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EFFECTS OF VARYING WEIGHT PERCENT MAGNESIUM IN RICE HUSK PARTICULATE CAPSULE ON HARDNESS AND MICROSTRUCTURAL PROPERTIES OF PRODUCED COMPACTED GRAPHITE IRON

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Abstract: Effects of varying weight percent of Magnesium in rice husk particulate capsule on hardness and microstructural properties of produced compacted graphite iron was studied. Varied percentage of magnesium ferrosilicon in the range of 0.4 and 0.6 wt. % was incorporated in different rice husk particulate capsules to treat the molten metal at a temperature of 1420°C in ladle before pouring 1415°C into prepared sand moulds. Specimens were cut from the cast using hacksaw machine for hardness and microstructural tests. Samples with 0.4 and 0.6 wt. % Mg incorporated in non-pulverized rice husk particulate capsule had hardness values of 52.2 and 52.5 HRA respectively. Microstructural property of 0.6 wt. % Mg in non-pulverized rice husk capsule improved compared to those ones from other particulate capsules.
Keywords: Compacted graphite iron; Rice husk; Particulate capsules; Hardness; Microstructural Properties

1. INTRODUCTION

Compacted graphite iron (CGI) is a new group of material produced in recent years, which has joined the family of commercially produced cast irons. It lies intermediate between flake graphite and nodular graphite. The microstructure of compacted graphite consists of shortened thickened flake with rounded ends [1]. Graphite morphologies in CGI are randomly oriented, elongated and interconnected within eutectic cells as in grey iron, but stubby, blunt-edged and have rounded ends and rough interfaces with matrix, and generally considered as a transitional form between flake and nodular. Therefore, CGI provides higher strength and ductility than grey iron and better thermal conductivity and damping properties than nodular iron, which represents an optimal combination of strength, ductility and thermal properties for certain engineering applications and has received considerable attention especially during recent years [2]. With at least 75% increase in tensile strength, 40% increase in elastic modulus and approximately double the fatigue strength of grey iron, CGI is ideally suited to meet the current and future requirements of diesel engine design [3].

In this research, rice husk (RH) was utilized as particulate capsules in three different forms namely: pulverized rice husk (PRH), non-pulverized rice husk (NRH) and rice husk ash (RHA). The rice husk particulates are used to form capsules with the aid of locally made starch which serve as a binder. The magnesium powder was introduced into dry capsules. The capsules were dropped in the ladle before tapping of the melt to produce the compacted graphite iron.

2. EXPERIMENTAL PROCEDURE

The engine block scraps, ferrosilicon (FeSi), FeSi-Mg, starch and rice husk particulates which were sourced locally. The rice husk particulates were utilized to form capsule. The rice husk particulates were prepared in three different forms, namely: pulverized, ash and the non-pulverized. Ball mill was used to pulverize the rice husk. This was done for 30 minutes. Sieve analysis was later carried out ranging from 50 µm to 100 µm. A simple metallic drum with mesh inside to allow for air circulation to aid combustion was used as burner for the preparation of the RHA [4]. The ash was prepared by burning sun-dried rice husk in a metallic drum which was thereafter conditioned at a temperature of 650°C for 180 minutes to reduce the carbonaceous and volatile constituents of the ash. Sieving of the rice husk ash (RHA) was then performed using a sieve shaker to obtain ashes with mesh size below 50 µm. The chemical compositions of FeSi, FeSi-Mg and the RHA determined using X-ray fluorescence spectroscopy are presented in Tables 1, 2 and 3.

Table 1: Chemical composition of FeSi-Mg. Size = 19 mm. [5]

Elements	% Composition
Si	44.4
Mg	5.0
Ce	0.56
Ca	1.02
Al	0.61
La	0.46
Fe	47.95

Table 2: Chemical Composition of the Ferro silicon used as Inoculant. Source: [5]

Elements	Si	Ce	Al	Ca	Ba	Fe
%	74.92	1.81	1.12	0.78	0.08	21.28

The starch was used as a binder to mould the particles to form capsules thereafter they were sundried to remove any excess water in the capsule. The FeSi-Mg of 0.4 and 0.6 wt. % Mg were introduced into the various forms of particulate capsules.

Pattern and mould preparations

The patterns used were made of wood with diameters of 20 mm by 200 mm long. The patterns were made larger than the original dimension to compensate for shrinkage during solidification and machining operation. A mixture of silica sand with considerable amount of bentonite was used to prepare the sand mould. The addition of bentonite improved the bonding strength. The molding of the pattern was carried out using a moulding box comprising of cope and drag that gave rigidity and strength to the sand. Parting sand was properly applied for the easy removal of the mould from the pattern. The gating system was properly designed for smooth channeling of the molten metal into the mould cavities through the sprue, runner, in-gates and riser that were perfectly placed in position [6].

Table 3: Chemical composition of the rice husk ash. Source: [4]

Compound/element (constituent)	Wt. %
Silica (SiO_2)	91.56
Carbon	4.8
Calcium oxide, CaO	1.58
Magnesium oxide, MgO	0.53
Potassium oxide, K_2O	0.39
Heamatite, Fe_2O_3	0.21
Others	0.93

Melting and Casting

Melting of the scraps was achieved by using indirect electric furnace of 4 Kg capacity after necessary charge calculations. The quantity required for FeSi and FeSi-Mg is expressed in equation 1. The charge materials with their quantities were shown in Table 4.

$$\text{Quantity Required} = \frac{\%\,\text{Element in the Melt x Total Mass}}{\%\,\text{Element of Ferro Alloy}} \quad (1)$$

From Table 4, it implies that 0.018 **Kg** of FeSi was added for every 2.986 **Kg** of scraps in the furnace while 0.0139**Kg** of FeSi was constantly added during tapping for inoculation. The particulate capsules contained 0.0576 **Kg** and 0.0864 **Kg** FeSi-Mg for 0.4 and 0.6 wt % Mg respectively. The dry particulate capsules which contained the magnesium alloy were dropped inside the ladle before tapping. This was done to ensure the capsules burnt off and release the magnesium powder to react with the melt. Tapping of the melts were done at 1420**℃**. The melt was then poured at a temperature of 1415**℃** into already prepared sand moulds. Thereafter the cast samples were shake-out from the sand mould after cooling and fettling operation was later performed. Table 5 shows the interpretations of the codes for produced samples.

Table 4: Summary of charged materials

Charged materials	Quantity (kg)
Cast Iron Scraps	2.986
Cacium Carbide (Desulphurizer)	0.150
Nodulizer (FeSi-Mg)	0.0576
FeSi in the furnace	0.0180
FeSi as inoculant (ladle)	0.0139
Total	3.0755

Samples Preparations

The as-cast samples were prepared for chemical composition analysis, hardness and metallographic examinations.

Spectrometric Analysis

Table 6 shows the chemical compositions of the grey cast iron scraps used while the compositions of the cast samples are presented in Table 7.

Hardness

The hardness of the cast samples was determined on a hardness test machine using the Rockwell hardness scale of HRA (60KN). Specimens cut out from each cast samples were polished to obtain a flat and smooth surface finish. The sample preparation and testing procedure was performed in accordance with ASTM E-92 standard. Three hardness indents were made on each specimen and readings within the margin of ± 2% were taken for the computation of the average hardness values of the specimens [7]. Hardness values of the cast samples for 0.4 and 0.6 wt. % Mg are presented in Table 8.

Table 5: The Produced Samples with Codes and their Interpretations

S/N	Sample Codes	Interpretations
1	0.4PRH	Sample treated with 0.4 wt.% Mg in Pulverized Rice Husk Capsule
2	0.4NRH	Sample treated with 0.4 wt.% Mg in non-pulverized Rice Husk Capsule
3	0.4RHA	Sample treated with 0.4 wt.% Mg in Rice Husk Ash Capsule
4	0.4WRH	Sample treated with 0.4 wt.% Mg Control Sample without Rice Husk Capsule
5	0.6PRH	Sample treated with 0.6 wt.% Mg in Pulverized Rice Husk Capsule
6	0.6NRH	Sample treated with 0.6 wt.% Mg in non-pulverized Rice Husk Capsule
7	0.6RHA	Sample treated with 0.6 wt.% Mg in Rice Husk Ash Capsule
8	0.6WRH	Sample treated with 0.6 wt.% Mg (Control Sample) without Rice Husk Capsule

Table 6: Percentage Chemical Compositions of Cast Iron Scraps Used

C	Si	S	P	Mn	Cr	Ni	Mo	Ti	Al	Fe
3.42	2.05	0.112	0.31	1.06	0.003	0.001	0.002	0.001	0.004	93.7

Table 7: Chemical Composition of the Cast Samples for 0.4 and 0.6 wt. % Mg

Sample Code	Composition, %							
	C	Si	Mn	P	S	Cr	Mg	CE
0.4PRH	3.70	3.03	1.38	0.03	0.10	0.13	0.005	4.72
0.4NRH	3.50	3.10	1.17	0.03	0.096	0.10	0.004	4.54
0.4RHA	3.58	3.13	1.18	0.04	0.082	0.11	0.003	4.64
0.4WRH	3.39	3.11	1.13	0.03	0.057	0.10	0.002	4.44
0.6PRH	3.50	3.04	1.42	0.04	0.110	0.13	0.0064	4.55
0.6NRH	3.70	3.02	1.21	0.04	0.097	0.14	0.0082	4.72
0.6RHA	3.50	3.09	1.13	0.03	0.088	0.11	0.0055	4.52
0.6WPR	3.47	3.05	1.13	0.03	0.100	0.10	0.004	4.52

Metallographic Analysis

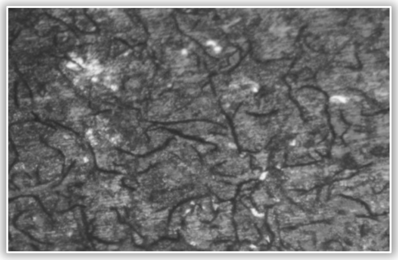
Metallographic samples were cut out from the cylindrical bars produced using hacksaw. Buehler metaser 2000 grinder and polisher were used to prepare the samples. Grinding was done through the following grits of grinding papers: 60, 120, 400, and 600 grits. After grinding, polishing was done using 800 and 1200 grits of polishing papers. Final polishing was done on polishing cloth with diamond polish suspension of 3 microns. Etchings were done using 2.5% nital solutions and the etching time was 12 seconds [7]. Photomicrographs were obtained using Nickon eclipse ME600 microscope.

Table 8: Hardness values (HRA) of the produced samples for 0.4 and 0.6 wt. Mg

Sample Code	Hardness (HRA)
0.4PRH	48.5
0.4NRH	52.2
0.4RHA	49.2
0.4WRH	35.7
0.6PRH	49.2
0.6NRH	52.5
0.6RHA	49.5
0.6WRH	42.0

3. RESULTS AND DISCUSSIONS

The composition of the scraps presented in Table 6 revealed that it has carbon equivalent value (CEV) of 4.21. This implies that it is hypoeutectic, the CEV is an indicator of the structure in relation to the potential for carbon precipitation as graphite in the eutectic iron formed [8]. The CEV of the treated samples are between 4.44–4.72. This indicated that the cast samples are hypereutectic, the higher the CEV, the greater the graphite precipitation during the eutectic iron formed [8]. It was observed that the silicon content significantly increase in the cast samples. This could be as a result of FeSi added and the use of magnesium powder incorporated in rice husk capsules for the castings. The Magnesium content was also observed to reduce drastically in some of the samples as in Table 4. This could be as a result of flaring, desulphurization and oxidation of magnesium [9]. The control samples treated with 0.4 wt. % Mg WRH and 0.6 wt. % Mg WRH capsules showed Type-A graphite flakes in a pearlite-ferrite matrix


a)

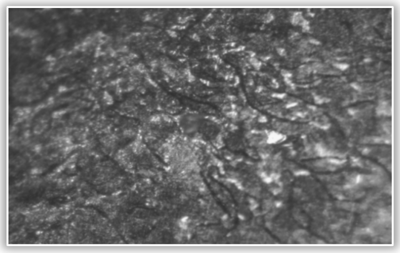

b)

Figure 1 and 2: Optical Micrographs of Control Samples: a) 0.4WRH (X200); b) 0.6WRH (X200)

Cast samples treated with 0.4 wt. % Mg and 0.6 wt. % Mg in PRH capsules showed less number of graphite flakes. Although, that of cast samples treated with 0.6 wt. % Mg in NRH capsules has better formation of graphite compare with that of sample treated with 0.4 wt. % Mg in NRH capsule.

Cast samples treated with 0.4 wt. % Mg and 0.6 wt. % Mg in RHA do not show any presence of graphite flakes. The absence of graphite flakes observed in samples treated with 0.4 wt. % Mg and 0.6 wt. % Mg in RHA capsules was as a result of high percentage of silica present shown in Table 2.

There was dissolution of magnesium in the melt to some extent in most of the encapsulate samples. The cast samples treated with 0.4 wt. % Mg and 0.6 wt. % Mg in NPR capsule still retain residual amount of magnesium content as shown in Table 7. The un-pulverized rice husk capsule delay to some extent the rate of dissolution of magnesium in the melt due to high specific density of the capsule. This results in loss of residual magnesium and production of grey cast iron instead of compacted graphite iron as seen in Figure 3 and 4. The magnesium treatments vapourize quickly in samples treated with 0.4 wt. % and 0.6 wt. % Mg in WRH capsules. Part of the active magnesium vapourizes from molten iron under high temperature while the rest magnesium powder combined with oxygen to form a stable oxide of MgO [9].

The hardness results of the cast samples treated with 0.4 and 0.6 wt. % Mg in different rice husk particle capsules are presented in Figure 9. The hardness of the produced samples was observed to increase with increase in the magnesium content as a result of pearlite formation (sample treated with 0.6 wt % Mg in WRH capsule).The hardness values of the 0.4WRH and 0.6WRH cast samples which served as the control samples had hardness values lower than that of the particulate capsules. However, 0.4NRH and 0.6NRH cast samples possessed highest hardness values of 52.2 and 52.5 HRA respectively. Increase in the addition of graphite in the cast iron promotes more pearlite to be formed that can result in high hardness value since it is known to be harder than ferrite [10]. However, a step reduction in hardness occurs as soon as flake patches begin to form [11] as observed in cast samples 0.4PRH and 0.6PRH.

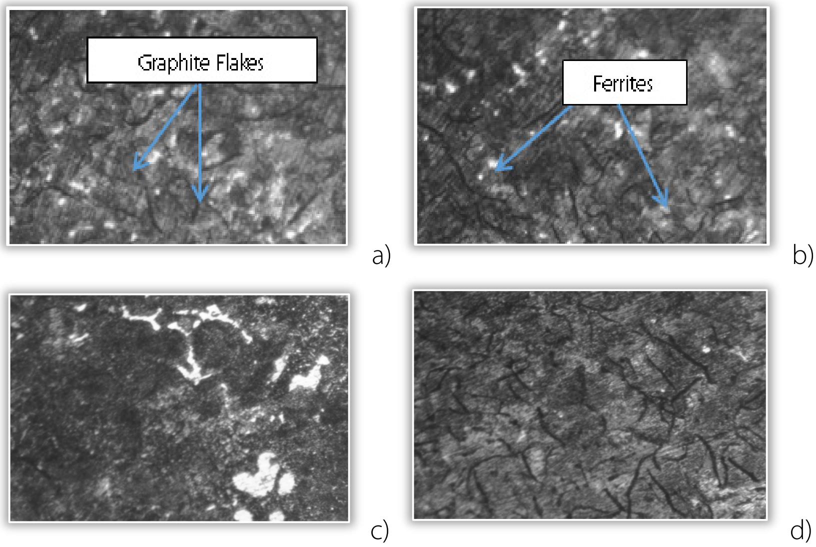


Figure 3-6: Optical Micrographs of Pulverized and Non-pulverized RH capsules for samples treated with 0.4 and 0.6 wt. % Mg. a) 0.4PRH(X200); b) 0.6PRH(X200); c) 0.4NRH(X200); d) 0.6NRH (X200)

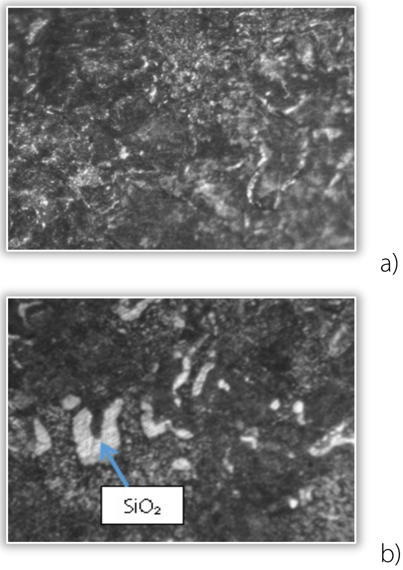


Figure 7-8: Optical Micrographs of Cast Samples Treated with 0.4 and 0.6 wt. % Mg in RHA Capsule. a) 0.4RHA: (X200); b) 0.6RHA: (X200)

4. CONCLUSIONS

The following conclusions were therefore drawn from the study:

- Sample with 0.4 and 0.6 wt. % Mg in non-pulverized rice husk capsule possessed highest hardness values;
- Dissolution of magnesium was observed to be more effective in 0.6 wt. % Mg for non- pulverized rice husk;
- 0.6 wt. % Mg in non-pulverized rice husk gave best microstructural property than other particulate capsules.

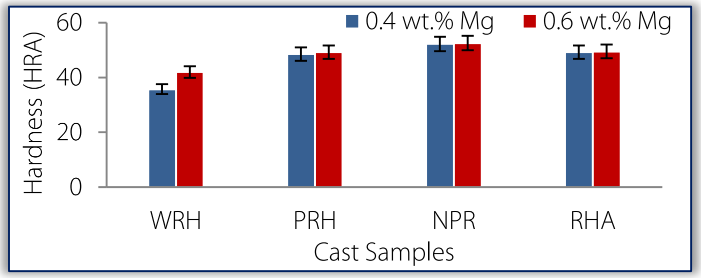


Figure 9: Hardness Values (HRA) against Cast Samples

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