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WEAR BEHAVIOUR OF NF-GREY 8 ALLOYED WITH FEMN NANOPARTICLES

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ABSTRACT: This study investigates the effects of ferromanganese nanoparticles additions on the hardness, impact energy and wear behaviour of a conventional(C=3.907%, Si=2.259%, Mn=0.509%, P=0.093%, S=0.081%) grey cast iron. The cast iron scraps were melted in a 40kg silicon crucible pit type furnace with and without addition of ferromanganese. A green sand mould of dimension 15 × 15 × 200mm was used for the production of the cast samples. The results obtained show an improvement in mechanical properties andwear resistance of the alloyed cast iron compared to the conventional cast iron. Comparison was also made to an earlier work in which microsized ferromanganese particles was used. It was found that smaller quantity of ferromanganese nanoparticles presented a better mechanical and wear properties.

Keywords: ferromanganese, nanoparticles, grey cast iron, mechanical, wear

1. INTRODUCTION

Grey cast iron is normally characterized with high brittleness and hardness. This property has to a larger existence limited its use to municipal castings, channel gratings, manhole cover, bollards and landscape gratings among others. However, in recent times, cast iron is gaining wide area of application in automobile (connecting rod, brake disc etc)and food grinding mills (grinding discs) because of its relative ease and low cost of production. Hence, it has become imperative for local foundry industries in Nigeria to produce grey cast iron parts with improved wear properties.

The properties of grey cast iron to a great extent depend on its composition. The difference in hardness between the alloys depends on the amount, type and distribution of carbide formed and on the volume and distribution of soft graphite flakes [1]. Despite favourable characteristics of grey cast iron, the presence of sharp edge of flake graphites often limits its area of applications. The limitation is more pronounced when the cast material is subjected to impact or used under applied shear stresses during dry sliding wearaplicatios [2]. Several researchers have investigated the contributions of various elements to the properties of grey cast iron [3,4,5]. A ferromanganese (FeMn) addition to its composition has also been studied as a means to increase its toughness and reduce its brittleness [6].

This study is an extension of the study carried out by Agunsoye et.al, 2012 [6]. Previously, the authors used ferromanganese microparticles to improve the wear resistance of grey cast iron. However, this study used ferromanganese nanoparticles to further improve the wear resistance and impact property of the grey cast iron in an attempt to extend its usefulness and applicability.

This study also provide the necessary platform for local foundries industry to produce better products that can favorably compete with imported parts and consequently help to improve Nigeria Gross Domestic Products.

2. MATERIALS AND METHOD

Materials

The NFGrey (8) cast iron withFeMn nanoparticles was used in this study. Samples were sand cast at a local foundry in Lagos, Nigeria.

Method

6kg of ferromanganese (FeMn) was crushed and ball milled for seventy-two hours to obtain FeMn nanoparticles. The ball mill operates at the speed of 195rpm with a power of 0.75kW.

Six pairs of moulds were prepared and labeled accordingly. A rectangular shaped pattern (11 x 11 x 200 mm) was used to make the mould cavity. The moulding sand was prepared from a mixture of dried fresh silica sand,bentonite and dextrin in accordance with BS14 standard [7].10kg quantity of grey cast iron was melted in a 40kg pit furnace as shown in Figure 1. The first batch which represents the control sample was poured into the mould without FeMn additions at 1270°C.

Thereafter, 15g of 75% ferromanganese nanoparticles were added to the molten bath, stirred mechanically to obtain homogeneous bath and poured into the already prepared mould. This process was repeated for otherbatches with increasing ferromanganese nanoparticles addition (Table 1). The results of the chemical compositions of the developed samples (Figure 2) are shown in Table 2. After pouring, the castings were allowed to solidify and cooled in the mould to room temperature (36°C) before they were carefully knock out and wired brush to remove the sand. Samples were machined to standard Charpy impact Brinell hardness and wear coupon. The hardness of the samples was determined using Brinell hardness tester carried out under a load of 60 kg and a dwell time of 10 seconds.

Table 1: Ferromanganese additions to Grey cast iron

Samples	Fe-Mn Additions (g)
Control	-
NF1	15
NF2	30
NF3	45
NF4	60
NF5	75

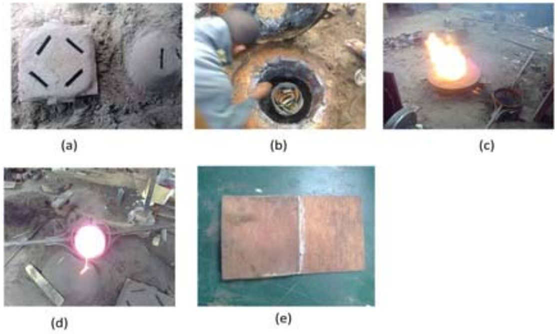

Figure 1: Production of alloyed grey cast iron

Figure 2: Grey cast samples

Wear Analysis

Rectangular shape specimen of dimensions 50 x 11 x 11mm of the control and developed samples were subjected to wear analysis to investigate their resistance to surface abrasion under dry lubrication conditions.

The wear test was carried out on a 200mm circular rotating disc with attached emery paper of 180 grit size. The surface of the test sample was placed against the rotating disc for a period of 60sec, 120sec, 180 sec and 240sec respectively under different loads. The experiment was repeated and each time, the corresponding weight was measured. The average weight loss for each runs of experiments at a given applied load and speed were calculated using equation 1. The wear rate was calculated using equation 2-5.

$$\text{Weight loss (wt)} = \text{initial weight} - \text{final weight} \qquad [1]$$

$$\text{Volume loss} = \frac{\text{wl}}{\rho} \qquad [2]$$

$$\text{Sliding distance} = \text{Sliding Speed} \times \text{time} \qquad [3]$$

$$\text{Sliding moment} = \text{Applied load} \times \text{sliding distance} \qquad [4]$$

$$\text{Wear rate} = \frac{\text{volume loss(vl)}}{\text{sliding moment(M)}} \qquad [5]$$

3. RESULTS AND DISCUSSION

Carbon equivalent (CE) is often used to predict carbide formation in cast irons. Agunsoye et al., 2012 has earlier shown that decreasing values of carbon equivalent signify improved toughness and reduced hardness. Higher values of CE will lead to the formation of large volume of hard carbide (Fe_3C) which is responsible for brittleness in gray cast iron.

Table 1 shows the chemical analysis results of the control and developed cast iron samples as well as their corresponding CE values. Carbon equivalent (CE) was calculated using equation 6 according to [8]. From Table 1, it can be seen that as the Mn content increase, the CE decreased. Consequently, the hardness value of the samples should decrease. This assumption agrees with results presented in Figure 4.

Table 2: Chemical analysis results

Element (%)	C	Si	S	P	Mn	Cr	Cu	Al	Mg	FE	CE
control	3.90	2.25	0.081	0.093	0.509	0.137	0.281	0.003	-0.00047	92.72	4.66
sample 1	3.67	1.78	0.092	0.159	0.618	0.071	0.186	0.003	0.00082	93.40	4.32
sample 2	3.53	1.83	0.048	0.148	0.854	0.139	0.302	0.001	0.00038	93.12	4.18
sample 3	3.52	1.84	0.072	0.139	0.981	0.129	0.325	0.001	-0.0004	92.98	4.18
sample 4	3.49	1.49	0.042	0.255	1.335	0.083	0.181	0.003	0.0042	92.10	4.08
sample 5	3.41	1.57	0.031	0.221	1.482	0.084	0.173	0.007	0.00553	91.99	4.02

Hardness and Impact Energy Results

To a reasonable extent, there is need to reduce the hardness of grey cast iron in other to improve its wear resistance. Figure 3 show that increasing additions of FeMn nanoparticles decreased the hardness value of the produced samples. These results agree with the deduction from the carbon equivalent values (Table 2) and further justify the results from Agunsoye et al., 2012. Furthermore, the hardness values obtained with additions of FeMn nanoparticles was lower compared to when FeMn microparticles was used in the earlier study. More interestingly, these low hardness values were obtained with lower additions of FeMn nanoparticles. For example, NF5 sample (1.48 %Mn) in this present study has lower hardness value (150 HB) compared to the hardness value of 250 HB gotten from sample with 1.71 %Mn in the earlier study [6]. The high surface area to volume ratio of nanoparticles provides the necessary driving force for diffusion, especially at elevated temperatures. It can be therefore be inferred that lower FeMn nanoparticles additions is required to obtain the desired hardness property compared to micro additions. Hence, the desired hardness can be achieved at reduced cost of ferroalloy (FeMn) with the additions of nanosized particles.

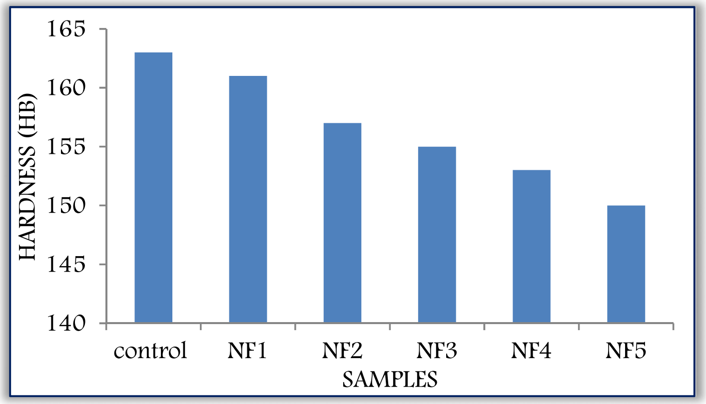

Figure 3: Hardness of the different compositions of grey cast iron

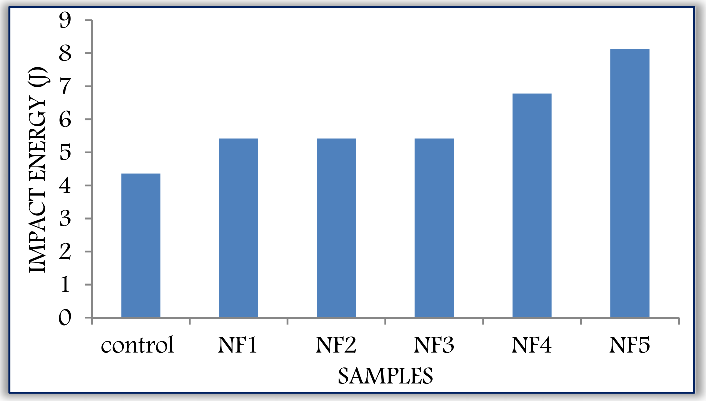

Figure 4: Impact energy of the different compositions of grey cast iron

The effect of FeMn nanoparticles additions on the impact energy of samples was represented in Figure 4. The graphite flakes in the microstructure of grey cast iron behave like microscopic fault lines allowing cracks propagation under loading. Hence, the impact and shock resistant of grey cast iron is almost non-existent. The addition of FeMn nanoparticles was found to increase the impact energy of the NFGrey cast iron used in this study. This improvement in impact energy is of significant importance for engineering applications.

XRD Results

Figure 5 and 6 shows the XRD result of the control and NF5 sample respectively. The extrapolated score count of the two samples is presented in Table 3 and 4. The increase percentage of Mn in the cast samples lead to the introduction of additional phases namely;$Mn_{22.6}$ $Si_{5.4}$ C_4, and FeC. The reduction in the hardness values was majorly due to the absence of hard and brittle cementite phase [9] in the cast matrix of the developed samples [Table 3].

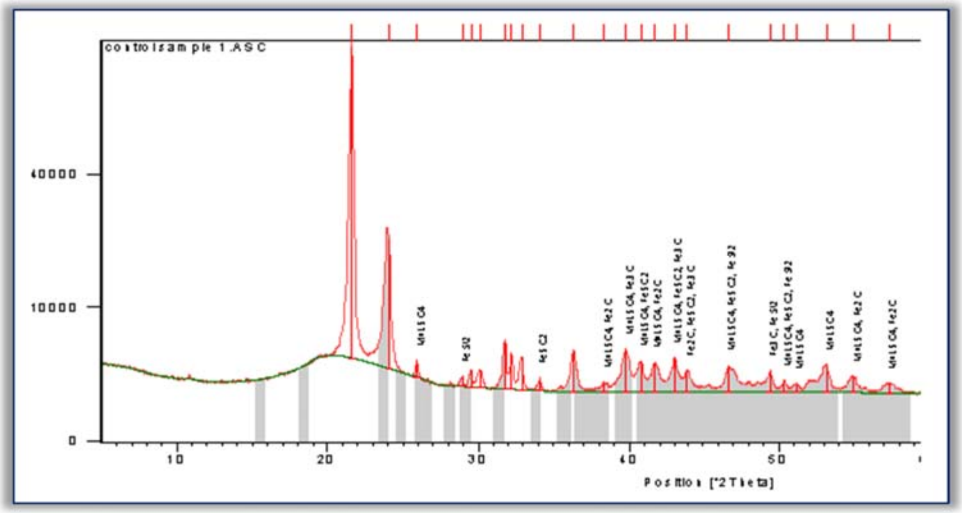

Figure 5: XRD Compositional Analysis of the control sample

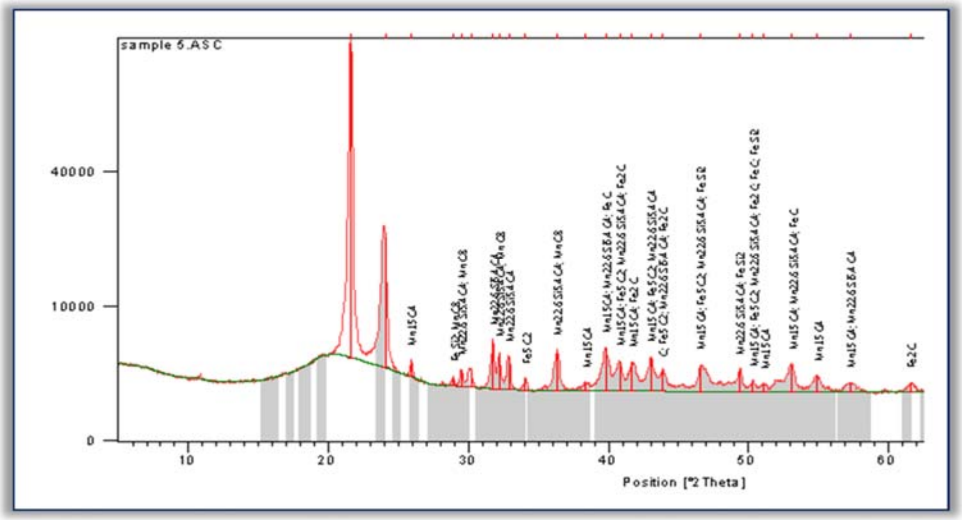

Figure 6: XRD Compositional Analysis of the NF5 sample

Table 3: Count Scores and Chemical Formulae of Identified Compounds present in the control sample

score	Compound name	Scale factor	Chemical formula
40	Manganses carbide	0.020	$Mn_{15} C_4$
25	Iron carbide	0.021	Fe_2C
32	Hagg carbide	0.018	Fe_5C2
27	Cementite	0.014	Fe_3C
38	Iron silicon	0.010	$FeSi_2$

Table 4: Count Scores and Chemical Formulae of Identified Compounds present in the NF5 sample

Score	Compound Name	Scale Factor	Chemical Formula
40	Manganese Carbide	0.020	$Mn_{15} C_4$
31	Bort	0.018	C
32	Hagg carbide	0.018	$Fe_5 C_2$
34	Manganese Silicon Carbide	0.015	$Mn_{22.6} Si_{5.4} C_4$
27	Iron Carbide	0.008	$Fe_2 C$
14	Iron Carbide	0.012	Fe C
38	Iron Silicon	0.010	$Fe Si_2$
31	Manganese Carbide	0.016	$Mn C_8$

Particle size Determination

Seherrea equation has been used to obtain the particle size of phases present within the matrix of a composition. To calculate the particle size of all the phases present from the XRD test, Seherrea equation was used according to equation 6.

$$d = \frac{\lambda k}{\beta \cos\theta} \quad [6]$$

where: d= particle size diameter, λ= wavelength of the radiation = 0.154 nm, k= shape factor (0.9), β= full width half maximum, Cos θ= angle of radiation

Extracting the full width half maximum, angle of refraction from the XRD data, the Table 5 was generated.

Table 5: Computed sizes of phases present in the samples from the XRD data

FWHM	Half of FWHM (radian)	Angle of radiation (°2 Th)	Half angle of radiation (radian)	cos θ	Diameter of phases (nm)
0.2676	0.002335	21.634	0.188792	0.982232	60.42489
0.3011	0.002628	24.0539	0.20991	0.97805	53.93171
0.1673	0.00146	25.9177	0.226175	0.974531	97.41461
0.1673	0.00146	29.4988	0.257426	0.967049	98.16838
0.3011	0.002628	30.1768	0.263342	0.965525	54.63129
0.1171	0.001022	31.7441	0.27702	0.961875	141.0069
0.1171	0.001022	32.2111	0.281095	0.960752	141.1717
0.184	0.001606	32.8746	0.286885	0.95913	89.99545
0.1673	0.00146	34.0573	0.297206	0.956158	99.28647
0.3011	0.002628	36.3096	0.316861	0.950218	55.51135
0.3346	0.00292	38.362	0.334772	0.944485	50.25678
0.3011	0.002628	39.7423	0.346817	0.940459	56.08737
0.4015	0.003504	40.7776	0.355852	0.93735	42.20156
0.4015	0.003504	41.7188	0.364065	0.934457	42.33221
0.3011	0.002628	43.0884	0.376017	0.930135	56.70996
0.2676	0.002335	43.9565	0.383593	0.927326	64.00256

From Table 5, the particle size of phases present in the alloy composition range from a minimum value of 42 nm to a maximum value of 141 nm.

Wear Results

The wear behaviour of the samples under dry sliding condition at a load of 6.37 N and speed of 2.36 m/s was captured in Figure 7.

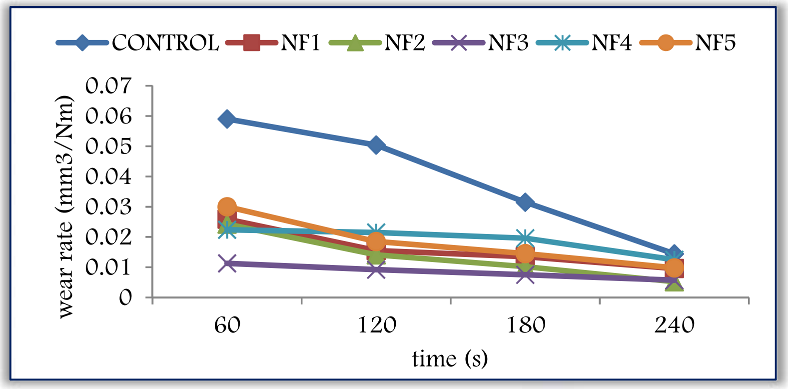

Figure 7: Wear rates of samples at 6.37 N, 2.36 m/s against increasing time

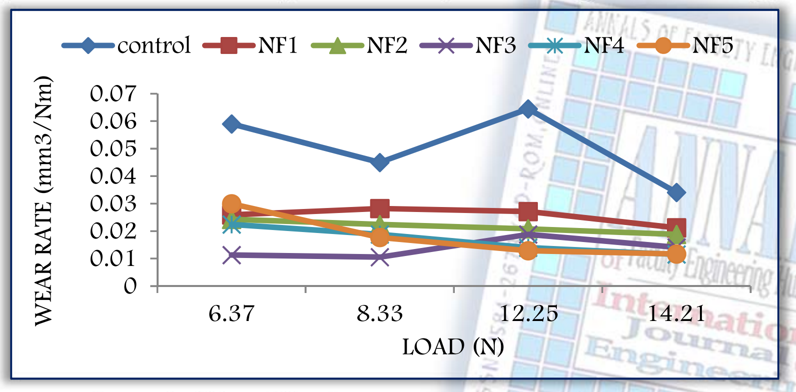

Figure 8: Effect of load on wear rate of cast iron samples

It can be seen from the figure that the control sample with no FeMn nanoparticles additions has the highest wear rate. With FeMn nanoparticles additions, the wear rate decreases until sample NF3 after which the wear rate begins to increases slightly again. However, the observed increase in wear rate for sample NF4 and NF5 is still significantly below that of the control sample. Sample NF3 represent the optimum composition and hardness value (155 HB) that will provide the best wear resistance under dry sliding condition. More so, a rapid increase in wear rate for the control occurs when compared to other samples (NF1-NF5) can also be observed. Therefore,a FeMn nanoparticles addition has a stabilizing effect on the wear behaviour of the samples. This observation to some extent may be attributed to increase interlocking of dislocation movement and work hardening propensity in grey cast iron due to the presence of manganese [6].

Figure 8 shows the effect of load on the wear pattern of the control and developed samples. Increasing load has significantly effect the wear behaviour of the developed samples.

4. CONCLUSION

FeMn nanoparticles addition to grey cast iron was found to reduce the hardness to the desired values, increase the impact energy and improve the material resistance to wear under dry sliding conditions. Also, the use of FeMn nanoparticles reduce the quantity of ferro-alloy required to achieve the desired properties compared to when FeMn microparticles was used in an earlier study.

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