WEAR BEHAVIOUR OF LOW ALLOY GREY CAST IRON (NF-GREY7): THE EFFECT OF FERROSILICON AND CARBONISED COCONUT SHELL NANOPARTICLE ADDITION

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Abstract
Effect of ferrosilicon and carbonised coconut shell nanoparticle additions on wear resistance of (NF-Grey 7) cast iron were studied. Alloys of (NF-Grey 7) cast iron were produced by a gradual increase in masses of the ferrosilicon and carbonised coconut shell nanoparticle additions using a green sand mould and stir cast technique. The behaviour of the material under shock energy impact and dry sliding wear conditions were studied. Results revealed that addition of the ferrosilicon and carbonised coconut shell nanoparticle additions to the (NG-Grey 7) cast iron enhanced the wear resistance and impact energy absorption more than what obtained in the earlier NG-Grey 7 cast iron reinforced with ferrosilicon and graphite micro particles. Hence, new alloy of cast iron for jaw crusher and other heavy equipment applications where wear resistance and energy absorption are a prime prerequisite has been developed.

Keywords: Wear; NF-Grey 7; Nanoparticle; Ferrosilicon; Carbonised coconut shell

INTRODUCTION
Grey cast irons are characterised with the presence of carbon in the form of free graphite. Production of grey cast iron required significant addition of carbon from 2 to 6.67 % by weight (Pales-Samaniego *et al*, 2008). It has found wide engineering applications because of their relative advantages such as cheapness, ease of melting and casting due to high fluidity, good machineability, high damping capacity, resistance to wear and good compressive strength (Min *et al.*, 2014). The structure of cast iron is usually affected by the rate of solidification, the presence of other elements and carbon content. Microscopically, all grey irons contain flake graphite dispersed in a silicon-iron matrix (Pales-Samaniego *et al*, 2008; Wadsley, 2001).

Annually, increase in agricultural produce to meet food requirement of rising human populations releases a huge amount of biomass agro wastes. The management of the waste from agricultural biomass is becoming a serious problem as rotten waste agricultural biomass emits methane and leachate, while open burning generates CO_2 and other local pollutants (Tangya, 2005). Biomass especially those that are by-products of agricultural activity offer the advantages of renewability and abundant supply. The term biomass is a general description of biologically produced material that readily burns or can be converted into char. Waste from biomass can be an additional source of carbon for cast iron production (Hunton, 2005; Tangya, 2005).

Whenever cost consideration is significant in the selection of a cast metal, first choice always goes to cast irons. The use of waste from biomass can be a way for tackling the environmental challenge of agro wastes, reducing the cost of production as well as improving mechanical properties of the materials developed using recycled agro waste additives (Bello *et al.,* 2015).

Biomass based carbon has been used in iron and steel making as fuel and recarburiser carbon for increasing the carbon content of liquid steel (Pales-Samaniego *et al*, 2008). It has also been used as reducing agents in metallurgical processes (Wadsley, 2001). As means of providing ways of reducing waste from biomass, reducing cost of production, and increasing productivity of local foundry in Nigeria, carbonised coconut shell (CCS) nanoparticles and ferrosilicon (FS) nanoparticles additions were used to improve the mechanical properties and wear resistance of grey cast iron scraps.

In this study, mechanical attrition method through ball milling process was employed to produce ferrosilicon (FeSi) and carbonised coconut shell nanoparticles. It is envisaged that the research will improve productivity of local foundry in Nigeria which depends mainly on the melting of cast scraps for the production of grey cast irons.

MATERIALS AND METHOD

Materials and Equipment

Grey cast iron scraps, coconut shell wastes and ferrosilicon alloy were sourced locally from Lagos state, Nigeria. A jam type ball mill at The Federal Institute of Industrial Research, Oshodi (**FIIRO**), Nigeria was used to produce the coconut shell nanoparticles whose detailed synthesis, characterisation and size determination are found in (Bello *et al.*, 2015; Bello *et al.*, 2016; Hassan *et al.*, 2015).

Method

Carbonisation and Ball Milling of Coconut Shell

Coconut shells were washed and cleaned with distilled water to remove other substances and waste in the material before they were sundried for 60 days. The clean and dried coconut shells were crushed into smaller sizes using a hammer mill and then carbonised. The carbonisation was done at a temperature of 1050˚C ± 50°C and holding time was 2 hours. The carbonisation process was carried out in a fabricated air tight steel crucible (80 x 100 x 150 mm^3) inside an electric control furnace. The carbonised coconut shells were pulverized into powders using a disc grinder after which they were intermittently ball milled for a maximum time of 90 hours in a jam type ball mill. The coconut shell nanoparticles were weighed into batches using a digital scale, with each batch having a weight of 15g.

Ball milling of ferrosilicon alloy

The FS was initially crushed with steel mortar and sieved to obtain150µm particles size. Thereafter, the micro particles FS was milled with jam type ball mill for 60hours. The ferrosilicon nanoparticles were weighed into batches using a digital scale, with each batch having a weight of 15g.

Production of Grey Cast Iron Alloy

Green sand moulding technique was employed to produce the grey cast iron. The moulding sand was prepared from a mixture of dried fresh silica sand, water, bentonite and dextrin in accordance with BS14 standard. Split rectangular wooden pattern of dimension 15.5 x 15.5 x 191 mm^3 was used to form a cavity in the moulding sand. The scraps were weighed and charged into a pit furnace of capacity 25kg. The molten grey cast iron was poured into the mould cavity at 1350 ±50°C. The first batch which represents the control sample was poured without the addition of FS and carbonised coconut shell nanoparticles. Thereafter 15g both of FS and carbonised coconut shell nanoparticles were added to the remaining melt and stirred manually with a dry wooden stick to facilitate a homogeneous bath before pouring the melt into the mould cavity. This sample was designated as NF1. This process was repeated for the remaining four samples with increasing additions of FS and carbonised coconut shell nanoparticles up to 45 g each at interval of 15 g. The castings were left to solidify and cool in the mould to room temperature (30°C) before they were knocked out. The cast bars were fettled to the required dimension (10 x 10 x 190 mm^3) and labelled accordingly. Sample representatives from each bar were cut and machined to standard samples for charpy impact, wear and Brinell hardness tests. Phase identification and morphological configuration were examined using XRD and SEM, respectively.

Table 1: Samples Designation

Name	FS	CCS
NF	-	-
NF1	15g	15g
NF2	30kg	30kg
NF3	45kg	45kg
NF4	60 kg	60 kg

Scanning Electron Microscope (SEM) was used to determine the surface morphology of the selected samples at 15 kV. The hardness of the samples was determined with a Brinell hardness tester. To determine the hardness values, the diameter of the impression was measured with Brinell reading microscope and the corresponding Brinell hardness number was obtained from the standard hardness table.

The wear test was carried out on a 200mm diameter surface with 150 µm mesh emery paper mounted on wear tester. The apparatus was used to investigate the dry sliding wear characteristics of the developed grey cast iron samples and control samples. Various wear parameters such as speed, time and load were varied during the experiment. Each sample was placed at 80mm diameter from the centre of emery paper during the test. The initial weight of the samples was measured before and after each test with a measuring electronic scale with 0.001 mg accuracy. Prior to weighing, the worn out samples were cleaned with wool soaked in acetone and wear particles on the emery paper were intermittently removed by compressed dry air blower. After running through a fixed distance, the samples were removed, cleaned with acetone, dried, and weighed to determine the weight loss due to wear. The difference in weight measured before and after tests gives the wear loss of the samples. A parameter referred to as wear rate was calculated according to Eq. 1 (Sharma *et al.*, 2016).

$$\text{Wear rate} = \frac{\text{Volume loss}}{(\text{Sliding distance x Applied load})} \tag{1}$$

Results and Discussion

Fig. 1 presents the X-ray diffractometry of the NF sample (without additions of FS and carbonised coconut shell nanoparticles). Phases present are eutectic compounds containing Fe which has been reacted with different alloying elements making the NF Grey cast iron compositions. They are mostly carbides which are hard and brittle in nature. They are responsible for high compressive strength of the NF. However, when the fillers (FS and carbonised coconut shell nanoparticles) were added, presence of new phases (see Fig. 2) such as $Fe_4Mn_{77}Si_{19}$, Fe_3Si and $C_{0.12}Fe_{0.79}Si_{0.09}$ justifies chemical interaction between phases of the fillers and NF. New compounds identified in Fig. 2 may be strong and tough and have tendency to improve the impact toughness of the alloy of NF (NF1-NF3) due to absence carbon in the compound.

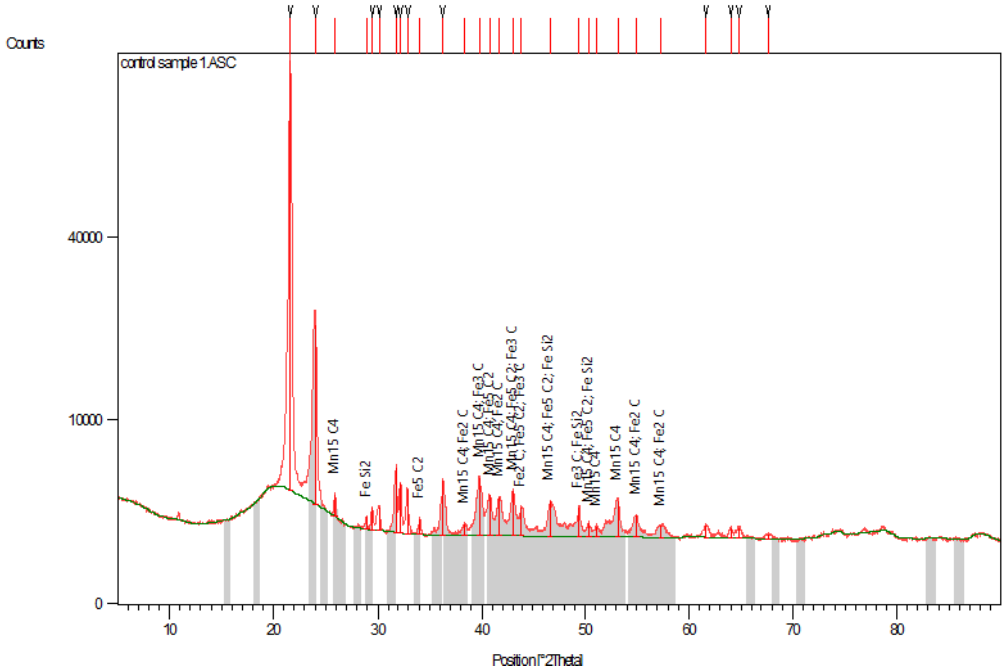

Fig. 1: XRD profiles of Nigeria Foundry Grey Cast Iron without additive (NF1)

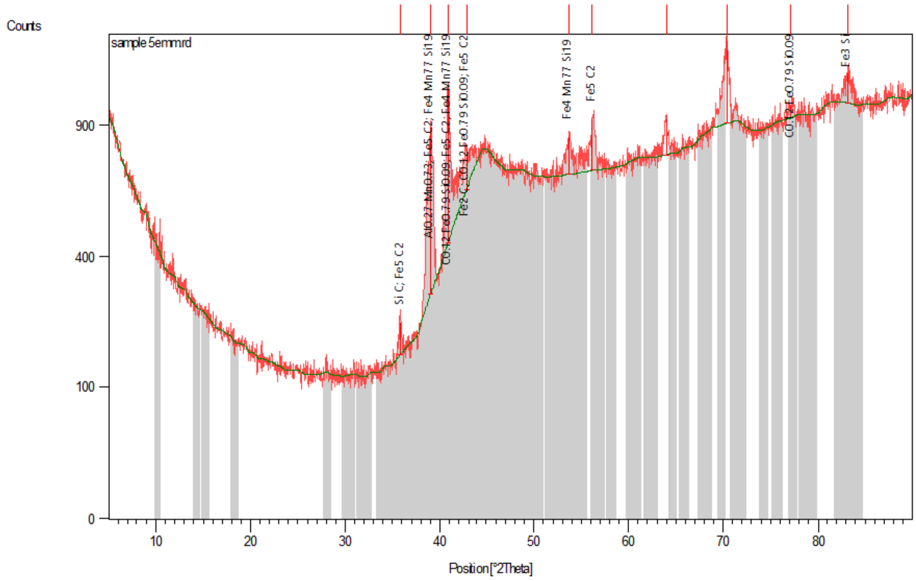

Fig. 2: XRD of Nigeria Foundry Grey Cast Iron containing 45 g coconut shell nanoparticles and 45 g ferrosilicon (NF 3)

Table 2 shows the chemical analysis results of the control sample (NF), samples NF1 and NF4. Due to oxidation during melting of the cast iron scraps, some of the carbon was oxidized. As expected, there is evidence of reduction of carbon in the developed samples. The addition of coconut shell nanoparticles compensated for this loss to achieve the desired compositions. Due to increased addition of FS nanoparticles, an increase in Si content was also observed. Carbon equivalent (CE) was calculated using Eq. 2 according to the reference (Rudnev, 2003). A decrease in CE was observed when the developed cast composition was compared with the control. Theoretically, the composition with a lower CE should possess better wear resistance properties. This assumption agrees with literature (Agunsoye *et al*, 2012).

Table 2: Chemical Compositions

SAMPLES	ELEMENTAL COMPOSITIONS (wt.%)							
	C	Si	Mn	P	S	Cu	Fe	CE
NF	3.162	1.774	0.3877	0.140	0.122	0.1437	93.89	3.80
NF1	2.832	1.908	0.3350	0.1315	0.133	0.2197	94.08	3.51
NF2	2.789	1.791	0.3976	0.179	0.137	0.15	94.16	3.33
NF3	2.777	1.788	0.3984	0.178	0.131	0.1485	94.19	3.31
NF4	2.818	1.917	0.3697	0.155	0.151	0.2088	93.52	3.39

$$CE = \%C + 0.3(\%Si) + 0.33\ (\%P) - 0.277(\%Mn) + 0.4(\%S) \qquad (2)$$

Wear Result

Fig. 3 shows the wear behaviour of the produced samples under dry sliding condition at a load of 8.36N and speed of 2.36m/s. The additions of both FS and carbonised coconut shell nanoparticles were found to improve the wear resistance of the control sample. The improvement in the resistance to wear of the samples might be attributed to the lubricating effect of the graphite flakes which was promoted by the additions of FS nanoparticles (Agunsoye *et al.*, 2012). The control sample SEM micrograph shows a cheeping off effect of worn out surface before alloying. This worn out surface is a reminiscence of a typical grey cast iron surface with high carbon content and high hardness (Fig. 4a). Compared to sample NF, the SEM micrograph of sample NF2 shows a mechanism of ductile fracture accompanied by plastic deformation (Fig.4b). The evolution of ductile fracture failure involves necking, void nucleation, void growth and linkage after which shearing at the surface takes place followed by the fracture. However, under the same applied loads, NF4 having maximum additions of FS and carbonised coconut shell nanoparticles wear more than the control sample. Beyond the threshold additions, the hardness value of NF4 sample increased (Fig. 5) and therefore has higher wear rate (6.24mm^3/Nm) than 5mm^3/Nm of the control sample. Therefore, sample NF3 represents the optimum composition with hardness value (155 HB) that will provide the best wear resistance under dry sliding condition. Also, it was observed that the wear rate of all samples decreased with increasing time. Grey cast iron has been observed to exhibit interlocking dislocation movement as well as hardening propensity. This observation therefore agrees with observation found in (Rudnev, 2003).

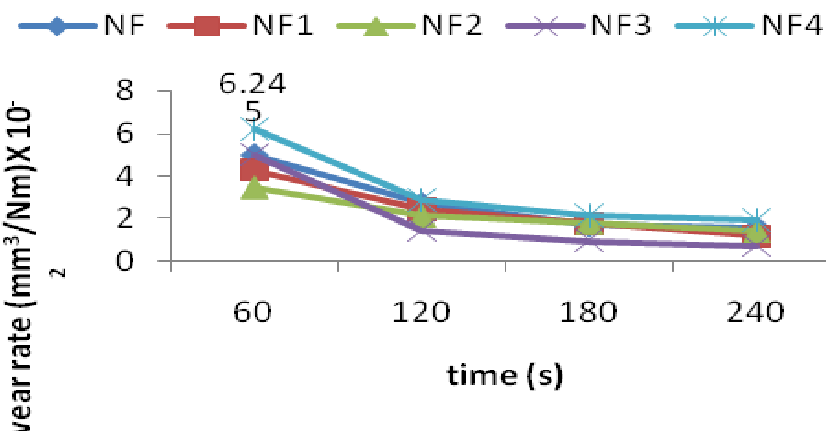

Fig. 3: Wear rate of cast iron samples with time

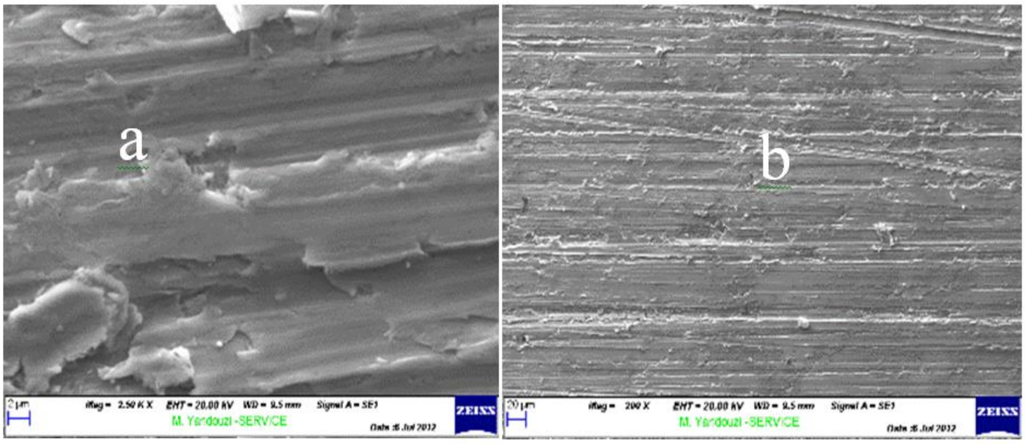

Fig. 4: SEM micrographs of worn out surface of samples: (a) NF sample (b) NF3 sample

Fig. 5 shows the wear behaviour of the grey cast iron samples under increasing load. It can be seen from the graph that the control sample wears more at 12.25 and 14.21N when compared with cast iron alloy. Sample NF2 shows a better wear resistance. Furthermore, a deteriorating effect was observed with increasing load. This behaviour is in contrast with a closely related work and may be attributed to the additions of carbonised coconut shell nanoparticles unlike in the previous work (Agunsoye *et al*, 2012).

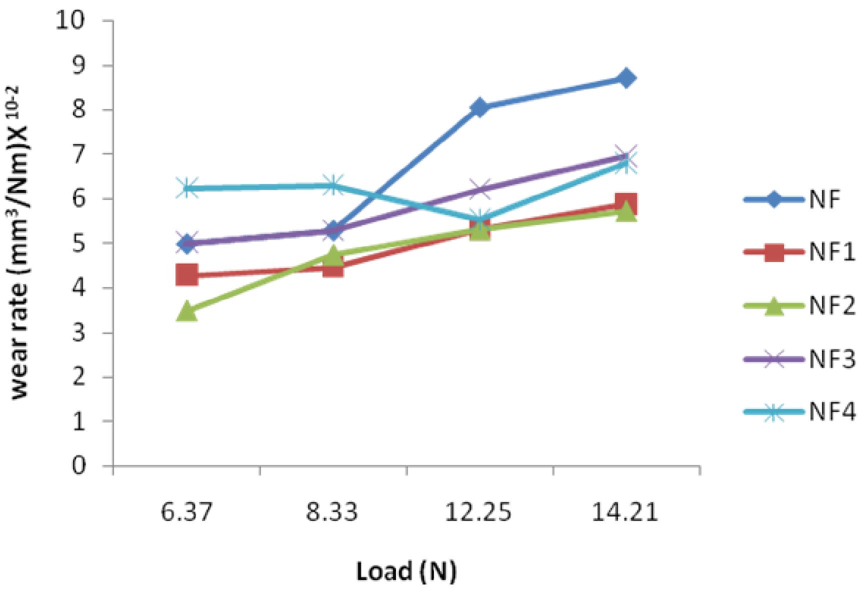

Fig. 5: Wear rate of cast irons samples with load

Impact and Hardness

Fig. 6 and 7 show the effect of additions of FS and carbonised coconut shell nanoparticles on the impact toughness and hardness of the samples, respectively. The impact energy increased until a maximum value of 5.4 J, after which it declined. NF3 shows the highest impact energy. Hardness of the alloy casts was sacrificed to improve the impact energy of the sample. The decrease in hardness can be attributed to the formation of soft graphite and tough compounds[10]. The SEM fractography of the NF3 in Fig. 8 reveals microstructure which is fibrous and having cup and cone appearance. This microstructure is typical of ductile failure. This implies that NF3 is tough unlike brittle NF. The toughness could be attributable to graphite flake and tough compounds (see Fig. 2) which enhance the energy absorbing capability of the produced alloy cast of grey iron. For application where impact energy is of importance such as in hammer and jaw crusher, NF3 composition is recommended.

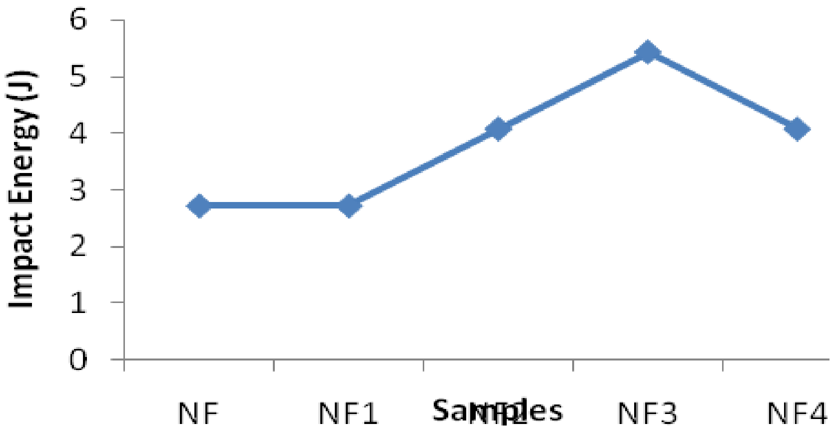

Fig. 6: Impact Energy of the different compositions of grey cast iron

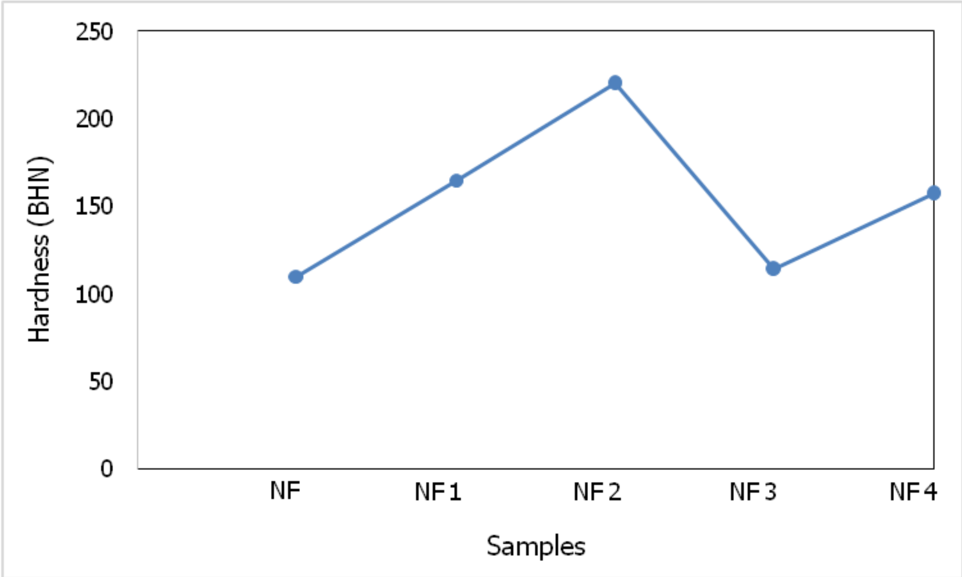

Fig. 7: Hardness of the different compositions of grey cast iron

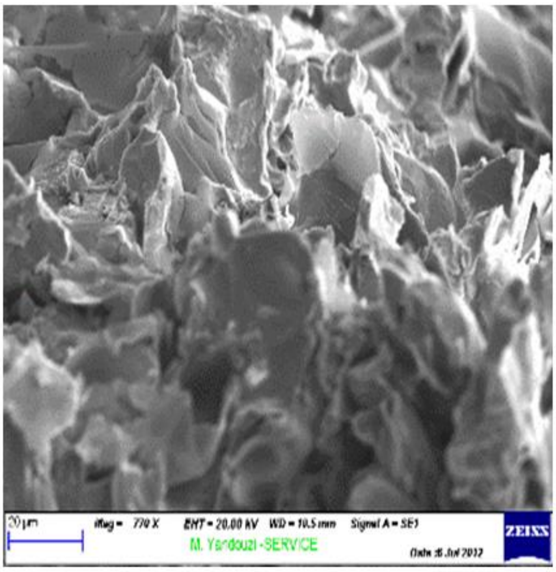

Fig. 8: SEM of the fractured surface for Nigerian Foundry cast iron containing 45 g coconut shell nanoparticles and 45 g ferrosilicon (NF 3)

Conclusion

Ferrosilicon nanoparticle additions to grey cast iron were found to reduce the hardness to the desired values, increase the impact energy and improve the material resistance to wear under dry sliding conditions. Moreover, carbonised coconut shell nanoparticles prevent expected reduction in carbon contents of the grey cast iron due to ferrosilicon addition and maintains the required carbon contents (between 2.0 and 6.67wt%) for grey cast iron production. Also, smaller amounts of ferrosilicon nanoparticles were used to achieve the desired properties compared to ferrosilicon micro particles used in the earlier study by (Agunsoye *et al*, 2012).

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References

Agunsoye J. O., Talabi S. I., Olumuyiwa I. A., Afemefuna T. O. (2013). Effect of Silicon Additions on the Wear Properties of Grey Cast Iron. Journal of Minerals and Materials Characterization and Engineering. **1**,61-67.

Agunsoye J.O., Ochulor E.F., Talabi S.I., Olatunji S. (2012). Effect of Manganese Additions and Wear Parameter on the Tribological Behaviour of NFGrey (8) Cast Iron.*Tribology in Industry*. (2012), **34** (4), 239-246.

Bello, S.A., Agunsoye, J.O., Adebisi, J.A., Kolawole, F.O., and Suleiman, B.H., (2106). Physical Properties of Coconut Shell Nanoparticles. *Kathmandu University Journal of Science, Engineering and Technology*. **12**(1), 63-79.

Bello, S.A., Agunsoye, J.O., and Hassan, S.B., (2015). Synthesis of Coconut Shell Nanoparticles Via a Top Down Approach: Assessment of Milling Duration on the Particle Sizes and Morphologies of Coconut Shell Nanoparticles. *Materials Letters*. **159**, 514-519.

Bello, S.A., Hassan, S.B., Agunsoye, J.O., Kana, M.G.Z., and Raheem I.A. (2015). Synthesis of Uncarbonised Coconut Shell Nanoparticles: Characterisation and Particle Size Determination *Tribology in Industry*. **37**(2), 257-263.

Hassan, S.B., Agunsoye, J.O., and Bello, S.A., (2015). Characterization of Coconut Shell Nanoparticles Using Electron Microscopes. *Proceedings of 10th UNILAG Annual Research Conference and Fair*. **2-3**, 221-225.

Hunton, P. (2005). Research on Eggshell Structure and Quality: An Historical Overview. *Brazilian Journal of Poultry Science, **7***(2),67-71.

Min, J. B., Ghosn, L. J., and Lerch, B. A. (2014). A study for stainless steel fan blade design with metal foam core. *Journal of Sandwich Structures and Materials, **17***(1), 56-73. doi: 10.1177/1099636214554181

Pelaez-Samaniego, M., Garcia-Perez, M., Cortez, L., Rosillo-Calle F. and Mesa, J. (2008) Renew. Sust. Energ. Rev., **12**, 1063-1075.

Rudnev V. (2003). *Handbook of Induction heating*, CRC Press.

Sharma, P., Khanduja, D., and Sharma, S. (2016). Dry sliding wear investigation of Al6082/Gr metal matrix composites by response surface methodology. *Journal of Materials Research and Technology*, ***5***(1),29-36. doi: 10.1016/j.jmrt.2015.05.001

Tangya, H. (2005). 10 Years of Recycling: The Good, The Bad and The Ugly.

Wadsley (2003). Proc. of Int. Symp. on Greenhouse gases in the Metallurgical Industries: Policies, Abatement and Treatment, Met. Soc. CIM, Montreal.