.000
4	6.813	6.755	0.058	0.501	6.871	6.840	0.031	0.268	6.685	6.407	0.278	2.317
8	6.803	6.699	0.104	0.450	6.633	6.570	0.063	0.272	6.781	6.395	0.386	1.609
12	6.795	6.651	0.144	0.415	6.725	6.630	0.095	0.274	6.679	6.185	0.494	1.373
16	6.660	6.479	0.181	0.391	6.903	6.772	0.131	0.283	6.245	5.679	0.566	1.180
20	6.656	6.438	0.218	0.377	6.942	6.780	0.162	0.280	6.812	6.178	0.634	1.057
24	6.950	6.688	0.262	0.378	6.695	6.505	0.190	0.274	6.307	5.518	0.789	1.096
28	6.760	6.458	0.302	0.373	6.699	6.478	0.221	0.273	6.977	5.988	0.989	1.178
32	6.876	6.522	0.354	0.383	6.949	6.704	0.245	0.265	6.116	4.927	1.189	1.239

Table 7: Weight Loss and Corrosion Rate of Samples in Medium C.

Samples	Unheated				Annealed				Normalized			
T (Days)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)
0	6.880	6.880	0.000	0.000	6.878	6.878	0.000	0.000	6.879	6.879	0.000	0.000
4	6.684	6.436	0.248	2.144	6.876	6.841	0.035	0.303	6.885	6.841	0.044	0.380
8	6.487	6.158	0.329	1.422	6.899	6.831	0.068	0.294	6.776	6.692	0.084	0.363
12	6.112	5.616	0.496	1.429	6.869	6.769	0.100	0.288	6.765	6.644	0.121	0.349
16	6.910	6.393	0.517	1.117	6.866	6.734	0.132	0.285	6.801	6.644	0.157	0.339
20	6.895	6.367	0.528	0.913	6.816	6.652	0.164	0.284	6.795	6.599	0.196	0.339
24	6.326	5.751	0.575	0.829	6.803	6.610	0.193	0.278	6.813	6.582	0.231	0.333
28	6.685	6.091	0.594	0.734	6.795	6.574	0.221	0.273	6.899	6.629	0.270	0.333
32	6.781	5.944	0.837	0.905	6.813	6.564	0.249	0.269	6.876	6.571	0.305	0.330

Samples	Hardened				Tempered				Untreated			
T(Days)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)
0	6.883	6.883	0.000	0.000	6.875	6.875	0.000	0.000	6.836	6.836	0.000	0.000
4	6.852	6.798	0.054	0.467	6.629	6.596	0.033	0.285	6.106	5.930	0.176	1.467
8	6.899	6.797	0.102	0.441	6.458	6.395	0.063	0.272	6.609	6.355	0.254	1.059
12	6.849	6.713	0.136	0.392	6.534	6.438	0.096	0.277	6.797	6.459	0.338	0.939
16	6.876	6.701	0.175	0.378	6.432	6.299	0.133	0.287	6.533	6.135	0.398	0.829
20	6.869	6.653	0.216	0.374	6.607	6.445	0.162	0.280	6.480	6.041	0.439	0.732
24	6.816	6.561	0.255	0.367	6.797	6.604	0.193	0.278	6.556	6.048	0.508	0.706
28	6.866	6.569	0.297	0.367	6.960	6.741	0.219	0.270	6.457	5.930	0.527	0.628
32	6.814	6.468	0.346	0.374	6.644	6.401	0.243	0.263	6.183	5.562	0.621	0.647

Table 8: Weight Loss and Corrosion Rate of Samples in Medium D.

Samples	Unheated				Annealed				Normalized			
T(Days)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)
0	6.838	6.838	0.000	0.000	6.836	6.836	0.000	0.000	6.837	6.837	0.000	0.000
4	6.679	6.436	0.243	2.101	6.803	6.767	0.036	0.311	6.803	6.759	0.044	0.380
8	6.245	5.887	0.358	1.548	6.825	6.759	0.066	0.285	6.814	6.731	0.083	0.359
12	6.813	6.410	0.403	1.161	6.829	6.730	0.099	0.285	6.866	6.743	0.123	0.354
16	6.307	5.867	0.440	0.951	6.846	6.716	0.130	0.281	6.876	6.718	0.158	0.342
20	6.978	6.529	0.449	0.776	6.847	6.687	0.160	0.277	6.899	6.705	0.194	0.335
24	6.650	6.092	0.558	0.804	6.818	6.632	0.186	0.268	6.869	6.639	0.230	0.331
28	6.376	5.750	0.626	0.773	6.825	6.607	0.218	0.269	6.813	6.543	0.270	0.333
32	6.478	5.758	0.720	0.778	6.836	6.589	0.247	0.267	6.795	6.487	0.308	0.333

Samples	Hardened				Tempered				Untreated			
T(Days)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)	W_1(g)	W_2(g)	ΔW(g)	CR(mm/yr)
0	6.839	6.839	0.000	0.000	6.835	6.835	0.000	0.000	6.833	6.833	0.000	0.000
4	6.825	6.773	0.052	0.450	6.799	6.765	0.034	0.294	6.419	6.307	0.112	0.934
8	6.803	6.705	0.098	0.424	6.600	6.535	0.065	0.281	6.723	6.489	0.234	0.975
12	6.829	6.694	0.135	0.389	6.633	6.536	0.097	0.280	6.154	5.825	0.329	0.914
16	6.846	6.672	0.174	0.376	6.860	6.729	0.131	0.283	6.431	6.092	0.339	0.706
20	6.818	6.602	0.216	0.374	6.607	6.445	0.162	0.280	6.632	6.258	0.374	0.624
24	6.847	6.591	0.256	0.369	6.725	6.533	0.192	0.277	6.125	5.743	0.382	0.531
28	6.836	6.537	0.299	0.369	6.481	6.261	0.220	0.272	6.454	6.026	0.428	0.510
32	6.841	6.504	0.337	0.364	6.557	6.316	0.241	0.260	6.621	6.167	0.454	0.473

Table 9: Total Weight Loss and Total Corrosion Rate of Different Samples in Different Media

SAMPLES	MEDIA							
	Medium A		Medium B		Medium C		Medium D	
	ΔW_{TOTAL} (g)	CR_{TOTAL} (mm/yr)	ΔW_{TOTAL} (g)	CR_{TOTAL} (mm/yr)	ΔW_{TOTAL} (g)	CR_{TOTAL} (mm/yr)	ΔW_{TOTAL} (g)	CR_{TOTAL} (mm/yr)
Unheated	6.669	15.253	6.078	13.146	4.124	9.493	3.797	8.892
Annealed	1.173	2.279	1.152	2.233	1.162	2.274	1.142	2.243
Normalized	1.402	2.744	1.407	2.760	1.408	2.766	1.410	2.276

Hardened	1.646	3.327	1.623	3.268	1.581	3.160	1.567	3.115
Tempered	1.148	2.231	1.138	2.189	1.142	2.212	1.115	2.227
Untreated	6.173	13.862	5.325	11.460	3.261	7.267	2.652	5.878

Table 10: Overall Total Weight Loss and Total Corrosion Rate of Samples in Different Media.
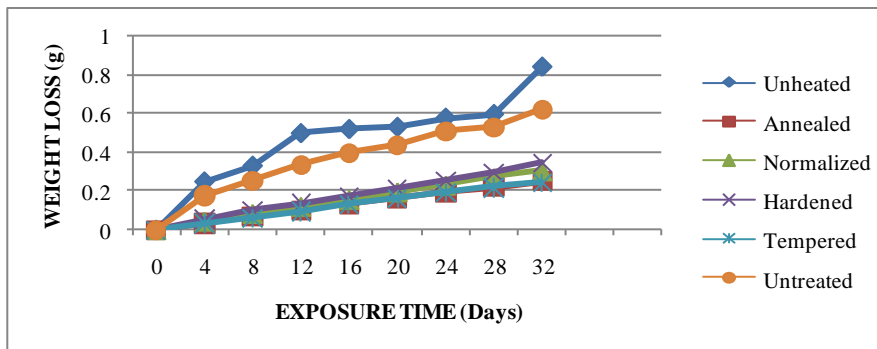
MEDIA	ΔW_{TOTAL} (g)	CR_{TOTAL}(mm/yr)
Medium A	18.211	39.197
Medium B	16.723	34.645
Medium C	12.678	26.912
Medium D	11.683	24.911
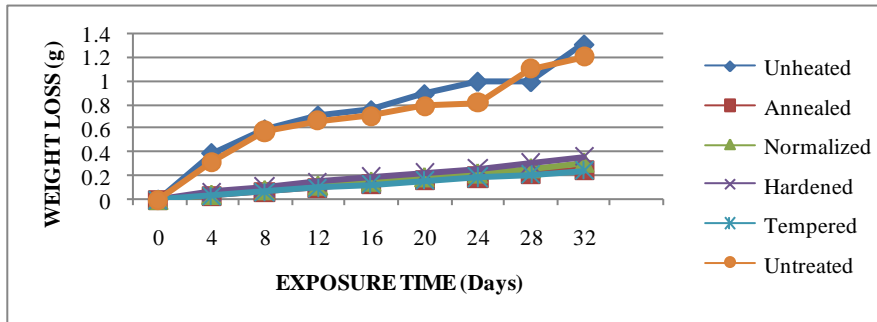
Figure 1: Weight loss against exposure time of different samples in medium A.
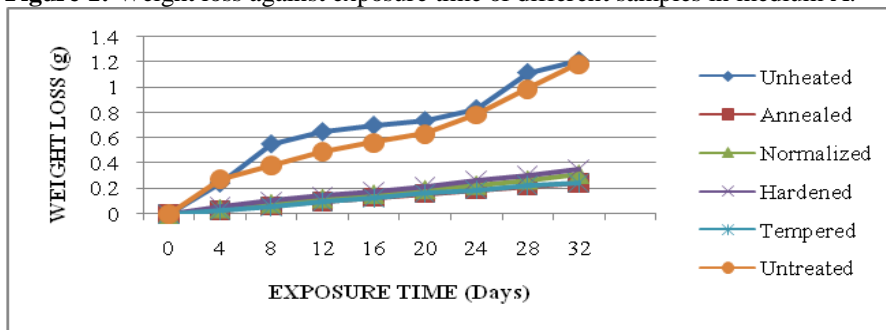
Figure 2: Weight loss against exposure time of different samples in medium B.

Figure 3: Weight loss against exposure time of different samples in medium C.
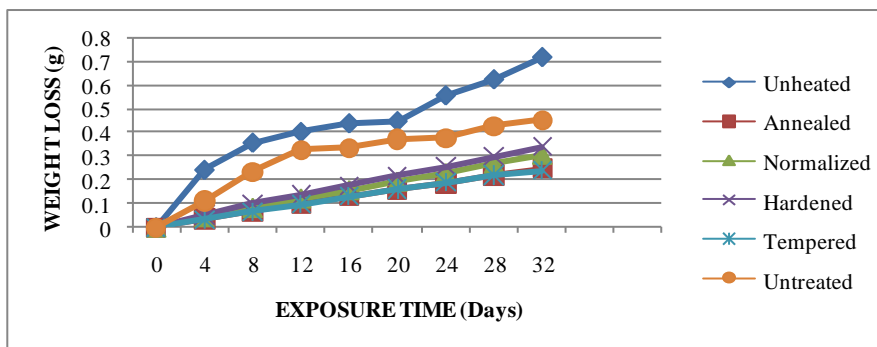
Figure 4: Weight loss against exposure time of different samples in medium D.
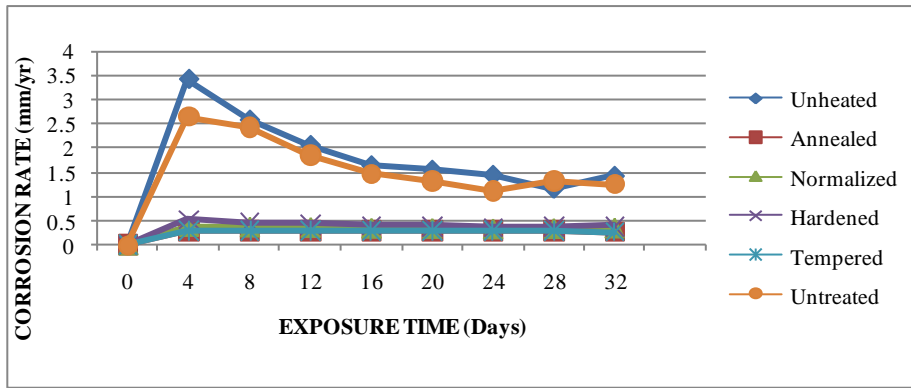
Figure 5: Corrosion rate against exposure time of different samples in medium A.
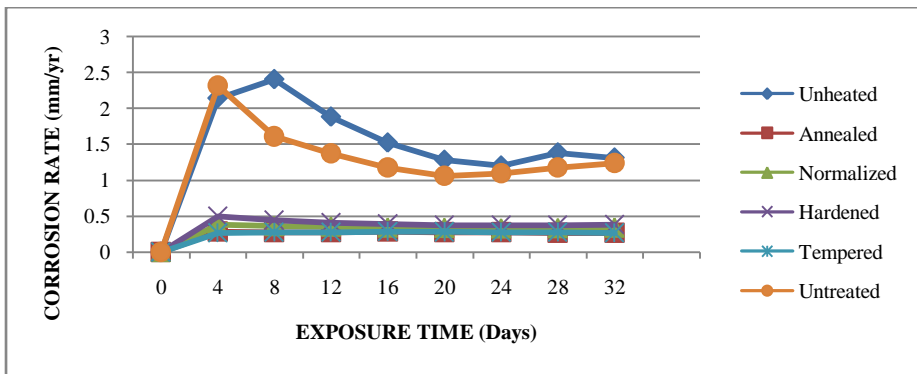
Figure 6: Corrosion rate against exposure time of different samples in medium B.
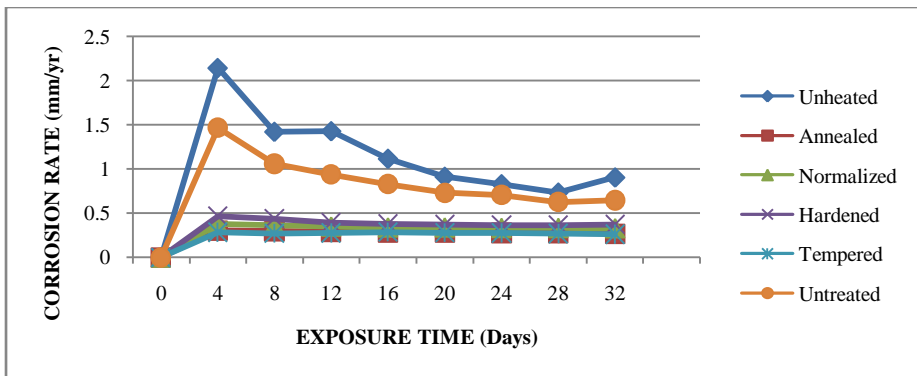
Figure 7: Corrosion rate against exposure time of different samples in medium C.
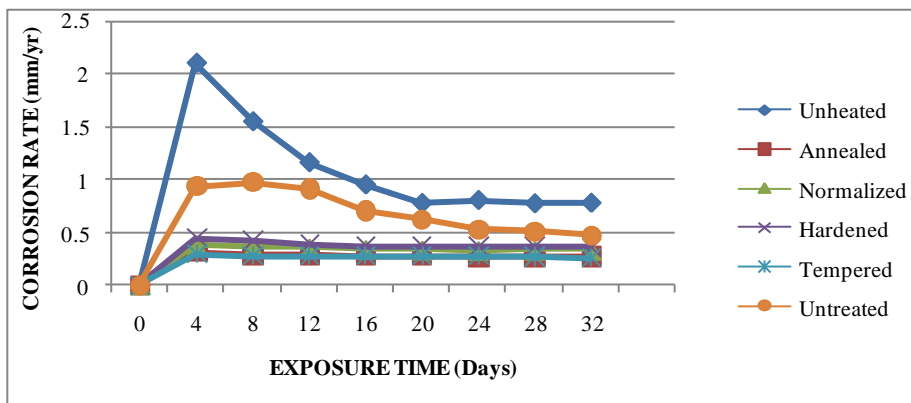
Figure 8: Corrosion rate against exposure time of different samples in medium D.
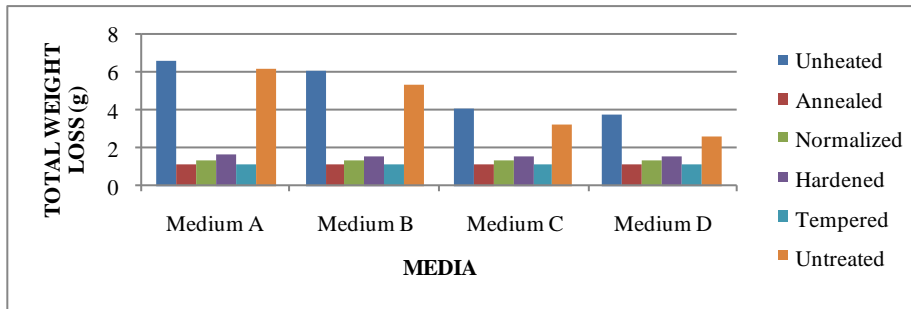
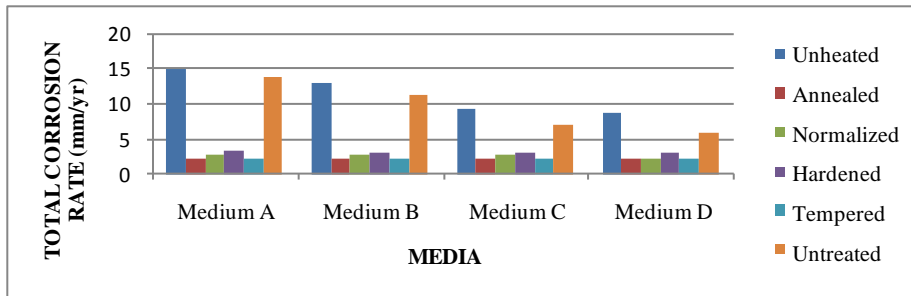**Figure 9:** Total weight loss (ΔW_{TOTAL}) of different samples in different media.

Figure 10: Total corrosion rate (CR_{TOTAL}) of different samples in different media.
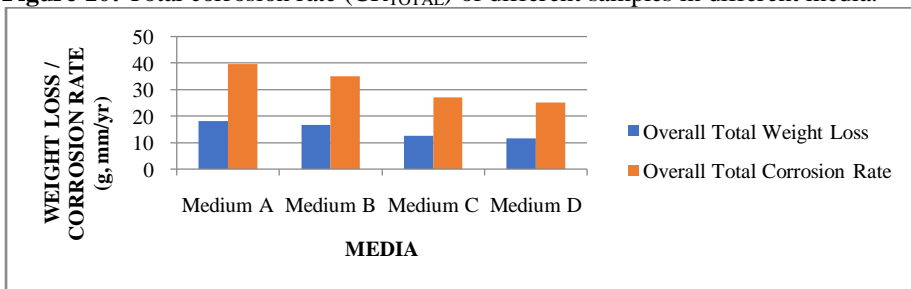
Figure 11: Overall total weight loss and total corrosion rate of samples in media.
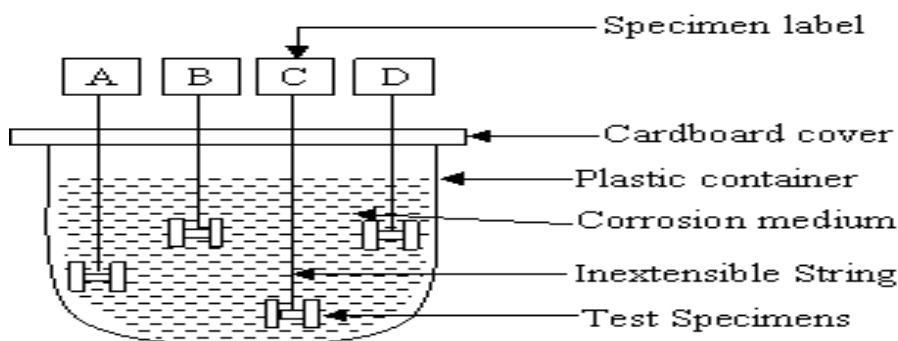
Figure 12: Samples in raw cassava tubers slurry
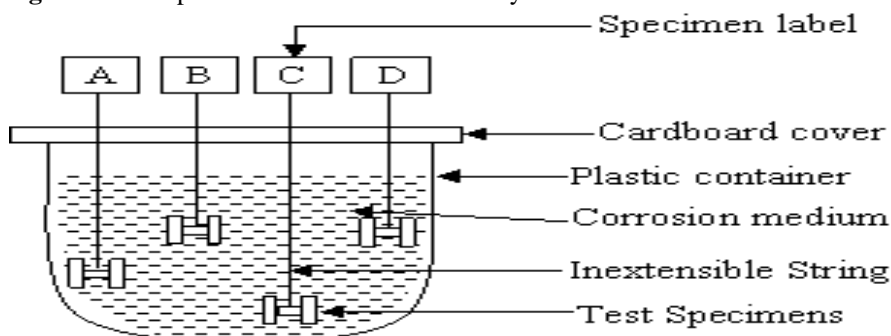
Figure 13: Samples in raw cassava tubers extract

Plate 1: Heat treating samples in electric resistance furnace

Plate 2: Cold working of samples with sledge hammer on avail

Plate 3: Peeling of raw cassava tubers with peeler (machine)

Plate 4: Weighing of samples in digital weighing balance.

### 3.2 Chemical Composition and Analysis of As-received Sample

The chemical composition of the as-received SAE 1030 steel samples used for the work is shown in table 1, the table showed that the percentage weight of the average of Iron, Fe is 98.819%; Carbon, C is 0.302%; Manganese, Mn is 0.689% while other elements represented 0.190% of the entire composition.

### 3.3 Mechanism of Corrosion Reaction of Samples in Cassava Fluids

The reaction mechanism between the metal surface and the raw cassava fluids were observed. The visual examination of the coupons after exposure indicated a uniform corrosion on the surface area. The colour of the coupons surface was almost brownish with the corrosion products when observed. Examination of the corrosion product indicated the presence of a mixture of iron oxides, hydroxides and cyanides. One of the most aggressive ions in media is the cyanide ion (CN^-). The behaviour of this group is analogous to that of the halogens in that it forms hydrocyanic acid, HCN, which is a very weak acid. Cyanogen and cyanate are easily reduced to form CN^- and HCN, respectively, in accordance with equations 11 and equation 13 [16].

$$\tfrac{1}{2} C_2 N_2 + H^+ + e^- = HCN \qquad (8)$$

$$2OCN^- + 2H^+ + 2e^- = CN^- + H_2O \qquad (9)$$

When mild steel samples were immersed in cassava fluid, corrosion commences with iron as the anode experiencing dissolution according to the reaction:

$$Fe = Fe^{2+} + 2e^- \qquad (10)$$
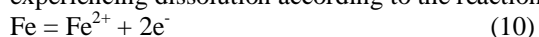
At the cathode, ionization of HCN occurs as follows [17]:

$$HCN = CN^- + H^+ \qquad (11)$$
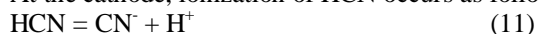
The overall reaction according to the anode and the cathode reactions can be given as:

$$Fe^{2+} + 2CN^- + 2H^+ = Fe\,(CN)_2 + H_2 \qquad (12)$$

$$Fe^{2+} + 3CN^- + H^+ = Fe\,(CN)_2 + HCN \qquad (13)$$
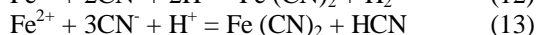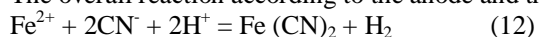
3.4 Effects of Raw Cassava Tuber Fluids on the Corrosion Resistance

The corrosion rates of the samples in the cassava fluids as were observed from the table and figure showed that the samples in media exhibited severe corrosion rates as results of the presence of cyanide ion (CN^-) in media which was very aggressive, and the presence of carbohydrates and fats in cassava slurry and extract [18, 19] which were the contributing factors for the corrosion of this metal. These constituents are sources of oxygen which increase oxidation process in the media thus promoting corrosion of the samples [18].

3.5 Effects of Exposure Time on Weight Loss of Samples

Table 5-8, 9-10 and figure 1-4, 9 and 11, show the values, curves and bars of the weight loss with exposure time, total weight loss and overall total weight loss of samples in media A, B, C and D. Weight loss of samples in the media increases with increase in exposure time and was constant with exposure time. However; it was generally lower than corrosion rate of samples in the same media due to the stagnant ions blocking more ions formation which decreased Fe^{2+} activities in the solution. But both remained active throughout the immersion time.

From table 9 and figure 9, in the media especially medium A, unheated sample exhibit the most severe weight loss (6.669g) followed by untreated sample weight loss (6.173g) while tempered sample exhibit the less severe weight loss (1.148g) followed by annealed sample weight loss (1.173g). Hardened sample weight loss (1.646g) was the highest followed by normalized sample weight loss (1.402g) while the lowest was tempered sample weight loss (1.148g) followed by annealed sample weight loss (1.173g) amongst the heat-treated and cold-worked samples. This was as a result of effect of cold working by forging the unheated sample undergone before immersion and exposure in the media due to increased dislocation concentration and heightened residual stresses. The unheated sample was non-heat-treated to reduce the higher level of induced stresses due to cold working. The untreated sample was non-heat-treated and non-cold-worked before immersion and exposure in the media, however the sample has minimal heightened dislocation concentration and induced internal stresses during hot working and solidification process to increased its weight loss compared to unheated sample with maximum increased dislocation concentration and residual stresses, therefore, the untreated sample exhibit an average weight loss amongst the unheated and heat-treated and cold-worked samples in the media.

The hardened sample weight loss was the highest amongst the heat-treated and cold-worked samples due to the heterogeneous microstructure consisting of two main phases-ferrite and pearlite, in addition to different phase- martensite. The chemical compositions of the three phases are different and hence more additional anodic and cathodic sites are established when the samples are in media; the anodic sites of hardened sample loss more weight compared to the tempered sample with only two main phases- ferrite and pearlite, hence fewer anodic and cathodic sites. Precipitates with electrochemical properties distinctly different from those of the matrix have a deleterious effect on corrosion [20]. The martensite phase is highly unstable and stressed, hence the highest weight loss exhibited by hardened sample while there was no martensite phase in tempered sample therefore tempered sample was susceptible to lowest weight loss. The tempered sample was tougher than the hardened sample due to more carbon precipitate from the finest pearlite during reheating of tempered sample. Annealed and normalized sample weight loss was of the average respectively amongst the heat-treated and cold-worked samples in the media because annealed sample was furnace cooled resulted in coarse pearlite (cathode) and greatest ferrite (anode) therefore reduced the cathodic to anodic area ratio since weight loss is proportional to cathodic to anodic area ratio, hence the second least weight loss exhibited by annealed sample amongst the samples. Normalized sample was air cooled with more ferrite and less pearlite, hence slightly increased in the cathodic to anodic area ratio, therefore the sample exhibitthe third least weight loss in media. Since the samples were subjected to the same forged cold-worked, the same effect of cold working on the weight loss was assumed on the samples except the untreated sample.

With respect to the media from table 10 and figure 11, the weight loss of samples in medium A (18.211g) were the highest followed by medium B (16.723g) while in medium D (11.683g) was the lowest. Samples in medium C (12.678g) exhibit the third most severe weight loss as were shown in table 10 and figure 13. Weight loss in cassava slurry, media A and C were generally higher than the weight loss in the cassava extract, media B and D. This was due to the more intense chemical reaction and corrosion processes of the anodic and cathodic reactivity at sample/media interface due to cyanide ions, corrosion products, oxygen concentration, microbial and electrolytic reactions with the media A and C while in media B and D, there less intense chemical reaction and corrosion processes of the anodic and cathodic reactivity at sample/media interface. More intense chemical reaction and corrosion processes were experienced by samples in Media A and C because the media have three phases (cassava starch, juice and fibers) hence more anodic sites for reactions while less intense chemical reaction and corrosion processes were experienced by samples in Media B and D because the media have one phase (cassava juice) hence less anodic sites for reactions. This might be due to the presence of a more protective insoluble corrosion products resulting from the presence of cassava juice with more water content, while for the cassava pulp with less water content, there were less protective insoluble

corrosion products. Higher oxygen concentration was in the cassava slurry and lower oxygen concentration was in the cassava juice, the weight loss is higher in high oxygen concentration and lower in low oxygen concentration as a result of increase corrosion rate with higher oxygen concentration. These were also as results of the fermentation process which causes a drop in pH of the fermenting cassava slurry and the increase in acidity of the media A and C, therefore higher weight loss of samples in media, while in the fermentation process of cassava juice with samples there was an increase in pH of the media B and D, hence lower weight loss of samples in the media. Lowest pH values indicate highest acidity level and highest corrosion rate as stated by [21] that corrosion rates almost always increase with decreasing pH (increasing acidity).

In media A and B, higher constant weight loss was experienced by continuous exposure with time by the samples while in media C and D, lower constant weight loss was experienced by intermittent exposure of samples with time. The continuous exposure weight loss was higher as a result of the anaerobic activities (high microbial activities) in the cassava slurry at continuous exposure while there was lower weight loss as a result of the aerobic activities (low microbial activities) in cassava extract at intermittent exposure. Medium C and D respective weight loss values were slightly lower than medium A and B respective weight loss values because in intermittent exposure, the atmospheric corrosion was limiting the water corrosion of the media as exhibited by the samples in medium C and D, while in continuous exposure, the atmospheric corrosion was not hindering the water corrosion of the media as exhibited by the samples in medium A and B.

Samples in medium A have the highest weight loss and generally higher than the samples in medium C because samples in medium A were continuously exposed while samples in medium C were intermittently exposed. Samples in medium B have the higher weight loss and generally higher than the samples in medium D because samples in medium B were continuously exposed while in medium D samples were intermittently exposed. Samples in medium A experienced more intense weight loss than samples in medium B because medium A has more compositions than medium B and samples in medium A were immersed and exposed in cassava slurry (starch, juice and fibers) while samples in medium B were immersed and exposed in cassava extract (juice). Samples in medium C waste higher than samples in medium D due to fact that medium C has greater contents than medium D and samples in medium C were submerged in cassava slurry (cassava fluid with juice, starch and fibers) while samples in medium D were submerged in cassava extract (cassava fluid with juice).

Comparing the final weight loss exhibited by the most and least susceptible sample in the highest and lowest corrosive media, the unheated and tempered samples weight loss was 1.315g and 0.248g in medium A; 0.720g and 0.241g in medium D from table 5 and table 8 respectively. This revealed that tempered sample has the lowest weight loss in medium D, hence used for cassava plants fabrication, preventing contact and exposure with other media than medium D.

3.6 Effects of Exposure Time on Corrosion Rate of Samples

Table 5-8, 9-10 and figure 5-8, 10 and 11, show the values, curves and bars of the corrosion rate against exposure time, total corrosion rate and overall total corrosion rate of different samples in media A, B, C and D. Corrosion rate of samples in the media generally decreases with increase in exposure time and was not constant with exposure time. However, it remained active throughout the exposure period and generally higher than the weight loss of samples in the same media as results of decrease in the pH of the media, and the inclusion of conversion constant of 87.6.

From Tables 9 and figures 10, in the media specifically medium A, the corrosion behavior of samples show that unheated sample corrosion rate values (15.253mm/yr) was the highest followed by untreated sample (13.862mm/yr) while the lowest was tempered sample (2.231mm/yr). Amongst the heat-treated and cold-worked samples, hardened sample value (3.327mm/yr) was the most followed by normalized sample value (2.744mm/yr) while the least was tempered sample value (2.231mm/yr) followed by annealed sample value (2.279mm/yr). The unheated sample corrosion rate was the highest as a result of effect of cold working by forging which induced residual stresses on sample. The sample was non-heat-treated to relieve the level of induced internal stresses, hence the highest corrosion rate exhibited by the sample in the media. The untreated sample was non-heat-treated and non-cold-worked, hence untreated sample corrosion rate was the average amongst unheated and heat-treated and cold-worked samples in media, while the heat-treated and cold-worked samples have the lowest corrosion rate in media. This was due to fact that heat treatments reduce the high stresses induced as result of fabrication processes and hence decrease the higher corrosion of samples in media. Untreated sample heightened dislocation concentration and internal stresses was minimal during hot working and solidification process, however unheated sample increased dislocation concentration and internal stresses was maximum during forge cold working, hence unheated sample corrosion rate in media was higher than untreated sample corrosion rate in media.

Corrosion rates amongst the heat-treated and cold-worked samples in the media showed that tempered sample was the lowest followed by annealed sample while hardened sample was the highest followed

normalized sample. The annealed sample was furnace cooled resulted in coarse pearlite (cathode) and greatest ferrite (anode) therefore reduced cathodic to anodic area ratio since corrosion rate is proportional to cathodic to anodic area ratio, hence the second least corrosion rate exhibited by annealed sample. Normalized sample was air cooled with more ferrite and less pearlite, hence slightly increased in the cathodic to anodic area ratio, therefore the sample exhibit the third least corrosion rate in the media after tempered sample. Since the samples were subjected to the same plastic deformation, a uniform effect of cold working on corrosion rates was assumed on samples except untreated sample. The discrepancies in the severity of sample corrosion rates can be explained using table 2. Tempered sample was subjected to stress relieved and precipitation of carbide/ferrite microstructure and hence the highest corrosion resistance exhibited by tempered steel than the unheated, untreated and heat-treated and cold-worked samples. Hardening sample has higher adverse effect on corrosion resistance because of martensitic microstructure precipitation; hence the lowest corrosion resistance the hardened sample exhibits among the heat-treated and cold-worked samples. The difference in corrosion resistances of the alloy was ascribable to their differences in microstructure [22].

Medium A was susceptible to highest corrosion rate of samples (39.197mm/yr) followed by the samples in medium B (34.645mm/yr) and the third was in medium C (26.912mm/yr), while the least was in medium D (24.911mm/yr). Medium B and C were of the average respectively as shown in table 10 and figure 11. In the media, the values were generally higher in (medium A and C) than in (medium B and D). Samples in medium A and C were susceptible to higher corrosion than samples in medium B and D due to more compositions (three phases) and hence greater anodic sites for higher corrosion reactions of samples in the media, while medium B and D have less compositions (one phase) and fewer anodic sites for lower samples corrosion reaction in the media. The cassava slurry (medium A and C) have 3 phases (cassava juice, starch and fibers) consequently samples immersed and exposed in the media experienced more severe corrosion compared to samples in the cassava extract (medium B and D) with 1 phase (cassava juice). Cassava slurry tends to absorbed or lower most of the fermentation process that increased the pH of the media and thereby lowering the pH of medium A and C, hence the increased in the corrosion rate of the samples in the media, while the pH of media in the cassava juice tend to increased during fermentation process due to less absorption and lowering, thereby decreasing the corrosion rates of samples immersed in media B and D. The additional cyanides ions, corrosion products, carbohydrates and fats in the cassava slurry serve as centres for more anodic corrosion thereby increasing the corrosion rate while in the cassava extract; there were fewer cyanides ions, corrosion products, carbohydrates and fats which serve as centres for less anodic corrosion, thereby decreasing the corrosion rate.

The corrosion rate of samples in medium C and D was generally lower than the corrosion rate of samples in medium A and B. Medium A and B exhibited severe corrosion on samples than medium C and D because of the continuous exposure of samples in medium A and B, but in medium C and D, the exposure of samples were intermittent hence the media exhibited less severe corrosion on its samples. For the continuous exposure condition, there were high activities of microbes and anaerobic reaction in medium A and B, hence high corrosion rates than in medium C and D with lower activities of microbes and aerobic reaction. Medium C and D respective corrosion rate values were slightly lower than medium A and B respective corrosion rate values because in interrupted exposure; the atmospheric corrosion was limiting the water corrosion of the raw cassava fluids as exhibited by the samples in medium C and D, while in steady exposure; the atmospheric corrosion was not hindering the water corrosion of the raw cassava fluids as exhibited by the samples in medium A and B.

Samples in medium A have the highest corrosion rate and generally higher than the samples in medium C because samples in medium A were continuously exposed while samples in medium C were intermittently exposed. Samples in medium B have the higher corrosion rate and generally higher than the samples in medium D because samples in medium B were continuously exposed while in medium D samples were intermittently exposed. Samples in medium A experienced more corrosion attack than samples in medium B because medium A has more compositions than medium B and samples in medium A were immersed and exposed in cassava slurry (starch, juice and fibers) while samples in medium B were immersed and exposed in cassava extract (juice). Samples in medium C deteriorated higher than samples in medium D due to fact that medium C has greater contents than medium D and samples in medium C were submerged in cassava pulp (cassava fluids with juice, starch and fibers) while samples in medium D were submerged in cassava juice (cassava fluids with juice).

Comparing the final corrosion resistances experienced by the most and least severed sample in the highest and lowest aggressive media, the unheated and tempered samples corrosion resistance was 1.421mm/yr and 0.268mm/yr in medium A; 0.778mm/yr and 0.260mm/yr in medium D from table 5 and table 8 respectively. This showed that tempered sample has the highest corrosion resistance in medium D, therefore applied in cassava machine fabrication, avoiding contact and exposure with other media than medium D.

IV.   CONCLUSIONS

The corrosion rates of the heat-treated and cold-worked samples in the media decreased below the corrosion rates of the unheated and untreated samples in the following descending order: Unheated > Untreated > Hardened > Normalized > Annealed > Tempered. The heat-treated and cold-worked samples order corrosion rates in the media were as follows (descending): Hardened > Normalized > Annealed > Tempered. Corrosion rates of samples immersed in the raw cassava tuber slurry were higher than the corrosion rates of samples immersed in the raw cassava tuber extract according to the media: Medium A > B and medium C > D; medium A and C > medium B and D. Corrosion rates of samples exposed continuously in the two media were higher than the corrosion rates of samples exposed intermittently in the two media as follows with respect to the media: Medium A or B > medium C or D; medium A and B > medium C and B. The media for samples corrosion rates were generally given in descending orders: Medium A > B > C > D. Samples in the media exhibit severe corrosion and were susceptible to mainly general corrosionas results of metal's anodic dissolution. The samples were inapplicable for the fabrication of cassava plant without heat treatments, lesser cold working and suitable media. Tempered sample offered the highest corrosion resistance in the media, hence was recommended to reduce the problem of faster corrosion rate of raw cassava tubers processing machines.

ACKNOWLEDGMENTS

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