KWARA STATE UNIVERSITY, MALETE

The University For Community Development



The Fifth (5th) Inaugural Lecture

Title

Striving for Global Relevance on the Platform of Minerals, Metals and Materials

By

Professor Abdulganiyu Funsho Alabi

B.Sc. (Ife);M.Sc./DIC (London);Ph.D. (Pitt, U.S.A.);FNSE, SPX, R.Eng

Department of Materials Science and Engineering

College of Engineering Technology

Kwara State University, Malete, Nigeria

Date: 27th March 2019

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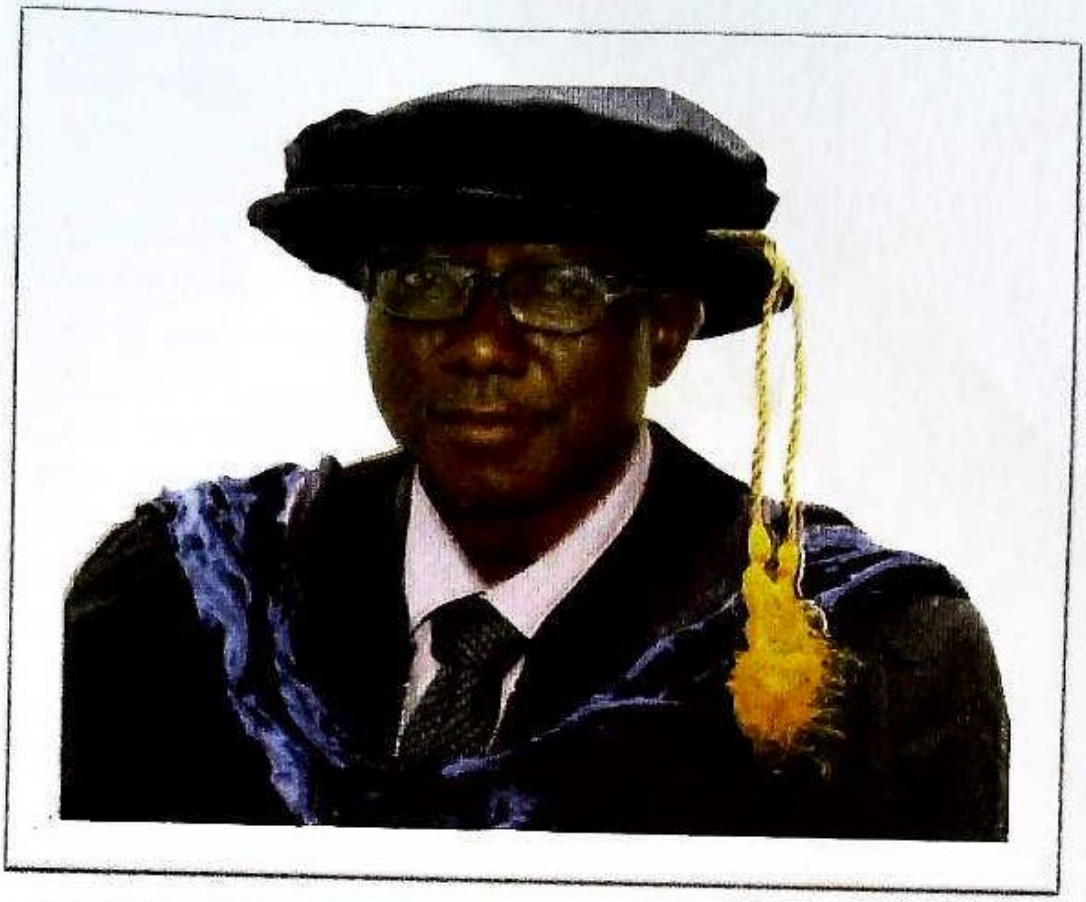
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The Vice Chancellor
Professor AbdulRasheed Na'Allah, PhD (Alberta)

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PROFESSOR ABDULGANIYU FUNSHO ALABI

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Professor of Materials Science and Engineering

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Government Officials,
My Lords Spiritual and Temporal,
Distinguished Students of the Department of Material Science and Engineering,
Distinguished Students of the College of Engineering Technology,
Gentlemen of the Press,
Distinguished Invited Guests,
Great KWASUITES,
Ladies and Gentlemen

1.0. Preamble

I give glory to the Almighty that today has come and also appreciate the Vice Chancellor, Professor AbdulRasheed Na'Allah for believing that I could make contributions to the development of KWASU as an educational institution of higher learning in general and the development of engineering training in particular, by hiring me as a Professor in KWASU.

An inaugural lecture is to provide an opportunity for the lecturer to showcase his contributions academically to the development of humanity economically and socially, and to educate the gathering/public on issues that boarder on his profession. In this case, Materials Science and Engineering constitutes the core of today's treatise. As a Professor of Metallurgy and Materials Engineering, my contributions to human and national development that have allowed Nigeria and Nigerians to aspire to "strive for global relevance" will be highlighted in this lecture. I am proud here today to say that I have affected learning and cultural development of KWASU as a former Dean of Student Affairs and as the current Provost of College of Engineering and Technology. For example, I inaugurated the first-ever Student Union activities as the Dean of Students Affairs with the support of our able Vice Chancellor, my staff and members of staff of other units of the university and, of course, my able student leaders from various departments who, at that time were referred to as Student Representative Assembly (SRA). In the College of Engineering and Technology (CET), I was instrumental to ensuring that many members of staff of the college were registered with Council for the Regulation of Engineering in Nigeria (COREN), a necessity to practise as engineers and even train engineering students in Nigeria. No graduate of engineering can practise the profession in Nigeria without registration with COREN. Any of such certification elsewhere (USA, China or Britain, for example) is only a precursor to assist registration with COREN, the body that permits an individual, a company or an engineering institution to practise in Nigeria. I am glad to report to you that, as the current and second Provost of the college (CET), all our engineering programs are accredited by both COREN

and National Universities Commission (NUC).

I therefore welcome you to this inaugural lecture which is unique in the sense that it marks three important things for the inaugural lecturer and hence, termed A TRIANGULAR ARCHIEVEMENT. It is a unique day for the Department of Materials Science and Engineering (MSE) as it is the first inaugural lecture from the Department, and second from CET. It is also unique because it marks a move by the inaugural lecturer towards retirement at the ripe age of 70 as a Professor and therefore a celebration of his birthday. I therefore give glory to the Almighty that the DAY has come for me to give this inaugural lecture which is different from the usual inaugural lecture because it is being given by an old lecturer. It is on this note that my lecture will be predicated on "Striving for Global Relevance" using the platform of Minerals, Metals and Materials as basis.

2.0. Introduction

2.1. My Sojourn into the World of Minerals, Metals and Materials (3M)

Mr. Vice Chancellor sir, It is of interest to alert the audience, particularly, parents, staff and students on how I got into Metallurgical and Materials Engineering as a Chemistry Graduate of the University of Ife now Obafemi Awolowo University (OAU) in Ile-Ife, Nigeria.

I started my educational career in Idanre, in the then western region of Nigeria and now, Ondo State. My father (of blessed memory) was interested in me finishing the Quran before going to school. Hence, I looked forward to the time when I would start school and learnt the rudiments that would carry me through school while in the local Madrasat

(Ile-Kewu). I thank Allaah who gave me the patience to agree with my father to finish the Quran which eventually gave me a good start in life and still forms a good basis for my patience and successes in later life. I started school at a very ripe age after completing the Quran and of course, with all I had learnt, I was always first in class. I spent only three years to get to class six in Idanre. I got admission to some secondary schools in the west but at that time, my parents could not afford the very high school fees (between 80 and 120 pounds). I started again to look forward to when I could get to secondary school because my interest from youth has been striving for relevance, locally, nationally and globally and I knew the only path to that base is through education. I came back to Ilorin in 1963 and enrolled in class six at Okesuna Senior Primary school located at Baaboko under our teacher of blessed memory, Teacher Amuda Alaya. As usual, I was the best in class and instead of going to class seven with my group, I did common entrance examination to secure admission to Oro Grammar school and came first. I was then given scholarship that reduced my fees to Thirteen pounds thirteen and four pence (£13.13.04) from Eighty-nine pounds (£89.13.04). I had the scholarship for as long as I was first in class. The competition was not too challenging as I always led the class with almost between 70 and 100 points each time. I was not satisfied with such performance. I looked forward to a school where competition would be more challenging for me and when my College brother (Senior Ayinla Laaro, of blessed memory) got to Government Secondary School (GSS), Ilorin for his A'Level, then called Provincial Secondary School (PSS), I visited him and discovered some of my class mates in the primary school were there in Form 1. I quickly asked if I

could seek admission there and I did. The Principal then was Mr. Macroft, a white man, who gave me instant admission on seeing my report sheets. The rest is history. I went on to become the Head-boy of the school at Higher School Certificate (HSC-Upper Six) Level. After my HSC, I got admitted for Chemistry at the University of Ife, now OAU and finished with a B.Sc. (Hons) degree. After graduation and NYSC, I started work as a Lecturer III at the Kwara State College of Technology (School of Basic Studies) now Kwara Polytechnic (KP), Chemistry Department where I taught great minds in various walks of life today many of whom are in the audience today. At that time, 1975-77, the steel companies, Ajaokuta-, Delta- Steel and a number of steel operations that could shape the Nigerian economy were coming on board. I started to look at the future and wanted an opportunity to be part of the industrialisation of Nigeria which I thought could propel Nigeria and Nigerians into global relevance. Iron and Steel making operation could provide that path as it was and still is the basis for industrialisation through effective policy formulation to enhance technology and infrastructural development.

It is obvious that steel operation brings a lot of value to national development as shown in figure 1; Industrial development, construction industry, power sector, transportation, agricultural sector among others.

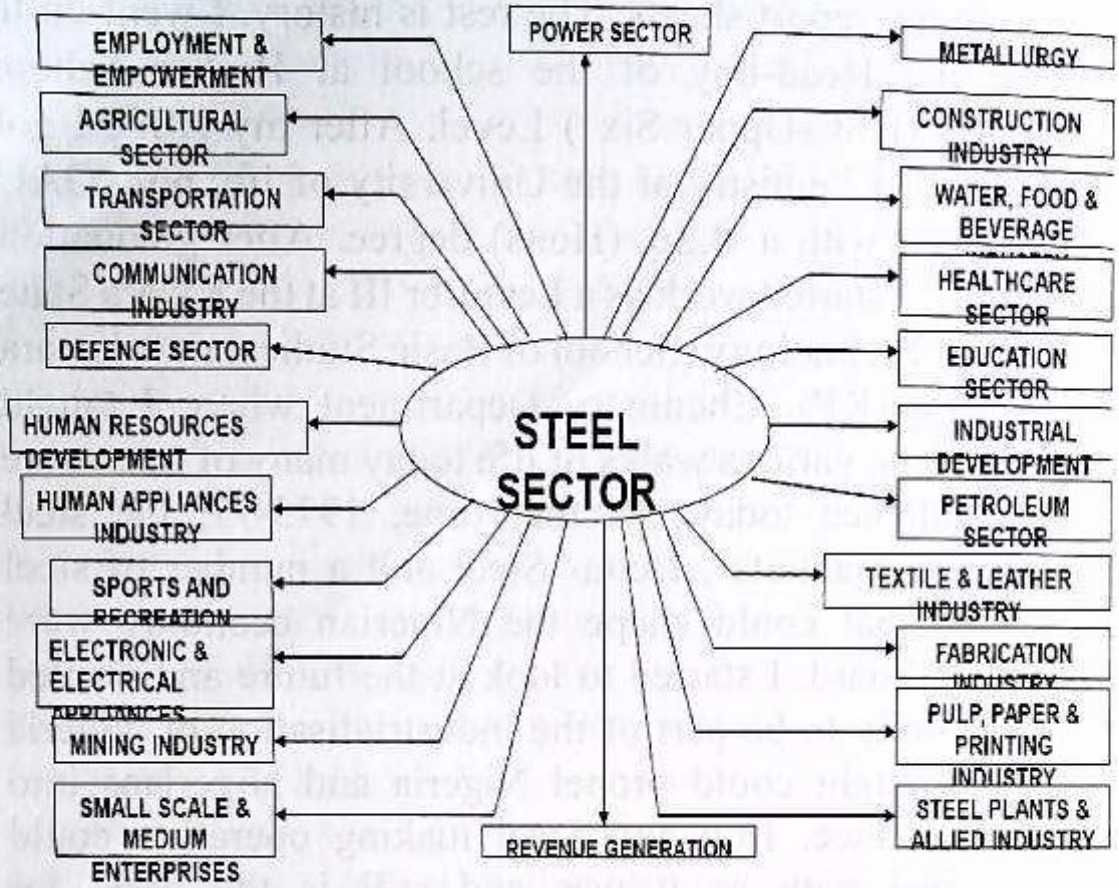


Figure 1: Effect of steel on the economy of a nation

I therefore decided I would study Metallurgical Engineering and on search, which was more rigorous search than today's internet search, I applied and got admitted to the Faculty of Engineering, Imperial College of Science and Technology, London to study Extractive Metallurgy of Primary and Secondary Metals. Unlike now, I applied and got scholarship for the program. All these were easy at the time because Nigerians, I included, and Nigeria were searching for global relevance. This was my first sojourn into Metallurgical Engineering. At the Imperial College, I researched into how we could improve the reducibility of

iron ore micro-pellets using hydrogen (H_2)/Carbon monoxide (CO) mixtures (Alabi, 1978), all in an attempt to improve productivity of Direct Reduced Iron (DRI) technology which is one of the products of Aladja Steel Plant, in Warri. After I graduated from Imperial College, I moved back to Nigeria and was part of the development of the School of Mines as a Lecturer at KP. Not satisfied, I later went for my Ph.D. at the University of Pittsburgh in the Steel city of Pittsburgh, Pennsylvania (PA), USA where this time, my interest was in the sale appeal of DRI as a commodity which could increase our foreign exchange earning apart from petroleum products and could move Nigeria into global relevance.

2.2. Understanding the Subject Areas of Minerals, Metals and Materials (3M)

Minerals are materials obtained from the earth crust, rivers or mountains through various mining techniques which is not particularly the subject of discussion here. However, value addition to these mined materials to serve various purposes in engineering and provide wealth for Nigeria and Nigerians is to be thoroughly discussed at this inaugural lecture which accentuates what inaugural lecture is all about, i.e., providing opportunity to understand a particular subject area and to open up avenues for the populace to benefit from that understanding, more so that our university is a university for community development (KWASU slogan).

Minerals, Metals and Materials are tripartite words that are capable of moving Nigeria, Nigerians and indeed, the world in positive directions. These three words are closely related to each other as one leads to the other in a triangular format shown below:

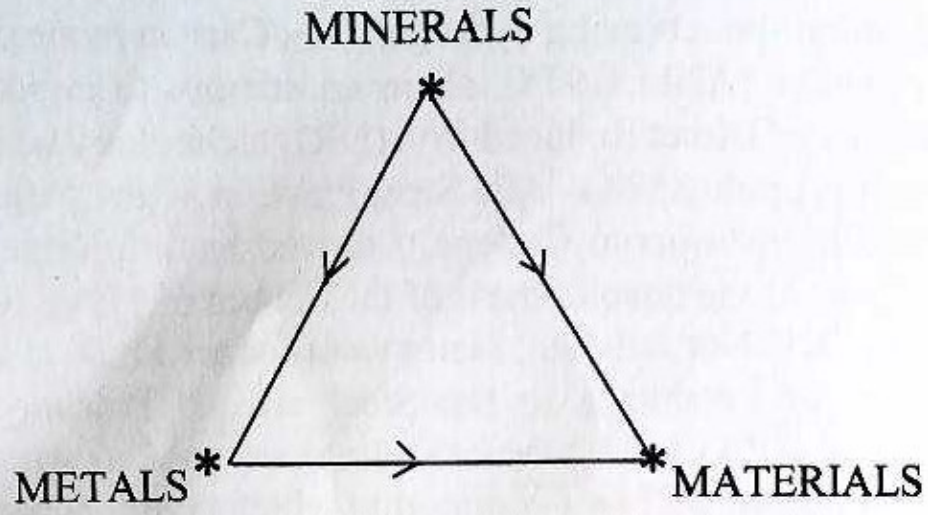


Figure 2: Triangulation of the three Ms

A mineral is obtained from its ore by mineral processing to release the valuable minerals of interest. Example of ore minerals are Iron oxides from rocks (Heamatite, Fe_2O_3; Magnetite, Fe_3O_4 and Wustite, Fe_xO), Gold from river beds and Mineral salt, Oil and Gas from seas. It is possible to obtain metals by taking the mineral ore through extractive metallurgical processes depending on the type of ore and its origin. Various other materials can be obtained from mixing the metals in certain proportions and types as it is done in alloying or adding various other metals, ceramics (high temperature resistance but brittle materials) and polymers (obtained from hydrocarbons, oil and gas) together in proportions that would have unique properties that are superior to the individual property of its constituents. This last group of materials is referred to as COMPOSITES or Engineered Materials. Most of the parts of Aeroplanes are made of composites because of the uniqueness of the properties such as lightness, strength, good corrosion and high temperature resistance. It is therefore obvious that looking ahead into the three Ms for any nation or their

inhabitants can be a good source of wealth and development for that nation and its nationals. Nigeria and Nigerians are good examples of this scenario. It can also lead to industrial development, employment opportunities, improved agricultural development and value addition to the nation's economy to reduce our over-dependence on oil. A United States Steel publication outfit has shown (Making, Shaping and Treating of Steels, 2018) how iron can be processed from its ore to provide various other materials (steel types) for use in infrastructural development:

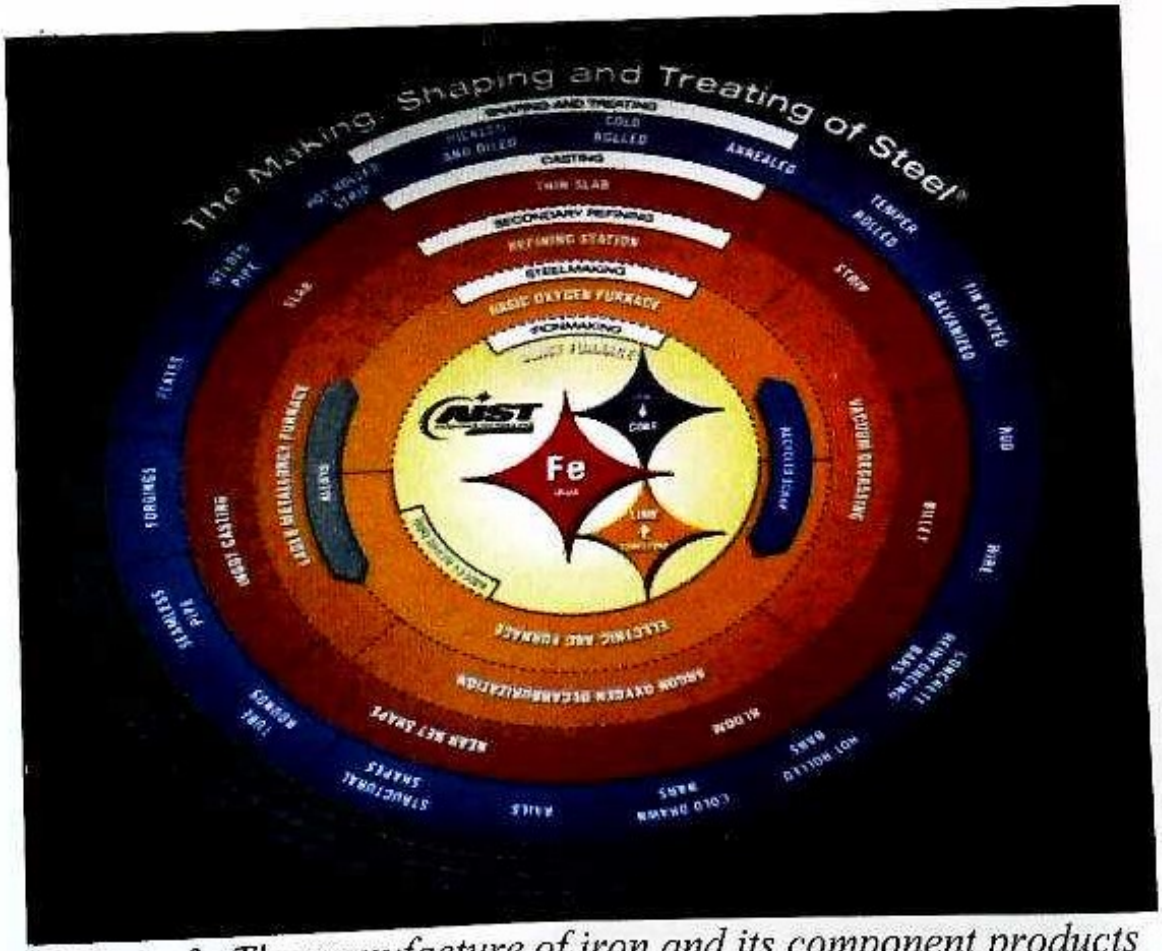


Figure 3: The manufacture of iron and its component products

Figure 3 shows how iron can be produced using the blast furnace method as it is practised at Ajaokuta Steel Company where the reductant is coking coal. The product, pig iron, can

be converted through processing to various types of steels with various heat treatment to modify the structure and hence, properties to suit its use in various environments. For example, Structural Steels are used in supporting structures as pillars or beams in high rise buildings, bridges or platforms and are also useful in the development of infrastructural facilities for transportation as shown below:



Figure 4: The relevance of steel in infrastructural development

The structural modifications are identified by the use of Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM). These and many more modern tools have revolutionised materials development. As

identified by Balasubramaniam (2011), the path Processing, Structure, Properties and Performance go together to grow new materials. A single material can be processed with structural modifications to generate properties that are relevant in various environments. Steel, for instance, can be processed to give Stainless Steels (by alloying) for use in corrosive environments or strengthened (by heat treatment) for structural applications, etc. The blast furnace method is the largest tonnage iron production in the world and the largest is now in China.

If the Ajaokuta project can be completed, the economic value chain that can develop from such a complex can be colossal and could move Nigeria into the much needed industrialisation era.

2.3 Materials Science and Engineering (MSE)

It will be of interest here to allude to the field of MSE as a department. Most universities in Nigeria (e.g. ABU, FUTA, FUTM) have named the department as Metallurgy/Materials Engineering and others (e.g. UNILORIN) have named it as Materials/Metallurgical Engineering. Only KWASU and OAU have adopted the universally accepted name, "Materials Science and Engineering".

The accrediting systems (NUC, COREN) must recognise that the course (MSE) is multi-disciplinary and must be treated as such. Chemists, Physicists and Biologists with relevant mathematical background can function adequately in the department (MSE). The problem of accreditation can be looked at from the two perspectives of Engineering and Sciences to accommodate the two groups. Those with engineering background and those with Science background could be accredited by a team of COREN and COMEG

(Council of Mining Engineers and Geo Scientists) respectively. This synergy will move the department forward and remove the acrimony presently existing whereby the future of anyone in the Science group in the department could not progress career-wise.

The interdisciplinary nature of MSE is best explained from the various aspects of studies that make it up. These are: Physical Metallurgy that requires good understanding of physical phenomena like conductivity, density, magnetic susceptibility, etc. which are more needed in impacting the required properties in the material, including structural modifications which are better understood with a physics background. On the other hand, Chemical Metallurgy requires the understanding of chemical properties that permit a good understanding of extractive metallurgy of winning metals from their ores, modifications of same and deterioration phenomena observed in corrosion processes, all of which are better understood from chemistry perspectives. While the science aspect addresses the generation of materials, the engineering aspect addresses the processing of the materials to generate new materials of the same type but different structural features and hence, different properties. In recent time, bio-processing has joined the group and is used in medicine as heart and other body parts replacement which requires understanding of biology (Baba et al., 2018). Hence, for the growth of the profession and development of materials to benefit humanity, these groups of professionals must be allowed to exist together to move our nation, Nigeria, forward and be counted among comity of nations. By so doing, Nigeria would be striving for global relevance on the platform of minerals, metals and materials.

3.0. Contributions in the Field of Minerals, Metals and Materials

Mr. Vice Chancellor, Sir, at this juncture, I would like to identify my various contributions to the development of the field of MSE and to the nation in general. My contributions are in the following areas: Extractive Metallurgy which creates opportunities for Nigeria to earn forex from other sources than oil and gas by adding values to our natural mineral resources (Mineral Processing or Mineral beneficiation) and extracting the metal of importance from the beneficiated ore. Extractive Metallurgy could be for iron (Ferrous) and non-iron-based (Non-ferrous). The understanding of these would be expanded in future discussion. Other area of interest is Corrosion processes and their mitigation because of their adverse effects on the national economy and productivity. In addition, I have contributed to knowledge in materials for construction, their uses in manufacturing and education of the populace on safety/allied engineering issues.

3.1. Mineral Processing and Extractive Metallurgy (MP & EM)

Earlier on, I identified EM as a process of winning metals from their ores in an economic way that is acceptable environmentally. These ores must be beneficiated by mineral processing technique, often at mine sites, to improve their quality, reduce waste products and hence, economy of extraction. This was the basis for establishing the Nigerian Iron Ore Mining Company (NIOMCO) at Itakpe, near Okenne in Kogi State to improve the quality of iron ores from Itakpe mines to a state that could be used either at Ajaokuta or Aladja steel operations. Such value addition to our

minerals, particularly, the non-ferrous minerals like Copper, Tantalum, Tin, Bayrite and Gold among others is lacking and governments must enact laws on those prospecting for minerals in Nigeria to add value before being exported. Such activity would provide jobs, open the eyes of Nigerians to the wealth of this country and give the younger ones opportunity to plan for a take-over on the long run. Extractive metallurgical processes are in three major facets (Ray and Gosh) viz: Pyro-metallurgical involving high temperatures as it relates to reduction of oxide ores, calcination reactions and roasting of sulfides' Hydrometallurgical operations occurring at low temperatures and in aqueous media and often employed for the extraction of non-ferrous ores of copper, manganese, zinc, lead and in beneficiation of ores of bayrite, berrylium, gold and calcite among others. The last extractive metallurgical process, Electrometallurgy involves the passage of electricity through electrodes (cathode and anode) connected to an electrolyte. This is often employed to refine metals like copper, zinc, lead and aluminium of higher purity.

3.1.1. Primary Iron-Making Routes in Nigeria (Pyrometallurgy)

In Nigeria, there are two iron and steel plants built (supposedly) to produce iron from the primary ore sources. The Ajaokuta Steel Company of Nigeria located near Okenne in Kogi State and the Delta Steel Company in Ovian, Warri, Delta State. The Ajaokuta product is called pig iron solidified from liquid melt and employs coking coal for reduction purposes in a Blast Furnace. Large tonnages are obtainable by this method and China is said to house the largest in the world at POSCO's Gwangyang

Steelworks in South Jeolla Province (http://www.haptic.ro).

The Delta Steel Company on the other hand, produces low tonnage solid product called sponge iron or Direct Reduced Iron (DRI) using gas mixtures of H_2 and CO that are obtained by the cracking of natural gas that is otherwise flared from the oil fields. Both products (Pig Iron and Sponge Iron) can be processed further to produce steel and when high quality low carbon-alloy steels are required, DRI presents a better route because it's cleaner and the quality can be predicted (Birks & Alabi, 1992). My interest therefore was to research into DRI production (Alabi, 1978) during which I discovered that higher reducibility (% reduction) was obtained in H_2/CO mixtures rather than using CO or H_2 alone. H_2 produces faster reduction at the beginning because of its lightness and ability to penetrate the pores of the pelletised ore. However, at a later stage of reduction, the material sinters and the pores blocked thus stifling reduction and incomplete reduction is obtained. With CO, the reduction is slow to start with and would take longer for higher reduction to be attained. The research concluded that 5%H_2/CO mixtures gave a higher reducibility and a porous material. Higher reducibility produces higher market value for the product but the porous nature has implication in storage and transportation as will be shown later. In-fact, mixed gases H_2/CO form the basis for the Midrex plant at Delta Steel Operation, taking advantage of the free natural gas (Methane, CH_4) in the environ; hence, it is economic that the facility be located in Warri, Delta State, where methane is in abundance.

When I went for my Ph.D. in Pittsburgh, my initial interest was to continue work on improving production of

DRI but got funded for addressing the problems encountered in the storage and transportation of DRI as identified by Clancey (1982), which is, the re-oxidation of DRI during storage or transportation, particularly across the seas. This would reduce the sale appeal of the material because of deterioration/de-metallisation. In addition, the maritime organisations were worried because of metal fires occurring in the high seas. My interest in DRI arose because Nigeria was at that time, going to be a major producer of DRI and the users are more likely going to be overseas where high quality steels requiring the product would be needed. My proposal to the National Science Foundation (NSF) in the US was approved and formed the basis for my Ph.D. research on the "Auto-ignition tendency of DRI" (Alabi, 1988a). I felt the work would allow Nigeria to export our DRI products with little losses to earn some forex and reduce our dependence on oil and gas.

My research showed that the problem encountered either during storage or shipping of DRI resulted from the porous nature of the material which makes the pile of DRI a heat sink coupled with the very high reactivity of flocculent rusted and reduced pellets with ingress of water (particularly salt water at seas) and air. The scenario is that with an ingress of sea water and air, the DRI corrodes to form finely divided rust in the interstices of the pile or away from the pile surfaces as shown in Figure 5:

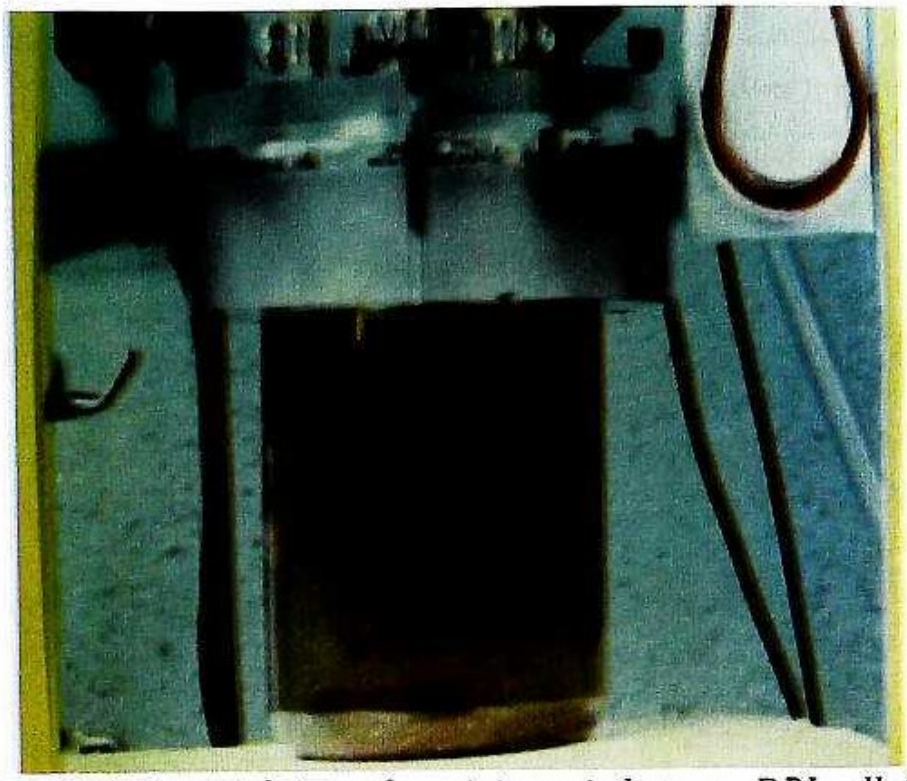


Figure 5: Pictorial view of precipitates in between DRI pellets soaked in simulated sea water

At the same time, hydrogen gas generated rises into the reflux zone (above the aqueous zone) of the pile. The reactions forming goethite (FeOOH) or Ferric Chloride ($Fe(OH)_3$) are exothermic and such reactions occur both at the aqueous and reflux zones:

$$2Fe + 3H_2O(l) + 3\underline{O} + = 2Fe(OH)_3 + Heat \quad (3.1.1.1)$$
$$2Fe + H_2O(l) + 3\underline{O} + = 2FeOOH + Heat \quad (3.1.1.2)$$

As the oxygen is consumed, the lower oxidation state of iron, Ferrous hydroxide ($Fe(OH)_2$) is formed with hydrogen as:

$$Fe + 2H_2O(l) = Fe(OH)_2 + H_2(g) \quad (3.1.1.3)$$

The ferrous hydroxide formed transforms to magnetite (Fe_3O_4) according to Jelinek and Neufeld (1982) as:

$$3Fe(OH)_2 = Fe_3O_4 + 2H_2O + H_2 \quad \text{.....(3.1.1.4)}$$

and producing more hydrogen.

An experiment performed on DRI pellets soaked in water as in Figure 6 shows that hydrogen generation increases as the oxygen content reduces and temperature has not significantly affected the hydrogen evolution rate (Birks & Alabi, 1986).

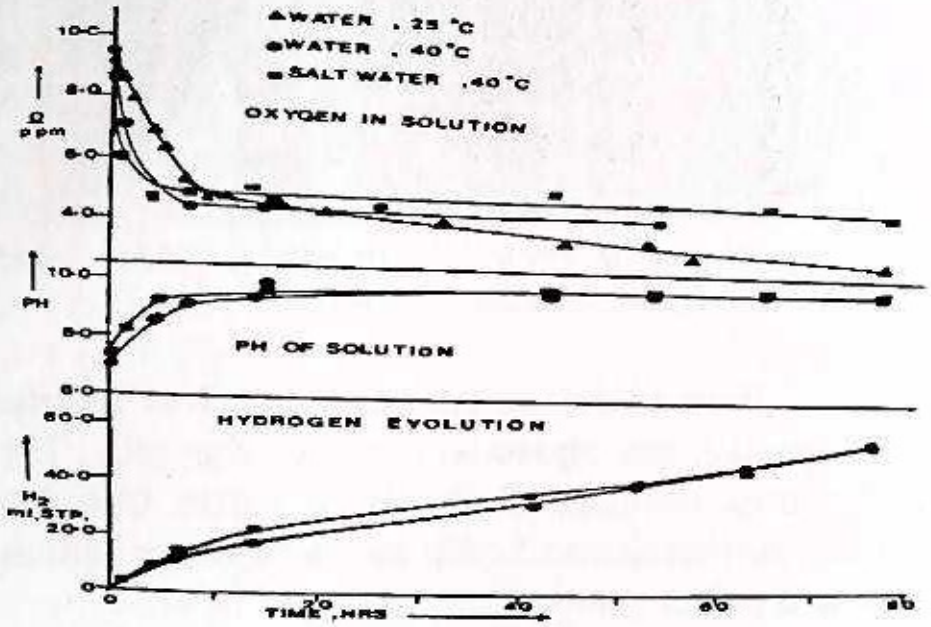


Figure 6: Hydrogen evolution rate with oxygen contents and temperatures

The heat generated from reactions 3.1.1.1 and 3.1.1.2 dries the goethite (FeOOH) further, particularly at the reflux zone to produce haematite (Fe_2O_3), according to the equation:

$$2FeOOH = Fe_2O_3 + H_2O$$

The rising H_2/H_2O is equally dried in the process.

At the right H_2/H_2O ratio, the precipitates identified by X-ray diffraction as FeOOH and Fe_2O_3 are reduced to more finely divided iron with very high specific surface area and therefore highly reactive (Birks & Alabi, 1992). Figure 7 shows the micrographs of rusted and reduced pellets with finely divided acicular iron.

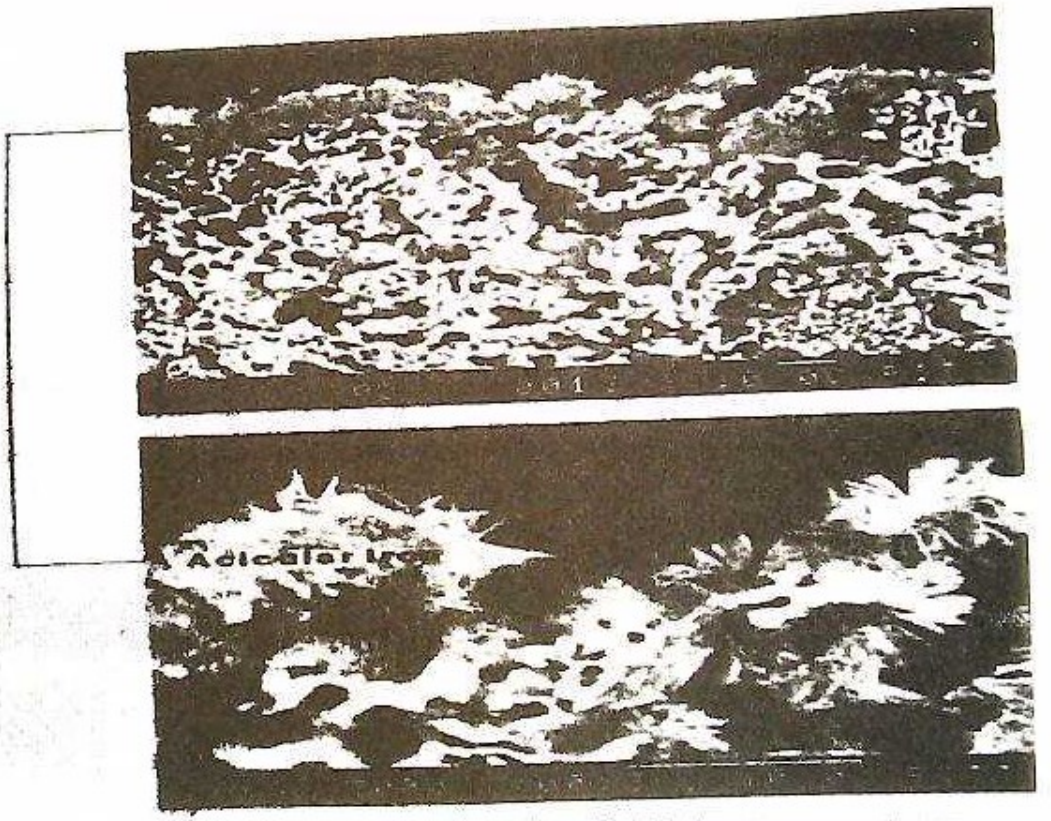


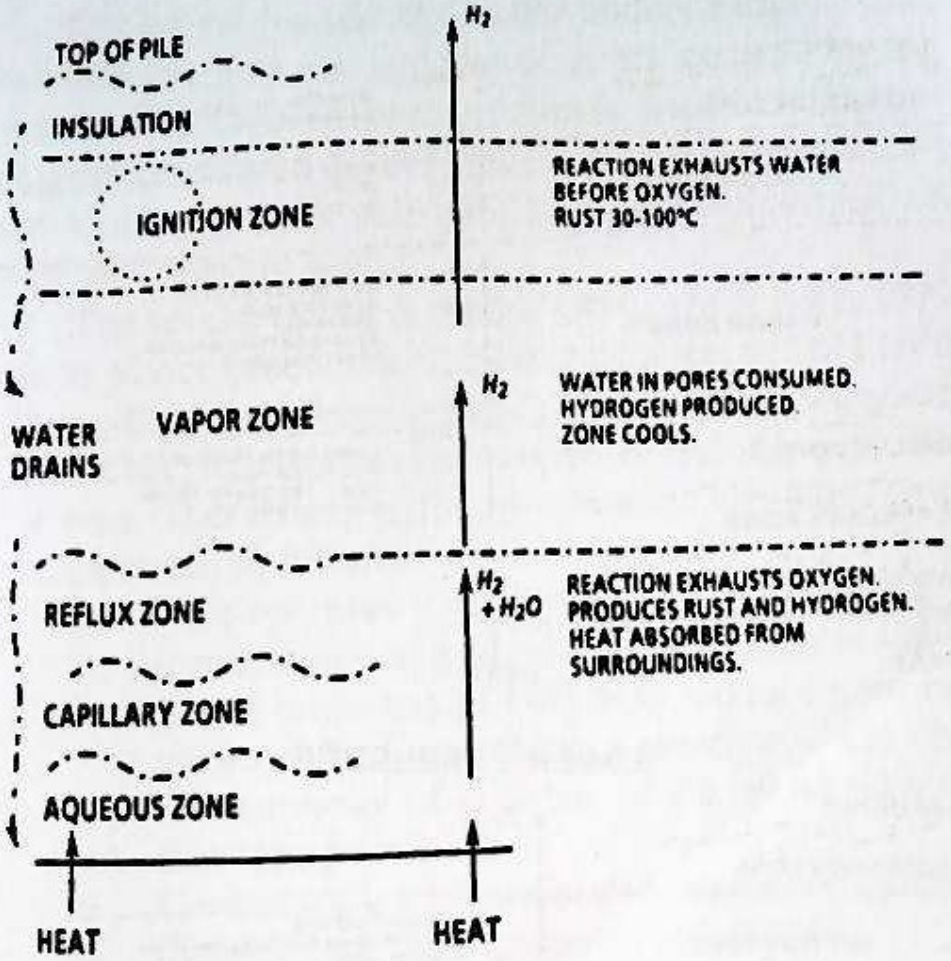
Figure 7: A rust product reduced in H_2/H_2O at temperatures above 120°C to produce more finely divided iron.

The finely divided iron coming into contact with more oxygenated water reacts more exothermically, releasing heat

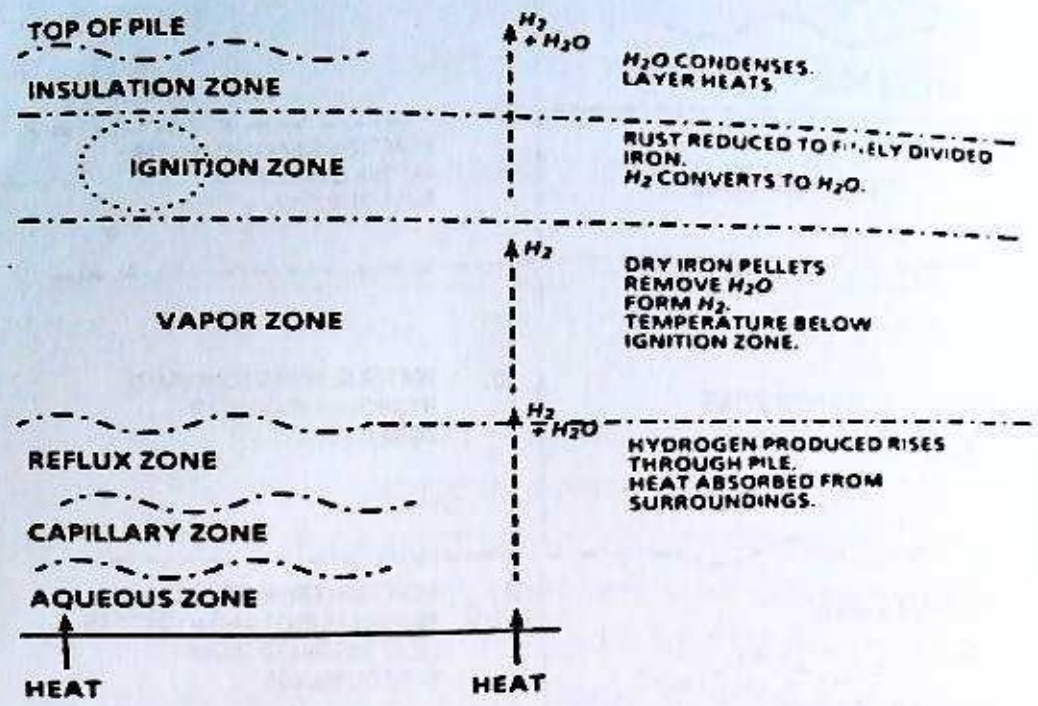
which again increases the temperature of the pile and forming oxides and oxy-hydroxides which is again reduced in the right H_2/H_2O ratio. It is these series of oxidation-reduction reactions that eventually lead to temperature run away or self-ignition of the pile.

A mechanism leading to the self-ignition phenomena was developed (Birks & Alabi, 1987, 1988, 1992) as shown in Figure 8.

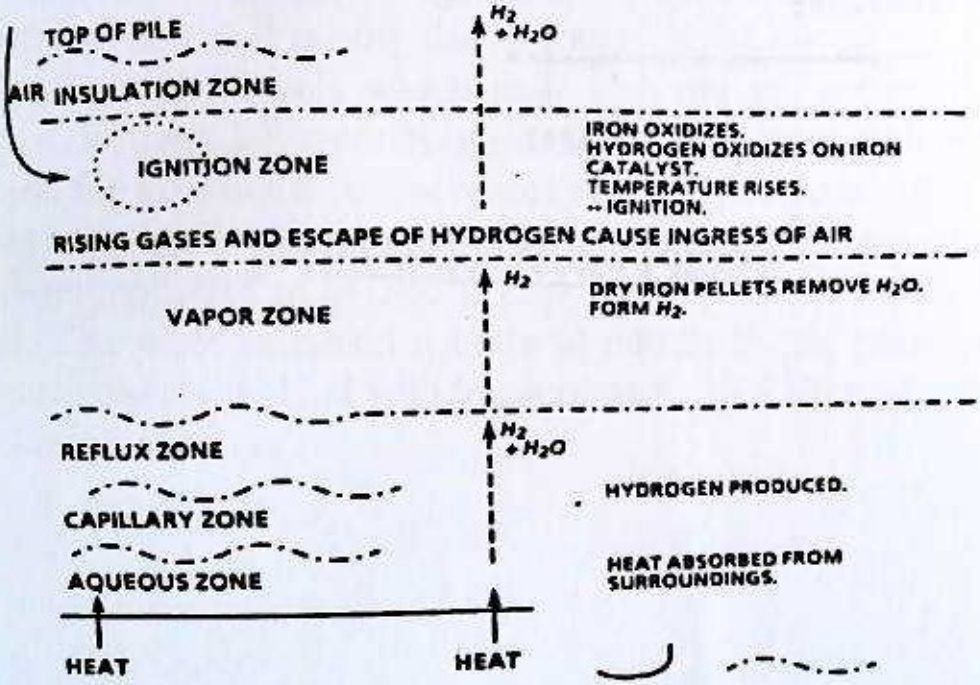
The auto-ignition path is proposed to have progressed through a rust formation stage as a result of water percolation into the pile either during storage or transportation followed by hydrogen generation from reactions with water or water vapour. At the right temperature and H_2/H_2O ratio, the finely divided rust is reduced to more finely divided iron. When such finely divided iron is dowsed with oxygenated water in a stormy environment or high seas, it reacts exothermically, releasing heat and raising the temperature of the pile in the hold to higher levels which may become uncontrollable; hence, initiates a temperature run away. The temperature at which the heat in the pile becomes uncontrollable is referred to as auto-ignition temperature, T_i. This critical temperature, T_i, was modelled to be 200^0C depending on the size of the pile. The work provided a basis of action to the Maritime organisations involved with transportation of such materials, including coal.



STAGE I - RUST FORMATION



STAGE II - REDUCTION



STAGE III - OXIDATION AND IGNITION

Figure 8: Path to auto-ignition of DRI pile

The model permitted a better understanding of the self-ignition phenomena and hence some control on the sale appeal of DRI products to producers, users and the maritime organisations who are very much interested in safety. Advice on how to control self-ignition was given based on this globally relevant work.

The results (Birks & Alabi, 1986, 1987, 1988, 1992) led us to advice producers, users and shippers of DRI on things they can do to reduce incidence of fire during transportation or storage, loss of lives and properties and above all, disaster at seas. The various safety precautions identified from the research are as follows:

a. Develop piles of low height to reduce heat accumulation and therefore temperature build up;
b. Create briquettes of DRI with reduced porosity and surface area to reduce reactivity and hence, exothermicity of reaction which could lead to run away temperatures;
c. Cover the pile with perforated tarpaulin to release any hydrogen and heat generated at intervals.

All these precautions would reduce the economic losses and increase the sale appeal of DRI at the discharge point since the deterioration is reduced by so doing.

3.1.2. Hydrometallurgical

Hydrometallurgical method has been employed to characterise ores in a way to impove the mineral values and kinetics of leaching. Baba et al. (2013a, 2016a) worked on improving manganese ore-pyrolusite concentrate and concluded that leaching produced higher concentrate (78.7%) in 4M H_2SO_4 at 80°C than in 4M HCl at 80°C for

similar particle sizes of -90+75um for which the leach concentrate is 67.3%. Similar work on Chalcopyrite ($CuFeS_2$) dissolution in 4M $FeCl_3$ solution by Baba et al. (2013b), shows some positive results. Chalcopyrite is a low grade ore of copper and copper has a lot of value in engineering because of its conductivity. Hence, any process that can increase the value of the concentrate before extraction is welcomed as a value addition to Nigerian ore resources. Gold ore from Bargu, Niger State was leached in ammoniacal thiosulphate solution and found to give a gold ore concentrate of 88.4% at 80°C using 0.2M NH_3 and 1M $Na_2S_2O_3$ (Baba et al., 2013c, 2016b). The value of Talc used in the manufacture of paints was improved by removing iron to very low level (Baba et al., 2015). Further work on calcite enrichment for hydroxyl apatite production using di-ammonium hydrogen phosphate as a source of phosphorus by Baba et al. (2016) was done as a value addition to a Nigerian mineral. In addition, copper sulphate chemical was produced by Baba et al. (2016, 2017) from malachite ($CuCO_3Cu(OH)$ which can further be processed for the manufacture of copper metal, thus reducing the high temperatures often employed in the copper production route. Hydrometallurgical method had also been used to turn waste to wealth by recovering lead and zinc from spent car battery (Baba et al., 2013d) and copper from leach liquor of discarded cell phones (Baba et al., 2016).

It is important to note that *Non-Ferrous metals* are equally versatile in adding values to iron as alloying elements or as an entity (e.g., Aluminium, Copper, Tin, manganese, etc), or as an alloy (e.g., Inconel- a Ni-Cr-Fe based alloy resistant to corrosion at high temperatures often used in boiler tubes, Brass – Cu-Zn alloy, Bronze --Cu-Sn

alloy, etc.). All these metallic materials are available in abundance in Nigeria as confirmed in Table 1 (Ministry of Mines Development).

Table 1: Commodity distribution per state in Nigeria

No	States	Potential Minerals in Commercial Quantities Per State
1	**Abia**	Glass sand, limestone, salt, shale, ball clay, granite, galena, marble laterite, bentonite, phosphate, kaolin, pyrite, feldspar, petroleum, lignite, gypsum, sphalerite, clay
2	**Adamawa**	Feldspars, flourspar, marble, gypsum, magnesite, tantalite, rock crystal, laterites, topas, sandstones, mercury, glass sand, zircon, spinel, emerald, graphite, beryil, tourmaline, mica, iron ore, clay minerals, diatomite, coal, garnet, aquamarine, gold dust, zoisite, cassaterite, agates, amethyst chalcopyrite, kaolin, limestone, chalcedony, onyx, barytes, zinc, tin, uranium, quartz, mica, wolframite, columbite, platinum, ruby
3	**Akwa Ibom**	Clay, glass sand, salt, silica sand, granite, coal, petroleum, natural gas, kaolin, limestone, lignite
4	**Anambra**	Clay, iron stone, natural gas, petroleum, sand stone, kaolin, pyrite, lignite
5	**Bauchi**	Kaolin, trona, gypsum, cassiterite, mica, clay, tantalite, galena, iron ore, gemstone, sphalerite, silica sand, barite, columbite, zinc, lead, muscovite, quartz, tin, glass sand, monazite, feldspar, graphite, wolfram, coal, agate, rutile, tungsten, copper, talc, limenite, ziron
6	**Bayelsa**	Salt, petroleum, natural gas, silica sand, bentonite, petroleum, limestone, glass sand

7	**Benue**	Gemstone, barites, feldspar, marble, mica, silica sand, quartz, galena, lead, zinc ore, silica sand, clay, crushed and dimension stone, fluorspar, wolframite, bauxite, shale, magnesite, illmenite.
8	**Borno**	Silica sand, natural salt, sapphire, topaz, mica, quartz, gypsum, uranium, iron ore, megnesite, fedspar, granite aquamarine, nepheline, limestone, kaolin, bentonite, laterite, refractory clay, trona, gold, tin, potash
9	**Cross Rivers**	Salt limestone, coal, maganese, mica, limenite, gold, quartz, glass sand, tourmaline, petroleum, natural gas, kaolin, tin ore, sharp sand, spring water, salt deposit, talc , granite, galena, lead, zinc, tin ore, muscovite, uranium, barite
10	**Delta**	Kaolin, lateritic clay, gravel, silica sand, natural gas, petroleum, ball clay, bauxite, granite, river sand, clay, spring water
11	**Ebonyi**	Lead, zinc ore, salt, limestone, ball clay, refractory clay, gypsum, granite
12	**Edo**	Charonokite, copper, gold, marble, granite, gypsium, petroleum, dorite, lignite, limestone, ceramic clay
13	**Ekiti**	Clay, charnokite, quartz, lignite, limestone, granite, gemstone, bauxite, cassiterite, clumbite, tantalite, feldspar, kaolin
14	**Enugu**	Laterite clay, crude oil, kaolinitic clay, iron ore, glass sand, petroleum, gypsum, coal, silica sand ceramics
15	**Gombe**	Graphite, kaolin, limestone, silica sand, uranium, coal, halites, clay, gypsum, diatomite, granite
16	**Imo**	Crude oil, shale, natural gas, kaolin, laterite

		sand, limestone, salt, marble
17	**Jigawa**	Glass sand, granite, laterite clay, silica, kaolin, iron ore, quartz, potash, talc, illmenite, gemstone, columbite
18	**Kaduna**	Muscovite, granite, gold, manganese, clay, graphite, sand, zircon, kyanite, tin ore, illmenite, gemstone, columbite
S/ No .	States	Potential Minerals in Commercial Quantities Per State
19	**Kano**	Clay, laterite, cassiterite, columbite, illmenite galena, phyrochlorite, kaoline, gemstone, silica, tin ore, monazite, wolframite, thorium, granite, hyalite, kaolin, beryl, amethyst, gold
20	**Katsina**	Gold, manganese, lateritic, clay, feldspar, black tourmaline, amethyst, quartz, kaolin, mica, gypsum, silimanite, clay, granite, sand, uranium asbestos, tourmalin, chromites, illmenite, diamond, graphite, iron ore, potash, silica sand
21	**Kebbi**	Salt, iron ore, gold, feldspar, limestone, quartz, bauxitic clay, manganese, kaolin, mica
22	**Kogi**	Clay, iron ore, gemstone, marble, limestone, feldspar, dolomite, phosphate, mica, cassiterite, granite, ornamental stone, coal
23	**Kwara**	Clay, kaolin, silica sand, quartz, dolomite, marble, feldspar, gold, tantalite, cassiterite, granite, limestone
24	**Lagos**	Silica sand, bitumen, sharp sand, gravel, petroleum, laterite
25	**Nassarawa**	Cassiterite, gemstone, amethyst, beryl, chrysolite, emerald, gamet, sapphire, topaz, barites, galena, monazite, zicron, glass sand,

		coal
26	**Niger**	Bell clay, kaolin, limestone, granite, glass sand, iron ore, red clay, feldspar, silica sand, quartz, asbestos, marble, talc, gemstone, gold, manganese and tantalite
27	**Ogun**	Kaolin, feldspar, silica sand, mica, granite, clay, phosphate, gypsum, limestone, quartz, tar sand
28	**Ondo**	Marble, gold, gemstone, diorite, lignite
29	**Osun**	Clay, granite, talc, dolomite, feldspar, quartz, limestone, mica, gold
30	**Oyo**	Clay, feldspar, granite, limonite, iron ore, kaolin, quartz, talc, marble, dolomite, tourmaline, aquamarine, amethyst, gemstones
31	**Plateau**	Monazite, columbite, feldspar, clay, cassiterite, gemstone, kaolin, dolomite, mica, zicron, marble, limonite, barite, quartz, talc, galena
32	**Rivers**	Petroleum, natural gas, silica sand, glass sand, clay
33	**Sokoto**	Silica sand, clay, salt, limestone, phosphate, gypsum, kaolin, laterite, potash, granite
34	**Taraba**	Fluorspar, gamet, tourmaline, sapphire, zicron, tantalite, columbite, cassiterite, barite, gelena, limestone, laterite, calcite, bentonitic clay, Sapphire
35	**Yobe**	Salt, trona, diatomite, clay, gypsum, kaolin silica sand, limestone, epsomite, iron ore, shale, uranium, granite, bentonic clay
36	**Zamfara**	Gold, alluvia gold, granite, chromites, chamorckite, clay, feldspar, spring water
37	**FCT**	Limestone, kaolin, granite, marble, feldspar, mica, dolomite, clay, sand, talc, Lead, Zinc and Gold

These minerals can be huge sources of wealth for Nigeria and Nigerians thus making Nigeria a force to be reckoned with globally in economic parlance.

3.2. Corrosion

Corrosion is the degradation of materials and more significant in Marine environments for which the aqueous solution contains corrosive chlorides (Metals Hand book. Corrosion. 1978. pp. 894). This explains why iron roofing sheets in such locations as Lagos or Port-Harcourt corrodes heavily (Alabi. 2018).

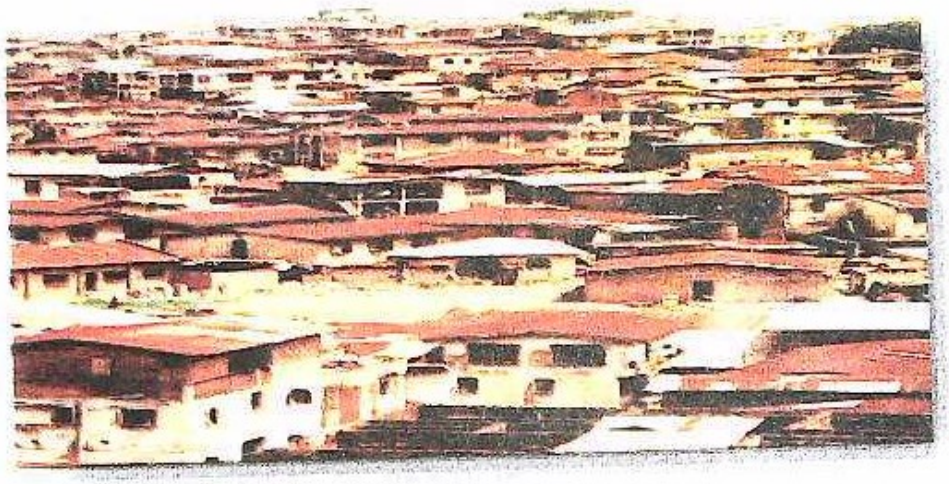


Figure 9: Brown roof caused by corrosion

Additionally and most commonly, vehicles in such environment have short life cycle.

3.2.1. Forms of Corrosion and Passivity

Corrosion takes many forms (Lawrence. 1987). Uniform corrosion where the corrosion product is uniformly laid. If

such a layer is compact, non-porous and adherent, it is often referred to as passivating as identified morphologically using SEM by Birks and Alabi (1986) when Fe-C foils are exposed to simulated sea water at temperatures between 25°C and 70°C. The adherent products was shown by X-ray diffractometer to be magnetite (Fe_3O_4), a feature that keeps the boiler operators happy. The work was to simulate how DRI (which is mostly Fe-C) would behave when embedded, in sea water (Aqueous Zone) or when not totally embedded called the reflux zone of a DRI pile. As discussed previously, a proposed path for auto-ignition of DRI was developed from this idea Alabi (1988a). Pitting corrosion mostly observed in acidified waters is catastrophic since it can develop pits that may result in losses. Trans-granular corrosion or Stress Corrosion cracking is common in oil and gas industry. Bimetal corrosion occurs in electrical cables and other buried bimetallic strips, etc. The products of oil and gas could be used to develop inhibitors which are organic-based that we import often. Such inhibitors were researched into to identify conditions for passivation using Di-ethyl-hydroxyl amine (DEHA), Methoxyl-propyl amine (MPA) and Hydroquinone (HQ) (Alabi et al., 1989) in place of hydrazine because of its environmental effects. Initial research was done (Alabi, 1988b) to see if the hydrazine analyser could be used to monitor other reducing agents identified above (DEHA, MPA and HQ) and the feasibility of such an application was confirmed. This then made it easy for the chemicals to be used as passivating agents in field situations as demonstrated in condensate corrosion by Alabi et al. (1989). HQ/MPA was found to be more passivating (Alabi, 1989) than others and became industrial standard for company's condensate corrosion control products since a new monitoring machine

would not be necessary. Indeed, I was being pencilled down to sell the ideas to oil and processing industries in Nigeria and some African countries but I felt my place was in the university rather than industry at that time even though the pay was a lot higher. Such research activities should be encouraged by the government forcing industries to patronise universities and research centres in Nigeria for their research needs. Tax haven and other sources of encouragement could be created by government for this purpose.

Corrosion generally affects manufacturing, oil and gas environments and industrial operations. The cost of corrosion to governments and industries can be colossal, and hence the need to control the menace (Alabi, 2018).

PH, hydrogen ion concentration index is very important in corrosion. While a PH of 7 is neutral, a PH less than 7 is acidic and more than 7 is alkaline. Metals (M) corrode generally in acidic solution to generate hydrogen as:

$$M + 2HCl = MCl_2 + H_2$$

In alkaline solution, it forms hydroxide and not as corrosive, In-fact, a PH of 9 to 10 has been established (Silverman, 1982), as the range of stability of $Fe(OH)_2$ which reacts to form Fe_3O_4, and H_2 according to Jelinek (1982). Birks and Alabi (1986) showed that the Fe_3O_4 formed on Fe-C foil to be uniform, compact and adherent. Such tenacious adherent layer is a boiler's delight during short-down.

Steel is a universally accepted material of construction and adequately researched. Shuaib-Babata and Alabi (2010) examined how commercially available mild steel used as implement or container during harvesting or processing

could be affected by cassava fluid. They concluded that ammonia solution could inhibit the corrosion of mild steel by 36%. When mild steel is used to convey municipal water or sea water however (Shuaib-Babata & Alabi, 2009, 2010) recommended the annealing of the steel in order to reduce the corrosive effect. In Durowaye et al. (2014a), mild steel corroded in bore-hole water at a rate of 8.650mpy when the solution PH is 11.2 and when 2ml sodium sulphite is added as inhibitor, the corrosion of the steel in bore-hole water at a PH of 11.1 is lesser, 5.504mpy (Durowaye et al., 2014b) showing sodium sulphite in low amount can inhibit corrosion. The draw-back is the formation of sludge and sulphite is no longer used for water treatment.

The prediction of aquifers in bore holes have been computerised to create a data base and to replace the manual predictions. Alabi and Aro (2003) used AutoCAD to create data base for prediction of fractured aquifer which was found to be more accurate, reliable and more specific than hitherto. It is easier now to locate depths of aquifers using this technique. The idea was developed at that time to create awareness of the use of computers in such predictions.

3.2.2. Green Corrosion Inhibitors

Oil and gas are mineral resources for Nigeria and the country has benefited not only from the primary sources but also from secondary and tertiary sources such as Petrochemical companies to manufacture Plastics, Pharmaceuticals and a host of tertiary businesses that could develop from the chemicals so manufactured. The Eleme Petrochemical asset for which the FG has 5% share (worth $27 million) was sold to Indorama during privatisation and Indorama recovered the sale amount in only 14 months selling polyethylene and urea

to West Africa sub-region. With the refinery now undergoing rehabilitation to produce in-house, the government can start to think in that direction in order to diversify our economy and reduce our dependence on oil and gas alone and add values to our oil and gas.

The thought that the industries to develop from oil and gas would face serious deterioration from corrosion which has been established to be an economic drain on any nation (Alabi, 2018) encouraged my research on corrosion and its inhibitors. Work is ongoing using cucumber seeds and banana peels as green inhibitors (Yakubu, 2014; Ayinde 2015) to generate inhibitors from our local herbs, vegetable and fruits. Such extracts are obtained from agricultural products that are otherwise discarded and are called Green inhibitors, particularly for the beverages industries (Kumar et al., 2010, Odusote & Ajayi, 2013). Once these inhibitors efficacy is fully established, Nigeria and Nigerians will be generating more revenue from agricultural products and we will become quite relevant globally. This is in addition to developing chemicals using our petroleum products. By so doing, the knowledge can benefit humanity, provide jobs and assist Nigeria and Nigerians to strive for global relevance.

3.3. Materials Development

In the area of materials development, Alabi et al., 2017, assessed the influence of ferro-silicon-manganese in reducing the sulphur content of Aus-tempered Ductile Iron (ADI) since sulphur is known to be deleterious to steel (Smailer et al., 1974). The sulphur level was brought down to 0.027 from 0.088 by appropriate processing (Alabi et al., 2017). This would have increased the use of ADI in car parts manufacturing. ADI is used in the automobile industries

because of its unique properties, ease of fabrication, good wear resistance, and high strength with good ductility (Alabi et al., 2017). Talabi et al. (2013) working with Al-4%Ti showed that heat treatment only affects the material ductility not the strength, hence suitable for application involving toughness as is the case in the aerospace industries. Heat treatment therefore is a good processing technique for relating microstructure to applications. In-fact, the technique is equally employed in assessing cutting forces (Alabi et al., 2010) and temperature distributions (Alabi et al., 2012) to effect a fine surface finish and concluded that tempered and annealed samples have higher cutting forces than hardened materials. Hence, for good machinability, structures that produces discontinuous chips are encouraged. All these were attempts to develop materials for industrial applications which can impact the Nigerian economy. A nation with an industrial base is destined for global relevance and minerals, metals and materials are excellent platform for such.

Composite materials are with unique properties which is superior to the individual properties of the unit and find applications in the Aerospace and automobile industries because of their light weight to volume ratio and superior application at high temperatures when developed with refractory materials such as Ti (Talabi et al., 2013). My involvement in this area of study is to add value to our waste products which would have been a menace otherwise. Ofuiwale et al., 2016 used coconut fibre and wood dust as reinforcement for a polyester composite. The results showed an increase in flexural properties with increased filler loading up to 7w% taken to be optimum composition of the wood filler. SEM studies showed good interfacial bonds between the reinforcements and polyester matrix at this composition

7w% compared to 12w% respectively where there are fibre cracks initiating fibre pull, Figure 10a and b.

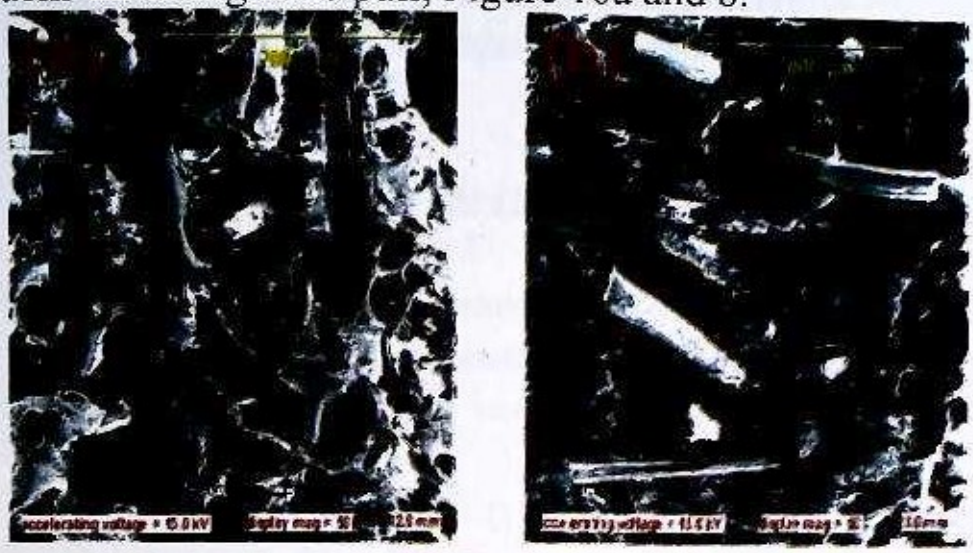


Figure 10: SEM micrographs of composites, showing (a) C10S7 and (b) C10S12

However, at 1w% and 12w%, the breaking strength are higher with substantial tensile strain reported for the 1w% composite (Omiwale et al., 2016) and shown in Figures 11 and 12 respectively.

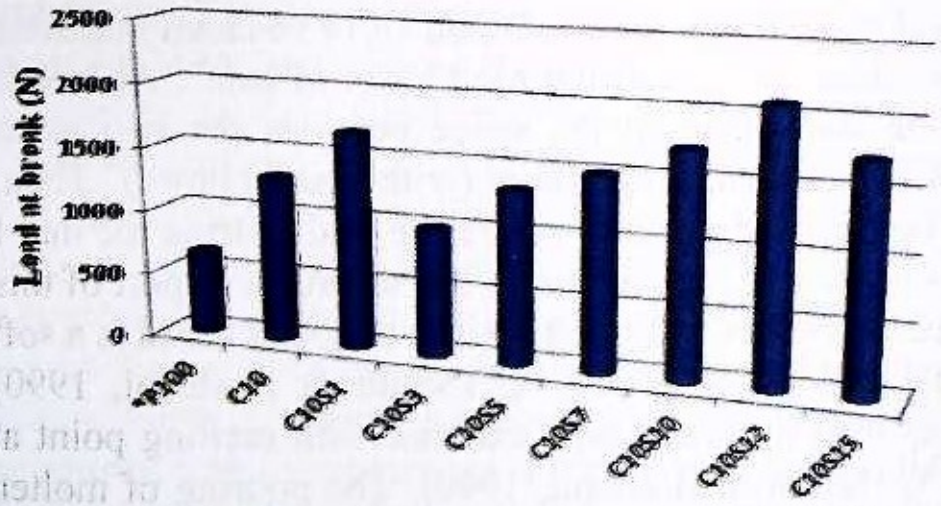


Figure 11: Maximum force exerted on composites before failure

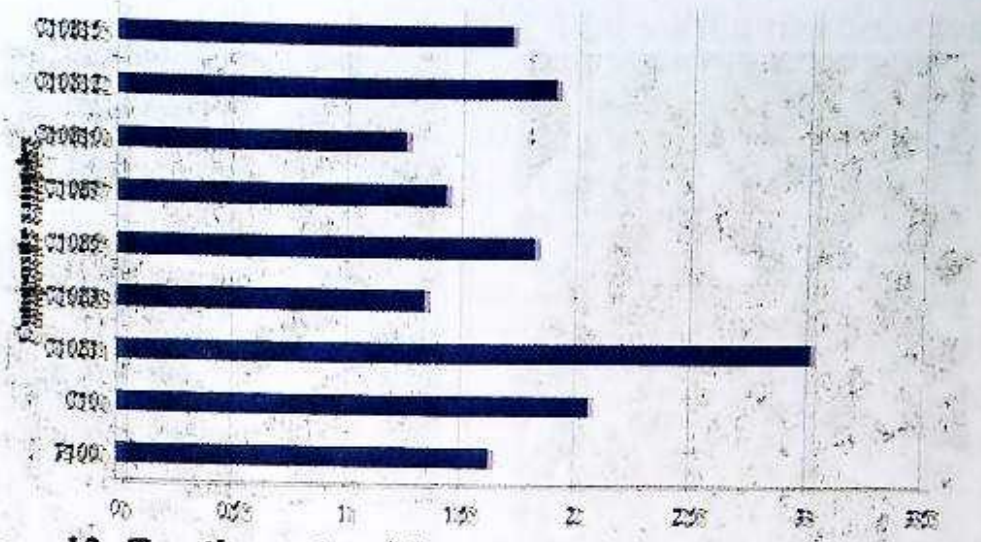


Figure 12: Tensile strain of the composite at break

Similar work on epoxy using aluminium particles as fillers (Bello et al., 2018) shows increase in flexural strength with decreasing particle sizes of the filler.

3.4. Value of metals and materials in construction

The value of metals in construction had been emphasised from time immemorial as very important to human existence in defence, in transportation, infrastructural facilities, home uses and many more. In fact, Quran 18 vs 96 clearly testifies to this when it says:" Bring me blocks of iron". At length when he had filled up the space between the two steep mountain sides, He said, "Blow (with your bellows)" Then, when he had made it (red) as fire, he said: "Bring me that I may pour over it, molten lead". The technical import of this is in the properties exhibited by iron and lead. Lead is a soft material and melts at 326 ^{0}C (Smith & Hashemi, 1990) whereas iron is a very hard material with melting point at 1560 ^{0}C (Smith & Hashemi, 1990). The pouring of molten lead is to deceive the invaders in identifying the people in the

café because an attempt by the invaders to remove the soft lead will lead them to a much harder more difficult to remove iron material and thus would give up any attempt to go further. This is the basis of using iron for construction purposes. Alabi and Onyeji (2010) compared the quality of iron rods manufactured in Nigeria with that of import and concluded that all the products conform to standards. It was therefore advised that the materials to be used for construction must be certified okay by metallurgical engineering experts in order to avoid incessant building failures often reported (Building Safe, 2014). Alabi and Yahaya, 2012 further researched into the iron rods for construction that are available in Ilorin markets and concluded that many of the samples conformed to standards while some did not thereby requiring the need for users to subject the materials to testing before use. Similar work was done on construction site that had failed (Adeleke & Odusote, 2013) and concluded that the failure had emanated from the use of inferior materials apparently made from secondary sources (scrap). It was advocated that the iron making industries in Nigeria be resuscitated to produce primary products from which more quality products could be obtained. More recently, Alabi and Kayode (2019) assessed the quality of rods (Imports) used for construction in a cement manufacturing site and concluded they complied with standards. The overall import of the work is to ensure safety of operations in construction and manufacturing and to avoid failure of structures that are rampant in Nigeria. This is why more work needs to be done to ensure that the manufacturers, contractors and sellers of iron rods in Nigeria are warned about producing according to standards (BS4449, 1997; ASTM A706, 2009; NISt-65-Mn, 2004). Contractors

and consultants on the other hand, must ensure the procured materials are tested to have the required mechanical properties that permit their use in construction. This is why it is very necessary that both Ajaokuta and the Delta steel companies be allowed to operate effectively to provide primary raw materials for making iron rods and other steel products that could be used for construction in manufacturing and transportation. Substandard materials have often been shown to emanate from the use of scrap alone for producing the steel products instead of using combinations of primary raw materials from the iron making mills and scrap rather than scrap alone.

It's a generic quote that a nation that fails to develop its iron and steel resources (If it is as lucky as Nigeria), would be far from industrialisation. Our steel industries (Ajaokuta and Delta Steel companies) must be revitalised in order for Nigeria to achieve its potentials industrially so that we can be reckoned with in the comity of nations. (Ajaokuta Steel Presentation, 2016).

Another metal prevalent and important to Nigeria is Aluminum and the production was set up at Ikot Abbassi in Akwa Ibom State because of its proximity to energy (Gas that is otherwise flared). Gas is consumed to the tune of 70% in the production path and water obtained from Oron River are used in the smelting of aluminium ores. Availability of these resources (gas and water) supported the citing of the industry at the location, Oron, Akwa-Ibom State. The company, Aluminium Smelting company of Nigeria (ALSCON) was about to start operation when privatisation order came in 2011.

Mr. Vice Chancellor, sir, I hereby plead with the Federal government to ensure the revitalisation of the company

(ALSCON) because of the wide advantages in its operation. It is a deoxidiser in steel making, a good alloying element, it is extensively used by small scale smelters and in a number of manufacturing concerns within and outside Nigeria. Alabi and Abdul (1997) produced a Kwara State Staff of Office Mace using Brass (Cu-Zn), cast iron and aluminium in 4 splits instead of six to reduce joining and hence, crevice corrosion. Sand casting was used in place of die casting. The cast cost four times less than that made by die casting (Alabi and Abdul, 1997) and that cast is still available today at the mechanical engineering department of Unilorin. It is advised that local casters be encouraged by government to observe such modifications for personal development to eradicate poverty and create wealth as demanded by the Millennium Development Goals (2000).

In the Buhari administration report of May, 2018, it was reported that solid minerals contributions to the Federation account moved from $700 million to $3.5 billion between 2015 and 2017. In addition, solid minerals export went up by 565% between 2016 and 2017 indicating the upward swing of solid minerals in Nigeria's economic dispensations. Nigerian governments and Nigerians should invest heavily in solid minerals because it is going to be next gold mine for Nigeria in striving for global relevance. As shown previously in Table 1, Nigeria is highly endowed with tremendous solid minerals resources (Nigeria's Mining and Metal Sector Investment, 2016). I will like be specific here on some metals that are expected to be sources of wealth for the country and its inhabitants. According to the Ministry of Solid Minerals Report of 2016, the seven most important minerals are: Coal for energy generation and as reductant by Ajaokuta Steel, Bitumen for road development, Limestone for the cement

industries, Iron ores for Iron and Steel making operations and hence infrastructural development, Bayrites for use as dampers in the Oil and gas industries and hence, a stoppage of our forex usage, Gold as a major world commodity that can enhance economic well-being of Nigeria and Nigerians and Lead/Zinc for industrial growth. China has demonstrated the importance of steel in infrastructural development by building road to link Beijing and Pakistan using tons and tons of steel. The social media demonstrated this in recent time.

3.5.0. Contribution to Education and Allied Safety Issues in Engineering

My goal from the onset is to contribute my quota to societal growth by my knowledge and my actions. These, I have demonstrated over the years.

As a young promising scientist in secondary school, I was doing home lessons for primary school pupils to enhance their mathematical acumen. Some of them have gone to become Accountants, Engineers, Nurses, Surveyors and important personalities in society today and are here. Some, however, have gone beyond. May the souls of the departed rest in perfect peace, amen. During and after my higher school (HSC), I had encouraged friends and my students at the Government Technical School, Ilorin to aspire higher by giving them extra lesson in Mathematics and Sciences. Many of them are equally here today. Thank you all for gracing the occasion.

The same story of enhancing the value of people for global relevance occurred while at the University of Ife now OAU and when I started as a Chemistry Lecturer at the School of Basic Studies in Kwara State College of Technology, now Kwara State Polytechnic (KP), Ilorin.

Most of the students and friends I mentored then are all in responsible positions today even though some of them may have retired and are here.

It was also at the KP that I started to look at the future of this country (Nigeria) and how I could contribute to its development so that it could be counted among committee of responsible nations in the world. Since my speciality, Chemistry, is universal (Alabi, 2006), I could venture into Chemical or Materials Engineering. In order to do this, you will need to identify your area of speciality ahead of time. It was easy for me to go into engineering because my speciality was Physical-organic chemistry. On the contrary, Organic Chemists are good for Medical fields /Pharmacy. I thank God I became a Metallurgy/Materials Engineer and I have been able to make my mark in the field and fulfilled my obligations to society, viz: that of enhancing the values of mineral resources in Nigeria to make Nigeria strive for global relevance in Minerals, educating the public and graduates of engineering on engineering education through conference attendance (Talabi et al., 2014) and sensitisation talks (Alabi, 1996, 2015, 2016, 2018) their relevance in society and how they can contribute their quota to making Nigeria great through maintenance of infrastructures for safety and Materials development. Alabi and Aremu (2008) averted disaster by writing a report on a failing structure at Muritala Mohammed Road, Ilorin and advised the land lord on what to do. Similar reports to educate corporate bodies (Alabi, 2000, 2006, 2009) were commissioned and such reports had assisted in averting failures that could have been catastrophic. The book on the technology of Ilorin (Alabi & Abdulkareem, 2011) also educated the public on values of local technology in Ilorin metropolis.

At Pittsburgh, my usual enthusiasm to benefit humanity was with me and many with whom we were together in Pittsburgh will bear witness. My family assisted many with free Child care because I was lucky to have my Mom with us. May her soul rest in perfect peace and be accepted into Aljanat Fridouz, Ameen. These are the various ways I had used my knowledge and exposure to benefit academics, my profession and humanity all on the platform of minerals, metals and materials.

4.0. Conclusion

Mr. Vice Chancellor, sir, I have given an account of my stewardship to humanity and education, engineering education in particular. I have tried to sensitise the audience on the value of extractive metallurgy and mineral processing as activities that can add value to Nigerians and Nigeria in an attempt to strive for global relevance. My contributions to the development of DRI in its production, storage and transportation to enhance the value of the commodity were discussed. I equally ventured into the use of steel rods for structural applications, with respect to its conformity with the standards, British (BS), American (ASTM) and Nigerian (NIS) standards. My contributions in human development and safety issues in engineering were also discussed. It is my hope that we are leaving here today with good understanding of what the field of materials science and engineering is all about and the future that surrounds that discipline in moving Nigeria to the next level.

5.0. Recommendations

1. The department of MSE must be interdisciplinary to accommodate physicist, chemist, and biologists with

strong mathematical background. The specialists must work together with materials/ metallurgical engineers to grow new materials for the advancement of technology.

2. All members of staff of the department must register either with COREN if he/she has engineering background or with COMEG- Council of Mining Engineers and Geo-Scientists if he is a scientist to develop career-wise.
3. Government must enact laws that would force industries to patronise Nigerian universities and research centres by providing funds for research.
4. Government must also enact laws to force mineral prospecting agents in Nigeria to add value to the mineral ores before export.
5. The primary iron making facilities at Ajaokuta and Warri should be resuscitated in order to provide quality iron products in the Nigerian market.
6. Nigerian governments and Nigerians must invest heavily in solid minerals, in order to key into our next major economic resource after oil.

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