Recycling Of Ferrous Metal Scrap for Production of Automobile Brake Drum in Nigeria

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Abstract- The work presented in this paper focused on the recycling of ferrous scrap metal and its utilization in the production of automobile brake drum. Cast iron scrap and steel scrap from old automobiles were selected as a case study with addition of graphite to improve the percentage of carbon and Ferro-silicon for inoculation. Brake drum and test bars were casted employing Electric Arc Furnace (EAF) and green sand-casting method. Micro-structural property of the recycled product was determined using metallurgical microscope with 200x magnification while chemical composition was determined using Optical Electron Spectrometer (OES). The photo-micrograph of the cast brake drum showed that a gray cast iron microstructure was obtained while the OES analysis showed an average composition of elements as: Fe 94.61 %, C 3.12 %, Si 1.38 %, Mn 0.475 %, S 0.003 %, P 0.008 %, and Cr 0.113 % along with trace amount of some other twelve elements which meets the minimum standard for Brake Drum application designated by Society of Automotive Engineering (SAE). Results from mechanical tests showed that Maximum Tensile strength of the of the material was 81.45317 MPa when the load was gradually applied within 7.788 sec to fracture, Hardness strength 97.73 HRB/228 HB, while Impact strength 2 J. The cast iron produced can be modified for use in other applications such as automobile engine blocks, discs, etc.

Indexed Terms- Automobile Brake Drum, Electric Arc Furnace, Ferrous Scrap, Mechanical properties, Melting, Optical Electron photo-micrograph, Spectrometer, Sand Casting, Recycling

I. INTRODUCTION

Production of metals from ores involves high energy demand in addition to high risk and consequent negative impact of minerals exploration activities to the environments [1]. Alternative to conventional ways of metal production could be sought in utilization of abandoned metal scraps that when left unattended to, poses environmental challenges with regards to quality of water, soil and air pollution [2] and [3]. Recycling of metal scraps now becomes necessary not only as alternative to metal production methods but for environmental safety as recycling of steel for instance has been found to save energy and material with consequential reduction in greenhouse gas emissions [4]. [1] Reported that recovery of 1 metric tonne of steel from scraps conserves an estimated 1,030kg of iron ore, 580kg of coal and 50kg of limestone. United States Environmental Protection Agency (US EPA) reported that for every tonne of steel produced from scrap steel saves 1,115kg of iron ore, 625kg of coal and 53kg of limestone. Generally, recycling of metals saves 75% of energy, 90% raw materials, reduces air pollution by 86%, water use by 40%, water pollution by 76% and mining wastes by 97% [3]. Generally, recycling of metals has been gaining wide acceptability globally since the last two decades [5] and [6].

Modern automobile typically is made up of thousands component parts, all of which could be very difficult or impossible to be produced all in-house even by the largest manufacturers. This make automobile manufacturing an integrated industry requiring many supporting industries for the production of a great diversity of materials and components it uses [7]. The brake drum is one of such very important components in an automobile used for slowing or stopping the motion of a wheel while it runs at a certain speed using friction caused by a set of shoes that press outward against the inner surface of a rotating drum connected to the rotating wheel. The frictional force applied to the drum is usually converted to kinetic energy and subsequently to heat energy which is then transferred to the atmosphere [8] and [9]. According to [10], for effectiveness, brake drums must possess some desired properties which include high strength and durability to sustain torque loads from braking, stable mechanical and high wear resistance properties through range of expected service temperatures, high heat absorption capability to absorb braking energy, high thermal conductivity to transport the heat generated away from braking surfaces, high vibration damping capacity, minimal thermal expansion to minimize performance variability, high degree of corrosion resistance, excellent machinability and inexpensive material and processing costs. The most important parameters to achieving these properties in brake drums are the design procedures and materials of brake drums [9].

Cast iron and its alloys are the major engineering materials generally used for automotive brake rotors because of their characteristic color, considerable cost, relative ease of manufacture and thermal stability. In addition, they typically have low ductility and moderate strength, high thermal conductivity and excellent vibration damping properties [8]. These materials are mostly sourced directly from Ores with attendant high cost, risks to human and environments. Recycling ferrous scraps for the purpose of producing automobile components has high benefits and is in the right direction especially in places like Nigeria with high deposit of metallic scraps [11]. Additionally, the production of these cast irons using recycled metal scrap has proved to be encouraging as Nigeria has not been able to meet the growing increase of the annual per capita consumption of steel estimated as ranging from 5 kg in 1968 [12] to 130 kg in 2012 [13] and [14] from ores despite the abundant iron ore, coal and limestone reserves in the country. However, care must be taken while using recycling as alternative method of production as ferrous metals appear to be more unpredictable because scraps are mixed with tolerable quantities of unwanted metals due to the high cost of efficiently separating all metal elements in collections of steel scrap [15]. Also, caution should be applied in terms of mechanical properties of the products from scraps as such properties are defined solely by their carbon content, other alloying composition, and the method of processing. According to [16], the control of processing parameters such as alloy composition (Silicon and Carbon contents) affects the quantity and morphology of the carbides formed which are strictly responsible for mechanical behavior whilst shakeout time affects the size of the carbide (microstructure). The correct ranges of hardness, chemical composition, tensile strength, and other properties that are necessary for the manufacture of gray cast iron for normal car and light truck applications maintained by the Society of Automotive Engineering (SAE) is J431 G3000 (superseded to G10) as shown in Table I.

This work focused on the production of automobile brake drum by recycling ferrous scraps to produce gray cast iron that meets the specification and standards for automobile brake drum in Nigerian automobile industry.

II. MATERIALS, EQUIPMENT AND METHOD

In this research, the following materials, equipment and methods were used as adopted by international standards.

2.1 Materials

Materials used in this research for the casting of automobile brake drums include cast iron scrap from old automobile parts mainly the engine blocks which were selected due to their wide variety of chemical composition, steel scrap mainly from automobile body, graphite, and ferro-alloys which when blended yields the specification desired for the casting. The process of the materials selection involved collection, sorting, preliminary chemical analysis, and charge calculations.

2.2 Equipment

The following equipment were used according to standard specifications of respective areas:

- i Electric Arc Furnace, 500 kg capacity with provision for temperature measurement using a pyrometer.
- ii Lathe machine, drilling machine, cutting machine, and grinding machine.
- iii Universal strength testing machine; Instron computer controlled table top machine (Wintech software).
- iv Rockwell Hardness Tester (4150 AK Rockwell Hardness Tester) with serial No. 134710.

Table I: Gray cast iron classifications and their mechanical properties

Casting J431 Current	Grade SAE Previous	Class per ASTM A48M	Typical Carbon Content %	Theoretical Minimum Tensile Strength (MPa)	Typical Brinnel Hardness Range (BHN)
G7	G1800	20	3.50 – 3.70	124	163 - 223
G9	G2500	25	3.45 – 3.65	170	170 - 229
G10	G3000	30	3.35 – 3.60	198	187 - 241
G11	G3500	35	3.30 – 3.55	217	207 - 255
G12	G4000	40	3.25 – 3.50	272	217 - 259
G13	G4000	40	3.15 – 3.40	268	217 - 259

Source :(http://en.wikipedia. Org/wiki/Disc_ brake)

Table II: Specification of brake drum

Grade	GL 250							
Component	Brake Drum							
Chemical Composition	CE.V 3.9-4.0	C 3.2-3.4	Si 2.1-2.3	Mn <0.8	P <0.15	S <0.12	Cu <0.8	Sn <0.8
Micrographic Structure	Graphite	1A, Type C Prohibited						
	Matrix	Pearlite-Ferrite <10%						
		Free Carbide <2%						
Mechanical Properties	Hardness (BHN)	220±25						

Source: Oluwadare and Atanda (2017)

Table III: Typical properties of molding sand for casting brake drum

AFS	Permeability	Mould Strength ($KN\ m^{-2}$)	Humidity (Moisture Content) (%)	Clay Content (%)	Shatter Index	Sand Strength ($KN\ m^{-2}$) Green Compression	Sand Strength ($KN\ m^{-2}$) Green Shear
58-70	100-140	75-95	3-5	<3	85-95	100-120	30-40

Source: Oluwadare and Atanda (2017)

Table IV: Chemical compositions of charge materials

Material	C (%)	Si (%)	Mn (%)	P (%)	S (%)	Cr (%)	Mo (%)	Ni (%)	Al (%)	Cu (%)	V (%)	Nb (%)
Cast Iron Scrap	3.50	1.62	0.652	0.05	0.002	1.0	0.005	5.0	0.001	0.095	0.002	0.01
Steel Scrap	0.003	0.005	0.011	0.005	0.003	0.002	0.005	0.004	0.003	0.03	0.003	0.002
Graphite	95	-	-	-	-	-		-		-		-
Ferro-Silicon	-	75	-	-	-	-		-		-		-

v. Impact Testing Machine (Charpy Impact testing machine Avery-Denison LTD, Leeds-LS102DE).
vi. Metallographic equipment (Metallurgical Microscope) 200X resolution.
vii. Optical Emission Spectrometer, OES (Arun Poly spek Jnr optical emission spectrometer).

2.3 Methods

A Peugeot 504 brake drum sourced from the market was used as a pattern for producing the brake drum mold using green sand molding techniques. The mold materials include the refractory sand accounting for up to 92% by weight, binder (Bentonite) 4-5% by weight, and the balance for moisture and little addition of starch. The mold mixture was mixed using a small capacity sand mixer. The order of addition is the sand, binder, followed by water.

2.3.1 Charge Calculation, Melting and Casting

Prior to carrying out the charge calculations and subsequent melting, the collected scraps were first characterized by preparing samples from the various sourced scrap and analyzing them using a computer controlled Polyspek Junior Table Top Optical Electron Spectrometer (OES) to determine their chemical compositions. Spark results were generated at different spots on each sample and the average taken. The results obtained are displayed in Table IV. The results were used to formulate a charge calculation that determined the mass of each charge material required to yield the expected chemical composition.

The result of the chemical composition in conjunction with the standard chemical content requirements for automobile brake drums were taken into consideration in carrying out the charge calculation for the casting processes. Result of the charge calculation is shown in Table V.

After the charge calculations, the scraps were charged into the furnace and heated to molten stage. Graphite was added to improve the carbon content whilst ferro-silicon was introduced at the ladle just before pouring for inoculation. The liquid metal was sampled and analyzed using carbon equivalent analyzer. The final metal temperature was determined using immersion type of pyrometer. The metal was poured into the mold via a ladle at 1420^{o}C. The molds were opened after the castings have cooled to room temperature. The casted brake drums were removed, cleaned and dressed as shown in Fig. 1.

2.3.3 Characterization of Recycled Scrap

After casting, spectrometric analysis of the recycled scrap was done and the results are shown in Table VII.

2.3.4 Metallographic Examination

Specimens were prepared for micro-structural examination using standard method of preparation. Polished and etched specimens were observed under the metallurgical microscope at 200x magnification. Plate II shows the photomicrograph of the test sample.

2.3.5 Mechanical Properties

Hardness, tensile strength and impact strength of the recycled products were determined according to standard practice [17] and [18]. The results are summarized as shown in Fig. 3.

III. RESULTS AND DISCUSSION

Successful casting of two brake drums which are the exact replica of the original brake drum shows that the combination of the two scrap grades met the standard requirement for material specifications recommended for casting brake drums. Table VI shows the chemical composition obtained for the produced brake drum which is within the range suitable for brake drum application.

Fig. 2 shows the photo-micrograph obtained from microscopic examination of the cast sample. It was evident that the desired gray iron microstructure was achieved which can be observed from the distribution of graphite flakes throughout the matrix.

Results from mechanical tests showed that maximum tensile strength of the material reached 81.45317 MPa when the load was gradually applied within 7.788 sec to fracture, hardness value was 97.73 HRB/228 HB, while Impact strength of 2 J.

Fig. 1: Inner/Outer faces of brake drum

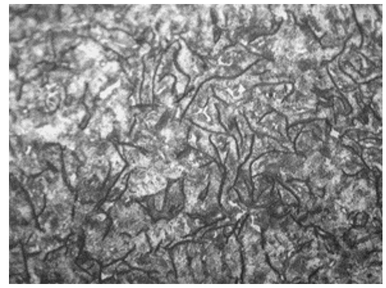

Fig. 2: Photo-Micrograph of the Cast Sample

Table V: Charge Calculation

Material	Charge Mass (kg)	C (kg)	Si (kg)	Mn (kg)	P (kg)	S (kg)	Cr (kg)	Ni (kg)	Cu (kg)
Cast Iron Scrap - 75% wt	375	13.125	6.075	2.445	0.1875	0.075	3.75	18.75	0.3563
Steel Scrap – 24% wt	120	0.036	0.006	0.0132	0.006	0.0036	0.0024	0.0048	0.036
Graphite - 0.8% wt	4	3.8	_	_	_	_			
Ferro-Silicon - 0.2% wt	1	_	0.75	_	_	_			
Total	500	16.961	6.831	2.458	0.1935	0.0786	3.7524	18.755	0.3923
Material		% C	% Si	% Mn	% P	% S	% Cr	% Ni	% Cu
Final Analysis		3.3922	1.3662	0.4916	0.0387	0.0157	0.7505	3.751	0.078

Table VI: Chemical Analysis of the New Brake Drum

S/No	Fe	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Ti	Nb
1	94.49	3.18	1.41	0.490	0.008	<0.003	0.119	0.002	0.046	0.009	0.115	0.014	0.001
2	94.67	3.06	1.37	0.478	0.008	<0.003	0.117	<0.005	0.043	0.010	0.118	0.011	0.001
3	94.66	3.14	1.36	0.458	0.008	<0.003	0.103	<0.005	0.043	0.012	0.097	0.013	0.001
Average	94.61	3.12	1.38	0.475	0.008	<0.003	0.113	0.006	0.044	0.010	0.11	0.013	0.001

Table VII: Comparison of spectrometric analysis with charge calculation

	Composition in %							
Charge	C	Si	Mn	P	S	Ni	Cr	Cu
By Calculation	3.40	1.66	0.492	0.04	0.02	3.75	0.75	0.078
By Spectrometer	3.12	1.38	0.475	0.008	<0.003	0.044	0.113	0.11

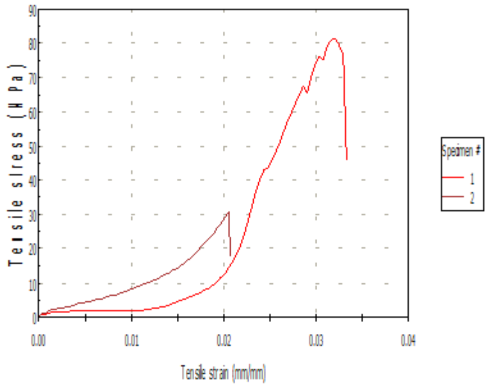

Fig. 3: Stress-Strain graphs for the two Specimens

Result from the OES analysis of the casting showed that alloying composition in iron fell a little below expectation from charge calculation as shown in Tables VII. Nickel (Ni) appeared far below that which was expected in the final brake drum (3.751 % from charge calculation), this was mainly due to oxidation of the alloying elements that took place in the furnace.

CONCLUSION

Automobile brake drum was produced by recycling ferrous scraps which if left un-attended to could cause serious environmental concern. This research has shown that waste to wealth campaign is applicable in automobile industries too.

The utilization of ferrous scrap has shown to be a viable alternative for production of engineering components with benefits in energy and cost savings which could otherwise be encountered if the production were to be from the Ores. In addition, recycling scraps could be of advantage in that huge savings in terms of environment as it relates to degradation due to ore mining activities and greenhouse effects by reduction in gas emission and pollution. For brake drum application, the achievement of required properties of these recycled cast irons is greatly dependent on its chemical composition. Generally, the results of this research have shown that other engineering components could easily be produce from recycling of metallic scraps.

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