Comparative Analysis of the Mechanical Properties of Cast Irons Produced from *Erythrophleum Suaveolens* Charcoal and a blend of Okaba Coal with E.s charcoal

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Abstract

Cast iron scraps sourced from car engine blocks were melted in an erythrophleum suaveolens cupola furnace. The experiment was firstly conducted by melting a predetermined quantity of metal (17 kg) with 3 kg of Es charcoal per charge on one hand while on the other hand, mixture of Ok/Es (2.5 kg of Okaba coal + 0.5 kg of Es charcoal) was burnt as fuel with the same quantity of metal maintained. Both processes were accompanied with 1 kg of limestone per charge. After casting, strips of metal sample 16 mm diameter and length of 130 mm were cut from Es and Ok/Es ingots. The strips were subjected to tensile test, yield stress, maximum stress and percentage elongation, Brinell hardness tests and impact tests. The values of the ultimate strength were given as 447.87, 447.87 and 439.0 N/mm^2 for Ok/Es, cast iron of grade 65-45-12 (D65-45-12) and Es products respectively, the yield stress for Ok/Es, D65-45-12 and Es samples were 314.81, 310.05 and 309.64 N/mm^2 respectively, the hardness (BNH) values of 223.9 and 219.5 were obtained for Ok/Es and Es samples respectively, the impact strength values of Ok/Es and Es samples as 24 J and 21 J respectively. The values of percentage elongation of the samples were 15.4, 12 and 15 respectively for Ok/Es, D65-45-12 and Es products. Ok/Es and Es products have CE values of 4.12 and 3.91 respectively, showing that they are hypoeutectic gray cast irons with the CE value less than 4.3. The microstructure shows that the samples of Es and Ok/Es are of higher strength because of the amount and size of their graphite flakes that decreased with the CE value. It was concluded that Es charcoal and a blend of it with Okaba coal could serve as quality alternative fuel to coke in iron melting industries.

1.0 Introduction

Cast iron is made by re-melting pig iron in cupola furnace, often along with substantial quantities of scrap iron, scrap steel, lime stone, carbon (coke) and taking various steps to remove undesirable contaminants. Phosphorus and sulfur may be burnt out of the molten iron, but this also burns out the carbon, which must be replaced. Depending on the application, carbon and silicon content are adjusted to the desired levels, which may be anywhere from 2 to 3.5 % and 1 to 3 % respectively. Other elements are then added to the melt before the final form is produced by casting (Donald, 1993). After melting is complete, the molten iron is poured into a holding furnace or ladle.

Gray cast iron is characterized by its graphitic microstructure, which causes fractures of the material to have a grey appearance. It is the most commonly used cast iron and the most widely used cast material based on weight. Most cast irons have a chemical composition of 2.5 to 4.0 % carbon, 1 to 3 % silicon, and the remainder is iron. Gray cast iron has less tensile strength and shock resistance than steel, but its compressive strength is comparable to low and medium carbon steel (Gillespie, 1988).

White cast iron is the iron that displays white fractured surface due to the presence of cementite. With a lower silicon content and faster cooling, the carbon in white cast iron precipitates out of the melt as the metastable phase cementite, Fe_3C, rather than graphite. The cementite which precipitates from the melt forms as relatively large particles, usually in a eutectic mixture, where the other phase is austenite (which on cooling might transform to martensite). These eutectic carbides are much too large to provide precipitation hardening (as in some steels, where cementite precipitates might inhibit plastic deformation by impeding the movement of dislocations through the ferrite matrix). Rather, they increase the bulk hardness of the cast iron simply by virtue of their own very high hardness and their substantial volume fraction, such that the bulk hardness can be approximated by a rule of mixtures. In any case, they offer hardness at the expense of toughness. Since carbide makes up a large fraction of the material, white cast iron could reasonably be classified as a cermet. White iron is too brittle for use in many structural components, but with good hardness and abrasion resistance and relatively low cost, it finds use in such applications as the wear surfaces (impeller and volute) of slurry pumps, shell liners and lifter bars in ball mills and autogenous grinding mills, balls and rings in coal pulverisers, and the teeth of a backhoe's digging bucket (although cast medium-carbon martensitic steel is more common for this application).

It is difficult to cool thick castings fast enough to solidify the melt as white cast iron all the way through. However, rapid cooling can be used to solidify a shell of white cast iron, after which the remainder cools more slowly to form a core of grey cast iron. The resulting casting, called a chilled casting, has the benefits of a hard surface and a somewhat tougher interior.

High-chromium white iron alloys allow massive castings (for example, a 10-tons impeller) to be sand cast, that is a high cooling rate is not required, as well as providing impressive abrasion resistance (Donald, 1993).

Malleable iron starts as a white iron casting that is then heat treated at about 900 °C (1,650 °F). Graphite separates out much more slowly in this case, so that surface tension has time to form it into spheroidal particles rather than flakes. Due to their lower aspect ratio, spheroids are relatively short and far from one another, and have a lower cross section vis-a-vis a propagating crack or phonon. They also have blunt boundaries, as opposed to flakes, which alleviates the stress concentration problems faced by grey cast iron. In general, the properties of malleable cast iron are more like mild steel. There is a limit to how large a part can be cast in malleable iron, since it is made from white cast iron (Donald, 1993).

A more recent development is nodular or ductile cast iron. Tiny amounts of magnesium or cerium added to these alloys slow down the growth of graphite precipitates by bonding to the edges of the graphite planes. Along with careful control of other elements and timing, this allows the carbon to separate as spheroidal particles as the material solidifies. The properties are similar to malleable iron, but parts can be cast with larger sections (Donald, 1993).

The use of cast irons ranges from the production of bearing surfaces, axle bearings, track wheels, automotive crankshafts gears, camshafts, crankshafts and lot more.

In this work rather than using the traditional cupola fuel (coke) in melting the scrap irons, erythrophleum suaveaolens charcoal (Es) and a blend of it with Okaba coal (Ok/Es) were used.

On the list of highly profitable and easy to find exportable products is charcoal. Apart from heating purposes, charcoal is being used for water purification (Ajaero, 2015). Charcoal is one of the main sources of domestic energy in Cote d'Ivoire. The overall share of charcoal use in the total national fuel consumption stood at 20% in 2002 and as at 2012 it was a choice fuel for 52% of the urban population (UNDP, 2015). Nigeria has lost over N1 billion (U$6M) to illegal export of charcoal and logs from states in the South West and North Central to the Middle East and Europe in the last four years (Alex, 2012). Erythrophleum suaveaolens charcoal was reported to be a good fuel for iron melting (Olorunnishola and Akintunde, 2013). Okeyo (2006) also established that though *Erythrophleum Suaveolens* wood is not highly valued as firewood but charcoal made from it is excellent.

A total of 100 million tonnes of demonstrated coal have been estimated to underlie 2,770 hectares in the Okaba area and an additional 435 million tonnes of non-reportable coal resource are projected to the west of existing drilling. In total, Kogi State is estimated to have a demonstrated coal resource of 223 million tonnes averaging 3.6 m thick, which underlies 8,900 hectares (4%) of the State (Mining Cadastre, 2012).

Therefore, mechanical properties of the products of this work (Es and Ok/Es ingots) were compared with D65-45-12 grade of cast iron, being a grade with a closely related properties.

2.0 DETERMINATION OF MECHANICAL PROPERTIES AND CHEMICAL COMPOSITION OF ES AND OK/ES INGOTS

For the casting of Es and Ok/Es ingots, cast iron scraps were sourced from car engine blocks. In the experimentation, firstly, a predetermined quantity of metal (17 kg) was melted with 3 kg of Es charcoal per charge. Each charge was accompanied with 1 kg of limestone in order to separate the slag from the molten iron. Also 1 kg of ferrosilicon was introduced to the charge at an interval before the iron was tapped in order to improve the machinability of the cast iron.

Secondly, the experiment was repeated with the mixture of Ok/Es (2.5 kg of Okaba coal + 0.5 kg of Es charcoal) burnt as fuel while following the same procedure as in the first experiment. The cupola furnace used was an erythrophleum suaveolens charcoal-fired cupola fuenace developed by Olorunnihola and Anjorin (2015).

After casting, strips of metal sample 16 mm diameter and length of 130 mm were cut from Es and Ok/Es ingots. The strips were subjected to tensile test using Tensile Machine Pressure (40.38) and the results (yield stress, maximum stress and percentage elongation) were presented in Table 1. Other samples cut from Es and Ok/Es ingots were subjected to Brinell hardness tests and impact tests using computerized Universal Testing machine (UTS) made by Testometric Co.Ltd. Rochdale, England while the impact energy was determined with Charpy V-notch machine. The results were also presented in Table 1. Mechanical properties of D65-45-12 grade of cast iron as reported by Day counter (2004) are also presented in Table 1. The optical microstructure of the products sample was viewed under metallurgical microscope (Accuscope microscope with camera (serial no 0524011, maker: Princeton, USA) with magnification 40 x 16 and presented in plate 1.

Plate 1: Metallurgical Microscope with Camera

Table 1: Mechanical properties of cast irons produced from Es charcoal and Ok/Es

S/N	**Types of product**	**Types of iron**	**Diameter (mm)**	**Length (mm)**	**Area (mm^2)**	**Yield stress (N/mm^2)**	**Tensile strength Max. (N/mm^2)**	**% Elongation**	**Hardness (Brinell scale)**	**Impact tests (Joules)**	**Strain**	**Tested centre pointed**
1	Ok/Es product	Gray iron (as cast)	16	130	78.57	314.81	447.87	15.4	223.9	24	0.69	223.90
2	Es product	Gray iron (as cast)	16	130	62.35	309.64	439.0	15	219.5	21	0.61	219.5
3	*D65-45-12	Ductile cast iron				310.05	447.87	12				

Results of present research and *Day counter (2004)

3.0 Discussion of mechanical Properties of Cast Irons Produced from *Erythrophleum Suaveolens* Charcoal and Okaba Coal

From Table 1 and Figure 1, the as cast metal samples exhibited insignificant variability in ultimate strength with the values of 447.87, 447.87 and 439.0 N/mm^2 for Ok/Es, cast iron of grade 65-45-12 (D65-45-12) and Es products respectively. The yield stress for Ok/Es, D65-45-12 and Es samples were 314.81, 310.05 and 309.64 N/mm^2 respectively. Figure 2 shows that the variability in yield stress of Ok/Es, D65-45-12 and Es products was insignificant. The hardness (BNH) values of 223.9 and 219.5 were obtained for Ok/Es and Es samples respectively. Table 1 also gave the determined values of the impact strength of Ok/Es and Es samples as 24 J and 21 J respectively. The variation in the impact strength of the samples as shown in Table 1 was insignificant. The values of percentage elongation of the samples were 15.4, 12 and 15 respectively for Ok/Es, D65-45-12 and Es products. Figure 3 showed that there was no significant difference between the elongation of Ok/Es and Es samples and when both were compared with D65-45-12 the difference was significant. The higher percentage of carbon content of Es against the other samples could be responsible for the significant difference. The stress-strain values shown in Table 1 indicate a relatively long range of plasticity behavior of the Ok/Es and Es samples.

According to Day counter, Inc. Engineering services (2004), ductile cast iron of grade 65-45-12 (i.e. 447.85 N/mm^2 tensile strength, 310.05 N/mm^2 yield strength and 12 % elongation) is most widely used for normal service, machinery castings subject to shock and fatigue loading. The tensile strength, yield strength and percentage elongation of Ok/Es and Es products as presented in Table 1 compete favourably with 65-45-12 grade of cast iron. Moreover, the percentage elongation of Ok/Es and Es samples was higher than 65-45-12 grade of ductile iron. The samples were compared with the cast iron of grade 65-45-12 because of their close ranges of tensile and yield strengths.

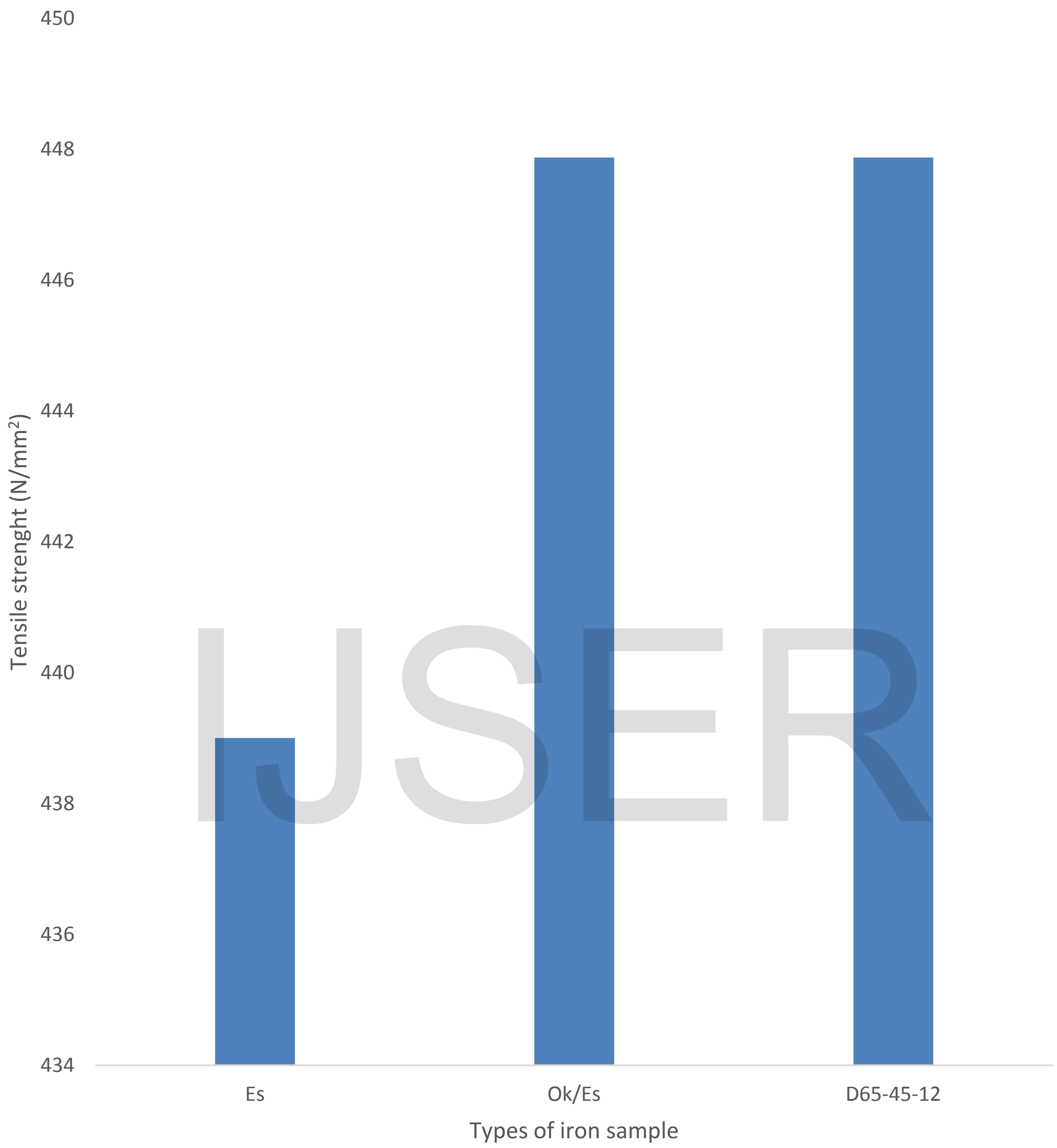


Figure 1: Variation of tensile strength of iron samples

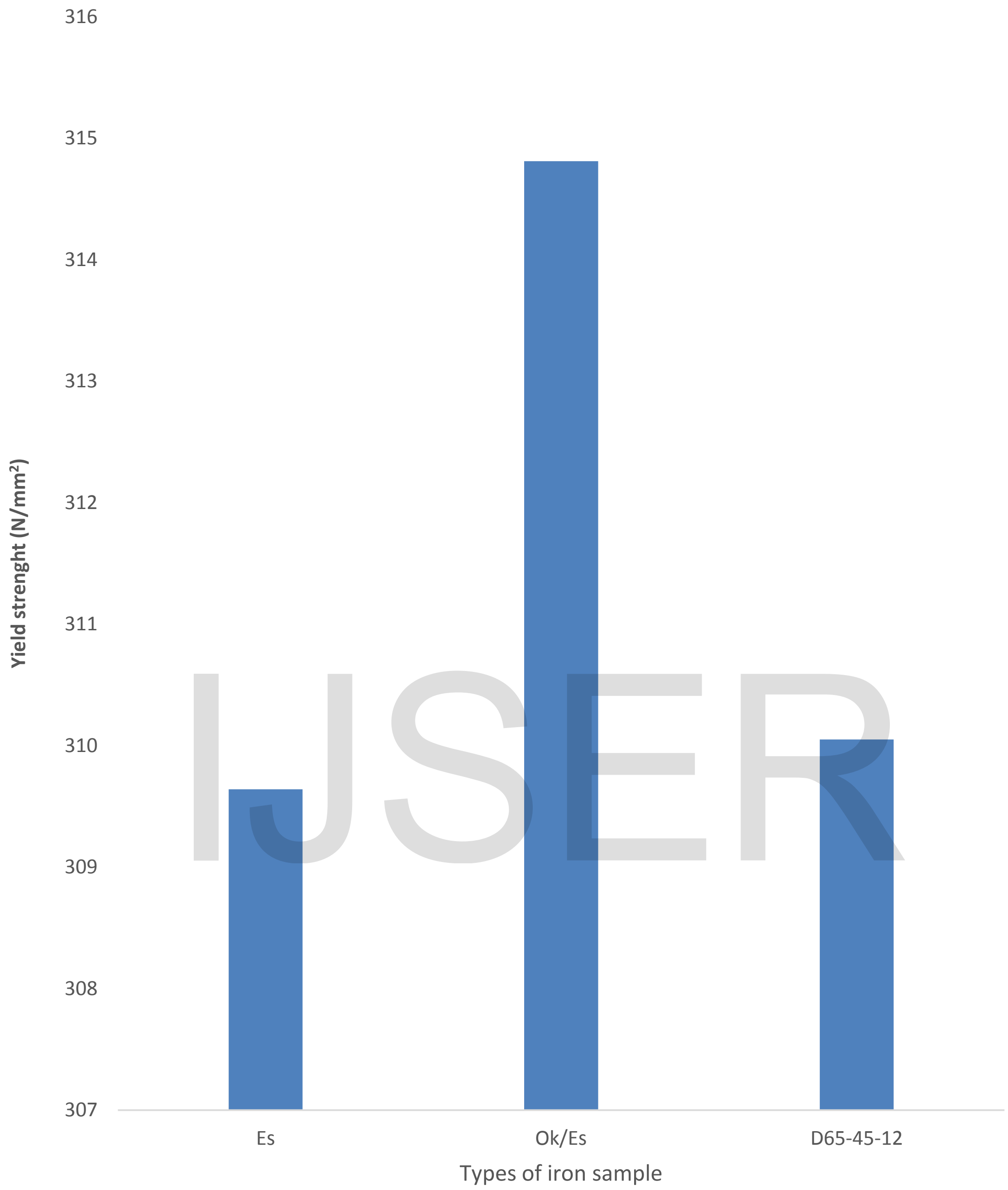


Figure 2: Variation of yield strength of iron samples

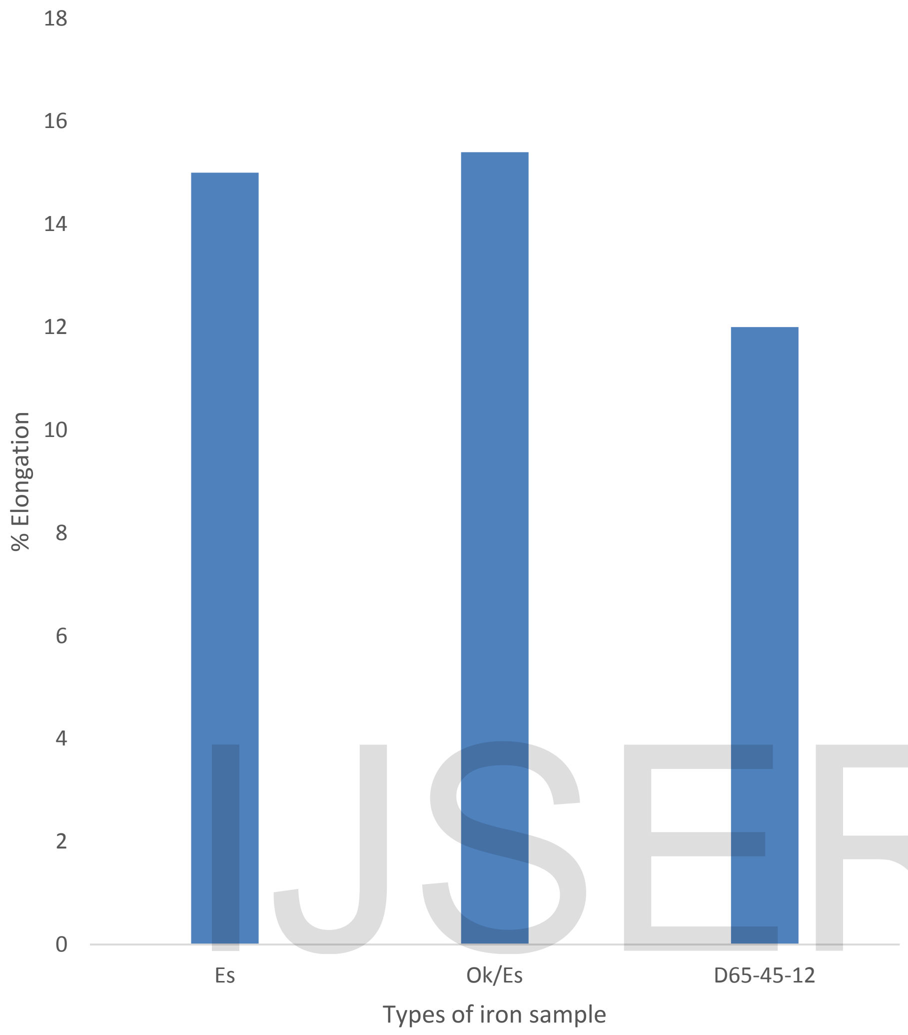


Figure 3: Variation of % elongation of iron samples

3.1 Chemical Composition of Cast Samples and Discussion

The tensile strength of gray cast is influenced by both the normal elements present in plain irons such as carbon, silicon, phosphorus, sulphur and manganese, and the presence of alloying additions and trace elements. Carbon and silicon are very important elements and are combined, usually with phosphorus, in a carbon equivalent expression.

Irons with a carbon equivalent of more than 4.3 are hypereutectic and usually contain coarse graphite. They are of lower strength, but are excellent in thermal shock applications and for vibration damping (Mid-Atlantic, 2015). Gray irons with less than 4.3 carbon equivalent as shown in Tables 2 and 3 are hypoeutectic and of higher strength because the amount and size of the graphite flakes decrease with the CE value as shown in plates II and III.

Table 2: Chemical composition of Es charcoal cast iron sample

	C %	Si %	Mn %	P %	S %	Cr %	Ni %	Mo %	Al %
Mean	3.27	1.75	0.64	0.156	0.145	0.139	0.047	0.0085	0.0023
	Cu %	**Co %**	**Ti %**	**Nb %**	**V %**	**W %**	**Pb %**	**Mg %**	**B %**
Mean	0.161	0.012	0.019	<0.0025	0.011	<0.010	0.0076	0.0022	<0.0005
	Sn %	**Zn %**	**As %**	**Bi %**	**Ce %**	**Zr %**	**La %**	**Fe %**	**CE**
mean	0.012	0.0077	0.011	<0.0015	0.0035	<0.0015	0.0023	93.6	3.91

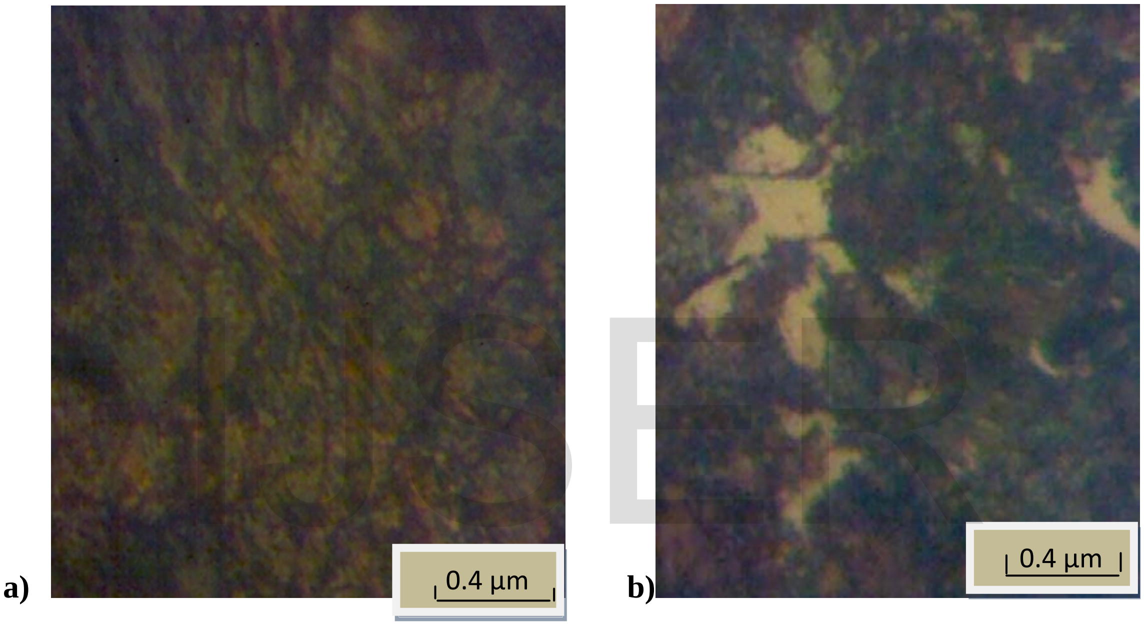
Results of present research

Table 3: Chemical composition of sample of Ok/Es cast iron sample

	C %	Si %	Mn %	P %	S %	Cr %	Ni %	Mo %	Al %
Mean	3.48	1.74	0.64	0.167	0.144	0.141	0.049	0.0092	0.0074
	Cu %	**Co %**	**Ti %**	**Nb %**	**V %**	**W %**	**Pb %**	**Mg %**	**B %**
Mean	0.201	0.011	0.022	<0.0025	0.012	0.038	0.012	0.0034	<0.0005
	Sn %	**Zn %**	**As %**	**Bi %**	**Ce %**	**Zr %**	**La %**	**Fe %**	**CE**
mean	0.012	0.0011	0.014	0.0022	0.0031	<0.0015	0.0043	93.3	4.12

Results of present research

The effect of higher carbon equivalent is to reduce strength because of the formulation of larger amounts of coarse graphite and, commonly more ferrite. Manganese, sulphur and phosphorus are present in plain gray irons and influence the tensile strength to some extent. Sulphur is a very significant element because it exerts marked effects on the solidification behavior of iron. For this reason, the sulphur content in iron is usually controlled within limits and with a selected ratio to the manganese content since sulphur combines chemically with manganese to form manganese sulphide. An excess of manganese or phosphorus can cause dispersed internal porosity in heavier sections such as bosses. For this reason, phosphorus is kept as low as practical except for special purpose irons. Increasing phosphorus provides a somewhat higher strength, but contents over 0.20 % reduce machinability particularly in drilling operations (Mid-Atlantic, 2015).



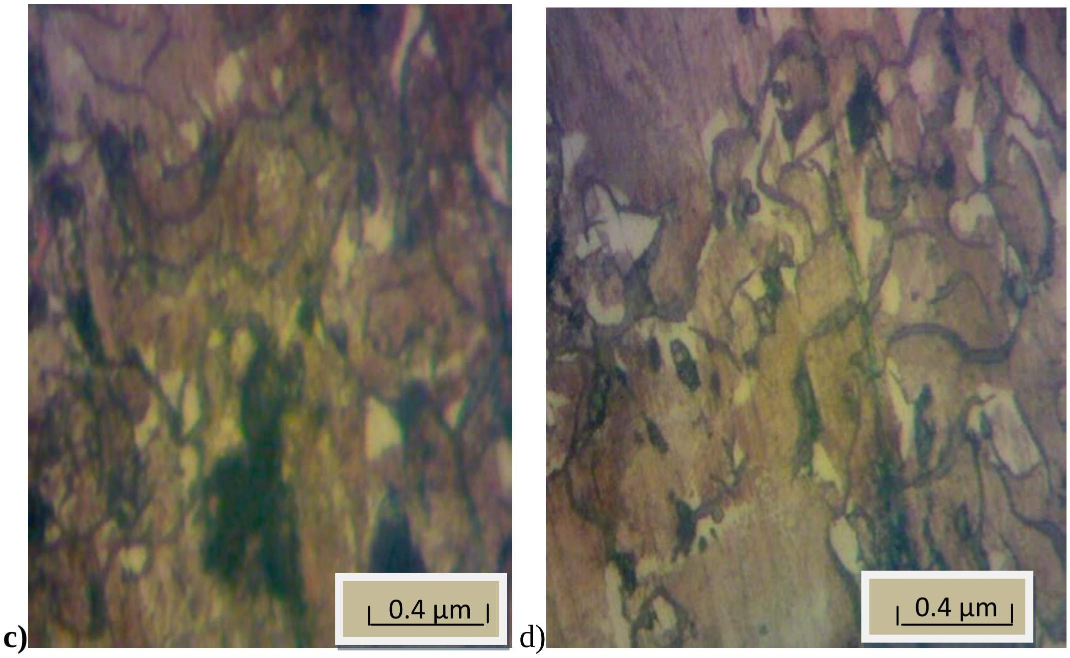
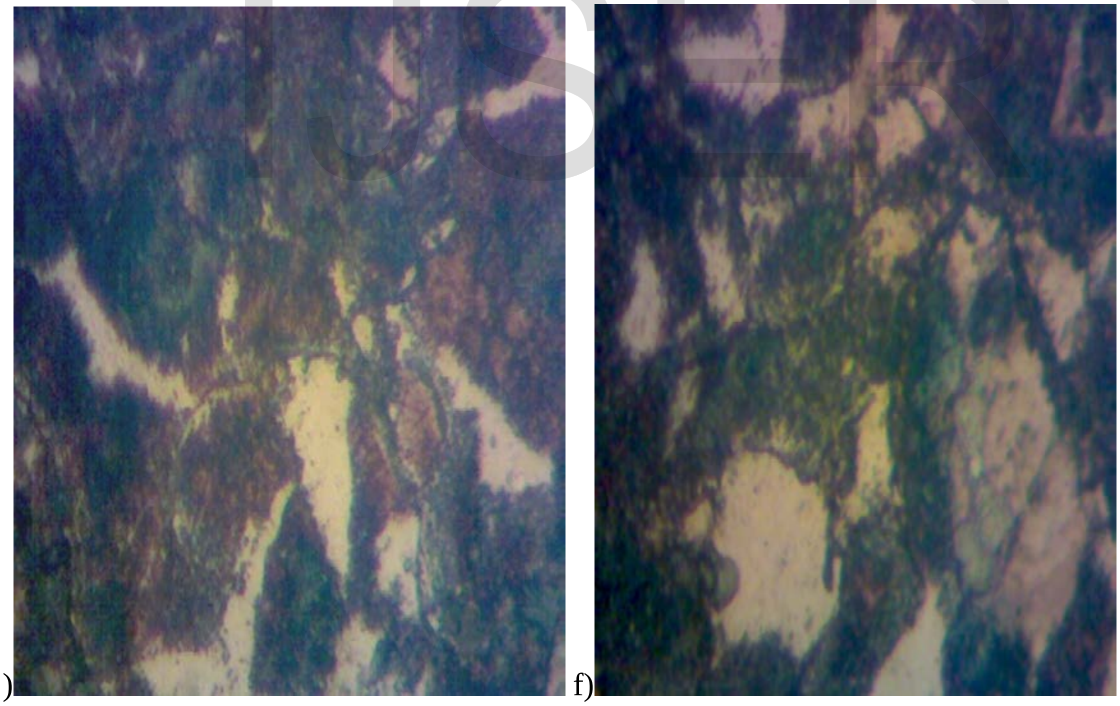


Plate II. Optical microstructure of Es product sample



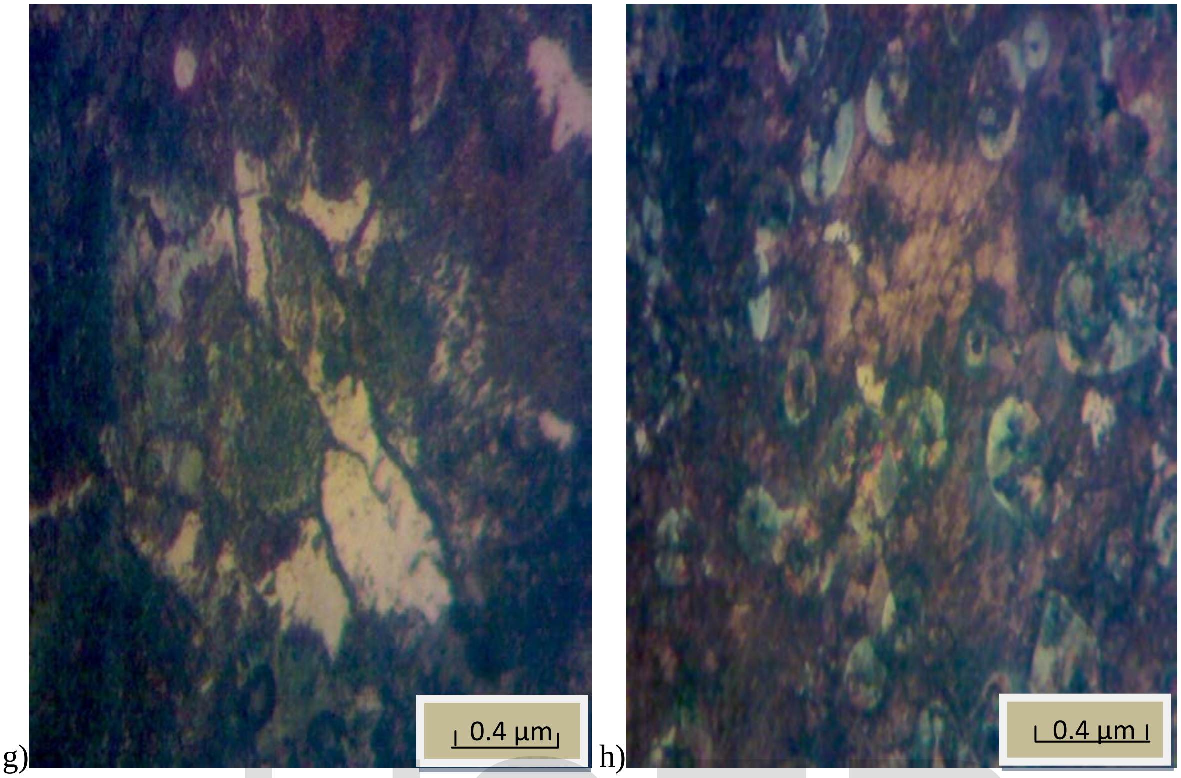


Plate III. Optical microstructure of Ok/Es product sample.

4.0 Conclusion

The tensile strength, yield strength and percentage elongation of Ok/Es and Es products compete favourably with 65-45-12 grade of cast iron. Moreover, the percentage elongation of Ok/Es and Es samples was higher than 65-45-12 grade of ductile iron.

The higher percentage of carbon content of Es against the other samples of fuel could be responsible for the significant difference.

Ok/Es and Es products are gray irons with less than 4.3 carbon equivalent wish shows that they are hypoeutectic and of higher strength because the amount and size of their graphite flakes decrease with the CE value. The conclusion could therefore be summarized as follows:

I. Mechanical properties of iron produced with *Erythrophleum Suaveolens* charcoal could compete favourably with that of mixed Ok/Es aand conventional fuel (coke).

II. Samples of cast iron produced with *Erythrophleum Suaveolens* charcoal and mixed Ok with Es could be classified as gray cast iron with high range of plasticity.

From the results, it could therefore be concluded that Es charcoal and a blend of it with Okaba coal could serve as quality alternative fuel to coke in iron melting industries.

References

Ajaero, T.M (2015). How to Make Money from Exporting Activated Charcoal. www.mytop business ideas.com. Retrieved 16th of August, 2015.

Alex, A., (2012). Nigeria's Federal Government loses N1 billion to illegal charcoal, wood export. http://allafrica.com/stories. Retrieved 2012-11-20

Daycounter, Inc. Engineering services (2004). Physical and Magnetic Properties of Ductile Iron. Retrieved from: http://www.daycounter.com/

Donald B. Wagner (1993). Iron and steel in ancient China. BRILL, pp. 335–340

Gillespie, L.K. (1988). Troubleshooting manufacturing processes. 4th edition, SME, pp. 4-4

Mid-Atlantic Casting Services (2015). Mechanical Properties of Gray Iron. Retrieved November 2nd, 2015; from: **www.Mid-AtlanticCasting.com**

Mining Cadastre (2012). Coal Deposit in Nigeria; Retrieved July 7th, 2013 from: http://www. howwemadeitinafrica.com

Okeyo, J.M., (2006). Erythrophleum suaveolens (Guill. & Perr.) Brenan. In: Schmelzer, G.H.& GuribFakim, A. (Editors). Prota **11,** Vol.1: Medicinal plants/Plantes medicinal es 1. [CD Rom].PROTA, Wageningen, Netherlands.

Olorunnishola, A.A.G and Akintunde, M.A (2013). Characterizing *Erythrophleum Suaveolens* Charcoal as a Viable Alternative Fuel to Coke in Iron Melting In Nigeria. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 10, Issue 3 (Nov.- Dec. 2013), PP 06-11.

Olorunnishola, A.A.G. and Anjorin, S.A. (2015). Design, Construction and Testing of an Erythrophleum Suaveolens Charcoal-fired Cupola Furnace for Foundry Industries in Nigeria, Scientia Agriculturae, vol. 12, no. 1, pp. 1-12.

UNDP (2015). NAMA Study for a Sustainable Charcoal Value Chain in Cote d'Ivoire. www.mdgcarbon.org. Retrieved 16th of August, 2015.