An Investigative Study of Corrosion Effects of Cereals on the Grinding Components of Commercially Available Grinding Machines

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Abstract

This study investigates corrosion effects of household food products such as cereals on commercially available grinding machines. Samples of grinding machine materials, such as alloys of cast iron and mild steel, were exposed to water and to two identified cereal environments, i.e. corn and sorghum in solution. The loss in weight of the alloy samples in the various environments were determined over pre-determined intervals. The corrosion rates of the alloys were then determined from analysis and found to be 15.314 W/T and 13.863 W/T for cast iron and mild steel, respectively, where W is the weight loss and T is exposure time. It was discovered that corn had more corrosive effects on the alloy samples as compared to sorghum. Furthermore, cast iron has higher corrosion rate than mild steel. This research work reveals the extent of corrosion on grinder materials in cereal environments and so would aid the foundry men in appropriating the chemical composition of the alloys to suit such environment.

Keywords: *Household food products, corn, sorghum, cereal environments.*

1. Introduction

Corrosion is the breaking down of essential properties in materials due to chemical reactions with its surroundings. It is the destruction of materials caused by chemical or electrochemical action of the surrounding environment (Trimgham 1958).The fabrication process in the production field of Mechanical Engineering involves various stages that include the design, selection of materials which are appropriate for the design, decision on the optimum production methods and eventually, the final product. With the sundry technical contributions and developments, one would expect an almost-infinite durability of the design. On the contrary, this has never been the case due to the some influences, particularly environmental, on the design. Some of the influences include corrosion, fatigue, creep, crack, and many more. All these except corrosion are dependent on the actual working conditions of the device or machine; that is, they occur due to the particular work the devices are to perform. Corrosion, on the other hand, occurs at any point in time whether the device is working or not.

Moisture plays an active role in the corrosion of metals. Usually, the corrosion product is not adherent and therefore corrosion continues unabated resulting in material degradation. Ampadu-Mintah (2008) conducted a study on the wearability of corn-mill grinding plates and discovered that the corn-mill plates that are used in wet grinding tend to wear faster than corn-mill plates used in dry grinding. The synergistic attack of corrosion and wear of corn-mill grinding plates has not been investigated, even though it results in serious damage to wear/corrosion resistant materials. In a related work, it has been found that corrosion plays significant role in wearability of cast iron ball-mill grinding media during wet grinding (Rajagopal and Iwasaki 1992). It has therefore become necessary to investigate the effect of corrosion on the wearability of cast iron corn-mill grinding plates. Better understanding of the early degradation of cast-iron mill plates could go a long way to enhance the mechanical properties and hence reduce iron contamination in milled cereal. According to Bothwell *et al*. (1964) and Deugnier *et al*. (1992), Iron contamination in milled maize (cereal) could result in dietary iron overload when consumed; some of the major health hazards are liver infections and anaemia. Andrew and Kwofie (2010) conducted an experiment on corrosion behaviours of two different cast iron corn-mill plates by using mass loss measurements. The relationship between pH and corrosion rate was developed and subsequently linked to its effect on the wearability of corn-mill plates when used in wet grinding environments. Researchers, such as Reda *et al*. (1988), Umoru *et al*. (2002), and Loper (2002), have shown that corrosion tests are significant in making several materials related decisions, such as to determine the best material for service in a specific environment and the quality or acceptability of a material for a specific application.

This study presents the ultimate analysis of identified cereals and their corrosion effects on cast iron and mild steel using weight loss experiments. The discovered weight loss gives the extent of accumulation of the grinder material in the cereal substance over the period of observation.

2. Materials and Methods

The materials selected for this investigation are test pieces from the commercially available mild steel and cast iron. Three test pieces of mild steel materials of 20-mm diameter and 40-mm length, and three test pieces of cast iron materials of 15-mm diameter and 40-mm length were used for the experiment. Other materials are plastic containers, distilled water, chemical balance, thread, powdered maize and powdered sorghum.

2.1 Experimental Procedure

The experiment was performed in the laboratory under a stable system, in the sense that experimental set-up was not disturbed while experiment lasted in order not to alter the system. Surfaces of the test pieces were prepared with 400 grit and 600 grit emery papers. At regular intervals, the grinder materials being experimented were weighed using a digital balance in order to establish any loss in weight over the period which would account for the dissolved material in the solution over the period. The set-up was arranged in a laboratory for a period of 34 days and Fig. 1 shows the experimental set-up used. Six bowls were used in the experiment and three out of these were for cast iron study and the other three for mild steel. For each of the three bowls, one contained sorghum powder in solution; another contained corn powder in solution while the last contained solely distilled water as control experiments. The powder in solution was made of equal concentrations, that is, equal grams of the powder in equal volume of water.

With the aid of threads tied around the alloy samples, a cast iron piece was let into each solution of the set of three bowls and similarly a mild steel piece was let into each solution of the other set of three bowls. The initial weight of the alloy samples were measured before the experiment was initiated. On the intervals of two days into the experiment, the samples were brought out, washed and measured. The weight loss, gotten from the deduction of the periodic measurements from the previous value, gave the weight loss over the interval of time.

Fig. 1. Experimental set-up.

2.2 Corrosion Rate in Cast Iron and Mild Steel

Having determined the weight loss of the two materials in different media and over a period of time, the rate of corrosion in each medium for each sample was determined.

Corrosion rates of the test samples were calculated in mils per year using the recommended relation (ASTM 1985) that has been used successfully by Sanusi and Hussein (2011), Orubite and Oforka (2004), and Osarolube *et al*. (2004):

Corrosion rate (mpy) = $534W/DAT$. (1)

where mpy is mils penetration per year (1 mil = 10^{-3} inch), W is the weight loss in mg, D is density of the sample in g/cm^3, A is the area of sample (inch^2), and T is the exposure time in hours. The density of the alloys is derived theoretically by:

$D = Mass/Volume$. (2)

The volume of a cylindrical shape is given by:

$V = \pi r^2 h$, (3)

where r is the radius and h is the height or length of the sample. The total surface area of cast iron, A, is given as:

$A_c = \pi dh + 2\pi r^2$. (4)

2.3 Chemical Analysis of Samples

The ultimate analysis of the identified cereals was determined by adopting digestion method of analysis. The chemical composition of the mild steel and cast iron samples was determined by sparkling method using Spark optical emission spectrometer for metal analysis (Bruker Corporation, Billerica, MA, USA). This operation determined the percentage elemental compositions of each alloy being investigated.

3. Results and Discussion

3.1 Chemical Composition of Mild Steel and Cast Iron

The chemical compositions of the mild steel and cast iron are presented in Tables 1-2.

3.2 Experimental Results

An extraction of the actual weight loss in the samples is represented in Tables 3, 4 and 5 for cast iron and mild steel samples in their different environments. In Table 3, there is statistics of the initial and final weights measured at the intervals of experiments. Table 6 displays the corrosion rate of mild steel in the selected cereal environments, and Table 7 has the corrosion rate of cast iron in the selected environments. Figs. 2a and 2b and 3a and 3b gave the statistics of the weight loss levels of each alloy samples in every experiment. The (b) parts give the weight-loss against exposure time. It is important to note that the pH of cereal solution increases (i.e., becomes more basic) with time; just as it was observed by Andrews and Kwofie (2010). However, the pH values at the start of the experiments were determined using a pH meter to be 4.62 for corn and 4.65 for sorghum. This, therefore, implied that the cereals were acidic at the ordinary initial state.

From Figs. 2 and 3, these observations are derived:

i. Each alloy has different response or behaviour in the different moist environments. This is to make known that the corrosive activities of the media or environments differ from one another.
ii. It is also noticeable that the alloys corroded least in water. Water, being a neutral medium, would not be as reactive as the cereals which are a bit acidic.
iii. Both mild steel and cast iron corrode most in corn solution. In other words, corn solution is more corrosive environment to grinding machines than sorghum is.
iv. The weight-loss level of cast iron in cereal environments was not that distant from each other. At certain points they almost had equal losses. This, however, was not the case in mild steel; the losses relatively varied.

Table 1. Chemical composition of mild steel.

Element	Fraction	% Composition
Fe	0.397	39.7
C	0.048	4.8
Mn	0.334	33.4
S	0.025	2.5
P	0.007	0.7
Si	0.012	1.2
Cr	0.054	5.4
Ni	0.07	7
Cu	0.012	1.2
Pb	0	0
Sn	0.025	2.5
Al	0.004	0.4
Mo	0.005	0.5
V	0.005	0.5
Ti	0.002	0.2

Table 2. Chemical composition of cast iron.

Element	Fraction	% Composition
Fe	0.917	91.7
C	0.0359	3.59
Mn	0.0045	0.446
S	0.0009	0.099
P	0.0021	0.207
Si	0.0263	2.63
Cr	0.0016	0.159
Ni	0.0005	0.046
Cu	0.0025	0.246
Pb	0.0002	0.0132
Sn	0.0003	0.026
Al	0.00006	0.006
Mo	0.0002	0.016
V	0.0002	0.017
Ti	0.0006	0.056
B	0.0000	0.003
Co	0.0001	0.01
Mg	0.0000	0.0001

Figs. 2 and 3 showing the plot of weight-loss have given an approximate indication of the corrosion effects of the various environments on the grinder machine materials. However, the point of interest is determining the rate of corrosion as a function of time as given in Eq. (1).

3.3 Cast Iron vs. Mild Steel

• **In water:** The behaviour of the individual alloy is clearly explained in this section from the obtained results of the conducted experiment. The point of interest of this observation is to determine which of the two is more affected by the cereal environments. Fig. 4 reveals the plot of the rate of corrosion of the alloys in ordinary water environment. This system is taken as a control system. It is so clear that an inter-play existed in their behaviour. At the initial stage, the rate of corrosion was more marked in Cast iron than in Mild steel. However, in the later run, the rate reduces and on the other hand an increase was found in mild steel. The reason for this can be explained as follows. Ordinarily, the rate of corrosion in cast iron would be more if the alloy was not left for a longer time in solution. That is, if it were to be that alloy surfaces are rinsed and cleaned every day, then more loss would have been experienced in cast iron than in mild steel as we have it.

Table 3. Weight loss data.

Substance	Mild Steel Initial Weight (g)	Final Weight (g)	Cast Iron Initial Weight (g)	Final Weight (g)
Experiment 1				
Water	98.96	98.95	70.02	70.00
Sorghum	99.36	99.32	71.54	71.46
Corn	99.95	99.88	71.55	71.47
Experiment 2				
Water	98.95	98.93	70.06	69.98
Sorghum	99.32	99.26	71.46	71.21
Corn	99.88	99.73	71.47	71.20
Experiment 3				
Water	98.93	98.89	69.98	69.95
Sorghum	99.26	99.18	71.21	70.95
Corn	99.73	99.54	71.20	70.93
Experiment 4				
Water	98.89	98.85	69.95	69.91
Sorghum	99.18	99.11	70.95	70.68
Corn	99.54	99.35	70.93	70.65
Experiment 5				
Water	98.85	98.81	69.91	69.87
Sorghum	99.11	99.05	70.68	70.41
Corn	99.35	99.16	70.65	70.37
Experiment 6				
Water	98.81	98.74	69.87	69.83
Sorghum	99.05	98.95	70.41	70.14
Corn	99.16	98.92	70.37	70.08
Experiment 7				
Water	98.74	98.67	69.83	69.79
Sorghum	98.95	98.84	70.14	69.86
Corn	98.92	98.68	70.08	69.79
Experiment 8				
Water	98.67	98.60	69.79	69.75
Sorghum	98.84	98.73	69.86	69.58
Corn	98.68	98.45	69.79	69.50
Experiment 9				
Water	98.60	98.52	69.75	69.71
Sorghum	98.73	98.59	69.58	69.29
Corn	98.45	98.21	69.50	69.20
Experiment 10				
Water	98.52	98.44	69.71	69.66
Sorghum	98.59	98.45	69.29	69.00
Corn	98.21	97.96	69.20	68.90

The explanation for this phenomenon may be explained that the cast iron material corrodes quickly on exposure to water; a covering (an oxide layer) is formed on the effective surface area of the remaining cast iron thus stifling the surface from further reactivity or against more corrosion. Although such occurs in mild steel too, it is evident that it is more pronounced in cast iron. This passivity in reaction is also the explanation for why it appears that the graphs attain a form of steadiness in the tail ends in the graph.

Table 4. Weight loss in mild steel.

No.	Water (g)	Sorghum (g)	Corn (g)	Duration of experiment (days)
1	0.01	0.04	0.07	1
2	0.02	0.06	0.15	2
3	0.04	0.08	0.19	3
4	0.04	0.07	0.19	3
5	0.04	0.06	0.19	3
6	0.07	0.10	0.24	4
7	0.07	0.11	0.24	4
8	0.07	0.11	0.23	4
9	0.08	0.14	0.24	5
10	0.08	0.14	0.25	5

Table 5. Weight loss in cast iron.

No.	Water (g)	Sorghum (g)	Corn (g)	Duration of experiment (days)
1	0.02	0.08	0.08	1
2	0.02	0.25	0.27	2
3	0.03	0.26	0.27	3
4	0.04	0.27	0.28	3
5	0.04	0.27	0.28	3
6	0.04	0.27	0.29	4
7	0.04	0.28	0.29	4
8	0.04	0.28	0.29	4
9	0.04	0.29	0.30	5
10	0.05	0.29	0.30	5

Table 6. Corrosion rate of mild steel.

No.	Water (mpy)	Sorghum (mpy)	Corn (mpy)
1	5.776	23.105	40.434
2	5.776	17.329	43.322
3	7.702	15.403	36.581
4	7.702	13.478	36.584
5	7.702	11.553	36.584
6	10.108	14.441	34.657
7	10.108	15.885	34.657
8	10.108	15.885	33.213
9	9.242	16.173	27.726
10	9.242	16.173	28.881

Table 7. Corrosion rate of cast iron.

No.	Water (mpy)	Sorghum (mpy)	Corn (mpy)
1	6.381	51.047	51.047
2	6.381	79.760	86.141
3	6.381	55.300	59.554
4	8.508	57.427	59.554
5	8.508	57.427	59.554
6	6.381	43.071	46.261
7	6.381	44.666	46.260
8	6.381	44.666	46.260
9	5.105	37.009	39.285
10	6.381	37.009	39.285

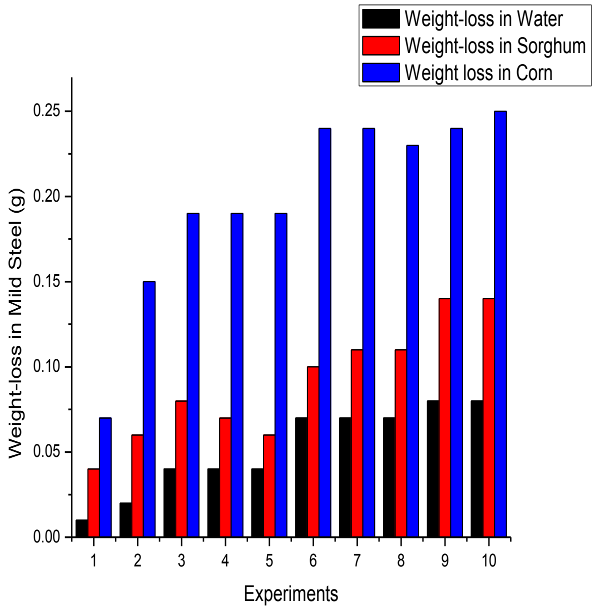

Fig. 2a. Mild steel weight-loss plot.

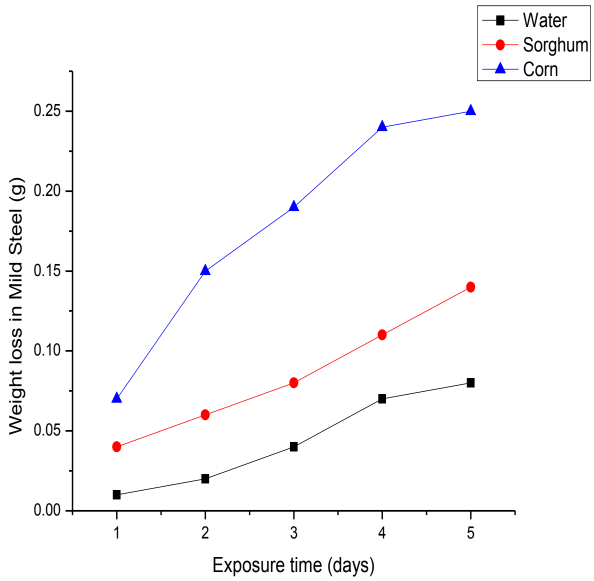

Fig. 2b. Mild steel weight-loss plot vs. exposure time.

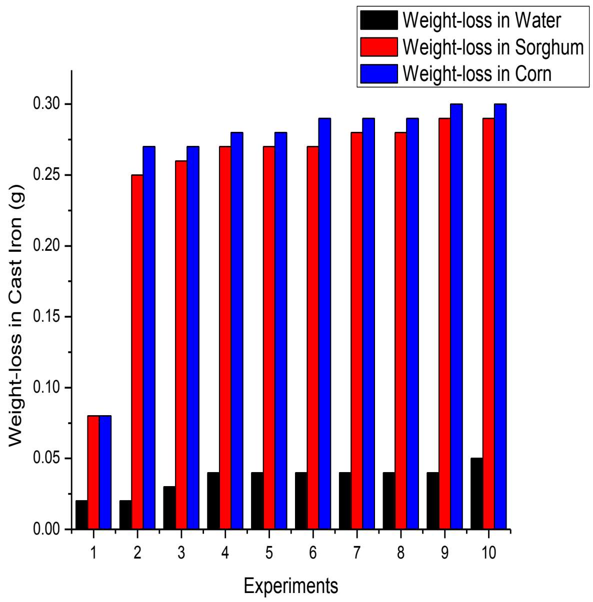

Fig. 3a. Cast iron weight-loss plot.

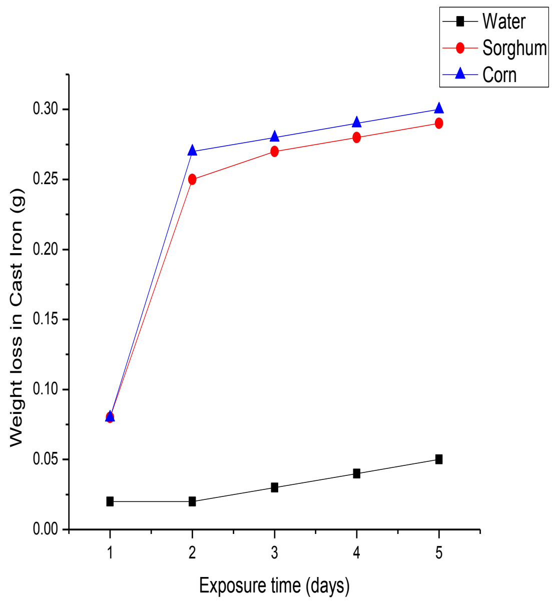

Fig. 3b. Cast iron weight-loss vs. exposure time.

• **In sorghum solution:** Figure 5 shows the behaviour of the alloys in sorghum environment. Corrosion rate of cast iron is highly pronounced while that of mild steel is highly limited. This means that in the wet-grinding of sorghum, cast iron would contribute to a large percentage of the iron contamination in the food product.

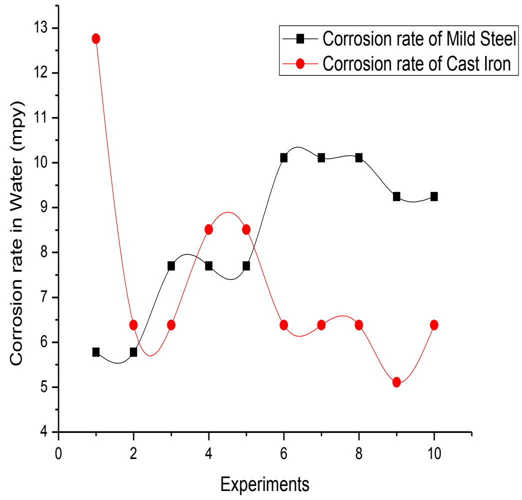

Fig. 4. Corrosion rates of alloys in water.

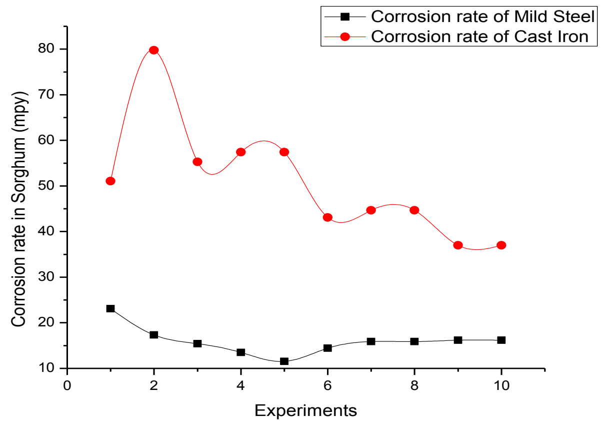

Fig. 5. Corrosion rates of alloys in sorghum solution.

• **In corn solution:** Just a similar occurrence as in sorghum solution above occurred in the corn powder solution as well. The corrosion rate was found to be more in cast iron than it is in mild steel. This is shown in Fig. 6. From the observations obtained above, it is seen clearly that of the two components of the cereal grinding machine, cast iron, which is even the make-up of the grinding plate, would give the larger ratio of corrosion into the food product. In other words, the available cast iron in use for the fabrication of locally available cereal grinders was not of the best design quality since it would lose a lot of its metallic constituents into the food products during operation.

3.4 Sorghum versus Corn (Reactivity Level)

The ultimate analysis of both sorghum and corn (or maize) was carried out and the result obtained from a 150 mg of each of the sample's solution is as given in Table 8.

• **On mild steel:** The behaviour of mild steel in the two cereal environments is shown in Fig. 7. From the graph, it is seen that the corn environment had more corrosive effect on mild steel than sorghum did. It is thus expected to have more heavy metal content in the processing of corn than we would in sorghum. The cause of this may be explained on the basis of chemical reactivity and relative material compositions of both the cereals and mild steel. From the ultimate analysis given in Table 8, it is seen that corn has less iron content than sorghum. This variance would affect the reactivity of iron alloy placed in their respective environments. It is expected that since iron content is less in corn, more corrosion would occur in it than in sorghum.

• **On cast iron:** The reactivity or corrosive action of the cereal environments on cast iron is similarly illustrated by the graph in Fig. 8. The response of the cast iron sample to the environments may be considered to be indifferent on the average. However, a more critical consideration reveals, in a little bit, that little higher corrosion rate occurs in the corn environment than in sorghum; a situation similar to the previous consideration. A similar reason can be advanced for this. However, the much reduced rate of corrosion in this particular case can only be explained by kinetics of the reactions; and that is not a point of interest in the scope of this study.

Table 8. Ultimate analysis of cereals.

	Content (mg)	
Mineral	Corn	Sorghum
Iron	0.4	0.65
Potassium	0.42	51.81
Magnesium	18.7	0.00
Calcium	1.04	4.14
Phosphorus	31.0	42.5
Sodium	5.2	0.90

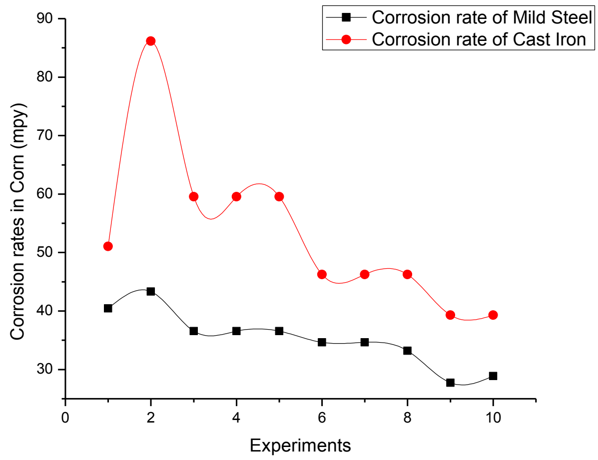

Fig. 6. Corrosion rates in corn solution.

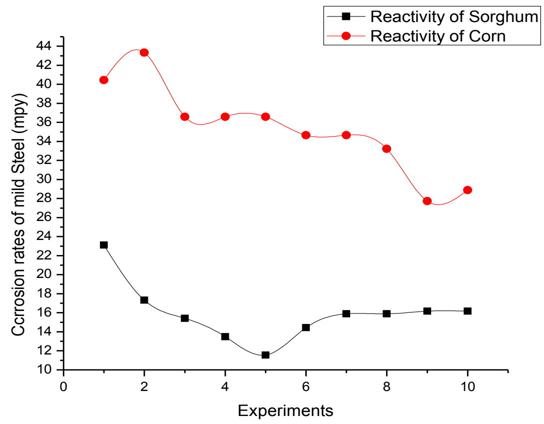

Fig. 7. Corrosion effects of cereals on mild steel.

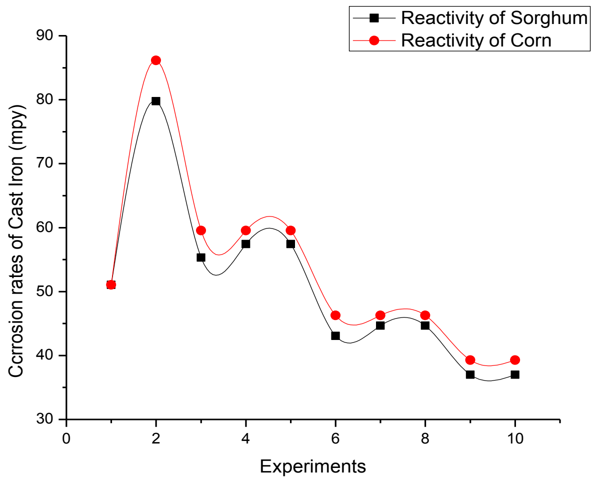

Fig. 8. Corrosion effects of cereals on cast iron.

4. Conclusion

In this research, it was shown that mild steel and cast iron are corrosive in cereal environments. However, their levels of corrosiveness are different from each other. It was proven that cast iron is more corrosive in the cereal environments than mild steel was. The measure of corrosiveness, of course, is the level of corrosion rates calculated for each alloy samples. Of the two grinder materials, cast iron plays the more active part as it is the make-up of the grinder plate which does the actual grinding while mild steel is only used for the pass-way for the cereal grains; therefore, the high level of corrosiveness of cast iron calls for control.

Furthermore, in the study it was evident that more metal loss occurred in the corn solution environment more than it occurred in sorghum. In other words, it could be said that in the real life situation, the threat of iron contamination would be more in corn (or maize grinding processes) than it would be in sorghum.

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