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A Study of Corrosion Behaviour of Chromium Alloyed Ductile Iron in Cassava Juice

John Friday Ogbodo, Raymond Taiwo Oluyori

Metallurgical Engineering Department, Kogi State Polytechnic, Lokoja, Nigeria
Email: rtoluyori@gmail.com

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Abstract

This paper investigated the efficiency of chromium, an alloying element in ductile cast iron, in inhibiting corrosion in cassava juice. Samples were prepared by adding chromium (0.5, 1.0, 1.5 and 2.0 wt.%) respectively to ductile cast iron and investigating the effect of increasing the chromium content on the corrosion of the ductile iron in cassava juice. Prepared samples were immersed in fresh water and cassava juice for a period of thirty two days (32) days and weight loss measured after every four days. A control sample was also produced and tested. Results showed that the control sample had the highest corrosion rate in both fresh water and cassava juice media. The sample containing the highest weight percent of chromium was found to resist corrosion the most, probably due to the increased content of chromium which resulted in enhanced formation of chromium oxide passive layer coupled with the reduction of the concentration of the cassava juice as exposure time increased. The decrease in corrosion rate of the alloys reflected on the micrographs as the micrographs of the alloyed samples showed fewer cavities on their surfaces when compared with the control sample where corrosion was severe. Effective protection of the ductile iron was observed as the chromiun content increases.

Keywords

Corrosion, Ductile Iron, Food Manufacturing Processes

1. Introduction

Cassava (*Manihot utillisima*) is an agricultural product that has found extensive application in the starch and food industry all over the world. In its processing however, one of the factors that have impeded its exploitation is the frequency with which the processing machines break down due to corrosion of component parts resulting from contact with the cassava juice, which contains 6% - 10% cyanic acid [1].

The cassava processing company is encountering numerous problems with the materials of construction of their machinery, most of which is often manufactured from carbon steel. The problem is attributable to the aggressive nature of the cyanide content of the cassava [2].

The monumental damage done to equipment and the cost of repair caused by corrosion has generated increasing interest in research into the environment/metal interface reactions and the means of reducing the damaging effects of corrosion on metals and alloys [3]. Effort has been made by several researchers to curtail this trend. A study of the corrosion of mild steel in cassava juice by electrochemical and non-electrochemical (weight-loss) methods revealed extensive corrosion of the mild steel in the plant juice. Subsequent coating of the steel specimen with two different kinds of paints could not provide effective protection [4]. The CN ions from the hydrocyanic acid content of the cassava juice are believed to be the reacting species that caused the corrosion [4].

Ductile iron, also known as ductile cast iron or nodular cast iron, or spheroidal graphite iron, is a type of cast iron invented in 1943 by Keith Millis. Ductile iron is not a single material but is part of a group of materials which can be produced to have a wide range of properties through control of the microstructure. The common defining characteristic of this group of material is the morphological structure of the graphite. In ductile irons the graphite is in form of spherical nodules rather than flakes (as in grey iron), thus inhibiting the creation of cracks and providing the necessary ductility that gives the alloy its name [5].

Spheroidal graphite iron also known as nodular iron is now replacing cast iron (grey and white iron) or cast steel as a result of many advantages it possesses. These advantages have led to expansions of its application throughout the manufacturing industries [5]. Ductile iron has significantly good combination of tensile strength, ductility and toughness, along with good wear resistance and hardenability.

With the use of chromium as an alloying element, it is anticipated that it will provide a protective film on the ductile iron. The film will then act as a barrier for the ductile iron and hence stop or reduce corrosion reactions on the iron surface. This research aims at investigating the effects of the variation in weight percent of chromium in order to study their inhibitive effects on ductile iron in cassava juice using weight loss immersion technique. The results of this work are expected to offer a possible remedy to excessive corrosion damage experienced by the cassava processing industry.

2. Experimental Procedure

The ductile iron specimens used for this work were commercially sourced from the Nigerian Machine Tools, Osogbo, Nigeria. The chemical composition of the ductile iron samples after spectroscopic analysis at Grand Foundry, Lagos is presented below:

Element wt.%	C	Si	Mn	P	S	Cr	Ni	Mo	Al	Cu	Co	Ti	V	W	Mg	Fe
Sample X	2.81	2.77	0.096	0.085	0.077	0.029	0.019	<0.0020	0.013	0.134	<0.0015	0.0045	<0.0010	<0.010	0.108	93.75
Sample A	3.41	3.35	1.29	0.259	0.054	0.498	0.077	0.033	0.0028	0.119	0.013	0.013	0.012	<0.010	0.012	91.0
Sample B	3.67	3.30	1.61	0.163	0.059	0.994	0.070	0.037	0.0059	0.121	0.012	0.013	0.013	<0.010	0.017	90.5
Sample C	3.46	3.36	0.51	0.206	0.096	1.496	0.071	0.019	0.0050	0.129	0.011	0.013	0.010	<0.010	0.017	91.5
Sample D	3.82	2.60	0.80	0.233	0.103	1.991	0.065	0.020	0.0041	0.085	0.011	0.013	0.013	<0.010	0.020	90.8

Three sets of samples of ductile iron samples containing 0.5, 1.0, 1.5 2.0 wt.% of chromium were produced in a coreless induction furnace. These were denoted as A, B, C and D respectively. Sixteen samples were cut from each set using a laboratory cutter. A control sample (X) was also produced and cut to similar dimensions and their surfaces were given similar surface finish in order to descale them. They were then ground with 240, 320, 400 and 600 grits silicon carbide abrasive papers, cleaned and dried for subsequent weight lost tests in the media involved. The samples were then machined, drilled and tied with wire rods and suspended in plastic containers containing cassava juice. Eight samples each of 0.5, 1.0, 1.5 and 2.0 wt.% of chromium were immersed in 300 ml of cassava juice and fresh water.

Subsequently, eight samples of the unalloyed samples were also immersed in 300 ml of both cassava juice and fresh water. The weights of the samples were recorded before immersion using a chemical weighing balance. Weight loss of the samples were recorded every four days for a whole period of immersion of thirty two days and the data generated was used to determine the corrosion rate of the ductile iron. Graphs of corrosion rates in mil per year (mpy) versus the exposure time were plotted for each set of the alloyed ductile iron in the media. The corrosion rate of the samples in the cassava fluid was determined from the relationship:

$$R = \frac{534W}{DAT}$$

where:

R = corrosion rate (mpy);

W = weight loss of samples (mg);

A = area of samples (in^2);

T = exposure time (hr.);

D = density of ductile iron (g/cm^3).

3. Results

Figure 1 and Figure 2 illustrate the corrosion behaviour of ductile iron in fresh water and cassava juice.

The variation of corrosion rate with exposure time in fresh water is shown in Figure 1. Corrosion rates were found to decrease with duration of exposure. The control sample recorded corrosion rate of 1.6705 mpy in the first four days (96th hour) while the 2.0% Cr-ductile iron displayed least corrosion rate of 0.5636 mpy

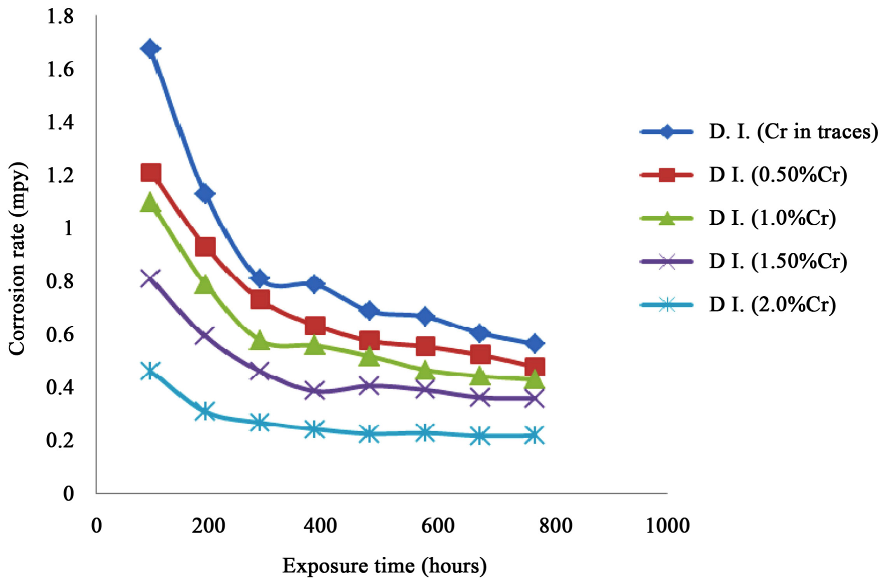

Figure 1. Variation of corrosion rate with exposure time of chromium alloyed ductile irons in fresh water.

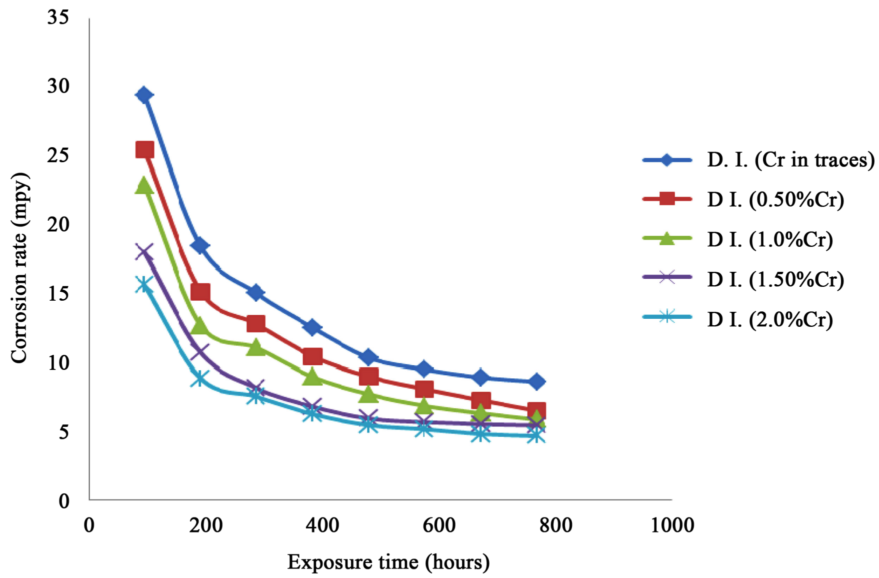

Figure 2. Variation of corrosion rate with exposure time of chromium alloyed ductile iron in cassava juice.

in the last day. Figure 2 describes the corrosion behaviour of both alloyed and control samples in cassava juice. The control sample recorded the highest corrosion rate of 29.437 mpy in the first four days (96th hour) and 8.5531 mpy in the 32nd day (768th hour) of the experiment. The 0.5% Cr-ductile iron has corrosion rate of 25.4045 mpy in the 96th hour and 6.4465 mpy in the last day of exposure. It is obvious from the curve that corrosion rate of the ductile iron decreased with its chromium content on immersion in cassava juice.

Figures 3-6 illustrate some of the micrographs of the corroded surfaces of the ductile irons removed on the 32nd day (768 hours) of exposure in cassava juice.

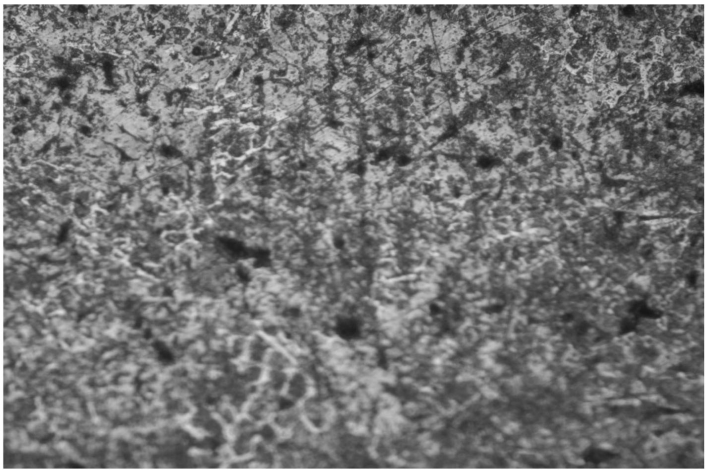

Figure 3. Micrograph of sample X (as cast ductile iron) after 32 days of exposure in cassava juice (×200).

Figure 4. Micrograph of sample A (0.5% chromium ductile iron) after 32 days of exposure in cassava juice (×200).

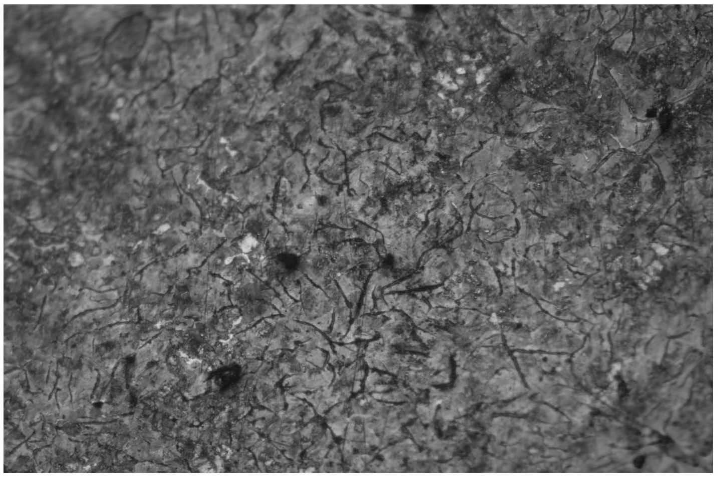

Figure 5. Micrograph of sample B (1.0% chromium ductile iron) after 32 days of exposure in cassava juice (×200).

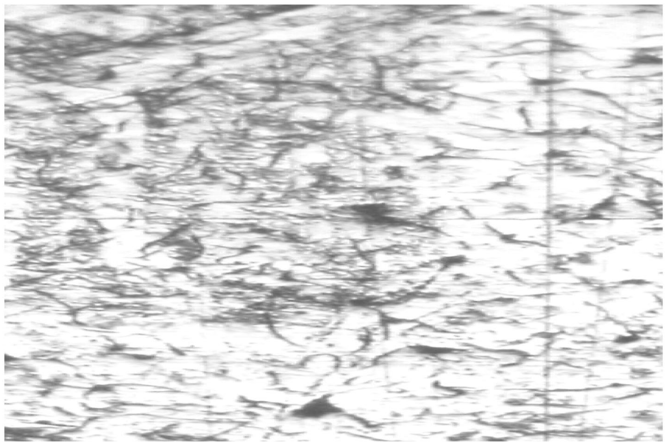

Figure 6. Micrograph of sample C (1.5% chromium ductile iron) after 32 days of exposure in cassava juice (×200).

The micrographs displayed evidence of localized attack with the appearance of cavities (dark spots) on their surfaces. Figure 3 illustrate the micrograph of the ductile iron with chromium in traces (control sample) exposed to cassava juice, showing high concentration of cavities of varying sizes. There are also evidence of non-metallic inclusions in the microstructure. Figure 4 and Figure 5 show typical micrographs of surfaces of 0.5% and 1.0% Cr-ductile iron respectively, which exhibit a lesser degree of attack and smaller cavities compared to the control samples. Figure 6 reveals the surface of the 1.5% Cr-ductile iron exposed to cassava juice, which contains few dark spots, and the attack is mild compared to sample B. Figure 6 depicts the surface of the 2.0% Cr-ductile iron in cassava juice, the size and distribution of cavities were drastically reduced compared to other samples. The micrograph shows that corrosion occurred along the grain boundaries making the nodules almost invisible. It is evident from the micrograph that, with increasing chromium content, the pearlite (dark background) gradually disappears and the ferrite phase is stabilized. Chromium acts as a ferrite stabilizer or carbide formers and the ferrite matrix is known to provide highly ductile cast iron of reasonable toughness, and the toughness of the ductile cast iron was more dependent on the area fraction of ferrite than the area fraction of intercellular carbide-like phases [5]. The micrographs of the control samples show a localized attack on the samples; this is seen as cavities (dark spots). The cavities were bigger and more distributed than those in the alloyed samples.

4. Discussion

The control samples do not seem to have good corrosion resistance in cassava juice probably due to trace quantity of chromium which is known to offer resistance to corrosion and oxidation [5].

In case of the 0.5%, 1.0%, 1.5% and 2.0% Cr-ductile iron samples, the reduction in their corrosion rates may be due to the inhibitive power of the alloying element (chromium) and the decrease in the concentration of the cassava medium as exposure time increases.

A cursory look at the graphs of corrosion rate to exposure times (**Figure 2**) corroborates the findings earlier described above. **Figure 2** shows that control sample has the highest corrosion rate of 29.4370 mpy in the first 96^{th} hours of exposure and reduced to 8.5531 mpy in the last day (768^{th} hour). The 0.5% Cr-ductile iron displayed the highest corrosion rate of 25.4045 mpy in the first four days (96^{th} hour) and reduced to 6.4465 mpy in the 768^{th} hour. The 1.0% Cr-ductile iron recorded initial corrosion rate of 22.8698 mpy and 5.7983 mpy at the end of exposure. The 1.5% Cr-ductile iron with corrosion rate of 17.9732 mpy in the first four days (96^{th} hours) reduced to 5.3763 mpy at the end of exposure. Similarly, the 2.0% Cr-ductile iron recorded maximum corrosion rate of 15.6114 mpy and minimum of 4.5936 mpy being the best-behaved samples throughout the duration of exposure. The corrosion attack was found to be most severe during the initial stages of exposure time but it invariably decreased to a very low value in the latter stages, probably due to the formation of an adherent protective layer on the metal surface which depends on the temperature and environment itself [5] [6]. The initial increase in corrosion of samples in cassava medium were probably because cassava contains hydrocyanic or prussic acid (HCN) called cyanide, the acid which is an organic solvent is known to be good corrosion medium for iron [6]. However it was observed that corrosion rate of the ductile iron increased in cassava juice compared with ductile iron in fresh water probably, because of the presence of cyanide, one of the most aggressive ions in cassava juice [7]. Corrosion rate of the control sample was highest in both media, and the 2.0% chromium ductile iron had the least corrosion rates in the media. Corrosion rate was visibly higher in 1.0% Cr-ductile iron compared with 1.5% Cr-ductile iron. However, there was drastic reduction in corrosion rate in the 2.0% Cr ductile iron sample. The reduction in the corrosion rate may have probably resulted from the formation of a product layer which might have shielded the iron surface from further corrosion. The high initial corrosion rate may be probably due to availability of fresh activated surface, and high initial oxygen content of the solution. Chromium addition confers good oxidation resistance to iron and steel, and enriches the innermost layer of the iron oxide and often generates a protective layer of chromium oxide (Cr_2O_3) on the metal surface below the iron oxides [7]. These layers are more resistant to ion or electron diffusion than iron oxides alone, and the oxidation rate is decreased. The chromium can also combine with carbon to form chromium carbide (hard, wear-resistant micro constituents).

5. Conclusions

The following main conclusions were drawn from this research works:

1) The corrosion of ductile iron in cassava juice can be minimized by alloying with chromium.

2) Corrosion rate decreases with increase in both exposure time and chro-

mium content.

3) The microstructure evolved with increase in chromium content restrains nodularization and stabilized ferrite.

4) The alloyed ductile iron was more resistant to corrosion compared with the unalloyed samples in cassava juice.

5) The resistance of the ductile iron samples in cassava juice decreased in the following order: D, C, B, A and X.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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